
**Information technology —
Telecommunications and information
exchange between systems —
MAC/PHY standard for ad hoc wireless
network to support QoS in an industrial
work environment**

*Technologies de l'information — Télécommunications et échange
d'information entre systèmes — Norme MAC/PHY pour un réseau ad
hoc sans fil qui supporte QoS dans un environnement de travail
industriel*



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Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

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Information technology — Telecommunications and information exchange between systems — MAC/PHY standard for ad hoc wireless network to support QoS in an industrial work environment

1 Scope

This International Standard defines a protocol for the physical layer (PHY) and the data link layer in order to construct a reliable and high-speed data transmission network between devices on industrial sites such as factories and plants. This network specification provides a standardized protocol to provide a framework for various industrial devices to establish a simple, low-cost, energy-efficient, and high-speed network between them. In order to fulfil the service requirements of the factories and large plants, this network specification is designed to enable devices to establish a network by themselves without the help of any infrastructure and to reliably exchange various kinds of data, including real-time audio and video data, between them. In addition to high transmission rates, Quality of Service (QoS) for multimedia data - such as video - is also provided.

The devices mentioned in this International Standard refer to equipment that can be used on industrial sites such as factories and automated assembly lines. Devices include PLC (Programmable Logic Controller), and CNC (Computerized Numerical Controller) and manufacturing robots. However, beyond such conventional devices, devices mentioned in this document include personal IT devices that workers may carry and use while working, including cellular phones, personal industrial digital assistants (PDA), and laptop PCs.

2 Terms and definitions, and abbreviated terms

For the purposes of this document, the following terms and definitions, and abbreviated terms apply.

2.1 Terms and definitions

2.1.1

access control

control process to prevent unauthorized use of resources or bandwidth

2.1.2

ad hoc network

network that is spontaneously formed usually without system installation

NOTE Such networks are mainly characterized by time and space limitations.

2.1.3

association

service used to connect authorized devices in the network

2.1.4

authentication

device verification process allowing devices within the network to connect to one another

2.1.5

coverage area

territory over which two devices can achieve acceptable quality and performance while exchanging data

2.1.6

dissociation

service used in an established network

2.1.7

frame

format of bits in a data exchange

2.1.8

K

prefix indicating multiplication by 1024

2.1.9

K μ s

unit of 1024 μ s

2.1.10

k

prefix indicating multiplication by 1000

2.1.11

logical channel

data link channel sitting distinctly above the physical layer

2.1.12

master

station that manages the network by periodically transmitting a beacon packet

2.1.13

MAC management protocol data unit

MMPDU

data unit exchanged between two media access control apparatuses in order to implement the media access control management protocol

2.1.14

MAC protocol data unit

MPDU

data unit exchanged between two media access control apparatuses by means of utilizing the physical layer services

2.1.15

MAC service data unit

MSDU

data unit transmitted between media access control service access points

2.1.16

mobile device

device that utilizes communication networks while in motion

2.1.17

packet

structure of bits sent in one data transmission

2.1.18

portable device

station that is normally portable but must be in a fixed location in order to link to the communication network

2.1.19

slave

station in the network other than the master

2.1.20

station

device that can operate according to this International Standard

2.2 Abbreviated terms

ARQ	automatic repeat request
ARQN	automatic repeat request N
ASN.1	abstract syntax notation 1
BER	bit error rate
CAP	contention access period
CCA	clear channel assessment
CDMA	code division multiple access
CODEC	coder/decoder
CRC	cyclic redundancy check
CTS	clear to send
DA	destination address
DBPSK	differential binary phase shift keying
DCE	data communication equipment
DLL	data link layer
DOQPSK	differential offset quadrature phase shift keying
DQPSK	differential quadrature phase shift keying
FCS	frame check sequence
FEC	forward error correction
FER	frame error rate
HCS	header check sequence
IETF	internet engineering task force
IDU	interface data unit
IP	internet protocol
ISM	industrial scientific medicine
IWN	industrial wireless network
LAN	local area network
LFSR	linear feedback shift register
LLC	logical link control
LM	link manager

LME	layer management entity
LMP	link manager protocol
LSB	least significant bit
MAC	medium access control
Master	network coordinator
MC-CDMA	multi-code CDMA
MCDU	MAC command data unit
MCPDU	MAC command protocol data unit
MDF	management-defined field
MIB	management information base
MLME	MAC layer management entity
MPDU	MAC protocol data unit
MSB	most significant bit
MSC	message sequence chart
MSDU	MAC service data unit
MTU	maximum transmission unit
NID	network ID
PAN	personal area network
PAR	project authorization request
PDU	protocol data unit
PER	packet error ratio
PHY	physical layer
PIB	PAN information base
PLME	physical layer management entity
PN	pseudo noise
PPDU	PHY protocol data unit
PPM	parts per million
PRNG	pseudo random number generator
PSDU	PHY service data unit
QAM	quadrature amplitude modulation

QoS	quality of service
QPSK	quadrature phase shift keying
OQPSK	offset quadrature phase shift keying
RF	radio frequency
RFC	request for comments
RSSI	received signal strength indication
RTS	request to send
RTX	response timeout expired
RX	receive or receiver
SAP	service access point
SDP	service discovery protocol
SDU	service data unit
SEQN	sequential numbering scheme
SME	station management entity
SQ	signal quality
SRC	short retry count
SRES	signed response
SS	station service
TA	transmitter address
TCM	trellis coded modulation
TDD	time division duplex
TDMA	time division multiple access
TX	transmit or transmitter
TXE	transmit enable
WAN	wide area network
WLAN	wireless local area network
WM	wireless medium

3 Overview

This section defines the general attributes of the industrial wireless network and describes the attributes of the physical layer and data link layer. The physical layer is built upon a binary CDMA, and the data link layer is composed of the media access control (MAC) layer.

3.1 Characteristics

This International Standard is designed for the construction and management of an optimal network for industrial use applications.

3.1.1 Ad hoc network

This International Standard is based upon an ad hoc network that can be established even without a network infrastructure. A network is made up of two kinds of devices - a master and a slave, which is differentiated according to their functions. All stations can function as a master or a slave and one of them is selected as a master based on the device layout and its capabilities. An independent network structure is feasible without requiring infrastructure.

3.1.2 Quality of service

The number of devices participating in an industrial wireless network changes vastly over time due to the channel conditions and industrial mobile device operation characteristics of a wireless environment. The bandwidth allocated to each device and the transmission delay time also have a significant effect, making it difficult to support real-time multimedia traffic services that require a certain quality of service.

This document requires one station in the network to be the master, which allocates and controls resources and thereby manages the connection quality of each network traffic.

3.1.3 Binary CDMA technology

This International Standard uses Binary-CDMA technology so that it has strong noise resistance, inherent advantage of CDMA, and has another good capability of changing bandwidth finely,

and thereby has the advantages of noise resistance and finely tuned and flexible resource allocation.

First, Binary-CDMA possesses superior noise resistance that is characteristic of CDMA technology, and this is an outstanding attribute in a wireless network environment which, unlike a wireline network, has a high noise factor. In addition, the nature of Binary CDMA makes it possible to adjust the bandwidth by changing the number of codes used, thereby allowing flexible and finely-tuned resource allocation.

3.2 Components of network

The components of a network can be roughly depicted as shown in Figure 1. The primary component is the station. The first station trying to connect or establish a network becomes the master of the network and helps other stations to associate with it by periodically transmitting beacons. It also takes responsibilities such as quality of service and power management. The network is made up of two or more stations operating on the same wireless frequency channel in an industrial activity area.

3.2.1 Station

The station is the primary component of the network and is classified as either master or slave depending on its role. The master assumes full management, and no more than one can exist in a particular network. The master controls slaves by broadcasting beacons. Slaves send or receive data as directed by the master. To acquire time slots for data transfer, slaves make resource allocation requests to the master during the contention period.

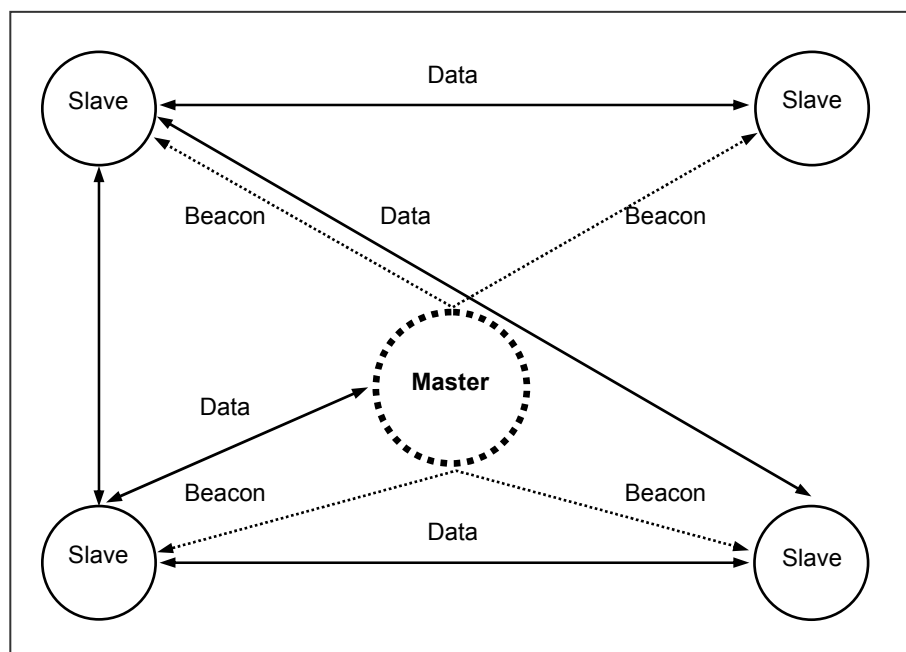


Figure 1 - Network

3.2.2 Resources

Stations in the network should acquire time slots from master to perform their aimed job – exchanging data. After a station acquired rights to use some time slots from master, it can transmit packets exclusively during assigned time slots. In this sense, this International Standard depicts time slots as resources, which stations in the network share and compete for. Time slots are supervised by the master and are distributed according to requests from slaves at the discretion of the master.

3.3 Functional overview

The media access control layer provides the following services:

- Network synchronization
- Data transmission
- Power management
- Change of the master

Data transmission and reception between stations are possible under different standards of quality of service.

3.3.1 Network synchronization

The network is established once the master transmits the beacon packet. The beacon packet contains the status information of the network, and all slaves in the network use this information to sync with the network. The superframe is roughly composed of three parts as shown in Figure 2, and each period has a variable length. (The allocation period must be a multiple of the timeslot length.)

Beacon period	Contention period	Allocation period			
		Time slot 1	Time slot 2	...	Time slot n

Figure 2 - Superframe

- a) beacon period: the master transmits the beacon packet containing the network status information to the slaves.
- b) contention period: the slaves and master send command packets such as associate/disassociate/grant packets, resource request/grant packets, and connect request/grant packets in a random access fashion.
- c) allocation period: this is divided into multiple time slots, each allotted for one station. The station receiving the time slot can send synchronous/asynchronous data or command packets during that interval.

3.3.2 Data transmission

For data transmission, two types of connections – synchronous and asynchronous - are supported. Asynchronous connections, which have minimal overhead when establishing connections but do not have a guaranteed bandwidth, are primarily used when transmitting general data that is relatively insensitive to delays. Synchronous connections, which carry a large overhead when establishing connections but have a guaranteed bandwidth, are used to transmit data for real-time services such as audio and video.

This International Standard manages communication quality in three characteristics – delay, data rate, BER. Each device defines the communication quality of data stream to send in these three parameters and sends the defined quality parameters to master to get channel time allocation. Master collects communication request from slaves and allocate time slots to streams in order that each stream can be transmitted satisfying each one's needed communication quality. Afterward a master monitors quality of communication of stream to check whether it meets initial QoS request. If the communication quality deteriorates below initial request quality, master changes time slot allocation to meet initial QoS request.

This International Standard covers MAC-to-MAC QoS within 1-hop network that MAC layer can control.

3.3.2.1 QoS parameter

Data transfers in this International Standard are differentiated as streams which are largely divided into synchronous stream and asynchronous stream, depending on whether a stream has QoS characteristic or not. Synchronous stream has 3 QoS parameter – Period, Data size to transmit per each period, BER, while asynchronous stream have only data size as a parameter.

Synchronous stream in this International Standard manages QoS with the following three parameters.

- Period: the period with which master allocates time slot. Each device is assigned at least a time slot within this period so that this value is equal to maximum delay.
- Data size to transmit per each period: the size of data that a slave will send during each period. Combined with period, this value decides data rate.
- BER: This value defines quality of communication in Bit Error Rate

Using above QoS parameters, devices can define their communication request with detail characteristics.

3.3.2.2 Maintenance of QoS

A master of a network manages communication resource (time slots) centrally. Master collects network information (usage status of allocated time slots, channel quality of each channel) and communication request by itself or from slaves and allocates time slots to slaves in order that each communication can meet its QoS request. After allocating time slots, a master checks whether each communication meets its initial QoS request. If communication does not meet its QoS requirements, a master makes communication to meet its initial requirements by using the following actions.

3.3.2.2.1 Check and estimation of wireless channel environment

Master continuously monitors BER and SNR value of current wireless channel environment. When it detects the serious change of channel environment, a master takes an action to counterpart the change such as data rate change or frequency channel change.

3.3.2.2.2 Dynamic link quality control

A master continuously monitors actual communication status of data streams in a network. When a communication quality of a stream goes worse than its pre-determined level, a master changes resource allocations in order that the communication quality should meet its pre-determined level. To increase communication quality of a stream, a master decreases data rate of the stream and allocates more time slots to compensate reduced data rate through resource allocation and change mechanism.

3.3.2.2.3 Dynamic channel selection and change

When a master estimates that the network-wide communication quality of the current frequency channel goes worse than the acceptable level, it decides to change a frequency channel. Master notifies the new channel where network will be re-established to slaves, slaves leave current frequency channel and rejoin at the notified new channel. This function provides not only the ability to maintain the certain network-wide communication quality, but also interoperability to avoid collision with other kinds of wireless network.

3.3.3 Power management

In order to support mobile devices, efficient power management is critical. Each station is notified of the presence and timing of the incoming data during the corresponding superframe by means of the beacon packet, and can reduce power consumption by disabling the physical layer when not transmitting data. During a particular superframe, stations that are not transmitting data can be disabled until the next superframe period starts. Stations receiving data are enabled only during beacon periods and intervals during which they receive frames. Stations sending data or making requests are enabled during intervals when there is data to transmit.

3.3.4 Handover of the master

The master can decide whether to appoint another slave as the master based on the information it possesses about each slave's capabilities. If a newly connected station is determined to be better for the master, the master role may be handed over. Also, due to the nature of an ad hoc network, the master may unexpectedly cease operating or depart from the established service area. In such an event, one of the remaining slaves which is most suitable for the master is selected to manage the network.

3.4 Summary of operations

The superframe is divided into the beacon period, contention period, and allocation period, and the stations operate in different modes depending on the period.

3.4.1 Broadcasting during the beacon period

During the beacon period the master broadcasts a beacon packet to all slaves. The beacon packet includes information about the status and resource availability of the network, and the slaves receiving the beacon packet use this information to verify the correctness of the corresponding superframe as well as the allocated resources.

The master places network status information into the beacon packet and sends it out to all slaves.

3.4.2 Random access during the contention period

During the contention period the slave and master communicate via the CSMA/CA scheme. Slave sends command packets such as resource allocation requests to the master during this period, and the master sends back an acknowledgement or response packet.

3.4.3 Exclusive access during the allocation period

During the allocation period, only the stations permitted by the master can communicate using the time slot and code assigned to them in the beacon packet. The master evaluates the currently available resources and decides whether or not to grant the slave's service request and allocate the resources. Data services that use asynchronous connections receive acknowledgements for the dispatched frames by default, and synchronous connections receive acknowledgements selectively.

3.5 Summary of states

A station has the following operational states.

- establishing the network
- associating with the network
- sending data
- changing the master
- disassociating from the network
- terminating the network

3.5.1 Establishing the network

The master establishes the network by filling a beacon packet with synchronization information such as the length of the superframe, contention period, and allocation period, and sending it out. The beacon packet includes the network ID as well as synchronization information, enabling the stations to identify the network they will connect with.

3.5.2 Associating with the network

Stations attempting to associate with the network periodically scan each frequency channel to listen for the beacon packet from the master. If the received packet is the beacon packet for the desired network, the process of associating with the relevant network's master is started, and if this succeeds, the link to the network is established.

When the station associates with the network, it sends its own capability information to the master. This capability information contains such information as the physical layer data transfer rate that can be supported, power management status, ability to function as the master, and size of memory, and based on this information the master may decide to initiate the process of changing the master.

3.5.3 Sending data

A slave to send data first requests resources for the transmission from the master during the contention period, and once it is allocated to the resources it uses them to send the data. Data transfer is possible between any stations – not only between master and slave, but also between slaves themselves. The master is involved only during the initial resource allocation process, thus enabling the stations to exchange data freely afterwards.

3.5.4 Changing the master

The nature of an ad hoc network entails frequent changes of the master. The following cases are the two most likely scenarios.

- The current master is no longer able to service requests. (For example, it cannot meet the decided quality of service.)
- The master abruptly vanishes from the network. (It loses power or moves out of the network.)

3.5.5 Disassociating from the network

Stations currently associated with the network can disassociate from the network either spontaneously or at the will of the master.

In the case of spontaneous disassociation, the station sends a disassociate request to the master. If the master wants to disassociate from the network, it first hands over the master role to the most capable slave among the stations before disassociating.

If a certain slave is having trouble in receiving service due to network conditions, the master can forcibly disassociate it by sending a disassociate command.

3.5.6 Terminating the network

Terminating of the network can be categorized in two ways: normal termination by station request and abnormal termination due to unexpected events.

Normal termination refers to the case where the master receives the request from a slave, decides whether or not to terminate, then broadcasts this decision to all slaves, thereby dissolving the network. The master can also initiate this request.

Abnormal termination of the network refers to cases where the network is dissolved due to situations such as a network-wide power outage or exodus out of the industrial coverage area. However, such occurrences are highly unlikely.

4 Inter-layer interfaces

4.1 Summary

Both the MAC layer and the physical layer conceptually have management entities, called the MAC Layer Management Entity (MLME) and the Physical Layer Management Entity (PLME) respectively. These entities provide a service interface for layer management functions.

The physical layer provides an interface between the MAC sublayer and the wireless channel by means of the PHY firmware and the PHY hardware. The physical layer includes a conceptual management entity called a PLME. This entity provides a service interface by means of layer management functions. The PLME maintains a database for managed objects in the physical layer, also called the Management information base (MIB). The Device Management Entity (DME) is a layer independent from the other management entities and its functionality is beyond the scope of this International Standard. Simply stated, however, it is responsible for the inter-layer interfaces providing device management functions. The physical layer provides services through two Service Access Points (SAP). Data services are provided through the PD-SAP and management services are provided through the PLME-SAP. In addition, the physical layer provides DME-PLME-SAP interface, which is equivalent to the PLME-SAP interface except that it operates through DME rather than MLME.

In order for the MAC to operate correctly, each station must possess a Device Management Entity (DME). DME exists in each layer and is layer-independent. The functions of DME are beyond the scope of this International Standard and vary depending on implementation, but in general they carry out tasks such as receiving data from a layer or initializing another layer. Generally DME acts under the direction of a higher-level management application. Figure 3 shows the relationships between the various management entities.

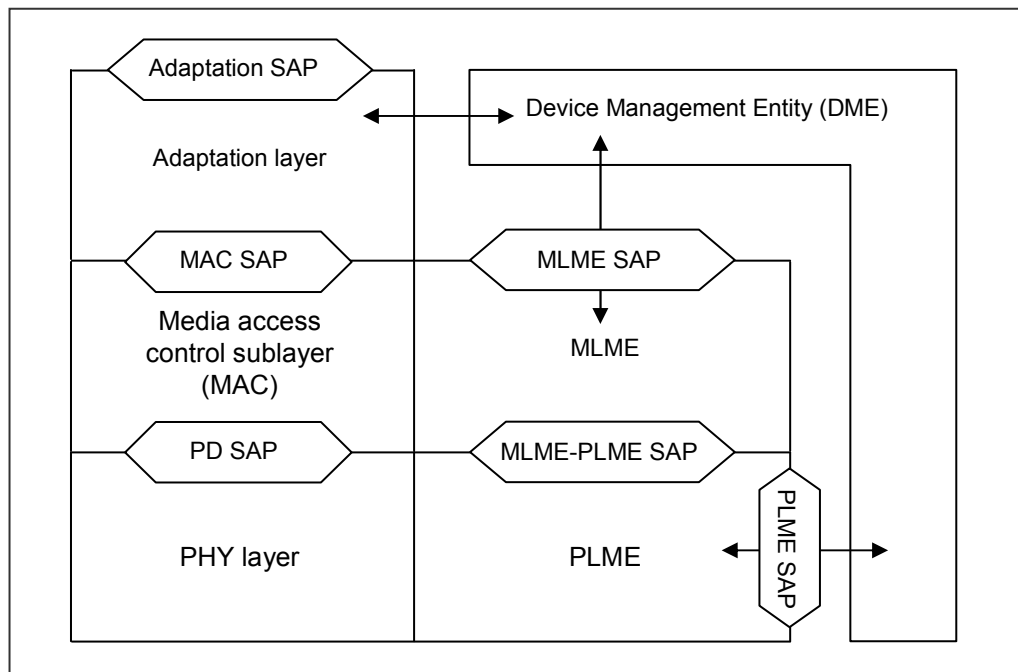


Figure 3 - Protocol stack configuration

4.2 General format of management primitives

Each sublayer's specific management information is organized into the relevant Management information base (MIB). Corresponding to the MIB of the PAN, the LAN/MAN contains the Management Information Base (MIB) that operates according to the Simple Network Management Protocol (SNMP). However, since management within Network is restricted to an individual network (i.e. one network does not interfere in the management of another) the MIB is used to define the specifications of each sublayer.

MLME and PLME are assumed to have a MIB for each sublayer, and the management primitives of the MIB are exchanged by means of management SAPs. The manager can "GET" or "SET" the value of the MIB attribute via the primitives. The "SET" request primitive can also trigger certain actions within the relevant layer.

A "GET" or "SET" primitive may be expressed in the form of a request accompanying a confirm primitive. Such primitives have the prefix MLME or PLME depending on whether the point of exchange is the MAC SAP or the PD SAP. DME utilizes the services provided by MLME through the MLME SAP.

In Table 1, "XX" stands for "MLME" or "PLME", and the parameters of the primitives are defined in Table 2.

Table 1 - General management primitive overview

Name	Request	Confirm
XX-GET	Refer to 4.2.1	Refer to 4.2.2
XX-SET	Refer to 4.2.3	Refer to 4.2.4

Table 2 - MLME/PLME general management primitive parameters

Name	Type	Valid range	Description
MIBattribute	Octet string	Any MIB attribute	MIB attribute name
MIBValue	Variable		MIB value
ResultCode	Enumeration	SUCCESS, INVALID_MIB_ATTRIBUTE, READ_ONLY_MIB_ATTRIBUTE, WRITE_ONLY_MIB_ATTRIBUTE	Result of MLME or PLME request

4.2.1 MLME-GET.request and PLME-GET.request

These primitives request information about the relevant MAC MIB or PHY MIB. The semantics of these primitives are as follows.

```
XX-GET.request (
    MIBattribute
)
```

The primitive parameters are defined in Table 2.

4.2.1.1 Time of creation

DME and MLME (in the case of a PLME-GET.request) create these primitives to retrieve information from the MAC or PHY MIB.

4.2.1.2 Effect

The relevant management entity fetches the requested MIB attribute from the database and returns the value as the result of XX-GET.confirm.

4.2.2 MLME-GET.confirm and PLME-GET.confirm

These primitives return the result of an information request to the relevant MAC MIB or PHY MIB. The semantics of these primitives are as follows.

```
XX-GET.confirm (
    Status,
    MIBattribute,
    MIBattributevalue
)
```

The primitive parameters are defined in Table 2.

4.2.2.1 Time of creation

DME or MLME (in the case of a PLME-GET.confirm) create these primitives in response to an XX-GET.request.

4.2.2.2 Effect

If the status is SUCCESS, these primitives return the value of the relevant MIB attribute, otherwise they return the error code in the status field. Valid error status values include INVALID_MIB_ATTRIBUTE and WRITE_ONLY_MIB_ATTRIBUTE.

4.2.3 MLME-SET.request and PLME-SET.request

These primitives attempt to set the value of the relevant MAC MIB or PHY MIB attribute to the specified parameter. The semantics of these primitives is as follows.

```
XX-SET.request (  
    MIBAttribute,  
    MIBAttributevalue  
)
```

The primitive parameters are defined in Table 2.

4.2.3.1 Time of creation

These primitives are created when DME or MLME (in the case of PLME-SET.request) tries to set the relevant MAC/PHY MIB attribute.

4.2.3.2 Effect

The relevant management entity tries to alter the value of the MIB attribute in the database. If the MIB is a reference to certain actions, this is interpreted as a request to execute the action. The management entity that receives this command responds by returning the result through a call to XX-SET.confirm.

4.2.4 MLME-SET.confirm and PLME-SET.confirm

These primitives return the result of the attempt to set the MAC MIB or PHY MIB attribute. The semantics of this primitive are as follows.

```
XX-SET.confirm (  
    Status,  
    MIBAttribute  
)
```

The primitive parameters are defined in Table 2.

4.2.4.1 Time of creation

DME or MLME (in the case of PLME-SET.confirm) create these primitives in order to respond to the XX-SET.request.

4.2.4.2 Effect

If the Status is SUCCESS, this means that the MIB attribute was set to the requested value. Otherwise, the Status field shows the error description. If the specified MIB attribute refers to a certain action, the primitive represents the success or failure of the execution of that action. Possible error status values include INVALID_MIB_ATTRIBUTE and READ_ONLY_MIB_ATTRIBUTE.

4.3 MLME SAP

In this subclause, the services that MLME provides to DME are defined. These definitions are conceptual and do not specify a certain implementation or external interface.

The MLME SAP primitive generally follows the format of an ACTION.confirm in response to an ACTION.request. The ACTION.indication is used to inform DME of events from other stations, and the station selectively sends an ACTION.response to the indication. DME uses the services provided by MLME through MLME SAP, and those primitives are outlined in Table 3.

Table 3 - MLME primitive summary

Name	Request	Indication	Response	Confirm
MLME-RESET	4.3.1.1			
MLME-SCAN	4.3.2.1			4.3.2.2
MLME-START	4.3.3.1			4.3.3.2
MLME-SYNCH	4.3.4.1			4.3.4.2
MLME-ATP-EXPIRED		4.3.4.3		
MLME-ASSOCIATE	4.3.5.1	4.3.5.2	4.3.5.3	4.3.5.4
MLME-STN-ASSOCIATION-INFO		4.3.5.5		
MLME-DISASSOCIATE	4.3.6.1	4.3.6.2		4.3.6.3
MLME-MASER-HANDOVER	4.3.7.1	4.3.7.2	4.3.7.3	4.3.7.4
MLME-MASTER-INFO	4.3.8.1	4.3.8.2	4.3.8.3	4.3.8.4
MLME-PROBE	4.3.9.1	4.3.9.2	4.3.9.3	4.3.9.4
MLME-CREATE-STREAM	4.3.10.1			4.3.10.2
MLME-MODIFY-STREAM	4.3.10.3			4.3.10.4
MLME-TERMINATE-STREAM	4.3.10.5	4.3.10.6		4.3.10.7
MLME-CHANNEL-STATUS	4.3.11.1	4.3.11.2	4.3.11.3	4.3.11.4
MLME-REMOTE-SCAN	4.3.12.1	4.3.12.2	4.3.12.3	4.3.12.4
MLME-NETWORK-PARM-CHANGE	4.3.13.1			4.3.13.2
MLME-TX-POWER-CHANGE	4.3.14.1	4.3.14.2		4.3.14.3
MLME-SLEEP	4.3.15.1	4.3.15.2	4.3.15.3	4.3.15.4

4.3.1 Reset

This mechanism describes the process of resetting the MAC. The parameters of this primitive are defined in Table 4.

Table 4 - MLME-RESET primitive parameters

Name	Type	Valid range	Description
SetDefaultMIB	Boolean	TRUE, FALSE	If TRUE, all MIB attributes are reset to their default values. If FALSE, the MAC is reset but all MIB values remain what they were prior to the execution of the MLME-RESET.request primitive
ResetTimeout	Duration	0 ~ 65535	The time in which the reset process must be completed, in msec

4.3.1.1 MLME-RESET.request

This primitive requests a reset of the MAC entity. The semantics are as follows.

```
MLME-RESET.request    (  
                        SetDefaultMIB,  
                        ResetTimeout  
                        )
```

The primitive parameters are defined in Table 4.

4.3.1.1.1 Time of creation

DME sends this message to MLME to restore the MAC to its initial state.

4.3.1.1.2 Effect

When the primitive is received, if the station is associated with the current network, MLME sends a disassociate request command to the master (see 5.5.1.3). In all cases, the slave MLME sets the MAC to its initial state, and resets all variables but is still consistent with the SetDefaultMIB (see Table 4).

When the master MLME receives this primitive, it behaves the same way as a slave MLME, except for cases when it has been disassociated from the network after transferring the master role or is performing a shutdown of network.

If the ResetTimeout occurs while MLME is still executing network disassociations, master handover, or network shutdown, MLME resets the MAC and cancels the interrupted process.

4.3.2 Scan

This mechanism determines the existence of the network in the communication channel. The parameters of this primitive are defined in Table 5.

PiconetDescriptionSet is the set of PiconetDescriptions, and a PiconetDescription is composed of the elements in Table 6.

Table 5 - MLME-SCAN primitive parameters

Name	Type	Valid range	Description
OpenScan	Boolean	TRUE, FALSE	Whether or not the scan is open (an open scan refers to search for any beacon frame)
NID	integer	0-65535	ID of the specific network to scan
ChannelList	Array of integers	0 – maximum channels supported by the physical layer	List of channels to search during a scan
Channel scanDuration	time	0-65535	The time it takes for the station to scan one channel
NumberOfNetworks	integer	0-255	Number of discovered networks (number of PiconetDescriptions in the PiconetDescriptionSet)
PiconetDescriptionSet	Network Description set	As defined in Table 6	The set of all attributes of the discovered networks, returned as the result of a scan request
NumberOfChannels	integer	0 - maximum channels supported by the physical layer	Number of channels to scan
ChannelRating List	Array of integers	0- maximum channels supported by the physical layer	List of channels sorted by quality (best to worst)
ResultCode	enumeration	SUCCESS, INVALID_PARAMETERS	Result of MLME request

Table 6 - PiconetDescription elements

Name	Type	Valid range	Description
MasterSTNAddress	MACaddress	all MACaddress	MACaddress of the master of the discovered network
NID	As defined in Table 5	As defined in Table 5	NID of the discovered network
ScannedFrameType	enumeration	BEACON, NON-BEACON	Type of the discovered frame
ChannelIndex	integer	0-255	Index of frequency channel on which the network was discovered
SuperframeDuration	time	0-65536	Length (msec) of the superframe of the discovered network
CPEndTime	integer	0-65525	The end time of the contention period of the discovered network

4.3.2.1 MLME-SCAN.request

This primitive requests a scan of the MAC entity. The semantics are as follows.

```
MLME-SCAN.request      (  
    OpenScan,  
    NID,  
    ChannelList  
    Channel scanDuration  
)
```

The primitive parameters are defined in Table 5.

4.3.2.1.1 Time of creation

When a manual SCAN is initiated for a search of a specified NID or an arbitrary NID of a network, DME sends this message to MLME.

4.3.2.1.2 Effect

When MLME receives this primitive from DME, it executes a manual SCAN of the channels in the Channel List. When this SCAN is completed, MLME responds to DME with the result of the SCAN through a call to MLME-SCAN.confirm.

4.3.2.2 MLME-SCAN.confirm

This primitive and its parameters are collected during the SCAN and sent back upon the completion of the SCAN. The semantics are as follows.

```
MLME-SCAN.confirm      (  
    NumberOfNetworks,  
    PiconetDescriptionSet,  
    NumberOfChannels,  
    ChannelRatingList,  
    ResultCode  
)
```

The primitive parameters are defined in Table 5.

4.3.2.2.1 Time of creation

This message is sent to DME when MLME completes the requested SCAN or when the parameters of MLME-request are incorrect.

4.3.2.2.2 Effect

DME sends a notification of the result of the SCAN process.

4.3.3 Startup of network

This mechanism supports the process of creating a new network. The parameters used in this primitive are outlined in Table 7.

Table 7 - MLME-START primitive parameters

Name	Type	Valid range	Description
NID	As defined in Table 5	As defined in Table 5	new network NID
ChannelIndex	As defined in Table 6	As defined in Table 6	Index of frequency channel on which to create network
SuperframeDuration	As defined in Table 6	As defined in Table 6	As defined in Table 6
PiconetMaxTxPower	As defined in 5.4.7	As defined in 5.4.7	As defined in 5.4.7
ResultCode	enumeration	SUCCESS, ALREADY_STARTED, NETWORK_DETECTED, INVALID_PARAMETER, CHANNEL_INTERFERENCE	Result of MLME request

4.3.3.1 MLME-START.request

This primitive requests the creation of a new network to the MAC entity. The semantics are as follows.

```
MLME-START.request (
    NID,
    ChannelIndex,
    SuperframeDuration,
    PiconetMaxTXPower
)
```

The primitive parameters are defined in Table 7.

4.3.3.1.1 Time of creation

This is created when DME requests that a station become the master and startup a new network.

4.3.3.1.2 Effect

MLME begins the creation process described in 6.1, and invokes MLME-START.confirm to report the result.

4.3.3.2 MLME-START.confirm

This primitive reports the result of the network creation.

```
MLME-START.confirm (
    ResultCode
)
```

The primitive parameters are defined in Table 7.

4.3.3.2.1 Time of creation

This is created as a result of an MLME-START.request from DLME.

4.3.3.2.2 Effect

DME reports the result of the creation process of network. A ResultCode of SUCCESS indicates that the station is now the master. If all channels have already been taken by another Network, the ResultCode is set to NETWORK_DETECTED. If network is already started, ResultCode is set to ALREADY_STARTED. If network cannot be started because the noise on the frequency channel indicated for the startup is too severe, the ResultCode is set to CHANNEL_INTERFERENCE. If there is an error in a parameter, the ResultCode is set to INVALID_PARAMETERS.

MLME begins the creation process described in 6.1, then calls MLME-START.confirm to report the result.

4.3.4 Synchronization

This mechanism is a preparatory step for a station to network. This primitive also notifies DME when a station has gone out-of-sync. The primitive parameters are defined in Table 8.

Table 8 - MLME-SYNCH primitive parameters

Name	Type	Valid range	Description
NID	As defined in Table 5	As defined in Table 5	ID of network to sync
ChannelIndex	As defined in Table 6	As defined in Table 6	The frequency channel on which to search network
Channel scan-Duration	As defined in Table 5	As defined in Table 5	Time to scan network
ResultCode	Enumeration	SUCCESS, TIMEOUT, INVALID_PARAMETER	Result of MLME-SYNCH.request

4.3.4.1 MLME-SYNCH.request

This primitive initiates the process of synchronizing with a network. The semantics are as follows.

```
MLME-SYNCH.request  (
    NID,
    ChannelIndex,
    ChannelScanDuration
)
```

The primitive parameters are defined in Table 8.

4.3.4.1.1 Time of creation

DME creates this when initiating the process of synchronizing with a specific beacon.

4.3.4.1.2 Effect

When MLME receives this primitive from DME, MLME scans until it finds the beacon corresponding to the specific channel or the channel scan duration time is exceeded. If the desired beacon is found, an MLME-SYNCH.confirm is sent to DME with the ResultCode set to SUCCESS. If the channel scan duration time limit is exceeded the ResultCode is set to TIMEOUT.

4.3.4.2 MLME-SYNCH.confirm

This primitive notifies DME of the success or failure of the requested network synchronization. The semantics are as follows.

```
MLME-SYNCH.confirm    (
                        ResultCode
                        )
```

The primitive parameters are defined in Table 8.

4.3.4.2.1 Time of creation

MLME creates this when the requested network synchronization task is completed.

4.3.4.2.2 Effect

DME is notified of the result of the synchronization task.

4.3.4.3 MLME-ATP-EXPIRED.indication

This primitive indicates that the station is no longer able to hear the beacon. The semantics are as follows.

```
MLME-ATP-EXPIRED.indication    ()
```

4.3.4.3.1 Time of creation

An MLME other than the master creates this when it has been unable to receive a beacon for longer than the Association Timeout Period (ATP).

4.3.4.3.2 Effect

DME receives notice that the ATP has timed out.

4.3.5 Association

The following primitives support the association of stations to network. The primitive parameters are defined in Table 9.

Table 9 - MLME-ASSOCIATE.primitive parameters

Name	Type	Valid range	Description
OrigID	Integer	Valid addresses as defined in 5.2.1.3	The address to associate or the address assigned by the master
STNAddress	MACAddress	valid MACAddress	The MACAddress of the station sending the associate request
CapabilityField	As defined in 5.4.5	As defined in 5.4.5	The capability of the station sending the associate request to the master
Association-TimeoutPeriod	Duration	as defined in 5.5.1.1	Maximum association time as defined in 5.5.1.1
Max-Associations	Integer	0-255	Maximum number of stations that the master can manage
MaxRRBs	Integer	0-255	The maximum number of resource request blocks that the master can manage
TxPowerLevel	As defined in 5.4.7	As defined in 5.4.7	As defined in 5.4.7
STNID	integer	Valid address as defined in 5.2.1.3	If the association is successful, the assigned address of the station, otherwise the assigned association address
Association-Status	enumeration	DISASSOCIATED, ASSOCIATED	Indication of whether the station is newly associating or disassociating
AssocTimeout	time	0-65535	The time in which MLME must receive a reply to the associate request
ReasonCode	integer	As defined in 5.5.1.2	The explanation for the reply to the associate request
ResultCode	enumeration	SUCCESS, DENIED, NEIGHBOR_UNSUPPORTED, TIMEOUT	Indication of whether or not the request was granted or denied, or whether the timeout was exceeded

4.3.5.1 MLME-ASSOCIATE.request

This primitive initiates the association process with a network. The semantics are as follows.

```
MLME-ASSOCIATE.request      (
                                PiconetType,
                                CapabilityField,
                                AssociationTimeoutPeriod,
                                MAXRRBs,
                                TxPowerLevel,
                                NetworkserviceInquiry,
                                AssocTimeout
                                )
```

The primitive parameters are defined in Table 9.

4.3.5.1.1 Time of creation

This is created when DME attempts to associate with network.

4.3.5.1.2 Effect

When DME receives this primitive through the MLME-SAP, it creates an associate request command packet and sends it to the master MLME.

4.3.5.2 MLME-ASSOCIATE.indication

This primitive reports that an associate request packet has been received.

```
MLME-ASSOCIATE.indication    (
                                OrigID,
                                STNAddress,
                                CapabilityField,
                                AssociationTimeoutPeriod,
                                MaxAssociations
                                )
```

The primitive parameters are defined in Table 9.

4.3.5.2.1 Time of creation

This is created to notify DME that the master MLME has received an associate request packet from a currently unassociated station.

4.3.5.2.2 Effect

When DME receives this primitive, if the OrigID is the UnassocID, DME determines whether to grant the associate request of the station, and sends back the result via MLME-ASSOCIATE.response through MLME-SAP.

When DME receives this primitive, if OrigID is the STNID that has just been assigned to the station desiring association, the master is being notified that the station has successfully received the assigned STNID, and does not reply with MLME-ASSOCIATE.response.

4.3.5.3 MLME-ASSOCIATE.response

This primitive is created as a response to an MLME-ASSOCIATE.indication. The semantics are as follows.

```
MLME-ASSOCIATE.response    (
                                OrigID,
                                STNAddress,
                                AssociationTimeoutPeriod,
                                ReasonCode
                                )
```

The primitive parameters are defined in Table 9.

4.3.5.3.1 Time of creation

This is created when the master MLME receives an MLME-ASSOCIATE.indication.

4.3.5.3.2 Effect

When the master MLME receives this primitive from DME, it creates an association response packet and sends it back.

4.3.5.4 MLME-ASSOCIATE.confirm

This primitive informs DME that initiated the association whether the associate request was successfully carried out. The semantics are as follows.

```
MLME-ASSOCIATE.confirm      (
                                STNID,
                                AssociationTimeoutPeriod,
                                ReasonCode,
                                ResultCode
                                )
```

The primitive parameters are defined in Table 9.

4.3.5.4.1 Time of creation

MLME sends this to DME when the association is completed or the timeout is exceeded.

4.3.5.4.2 Effect

The DME that initiated the association receives this primitive and determines whether the associate request was successfully carried out. If successful, it receives a unique STNID, otherwise it remains in an unassociated state with no unique STNID.

4.3.5.5 MLME-STN-ASSOCIATION-INFO.indication

This primitive informs all associated stations in network of the station association information in the beacon. The semantics are as follows.

```
MLME-STN-ASSOCIATION-INFO.indication (
                                STNAddress,
                                STNID,
                                AssociationStatus
                                )
```

The primitive parameters are defined in Table 9.

4.3.5.5.1 Time of creation

MLME sends this to DME when it receives the beacon containing the association information of other stations.

4.3.5.5.2 Effect

DME collects information about the station that has just been associated or disassociated from network through this primitive.

4.3.6 Disassociation

The following primitives are used when a station is disassociated from network or when the master is trying to disassociate a station. The primitive parameters are defined in Table 10.

Table 10 - MLME-DISASSOCIATE primitive parameters

Name	Type	Valid range	Description
TrgtID	integer	Valid addresses as defined in 5.2.1.3	Address of destination station of MLME request
OrigID	integer	Valid addresses as defined in 5.2.1.3	Address of station initiating the MLME request
DisassocTimeout	time	0-65535	Time in which the task must be completed once the MLME disassociate request is made
ReasonCode	integer	As defined in 5.5.1.2	Reason for disassociate request
ResultCode	enumeration	SUCCESS, ACK_TIMEOUT	Result of MLME request

4.3.6.1 MLME-DISASSOCIATE.request

This primitive initiates the disassociate request. The semantics are as follows.

```
MLME-DISASSOCIATE.request  (
                                TrgtID,
                                ReasonCode,
                                DisassocTimeout
                              )
```

The primitive parameters are defined in Table 10.

4.3.6.1.1 Time of creation

DME sends this to MLME when attempting to start the disassociation process.

4.3.6.1.2 Effect

When the slave MLME receives this primitive, the slave MLME sends a disassociate request command to the master DME.

When the master MLME receives this primitive, it sends a disassociate request command to the DME of the station to disassociate.

4.3.6.2 MLME-DISASSOCIATE.indication

This primitive reports that a disassociate request packet has been received. The semantics are as follows.

```
MLME-DISASSOCIATE.indication (
    OrigID,
    ReasonCode
)
```

The primitive parameters are defined in Table 10.

4.3.6.2.1 Time of creation

MLME sends this to DME when the master or a station receives a disassociate request packet.

4.3.6.2.2 Effect

The target DME is notified of the reason for the disassociate request.

4.3.6.3 MLME-DISASSOCIATE.confirm

This primitive reports the result of the disassociate request. The master MLME receives notification of the station to disassociate by means of this primitive. The semantics are as follows.

```
MLME-DISASSOCIATE.request (
    TrgtID,
    ResultCode,
)
```

The primitive parameters are defined in Table 10.

4.3.6.3.1 Time of creation

After the disassociate request command is sent, once the acknowledgement packet is received or the acknowledgement timeout is exceeded, MLME sends this to DME. If the MLME initiating the disassociate process receives the acknowledgement packet, it considers the disassociate process to have been successfully carried out, and if the acknowledgement time limit has been exceeded, it considers the process to have failed.

4.3.6.3.2 Effect

The result of the disassociation is reported through this primitive which initiated the disassociation.

4.3.7 Handover of master role

The following primitives are used when the current master transfers its authority to the most capable station within network. The primitive parameters are defined in Table 11.

Table 11 - MLME-Master-HANDOVER primitive parameters

Name	Type	Valid range	Description
MasterCapable-STNID	integer	Valid STNID as defined in 5.2.1.3	STNID of station to which the master wants to handover its authority
NumberOfSTNs	integer	0-255	Number of stations in network
NmbrHndOvrBcns	integer	(1+maximum beacon loss)-255	Number of times that a beacon containing the relevant information blocks must be broadcasted prior to the actual handover of master authority
HandoverTimeout	time	0-65535	Time limit in which the MLME request must be actually executed
HandoverStatus	enumeration	STARTED, CANCELLED	Indicates whether the handover of the master role to another station has been started or cancelled
ResultCode	enumeration	SUCCESS, TIMEOUT	Result of MLME request

4.3.7.1 MLME-MASTER-HANDOVER.request

This primitive requests the start of the handover of the master authority to another station. The semantics are as follows.

```
MLME-MASTER-HANDOVER.request    (
                                   MasterCapableSTNID
                                   NmbrHdnOvrBcns,
                                   HandoverStatus,
                                   HandoverTimeout
                                   )
```

The primitive parameters are defined in Table 11.

4.3.7.1.1 Time of creation

This primitive is sent to MLME when the master DME tries to handover its authority to another station or cancels the handover operation.

4.3.7.1.2 Effect

When MLME receives this primitive, it sends a master handover command packet to the destination station.

4.3.7.2 MLME-MASTER-HANDOVER.indication

This primitive reports that a master handover command packet has been received. The semantics are as follows.

```
MLME-MASTER-HANDOVER.indication (
                                   NumberOfSTNs,
                                   HandoverStatus,
                                   )
```

The primitive parameters are defined in Table 11.

4.3.7.2.1 Time of creation

When MLME receives the master handover command packet from the master, it sends this primitive to DME. It also sends this primitive to DME the first time it broadcasts the beacon as the new master.

4.3.7.2.2 Effect

If HandoverStatus is STARTED, DME receives notice that MLME has begun the process of master handover, and if HandoverStatus is CANCELED, DME learns that the master handover process has been cancelled.

4.3.7.3 MLME-MASTER-HANDOVER.response

This primitive initiates the response to an MLME-MASTER-HANDOVER.indication. The semantics are as follows.

MLME-MASTER-HANDOVER.response ()

4.3.7.3.1 Time of creation

Once the master DME receives an MLME-MASTER-HANDOVER.indication with a HandoverStatus of SUCCESS and an MLME-MASTER-INFO.confirm, the master DME sends this primitive to MLME.

4.3.7.3.2 Effect

When the new master MLME receives this primitive from DME, it is notified that DME is ready to take on the role of master.

4.3.7.4 MLME-MASTER-HANDOVER.confirm

This primitive notifies the requesting DME that the job is completed. The semantics are as follows.

MLME-MASTER-HANDOVER.confirm (
 ResultCode
)

The primitive parameters are defined in Table 11.

4.3.7.4.1 Time of creation

After the master MLME hands over its master function and sends its last beacon, it sets ResultCode to SUCCESS and sends this primitive to DME. If the master was unable to send the desired data to the destination station, it sends a primitive to DME with ResultCode set to TIMEOUT.

4.3.7.4.2 Effect

The master DME is notified of the success or failure of the MLME-MASTER-HANDOVER.request. If the master sends the last beacon before the master handover timeout, ResultCode is set to SUCCESS, otherwise it is set to TIMEOUT.

4.3.8 Data request

This mechanism is used when a station requests information from the master about a specific station or all stations in network. The primitive parameters are defined in Table 12.

Table 12 - MLME-MASTER-INFO primitive parameters

Name	Type	Valid range	Description
QueriedSTNID	integer	Valid addresses as defined in 5.2.1.3	ID of the station about which information is being requested from the master (if set to the broadcasting address, this indicates a request for information about all stations)
OrigID	integer	Valid addresses as defined in 5.2.1.3	ID of station initiating the MLME request
STNInfoSet	As defined in 5.5.4.2	As defined in 5.5.4.2	Set of information about the station being queried
MasterInfo-Timeout	time	0-65535	Time in which the task must be completed once the MLME receives the request
ResultCode	enumeration	SUCCESS, TIMEOUT	Result of MLME request

4.3.8.1 MLME-MASTER-INFO.request

This initiates the process of requesting information concerning a specific station or all stations. The semantics are as follows.

```
MLME-MASTER-INFO.request    (
                                QueriedSTNID,
                                MasterInfoTimeout
                                )
```

The primitive parameters are defined in Table 12.

4.3.8.1.1 Time of creation

This primitive is sent to MLME when DME requests information from the master about a specific station or all stations.

4.3.8.1.2 Effect

When MLME receives this primitive, it sends the station information request packet to the master.

4.3.8.2 MLME-MASTER-INFO.indication

This primitive indicates that the station information request command packet has been received. The semantics are as follows.

```
MLME-MASTER-INFO.indication (
                                QueriedSTNID,
                                OrigID
                                )
```

The primitive parameters are defined in Table 12.

4.3.8.2.1 Time of creation

MLME sends this to DME upon receiving the station information request packet.

4.3.8.2.2 Effect

When DME receives this primitive, it responds to MLME with MLME-MASTER-INFO.response.

4.3.8.3 MLME-MASTER-INFO.response

This primitive initiates a response to MLME-MASTER-INFO.indication. The semantics are as follows.

```
MLME-MASTER-INFO.response  (  
                                OrigID,  
                                STNInfoSet  
                                )
```

The primitive parameters are defined in Table 12.

4.3.8.3.1 Time of creation

DME sends this primitive to MLME as a response to MLME-MASTER-INFO.indication.

4.3.8.3.2 Effect

When the master MLME receives this primitive, it sends the station information response packet to the requesting station.

4.3.8.4 MLME-MASTER-INFO.confirm

This primitive informs the DME which initiated the station information probe that the process has been completed. The semantics are as follows.

```
MLME-MASTER-INFO.confirm    (  
                                TrgtID,  
                                InfoElementList,  
                                ResultCode  
                                )
```

The primitive parameters are defined in Table 12.

4.3.8.4.1 Time of creation

MLME sends this primitive to DME when the station information response command packet is received or the time limit has been exceeded.

4.3.8.4.2 Effect

When the DME requesting the station information receives this primitive, it learns the success or failure of the station information request it sent to the master. If failure, it retransmits another MLME-MASTER-INFO.request for the same information. If success, DME receives the information it requested.

4.3.9 Network node data probe

The following primitives are used when a station requests information about another station in network. The primitive parameters are defined in Table 13.

Table 13 - MLME-PROBE primitive parameters

Name	Type	Valid range	Description
TrgtID	integer	Valid addresses as defined in 5.2.1.3	Address of destination station of the MLME request
OrigID	integer	Valid addresses as defined in 5.2.1.3	Address of station initiating the MLME request
InfoElementMap	2 byte	0x0000 – 0xFFFF	Information request as defined in 5.5.4.1
InfoElementList	Variable length of byte	-	Response to information request as defined in 5.5.4.2
ProbeTimeout	time	0-65535	Time limit in which the task must be completed once the MLME has made the request
ResultCode	enumeration	SUCCESS, TIMEOUT	Result of MLME request

4.3.9.1 MLME-PROBE.request

This primitive initiates the process of requesting specific information from a destination station. The semantics are as follows.

```
MLME-PROBE.request (
    TrgtID,
    InfoElementMap,
    InfoElementList,
    ProbeTimeout
)
```

The primitive parameters are defined in Table 13.

4.3.9.1.1 Time of creation

This primitive is sent to MLME when DME requests information about another station in network.

4.3.9.1.2 Effect

When MLME receives this primitive, it sends an information request command packet to the destination station.

4.3.9.2 MLME-PROBE.indication

This primitive reports that there has been a request made for specific information through an information probe packet. The semantics are as follows.

```
MLME-PROBE.indication (
    OrigID,
    InfoElementMap
)
```

The primitive parameters are defined in Table 13.

4.3.9.2.1 Time of creation

MLME sends this to DME when it receives the information probe packet.

4.3.9.2.2 Effect

When DME receives the MLME-PROBE.indication, it responds to MLME through MLME-PROBE.response.

4.3.9.3 MLME-PROBE.response

This primitive initiates a response to MLME-PROBE.indication. The semantics are as follows.

```
MLME-PROBE.response (
    OrigID,
    InfoElementMap,
    InfoElementList,
    ProbeTimeout
)
```

The primitive parameters are defined in Table 13.

4.3.9.3.1 Time of creation

DME sends this primitive to MLME as a response to MLME-PROBE.indication.

4.3.9.3.2 Effect

When MLME receives this primitive, it sends the information probe command packet to the station that initiated the information probe.

4.3.9.4 MLME-PROBE.confirm

This primitive notifies the DME that initiated the information probe that the process has completed. The semantics are as follows.

```
MLME-PROBE.confirm (
    TrgtID,
    InfoElementList,
    ResultCode
)
```

The primitive parameters are defined in Table 13.