

BRITISH STANDARD

**BS ISO 8802-3 :
1989**

Implementation of ISO 8802-3 : 1989

**Information processing
systems —
Local area networks —**

**Part 3. Carrier sense multiple access with
collision detection (CSMA/CD) access
method and physical layer specifications**

National foreword

This British Standard reproduces verbatim ISO 8802-3 : 1989 and implements it as the UK national standard.

This British Standard is published under the direction of the Information Technology Systems Standards Policy Committee whose Technical Committee IST/6 has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international committee any enquiries on interpretation, or proposals for change, and keep UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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International Standard ISO 8802-3 : 1989
ANSI/IEEE Std 802.3-1988

(Editorial revision of
ANSI/IEEE Std 802.3-1985 and 802.3a-1988)

Information processing systems— Local area networks—

Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications

Sponsor

**Technical Committee on Computer Communications
of the
IEEE Computer Society**

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American National Standards Institute

Approved 1988 by the
International Organization for Standardization



Adopted as an International Standard by the
International Organization for Standardization



Published by
The Institute of Electrical and Electronics Engineers, Inc



International Standard ISO 8802-3 : 1989

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In 1985, ANSI/IEEE Std 802.3-1985 was adopted by ISO Technical Committee 97, *Information processing systems*, as draft International Standard ISO/DIS 8802-3. Following the procedures described above, the Standard was subsequently approved by ISO in the form of this new edition, which is published as International Standard ISO 8802-3 : 1989. This edition also includes ISO 8802-3/DAD 1 which resulted from the adoption in 1987 of ANSI/IEEE Std 802.3a-1988.

For the purpose of assigning global addresses, the Institute of Electrical and Electronics Engineers, Inc., USA, has been designated by the ISO Council as the Registration Authority. Communications on this subject should be addressed to

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c/o The Institute of Electrical and Electronics Engineers, Inc
445 Hoes Lane
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Piscataway, NJ 08855-1331
USA

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Xerox Corporation
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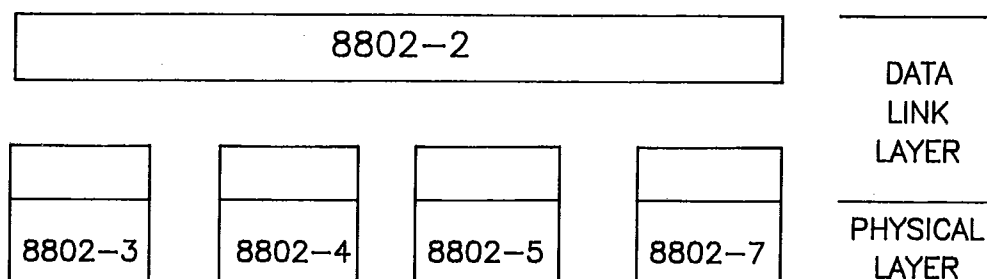
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Foreword to International Standard ISO 8802-3 : 1989

This standard is part of a family of standards for Local Area Networks (LANs). The relationship between this standard and the other members of the family is shown below. (The numbers in the figure refer to ISO Standard numbers.)



This family of standards deals with the physical and data link layers as defined by the ISO Open Systems Interconnection Reference Model (ISO 7498 : 1984). The access standards define four types of medium access technologies and associated physical media, each appropriate for particular applications or system objectives. The standards defining these technologies are:

- (1) ISO 8802-3 [ANSI/IEEE Std 802.3-1988], a bus utilizing CSMA/CD as the access method,
- (2) ISO 8802-4 [ANSI/IEEE Std 802.4-1985], a bus utilizing token passing as the access method,
- (3) ISO 8802-5 [ANSI/IEEE Std 802.5-1985], a ring utilizing token passing as the access method,
- (4) ISO 8802-7, a ring utilizing slotted ring as the access method.

ISO 8802-2 [ANSI/IEEE Std 802.2-1985], Logical Link Control protocol, is used in conjunction with the medium access standards.

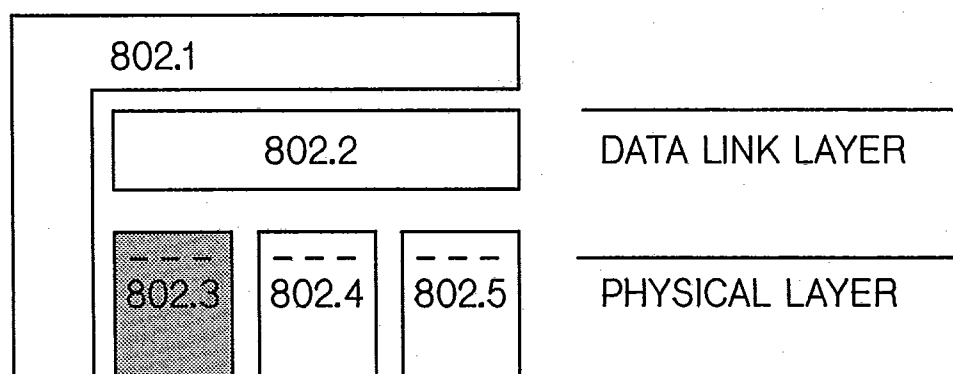
The reader of this document is urged to become familiar with the complete family of standards.

The main body of this standard serves for both the ISO 8802-3 : 1989 and ANSI/IEEE 802.3-1988 standards. ISO and IEEE each have unique foreword sections. The Annex applies to the IEEE standard only. The Appendices serve as useful reference material to both standards.

Foreword to ANSI/IEEE Std 802.3-1988
(Editorial Revision of ANSI/IEEE Std 802.3-1985 and
ANSI/IEEE Std 802.3a-1988)

(This Foreword is not a part of ISO 8802-3 : 1989 or of ANSI/IEEE Std 802.3-1988.)

This standard is part of a family of standards for Local Area Networks (LANs). The relationship between this standard and other members of the family is shown below. (The numbers in the figure refer to IEEE standard numbers.)



This family of standards deals with the Physical and Data Link Layers as defined by the ISO Open Systems Interconnection Reference Model. The access standards define three types of medium access technologies and associated physical media, each appropriate for particular applications or system objectives. The standards defining these technologies are:

- (1) ANSI/IEEE Std 802.3-1988 [ISO 8802-3], a bus utilizing CSMA/CD as the access method,
- (2) ANSI/IEEE Std 802.4-1985 [ISO 8802-4], a bus utilizing token passing as the access method,
- (3) ANSI/IEEE Std 802.5-1985 [ISO 8802-5], a ring utilizing token passing as the access method.

ANSI/IEEE Std 802.2-1985 [ISO 8802-2], the Logical Link Control standard, is used in conjunction with the medium access standards.

IEEE P802.1 describes the relationship among these standards and their relationship to the ISO Open Systems Interconnection Reference Model in more detail. This companion document also will contain networking management standards and information on internetworking. The reader of this standard is urged to become familiar with the complete family of standards.

The local area network access mechanism specified by this standard may

include patented matter. The IEEE Standards Office calls attention to the fact that it is claimed that the process of the local area network access mechanism described throughout this standard is the subject of United States patent numbers 4 063 220 and 4 099 024 and corresponding patents of foreign countries owned by the Xerox Corporation. Although these patents appear to cover the access mechanism subject in this standard, the IEEE takes no position with respect to patent validity. The Xerox Corporation has assured the IEEE that it is willing to grant a license under these patents on reasonable and nondiscriminatory terms and conditions to anyone wishing to obtain such a license. The Xerox Corporation's undertakings in this respect are on file with the IEEE Standards Office and the license details may be obtained from the Office of General Counsel of Xerox Corporation, whose address is Post Office Box 1600, Stamford, Connecticut 06904, USA.

This edition of the standard defines a 10 Mb/s baseband implementation of the Physical Layer using the CSMA/CD access method. It is anticipated that future editions of the standard may provide additional implementations of the physical layer to support different needs (for example, media, and data rates).

This standard contains state-of-the-art material. The area covered by this standard is undergoing evolution. Revisions are anticipated to this standard within the next few years to clarify existing material, to correct possible errors, and to incorporate new related material.

Readers wishing to know the state of revisions should contact

Secretary
IEEE Standards Board
Institute of Electrical and Electronics Engineers, Inc
PO Box 1331, 445 Hoes Lane
Piscataway, NJ 08855-1331

When the IEEE 802.3 Working Group approved this standard in 1983 it had the following membership:

Donald C. Loughry, *Chairman*

Phil L. Arst
Robert F. Bridge
Charles Brill
G.J. Clancy
John Davidson
Ralph DeMent
Hank (H. N.) Dorris
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Daniel Sze
Victor J. Tarasov
P. E. Wainwright
Lyle Weiman
Hugh E. White
Choa-Ping Wu
Nick Zades
Mo R. Zonoun

Individuals who contributed actively in the development of this standard throughout its elaboration were

Juan Bulnes
Ron Crane
Dane Elliot
Alan Flatman
Maris Graube
Guy Harkins

Dean Lindsay
Then. T. Liu
Robert Moles
Tony Lauck
Joseph St. Amand
Richard Seifert
Nathan Tobol

Mark Townsend
Roger Van Brunt
Bo Vicklund
Chris Wargo
Richard Williams
Ron Yara

The ECMA TC24 Committee on Communication Protocols also provided helpful input in the development of this standard.

The IEEE 802.3 Working Group acknowledges and appreciates that many concepts embodied in this standard are based largely upon the CSMA/CD access method earlier described in *The Ethernet* specification as written jointly by individuals from Xerox Corporation, Digital Equipment Corporation, and Intel Corporation. Appreciation is also expressed to Robert M. Metcalfe and David R. Boggs for their pioneering work in establishing the original concepts.

When the IEEE 802.3 Working Group approved ANSI/IEEE Std 802.3a-1988 (Section 10) in November 1984, it had the following membership:

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Alan Flatman, Chairman, Type 10BASE2 Task Force

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William Belknap
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Juan Bulnes
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Information processing systems— Local area networks—

Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications

1. Introduction

1.1 Overview

1.1.1 Basic Concepts. The Carrier Sense Multiple Access with Collision Detection (CSMA/CD) media access method is the means by which two or more stations share a common transmission medium. To transmit, a station waits (defers) for a quiet period on the medium (that is, no other station is transmitting) and then sends the intended message in bit-serial form. If, after initiating a transmission, the message collides with that of another station, then each transmitting station intentionally sends a few additional bytes to ensure propagation of the collision throughout the system. The station remains silent for a random amount of time (backoff) before attempting to transmit again. Each aspect of this access method process is specified in detail in subsequent sections of this standard.

This is a comprehensive standard for Local Area Networks employing CSMA/CD as the access method. This standard is intended to encompass several media types and techniques for signal rates of from 1 Mb/s to 20 Mb/s. This edition of the standard provides the necessary specification and related parameter values for 10 Mb/s baseband implementations. It is expected that subsequent editions of this standard will provide similar specifications for additional implementations (for example, other data rates and physical media).

1.1.2 Architectural Perspectives. There are two important ways to view local area network design corresponding to

(1) *Architecture.* Emphasizing the logical divisions of the system and how they fit together.

(2) *Implementation.* Emphasizing actual components, their packaging and interconnection.

This standard is organized along architectural lines, emphasizing the

large-scale separation of the system into two parts: the Media Access Control (MAC) sublayer of the Data Link Layer, and the Physical Layer. These layers are intended to correspond closely to the lowest layers of the ISO Model for Open Systems Interconnection (see Fig 1-1). See reference [10].¹ The Logical Link Control (LLC) sublayer and MAC sublayer together encompass the functions intended for the Data Link Layer as defined in the OSI model.

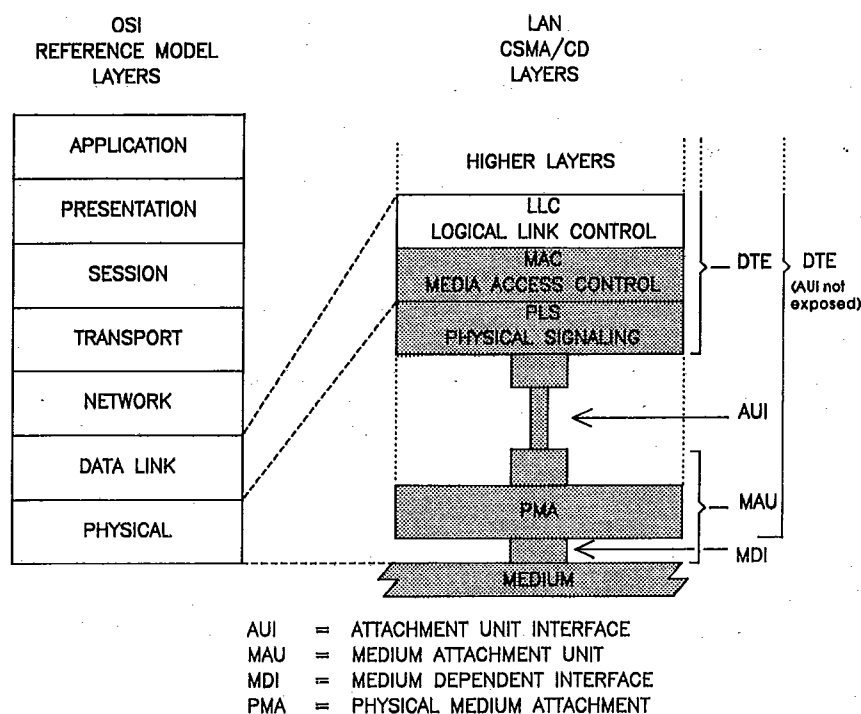
1.1.2.1 An architectural organization of the standard has two main advantages:

(1) *Clarity*. A clean overall division of the design along architectural lines makes the standard clearer.

(2) *Flexibility*. Segregation of medium-dependent aspects in the Physical Layer allows the LLC and MAC sublayers to apply to a family of transmission media.

Partitioning the Data Link Layer allows various media access methods within the family of Local Area Network standards.

Fig 1-1
LAN Standard Relationship to the
OSI Reference Model



¹ The numbers in brackets correspond to those of the references listed in 1.3; when preceded by A, they correspond to those listed in the Annex.

The architectural model is based on a set of interfaces that may be different from those emphasized in implementations. One critical aspect of the design, however, shall be addressed largely in terms of the implementation interfaces: compatibility.

1.1.2.2 Two important compatibility interfaces are defined within what is architecturally the Physical Layer.

(1) *Medium-Dependent Interface (MDI)*. To communicate in a compatible manner, all stations shall adhere rigidly to the exact specification of physical media signals defined in Section 8 (and beyond) in this standard, and to the procedures that define correct behavior of a station. The medium-independent aspects of the LLC sublayer and the MAC sublayer should not be taken as detracting from this point; communication by way of the ISO 8802-3 [IEEE 802.3] Local Area Network requires complete compatibility at the Physical Medium interface (that is, the coaxial cable interface).

(2) *Attachment Unit Interface (AUI)*. It is anticipated that most DTEs will be located some distance from their connection to the coaxial cable. A small amount of circuitry will exist in the Medium Attachment Unit (MAU) directly adjacent to the coaxial cable, while the majority of the hardware and all of the software will be placed within the DTE. The AUI is defined as a second compatibility interface. While conformance with this interface is not strictly necessary to ensure communication, it is highly recommended, since it allows maximum flexibility in intermixing MAUs and DTEs. The AUI may be optional or not specified for some implementations of this standard that are expected to be connected directly to the medium and so do not use a separate MAU or its interconnecting AUI cable. The PLS and PMA are then part of a single unit, and no explicit AUI specification is required.

1.1.3 Layer Interfaces. In the architectural model used here, the layers interact by way of well defined interfaces, providing services as specified in Sections 2 and 6. In general, the interface requirements are as follows:

(1) The interface between the MAC sublayer and the LLC sublayer includes facilities for transmitting and receiving frames, and provides per-operation status information for use by higher-layer error recovery procedures.

(2) The interface between the MAC sublayer and the Physical Layer includes signals for framing (carrier sense, transmit initiation) and contention resolution (collision detect), facilities for passing a pair of serial bit streams (transmit, receive) between the two layers, and a wait function for timing.

These interfaces are described more precisely in 4.3. Additional interfaces are necessary to allow higher level network management facilities to interact with these layers to perform operation, maintenance, and planning functions. Network management functions will be discussed in Section 5.

1.1.4 Application Areas. The applications environment for the Local Area Network is intended to be commercial and light industrial. Use of CSMA/CD LANs in home or heavy industrial environments, while not precluded, is not considered within the scope of this standard.

1.2 Notation

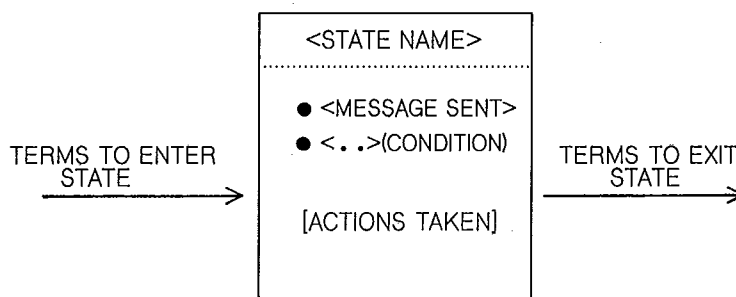
1.2.1 State Diagram Conventions. The operation of a protocol can be described by subdividing the protocol into a number of interrelated functions. The operation of the functions can be described by state diagrams. Each diagram represents the domain of a function and consists of a group of connected, mutually exclusive states. Only one state of a function is active at any given time (see Fig 1-2).

Each state that the function can assume is represented by a rectangle. These are divided into two parts by a horizontal line. In the upper part the state is identified by a name in capital letters. The lower part contains the name of any ON signal that is generated by the function. Actions are described by short phrases and enclosed in brackets.

All permissible transitions between the states of a function are represented graphically by arrows between them. A transition that is global in nature (for example, an exit condition from all states to the IDLE or RESET state) is indicated by an open arrow. Labels on transitions are qualifiers that must be fulfilled before the transition will be taken. The label UCT designates an unconditional transition. Qualifiers described by short phrases are enclosed in parentheses.

State transitions and sending and receiving of messages occur instantaneously. When a state is entered and the condition to leave that state is not immediately fulfilled, the state executes continuously, sending the messages and executing the actions contained in the state in a continuous manner.

Fig 1-2
State Diagram Notation Example



Key: () = condition, for example, (if no_collision)
 [] = action, for example, [reset PLS functions]
 * = logical AND
 + = logical OR
 Tw = Wait Time, implementation dependent
 Td = Delay Timeout
 Tb = Backoff Timeout
 UCT = unconditional transition

The state diagrams contain the authoritative statement of the functions they depict; when apparent conflicts between descriptive text and state diagrams arise, the state diagrams are to take precedence. This does not override, however, any explicit description in the text that has no parallel in the state diagrams.

The models presented by state diagrams are intended as the primary specifications of the functions to be provided. It is important to distinguish, however, between a model and a real implementation. The models are optimized for simplicity and clarity of presentation, while any realistic implementation may place heavier emphasis on efficiency and suitability to a particular implementation technology. It is the functional behavior of any unit that must match the standard, not its internal structure. The internal details of the model are useful only to the extent that they specify the external behavior clearly and precisely.

1.2.2 Service Specification Method and Notation. The service of a layer or sublayer is the set of capabilities that it offers to a user in the next higher (sub)layer. Abstract services are specified here by describing the service primitives and parameters that characterize each service. This definition of service is independent of any particular implementation (see Fig 1-3).

Specific implementations may also include provisions for interface interactions that have no direct end-to-end effects. Examples of such local interactions include interface flow control, status requests and indications, error notifications, and layer management. Specific implementation details are omitted from this service specification both because they will differ from implementation to implementation and because they do not impact the peer-to-peer protocols.

1.2.2.1 Classification of Service Primitives. Primitives are of two generic types:

(1) **REQUEST.** The request primitive is passed from layer N to layer N-1 to request that a service be initiated.

(2) **INDICATION.** The indication primitive is passed from layer N-1 to layer N to indicate an internal layer N-1 event that is significant to layer N. This event may be logically related to a remote service request, or may be caused by an event internal to layer N-1.

The service primitives are an abstraction of the functional specification and the user-layer interaction. The abstract definition does not contain local detail of the user/provider interaction. For instance, it does not indicate the local mechanism that allows a user to indicate that it is awaiting an incoming call. Each primitive has a set of zero or more parameters, representing data elements that shall be passed to qualify the functions invoked by the primitive. Parameters indicate information available in a user/provider interaction; in any particular interface, some parameters may be explicitly stated (even though not explicitly defined in the primitive) or implicitly associated with the service access point. Similarly, in any particular protocol specification, functions corresponding to a service primitive may be explicitly defined or implicitly available.

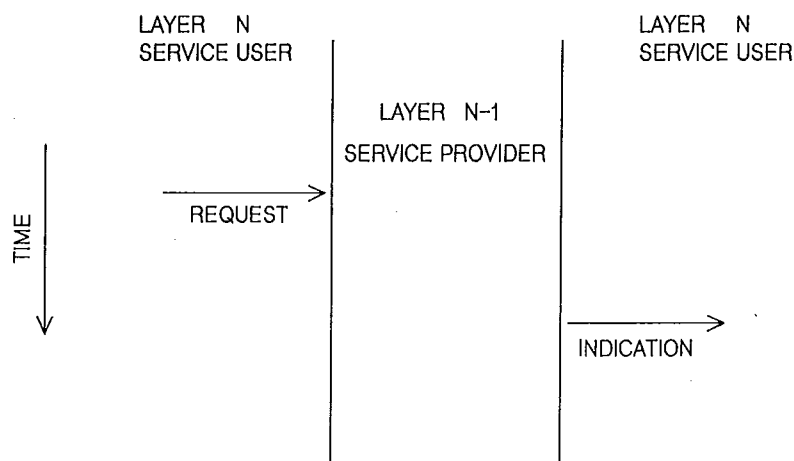


Fig 1-3
Service Primitive Notation

1.2.3 Physical Layer and Media Notation. Users of this standard need to reference which particular implementation is being used or identified. Therefore, a means of identifying each implementation is given by a simple, three-field, type notation that is explicitly stated at the beginning of each relevant section. In general, the Physical Layer type is specified by these fields:

<data rate in Mb/s> <medium type> <maximum segment length (x 100 m)>

For example, the standard contains a 10 Mb/s baseband specification identified as "TYPE 10BASE5," meaning a 10 Mb/s baseband medium whose maximum segment length is 500 m. Each successive Physical Layer specification will state its own unique TYPE identifier along similar lines.

1.2.4 Physical Layer Message Notation. Messages generated within the Physical Layer, either within or between PLS and the MAU (that is, PMA circuitry), are designated by an italic type to designate either form of physical or logical message used to execute the physical layer signaling process (for example, *input_idle* or *mau_available*).

1.3 References

- [1] CISPR Publication 22 (1985), Limits and Methods of Measurement of Radio Interference Characteristics of Information Technology Equipment.²
- [2] IEC Publication 96-1 (1971) (3rd Edition), Radio Frequency Cable, Part 1: General Requirements and Measuring Methods.

² CISPR and IEC documents are available in the US from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, USA. These documents are also available from International Electrotechnical Commission, 3 rue de Varembe, Case Postale 131, CH-1211, Genève 20, Switzerland/Suisse.

- [3] IEC Publication 96-1A (1976), 1st Supplement, Radio Frequency Cable, Part 1: Appendix Section 5.4, Terminated Triaxial Test Method for Transfer Impedance up to 100 MHz.
- [4] IEC Publication 169-8 and -16, Radio Frequency Coaxial Connections with Screw Coupling, 50 Ω (Type BNC and Type N).
- [5] IEC Publication 380 (1985) (3rd Edition), Safety of Electrically Energized Office Machines.
- [6] IEC Publication 435 (1983) (2nd Edition), Safety of Data Processing Equipment.
- [7] IEC Publication 807-2 (1985) (1st Edition), Detail Specification for a Range of Connectors with Round Contacts—Fixed Solder Contact Types.
- [8] IEC Publication 950 (1986), Safety of Information Technology Equipment Including Electrical Business Equipment.
- [9] ISO 2382/09, The Information Processing Vocabulary, IPV, Section 09: Data Communication.³
- [10] ISO 7498, Information Processing Systems—Open Systems Interconnection—Basic Reference Model, November 15, 1984.

Local and national standards such as those supported by ANSI, EIA, IEEE, MIL, NFPA, and UL are not a formal part of the ISO 8802-3 standard. Reference to such local or national standards may be useful resource material and are identified by a bracketed number beginning with the letter A and located in the Annex.

1.4 Definitions. The definitions used in this standard are consistent with ISO 2382/09, the Information Processing Vocabulary, IPV, Part 09, Data Communication. A more specific IPV Part 25 pertaining to LAN systems is in development. See reference [9].

³ ISO documents are available in the US from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, USA. ISO documents are also available from ISO member bodies and from ISO Central Secretariat, 1 rue de Varembe, Case Postale 56, CH-1211, Genève 20, Switzerland/Suisse.

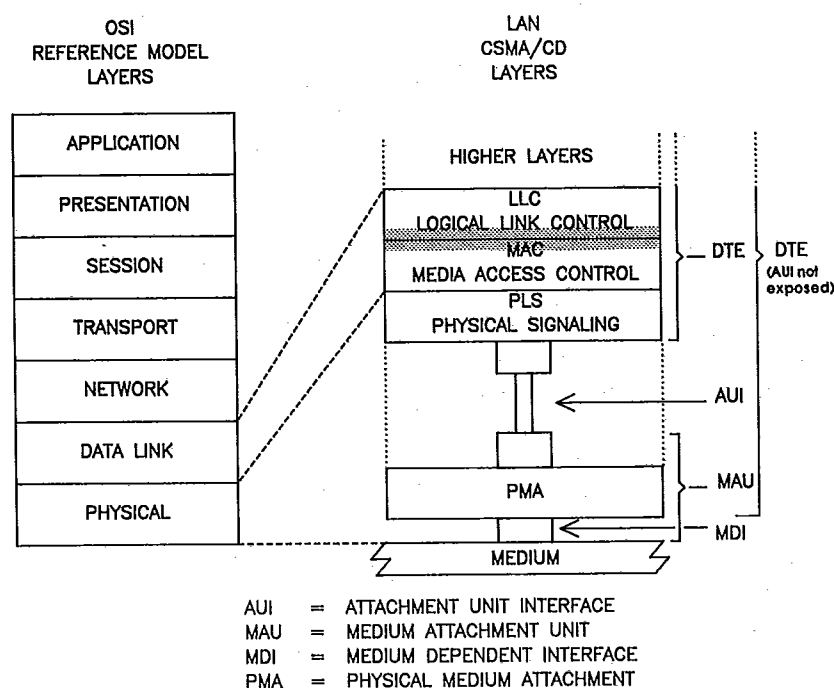
2. MAC Service Specification

2.1 Scope and Field of Application. This section specifies the services provided by the Media Access Control (MAC) sublayer to the Logical Link Control (LLC) sublayer for the ISO [IEEE] Local Area Network standard (see Fig 2-1). The services are described in an abstract way and do not imply any particular implementation, or any exposed interface. There is not necessarily a one-to-one correspondence between the primitives and the formal procedures and interfaces described in 4.2 and 4.3.

2.2 Overview of the Service

2.2.1 General Description of Services Provided by the Layer. The services

Fig 2-1
Service Specification Relation to the LAN Model



provided by the MAC sublayer allow the local LLC sublayer entity to exchange LLC data units with peer LLC sublayer entities. Optional support may be provided for resetting the MAC sublayer entity to a known state.

2.2.2 Model Used for the Service Specification. The model used in this service specification is identical to that used in 1.2.

2.2.3 Overview of Interactions

MA_DATA.request
MA_DATA.indication

2.2.4 Basic Services and Options. The MA_DATA.request and MA_DATA.indication service primitives described in this section are considered mandatory.

2.3 Detailed Service Specification

2.3.1 MA_DATA.request

2.3.1.1 Function. This primitive defines the transfer of data from a local LLC sublayer entity to a single peer LLC entity or multiple peer LLC entities in the case of group addresses.

2.3.1.2 Semantics of the Service Primitive. The semantics of the primitive are as follows:

```
MA_DATA.request (
    destination_address,
    m_sdu,
    service_class
)
```

The destination address parameter may specify either an individual or a group MAC entity address. It must contain sufficient information to create the DA field that is appended to the frame by the local MAC sublayer entity and any physical information. The m_sdu parameter specifies the MAC service data unit to be transmitted by the MAC sublayer entity. There is sufficient information associated with m_sdu for the MAC sublayer entity to determine the length of the data unit. The service_class parameter indicates a quality of service requested by LLC or higher layer (see 2.3.1.5).

2.3.1.3 When Generated. This primitive is generated by the LLC sublayer entity whenever data shall be transferred to a peer LLC entity or entities. This can be in response to a request from higher protocol layers or from data generated internally to the LLC sublayer, such as required by Type 2 service.

2.3.1.4 Effect of Receipt. The receipt of this primitive will cause the MAC entity to append all MAC specific fields, including DA, SA, and any fields that are unique to the particular media access method, and pass the properly formed frame to the lower protocol layers for transfer to the peer MAC sublayer entity or entities.

2.3.1.5 Additional Comments. The CSMA/CD MAC protocol provides a single quality of service regardless of the service_class requested.

2.3.2 MA_DATA.indication

2.3.2.1 Function. This primitive defines the transfer of data from the MAC sublayer entity to the LLC sublayer entity or entities in the case of group addresses.

2.3.2.2 Semantics of the Service Primitive. The semantics of the primitive are as follows:

```
MA_DATA.indication (
    destination_address,
    source_address,
    m_sdu,
    reception_status
)
```

The destination_address parameter may be either an individual or a group address as specified by the DA field of the incoming frame. The source_address parameter is an individual address as specified by the SA field of the incoming frame. The m_sdu parameter specifies the MAC service data unit as received by the local MAC entity. The reception_status parameter is used to pass status information to the peer LLC sublayer entity.

2.3.2.3 When Generated. The MA_DATA.indication is passed from the MAC sublayer entity to the LLC sublayer entity or entities to indicate the arrival of a frame to the local MAC sublayer entity. Such frames are reported only if they are validly formed, received without error, and their destination address designates the local MAC entity.

2.3.2.4 Effect of Receipt. The effect of receipt of this primitive by the LLC sublayer is unspecified.

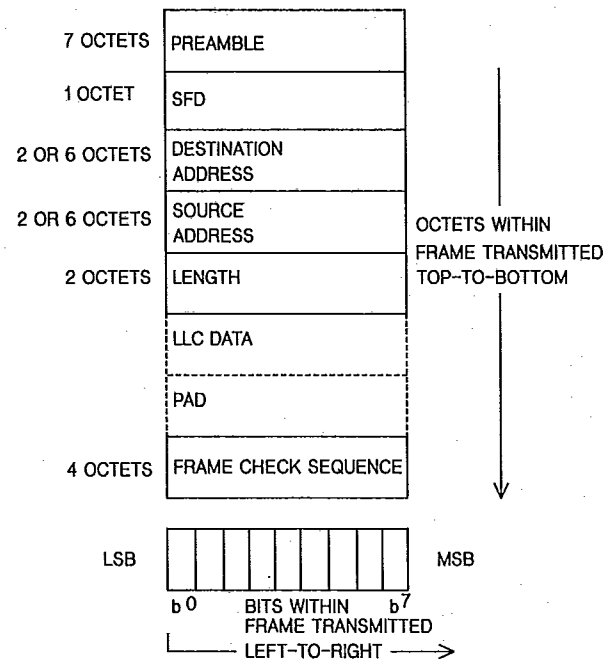
2.3.2.5 Additional Comments. If the local MAC sublayer entity is designated by the destination_address parameter of an MA_DATA.request, the indication primitive will also be invoked by the MAC entity to the local LLC entity. This full duplex characteristic of the MAC sublayer may be due to unique functionality within the MAC sublayer or full duplex characteristics of the lower layers (for example, all frames transmitted to the broadcast address will invoke MA_DATA.indication at all stations in the network including the station that generated the request).

3. Media Access Control Frame Structure

3.1 Overview. This section defines in detail the frame structure for data communication systems using local area network MAC procedures. It defines the relative positions of the various components of the MAC frame. It defines the method for representing station addresses. It defines a partition of the address space into individual (single station) and group (multicast or multi-station) addresses, and into user administered and globally administered addresses.

3.1.1 MAC Frame Format. Figure 3-1 shows the eight fields of a frame: the preamble, Start Frame Delimiter (SFD), the addresses of the frame's source and destination, a length field to indicate the length of the following field

Fig 3-1
MAC Frame Format



containing the LLC data to be transmitted, a field that contains padding if required, and the frame check sequence field containing a cyclic redundancy check value to detect errors in received frames. Of these eight fields, all are of fixed size except the LLC data and PAD fields, which may contain any integer number of octets between the minimum and maximum values determined by the specific implementation of the CSMA/CD Media Access mechanism. See 4.4 for particular implementations.

The minimum and maximum frame size limits in 4.4 refer to that portion of the frame from the destination address field through the frame check sequence field, inclusive.

Relative to Fig 3-1, the octets of a frame are transmitted from top to bottom, and the bits of each octet are transmitted from left to right.

3.2 Elements of the MAC Frame

3.2.1 Preamble Field. The preamble field is a 7-octet field that is used to allow the PLS circuitry to reach its steady-state synchronization with the received frame timing (see 4.2.5).

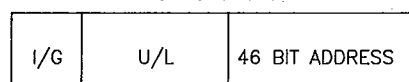
3.2.2 Start Frame Delimiter (SFD) Field. The SFD field is the sequence 10101011. It immediately follows the preamble pattern and indicates the start of a frame.

3.2.3 Address Fields. Each MAC frame shall contain two address fields: the Destination Address field and the Source Address field, in that order. The Destination Address field shall specify the destination addressee(s) for which the frame is intended. The Source Address field shall identify the station from which the frame was initiated. The representation of each address field shall be as follows (see Fig 3-2):

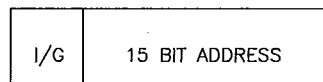
(1) Each address field shall contain either 16 bits or 48 bits. However, at any

Fig 3-2
Address Field Format

48 BIT ADDRESS FORMAT



16 BIT ADDRESS FORMAT



I/G = 0 INDIVIDUAL ADDRESS
 I/G = 1 GROUP ADDRESS
 U/L = 0 GLOBALLY ADMINISTERED ADDRESS
 U/L = 1 LOCALLY ADMINISTERED ADDRESS

given time, the Source and Destination Address size shall be the same for all stations on a particular local area network.

(2) The support of 16 or 48 bit address length for Source and Destination Address shall be left to the manufacturer as an implementation decision. There is no requirement that manufacturers support both sizes.

(3) The first bit (LSB) shall be used in the Destination Address field as an address type designation bit to identify the Destination Address either as an individual or as a group address. In the Source Address field, the first bit is reserved and set to 0. If this bit is 0, it shall indicate that the address field contains an individual address. If this bit is 1, it shall indicate that the address field contains a group address that identifies none, one or more, or all of the stations connected to the local area network.

(4) For 48 bit addresses, the second bit shall be used to distinguish between locally or globally administered addresses. For globally administered (or U, universal) addresses, the bit is set to 0. If an address is to be assigned locally, this bit shall be set to 1. Note that for the broadcast address, this bit is also a 1.

(5) Each octet of each address field shall be transmitted least significant bit first.

3.2.3.1 Address Designation. A MAC sublayer address is of one of two types:

(1) *Individual Address.* The address associated with a particular station on the network.

(2) *Group Address.* A multidestination address, associated with one or more stations on a given network. There are two kinds of multicast address:

(a) *Multicast-Group Address.* An address associated by higher-level convention with a group of logically related stations.

(b) *Broadcast Address.* A distinguished, predefined multicast address that always denotes the set of all stations on a given local area network.

All 1's in the Destination Address field (for 16 or 48 bit address size LANs) shall be predefined to be the Broadcast address. This group shall be predefined for each communication medium to consist of all stations actively connected to that medium; it shall be used to broadcast to all the active stations on that medium. All stations shall be able to recognize the Broadcast address. It is not necessary that a station be capable of generating the Broadcast address.

The address space shall also be partitioned into locally administered and globally administered addresses. The nature of a body and the procedures by which it administers these global (U) addresses is beyond the scope of this standard.⁴

3.2.4 Destination Address Field. The Destination Address field specifies the station(s) for which the frame is intended. It may be an individual or multicast (including broadcast) address.

⁴ Information concerning the Registration Authority and its procedures may be obtained on request to the Secretary General, ISO Central Secretariat, Case Postale 56, CH-1211 Genève, Switzerland, quoting the number of this International Standard. The ISO Global (U) address administration has been delegated to the Secretary, IEEE Standards Board, 345 East 47 Street, New York, NY 10017.

3.2.5 Source Address Field. The Source Address field specifies the station sending the frame. The Source Address field is not interpreted by the CSMA/CD MAC sublayer.

3.2.6 Length Field. The length field is a 2-octet field whose value⁵ indicates the number of LLC data octets in the data field. If the value is less than the minimum required for proper operation of the protocol, a PAD field (a sequence of octets) will be added at the end of the data field but prior to the FCS field, specified below. The procedure that determines the size of the pad field is specified in 4.2.8. The length field is transmitted and received with the high order octet first.

3.2.7 Data and PAD Fields. The data field contains a sequence of n octets. Full data transparency is provided in the sense that any arbitrary sequence of octet values may appear in the data field up to a maximum number specified by the implementation of this standard that is used. A minimum frame size is required for correct CSMA/CD protocol operation and is specified by the particular implementation of the standard. If necessary, the data field is extended by appending extra bits (that is, a pad) in units of octets after the LLC data field but prior to calculating and appending the FCS. The size of the pad, if any, is determined by the size of the data field supplied by LLC and the minimum frame size and address size parameters of the particular implementation. The maximum size of the data field is determined by the maximum frame size and address size parameters of the particular implementation.

The length of PAD field required for LLC data that is n octets long is $\max(0, \text{minFrameSize} - (8 \times n + 2 \times \text{addressSize} + 48))$ bits. The maximum possible size of the LLC data field is $\text{maxFrameSize} - (2 \times \text{addressSize} + 48)/8$ octets. See 4.4 for a discussion of implementation parameters; see 4.2.3.3 for a discussion of the minFrameSize.

3.2.8 Frame Check Sequence Field. A cyclic redundancy check (CRC) is used by the transmit and receive algorithms to generate a CRC value for the FCS field. The frame check sequence (FCS) field contains a 4-octet (32-bit) cyclic redundancy check (CRC) value. This value is computed as a function of the contents of the source address, destination address, length, LLC data and pad (that is, all fields except the preamble, SFD, and FCS). The encoding is defined by the following generating polynomial.

$$G(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$$

Mathematically, the CRC value corresponding to a given frame is defined by the following procedure:

- (1) The first 32 bits of the frame are complemented.
- (2) The n bits of the frame are then considered to be the coefficients of a polynomial $M(x)$ of degree $n-1$. (The first bit of the Destination Address field cor-

⁵ Packets with a length field value greater than those specified in 4.4.2 may be ignored, discarded, or used in a private manner. The use of such packets is beyond the scope of this standard.

responds to the $x^{(n-1)}$ term and the last bit of the data field corresponds to the x^0 term.)

(3) $M(x)$ is multiplied by x^{32} and divided by $G(x)$, producing a remainder $R(x)$ of degree <31 .

(4) The coefficients of $R(x)$ are considered to be a 32-bit sequence.

(5) The bit sequence is complemented and the result is the CRC.

The 32 bits of the CRC value are placed in the frame check sequence field so that the x^{31} term is the left-most bit of the first octet, and the x^0 term is the right-most bit of the last octet. (The bits of the CRC are thus transmitted in the order $x^{31}, x^{30}, \dots, x^1, x^0$.) See reference [A20].

3.3 Order of Bit Transmission. Each octet of the MAC frame, with the exception of the FCS, is transmitted low-order bit first.

3.4. Invalid MAC Frame. An invalid MAC frame shall be defined as one that meets at least one of the following conditions:

(1) The frame length is inconsistent with the length field.

(2) It is not an integral number of octets in length.

(3) The bits of the incoming frame (exclusive of the FCS field itself) do not generate a CRC value identical to the one received.

The contents of invalid MAC frames shall not be passed to LLC. The occurrence of invalid MAC frames may be communicated to network management.

4. Media Access Control

4.1 Functional Model of the Media Access Control Method

4.1.1 Overview. The architectural model described in Section 1 is used in this section to provide a functional description of the Local Area Network CSMA/CD MAC sublayer.

The MAC sublayer defines a medium-independent facility, built on the medium-dependent physical facility provided by the Physical Layer, and under the access-layer-independent local area network LLC sublayer. It is applicable to a general class of local area broadcast media suitable for use with the media access discipline known as Carrier Sense Multiple Access with Collision Detection (CSMA/CD).

The LLC sublayer and the MAC sublayer together are intended to have the same function as that described in the OSI model for the Data Link Layer alone. In a broadcast network, the notion of a data link between two network entities does not correspond directly to a distinct physical connection. Nevertheless, the partitioning of functions presented in this standard requires two main functions generally associated with a data link control procedure to be performed in the MAC sublayer. They are as follows:

- (1) Data encapsulation (transmit and receive)
 - (a) Framing (frame boundary delimitation, frame synchronization)
 - (b) Addressing (handling of source and destination addresses)
 - (c) Error detection (detection of physical medium transmission errors)
- (2) Media Access Management
 - (a) Medium allocation (collision avoidance)
 - (b) Contention resolution (collision handling)

The remainder of this section provides a functional model of the CSMA/CD MAC method.

4.1.2 CSMA/CD Operation. This section provides an overview of frame transmission and reception in terms of the functional model of the architecture. This overview is descriptive, rather than definitional; the formal specifications of the operations described here are given in 4.2 and 4.3. Specific implementations for CSMA/CD mechanisms that meet this standard are given in 4.4. Figure 4-1 provides the architectural model described functionally in the sections that follow.

The Physical Layer Signaling (PLS) component of the Physical Layer provides an interface to the MAC sublayer for the serial transmission of bits onto the physical media. For completeness, in the operational description that follows some of these functions are included as descriptive material. The

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ANSI/IEEE Std 802.3-1988

LOCAL AREA NETWORKS:

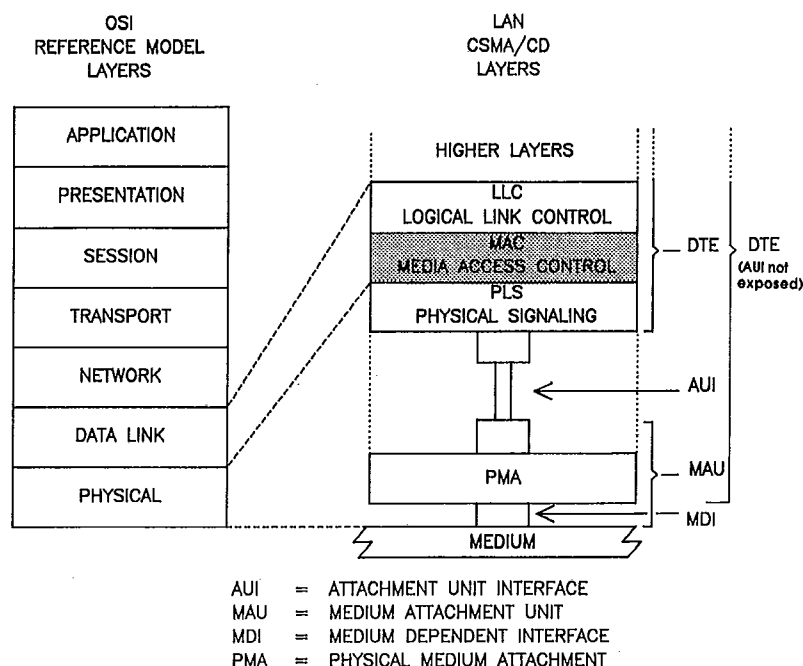


Fig 4-1
MAC Sublayer Partitioning, Relationship to
OSI Reference Model

concise specification of these functions is given in 4.2 for the MAC functions and in Section 7 for PLS.

Transmit frame operations are independent from the receive frame operations. A transmitted frame addressed to the originating station will be received and passed to the LLC sublayer at that station. This characteristic of the MAC sublayer may be implemented by functionality within the MAC sublayer or full duplex characteristics of portions of the lower layers.

4.1.2.1 Normal Operation

4.1.2.1.1 Transmission Without Contention. When a LLC sublayer requests the transmission of a frame, the Transmit Data Encapsulation component of the CSMA/CD MAC sublayer constructs the frame from the LLC-supplied data. It appends a preamble and a start of frame delimiter to the beginning of the frame. Using information passed by the LLC sublayer, the CSMA/CD MAC sublayer also appends a PAD at the end of the MAC information field of sufficient length to ensure that the transmitted frame length satisfies a minimum frame size requirement (see 4.2.3.3). It also appends destination and source addresses, a length count field, and a frame check sequence to provide for error detection. The frame is then handed to the Transmit Media Access Management component in the MAC sublayer for transmission.

Transmit Media Access Management then attempts to avoid contention with other traffic on the medium by monitoring the carrier sense signal provided by the Physical Layer Signalling (PLS) component and deferring to passing traffic. When the medium is clear, frame transmission is initiated (after a brief interframe delay to provide recovery time for other CSMA/CD MAC sublayers and for the physical medium). The MAC sublayer then provides a serial stream of bits to the PLS interface for transmission.

The PLS performs the task of actually generating the electrical signals on the medium that represent the bits of the frame. Simultaneously, it monitors the medium and generates the collision detect signal, which, in the contention-free case under discussion, remains off for the duration of the frame. A functional description of the Physical Layer is given in Sections 7 and beyond.

When transmission has completed without contention, the CSMA/CD MAC sublayer so informs the LLC sublayer using the LLC to MAC interface and awaits the next request for frame transmission.

4.1.2.1.2 Reception Without Contention. At each receiving station, the arrival of a frame is first detected by the PLS, which responds by synchronizing with the incoming preamble, and by turning on the carrier sense signal. As the encoded bits arrive from the medium, they are decoded and translated back into binary data. The PLS passes subsequent bits up to the MAC sublayer, where the leading bits are discarded, up to and including the end of the preamble and Start Frame Delimiter.

Meanwhile, the Receive Media Access Management component of the MAC sublayer, having observed carrier sense, has been waiting for the incoming bits to be delivered. Receive Media Access Management collects bits from the PLS as long as the carrier sense signal remains on. When the carrier sense signal is removed, the frame is truncated to an octet boundary, if necessary, and passed to Receive Data Decapsulation for processing.

Receive Data Decapsulation checks the frame's Destination Address field to decide whether the frame should be received by this station. If so, it passes the Destination Address (DA), the Source Address (SA), and the LLC data unit (LLCDU) to the LLC sublayer along with an appropriate status code indicating `reception_complete` or `reception_too_long`. It also checks for invalid MAC frames by inspecting the frame check sequence to detect any damage to the frame enroute, and by checking for proper octet-boundary alignment of the end of the frame. Frames with a valid FCS may also be checked for proper octet boundary alignment.

4.1.2.2 Access Interference and Recovery. If multiple stations attempt to transmit at the same time, it is possible for them to interfere with each other's transmissions, in spite of their attempts to avoid this by deferring. When transmissions from two stations overlap, the resulting contention is called a collision. A given station can experience a collision during the initial part of its transmission (the collision window) before its transmitted signal has had time to propagate to all stations on the CSMA/CD medium. Once the collision window has passed, a transmitting station is said to have acquired the

medium; subsequent collisions are avoided since all other (properly functioning) stations can be assumed to have noticed the signal (by way of carrier sense) and to be deferring to it. The time to acquire the medium is thus based on the round-trip propagation time of the physical layer whose elements include the PLS, PMA, and physical medium.

In the event of a collision, the transmitting station's Physical Layer initially notices the interference on the medium and then turns on the collision detect signal. This is noticed in turn by the Transmit Media Access Management component of the MAC sublayer, and collision handling begins. First, Transmit Media Access Management enforces the collision by transmitting a bit sequence called jam. In 4.4 an implementation that uses this enforcement procedure is provided. This ensures that the duration of the collision is sufficient to be noticed by the other transmitting station(s) involved in the collision. After the jam is sent, Transmit Media Access Management terminates the transmission and schedules another transmission attempt after a randomly selected time interval. Retransmission is attempted again in the face of repeated collisions. Since repeated collisions indicate a busy medium, however, Transmit Media Access Management attempts to adjust to the medium load by backing off (voluntarily delaying its own retransmissions to reduce its load on the medium). This is accomplished by expanding the interval from which the random retransmission time is selected on each successive transmit attempt. Eventually, either the transmission succeeds, or the attempt is abandoned on the assumption that the medium has failed or has become overloaded.

At the receiving end, the bits resulting from a collision are received and decoded by the PLS just as are the bits of a valid frame. Fragmentary frames received during collisions are distinguished from valid transmissions by the MAC sublayer's Receive Media Access Management component.

4.1.3 Relationships to LLC Sublayer and Physical Layer. The CSMA/CD MAC sublayer provides services to the LLC sublayer required for the transmission and reception of frames. Access to these services is specified in 4.3. The CSMA/CD MAC sublayer makes a best effort to acquire the medium and transfer a serial stream of bits to the PLS. Although certain errors are reported to the LLC, error recovery is not provided by MAC. Error recovery may be provided by the LLC or higher (sub)layers.

4.1.4 CSMA/CD Access Method Functional Capabilities. The following summary of the functional capabilities of the CSMA/CD MAC sublayer is intended as a quick reference guide to the capabilities of the standard, as depicted in Fig 4-2:

(1) For Frame Transmission

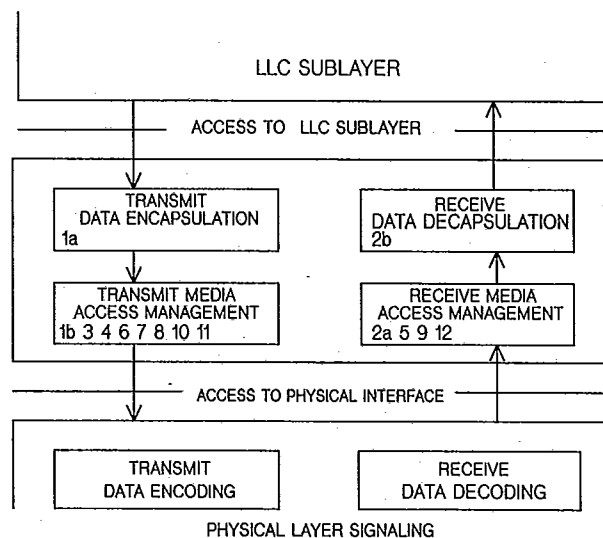
(a) Accepts data from the LLC sublayer and constructs a frame

(b) Presents a bit-serial data stream to the physical layer for transmission on the medium

NOTE: Assumes data passed from the LLC sublayer are octet multiples.

(2) For Frame Reception

(a) Receives a bit-serial data stream from the physical layer



NOTE: Numbers refer to functions listed in 4.1.4.

Fig 4-2
CSMA/CD Media Access Control Functions

(b) Presents to the LLC sublayer frames that are either broadcast frames or directly addressed to the local station

(c) Discards or passes to Network Management all frames not addressed to the receiving station

(3) Defers transmission of a bit-serial stream whenever the physical medium is busy

(4) Appends proper FCS value to outgoing frames and verifies full octet boundary alignment

(5) Checks incoming frames for transmission errors by way of FCS and verifies octet boundary alignment

(6) Delays transmission of frame bit stream for specified interframe gap period

(7) Halts transmission when collision is detected

(8) Schedules retransmission after a collision until a specified retry limit is reached

(9) Enforces collision to ensure propagation throughout network by sending jam message

(10) Discards received transmissions that are less than a minimum length

(11) Appends preamble, Start Frame Delimiter, DA, SA, length count, and FCS to all frames, and inserts pad field for frames whose LLC data length is less than a minimum value

(12) Removes preamble, Start Frame Delimiter, DA, SA, length count, FCS and pad field (if necessary) from received frames

4.2 CSMA/CD Media Access Control Method (MAC): Precise Specification

4.2.1 Introduction. A precise algorithmic definition is given in this section, providing procedural model for the CSMA/CD MAC process with a program in the computer language Pascal. See references [A2] and [A19] for resource material. Note whenever there is any apparent ambiguity concerning the definition of some aspect of the CSMA/CD MAC method, it is the Pascal procedural specification in 4.2.7 through 4.2.10 which should be consulted for the definitive statement. Sections 4.2.2 through 4.2.6 provide, in prose, a description of the access mechanism with the formal terminology to be used in the remaining subsections.

4.2.2 Overview of the Procedural Model. The functions of the CSMA/CD MAC method are presented below, modeled as a program written in the computer language Pascal. This procedural model is intended as the primary specification of the functions to be provided in any CSMA/CD MAC sublayer implementation. It is important to distinguish, however, between the model and a real implementation. The model is optimized for simplicity and clarity of presentation, while any realistic implementation shall place heavier emphasis on such constraints as efficiency and suitability to a particular implementation technology or computer architecture. In this context, several important properties of the procedural model shall be considered.

4.2.2.1 Ground Rules for the Procedural Model

(1) First, it shall be emphasized that *the description of the MAC sublayer in a computer language is in no way intended to imply that procedures shall be implemented as a program executed by a computer.* The implementation may consist of any appropriate technology including hardware, firmware, software, or any combination.

(2) Similarly, it shall be emphasized that it is the behavior of any MAC sublayer implementations that shall match the standard, not their internal structure. The internal details of the procedural model are useful only to the extent that they help specify that behavior clearly and precisely.

(3) The handling of incoming and outgoing frames is rather stylized in the procedural model, in the sense that frames are handled as single entities by most of the MAC sublayer and are only serialized for presentation to the Physical Layer. In reality, many implementations will instead handle frames serially on a bit, octet or word basis. This approach has not been reflected in the procedural model, since this only complicates the description of the functions without changing them in any way.

(4) The model consists of algorithms designed to be executed by a number of concurrent processes; these algorithms collectively implement the CSMA/CD procedure. The timing dependencies introduced by the need for concurrent activity are resolved in two ways:

(a) *Processes Versus External Events.* It is assumed that the algorithms are executed "very fast" relative to external events, in the sense that a process never falls behind in its work and fails to respond to an external event in a timely manner. For example, when a frame is to be received, it is assumed

that the Media Access procedure `ReceiveFrame` is always called well before the frame in question has started to arrive.

(b) *Processes Versus Processes*. Among processes, no assumptions are made about relative speeds of execution. This means that each interaction between two processes shall be structured to work correctly independent of their respective speeds. Note, however, that the timing of interactions among processes is often, in part, an indirect reflection of the timing of external events, in which case appropriate timing assumptions may still be made.

It is intended that the concurrency in the model reflect the parallelism intrinsic to the task of implementing the LLC and MAC procedures, although the actual parallel structure of the implementations is likely to vary.

4.2.2.2 Use of Pascal in the Procedural Model. Several observations need to be made regarding the method with which Pascal is used for the model. Some of these observations are as follows:

(1) Some limitations of the language have been circumvented to simplify the specification:

(a) The elements of the program (variables and procedures, for example) are presented in logical groupings, in top-down order. Certain Pascal ordering restrictions have thus been circumvented to improve readability.

(b) The *process* and *cycle* constructs of the Pascal derivative. Concurrent Pascal have been introduced to indicate the sites of autonomous concurrent activity. As used here, a process is simply a parameterless procedure that begins execution at "the beginning of time" rather than being invoked by a procedure call. A cycle statement represents the main body of a process and is executed repeatedly forever.

(c) The lack of variable array bounds in the language has been circumvented by treating frames as if they are always of a single fixed size (which is never actually specified). The size of a frame depends on the size of its data field, hence the value of the "pseudo-constant" `frameSize` should be thought of as varying in the long-term, even though it is fixed for any given frame.

(d) The use of a variant record to represent a frame (as fields and as bits) follows the spirit but not the letter of the Pascal Report, since it allows the underlying representation to be viewed as two different data types.

(2) The model makes no use of any explicit interprocess synchronization primitives. Instead, all interprocess interaction is done by way of carefully stylized manipulation of shared variables. For example, some variables are set by only one process and inspected by another process in such a manner that the net result is independent of their execution speeds. While such techniques are not generally suitable for the construction of large concurrent programs, they simplify the model and more nearly resemble the methods appropriate to the most likely implementation technologies (microcode, hardware state-machines, etc.)

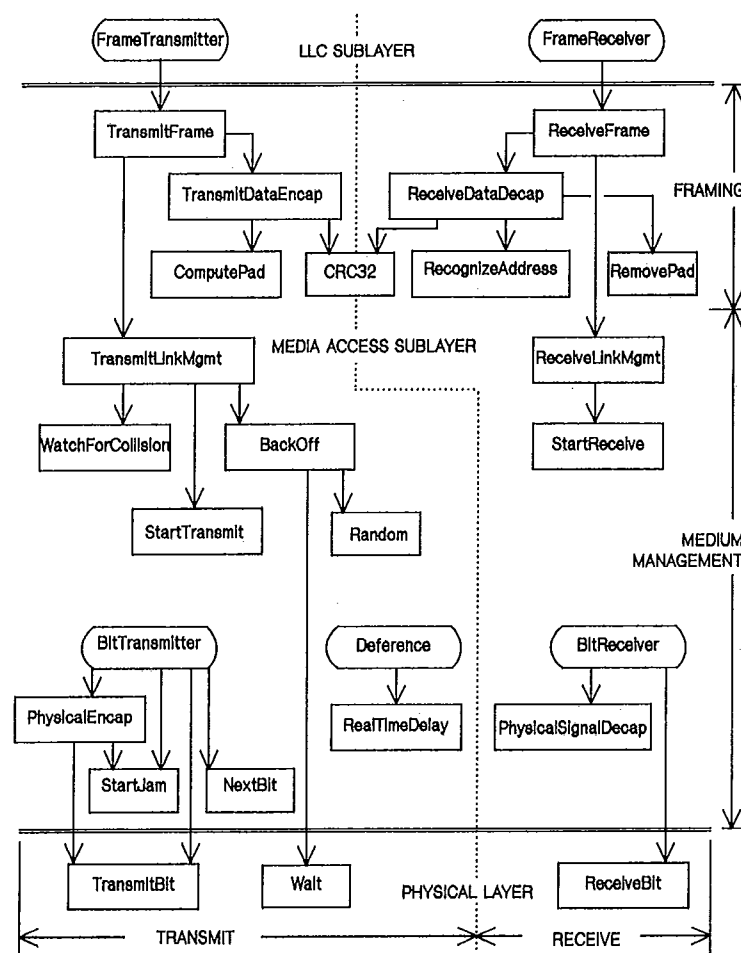
4.2.2.3 Organization of the Procedural Model. The procedural model used here is based on five cooperating concurrent processes. Three are actually defined in the MAC sublayer. The remaining two processes are provided by the clients of the MAC sublayer (which may include the LLC sublayer) and utilize

the interface operations provided by the MAC sublayer. The five processes are thus:

- (1) Frame Transmitter Process
- (2) Frame Receiver Process
- (3) Bit Transmitter Process
- (4) Bit Receiver Process
- (5) Deference Process

This organization of the model is illustrated in Fig 4-3 and reflects the fact that the communication of entire frames is initiated by the client of the MAC sublayer; while the timing of collision backoff and of individual bit transfers

Fig 4-3
Relationship Among CSMA/CD Procedures



is based on interactions between the MAC sublayer and the Physical-Layer-dependent bit time.

Figure 4-3 depicts the static structure of the procedural model, showing how the various processes and procedures interact by invoking each other. Figures 4-4 and 4-5 summarize the dynamic behavior of the model during transmission and reception, focusing on the steps that shall be performed, rather than the procedural structure that performs them. The usage of the shared state variables is not depicted in the figures, but is described in the comments and prose in the following sections.

4.2.3 Frame Transmission Model. Frame transmission includes data encapsulation and Media Access management aspects:

(1) Transmit Data Encapsulation includes the assembly of the outgoing frame (from the values provided by the LLC sublayer) and frame check sequence generation.

(2) Transmit Media Access Management includes carrier deference, interframe spacing, collision detection and enforcement, and collision backoff and retransmission.

4.2.3.1 Transmit Data Encapsulation

4.2.3.1.1 Frame Assembly. The fields of the CSMA/CD MAC frame are set to the values provided by the LLC sublayer as arguments to the Transmit-Frame operation (see 4.3) with the exception of the padding necessary to enforce the minimum framesize and the frame check sequence that is set to the CRC value generated by the MAC sublayer.

4.2.3.1.2 Frame Check Sequence Generation. The CRC value defined in 3.8 is generated and inserted in the frame check sequence field, following the fields supplied by the LLC sublayer.

4.2.3.2 Transmit Media Access Management

4.2.3.2.1 Carrier Deference. Even when it has nothing to transmit, the CSMA/CD MAC sublayer monitors the physical medium for traffic by watching the carrierSense signal provided by the PLS. Whenever the medium is busy, the CSMA/CD MAC sublayer defers to the passing frame by delaying any pending transmission of its own. After the last bit of the passing frame (that is, when carrierSense changes from true to false), the CSMA/CD MAC sublayer continues to defer for a proper interFrameSpacing (see 4.2.3.2.2).

If, at the end of the interFrameSpacing, a frame is waiting to be transmitted, transmission is initiated independent of the value of carrierSense. When transmission has completed (or immediately, if there was nothing to transmit) the CSMA/CD MAC sublayer resumes its original monitoring of carrierSense.

When a frame is submitted by the LLC sublayer for transmission, the transmission is initiated as soon as possible, but in conformance with the rules of deference stated above.

NOTE: It is possible for the PLS carrier sense indication to fail to be asserted briefly during a collision on the media. If the Deference process simply times the interFrame gap based on this indication it is possible for a short interFrame gap to be generated, leading to a potential reception failure of a subsequent frame. To enhance system robustness the following optional measures, as specified in 4.2.8, are recommended when interFrame SpacingPart1 is other than zero:

ISO 8802-3 : 1989
ANSI/IEEE Std 802.3-1988

LOCAL AREA NETWORKS:

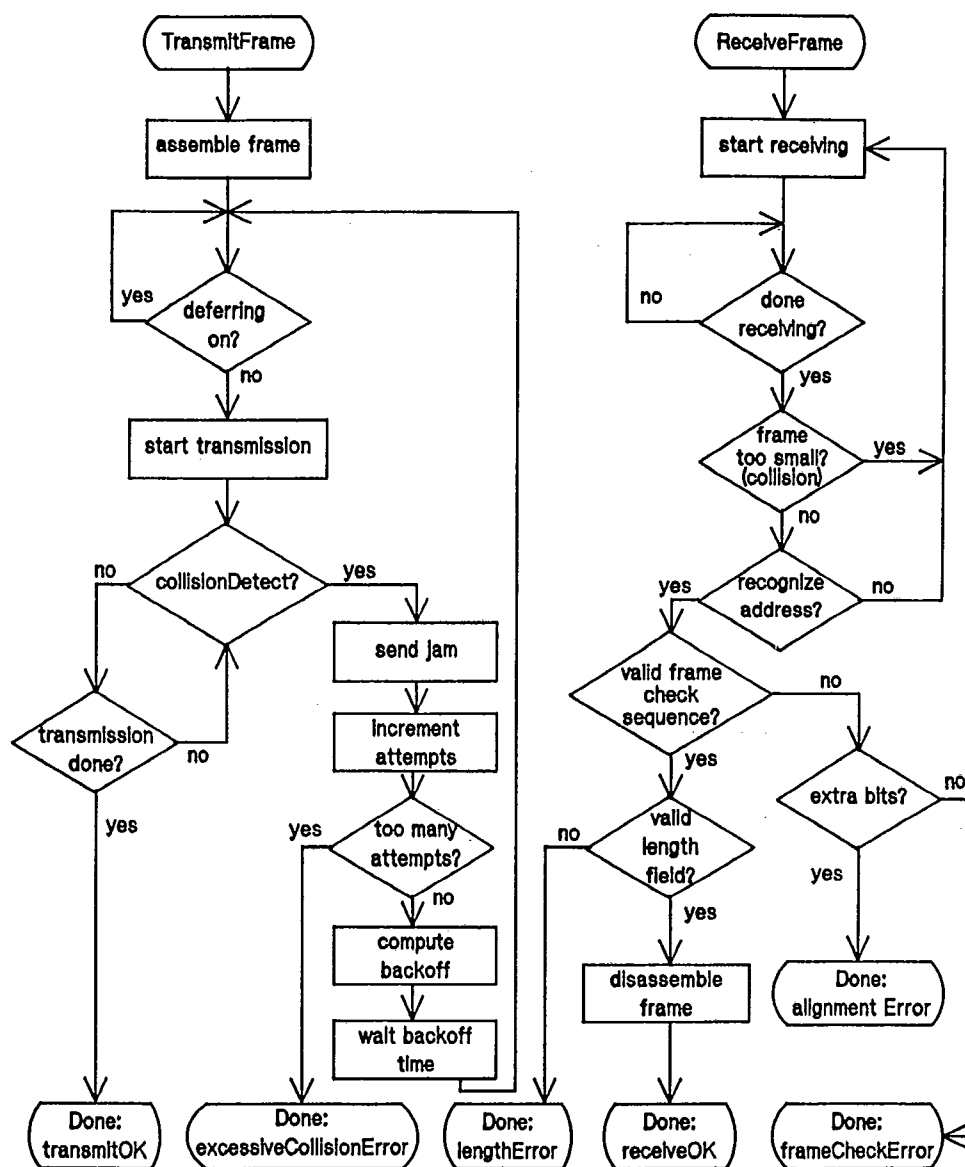


Fig 4-4
Control Flow Summary

CSMA/CD

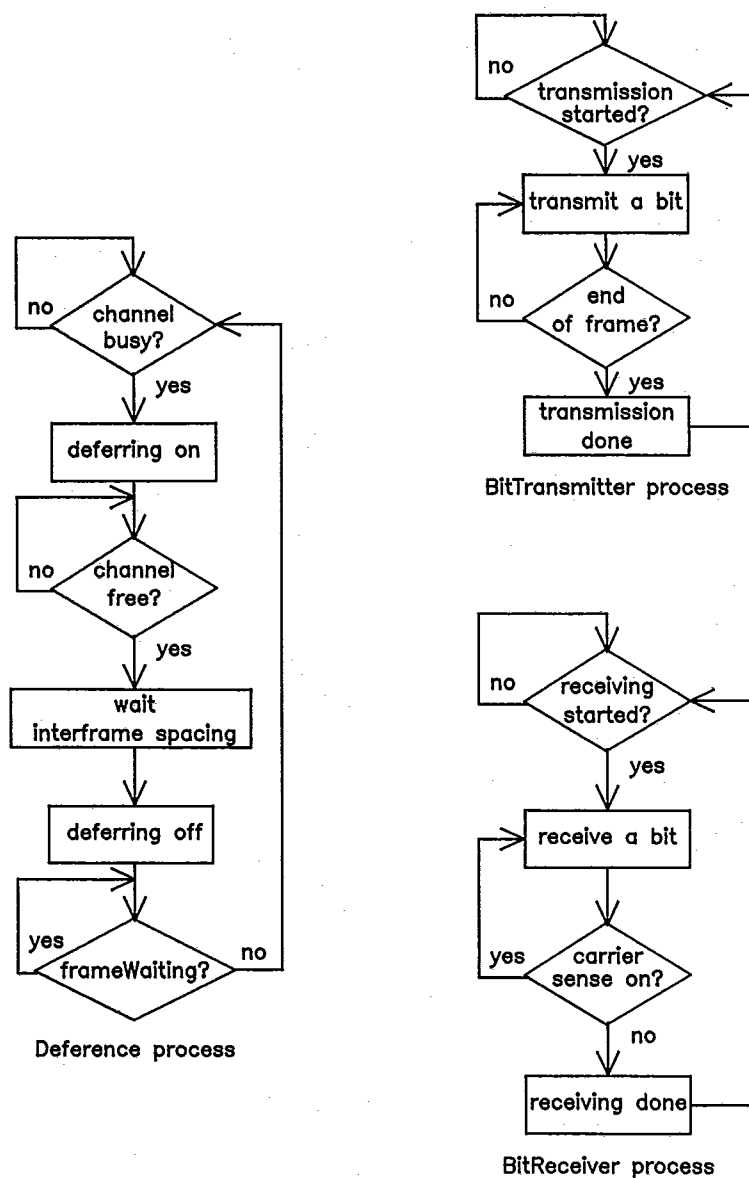
ISO 8802-3 : 1989
ANSI/IEEE Std 802.3-1988

Fig 4-5
Control Flow: MAC Sublayer

- (1) Upon completing a transmission, start timing the interpacket gap as soon as transmitting and carrierSense are both false.
- (2) When timing an interFrame gap following reception, reset the interFrame gap timing if carrierSense becomes true during the first 2/3 of the interFrame gap timing interval. During the final 1/3 of the interval the timer shall not be reset to ensure fair access to the medium. An initial period shorter than 2/3 of the interval is permissible including zero.

4.2.3.2.2 Interframe Spacing. As defined in 4.2.3.2.1, the rules for deferring to passing frames ensure a minimum interframe spacing of interFrameSpacing seconds. This is intended to provide interframe recovery time for other CSMA/CD sublayers and for the physical medium.

Note that interFrameSpacing is the minimum value of the interframe spacing. If necessary for implementation reasons, a transmitting sublayer may use a larger value with a resulting decrease in its throughput. The larger value is determined by the parameters of the implementation, see 4.4.

4.2.3.2.3 Collision Handling. Once a CSMA/CD sublayer has finished deferring and has started transmission, it is still possible for it to experience contention for the medium. Collisions can occur until acquisition of the network has been accomplished through the deference of all other stations' CSMA/CD sublayers.

The dynamics of collision handling are largely determined by a single parameter called the slot time. This single parameter describes three important aspects of collision handling:

- (1) It is an upper bound on the acquisition time of the medium.
- (2) It is an upper bound on the length of a frame fragment generated by a collision.
- (3) It is the scheduling quantum for retransmission.

To fulfill all three functions, the slot time shall be larger than the sum of the Physical Layer round-trip propagation time and the Media Access Layer maximum jam time. The slot time is determined by the parameters of the implementation, see 4.4.

4.2.3.2.4 Collision Detection and Enforcement. Collisions are detected by monitoring the collisionDetect signal provided by the Physical Layer. When a collision is detected during a frame transmission, the transmission is not terminated immediately. Instead, the transmission continues until additional bits specified by jamSize have been transmitted (counting from the time collisionDetect went on). This collision enforcement or jam guarantees that the duration of the collision is sufficient to ensure its detection by all transmitting stations on the network. The content of the jam is unspecified; it may be any fixed or variable pattern convenient to the Media Access implementation, however, the implementation shall not be intentionally designed to be the 32-bit CRC value corresponding to the (partial) frame transmitted prior to the jam.

4.2.3.2.5 Collision Backoff and Retransmission. When a transmission attempt has terminated due to a collision, it is retried by the transmitting CSMA/CD sublayer until either it is successful or a maximum number of attempts (attemptLimit) have been made and all have terminated due to collisions. Note that all attempts to transmit a given frame are completed before

any subsequent outgoing frames are transmitted. The scheduling of the retransmissions is determined by a controlled randomization process called "truncated binary exponential backoff." At the end of enforcing a collision (jamming), the CSMA/CD sublayer delays before attempting to retransmit the frame. The delay is an integer multiple of slotTime. The number of slot times to delay before the *n*th retransmission attempt is chosen as a uniformly distributed random integer *r* in the range:

$$0 \leq r < 2^k$$

where

$$k = \min(n, 10)$$

If all attemptLimit attempts fail, this event is reported as an error. Algorithms used to generate the integer *r* should be designed to minimize the correlation between the numbers generated by any two stations at any given time.

Note that the values given above define the most aggressive behavior that a station may exhibit in attempting to retransmit after a collision. In the course of implementing the retransmission scheduling procedure, a station may introduce extra delays that will degrade its own throughput, but in no case may a station's retransmission scheduling result in a lower average delay between retransmission attempts than the procedure defined above.

4.2.3.3 Minimum Frame Size. The CSMA/CD Media Access mechanism requires that a minimum frame length of minFrameSize bits be transmitted. If frameSize is less than minFrameSize, then the CSMA/CD MAC sublayer shall append extra bits in units of octets, after the end of the LLC data field but prior to calculating, and appending, the FCS. The number of extra bits shall be sufficient to ensure that the frame, from the DA field through the FCS field inclusive, is at least minFrameSize bits. The content of the pad is unspecified.

4.2.4 Frame Reception Model. CSMA/CD MAC sublayer frame reception includes both data decapsulation and Media Access management aspects:

(1) Receive Data Decapsulation comprises address recognition, frame check sequence validation, and frame disassembly to pass the fields of the received frame to the LLC sublayer.

(2) Receive Media Access Management comprises recognition of collision fragments from incoming frames and truncation of frames to octet boundaries.

4.2.4.1 Receive Data Decapsulation

4.2.4.1.1 Address Recognition. The CSMA/CD MAC sublayer is capable of recognizing individual and group addresses.

(1) *Individual Addresses.* The CSMA/CD MAC sublayer recognizes and accepts any frame whose DA field contains the individual address of the station.

(2) *Group Addresses.* The CSMA/CD MAC sublayer recognizes and accepts any frame whose DA field contains the Broadcast address.

The CSMA/CD MAC sublayer is capable of activating some number of group addresses as specified by higher layers. The CSMA/CD MAC sublayer recognizes and accepts any frame whose Destination Address field contains an active group address. An active group address may be deactivated.

4.2.4.1.2 Frame Check Sequence Validation. FCS validation is essentially identical to FCS generation. If the bits of the incoming frame (exclusive of the FCS field itself) do not generate a CRC value identical to the one received, an error has occurred and the frame is identified as invalid.

4.2.4.1.3 Frame Disassembly. Upon recognition of the Start Frame Delimiter at the end of the preamble sequence, the CSMA/CD MAC sublayer accepts the frame. If there are no errors, the frame is disassembled and the fields are passed to the LLC sublayer by way of the output parameters of the Receive-Frame operation.

4.2.4.2 Receive Media Access Management

4.2.4.2.1 Framing. The CSMA/CD sublayer recognizes the boundaries of an incoming frame by monitoring the carrierSense signal provided by the PLS. There are two possible length errors that can occur, that indicate ill-framed data: the frame may be too long, or its length may not be an integer number of octets.

(1) *Maximum Frame Size.* The receiving CSMA/CD sublayer is not required to enforce the frame size limit, but it is allowed to truncate frames longer than `maxFrameSize` octets and report this event as an (implementation-dependent) error.

(2) *Integer Number of Octets in Frame.* Since the format of a valid frame specifies an integer number of octets, only a collision or an error can produce a frame with a length that is not an integer multiple of 8 bits. Complete frames (that is, not rejected as collision fragments; see 4.2.4.2.2) that do not contain an integer number of octets are truncated to the nearest octet boundary. If frame check sequence validation detects an error in such a frame, the status code `alignmentError` is reported.

4.2.4.2.2 Collision Filtering. The smallest valid frame shall be at least one `slotTime` in length. This determines the `minFrameSize`. Any frame containing less than `minFrameSize` bits is presumed to be a fragment resulting from a collision. Since occasional collisions are a normal part of the Media Access management procedure, the discarding of such a fragment is not reported as an error to the LLC sublayer.

4.2.5 Preamble Generation. In a LAN implementation, most of the Physical Layer components are allowed to provide valid output some number of bit times after being presented valid input signals. Thus it is necessary for a preamble to be sent before the start of data, to allow the PLS circuitry to reach its steady-state. Upon request by `TransmitLinkMgmt` to transmit the first bit of a new frame, `PhysicalSignalEncap` shall first transmit the preamble, a bit sequence used for physical medium stabilization and synchronization, followed by the Start Frame Delimiter. If, while transmitting the preamble, the PLS

asserts the collision detect signal, any remaining preamble bits shall be sent. The preamble pattern is:

10101010 10101010 10101010 10101010 10101010 10101010 10101010

The bits are transmitted in order, from left to right. The nature of the pattern is such that, for Manchester encoding, it appears as a periodic waveform on the medium that enables bit synchronization. It should be noted that the preamble ends with a "0."

4.2.6 Start Frame Sequence. The PLS recognizes the presence of activity on the medium through the carrier sense signal. This is the first indication that the frame reception process should begin. Upon reception of the sequence 10101011 immediately following a latter part of the preamble pattern, PhysicalSignalDecap shall begin passing successive bits to ReceiveLinkMgmt for passing to the LLC sublayer.

4.2.7 Global Declarations. This section provides detailed formal specifications for the CSMA/CD MAC sublayer. It is a specification of generic features and parameters to be used in systems implementing this media access method. Section 4.4 provides values for these sets of parameters for recommended implementations of this media access mechanism.

4.2.7.1 Common Constants and Types. The following declarations of constants and types are used by the frame transmission and reception sections of each CSMA/CD sublayer:

const

addressSize = ... ; (16 or 48 bits in compliance with 3.2.3)
lengthSize = 16; (in bits)
LLCdataSize = ...; (LLC Data, see 4.2.2.2, (1)(c))
padSize = ...; (in bits, = max (0, minFrameSize - (2 x addressSize
+ lengthSize + LLCdataSize + crcSize)))
dataSize = ...; (= LLCdataSize + padSize)
crcSize = 32; (32 bit CRC = 4 octets)
frameSize = ...; (= 2 x addressSize + lengthSize + dataSize + crcSize,
see 4.2.2.2(1))
minFrameSize = ... ; (in bits, implementation-dependent, see 4.4)
slotTime = ... ; (unit of time for collision handling,
implementation-dependent, see 4.4)
preambleSize = ... ; (in bits, physical-medium-dependent)
sfdSize = 8; (8 bit start frame delimiter)
headerSize = ...; (sum of preambleSize and sfdSize)

type

Bit = 0..1;
AddressValue = array [1..addressSize] of Bit;
LengthValue = array [1..lengthSize] of Bit;
DataValue = array [1..dataSize] of Bit;
CRCValue = array [1..crcSize] of Bit;
PreambleValue = array [1..preambleSize] of Bit;

```

SfdValue = array [1..sfdSize] of Bit;
ViewPoint = (fields, bits); (Two ways to view the contents of a frame)
HeaderViewPoint = (headerFields, headerBits);
Frame = record (Format of Media Access frame)
  case view: ViewPoint of
    fields: (
      destinationField: AddressValue;
      sourceField: AddressValue;
      lengthField: LengthValue;
      dataField: DataValue;
      fcsField: CRCValue);
    bits: (contents: array [1..frameSize] of Bit)
  end; (Frame)
Header = record (Format of preamble and start frame delimiter)
  case headerView : HeaderViewPoint of
    headerFields : (
      preamble : PreambleValue;
      sfd : SfdValue);
    headerBits : (
      headerContents : array [1..headerSize] of Bit)
  end; (defines header for MAC frame)

```

4.2.7.2 Transmit State Variables. The following items are specific to frame transmission. (See also 4.4.)

const

```

interFrameSpacing = ... ; (minimum time between frames)
interFrameSpacingPart1 = ... ; (duration of first portion of interFrame
    timing. In range 0 up to 2/3
    interFrameSpacing)
interFrameSpacingPart2 = ... ; (duration of remainder of interFrame
    timing. Equal to interFrameSpacing
    - interFrameSpacingPart1)
attemptLimit = ... ; (Max number of times to attempt transmission)
backOffLimit = ... ; (Limit on number of times to back off)
jamSize = ... ; (in bits: the value depends upon medium and collision
    detect implementation)

```

var

```

outgoingFrame: Frame; (The frame to be transmitted)
outgoingHeader: Header;
currentTransmitBit, lastTransmitBit: 1..frameSize;
(Positions of current and last outgoing bits in outgoingFrame)
lastHeaderBit: 1..headerSize;
deferring: Boolean; (Implies any pending transmission must wait for
    the medium to clear)
frameWaiting: Boolean; (Indicates that outgoingFrame is deferring)

```

attempts: 0..attemptLimit; (Number of transmission attempts on outgoingFrame)
 newCollision: Boolean; (Indicates that a collision has occurred but has not yet been jammed)
 transmitSucceeding: Boolean; (Running indicator of whether transmission is succeeding)

4.2.7.3 Receive State Variables. The following items are specific to frame reception. (See also 4.4.)

var
 incomingFrame: Frame; (The frame being received)
 currentReceiveBit: 1..frameSize; (Position of current bit in incomingFrame)
 receiving: Boolean; (Indicates that a frame reception is in progress)
 excessBits: 0..7; (Count of excess trailing bits beyond octet boundary)
 receiveSucceeding: Boolean; (Running indicator of whether reception is succeeding)
 validLength: Boolean; (Indicator of whether received frame has a length error)

4.2.7.4 Summary of Interlayer Interfaces

(1) The interface to the LLC sublayer, defined in 4.3.2, is summarized below:

type
 TransmitStatus = (transmitOK, excessiveCollisionError);
 (Result of TransmitFrame operation)
 ReceiveStatus = (receiveOK, lengthError, frameCheckError, alignmentError);
 (Result of ReceiveFrame operation)

function TransmitFrame (
 destinationParam: AddressValue;
 sourceParam: AddressValue;
 lengthParam: LengthValue;
 dataParam: DataValue): TransmitStatus; (Transmits one frame)

function ReceiveFrame (
 var destinationParam: AddressValue;
 var sourceParam: AddressValue;
 var lengthParam: LengthValue;
 var dataParam: DataValue): ReceiveStatus; (Receives one frame)

(2) The interface to the Physical Layer, defined in 4.3.3, is summarized in the following:

```

var
  carrierSense: Boolean; (Indicates incoming bits)
  transmitting: Boolean; (Indicates outgoing bits)
  wasTransmitting: Boolean; (Indicates transmission in progress or
                             just completed)
  collisionDetect: Boolean; (Indicates medium contention)
  procedure TransmitBit (bitParam: Bit); (Transmits one bit)
  function ReceiveBit: Bit; (Receives one bit)
  procedure Wait (bitTimes: integer); (Waits for indicated number of
                                       bit-times)

```

4.2.7.5 State Variable Initialization. The procedure Initialize must be run when the MAC sublayer begins operation, before any of the processes begin execution. Initialize sets certain crucial shared state variables to their initial values. (All other global variables are appropriately reinitialized before each use.) Initialize then waits for the medium to be idle, and starts operation of the various processes.

```

procedure Initialize;
begin
  frameWaiting := false;
  deferring := false;
  newCollision := false;
  transmitting := false; (In interface to Physical Layer; see below)
  receiving := false;
  while carrierSense do nothing;
  (Start execution of all processes)
end; (Initialize)

```

4.2.8 Frame Transmission. The algorithms in this section define MAC sublayer frame transmission. The function TransmitFrame implements the frame transmission operation provided to the LLC sublayer:

```

function TransmitFrame (
  destinationParam: AddressValue;
  sourceParam: AddressValue;
  lengthParam: LengthValue;
  dataParam: DataValue): TransmitStatus;
  procedure TransmitDataEncap; ... (nested procedure; see body below)
begin
  TransmitDataEncap;
  TransmitFrame := TransmitLinkMgmt
end; (TransmitFrame)

```

First, TransmitFrame calls the internal procedure TransmitDataEncap to construct the frame. Next, TransmitLinkMgmt is called to perform the actual