Description of IEC 61850 Communication

Technical Report

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Abstract

IEC 61850 is a new international standard for communication of industrial communication systems (ICSs), especially in electric power system. The standard describes the system using abstract objects (logical nodes, data objects) that are accessed via Abstract Communication Service Interface (ACSI). The communication between devices and control station is designed as the client-server communication using Manufacturing Message Specification (MMS) protocol or via peer-to-peer system using Generic Object-Oriented Substation Event (GOOSE) protocol.

This document describes the abstract model of the system as recommended by IEC 61850 standard and also both communication protocols GOOSE and MMS. Intention of this paper is to focus on security monitoring, thus detailed description of both protocol is present.

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1 Introduction

Existing serial-based SCADA systems running on Modbus, IEC 60870-5-101, or DNP3 are not equipped enough to support next-generation capabilities of modern Intelligent Electronic Devices (IEDs). Even with IP-based protocol translation services, they lack deployment flexibility and ultimately rely on aging serial communications at the RTU. In an effort to modernize substation communication and leverage protocols that can take advantage of Ethernet and IP, the IEC Technical Committed 57 developed the IEC 61850 standard.

IEC 61850 is an international standard defining communication protocols for intelligent electronic devices at electrical substations. It is a part of the International Electrotechnical Commission's (IEC) Technical Committee 57 reference architecture for electric power systems. The abstract data models defined in IEC 61850 can be mapped to a number of protocols. Current mappings in the standard are to MMS (Manufacturing Message Specification), GOOSE (Generic Object Oriented Substation Event), or SMV (Sampled Measured Values):

- *MMS* protocol (IEC 61850-8-1) supports client/server communications over IP and is used for SCADA. It is used for monitoring purposes.
- *GOOSE* (IEC 61850-8-1) uses Ethernet-based multicast (one-to-many) communications in which IEDs can communicate with each other and between bays. GOOSE is of the used for passing power measurements and between protection relays, as well as for tripping and interlocking circuits. It is used for status updates and sending command requests.
- *Sampled Measured Values* (IEC 61850-9-2) carry power line current and voltage values. A common use for SMVs is for bus-bar protection and synchrophasors[1].

These protocols can run over TCP/IP networks or substation LANs using high speed switched Ethernet to obtain the necessary response times below four milliseconds for protective relaying.

The IEC 61850 protocol enables the integration of all protection, control, measurement and monitoring functions by one common protocol. It provides the means of high-speed substation applications, station wide interlocking and other functions which needs intercommunication between IEDs. The well described data modelling, the specified communication services for the most recent tasks in a station makes the standard to a key element in modern substation systems.

[1] *Synchrophasors* are time-synchronized electrical numbers that monitor phase and power. They are measured by devices called *phase measurement units* (PMUs) in the substation [4].

2 IEC 61850 Standard

Standard IEC 61850 defines various aspects of the substation communication network in ten major sections as shown in Figure 1. The architecture of 61850 standard abstracts the definition of data items and the services by creating data items/objects and services that are independent of any underlying protocols. The abstract definition allows mapping of the data objects and services to any other protocol that can meet the data and service requirements [1].

Part 6 of the standard describes Configuration Description Language (CDL) for communication in electrical substations related to IEDs. Part 7 describes basic communication structure. It includes

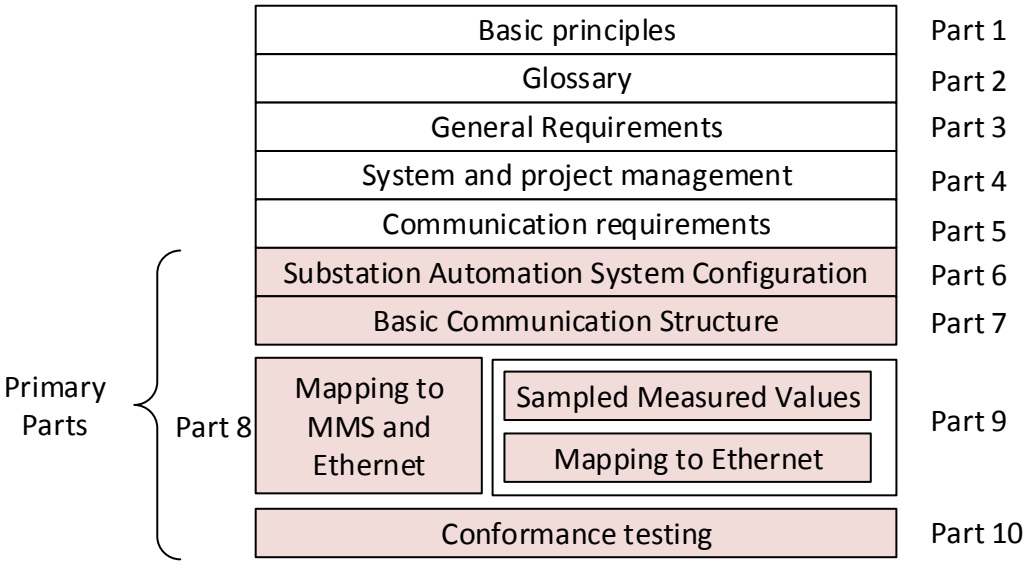

Figure 1: Structure of the IEC 61850 Standard

the definition of the abstract services in part 7.2 and the abstraction of the data objects referred to as Logical Nodes in part 7.4. The definition of common objects is in part 7.3. The structure of part 7 of the standard is the following:

- IEC 61850-7-1: Principles and models
- IEC 61850-7-2: Abstract communication service interface (ACSI)
- IEC 61850-7-3: Common Data Classes (CDC)
- IEC 61850-7-4: Compatible logical node classes and data classes

Given the data and services abstract definitions, the final step is mapping the abstract services into an actual protocol. Part 8 describes Specific Communication Service Mapping (SCSM) which covers:

- IEC 61850-8-1: Mappings to MMS (ISO/IEC 9506 – Part 1 and 2) and to ISO/IEC 8802-3

Part 9 also defines Specific Communication Service Mapping to:

- IEC 61850-9-1: Sampled Values over Serial Unidirectional Multidrop Point-to-Point Link and Bi-directional multipoint onto an Ethernet data frame
- IEC 61850-9-2: Sampled Values over ISO/IEC 8802-3 (Process Bus)

Relation between the substation automation system and the substation (swichyard) is formally described an XML based Substation Configuration Language (SCL) that is defined in Part 6.

2.1 IEC 61850 Information Model

Information model of IEC 61850 consists of physical devices, logical devices, logical nodes and data objects, see Figure 2.

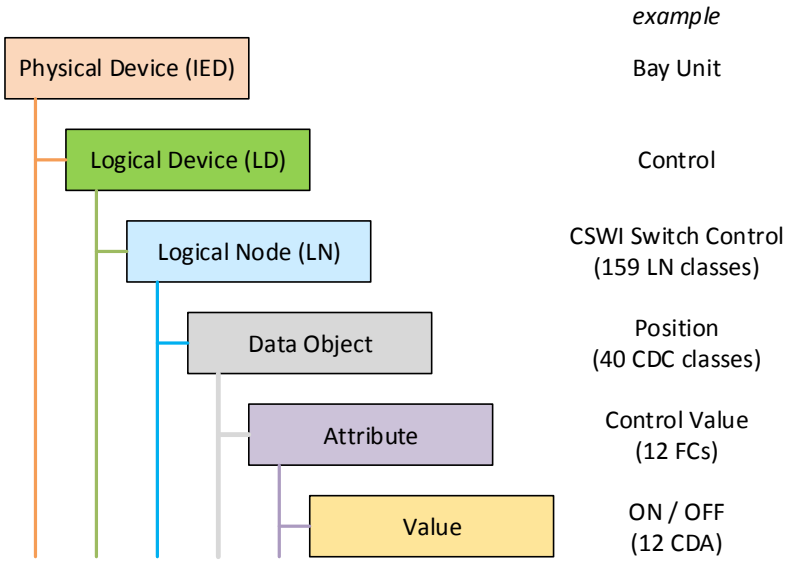

Figure 2: IEC 61850 information model

Physical device contains various functional modules that are modelled as logical devices. Each logical device can provide various operations defined as logical nodes. IEC 61850-7-4 standard defines 159 unique logical node classes. Logical nodes contain data objects that represent application functionality. Variables of a logical nodes are represented as a collection of Common Data Classes. Standard IEC 61850-7-3 defines 40 different CDCs, see Appendix B. Each data object contains a set of elements called data attributes that belong to 12 functional constraints, see Appendix C3. Attributes contains values defined by Common Data Attribute (CDA).

2.1.1 Physical Device (PD)

The IEC 61850 device model begins with a *physical device,* e.g., relay or substation. A physical device is the device that connects to the network, therefore. The physical device is defined by its network address. Physical device is sometimes called IED (Intelligent Electronical Device).

2.1.2 Logical Device (LD)

Within each physical device, there may be one or more *logical devices*. Logical device aggregates data from multiple devices into as single physical device.

Each logical device contains the following attributes:

- *LDName* uniquely defines the logical device on the network.
- *LogicalNode[1..n]* is a list of all logical nodes that are part of the logical device; each LD must contain one Logical Node Zero (LLN0). It can contain zero or more logical nodes.
- *GetLogicalDeviceDirectory* service returns a list of RefObjects of all logical nodes so that these logical nodes can be accessed by a client.

Each logical device contains one or more logical nodes.

2.1.3 Logical Node (LN)

IEC 61850 assigns to each function within a substation equipment (transformer, circuit breaker, protection function, etc.) *a logical node*. A logical node is a virtual representation of devices. It is a grouping of *data* and *services* related to certain substation function. Therefore, all data generated by the substation can be assigned to a certain logical node. In the standard, a logical node is specified as the smallest entity that can exchange data.

Logical nodes are combined into groups based on functionality. There are logical nodes for automatic control, for metering and management, supervisory control, etc. Standard defines 19 different LN groups which contain LN classes with 159 unique classes, see Appendix A.

A special group is a system logical node group (L) that contains information specific for the system. This includes common logical node information (class Common LN, e.g., LN behavior, plate information, operation counters) and also information related to a specific hardware (physical device information – class LPHD).

Common LN class provides data objects that are mandatory or conditional for all other LN classes. It also contains data that can be used in all other LN groups, e.g., input reference, statistical data objects, etc. The structure of Common LN class is depicted in Figure 3.

Common LN Class			
Data Object Name	**Common data class**	**Explanation**	**Mandatory**
Data objects			
Mandatory and conditional LN information (shall be inhereted by ALL LN but LPHD)			
Description			
NamPlt	LPL	Name plate	C1
Status			
Beh	ENS	Behavior	M
Health	ENS	Physical status	C1
Blk	SPS	Dynamic function blocking	O
Measures			
SumSwARs	BCR	Sum of switched amperes, resetable	
Controls			
Mod	ENC	Mode	C1
CmdBlk	SPC	Control sequence blocking and activation of remote data objects	C2
Settings			
InRef1	ORG	Common input reference	O
BlkRef1	ORG	Blocking reference	O
Condition C1: Mod, Health and NamPlt shall LLN0 take from LD as mandatory, all other LNs as optional			
Condition C2: CmdBlk must be taken with Mod as optional data object by all LNs with control data objects			

Figure 3: Common LN class (without statistical LN information)

At least three logical nodes must be within a logical device, namely two LNs related to common issues for the logical device (Logical Node Zero, LLN0 and Physical Device Information, LPHD), and at least one LN performing some functionality. A complete list of logical nodes is defined in [2]. Special L-group classes:

- *Logical Node Zero (LLN0)* – it administers the virtual device it is part of. It defines in particular the communication objects and the log of the virtual devices.

- *Physical Device Logical Node (LPHD1)* – it represents the physical device, and in particular its communication properties, that are identical for all Logical Devices.

All logical nodes are constructed according to the Generic Logical Node Class template, see Fig. 4.

GenLogicalNode class		
Attribute	**Attribute Type**	**Explanation**
LNName	ObjectName	Instance name unambiguously identifying the logical node within the scope of logical device, e.g., XCBR1
LNRef	ObjectReference	Unique path-name of the logical node: LDName/LNName, e.g., Q1B1W2/XCBR1
DataObject [1..n]	GenDataObjectClass	All data objects contained in the logical node.
DataSet [0..n]	DATA-SET	All DataSets contained in the logical node.
BufferedReportControlBlock [0..n]	BRCB	All buffered report control blocks contained in the logical node.
UnbufferedReportControlBlock [0..n]	URCB	All unbuffered report control blocks contained in the logical node.
LogControlBlocks [0..n]	LCB	All log control blocks contained in the logical node.
Only for LLN0		
SettingGroupsControlBlock [0..1]	SGCB	Setting group control block contained in the logical node.
Log [0..n]	LOG	All logs contained in the logical node.
GOOSEControlBlock [0..n]	GoCB	All GOOSE control blocks contained in the logical node.
MulticastSampledValues [0..n]	MSVCB	All multicast sampled value control blocks contained in the logical node.
UnicastSampledValues [0..n]	USVCB	All unicast sampled value control blocks contained in the logical node.
Services		
GetLogicalNodeDirectory		
GetAllDataValues		

Figure 4: Logical Node Model [3]

If there are two instances of the same logical name, there are distinguished by a number that follows the LN, e.g., the measurement class has logical name MMXU and its instances would have names MMXU1 and MMXU2, see Figure 5. Each logical node may also use an optional application specific LN-prefix to provide further identification of the purpose of a logical node.

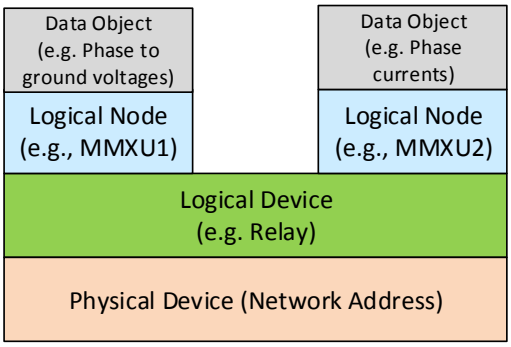

Figure 5: IEC 61850 Information Model

2.1.4 Data object (DO)

A logical node contains *data objects* that represent application (substation) objects. Each data object has a unique name. These data names are determined by the standard and are functionally related to the power system purpose.

A collection of data objects related to a given logical node is defined by standard IEC 61850-7-3. The standard describes 40 common data classes (CDC, see Appendix B) which assign a collection of data objects to a specific class. For instance, a circuit breaker is modeled as an XCBR logical node. It contains a variety of data objects including *Loc* (class SPS, Single point status) for determining if operation is remote or local, *OpCnt* (class INS, Integer status) for an operations count, *Pos* (class DPC, Controllable double point) for the position, *BlkOpn* (class SPC, Controllable single point) for block breaker open commands, *BlkCls* (class SPC) for block breaker close commands, or CBOpCap (class ENS, Controllable enumerated status) for the circuit breaker operating capability, see Fig. 6.

XCBR class			
Data Object Name	**Common data class**	**Explanation**	**Mandatory**
LLName		The name shall be composed of the class name, the LN-Prefix and Ln-Instance-ID according to IEC 61850-7-2, Clause 22	
Data objects			
Description			
EEName	DPL	External equipment name plate	
Status			
EEHealth	INS	External equipment health	O
LocKey	SPS	Local or remote key (local means without substation automation communication, hardwired direct control)	O
Loc	SPS	Loc control mode	M
OpCnt	INS	Operation counter	M
CBOpCap	ENS	Circuit breaker operating capability	O
POWCap	ENS	Point on wave switching capability	O
MaxOpCap	INS	Circuit breaker operationg capability when fully charged	O
Dcs	SPS	Discrepancy	O
Measures			
SumSwARs	BCR	Sum of switched amperes, resetable	
Controls			
LocSta	SPC	Switching authrority at station level	O
Pos	DPC	Switch position	M
BlkOpn	SPC	Block opening	M
BlkCls	SPC	Block closing	M
ChaMotEna	SPC	Charger motor enable	O
Settings			
CBTmms	ING	Closing time of breaker	O

Figure 6: Example of Data Objects in a Logical Node XCBR [2]

As seen, data objects defined for a specific LN class are grouped into the following categories:

- *Description* – basic information independent from the dedicated function represented by the LN, e.g, name plate, health, etc.
- *Status* – represents either the status of the process or of the function of the LN, e.g., switch type, position of a switch
- *Measures* – analog data measured from the process, e.g., line current, voltage, power, or calculated in the LN, e.g., total active power, net energy flow
- *Controls* – data which are changed by commands, e.g., switchgear state (ON-OFF), tap changer position or resetable counters
- *Settings* – parameters for the function of a logical node, e.g., first, second, or third reclosure time, close pulse time

Standard 61850-7-2 also defines which data objects are mandatory (M), optional (O), or conditional (C) for a given logical node.

2.1.5 Common Data Class (CDC)

As stated before, each data object within the logical node conforms to the specification of a common data class to which data belongs. A common data class (CDC) defines structure for common types that are used to describe data objects. CDC description includes the type and the structure of the data within a logical node. Each CDC has a defined name and a set of attributes, which in turn have a defined name, a defined type and specific purpose. In addition, a data attribute type belongs to specific functional constraints (FC).

Data attributes can be primitive (e.g., BOOLEAN), or composite (constructed, e.g., Quality), see Appendix C.

Table 1 shows an example of Single Point Status (SPS) class. SPS class consists of three status attributes (ST), four substitution attributes (SV), two description attributes (DC), and three extended definition (ED) attributes. SPS status attributes include a status value *stVal* of data type BOOLEAN, a quality flag *q* of data type Quality, and a timestamp *t* of data type TimeStamp. A list of standardized data types is in Appendix C and D.

Single Point Setting (SPS) class					
Attribute	**Attribute Type**	**FC**	**TrgOp**	**Value/Range**	**M/O/C**
status					
stVal	BOOLEAN	ST	dchg	TRUE/FALSE	M
q	Quality	ST	qchg		M
t	TimeStamp	ST			M
substitution					
subEna	BOOLEAN	SV			PICS_SUBST
subVal	BOOLEAN	SV		TRUE/FALSE	PICS_SUBST
subQ	Quality	SV			PICS_SUBST
subID	VISIBLESTRING64	SV			PICS_SUBST
configuration, description and extension					
d	VISIBLESTRING255	DC	Text		O
dU	UNICODE STRING255	DC			O
cdcNs	VISIBLESTRING255	EX			AC_DLNDA_M
cdcName	VISIBLESTRING255	EX			AC_DLNDA_M
dataNs	VISIBLESTRING255	EX			AC_DLN_M

Table 1: Example of common data class (CDC)

The first two columns in Table 1 define the *name* and *type* of the attribute which is a part of SPS class. The individual attributes of a common data class are grouped into categories by *functional constraints* (FC). The *trigger option* column defines when for instance reporting or reading of the data will occur. The fourth column describes the *predefined values* or *value range* of the attribute. The last column refers to whether the data attribute is *mandatory* (M), *optional* (O) or *conditional* (C). For example, the first data attribute in Table 1 is *stVal*. It has data type *BOOLEAN* and belongs to a function constrain for status attributes (ST). The trigger option is *data-change (dchg)* and the attribute is mandatory.

2.1.6 Naming Scheme

The name of the logical node is that of an instance of the standard logical nodes, unique in the logical device, e.g., XCBR2.

The *Object reference* is a full path of the object, completed with the functional constraint, see IEC 61850-7-2, clause 22. For example, object reference EA1QA5/XCBR8.Pos.ctlVal ST, see Figure 7, refers to the logical device *EA1QA5* and logical node *XCBR8* which is an instance of logical node XCBR (circuit breaker). This specific logical node (with name EA1QA5/XCBR8) contains data object *Pos* (switch position, see Figure 6) which is derived from the common data class DPC (Controllable double point). DPC class contains various attributes, e.g., *ctlVal, stVal, q, t,* or *ctlModel*. Attribute *ctlVal* has BOOLEAN data type with values FALSE (switch off) or TRUE (switch on). This attribute contains functional constraint ST (status attribute).

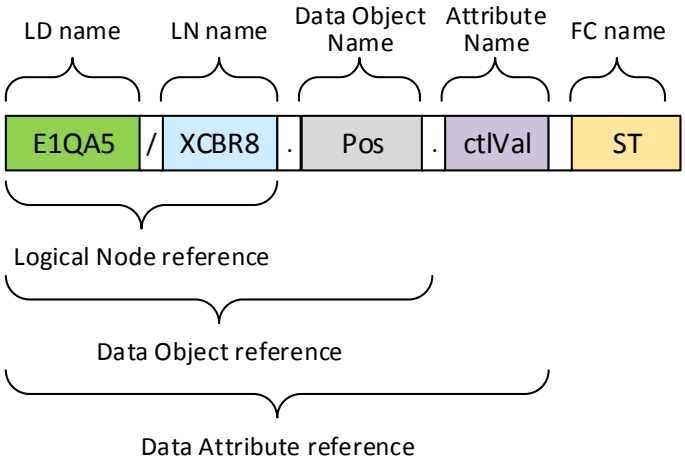

Figure 7: Example of an object reference

LN reference, data object reference or data attribute reference refers to the specific logical node, data object on the node, or the attribute of the given data object.

2.2 Abstract Communication Service Interface (ACSI)

The abstract data and object models of IEC 61850 define a standardized method of describing power system devices that enables all IEDs to present data using identical structures that are directly related to their power system function. The Abstract Communication Service Interface (ACSI) [3] describes communication between a client and a remote server for:

- real-time data access and retrieval,
- device control
- event reporting and logging,
- setting group control,
- self-description of devices (device data dictionary),
- data typing and discovery of data types, and
- file transfer.

ACSI also provide the abstract interface for fast and reliable system-wide event distribution between an application in one device and many remote applications in different devices (publisher/subscriber) and for transmission of sampled measured values.
In the ACSI model there are two groups of communication services. The first group uses client-server model, e.g., getting data values from IEDs. The second group is a peer-to-peer model with Generic Substation Event (GSE) services which are used for fast communication between IEDs using GOOSE messages and periodic sampled value (SV) transmissions.

- Client-server communication is a service where the client requests data from a server. The server contains the content of a logical device, the association model, time synchronization and file transfer. This client-server communication is used for transferring large amounts of data which are not time-critical.
- Sampled Values (SV) are messages related to instrumentation and measurement. Therefore, they are transferred between bay and process levels, see Figure 8. The SV messages are time-critical, need to be processed in chronological order, and possible losses have to be detected. These messages can be sent as unicast to one receiver or as multicast to several receivers, see Table 2.

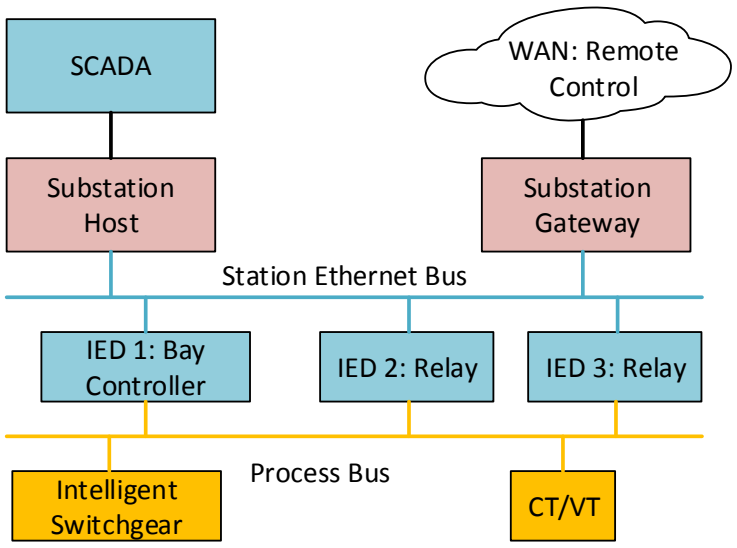

Figure 8: An IEC 61850 network

Recommended L2 multicast addresses		
Service	**Starting address**	**Ending address**
GOOSE	01:0c:cd:01:00:00	01:0c:cd:01:01:ff
GSE	01:0c:cd:02:00:00	01:0c:cd:02:01:ff
Sampled Values	01:0c:cd:04:00:00	01:0c:cd:04:01:ff

Table 2: Recommended multicast addresses [6]

- GOOSE messages have been defined for fast horizontal communication between IEDs. They are used to transfer state and control information between IEDs. GOOSE messages are transmitted as a multicast over LAN, from which all IEDs configured to receive the message can subscribe to it.

ACSI defines a set of services and their responses to those services that enables all IEDs to behave in an identical manner from the network behavior perspective. IEC 61850-8-1 [6] maps the abstract objects and services to the Manufacturing Message Specification (MMS) protocol of ISO 9506.
The mapping of IEC 61850 object and service models to MMS is based on a service mapping where a specific MMS services are chosen as the means to implement the various services of ACSI, see Appendix I. Then the various object models of IEC 61850 are mapped to specific MMS objects. For instance, the IEC 61850 logical device object is mapped to an MMS domain.

2.3 Mapping Object reference and Data Attribute reference to MMS

IEC 61850 object are according to the standard IEC 61850-8-1 [6] mapped to MMS object.

- Server class: an instance of IEC 61850-7-2 server class is mapped one-to-one to an MMS Virtual Manufacturing Device (VMD) object, see Appendix E.
- Logical device (LD): an instance of a logical device object is mapped to an MMS domain object. An MMS domain represents a collection of information associated with a specific name.
- Logical node (LN): an instance of a logical node class maps to a single MMS NamedVariable.

Logical nodes consist of one or more DataObjects. The names of DataObjects are based upon the hierarchically named component of the data found within the MMS named variable. Each level of hierarchy is determined through the use of a "$" within the MMS name variable that represents the data: <LNVariableName>$<FC>$<LNDataObjectName1>, e.g., *XCBR1STPos*, cf. Figure 7.

The data attributes DataAttr of the DataObjects map in a similar manner to the DataObjects: <LNVariableName>$<FC>$<LNDataName1>$<AttributeName1>, e.g., *XCBR1STPos$stVal*.

2.4 Communication profiles

In order to communicate using OSI model, communication services have to be mapped to real communication protocols using different communication profiles. The profiled are defined by IEC 61850-8-1, see Figure 9.

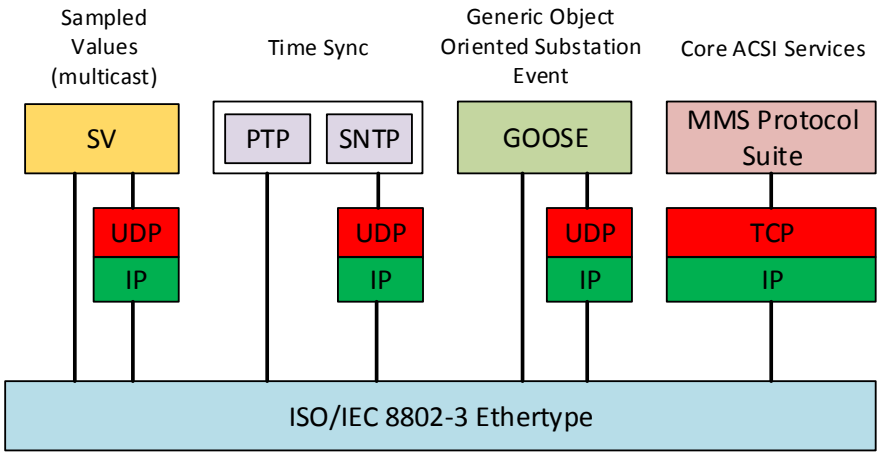

Figure 9: An overview of functionality and profiles defined in IEC 61850

For client-server communication MMS protocol is used. This protocol was originally designed for manufacturing. It supports the complex naming and services, so it was chosen for IEC 61850. MMS covers the application layer of OSI model while transport and network layers are covered either by TCP/IP or ISO protocols. MMS protocol is further described in section 4.
For GOOSE communication connection-less OSI and non-MMS profiles are used. This means that the connection between IEDs prior to sending is not confirmed. The GOOSE message is simply sent to the network. This is needed to meet the time-critical demand of GOOSE communication. As seen in Figure 9, GOOSE messages are directly mapped to the Ethernet data frames in order to eliminate processing time of middle layers. GOOSE protocol is further described in Section 3.

Detailed mapping on OSI communication stack is depicted in Figure 10. IEC 61850-8-1 defines two profiles: application profile (A-Profile) that specified services and protocols of 3 upper layers of OSI model, and transport profile (T-Profile) that specifies services and protocols of 4 lower layers.

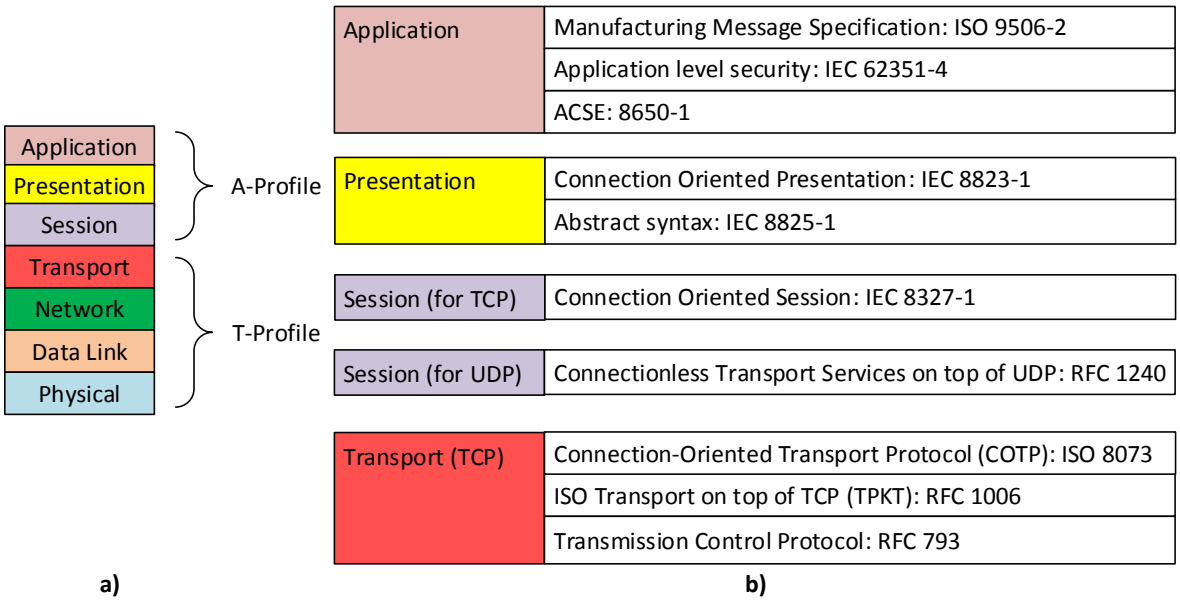

Figure 10: Communication stack: (a) A-profile, T-profile and (b) protocols for the client/server communication

Various combinations of A-Profiles and T-Profiles can be combined in order to allow certain types of information/services to be exchanged. The services, as specified in IEC 61850-7-2, are mapped into four different combinations of A- and T- profiles and are used for:

- Client-server services (MMS),
- GOOSE/GSE management services,
- GSSE services, and
- Time synchronization (PTP, SNTP).

Protocols defined in A-profiles for MMS are mandatory except Application Layer Security (IEC 62351-4) which is conditional. A-profile for GOOSE requires RFC 1240 header on top of UDP. T-profile for MMS requires TPKT protocol on top of TCP when TCP is used which is typical for MMS. More details about MMS and GOOSE communication are mentioned in the following sections.

3 GOOSE Protocol

Generic Object-Oriented Substation Event (GOOSE) protocol implements transfer of time-critical events such as protection of electrical equipment between IEC 61850 devices. IEC 61850 standard defines two groups of communication services: a client-server model and a peer-to-peer model. The peer-to-peer model is utilized for Generic Substation Event (GSE) services associated with time-critical activities such as fast and reliable communication between IEDs. One of the messages associated with the GSE services are GOOSE messages that allow for the broadcast or multicast messages across the LAN.

3.1 GOOSE Message Format

The GOOSE message is associated with three layers of the OSI model, namely the physical layer, data-link layer and the application layer. On data link layer, GOOSE is encapsulated in 802.3 Ethernet frame, see Figure 11.

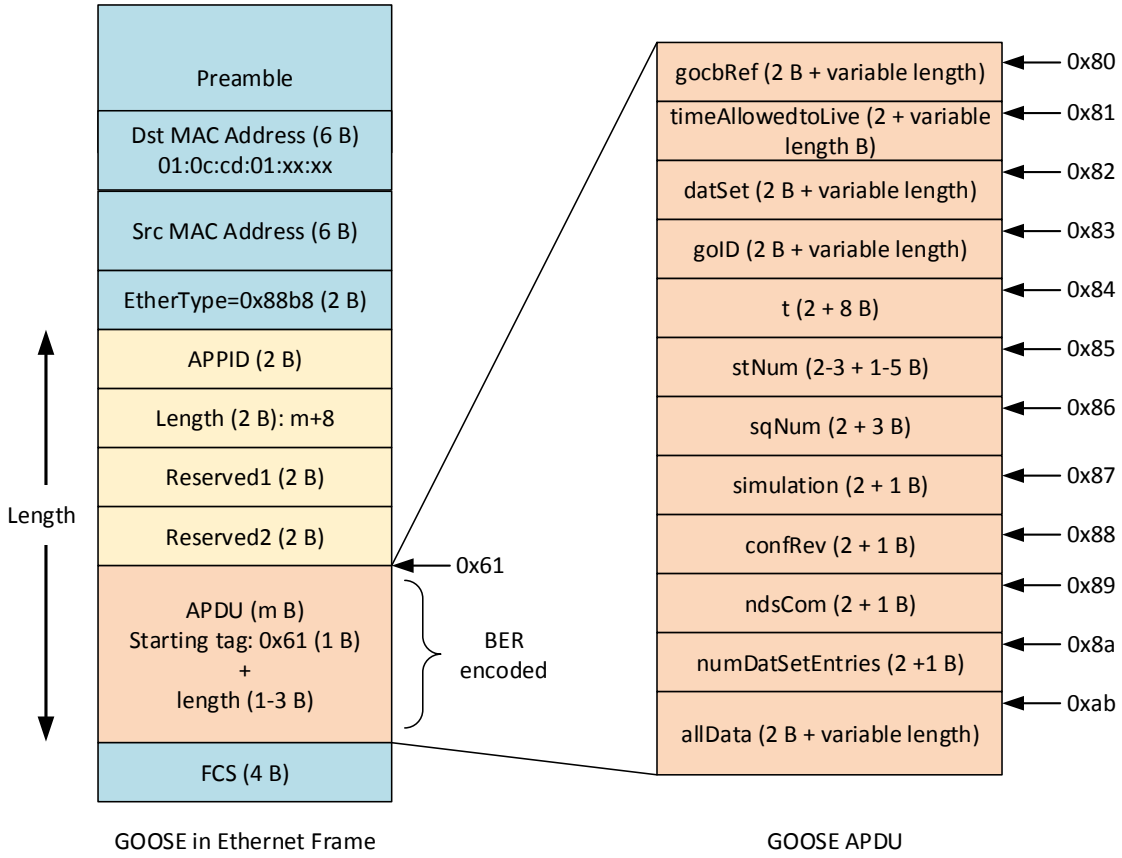

Figure 11: GOOSE message format

As seen in the Figure, GOOSE defines four fixed-length fields on L2 layer. An APDU is a sequence of BER-encoded TLV triplets, where the fields have either fixed or variable length. The TLV structure is composed of 1 byte identifier (type), see Table 4, one or more bytes defining length *n* of the value, and an *n*-byte value. The Figure above shows ASN.1 identifiers for each field. The identifiers is at the beginning of the field, followed by the length and the value (TLV triplet). Some fields can be optional, see details in Appendix F.

3.1.1 GOOSE on Data Link Layer

GOOSE messages are usually transmitted over Ethernet with a reserved multicast destination MAC address *01:0c:cd:01:xx:xx* (6 bytes) defined by IEC 61850 technical committed 57 (IEC-TC57), see Table 2. Optionally, an extended encapsulation with IEEE 802.1Q (VLAN) format or HSR (IEC 62439-3) or PRP (IEC 62439-3) link redundancy can be added, see [6, Appendix C].

Ethertype values (2 bytes) for GSE, GOOSE and sampled values are registered by the IEEE authority. The assigned values are listed in Table 3 [6, Appendix C.2].

Assigned Ethertype values			
Service	**Standard**	**Ethertype**	**APPID type**
GOOSE Type 1	IEC 61850-8-1	0x88b8	0 0
GSE Management	IEC 61850-8-1	0x88b9	0 0
Sampled Values	IEC 61850-9-2	0x88ba	0 1
GOOSE Type 1A	IEC 61850-8-1	0x88b8	1 0

Table 3: Assigned Ethertype values

Following Ethertype, four special fields are added in Ethernet frame:

- *APPID (application identifier)* sent in the message is used as a handle for the receiving application. It is used to select ISO/IEC-3 frames containing GSE Management and GOOSE messages and to distinguish the application association. The value of APPID is the combination of the APPID Type, defined as the most significant bits of the value, and the actual ID. The possible values are as follows:
  - Default value (not configured): 0x0000
  - GOOSE Type 1: 0x0000 – 0x3FFF
  - GOOSE Type 1A (Trip): 0x8000 – 0xBFFF
- *Length* give the number of octets include the Ethertype PDU header starting at APPID, and the length of the Application Protocol Data Unit (APDU). Therefore, the value of the length shall be *8+m*, where *m* is the length of the APDU and *m* is less than 1492. Frames with inconsistent or invalid length field shall be discarded.
- *Reserved 1* is a 2-byte structure that contains S (simulated) bit that is mapped from the service parameter Simulation of the SendGOOSE service, three R (reserved) bits reserved for future standardized application, and twelve reserved security bits that shall be used when GOOSE with security is transmitted, otherwise it shall be set to 0.
- *Reserved 2* is a 2-byte field defined by the security standard IEC 62351-6 and shall be used as defined when GOOSE with security is transmitted, otherwise it shall be set to 0.

3.1.2 GOOSE on Application Layer

On application layer, GOOSE messages is defined using ASN.1 notation, see Appendix F. The PDU has the following structure:

```
IECGoosePdu ::= SEQUENCE {
        gocbRef                 [0]     IMPLICIT   VISIBLE-STRING,
        timeAllowedtoLive       [1]     IMPLICIT   INTEGER,
        datSet                  [2]     IMPLICIT   VISIBLE-STRING,
        goID                    [3]     IMPLICIT   VISIBLE-STRING OPTIONAL,
```

```
        T                   [4]     IMPLICIT  UtcTime,
        stNum               [5]     IMPLICIT  INTEGER,
        sqNum               [6]     IMPLICIT  INTEGER,
        simulation          [7]     IMPLICIT  BOOLEAN DEFAULT FALSE,
        confRev             [8]     IMPLICIT  INTEGER,
        ndsCom              [9]     IMPLICIT  BOOLEAN DEFAULT FALSE,
        numDatSetEntries    [10]    IMPLICIT  INTEGER,
        allData             [11]    IMPLICIT  SEQUENCE OF Data,
}
```

The structure of GOOSE PDU is derived from GOOSE Control Block object as defined by IEC 61850-7-2 standard [3]. It consists of the following items:

- *GoCBRef* – GOOSE control block reference is a unique path-name of an instance of GOOSE Control Block (*GoCB*) within LLN0. The format is LDName/LLN0.GoCBName, e.g., *GEDeviceF650/LLN0GOgcb01* where LD name is *GEDeviceF650*, LN class is *LLN0* (Logical Node Zero), functional constraint is *GO* (GOOSE Control) and GoCB instance is *gcb01.*
- *TimeAllowedtoLive* – time at which the attribute *StNum* was incremented. It informs subscribers of how long to wait for the next repetition of the message.
- *DatSet* – references of the data set whose values of members shall be transmitted, e.g., *GEDeviceF650/LLN0$GOOSE1*. The members of the *DataSet* shall be uniquely numbered beginning with 1. This number is called the *MemberOffset* of a given member. Each member of the DataSet has a unique number and a *MemberReference* (the functional constraint data FCD or DataAttribute FCDA), see Figure 12.
- *GoID* – GOOSE ID is an attribute that allows a user to assign an identification for the GOOSE message, e.g., *F650_GOOSE1*.
- *T (timestamp)* – time at which the attribute *StNum* was incremented.
- *StNum* (status number) is a counter that increments each time a GOOSE message has been sent and a value change has been detected within the *DataSet* specified by *DatSet*. The initital value shall be 1. The value 0 is reserved.
- *SqNum* – is the current sequence number of the reports. It shall increment each time a GOOSE message sent. Following a *StNum* change, the counter *SqNum* shall be set to a value 0. The initial value for *SqNum* upon a transmission of *GoEna* to TRUE is 1. This number seems to be similar to the sequence number in TCP.
- *Simulation* (test bit) – if true, the message and therefore its value have been issued by a simulation unit and are not real values. The GOOSE subscriber will report the value of the simulated message to its application instead of the real message depending on the setting of the receiving IED.
- *ConfRev* – contains the configuration revision to indicate deletion of a member of the data set or the reordering of the members, or changing the *DatSet* reference. The number shall represent a count of the number of times that the configuration of the *DataSet* referenced by DatSet value has been changed.
- *NdsCom* – indicates in the message that some commissioning is required (need commission). If TRUE, the *GoCB* requires further configuration.
- *NumDatSetEntries* – a number of data set entries
- *allData* – a list of user defined information of the MMS NamedVariableList that is specified in GOOSE control block.

3.2 Communication

The generic substation event model provides the possibility for a fast and reliable system-wide distribution of input and output values. The generic substation event model is based on the concept of an autonomous decentralization, providing an efficient method allowing the simultaneous delivery of the same generic substation event information to more than one physical device through the use of multicast/broadcast services.

Two control classes and the structure of two messages are defined by the IEC 61850-7-2 [3]:

- Generic object oriented substation event (GOOSE) that supports the exchange of a wide range of possible common data organized by a data set,
- Generic substation state event (GSSE) provides the capability to convey state exchange information (bit pairs).

The peer-to-peer communication provides services for the exchange of generic substation events (GOOSE and GSSE; based on multicast) and for the exchange of sampled values (based on multicast or unicast). The GOOSE model uses data values to be published grouped into data sets. Many data and data attributes can be used to create a data set, e.g., analog, binary, or integer values.

GOOSE communication is based on publish-subscribe mechanism. The publisher writes the values into a local buffer at the sending side; the subscriber reads the values from a local buffer at the receiving side. The communication system is responsible to update the local buffers of the subscribers. A generic substation event control class (GoCB) in the publisher is used to control the procedure.

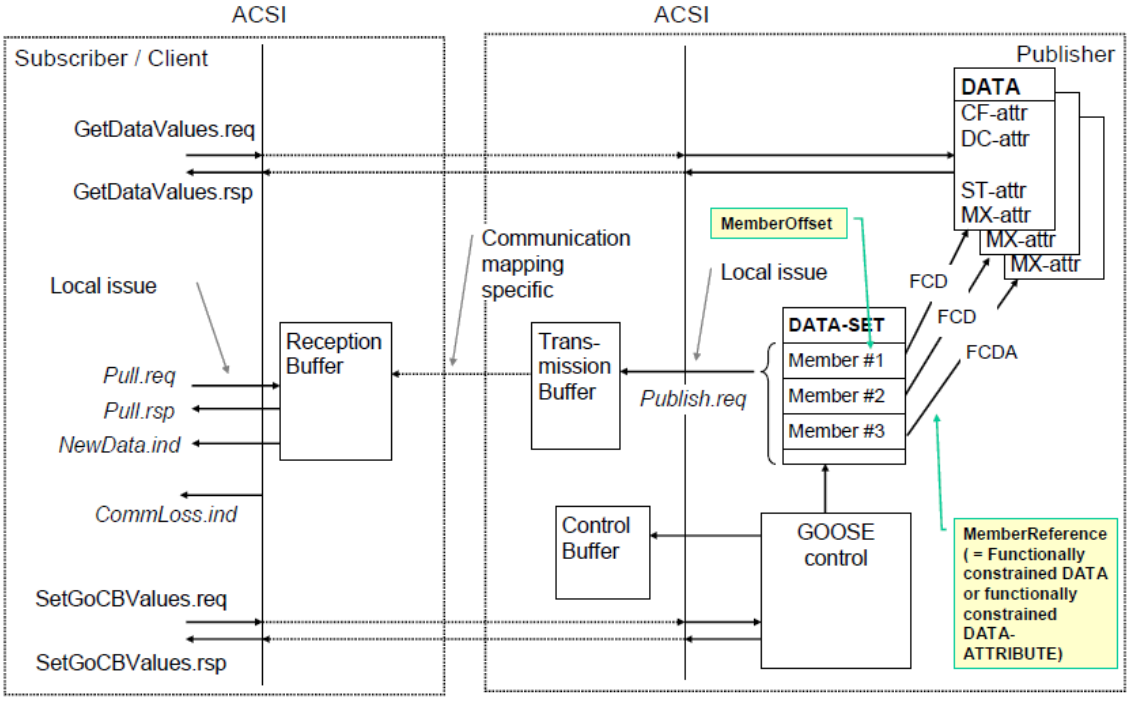

Figure 12: GoCB model [3]

Figure 12 gives an overview of the classes and services of the GOOSE model. The message exchange is based on the multicast application association. If the value of one or several *DataAttributes* of a special functional constraint (for example *ST*) in the *DataSet* changes, the transmission buffer of the publisher is updated with the local service *publish*, and all values are transmitted with a GOOSE message. The *DataSet* may have several members. Each member shall have a *MemberReference* referencing the *DataAttribute* with a specific functional constraint (FC). Mapping specific services of the communication network will update the content of the buffer in the subscribers. New values received in the reception buffer are signaled to the application.

The GOOSE messages contain information that allow the receiving device to know that a status has changed and the time of the last status change. The time of the last status change allows a receiving device to set local timers relating to a given event.

A newly activated device, upon power-up or reinstatement to service, shall send the current value of a data object (status) or values as the initial GOOSE message. Moreover, all devices sending GOOSE messages shall continue to send the message with a long cycle time, even if no status/value change has occurred. This ensures that devices that have been activated recently will know the current status values of their peer devices.

The GOOSE message is multicasted and received by the IEDs which have been configured to subscribe to it, see Figure 13.

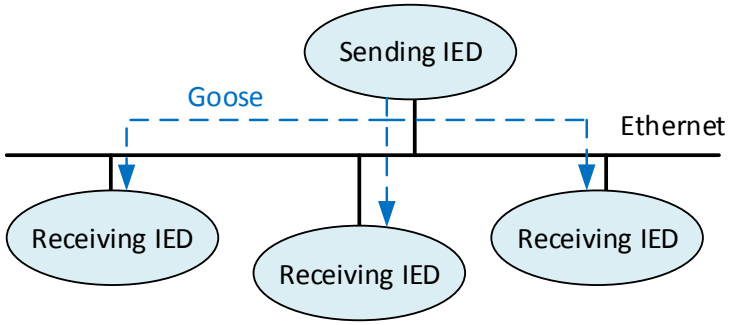

Figure 13: GOOSE publish-subscribe communication

First, GOOSE application shall be configured which includes the following steps:

1. Prepare a GOOSE data set.
2. Setup GOOSE Control Block parameter to specify how to send the data set.
3. Specify which IEDs are going to receive the GOOSE data set by subscribing.

A GOOSE data set is a collection of data attributes. A user can locally create this data set, add new data attributes to the list or remove them from the list, see Figure 14.

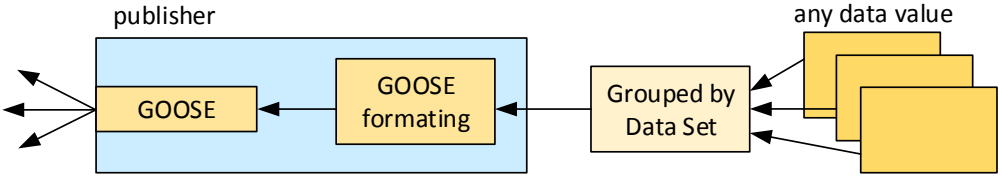

Figure 14: Peer-to-peer data value publishing model

A GOOSE control block specifies properties and behavior of the GOOSE message, e.g., destination MAC address, APPID, VLAN ID and Priority. While multiple GOOSE messages are sending to all devices on the network using multicast, GOOSE receiver uses this information to check if received GOOSE message is the one being expected. IEDs send GOOSE message every *MaxTime* milliseconds as defined in the configuration. When a GOOSE message is received, it will be compared with GOOSE control block on the receiving IED, especially destination MAC address, *APPID* and *ConfRev*. *ConfRev* represents how many times GOOSE data has been modified, see above. This *ConfRev* number should match between a GOOSE sending IED and a receiving IED. If they match, then the GOOSE message will be processed, otherwise it will be discarded.

When there is no new GOOSE event, IED still sends supervision heartbeat messages with time interval defined by parameter *MaxTime*. This value is encoded in *TimeAllowedToLive* parameter which is double the time of the *MaxTime*.

3.3 Examples of Message Parsing

GOOSE protocol parsing starts at Ethernet level since GOOSE is directly encapsulated in the Ethernet Frame, see Section 3.1.

3.3.1 GOOSE on Data Link Layer

Following EtherType field with value 0x88b8 for GOOSE, there is a two-byte APPID field, a two-byte Length field, a two-byte Reserved1 field, and a two-byte Reserved2 field. These fields are present in every GOOSE message with the fixed length. The following example shows an analysis of an Ethernet Frame with GOOSE protocol:

Example 1: 01 0c cd 01 00 01 00 09 8e fa b7 1c 88 b8 00 02 00 8e 00 00 00 00 61 81 83 80 1f 53 …

- 01 0c cd 01 00 01 (6 bytes) – multicast destination MAC address for GOOSE (prefix 0x 01 0c cd 01).
- 00 09 8e fa b7 1c (6 bytes) – the unicast source MAC address that identifies a sending device
- 88 b8 – EtherType which indicates GOOSE protocol, see Table 3.
- 00 02 (2 bytes) – the AppID (application ID) identifies a receiving application
- 00 8e (2 bytes) – the length of the GOOSE message including a part in Ethernet Frame. The value 0x8e indicates 142 bytes of the GOOSE message.
- 00 00 (2 bytes) – the Reserved1 field.
- 00 00 (2 bytes) – the Reserved2 field.

3.3.2 GOOSE on Application Layer

On the application layer, GOOSE PDU is encoded using ASN.1 notation, i.e., transmitted data forms TLV (Type-Length-Value) triplets, see Appendix G. The context-specific types encoded in GOOSE header are given in Table 4. The table shows ASN.1 context-specific tags as related to the IECGoosePdu format, see Appendix F.

Standard 61850-8-1 [6] defines the Fixed-length property for a GOOSE messages. This property means that the publisher will always use fixed offsets for each different field in the message. The Fixed-length property configuration occurs for each GOOSE Control Block. Table 4 shows the

ASN.1 data length for given fields when the Fixed-length property is set. If not, the length is specified in TLV format.

The following example shows decoding of a GOOSE message without the Fixed-length property, so the length of given GOOSE fields is given directly in the TLV structure.

Attribute Name	Data Type	ASN.1 Identifier	Tag number	ASN.1 Length (B)
goCBRef	Visible-string	0x80	0	variable
timeAllowedToLive	INT32U	0x81	1	5
datSet	Visible-string	0x82	2	variable
goID	Visible-string	0x83	3	variable
T	UtcTime	0x84	4	8
stNum	INT32U	0x85	5	5
sqNum	INT32U	0x86	6	5
simulation	Boolean	0x87	7	1
confRev	INT32U	0x88	8	5
ndsCom	Boolean	0x89	9	1
numDatSetEntries	INT32U	0x8a	10	5
allData	SEQUENCE of Data	0xab	11	variable

Table 4: ASN.1 Tags for context-specific data type in GOOSE message [6]

Example 2: 61 81 83 80 1f 53 49 50 43 54 52 4c 2f 4c 4c 4e 30 24 47 4f 24 43 6f 6e 74 72 6f 6c 5f 44 61 74 61 73 65 74 81 02 0b b8 82 14 53 49 50 43 54 52 4c 2f 4c 4c 4e 30 24 44 61 74 61 73 65 74 83 1d 53 49 50 2f 43 54 52 4c 2f 4c 4c 4e 30 2f 43 6f 6e 74 72 6f 6c 5f 44 61 74 61 73 65 74 84 08 59 31 8e 6a 25 e3 0a 89 85 01 05 86 03 0b 9b 2b 87 01 00 88 01 01 89 01 00 8a 01 02 ab 09 84 02 06 80 84 03 03 00 00

- Type 61 (0110 0001 in binary) is an identifier octet which describes the application class (01), in the constructed (1) form with data type 1. Application type 01 means *goosePDU* (see Appendix F).
- Length 81 83 is an extended length field where 0x81 (1000 0001) describes the long definite form of the length with 1 octet and 0x83 is the length value, that is, 131 bytes.
    - Type 80 (1000 0000) starts an embedded TLV triplet which is of the context-specific class (10), primitive form (0) and the type is 0 which is *gocbRef* (see Appendix F).
        - Length 1f is the length of the VISIBLE STRING in the *gocbRef* field, i.e., 31 bytes.
        - Value 53 49 50 43 54 52 4c 2f 4c 4c 4e 30 24 47 4f 24 43 6f 6e 74 72 6f 6c 5f 44 61 74 61 73 65 74 represents string "SIPCTRL/LLN0GOControl_Dataset" which refers to SIPCTRL device, logical name LLN0, functional constraint GO (GOOSE control) and control block name *Control_Dataset*.
    - A TLV 81 02 0b b8 denotes a context specific data type (10) in primitive form (0) and of type 1 which is *timeAllowedToLive* attribute with 2-byte value of 0x 0b b8, i.e., 3000 in decimal.
    - Next TLV 82 14 53 49 50 43 54 52 4c 2f 4c 4c 4e 30 24 44 61 74 61 73 65 74 has the context specific type 2 which is *datSet*, the length 20 bytes (14 in hex) and ASCII value "SIPCTRL/LLN0$Dataset".
    - TLV 83 1d 53 49 50 2f 43 54 52 4c 2f 4c 4c 4e 30 2f 43 6f 6e 74 72 6f 6c 5f 44 61 74 61 73 65 74 has the context specific type 3 (GOOSE ID) with length 29 bytes (1d in hex) and the value in ASCII "SIP/CTRL/LLN0/Control_Dataset".
    - TLV 84 08 59 31 8e 6a 25 e3 0a 89 represents the context-specific data type T (UTC time). Its 8-byte value can be interpreted as "Jun 2, 2017 16:12:26.147995591 UTC".

- TLV 85 01 05 encodes *stNum* field with value 5.
- TLV 86 03 0b 9b 2b encodes *sqNum* field with value 760619.
- TLV 87 01 00 encodes *simulation* field with BOOLEAN value 0 (False).
- TLV 88 01 01 encodes *confRev* number with value 1.
- TLV 89 01 00 encodes *ndsCom* field with BOOLEAN value 0 (False).
- TLV 8a 01 02 encodes *numDatSetEntries* field with integer value 2.
- TLV ab 09 84 02 06 80 84 03 03 00 00 has type 0xab (10101011) which means the context-specific type (10), constructed form (1) and of the type 11 (1011 in binary) which is SEQUENCE of Data.
  - The length is 9 bytes.
  - The first item of the sequence has type 84 (1000 0100) which is the context specific type (10), primitive (0). Data type identifier refers to the CODED ENUM, see Table 5, which is bit string (see Appendix D). The length of the value is 2 bytes. The value contains 6 padding bits (0x60) in byte 0x80 (*10* 00 00 00), so the value is 2.
  - The second item of the sequence has also type 84 (bit string), with length 3 bytes and value 03 00 00. The value field is composed of the padding bits length which is 3 and the value, which is 0.

IEC 61850-7-2 data type	ASN.1 Identifier	ASN.1 Length (B)	Comments
Boolean	0x83	1	False (0), True (1)
INT8	0x85	2	signed 8 bit big endian
INT16	0x85	3	signed 16 bit big endian
INT32	0x85	5	signed 32 bit big endian
INT64	0x85	9	signed 64 bit big endian
INT8U	0x86	2	unsigned 8 bit big endian
INT16U	0x86	3	unsigned 16 bit big endian
INT24U	*not used*		
FLOAT32	0x86	5	32 bit IEEE 754 floating point
ENUMERATED	0x87	5	signed 8-bit big endian
CODED ENUM	0x84	2	bit-string: 1st byte=unused bytes, 2nd byte=value
OCTET STRING	0x89	20	20 bytes ASCII text, Null terminated
VISIBLE STRING	0x8a	35	35 bytes ASCII text, Null terminated
Timestamp	0x91	8	64 bit timestamp
Quality	0x84	3	bit-string

Table 5: ASN.1 tags for allData structure [6] and their length

3.4 GOOSE datasets

The following section gives a short discussion about communication in a GOOSE dataset obtained for the project.

3.4.1 Dataset GOOSE.pcap

GOOSE.pcap is a sample file published by Wireshark[2]. It contains eight GOOSE packets sent by application on the same device. APPID is 1, GoID is F650_GOOSE1, control block is GEDeviceF650/LLN0GOgcb01 and dataSet name is GEDeviceF650/LLN0$GOOSE1. StNum and allData values do not change. Only values of timeAllowedtoLive and sqNum change during time.

[2] See https://wiki.wireshark.org/SampleCaptures?action=AttachFile&do=view&target=GOOSE.pcap.gz [June 2018]

Changes in timeAllowedtoLive are strange in this context and with respect to timestamp *t*, this changes seem to be artificial, see Table 6.

goCBRef	goID	datSet	stNum	sqNum	timeAllowed toLive	t
GEDeviceF650/LLN0GOgcb01	F650_GOOSE1	GEDeviceF650/LLN0$GOOSE1	1	10	40000	Jan 2, 2000 02:46:11.258165836 UTC
GEDeviceF650/LLN0GOgcb01	F650_GOOSE1	GEDeviceF650/LLN0$GOOSE1	1	11	40000	Jan 2, 2000 02:46:11.258165836 UTC
GEDeviceF650/LLN0GOgcb01	F650_GOOSE1	GEDeviceF650/LLN0$GOOSE1	1	12	40000	Jan 2, 2000 02:46:11.258165836 UTC
GEDeviceF650/LLN0GOgcb01	F650_GOOSE1	GEDeviceF650/LLN0$GOOSE1	1	1	1000	Jan 2, 2000 02:47:29.927595853 UTC
GEDeviceF650/LLN0GOgcb01	F650_GOOSE1	GEDeviceF650/LLN0$GOOSE1	1	2	1000	Jan 2, 2000 02:47:29.927595853 UTC
GEDeviceF650/LLN0GOgcb01	F650_GOOSE1	GEDeviceF650/LLN0$GOOSE1	1	3	1000	Jan 2, 2000 02:47:29.927595853 UTC
GEDeviceF650/LLN0GOgcb01	F650_GOOSE1	GEDeviceF650/LLN0$GOOSE1	1	4	2000	Jan 2, 2000 02:47:29.927595853 UTC
GEDeviceF650/LLN0GOgcb01	F650_GOOSE1	GEDeviceF650/LLN0$GOOSE1	1	5	40000	Jan 2, 2000 02:47:29.927595853 UTC

Table 6: Analyzing GOOSE data

3.4.2 Dataset goose1.pcapng

This file was created in the power system lab. Dataset contains 1093 GOOSE packets sent by three different devices to five different multicast groups: 01:0c:cd:01:00:00, 01, 02, 03, 04.

GOOSE packets from one IED to one destination multicast address are sent by 2 or by 10 seconds. For given destination MAC address, APPID (application ID), goCBRef (control block address), goID (GOOSE ID) and DatSet (date set reference) are constant, only sqNum (sequence number) value is incremented, see Table 7. There are no changes in allData block.

Src MAC	Dst MAC	APPID	goCBRef - goID - datSet	stNum	timeAllowed toLive	sqNum range	Packets
00:09:8e:fa:b7:1a	01:0c:cd:01:00:00	0x00000001	SIP1CTRL/LLN0GOControl_Dataset SIP1/CTRL/LLN0/Control_Dataset SIP1CTRL/LLN0$Dataset	3	3000	760626-760835	210
00:09:8e:fa:b7:1a	01:0c:cd:01:00:03	0x00000004	SIP1PROT/LLN0GOControl_Dataset_1 SIP1/PROT/LLN0/Control_Dataset_1 SIP1PROT/LLN0$Dataset_1	186	3000	760548-760757	210
00:09:8e:fa:b7:1c	01:0c:cd:01:00:01	0x00000002	SIPCTRL/LLN0GOControl_Dataset SIP/CTRL/LLN0/Control_Dataset SIPCTRL/LLN0$Dataset	5	3000	760617-760826	210
00:09:8e:fa:b7:1c	01:0c:cd:01:00:02	0x00000003	SIPPROT/LLN0GOControl_Dataset_1 SIP/PROT/LLN0/Control_Dataset_1 SIPPROT/LLN0$Dataset_1	81	3000	760617-760826	210
00:09:8e:fa:b7:1c	01:0c:cd:01:00:04	0x00000005	SIPCTRL/LLN0GOControl_Dataset_1_1 SIP/CTRL/LLN0/Control_Dataset_1_1 SIPCTRL/LLN0$Dataset_1_1	75	3000	760617-760826	210
00:21:c1:25:08:a2	01:0c:cd:01:00:00	0x00000001	AA1J1Q01A1LD0/LLN0GOLEDs_info AA1J1Q01A1LD0/LLN0.LEDs_info AA1J1Q01A1LD0/LLN0$LEDs_ON_OFF	23	11000	112568-112610	43
							1093

Table 7: GOOSE packets values in the dataset

When analyzing one outstation (GOOSE publisher), e.g., 00:09:8e:fa:b7:1c, we can see that it sends GOOSE messages iteratively to three different multicast groups where GOOSE subscribers read data. As stated in the standard, published data are grouped to datasets and each dataset is controlled by its application (instance). Any change of data attribute values are detected in *allData* field. If the status changes, *stNum* is incremented.

The following application are active at the outstation:

- Application with APPID=2 sends PDUs to group 01:0c:cd:01:00:01 with control block address SIPCTRL/LLN0GOControl_Dataset, dataset SIPCTRL/LLN0$Dataset and GOOSE ID SIP/CTRL/LLN0/Control_Dataset.
- Application with APPID = 2 sends PDUs to group 01:0c:cd:01:00:04 with control block address SIPCTRL/LLN0GOControl_Dataset_1_1, dataset SIPCTRL/LLN0$Dataset_1_1 and GOOSE ID SIP/CTRL/LLN0/Control_Dataset_1_1.
- Application with APPID = 3 sends PDUs to group 01:0c:cd:01:00:02 with control block address SIPPROT/LLN0GOControl_Dataset_1, dataset SIPPROT/LLN0$Dataset_1 and GOOSE ID SIP/PROT/LLN0/Control_Dataset_1.

PDUs are sent every 2 seconds for every multicast group. Since there are no changes on the sender side, *stNum* (status number) remains the same.

Sequence number value *sqNum* is incremented when every new message is sent. Since this variable have been initialized by the same starting value for each destination, its values during transmission are same for all destinations.

After 2 minutes of GOOSE communication, MMS communication is opened between the outstation (server) and a new device (client) with MAC address 00:0a:f7:4d:93:fc. The client establishes the connection and requests data. MMS communication includes the following phases, see Section 4.4.1 for details:

1. *Connection initialization* with MMS *Initiate-Request* and MMS *Initiate-Response* PDUs when connection parameters are negotiated and available services announced.
2. *Dataset initialization* when the client discovers available logical nodes, datasets, variable and attribute names using services *getNameList*, *getVariableListAttributes*.
    - In our case, following logical nodes (MMS domains) are discovered: SIPCTRL, SIPDR, SIPMEAS and SIPPROT.
    - For these LNs, following datasets are discovered: for SIPCTRL – LLN0$Dataset and LLN0$Dataset_1_1, for SIPDR – no dataset, for SIPMEAS – no dataset, and for SIPPROT – LLN0$Dataset_1
    - Following discovery of datasets, available attributes names are requested:
        - for SIPCTRL/LLN0$Dataset: XSWI1$STPosstVal, XSWI1STPos$q
        - for SIPCTRL/LLN0$Dataset_1_1: XCBR1$ST$TripOpnCmd$stVal, XCBR1STTripOpnCmd$q
        - for SIPPROT/LLN0$Dataset_1: ID_PTOC1$STStrgeneral, ID_PTOC1STStr$q.
3. Next phase is *data access* when data are accessed using *read* service.
    - Each LN is requested for *LLN0DCNamPlt$configRev* attribute for changes. Its value is regularly read by the client every 5 seconds per each dataset.

The above mentioned MMS communication is interleaved with GOOSE messages sent by the outstation to all multicast groups when it informs about changes.

Example of topology is in Figure 15.

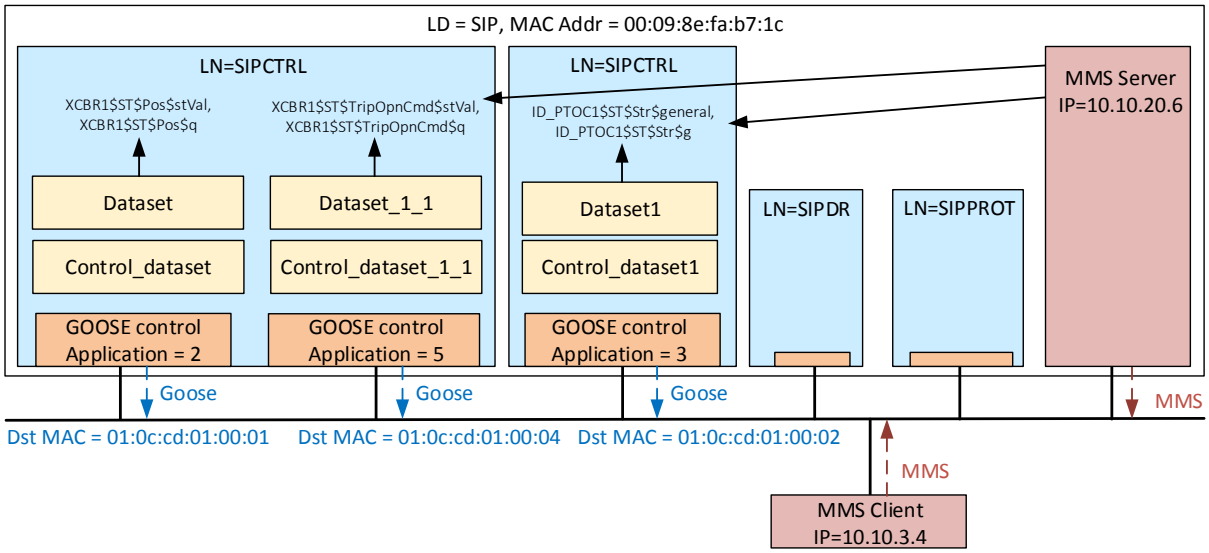

Figure 15: Example of communication topology

3.5 Summary

Based on the description of GOOSE protocol and analysis of available dataset, the following observations can be made:

- GOOSE protocol communicates using peer-to-peer mode where the sender (publisher) sends multicast Ethernet frames with GOOSE message to receivers (subscribers). One sender can send data to different multicast groups.
- A publisher defines a set of variables that will be published using GOOSE control block. Published data are referenced using *DatSet* variable in GOOSE PDU.
- GOOSE PDUs can be easily identified when encapsulated in Ethernet Frame by the reserved destination L2 address starting with 01:0c:cd:01 and EtherType equal to 0x88b8[3].
- GOOSE messages are regularly sent as keep-alive mechanism. Transmission time is locally configured. If no changes on the publisher side, transmitted messages are almost identical where onlysequence number *sqNum* is incremented.
- Standard IEC 61850-8-1 [6] defines several GOOSE services (*GetGoReference*, *GetGOOSEElementNumber*, *GetGoCBValues*, *SetGoCBValues*, *SendGOOSEMessage*) [3] but only two types of GOOSE PDUs are described in the standard, namely *MngtPdu* and *IECGoosePdu*, see Appendix F.
- When analyzing available datasets, only IECGoosePdu frames have been found. All GOOSE messages were sent by a physical device to a multicast address in the peer-to-peer mode.
- Data transmitted in *allData* field cannot be easily interpreted because no Data Attribute reference is given in the PDU. On the publisher side, *DatSet* identifier is used to refer to the original data, see Figure 14.
- Changes in data transmission can be identified when looking at status number *StNum.* This number is incremented each time when a value change has been detecting within the DataSet.

[3] See http://standards-oui.ieee.org/ethertype/eth.txt [August 2018]

4 MMS Protocol

MMS (Manufacturing Message Specification) is a messaging system for modeling real devices and functions and for exchanging information about the real device, and exchanging process data – under real-time conditions – and supervisory control information between networked devices and/or computer applications.

MMS is defined by standards ISO/IEC 9506-1 (Services) and ISO/IEC 9506-2 (Protocol).

- The service specification contains definition of the Virtual Manufacturing Device (VMD), services (and messages) exchanged between nodes on a network, and the attributes and parameters associated with the VMD and services.
- The protocol specification defines the rules of communication, i.e., the sequencing of messages across the network, the format and encoding of the messages, and the interaction of the MMS layer with the other layers of the communications network.

MMS communicates using a client-server model. A client is a network application or device (e.g., monitoring system, control center) that asks for data or an action from the server. A server is a device or application that contains a Virtual Manufacturing Device (VMD) and its objects (e.g., variables) that the MMS client can access. The VMD object represents a container in which all other objects are located, see Figure 16. The client issues MMS service requests and the server responds to these requests.

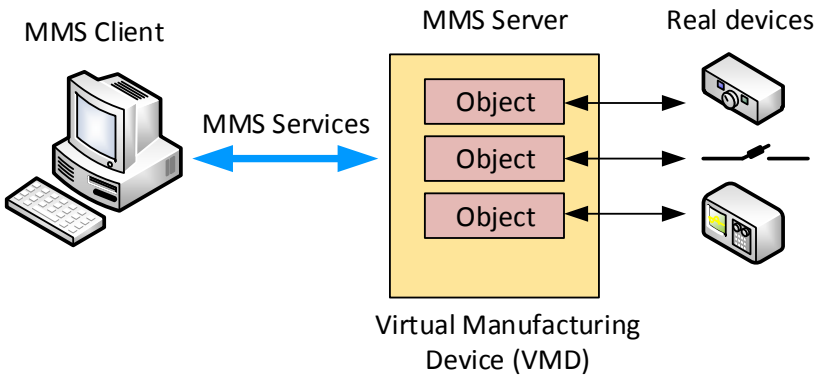

Figure 16: MMS client-server model

MMS uses an object-oriented approach with object classes (Named Variable, Domain, Program invocation), instances and methods (read, write, store, start, stop, etc.).

4.1 VMD model and MMS objects

The VMD model defines:

- *objects* (e.g., variables) and attributes (e.g., name, value, type) that are contained in the server,
- *services* (e.g., read, write) for accessing and managing the objects, and
- *behavior* that a device should exhibit when processing the services.

The VMD model only specifies the network visible aspects of communication. The internal detail of how a real device implements the VMD model are not defined by MMS.

MMS defines a variety of objects that can be found in many typical devices. For each of the object, standard ISO 9506-2 [9] defines corresponding services. Table 12 shows MMS objects and their mapping on IEC 61850 objects defined in IEC 61850-7-2 [3]. In addition to the objects in Table 11, ISO 9506-2 defines following objects: Program Invocation, Type, Semaphore, Operator Station, Event Condition, Event Action, Event Enrollment, and Transaction.

MMS Object	IEC 61850 Object	MMS Services
Application Process VMD	Server	Initiate
		Conclude
		Abort
		Reject
		Cancel
		Identify
Named Variable Objects	Logical Nodes and Data	Read
		Write
		InformationReport
		GetVariableAccessAttribute
		GetNameList
Named Variable List Objects	Data Sets	GetNamedVariableListAttributes
		GetNameList
		DefineNamedVariableList
		DeleteNamedVariableList
		Read
		Write
		InformationReport
Journal Objects	Logs	ReadJournal
		InitializeJournal
		GetNameList
Domain Objects	Logical Devices	GetNameList
		GetDomainAttributes
		StoreDomainContents
Files	Files	FileOpen
		FileRead
		ObtainFile
		FileClose
		FileDirectory
		FileDelete

Table 12: MMS Objects and Services

All objects (except unnamed variables) are identified by an object name which can be

- VMD-specific, i.e., persistent, pre-loaded, all clients see the same.
- Domain-specific, i.e., it exists as long as the corresponding domain exists.
- Application-Association specific, i.e., it exists as long as the client remains connected. This applies to non-persistent objects such as data sets that the client created.

Access to all objects can be controlled by a special object, *Access Control List* that tells which client can delete or modify the objects.

MMS services (methods) work with MMS objects. The service can create or delete objects (*creation, deletion*), read object values (*get, report*), modify object values (*write, alter*), upload or download *(domains, files*), operate instructions (*start, stop, …*).

MMS also provides service such as Status, Unsolicited Status, and Identify for obtaining information about the VMD. The service *GetNameList* provides managing and obtaining information about objects defined in the VMD by retrieving the name and type of all named objects in the VMD, see Appendix E.

MMS works with named and unnamed variables.

- Unnamed variables (vadr) are identified by a fixed physical address in the VMD, e.g., numericAddress (0xAF043BC0), symbolicAddress (MW%1004), or unconstrainedAddress (0x76AA).
- Name variables (vnam) are identified by an object name.

When accessing data, MMS provides serviced to build a Data Set which is a group of variables that is to be transmitted as a whole. This is generally done for each client specifically (application-association specific type). The client defines a list and populates it with the names of the variables and the transmission mode.

MMS domain is a named MMS object that is a representation of some resource within the real device. In many typical applications, domains are used to represent area of memory in a device. Objects (variables, events, program invocations, …) may be tied to a domain. Each domain is controlled by a state machine in MMS.

4.2 MMS Encapsulation

MMS does not specify how to address clients and servers and relies on the addressing scheme of underlying protocols. In practice, clients and servers are addresses by their IP address and the MMS is encapsulated over TCP, port 102. However, port 102 is dedicated to ISO TSAP Class 0 which is general encapsulation of ISO model protocols over TCP. Upper layers use ISO identifiers, e.g., TSAP (transport service access point), COTP source and destination references, OSI calling and called session selectors, etc.
The encapsulation includes several ISO protocols which are part of ISO stack, see Figure 17. Not all the protocols shall be presented in every MMS message. In the following text, each encapsulation protocol will be described.

<table>
<tr><th>Layer</th><th>PDU</th><th>Protocols</th></tr>
<tr><td rowspan="2">Application (L7)</td><td rowspan="2">APDU</td><td>Manufacturing Message Specification (MMS): ISO 9506</td></tr>
<tr><td>Association Control Service Element (ACSE): ISO/IEC 8650/X.227</td></tr>
<tr><td>Presentation (L6)</td><td>PPDU</td><td>OSI Connection Oriented Presentation ISO 8823/X.226</td></tr>
<tr><td>Session (L5)</td><td>SPDU</td><td>OSI Connection Oriented Session: ISO 8327/X.225</td></tr>
<tr><td rowspan="3">Transport (L4)</td><td rowspan="3">TPDU</td><td>Connection-Oriented Transport Protocol: ISO/IEC 8073/X.224</td></tr>
<tr><td>ISO Transport over TCP (TPKT): RFC 1006</td></tr>
<tr><td>Transmission Control Protocol (TCP): RFC 793</td></tr>
<tr><td>Network (L3)</td><td>NPDU</td><td>Internet Protocol (IP): RFC 791</td></tr>
<tr><td>Data Link (L2)</td><td>Data Frame</td><td rowspan="2">Ethernet: ISO/IEC 8802-3</td></tr>
<tr><td>Physical (L1)</td><td>Bits</td></tr>
</table>

Figure 17: MMS OSI model over TCP/IP

4.2.1 Transport Layer (L4): TPKT and COTP

On transport layer, MMS packets are encapsulated in TPKT and COTP protocols. TPKT (ISO Transport over TCP) is a protocol defined by RFC 1006 [10]. It implements ISO TP0 Protocol (Transport Protocol Class 0) on top of TCP/IP. A fundamental difference between the TCP and TP0 is that the TCP manages a continuous stream of octets without explicit boundaries. The TP0 expects information to be sent and delivered in discrete objects: NSDUs (network service data units). For class 0, an NSDU is identical to a TPDU (transport protocol data units), i.e., one TPDU is transported inside a single NSDU.

TPKT protocol uses a simple packetization scheme in order to delimit TPDUs. Each packet is viewed as an object composed of an integral number of octets, of variable length. Format of TPTK header is in Figure 18. The header contains version number 3, a one-byte reserved field and two-byte length. The length is the total length of TPKT PDU including the header. TPKT PDU is transported over TCP with destination port 102 (ISO-TSAP class 0).

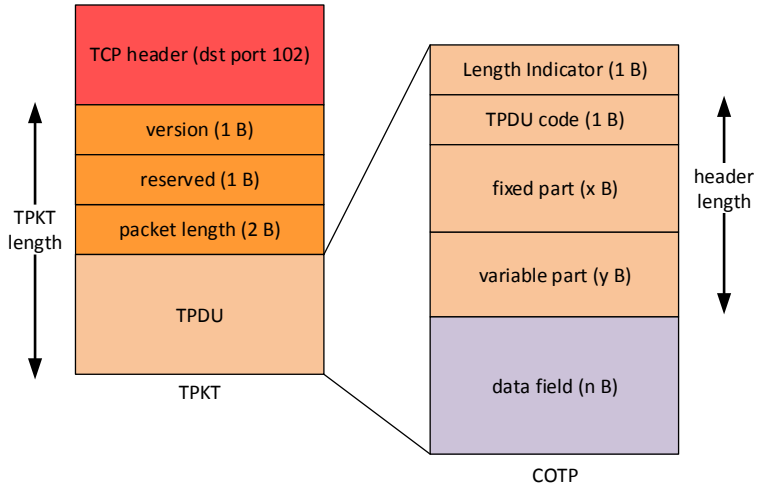

Figure 18: TPKT and COTP encapsulation

Connection-Oriented Transport Protocol (COTP) is defined by ISO 8073/X.224 standard [11] and RFC 905 [12]. Standard defines several COTP message, see Table 13.

Message	Code	Message	Code
Connection Request (CR)	1110 xxxx	Expedited Data (ED)	0001 0000
Connection Confirm (CC)	1101 xxxx	Data Acknowledgement (AK)	0110 zzzz
Disconnect Request (DR)	1000 0000	Expedited Data ACK (EA)	0010 0000
Disconnect Confirm (DC)	1100 0000	Reject (RJ)	0101 zzzz
Data (DT)	1111 0000	TPDU Error (ER)	0111 0000

Table 13: COTP messages

MMS communication mostly uses CR (TPDU code 0xd0), CC (TPDU code 0xe0) and DT (TPDU code 0xf0) messages. Their structure is depicted in Figure 19. CR and CC messages are used during connection establishment, DT packets transmit user data during normal operation phase.

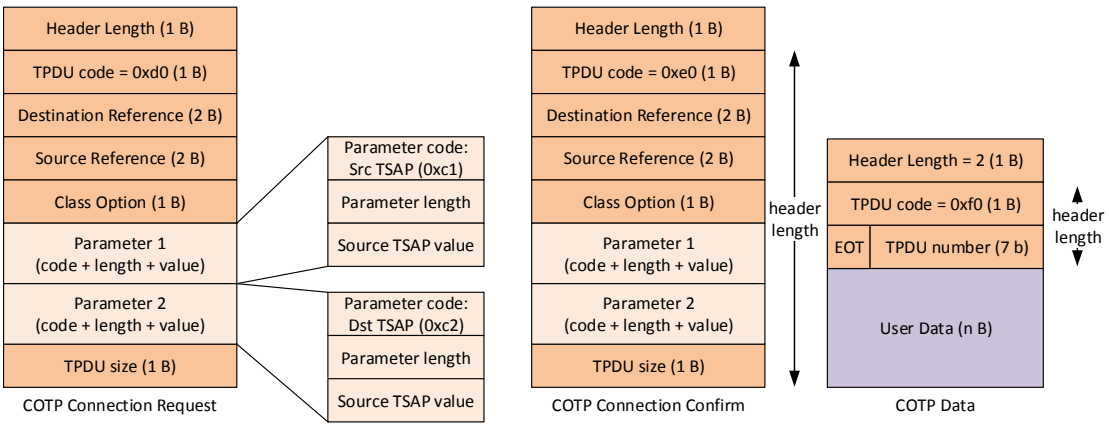

Figure 19: Format of COTP CR, CC and DT messages

The first octet of the TPDU is the length indicator field (LI). It indicates the length of the header in octets, excluding the LI field and user data. The structure of the message is given by next two-byte TPDU code. Valid TPDU codes are in Table 12 where *xxxx* or *zzzz* mean CDT (credit) field used for flow control. It represents the initial value of the upper window edge allocated by the peer entity. The value is set to zero for transport classes TP0 and TP1.

The structure of these messages is variable and given TPDU code. Messages CR and CC establish transport session over TCP. They contain source and destination references for identification of the transport connection, source and destination TSAP values (similar to TCP/UDP port numbers), and the maximum TPDU size. The CR and CC messages can also transmit other parameters. User data are not permitted in class TP0 for CR and CC messages. The length of User Data in COTP Data packet is not specified and shall be obtained from the lower layer, i.e., TPKT length.

When establishing TCP session using COTP, source and destination reference numbers are exchanged between communication partners using CR and CC messages, see Figure 20. At first, the sender transmits its SrcRef while DstRef is not initialized. When confirmed by CC message, both SrcRef and DstRef are established.

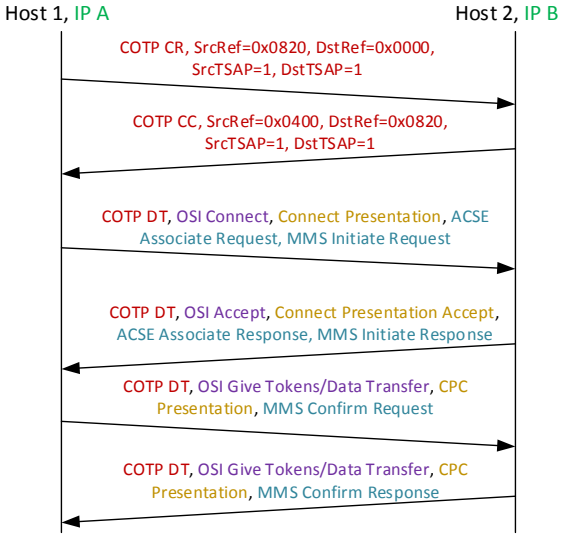

Figure 20: Opening MMS data connection

After COTP session is established, OSI connection oriented session on L5 shall be created. This is provided by ISO 8327/X.225 protocol [13] and the Association Control Service Element (ASCE) services [14], see below. On top of ASCE, there is MMS Initiate Request and Response.

As soon as L4 and L5 sessions are established, COTP employs Data messages (DT) to transport TP0 TPDU over TCP. COTP DT has a fixed length size (2 bytes) with TPDU code 0xf0. TPDU Number is always set to zero for TP0.

4.2.1.1 COTP Segmenting and Reassembling

The first bit of the next COTP DT byte (EOT, End of TSDU Mark) has a specific meaning: it indicates whether or not there are subsequent TPDUs in the sequence. The purpose of data transfer is to permit duplex transmission of TSDUs (Transport Service Data Units) by the transport connection. A large TSDU can be segmented into multiple TPDUs at the sending transport entity and reassemble into the original format at the receiving transport entity.

Value 1 indicates that the current DT TPDU is the last unit of a complete DT TPDU sequence. If set to 0, it is the last DT TPDU of the sequence (segmentation). In this case, the final recipient shall reassemble DT TPDUs on transport layer, so that upper layer PDUs (e.g., MMS) can be extracted. In this case TPKT length indicates only the length of the current DT TPDU segment, not a whole TSDU. This may happen when MMS requests *getNamedVariableListAttributes*, for example.

4.2.2 OSI Connection Oriented Session (L5)

OSI reference model defines connection-oriented session services provided by the session protocol on L5. Session services are specified by ISO/IEC 8326/X.215 and describe connection-oriented and connection-less session service primitives, connection establishment, and data transfer. Standard ISO-IEC 8327/X.225 [13] defines connection-oriented session protocol used by MMS.

The standard defines more than 30 different SPDUs (Session Protocol Data Units), however, MMS uses only three types: Connect (SPDU ID = 13), see Figure 21, and Accept (SPDU ID = 14) for establishing the connection, and Give Tokens/Data Transfer (SPDU ID = 1) for communication.

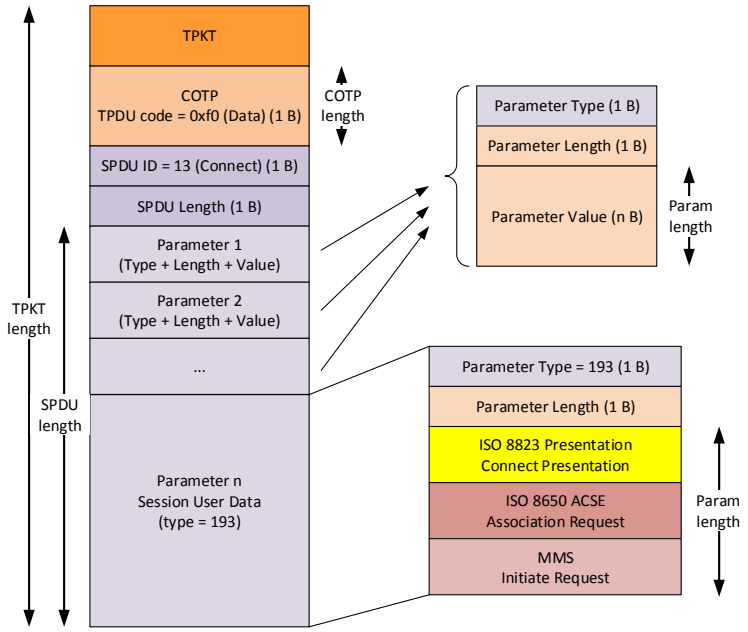

Figure 21: OSI Connect SPDU transmitted over TCP/IP

The structure of the SPDU is fixed: it starts with the SPDU identifier (1 byte) followed by the length indicator (LI, 1 byte) and a list of parameter fields. Each parameter field has TLV structure having type (1 B), length (1 B) and value.

4.2.2.1 Connect SPDU

Connect SPDU initiates a connection-oriented session connection. The type of Connect SPDU is 13 (decimal) and it contains the SPDU length and a list of parameter fields, see Figure 21. Possible parameters are *Connect Accept Item* (parameter type=5), *Session Requirement* (type=20), *Calling Session Selector* (type=51), *Called Session Selector* (type=52), or *Session User Data* (type=193), see [13, Annex C.2]. The latter parameter encapsulates upper layer PDUs: ACSE and MMS.

Connect SPDU encapsulates ACSE *Association Request* (AARQ) APDU as described by the standard X.227 [14]. The AARQ PDU is a BER-encoded packet with TLV structure, see Appendix H. The AARQ APDU defines MMS context using OID *iso(1).standard(0).iso9506(9506).part(2).mms-annex-version1(3)*. In the *user-information* field, ACSE AARQ transmits MMS *Initiate Request.* MMS *Initiate Request* includes MMS version (*proposedVersionNumber*), conformance parameters (*proposedParameterCBB*, conformance building block), a list of supported MMS services (*serviceSupportedCalling*), and other parameters, see Section 4.2.4.

4.2.2.2 Accept SPDU

A response to the *Connect* SPDU is an *Accept* SPDU which has similar format, see Figure 22. On application layer, it encapsulates ACSE *Association Response* (ACSE-AARE) and MMS *Initiate Response*. MMS transmits a negotiated protocol version (*negotiatedVersionNumber),* conformance parameters (*negotiatedParameterCBB*), a list of supported services (*servicesSupportedCalled*), etc.

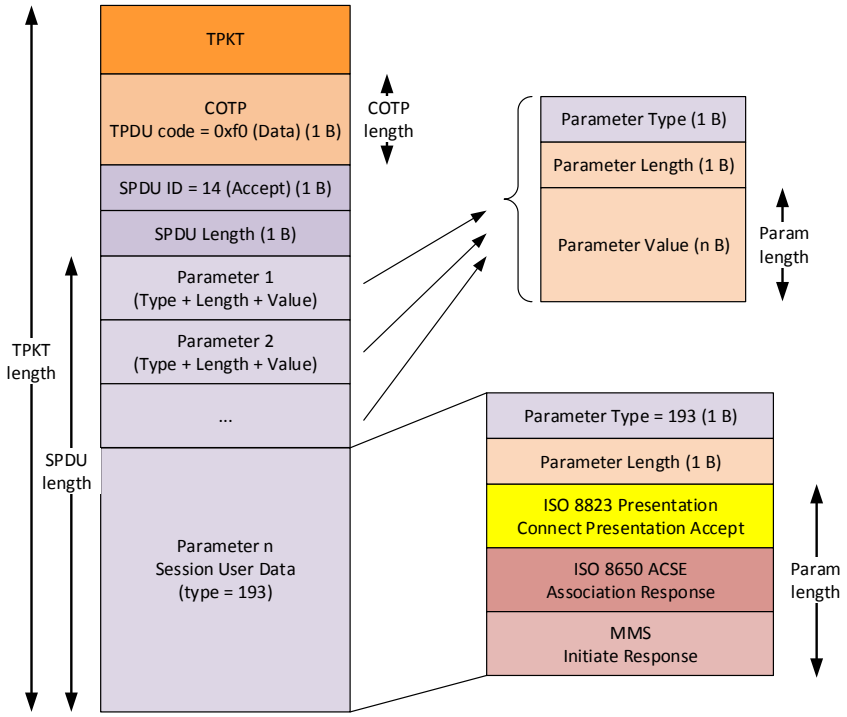

Figure 22: OSI Accept SPDU transmitted over TCP/IP

4.2.2.3 Give Tokens/Data Transfer SPDU

After successful exchange of OSI L5 *Connect* and *Accept* messages, following MMS messages are encapsulated only in a sequence of two L5 PDUs *Give tokens* and *Data Transfer*, presentation protocol ISO 8823, and MMS protocol. There is no ACSE encapsulation any longer. The format of the PDU is depicted in Figure 23.

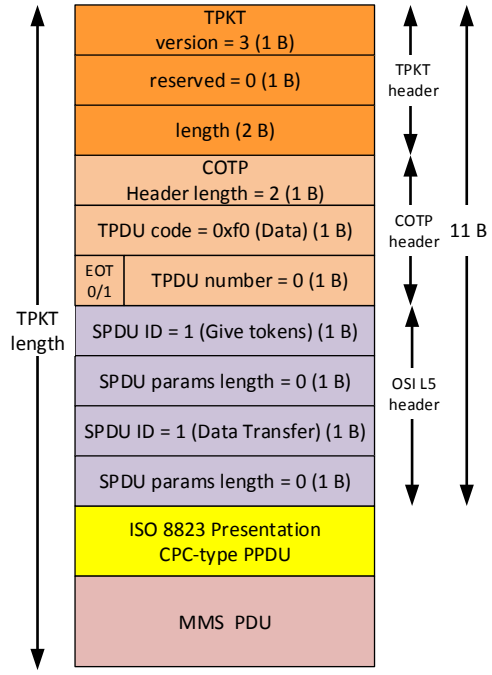

Figure 23: OSI Data Transfer SPDU transmitted over TCP/IP

As seen in Figure 23, standard X.225 allows SPDU concatenation [13, parts 6.3.7, 7.16]. In this case, the basic concatenation is applied, i.e., a *Give Tokens* SPDU is concatenated with a *Data Transfer* SPDU. Both SPDUs are without parameters. The *Give Tokens* SPDU is used to introduce a concatenated sequence of SPDU since the standard does not allow to send *Data Transfer* SPDU individually. *Data Transfer* SPDU is used to transfer user data after connection is established.

The PDU has a fixed format: 03 00 xx xx for TPKT (4 bytes), 02 0f 80/00 for COTP (3 bytes), and 01 00 01 00 for L5 header (4 bytes), i.e., 11 bytes of OSI headers. Then, the presentation layer follows.

4.2.3 OSI Connection Oriented Presentation (L6)

OSI Presentation Layer (L6) provides negotiation during presentation-connection establishment and specification of conformance requirements. It also provides data encoding during data transfer. The standard ISO 8822/X.216 defines presentation services and the standard ISO 8823/X.226 [15] describes Presentation Protocol Data Units (PPDUs).

The structure of PPDUs is defined by ASN.1 [15, part 8]. MMS communication employs only three types of PPDU: *Connect Presentation* PPDU (CP-type), *Connect Presentation Accept* PPDU (CPA-type), and *CPC-type* PPDU which contains user data. The formal description of these PPDUs is described by ASN.1, see Appendix I. As seen in the description, their structure is variable and BER-encoded. Length of a PPDU depends on options specified within the PPDU. The following part discusses the format of these three PPDUs.

4.2.3.1 Connect Presentation PPDU

The *Connect Presentation* (CP) PPDU is transmitted only at the beginning of the connection in L5 *Connect* SPDU and encapsulates *AARQ* and MMS *Initiate Request* on L7, see Figure 21. An L6 CP PPDU is a part of *Session user data* parameter (type=193) encapsulated in L5 *Connect* SPDU. The CP PPDU is placed after the parameter type and length of the SPDU *Session user data*.

The CP PPDU is BER-encoded, i.e., composed of TLV triplets. The PPDU format is given as follows:

```
CP-type ::= SET {
        mode-selector                   [0]     IMPLICIT    Mode-selector,
        normal-mode-parameters          [2]     IMPLICIT    SEQUENCE {
                protocol-version                    [0] IMPLICIT Protocol-version DEFAULT {version-1},
                calling-presentation-selector       [1] IMPLICIT Calling-presentation-selector OPTIONAL,
                called-presentation-selector        [2] IMPLICIT Called-presentation-selector OPTIONAL,
                presentation-context-definition-list [4] IMPLICIT Presentation-context-definition-list
OPTIONAL,
                default-context-name                [6] IMPLICIT Default-context-name OPTIONAL,
                presentation-requirements           [8] IMPLICIT Presentation-requirements OPTIONAL,
                user-session-requirements           [9] IMPLICIT User-session-requirements OPTIONAL
                user-data               User-data   OPTIONAL
        } OPTIONAL
}
Mode-selector ::= SET {
        mode-value              [0]     IMPLICIT    INTEGER {
                                x410-1984-mode      (0),
                                normal-mode         (1)     }
```

```
}
Calling-presentation-selector ::= Presentation-selector
Called-presentation-selector ::= Presentation-selector
Presentation-selector  ::= OCTET STRING
Presentation-context-definition-list ::= Context-list
Context-list ::= SEQUENCE OF SEQUENCE {
        presentation-context-identifier    Presentation-context-identifier,
        abstract-syntax-name               Abstract-syntax-name,
        transfer-syntax-name-list          SEQUENCE OF          Transfer-syntax-name
}
Presentation-context-identifier ::= INTEGER
Abstract-syntax-name  ::= OBJECT IDENTIFIER
Transfer-syntax-name  ::= OBJECT IDENTIFIER
Presentation-requirements ::= BIT STRING {
        context-management  (0),
        restoration         (1)
}
User-data ::= CHOICE {
        simply-encoded-data                [APPLICATION 0]      IMPLICIT    Simply-encoded-data,
        fully-encoded-data                 [APPLICATION 1]      IMPLICIT    Fully-encoded-data
}
Fully-encoded-data ::= SEQUENCE OF PDV-list
PDV-list ::= SEQUENCE {
        transfer-syntax-name               Transfer-syntax-name                OPTIONAL,
        presentation-context-identifier    Presentation-context-identifier,
        presentation-data-values           CHOICE {
                                   single-ASN1-type      [0]          ABSTRACT-SYNTAX.&Type (CONSTRAINED BY{
                                                                      -- Type corresponding to presentation context identifier --}
),
                                   octet-aligned         [1]          IMPLICIT    OCTET STRING,
                                   arbitrary             [2]          IMPLICIT    BIT STRING
        }
}
```

An example of the CP PPDU: 31 81 9e a0 03 80 01 01 a2 81 96 81 02 00 01 82 04 00 00 00 01 a4 23 30 0f 02 01 01 06 04 52 01 00 01 30 04 06 02 51 01 30 10 02 01 03 06 05 28 ca 22 02 01 30 04 06 02 51 01 88 02 06 00 61 61 30 5f 02 01 01 a0 5a 60 58 80 02 07 80 a1 07 06 05 28 ca 22 02 03 a2 06 06 04 2b ce 0f 17 a3 03 02 01 17 a6 06 06 04 2b ce 0f 17 a7 03 02 01 17 be 2f 28 2d 02 01 03 a0 28 a8 26 80 03 …

The PPDU starts with 0x31 byte which represents the Type of TLV structure. 0x31 (0011 0001 in binary) denotes the universal data type (00) in constructive form (1) with tag number 17 (10001) which is Set. Next bytes form the Length field. Since CP PPDU data is longer than 127 bytes, the ASN.1 Length field uses the long definite length format where the Length field includes several bytes, typically 2 bytes as seen in the available datasets. The number of the Length field bytes is given by the last seven bits of the first Length field byte, see Appendix G.

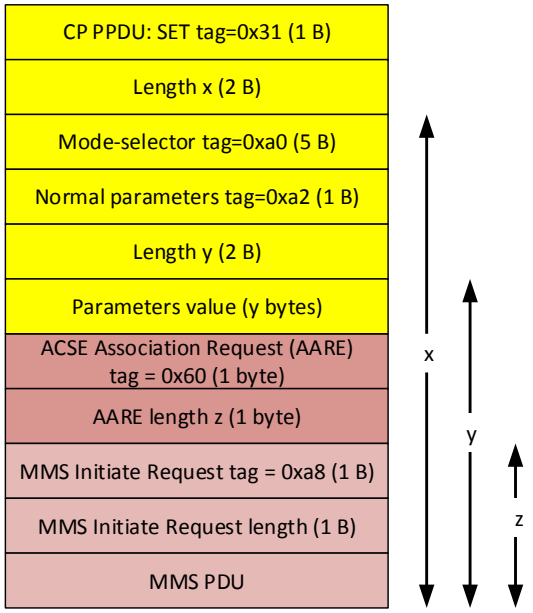

Figure 24: Format of CP PPDU for opening L6 association with embedded AARE and MMS messages

Following the Length field there is a TLV triplet with type identifier 0xa0 (1010 0000) which denotes the context specific data type in constructive form and type tag 0, i.e., the *mode-selector*. Since it is in constructive form, it encapsulates an embedded TLV with identifier 0x80 which refers to the context-specific data type with tag 0 (*mode-value)* and value 1 (*normal-mode*).

Next TLV starts with 0xa2 (1010 0010) byte which refers to *normal-mode-parameters* SEQUENCE and contains a list of optional parameters with their values. The frequently used parameters are:

- Parameters *calling-presentation-selector and called-presentation-selector* form an L6 destination and L6 source address, respectively. These addresses are not used any longer within the conversation after the PPDU association is established.
- A TLV with starting byte 0xa4 (1010 0100) denotes context specific data type in constructive form. Tag 4 means *presentation-context-definition-list*. There are two items in the list.
    - Each item of the list starts with 0x30 (0011 0000) byte denoting SEQUENCE.
    - The first item includes the *presentation-context-identifier* (tag 2, INTEGER) with value 1, the *abstract-syntax-name* (tag 06, OID) with value 2.2.1.0.1 (ACSE abstract syntax version 1), and the *transfer-syntax-name* with value 2.1.2 (ASN.1 BER).
    - The second item includes the *presentation-context-identifier* with value 3, the *abstract-syntax-name* with OID 1.0.9506.2.1 (mms-abstract-syntax-version1) and the *transfer-syntax-name* with value 2.1.2 (ASN.1 Basic Encoding Rules).

  This information is important since the *presentation-context-identifier* appears in the *user-data* where it denotes the type of the content, i.e., ACSE packet or MMS packet. The context list maps *presentation-context-identifier* (an integer) to the *abstract-syntax-name* (OID). The OID refers either to ACSE syntax or MMS syntax. Thus, the *presentation-context-identifier* in PDV-list says if the content is ACSE or MMS. This information can be also derived from the L5 SPDU type where an ACSE packet is usually encapsulated in Connect or Accept SPDU while MMS packet is placed in the Data Transfer SPDU.
- After the context-list is a SEQUENCE with identifier 0x88 (1000 1000) which refers to *presentation-requirements* type (tag 8). This two-byte field is BIT STRING where the first byte 0x06 denotes the

number of unused bits (6 bits) and the rest describes the value which is 0 for both bits. However, this field is not present in every CP PPDU that were tested.

- The last useful field starts with identifier 0x61 (0110 0001) which describes application specific class in constructive form with application tag 1 which means *fully-encoded-data*. The embedded TLV with identifier 0x30 (SEQUENCE) contains *a PDV-list* with presentation-context-identifier set to 1 (ACSE data) and application data encoded by *single-ANS1-type* (identifier 0xa0). After the identifier follows the one byte length of the contents and AARQ with starting identifier 0x60 and a MMS Initiate Request with tag 0xa8, see Section 4.2.4.

4.2.3.2 Connect Presentation Accept PPDU

Connect Presentation Accept (CPA) PPDU is a response to the CP PPDU during the initial phase of the L6 connection. CPA PPDU is transmitted within L5 *Accept* SPDU with *AARE* and MMS *Initiate Response* on L7, see Figure 22. The format of the packet is described by ASN.1 as follows:

```
CPA-PPDU ::= SET {
   mode-selector                    [0]          IMPLICIT    Mode-selector,
   normal-mode-parameters           [2]          IMPLICIT SEQUENCE {
      protocol-version                             [0] IMPLICIT Protocol-version DEFAULT {version 1},
      responding-presentation-selector             [3] IMPLICIT Responding-presentation-selector OPTIONAL,
      presentation-context-definition-result-list  [5] IMPLICIT Presentation-context-definition-result-list OPTIONAL,
      presentation-requirements                    [8] IMPLICIT Presentation-requirements OPTIONAL,
      user-session-requirements                    [9] IMPLICIT User-session-requirements OPTIONAL,
      user-data                                    User-data           OPTIONAL
    } OPTIONAL
}
Responding-presentation-selector ::= Presentation-selector
```

The format of CPA PPDU is similar to CP PPDU as described in Section 4.2.3.1, see Figure 25.

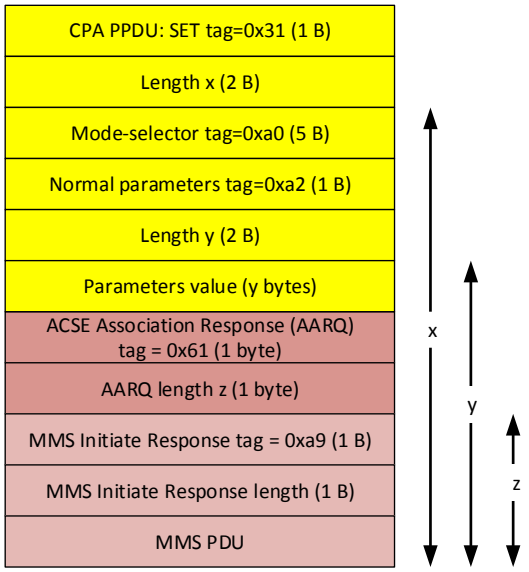

Figure 25: Format of CPA PPDU with embedded AARQ and MMS messages

It starts with tag 0x31. The interesting parameters within the *Normal-mode-parameters* section follow:

- The *Responding-presentation-selector* (identifier 0x83) hold the value of the *called-presentation-selector* in CP PPDU.

- The *presentation-context-definition-list* (identifier 0xa5) transmits the result of acceptance or non-acceptance of the proposed contexts with the *transfer-syntax-name*s as proposed by CP PPDU.
- There is also the *presentation-requirements* (identifier 0x88) and the *user-data* (identifier 0x61) fields.
- The *user-data* includes a *PDV-list* (identifier 0x30, SEQUENCE) that is similar to CP PPDU with the *presentation-context-identifier* (identifier 0x02, value 0x01) and *presentation-data-value* (identifier 0xa0). In case of CPA PPDU, the *presentation-context-identifier* points to context 1 which represents ACSE abstract syntax version 1 (OID 2.2.1.0.1).
- The encapsulated ACSE PDU is of type Application Response (AARQ) and follows the *presentation-data-value* field. Its identifier is 0x61, see Appendix H. The *user-information* field in AARQ contains MMS *Initiate-Response* PDU starting with tag 0xa9, see Section 4.2.4.

An example of the CPA PPDU follows: 31 81 86 a0 03 80 01 01 a2 7f 83 04 00 00 00 01 a5 12 30 07 80 01 00 81 02 51 01 30 07 80 01 00 81 02 51 01 88 02 06 00 61 5f 30 5d 02 01 01 a0 58 61 56 80 02 07 80 a1 07 06 05 28 ca 22 02 03 a2 03 02 01 00 a3 05 a1 03 02 01 00 a4 06 06 04 2b ce 0f 17 a5 03 02 01 17 be 2e 28 2c 02 01 03 a0 27 a9 25 80 02 …

4.2.3.3 CPC-type PPDU

CPC-type PPDU encapsulate MMS data transmitted during data transfer phase, see Figure 26. These PPDUs are the most frequent PDUs in the transmission. The format of this PPDU is specified using ASN.1 notation, see the following definition:

```
CPC-type ::= User-data
User-data ::= CHOICE {
        simply-encoded-data         [APPLICATION 0]     IMPLICIT    Simply-encoded-data,
        fully-encoded-data          [APPLICATION 1]     IMPLICIT    Fully-encoded-data
}

Fully-encoded-data ::= SEQUENCE OF PDV-list

PDV-list ::= SEQUENCE {
        transfer-syntax-name            Transfer-syntax-name            OPTIONAL,
        presentation-context-identifier Presentation-context-identifier,
        presentation-data-values        CHOICE {
                        single-ASN1-type    [0]     ABSTRACT-SYNTAX.&Type (CONSTRAINED BY{
                                                    -- Type corresponding to presentation context identifier --
}),
                        octet-aligned       [1]     IMPLICIT    OCTET STRING,
                        arbitrary           [2]     IMPLICIT    BIT STRING
        }
}
```

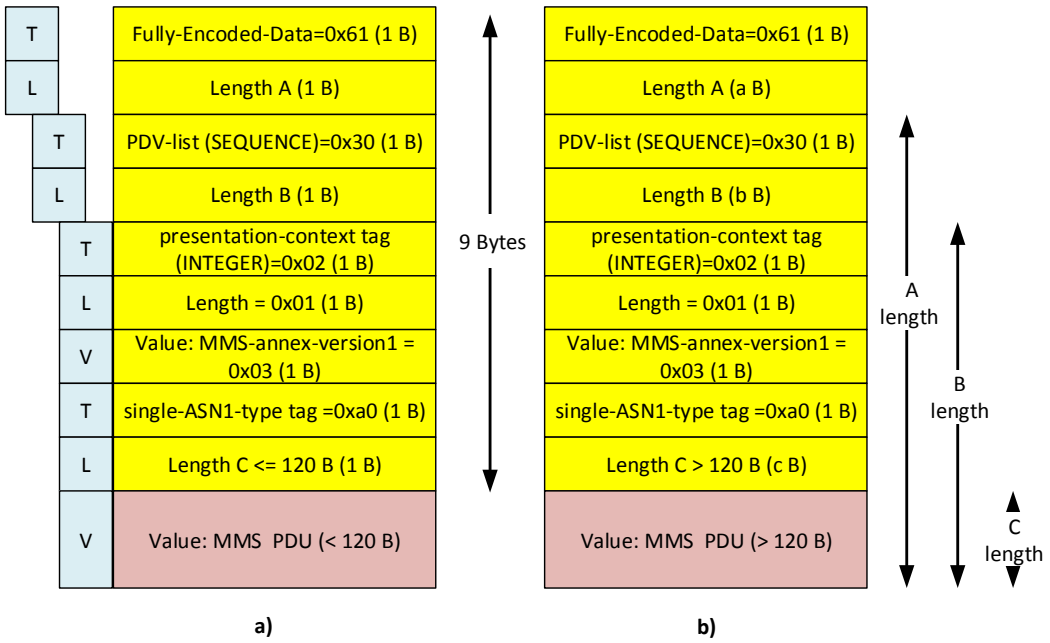

Figure 26: Format of CPC-type PPDU for MMS data transfer with MMS PDU lesser than 120 B (a) and greater (b).

Example of CPC-type PPDU: 61 18 30 16 02 01 03 a0 11 a0 0f 02 02 06 27 a1 09 a0 03 80 01 09 a1 02 80 00

The PPDU starts with byte *0x61* (0110 0001) which denotes application specific type in constructive form with tag 1 which denotes data type *Fully-encoded-data*. After this byte, the length of data and a new embedded TLV structure with identifier 0x30 (SEQUENCE, tag 16) follow. The tag refers to the *PDV-list* (presentation-data-values). The optional *transfer-syntax-name* is present only when more than one transfer syntax name is proposed for the presentation context which is not this case.

ISO 9506 [9] defines only one presentation context with OID 1.0.9506.2.3 (*mms-annex-version1*). The next TLV encoded the *presentation-context-identifier* with tag 0x02 and value 0x03. The value refers to the *presentation-context-list* as negotiated in CP and CPA PPDUs, see above.

The last TLV starts with *0xa0* (1010 0000) which denotes context-specific data type in constructed form with tag 0 (*single-ASN1-type*). This means that *PDV-list* value contains exactly one presentation data value which is a single ASN.1 type encoded according to BER [15]. The following byte denotes the length of the embedded PDU and then follows a MMS message starting with tag 0xa0.

The format of PPDU header does not change for most MMS messages. In messages where PPDU is shorter than 127 bytes, i.e., MMS PDU length is lower than 120 bytes, the Length fields of TLVs inside the PPDU have fixed length of 1 byte which means that the total length of the PPDU header is 9 bytes, see Figure 24 a). This is valid for messages with TPKT length lower than 145 bytes.

For messages with MMS PDU longer than 120 bytes, TLV length fields of the PPDU may be longer than 1 byte, see Appendix G (long definitive length). In this case the Length field starts with the value higher or equal 0x80, i.e., the highest bit is 1, and the remaining value indicates the number of bytes of the Length field. In this case, the PPDU header is longer than 9 bytes depending on the Length fields in the header, see Figure 24 b).

4.2.4 OSI Association Control Service (L7)

The original MMS standard ISO 9506 [9] requires the MMS services to be realized using Association Control Service Element (ACSE) and the Presentation layer services. Thus establishing the MMS association is connected with opening of the ACSE session which is provided by AARQ and AARE messages on top of Connect and Accept Presentation layer PDUs. Specification of AARQ and AARE PDUs is a part of ISO/IEC 8650 and X.227 [14], see Appendix H.

The format of AARQ and AARE PDU is in Figure 27. Since the header of the APDU can included a variable list of optional parameters, it is not easy to say where the *user-information* block with encapsulated MMS packet starts unless ACSE message is parsed.

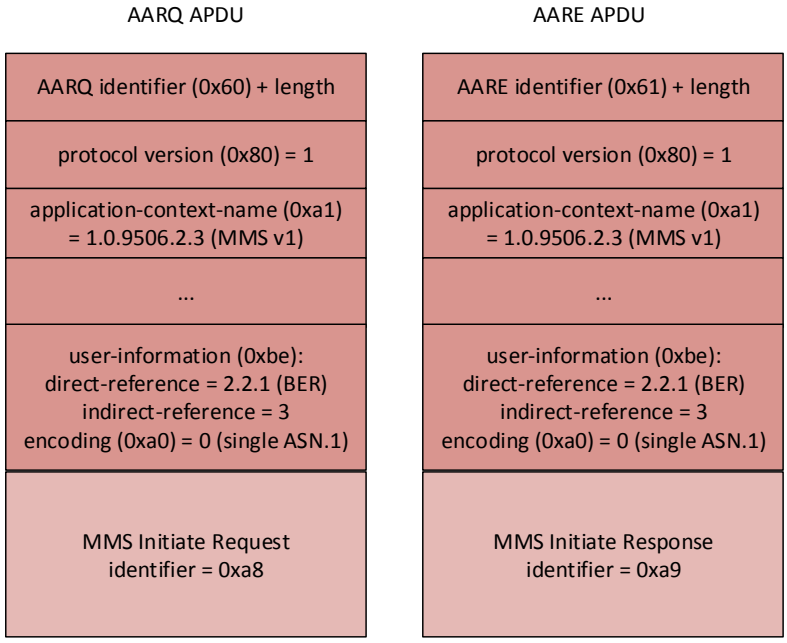

Figure 28: ACSE Request (AARQ) and Response (AARE) with encapsulated MMS packet

When parsing the *user-information* block, it should be noticed that this block is defined as a sequence of EXTERNAL data type, see Appendix G. This means that it allows to change the presentation context and encoding. In this case it means that ACSE context with *presentation-context-identifier*=1 (ACSE) changes to *presentation-context-identifier=3* (MMS).

MMS packets are encapsulated by ACSE only in the opening phase. During data transmission, MMS packets are directly encapsulated in PPDUs.

4.3 MMS Protocol

MMS protocol as defined in ISO 9506 [9] implements two types of communications:

- *Confirmed MMS Services*
  - Confirmed MMS services are requested through the use of the *Confirmed-Request* PDU which includes a request service, see Appendix J. Standard ISO 9506

defines 87 different services, e.g., *getNameList, read, write, getVariableAccessAttributes.*
    - Each *Confirmed-Request* PDU is confirmed by a *Confirmed-Response* PDU or a *Confirmed-Error* PDU.
    - In addition, the *Confirmed-Request* PDU can be suspended by the *Cancel-Request* PDU which is confirmed using a *Cancel-Response* PDU or *a Cancel-Error* PDU.
    - Each instance of the *Request* PDU is correlated to the corresponding *Response* PDU using the *InvokeID* which is a 32-bit unsigned integer.
- *Unconfirmed MMS Services*
    - For unconfirmed MMS services, no response PDU or error PDU will be received. Further, it is not possible to cancel an unconfirmed MMS service.
    - The standard defines three different unconfirmed services: *informationReport*, *unsolicitedStatus*, and *eventNotification.*

The standard defines 14 types of MMS PDUs which can be easily identified by the TLV identifier with the tag number given by the standard, see Appendix J and Table 14. Notice that services includes additional data sets P bit in the Type field to 1 (1010 = 0xa) while services with a simple content have the Type field set to 0 (1000 – 0x8).

MMS PDU	TLV identifier	Tag number
confirmed-RequestPDU	0xa0	0
confirmed-ResponsePDU	0xa1	1
confirmed-ErrorPDU	0xa2	2
unconfirmed-PDU	0xa3	3
rejectPDU	0xa4	4
cancel-RequestPDU	0x85	5
cancel-ResponsePDU	0x86	6
cancel-ErrorPDU	0xa7	7
initiate-RequestPDU	0xa8	8
initiate-ResponsePDU	0xa9	9
initiate-ErrorPDU	0xaa	10
conclude-RequestPDU	0x8b	11
conclude-ResponsePDU	0x8c	12
conclude-ErrorPDU	0xad	13

Table 14: Types and identifiers of all MMS PDUs

4.3.1 Opening the Communication

The connection is opened using *InitiateRequest* PDU and *InitiateResponse* PDU, see Appendix J, which are used to negotiate details of the connection and supported services. Supported services are encoding as bit string. The following examples show *InitiateRequest* and *InitiateResponse* PDUs.

Example 1: a8 26 80 03 00 fa 00 81 01 0a 82 01 0a 83 01 05 a4 16 80 01 01 81 03 05 e1 00 82 0c 03 a0 00 00 00 00 02 00 00 00 ed 10

- 0xa8 (1010 1000) with context-specific tag 8 specifies *InitiateRequest* PDU with length 38 B.
- 0x80 (1000 0000) with tag 0 describes *localDetailCalling* which is 3-byte integer with value 64.000.

- 0x81 (1000 0001) with tag 1 describes *ProposedMaxServOutstandingCalling* parameter with value10
- Similarly, 0x82 describes *ProposedMaxServOutstandingCalled* parameter with value 10.
- Tag 0x83 refers to *proposedDataStructureNestingLevel* parameter with value 5.
- 0xa4 (1010 0100) is a sequence of *initRequestDetail* with length 22 bytes (16 in hex). It contains the following data:
    - 0x80 refers to *proposedVersionNumber* with integer value 1
    - 0x81 refers to *proposedParameterCBB* (conformance building block). It is 11-bits string with value 0xe1 00 (1110 0001 0000 0000) which corresponds to options *str1* (array support), *str2* (structure support), *vnam* (named variable support) and *vlis* (named variable list).
    - 0x82 denotes 11-bytes bit string that encodes available services. The value is 1010 0000 0000 0000 0000 0000 0000 0000 0000 0000 0010 0000 0000 0000 0000 0000 0000 1110 1101 0010 0 which means that available services are *status, identify, obtainFile, fileOpen, fileRead, fileClose, fileDelete, fileDirectory, informationReport and conclude.*

Example 2: a9 25 80 02 7d 00 81 01 0a 82 01 08 83 01 05 a4 16 80 01 01 81 03 05 e1 00 82 0c 03 ee 08 00 00 04 00 00 00 01 ed 18

- The leading byte 0xa9 denotes the InitiateResponse PDU with length 37 bytes (25 in hex).
- 0x80 describes *localDetailCalled* parameter with value 32.000 (0x7d00)
- Next two parameters with tags 0x81 and 0x82 refer to *negotiatedMaxServOutstandingCalling* and *negotiatedMaxServOutstandingCalled* with values 10 and 8, respectively.
- 0x83 denotes *negotiatedDataStructureNestingLevel* with value 5.
- 0xa4 starts a new sequence of negotiated parameters:
    - 0x80 refers to negotiatedVersionNumber which is 1.
    - 0x81 refers to negotiatedParameterCBB which is a bit string with value 0xe10 (see above).
    - 0x82 refers to servicesSupportedCalled which is 11-byte string with value ee:08:00:00:04:00:00:00:01:ed:18 (1110 1110 0000 1000 0000 0010 0000 0000 0000 0000 0000 0000 0000 0001 1110 1101 0001 1). This bit string encodes the following services: *status, getNameList, identify, read, write, getVariableAccessAttributes, getNameVariableListAttributes, getDomainAttributes, getCapabilityList, fileOpen, fileRead, fileClose, fileDelete, fileDirectory, informationReport, conclude* and *cancel.*

An example of negotiated parameters using *initRequest* and *initResponse* is showed in Figure 29.

parameters	initRequest	initResponse
localDetailCalling	64000	32000
MaxServOutstandingCalling	10	10
MaxServOutsendingCalled	10	8
DataStructureNesting	5	5
Version	1	1
ConformanceBlock options	str1	str1
	str2	str2
	vnam	vnam
	vlis	vlis
Supported Services	status	status
		getNameList
	identify	identify
		read
		write
		getVariableAccessAttributes
		getNameVariableAttributes
		getDomainAttributes
		getCapabilityList
	obtainFile	
	fileOpen	fileOpen
	fileRead	fileRead
	fileClose	fileClose
	fileDelete	fileDelete
	fileDIrectory	fileDirectory
	informationReport	informationReport
	conclude	conclude
		cancel

Figure 29: Example of MMS parameter negotiation

4.3.2 Data Transfer

Majority of MMS communication is obtained by *confirmed-Request* and *confirmed-Response* message. The *confirmed-Request* PDU contains a request unambiguous identifier *InvokeID* and type of the *ConfirmedServiceRequest*, e.g., *status*, *getNameList*, *read*, *write*, etc. Each of these services transmits different data based on the type of the request.

Data transfer have two phase:

- Dataset initialization – during this phase a client requests names of available logical nodes, datasets, variables, and attributes using *getNameList*, *getVariableListAttributes, getNamedVariableListAttributes,* etc.
- Data access – after initialization, data objects are accessed for reading, writing and other operations.

The following part shows the format of the most frequent MMS PDUs with recommendation how to identify and parse these packets. Example of real communication are described in Section 4.4.

4.3.2.1 MMS PDUs with Payload Size Smaller Than 120 B

The *confirmed-Response* PDU has the same *invokeID* and the *confirmedServiceResponse* with request result (values, status, etc.). The format of the MMS PDU smaller than 120 bytes is in Fig 30.

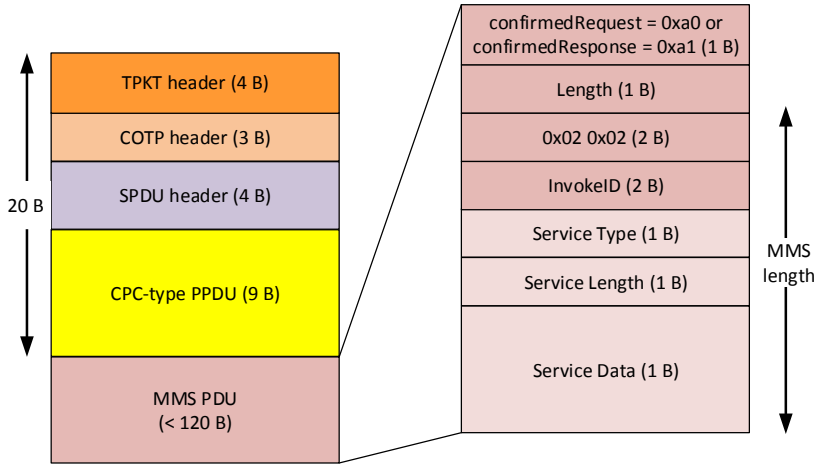

Figure 30: Format of MMS Confirmed-Request/Response packet with MMS PDU length less than 120 B

The following examples demonstrate MMS PDUs exchanged by the Confirmed Services: examples 1 and 2 shows *getNameList* service, examples 3 and 4 demonstrates *read* service.

Example 1: a0 0f 02 02 06 28 a1 09 a0 03 80 01 09 a1 02 80 00

- 0xa0 denotes MMS *confirmedRequest* PDU with the payload of 15 bytes (0x0f).
- *InvokeID* parameter starts with type 0x02 (INTEGER) and the length 2 bytes. The value is 1576 .
- 0xa1 refers to the type of the service, see Appendix J. Tag 1 denotes *getNameList* service.
    - *GetNameListRequest* is a sequence of *objectClass, objectScope* and *ContinueAfter* indicator. The length of the service data is 9 bytes.
    - 0xa0 refers to the *ObjectClass* (tag 0) which is constructive data type of length 3. It contains an embedded TLV structure with tag 0 (*basicObjectClass*), length 1 and value 9 (*domain).*
    - 0xa1 refers to the *ObjectScope* (tag 1) which is also constructive data type of length 2 where an embedded TLV has tag 0 (*vmdSpecific*) with value of length 0 (NULL).

Example 2: a1 27 02 02 06 28 a1 21 a0 1c 1a 0b 4b 4f 43 31 30 34 43 31 4c 44 30 1a 0d 4b 4f 43 31 30 34 43 31 53 45 53 5f 31 81 01 00

- 0xa1 denotes MMS *confirmedResponse* PDU with the payload of 39 bytes (0x27).
- *InvokeID* starts with type 0x02 and the length 2 bytes. Its value is 1576 (0x0628).
- 0xa1 refers to the type of the service, see Appendix J. Tag 1 denotes *getNameListResponse*.
    - *GetNameListResponse* is a sequence of *listOfIdentifiers* and *moreFollows* indicator. The length of the service data is 33 bytes.
    - 0xa0 refers to the *listOfIdentifier* (tag 0) which is constructive data type of length 28. It contains a sequence of embedded TLVs with tag 0x1a (0001 1010) which refers to the universal class data type VisibleString (tag 26). The length of the string is 11 bytes (0x0b) and its ASCII value is KOC104C1LD0. Next item of the sequence is also visible string (0x1a) with length 13 byte (0x0d) and value KOC104C1SES_1.
    - 0x81 refers to the *moreFollows* parameter (tag 1) with length 1 byte and the value 0 (FALSE).

Example 3: a0 30 02 02 06 2a a4 2a a1 28 a0 26 30 24 a0 22 a1 20 1a 0b 4b 4f 43 31 30 34 43 31 4c 44 30 1a
11 4c 4c 4e 30 24 42 52 24 52 65 70 43 6f 6e 46 30 31

- 0xa0 refers to the *confirmedRequest* PDU with length 48 bytes (0x30).

- 0x02 denotes *InvokeID* with value 1578 (0x06 2a).
- 0xa4 refers to the *read* service (tag 4). The length of service data is 42 bytes. The *Read-Request* is a sequence.
    - 0xa1 means *VariableAccessSpecification* type with length 40 bytes (0x28). It contains another TLV structure with type 0xa0 (*listOfVariables*) with length 38 bytes (0x26).
    - 0x30 denotes universal data type SEQUENCE (tag 16) of *VariableSpecification* with length 36 bytes.
    - 0xa0 refers to the choice *name* (tag 0) which is another TLV called *ObjectName*.
    - 0xa1 denotes the *domain-specific* type which is a structure (SEQUENCE) of two items: domainID and itemID.
        - The first embedded TLV with tag 0x1a is Visible String of length 11 bytes (0xb) and with value KOC104C1LD0.
        - The following embedded TLV starts with tag 0x1a (Visible String) with length 17 bytes (0x11) and value LLN0BRRepConF01.
        -

Example 4: a1 65 02 02 06 2a a4 5f a1 5d a2 5b 8a 0c 4d 41 4d 45 5f 52 65 70 43 6f 6e 46 83 01 00 8a 1a 4b 4f 43 31 30 34 43 31 4c 44 30 2f 4c 4c 4e 30 24 53 74 61 74 4e 72 6d 6c 44 86 01 01 84 03 06 00 03 86 02 01 f4 86 01 00 84 02 02 64 86 01 00 83 01 00 83 01 00 89 08 00 00 00 00 00 00 00 00 8c 06 00 00 00 00 00 00

- 0xa1 refers to the *confirmedResponse* PDU with length 101 bytes.
- 0x02 denotes *InvokeID* with value 1578 (0x06 2a).
- 0xa4 refers to the *read* service (tag 4). The *ReadResponse* is a sequence of *variableAccessSpecification* (which is optional) and *listOfAcccessResult.*
    - 0xa1 denotes the *listOfAccessResults.* It is a sequence of *AccessResults*.
        - 0xa2 refers to the successful result and Data type structure (tag 2). It is a sequence of Data with length 91 bytes.
            - 0x8a is a VISIBLE string (context-specific tag 10). Its length is 12 and the value MAME_RepConF.
            - 0x83 is a BOOLEAN with length 1 byte and value 0 (FALSE)
            - 0x8a is another VISIBLE string with length 26 bytes and value KOC104C1LD0/LLN0$StatNrmlD.
            - 0x86 is an integer of length 1 byte and value 1.
            - 0x84 is a BIT STRING with length 3 bytes and value 0.
            - 0x86 starts another integer of length 2 and value 500.
            - 0x86 starts another integer of length 1 byte and value 0.
            - 0x84 starts another BIT STRING with length 2 bytes and value 25.
            - 0x86 starts another integer of length 1 byte and value 0.
            - 0x83 is another BOOLEAN of length 1 byte and value 0 (FALSE).
            - 0x83 is another BOOLEAN of length 1 byte and value 0 (FALSE).
            - 0x89 starts an OCTET STRING of length 8 bytes and value 0x00 00 00 00.
            - 0x8c is a TimeOfDay with length 6 bytes and value 0x00 00 00.

4.3.2.2 MMS PDUs with Payload Size Greater Than 120 B

The above written messages transmit MMS packets lower than 120 bytes. In this case, a TLV structure in PPDU has length 1 byte, see Figure 26, and the total length of L5-L7 headers is 20 bytes. Thus, it is not difficult to find a starting point for MMS message parsing:

- Destination port is 102 (ISO TSAP Class 0)
    - The destination port is not sufficient to prove that it is a MMS packet. Additional checks shall be done:
        - TPDU code of COTP shall be 0xf0 for COTP Data (offset 5 bytes from the beginning of the TCP payload)
        - SPDU type shall be 0x01 (Give Tokens) on L5 (offset 7 bytes from the beginning of the TCP payload)
        - PPDU type shall be 0x61 (CPC-type PPDU) on L6 (offset 11 bytes from the beginning of the TCP payload)
        - MMS type for confirmed services shall be 0xa0 (Request) or 0xa1 (Response) on L7 (offset 20 bytes from the beginning of the TCP payload)
- The length of TCP payload shall be less than 140 bytes. Since the TCP header does not contain the length of the content, it is possible to use TPKT length which is a 2-bytes value inserted at the beginning of the TCP payload (offset 2 bytes from the beginning of the TCP payload). Thus, the TPKT length shall be less than 136 bytes.
    - By analyzing available datasets, the majority of MMS confirmed PDUs (cca 89%) fall into this category, see Section 4.4.
- In case that the length of the MMS payload is greater or equal to 120 bytes, length fields in TLV structure in PPDU will be longer than 1 byte, see Figure 26 b). In such case, the beginning of PPDU can be easily found using the offset 7 bytes from the beginning of the TCP payload. Then, PPDU should be parsed so that the beginning of MMS message can be found.
    - However, this happens only when longer data are requested, see the following requests: *getVariableAccessAttributes*, *getNamedVariableListAttributes*.
    - Analysis of datasets shows that only 5% of MMS confirmed PDUs have length greater than 120 Bytes, see Section 4.4.

The following examples show MMS request for *getVariableAccessAttributes*. The message is shorter than 120 Bytes, thus it can be easily parsed. However, the answer transmits more data than 120 bytes, thus the PPDU has not fixed size and each TLV shall be parsed to find the beginning of MMS message.

Example 5: a0 2a 02 02 06 28 a6 24 a0 22 a1 20 1a 0b 4b 4f 43 31 30 34 43 31 4c 44 30 1a 11 4c 4c 4e 30 24
42 52 24 52 65 70 43 6f 6e 43 30 32

- 0xa0 refers to the *confirmedRequest* PDU with length 42 bytes (0x2a).
- 0x02 denotes *InvokeID* with value 1576 (0x06 26).
- 0xa6 refers to the *getVariableAccessAttributes* service (tag 6). The length of service data is 36 bytes. The *getVariableAccessAttributes-Request* is a sequence.
    - 0xa0 refers to the choice *name* (tag 0) which is another TLV called *ObjectName*.
    - 0xa1 denotes the *domain-specific* type which is a structure (SEQUENCE) of two items: domainID and itemID.
        - The first embedded TLV with tag 0x1a is Visible String of length 11 bytes (0xb) and with value KOC104C1LD0.

- The following embedded TLV starts with tag 0x1a (Visible String) with length 17 bytes (0x11) and value LLN0BRRepConC02.

The following answer will be analyzed starting at presentation layer.

Example 6: 61 81 e2 30 81 df 02 01 03 a0 81 d9 a1 81 d6 02 02 06 28 a6 81 cf 80 01 00 a2 81 c9 a2 81 c6 a1
81 c3 30 0c 80 05 52 70 74 49 44 a1 03 8a 01 bf 30 0c 80 06 52 70 74 45 6e 61 a1 02 83 00 30 0d 80 06 …

- 0x61 starts a CPC-type PDU with length 226 bytes (0xe2). Byte 0x81 indicates that the Length field in this TLV has the long format with length 1 bytes.
- 0x30 indicates a PDV-list which is a SEQUENCE. Its length is 223 Bytes (0xdf)
  - 0x02 represents the *presentation-context-identifier* which is 3.
  - 0xa0 starts the *single-ASN1-type* field which contains a MMS message with the payload of 217 bytes (0xd9). Here, we can see that the Length fields in TLV structures in the MMS PDU have also the long format.
  - 0xa1 refers to *confirmed-Response* PDU. The length of the PDU is 214 bytes (0xd6)
    - 0x02 starts the *InvokeID* field with value 1576.
    - 0xa6 refers to the *getVariableAccessAttributes-Response* service (tag 6). The embedded structure is a SEQUENCE.
      - 0x80 denotes *mmsDeletable* flag (tag 0) which is 0 (FALSE).
      - 0xa2 refers to *TypeDescription* (tag 2) with length 201 bytes (0xc9) which encapsulates another TLV structure.
        - 0xa2 refers to the Structure data type (tag 2) which is a SEQUENCE. 0xa1 refers to the *components* which is a list of the *componentName* and *componentType.* These items are used to define data types with their new names and ASN.1 data types.
          - 0x30 (0011 0000) denotes universal data type, constructive and SEQUENCE. Thus, each attribute will start with this tag. Following value with starting tag 0x80 refers to the EXTERNAL data type of length 5. The value is RptID (a new data type). The next item (*componentType)* starts with 0xa1 tag and length 3 bytes. 0x8a (1000 1010) refers to primitive context-specific data type with tag 10 which means *visible-string.* The value is 0xbf.
          - The next *components* sequence also starts with 0x30 byte, the length and the first item (*componentName*, tag 0x80). The value of the *componentName* is is RptEna. The second item (*componentType,* tag 0xa1) refers to the embedded TLV with type tag 0x83 (1000 0011) which indicates Boolean with length 0.
          - Similarly, we can analyze other attribute data types.

The MMS PDU which size greater than 120 bytes usually has variable data structure on L6 (PPDU) and L7 (MMS). This is because TLV structure requires longer format of the Length field. However, parsing of the message can employ fixed values from L6 and L7 headers which do not depend on the payload size. Thus, the parser can use these values as marks when analyzing data structure, see Figure 31.

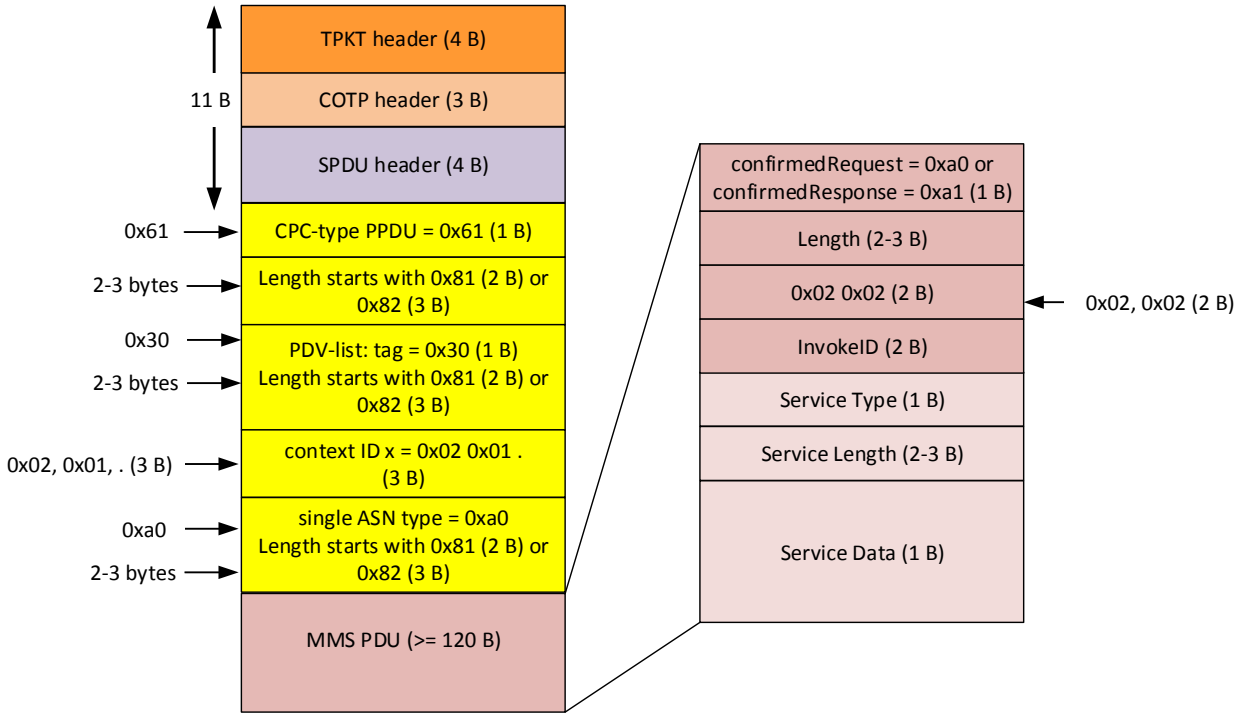

Figure 31: Analyzing MMS packet with payload greater than 120 bytes

4.3.2.3 MMS PDU Segmenting and Reassembling

The last group of MMS PDUs with specific parsing are *confirmedRequest* and *confirmedResponse* PDUs that were divided into several segments by COTP protocol on L4, see Section 4.2.1.1. Segmenting is initiated by the sending entity which maps one TSDU (Transport Service Data Unit) into an ordered sequence of one or more DT TPDUs (Data Transport Protocol Data Units). The EOT parameter of a DT TPDU indicates whether or not there are subsequent DT TPDUs in the sequence.

Reassembling is provided by the receiver. The first segment includes TPKT and COTP headers followed by L5, L6 and L7 protocols. The TPKT length indicates the real size of this segment while L6 and L7 Length fields count the size of the original assembled PDU. The next segments include only TPKT and COTP headers followed by uninterpreted data. These data directly follows uncompleted MMS PDU of the previous segment. The example of segments and reassembling is shown in Figure 32.

It is good to point out that segmenting mostly happened with MMS Response PDU, namely MMS *ConfirmedResponse* PDU (type 1, tag 0xa1) and *Unconfirmed* PDU (type 3, tag 0xa3).

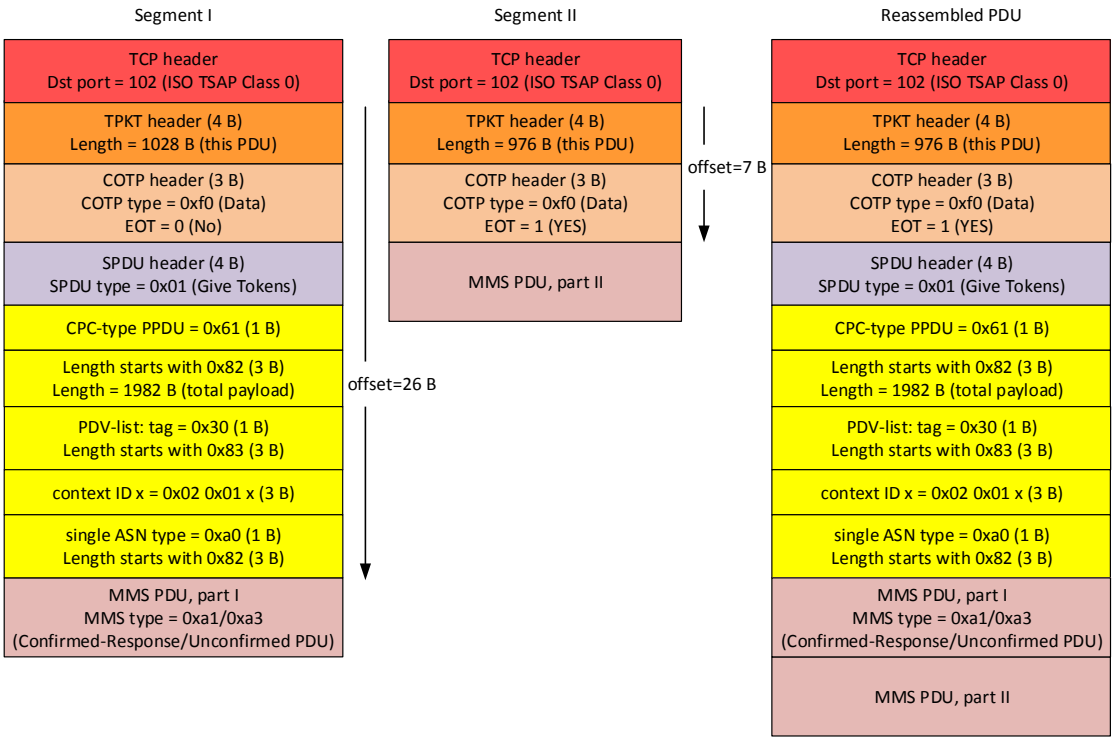

Figure 32: Segmentation and Reassembling of MMS PDUs

4.3.3 Unconfirmed Messages

Unconfirmed services are invoked by servers only. This class of service enables a server to notify a client that a predefined event has occurred. With this kind of service, it is possible to avoid time consuming operations such as periodically reading the value of variables through the network. With unconfirmed services, polling is delegated to the server that performs the polling locally.

MMS introduces three unconfirmed services: *UnsolicitedStatus*, *InformationReport*, and *EventNotification*. A powerful functionality is defined in MMS to specify the conditions in which event notification are sent.

Unconfirmed messages provides unconfirmed services. For unconfirmed MMM services, no response PDU or error PDU is issued. Further, it is not possible to cancel this service.

The *Unconfirmed* PDU shall be a sequence containing an *UnconfirmedService* and an *Uncofirmed-Detail* which is OPTIONAL. The *UnconfirmedService* type identifies the service type and the argument for that service. Unconfirmed services are *informationReport*, *unsolicitedStatus,* and *eventNotification.*
The following example analyses the structure of an *Unconfirmed* PDU, see also Figure 32.

Example 1: a3 64 a0 62 a1 05 80 03 52 50 54 a0 59 8a 1a 4b 4f 43 31 30 34 43 31 4c 44 30 2f 4c 4c 4e 30 24
52 65 70 43 6f 6e 45 30 31 84 03 06 63 00 86 03 00 00 01 8c 06 02 93 c0 77 31 19 83 01 00 …

- 0xa3 indicates the type of a MMS PDU which is *Unconfirmed-PDU* (tag 3), see Appendix J. The length of the message is 100 bytes.

- 0xa0 denotes *service* type which is CHOISE. Tag 0 indicates *informationReport* service. The services is a SEQUENCE of *variableAccessSpecification* and *listOfAccessResult.*
- 0xa1 denotes *variableListName* (tag 1) with length 5 bytes. The embedded TLV has tag 0x80 which denotes *vmd-specific* object (tag 0). The type is UTF8String with length 3 and value RPT.
- 0xa0 is the *listOfAccessResult* (tag 0) with length 89 B (0x59). This list is a SEQUENCE of *AccessResults*. In case of *success* it contains TLVs with the *Data.*
    - The first embedded TLV starts with 0x8a (1000 1010) which means *visible-string* (tag 10). The value of 26 bytes (0x1a) is KOC104C1LD0/LLN0$RepConE01.
    - Next TLV with tag 0x84 (bit string) has 3 bytes and 6 unused bits which gives value 99.
    - Next TLV with tag 0x86 (unsigned int) has length 3 bytes and value 1.
    - The TLV starting with 0x8c (tag 12 means binary time) has 6 bytes value with representation May 31, 2018 12:00:37.495000000 UTC.
    - ....

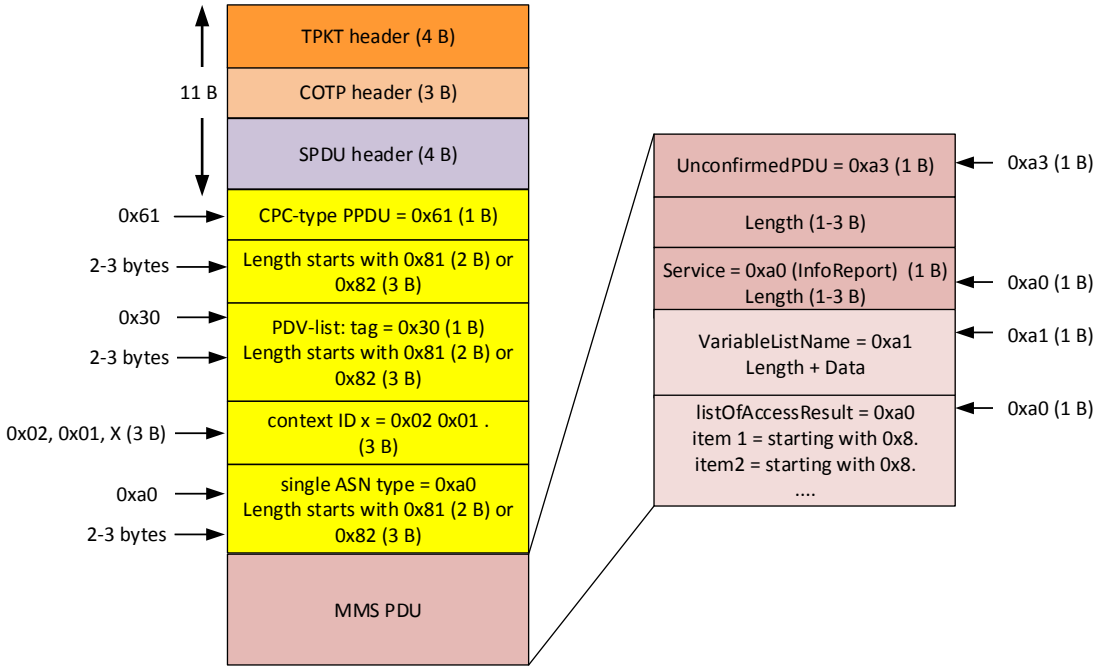

Figure 32: Encapsulation and format of the Unconfirmed PDU

Similarly to the *Confirmed* PDUs, the *Unconfirmed* PDU can be segmented, see Figure 32.

4.3.4 Concluding Messages

MMS conclude messages are used to close the connection to the server. This is used to properly release the resources used to establish the connection. If the server denies the conclude request by sending an error PDU, the connection remains open. In such case the close or abort request can be used to close the connection.

MMS defines three types of conclude PDUs: *Conclude-Request*, *Conclude-Response* and *Conclude-Error.* The MMS payload of *Conclude-Request* and *Conclude-Response* are empty, *Conclude-Error* PDU contains the *ServiceError* structure. All these messages are encapsulated in the Given Tokens/DT SPDU similarly to confirmed and unconfirmed PDUs. Since their payload is empty, they have a fixed size format.

The following examples show analysis of a *Conclude-Request* PDU and a *Conclude-Response* PDU.

Example 1: 8b 00

- Identifier 0x8b (1000 1011) defines application data type in primitive form with tag number 11 which means *Conclude Request* PDU. Its length is 0, i.e., no payload is present.

Example 2: 8c 00

- Similarly, identifier 0x8c (1000 1100) denotes *Conclude Response* PDU with length 0, i.e., no data present.

4.4 Example of MMS Communication

In this part available MMS datasets will be analyzed with the focus on security monitoring of MMS communication. We will analyze two datasets: mms.pcapng obtained from power system simulator in INPG Grenoble, and mms1.pcapng with real traffic from the commercial partner.

4.4.1 Dataset mms.pcapng

This dataset contains 506 MMS packets captured within 5 minutes. Dataset contains one sequence of *Initiate-Request* – *Initiate-Response* PDUs and 504 *confirmed-Request* and *confirmed-Response* PDUs. PDUs are transmitted between two stations and encapsulated in TCP/IP protocols and uses A-Profile.

4.4.1.1 Connection Opening

Connection is established using L4, L5, L6 and L7 protocols. On L4, TCP with destination port 102 opens connection. Session protocol (L5) sends Connect SPDU with Calling and Called Session Selectors. Presentation layer (L6) transmits CP PPDU with a list of defined presentation contexts: ACSE abstract syntax (OID 2.2.1.0.1) with identifier 1 and MMS abstract syntax (OID 1.0.9506.1) with identifier 2. Both contexts will be encoded using BER encoding (OID 2.1.1).

On L 7, AARQ and AARE are exchanged with MMS *initiate-Request* and *initiate-Response* messages. In these messages, connection parameters are negotiated: number of maximal served peers, level of data structure nesting, protocol version, supported conformance parameters, and a list of supported services, see Table 11. The MMS *initiate-Request* is confirmed by *initiate-Response* PDU.

4.4.1.2 Dataset Initialization

Next phases of communication are provided by sequences of *confirmed-Request* and *confirmed-Response* PDUs. The requests are bound with responses using *InvokeID* sequence number. The phases include data initialization and data access.

Data initialization discovers available Virtual Manufacturing Devices (VMDs) on the destination physical device. For each VMD, a list of logical nodes, data objects, and attributes will be obtained using *getNameList* and *getNamedVariableListAttributes* services.

- *getNameList* service (tag 0xa1) – 5x

  - *GetNameList* service returns the names of all MMS objects. It can be selectively determined from which classes of objects (named variable, event condition) the names of the stored objects shall be queried. The client can browse a VMD (vmd scope) or a logical node (domain specific scope) and then systematically query all names of the objects.
  - *GetNameList* request is done only once for each logical device (MMS domain) and the results are cached in the client for later calls.
  - These requests and responses were sent just after the connection was established.
  - The first request queries all domains (logical nodes) on the given VMD: objectClass is of type 9 (*domain*) and objectScope type is 0 (vmdSpecific). It is some kind of LN discovery.
  - As the response, a list of four identifiers (logical nodes, or MMS domains) is returned: SIPCTRL, SIPDR, SIPMEAS, and SIPPROT.
  - The following *getNameList* requests query named variables on the previously discovered logical nodes (MMS domains). Thus, the sent requests contain objectClass of type 2 (*nameVariableList)* for each of the above specified MMS domains, i.e., SIPCTRL, SIPDR, SIPMEAS, and SIPPROT. The response for SIPCTRL contained two identifiers (VMD names): LLN0$Dataset and LLN0$Dataset_1_1. The responses for SIPDR and SIPMEAS did not contain any data object. The response for SIPPROT contained one VMD object with identifier LLN0$Dataset_1.
- *getNamedVariableListAttributes* (tag 0xac) – 3x
  - Following *getNameList* requests, *getNameVariableListAttributes* requests are sent for discovered logical nodes and data objects, i.e., for LN SIPCTRL and object LLN0$Dataset, for LN SIPCTRL and object LLN0$Dataset_1_1, and for LN SIPPROT and domain LLN0$Dataset_1.
  - The following attributes were discovered: for SIPCTRL and item LLN0$Dataset attributes XSWI1$STPosstVal and XSWI1STPos$q. The names are data object references, see Section 2.1.6 which refers to the logical node XSWI1 (switch without short circuit breaking capability [7]). Data object Pos (switch position) belongs to CDC called DPC (controllable double point) which contains attributes stVal (status value) and q (quality) [5].
  - Similarly, for SIPCTRL and objects LLN0$Dataset_1_1 two attribute references were found: XCBR1STTripOpnCmd$stVal and XCBR1$ST$TripOpnCmd$q. These refer to XCBR class (circuit breaker with short breaking capability), functional group status, non-standard data object TripOpnCmd and attributes stVal (status) and q (quality).
  - The last attribute references were obtained from SIPPROT logical node and VMD LLN0$Dataset_1: ID_PTOC1$STStrgeneral and ID_PTOC1STStr$q. These refer to data object Str (start) and attributes general and quality. Object Str belongs to CDC called ACD (Directional protection activation information).

4.4.1.3 Data Access

Following data initialization, discovered logical nodes are queried for updates. A special attributes called LLN0DCNamPlt$configRev is regularly checked. The attribute belongs to the logical node LLN0 which administers a given VMD. *NamePlt* (name plate of the logical device) refers to class

LPL (logical node name plate) that contains attribute *configRev*. This attribute uniquely identifies the configuration of a logical device instance. The value of the attribute has to be changed at least on any semantic change of the data model of the logical device that may affect interpretation of the data by the client [5].

The observed communication contains only *Read-Requests* and *Read-Responses* as follows:

- *read* (tag 0xa4) – 244x
    - The read service requested in all cases an object LLN0DCNamPlt$configRev.
    - The client requests this object for four different MMS domains (logical nodes): SIPCTRL, SIPDR, SIPMEAS and SIPPROT.
    - The requests are repeated every 5 seconds for the given domain.
    - The response contains one item (visible string) with the same integer value, e.g., 636228633875233607. This means, that configuration does not change during monitoring.
    -

Example of communication is in Figure 33.

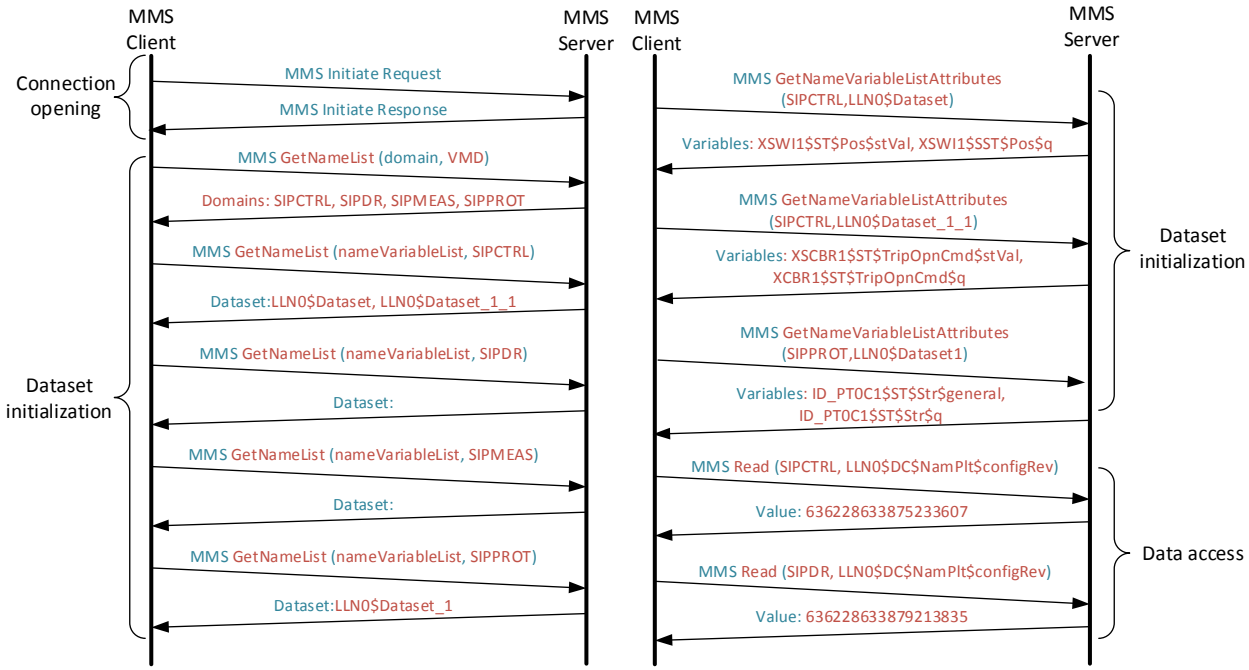

Figure 33: Example of MMS communication

4.4.2 Dataset mms1.pcapng

This dataset is obtained from the commercial partner of the project. It includes 15.840 packets (3.1 MB) transmitted over 5 minutes. Distribution of the protocols is in Table 16.

Layer 4		Layer 5		Layer 6	
Connect Request (0x0e)	50	connect (13)	50	CP-PDU (0x31)	50
Connect Confirm (0x0d)	50	accept (14)	50	CPA-PDU (0x31)	50
Data (0x0f), EOT = TRUE	15164	finish (9)	4	CPC-type (0x61)	15064
Data (0x0f), EOT = FALSE	265	disconnect (10)	4		
		give tokens/data (1,1)	15056		
total	15529	total	15164	total	15164
Layer 7		**MMS Request services**			
confirmed-Requests (0xa0)	7134	status (0xa0)	46		
confirmed-Response (0xa1)	7131	getNameList (0xa1)	34		
unconfirmed PDU (0xa3)	778	identify (0xa2)	13		
initRequest (0xa8)	50	read (0xa4)	339		
initResponse (0xa9)	50	write (0xa5)	601		
concludeRequest (0xab)	4	getVariableAccessAttributes (0xa6)	5840		
concludeResponse (0xac)	4	getNamedVariableListAttributes (0xac)	261		
total	15151	total	7134		

Table 16: Number of packets and their type in dataset mms1.pcapng

We can see that there were 50 packets opening the connection that include requests on all OSI layers (COTP Connect Request/Confirm, OSI L5 connect/accept, OSI L6 CP/CPA, and L7 initRequest /initResponse). L4 PDUs with EOT=FALSE means segmented PDUs. Not all L6 packets transmitted MMS: there were five MMS PDUs that were not properly analyzed by Wireshark and eight ACSE Release-Requests and Responses that do not encapsulate MMS content.

Majority of MMS packets are confirmed PDUs (requests and responses). *Unconfirmed* PDUs form 3,3% of all MMS packets and transmit only *Information Report* which contains values of various attributes. *Conclude* PDUs are without the payload, see Section 4.3.4.

4.4.2.1 MMS requests and responses

Following MMS services within *Confirmed PDUs* are present in the dataset:

- *Status Requests* (0xa0)
  - Requests logical and physical status of a VMD, e.g
  - Only following values were identified: vmdLogicalStatus = 0 (state-changes-allowed), vmdPhysical = 0 (operational)
- *GetNameList* (0xa1)
  - Requests logical node name of the physical device, e.g., LN names KOC104C1LD0 and KOC104C1SES_1.
  - All requests contains objectClass=9 (domain) and objectScope=0 (VMD specific). This is different to mms.pcapng dataset where GetNameList is used in two forms: with objectClass=9 (domain) and objectScope=0 (VMD specific), and with objectClass=2 (namedVariableList) and domain corresponding to the LN name.
- *Identify* (0xa2)
  - The request is without parameters.
  - The response returns a vendorName, modelName and revision of the device.

  - For this dataset, following values were discovered: vendor = ABB AB, model = IEC 8-1 Server, revision = V1.80.00.04p.
- *Read* (0xa4)
  - Reads value of a given list of variables. The *ReadRequest* contains a domainID (logical device name), e.g., KOC101C1LD0, and a listOfVariables structure identified by object reference, e.g., LLN0BRRepConG03$RptEna.
  - The *ReadRequest* may contain one or more variables to be read. In our dataset, the requests contain 1, 6, or 11 variables to be retrieved.
  - For each requested variable, the *ReadResponse* contains the success bit and the value of the variable. E.g., for the requested variable LLN0BRRepConA03$RptEna a Boolean value FALSE is returned.
- *Write* (0xa5)
  - The service sets values of a given list of variables. The *WriteRequest* transmits a list of variables which contains domain IDs and variable names for all requested variables. Following that is a list of data which contains values to be set. E.g., domainID=KOC104C1LD0, LLN0BRRepConF01$BufTm, value=500 (unsigned int).
  - The *WriteResponse* returns a list of write results, e.g., success (1).
- *GetVariableAccessAttributes* (0xa6)
  - The request retrieves MMS type specification for given domain and object, e.g., domainID=KOC104C1LD0, data object=SP16GGIO1STInd11.
  - The response contain the type specifications related to this object, e.g., name=stVal, type=boolean, name=q, type=bitstring
- *GetNamedVariableListAttributes* (0xac)
  - Requests available attributes (variables) in the given dataset. The request specifies a domain and the logical node (dataset), e.g., KOC104C1LD0, LLN0$StatNrmlD.
  - The response returns a list of attributes (variables) in the requested dataset, e.g., SP16GGIO9STInd6, SP16GGIO9STInd7, etc.
  - In our dataset, the list contains up to 50 variables.

4.4.2.2 Conversations

The captured communication contains 20 end points on L2 and L3 layer which include 3 MMS clients requesting services and 17 MMS servers (IEDs). We can see that each client requests several MMS servers.

Example of conversation between 10.164.253.207 (MMS client) and 10.164.253.6 (MMS server):

1. Connection is opened using *MMS initiate Request* and *MMS initiate Response.*
2. Dataset initialization
   i. *MMS identify* service is requested by the client.
      - The response include description of the server: vendor (ABB AB), model name (IEC 8-1 server), and revision (V1.80.00.04p).
   ii. *MMS read* variable: domain= KOC171C1LD0, variable= LLN0DCNamPlt$configRev
      - *MMS read response*: 3311665
   iii. *MMS getNamedVariableListAttributes*, domain= KOC171C1LD0, LN= LLN0$StatIEDA
      - *MMS response*: attribute= LPHD1STPhyHealth

iv. *MMS getVariableAccessAttributes,* domain= KOC171C1LD0, LN= LPHD1STPhyHealth
   - *MMS response:* name=stVal, type=integer, name=q, type=q

v. *MMS getNamedVariableAccessAttributes,* domain= KOC171C1LD0, LN= LLN0$StatUrgA
   - *MMS response:* 48 variables (domain ID + variable name), e.g., SCSWI1STPos, SCSWI10STPos, SCSWI11STPos, SCSWI2STPos, …

vi. MMS *getVariableAccessAttributes* for previous variables*,* domain= KOC171C1LD0, LN= SXSWI1STPos
   - *MMS response*: stVal (bit-string)=2, q (bit-string)=13

vii. *MMS getNamedVariableListAttributes*, domain= KOC171C1LD0, LN= LLN0$StatNrmlA
   - *MMS response*: 50 variables (domain ID + variable name), e.g., SP16GGIO1STInd, SP16GGIO1STInd10, etc.

viii. *MMS getNamedVariableListAttributes*, domain= KOC171C1LD0, LN= LLN0$StatNrmlB
   - *MMS response*: 50 variables, e.g., SP16GGIO14STInd13, SP16GGIO14STInd14, etc.

ix. *MMS getNamedVariableListAttributes*, domain= KOC171C1LD0, LN= LLN0$StatNrmlC
   - *MMS response*: 50 variables, e.g., SP16GGIO3STInd3, SP16GGIO3STInd4, etc.

x. MMS *getVariableAccessAttributes*, domain= KOC171C1LD0, LN= SP16GGIO6STInd
   - *MMS response*: StVal (boolean), q (bit-string)

xi. …

3. Data access
   i. *MMS Read* (domain-specific): domain= KOC171C1LD0, LN= LLN0BRRepConA03$RptEna
      - *MMS response*: Boolean (FALSE)

   ii. *MMS Read* (domain-specific): domain= KOC171C1LD0, 11 attributes of variable LLN0BRRepConA03
      - *MMS response*: RptID=MAME_RepConA, DatSet= KOC171C1LD0/LLN0$StatIEDA, ConfRev=6, OptFlds=4

   iii. *MMS Write*, domain= KOC171C1LD0, 6 attributes of variable LLN0BRRepConA03: RptID= KOC171C1LD0/LLN0BRRepConA03, IntgPd=4, TrgOps=64, OptFlds=5300, …
      - *MMS response*: success (6x)

   iv. …

4.5 Summary

When parsing MMS communication, we can focus on confirmed and unconfirmed MMS PDUs. Other PDUs like *initiate-Request*, *initiate-Response* or *conclude* messages are used only in the opening or closing phase of the communication.
There are several task that must be done when analyzing MMS communication for monitoring purposes:

- MMS PDU identification
    - One of the importing task in MMS parsing is to properly identify MMS PDU. This is not straightforward on the TCP level, since port 102 (ISO TSAP class 2) does not guarantee that it is a MMS PDU. However, additional checks can be done as recommended in Figure 34. Data offset in Figure 34 are valid only for packets with MMS payload less than 120 Bytes. For longer packets, PPDU type and MMS type have different offsets, see Section 4.3.2.2.

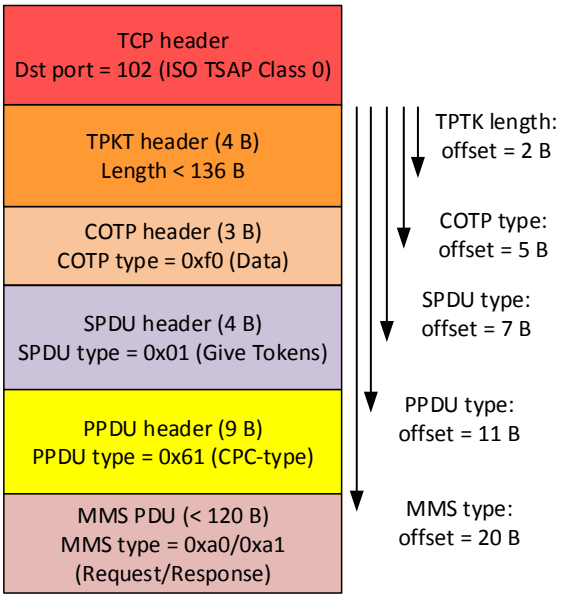

Figure 34: Identifying a MMS PDU with payload < 120 B as encapsulated via OSI protocol over TCP/IP

- MMS decapsulation
    - Another important task is to find where MMS data begins. This is easy for MMS confirmed PDUs with TCP payload lower than 140 bytes. For longer messages, the PDU format is variable depending on the Length field size in TLV structures.
    - For large MMS payload, segmentation may happen. In this case seems to be enough to analyze just the first segment with MMS header. Other segments can be ignored since we are not to parse the whole MMS content.
- Monitoring data extraction
    - Based on analysis of several MMS datasets, it seems to be reasonable to extract following data from MMS headers:
        - MMS PDU type: *initateRequest, initiateResponse*, *confirmedRequest, confirmedResponse, unconfirmedPDU, conclude*, etc.

- For confirmed and unconfirmed services it would be useful to determine the type of the service, e.g., *read, getNameList, informationReport,* etc. It can be also useful to know what variable is requested. However, it can be tens of variable. For example, dataset mms-kocin1.pcang contains *read* requests for 1, 6, or 11 variables depending on the type of the logical device.
- Similarly to *read* service, it can be also interesting to see detect *write* requests and what datasets or variable are involved. Also, the requests value to be written can be interesting to know. However, such detailed parsing would require too much execution time. In addition, there would be too much monitoring data to be stored.
- It is not feasible to extract names of datasets or variables from MMS messages unless it is specifically required. The reason is that a message may contain tens of variable in *getNameList*, *read*, *write*, and other services.
- Another approach to security monitoring is to monitor stations (clients) that are allowed to provide such operations and create a baseline how these operation are provided in time so that potential attacks on the communication can be detected.

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Appendix A: IEC 61850 Logical Node Groups and Classes

Standards IEC 61850-7-4, Ed. 2, IEC 61850-7-410 and IEC 61850-7-420 define the common groups of logical nodes based on the function. Full list of all 159 different LN classes can be found in [2].

Code	Logical Node (LN) Group	# of LN Classes
L	System LNs	9
A	Automatic Control	5
C	Control	6
D	Decentralized Energy Resources	
F	Funtional Blocks	9
G	Generic	4
H	Hydro Power	
I	Interfacing and Archiving	6
K	Mechanical and Nonelectric Primary Equipment	5
M	Metering and Measurement	13
P	Protection Functions	30
Q	Power Quality Events	6
R	Protection Related Functions	11
S	Supervising and Monitoring	11
T	Instrument Transformers and Sensors	20
W	Wind Turbines	
X	Switchgear	2
Y	Power Transformers	4
Z	Further Power System Equipment	18
Total		159

Each LN group contains a list of common LN classes. Example of system LN group follows:

System LNs (L Group) Logical Classes			
Number	**Clause**	**Description**	**Name**
1	5.3.2	Physical Device Information	LPHD
2	5.3.3	Common Logical Name	Common LN
3	5.3.4	Logical Node Zero	LLN0
4	5.3.5	Physical Communication Channel Supervision	LCCH
5	5.3.6	GOOSE Subscription	LGOS
6	5.3.7	Sampled Value Subscription	LSVS
7	5.3.8	Time Management	LTIM
8	5.3.9	Time Master Supervision	LTMS
9	5.3.10	Service Tracking	LTRK

Appendix B: Common Data Classes (CDC)

The following table contains a list of CDC based on IEC 61850-7-3, Ed.2 standard. The standard defines 40 different data classes.

Common Data Classes (CDC)			
Code	**Description**	**Code**	**Description**
CDC for status information		**CDC for status settings**	
SPS	Single point of status	SPG	Single point setting
DPS	Double point of status	ING	Integer status setting
INS	Integer status	ENG	Enumerated status setting
ENS	Enumerated status	ORG	Object reference setting
ACT	Protection activation Information	TSG	Time setting group
ACD	Directional protection activation information	CUG	Currency setting group
SEC	Security violation counting	VSG	Visible string setting
BCR	Binary couter reading		
HST	Histogram		
VSS	Visible string status		
CDC for measurand infomation		**CDC for analog settings**	
MV	Measured value	ASG	Analogue setting
CMV	Complex measured value	CURVE	Setting curve
SAV	Sampled value	CSG	Curve shape setting
WYE	Phase to ground/neutral realated measured values		
DEL	Phase to phase related measured values		
SEQ	Sequence		
HMV	Harmonic value		
HWYE	Harmonic value for WYE		
HDEL	Harmonic value for DEL		
CDC for controls		**CDC for description information**	
SPC	Controllable single point	DPL	Device name plate
DPC	Controllable double point	LPL	Logical node name plate
INC	Controllable integer status	CSD	Curve shape description
ENC	Controllable enumerated status		
BSC	Binary controlled step position information		
ISC	Integer controlled step position information		
APC	Controllable analogue process value		
BAC	Binary controlled analog process value		

Appendix C: Attribute Types and Functional Constraints

IEC 61850-7-3 defines 14 structured data attributes that are used by common data classes (see Appendix B). Data attribute types belong to 12 different functional constraints (FC).

Appendix C1: Common Data Attributes (CDA)

- Quality
- Analogue value
- Configuration of analog value
- Range configuration
- Step position with transient indication
- Pulse configuration
- Originator
- Unit definition
- Vector definition
- Point definition
- CtlModels definition
- SboClasses definition (Select Before Operate)
- Cell
- CalendarTime definition

Appendix C2: Trigger Options (TrgOp)

Trigger option specifies the conditions under which reporting on the data attribute can be triggered.

Trigger Option (TrgOp)		
Attribute name	**Attribute type**	**M/O/C**
data-change	BOOLEAN	M
quality-change	BOOLEAN	M
data-update	BOOLEAN	M
integrity	BOOLEAN	M
general-interrogation	BOOLEAN	M

Appendix C3: Functional Constraints (FC)

Functional constraints (FC) is a property of a data attribute that characterizes the specific use of the attribute. It indicates services applicable to a specific data attribute. From an application point of view, the data attributes are classified according to their specific use. Some attributes are used for controlling, other for reporting and logging, or measurement or setting groups, or the description of a specific data attributes.

The functional constraints serves as a data filter in the sense of defining the services applicable to specific data attributes of common data classes as defined in IEC 61850-7-3 (see Appendix B).

FC	Semantic	Description	Services allowed
ST	Status attributes	Data attribute shall represent status information. Initial value shall be taken from the process.	GetDataValues, GetDataDefinitions, GetDataDirectory, GetDataSetValues
MX	Measurand (analog values)	Data attribute shall represent measurand information.	GetDataValues, GetDataDefinitions, GetDataDirectory, GetDataSetValues
CO	Control		
SP	Set points	Data attribute shall represent setting parameter information	GetDataValues, SetDataValues, GetDataDefinition, GetDataDirectory, GetDataSetValues, SetDataSetValues
SV	Substituted values	Data attribute shall be used to handle substitution.	GetDataValues, SetDataValues, GetDataDefinition, GetDataDirectory, GetDataSetValues, SetDataSetValues
CF	Configuration	Data attribute shall represent configuration information.	GetDataValues, SetDataValues, GetDataDefinition, GetDataDirectory, GetDataSetValues, SetDataSetValues
DC	Description	Data attribute shall represent description information.	GetDataValues, SetDataValues, GetDataDefinition, GetDataDirectory, GetDataSetValues, SetDataSetValues
SG	Setting group	Data attribute shall represent the current active value of a setting member of a setting, see SETTING GROUP CONTROL	GetDataValues, GetDataDefinitions, GetDataDirectory, GetDataSetValues
SE	Setting groups editable	Data attribute shall belong to the editing services associated to a setting group, see SETTING GROUP CONTROL BLOCK.	GetDataDefinition, GetDataDirectory, GetEditSGValues, SetEditSGValues
SR	Service response	Data attribute shall represent data from different process objects with the same tracking object. These attributes are used for	GetDataValues, GetDataDefinitions, GetDataDirectory, GetDataSetValues
OR	Operate received	Data attribute shall represent the result of an Operate request at the data object receiving the Operate request, even if the execution of the Operate is blocked.	GetDataValues, GetDataDefinitions, GetDataDirectory, GetDataSetValues
BL	Blocking	Data attribute shall be used for blocking value updates	GetDataValues, SetDataValues, GetDataDefinition, GetDataDirectory, GetDataSetValues, SetDataSetValues
EX	Extended definition	Data attritube shall represent an application naem space, see IEC 61850-7-1.	GetDataValues, GetDataDefinitions, GetDataDirectory, GetDataSetValues
BR	Buffered report		
RP	Unbuffered report		
LG	Logging		
GO	GOOSE Control		
GS	GSSE Control		
MS	Multicast Sampled Value (9-2)		
US	Unicast Sampled Value (9-1)		
XX	Used as wild card in ACSI		

FCs CO, SR, OR and BL were defined by IEC 61850-7-3, Edition 2. FCs BR, RP, LG, etc. were reinserted for mapping to MMS.

Appendix D: Data Types

IEC 61850-7-2, Ed. 2 (2010) defines basic types and common ACSI types. The following table also includes mapping of data types to MMS data types as defined by IEC 61850-8-1, Ed. 2.1 (2017).

Basic Data Types		
Name	**Description**	**MMS data type**
BOOLEAN	BOOLEAN	Boolean
INT8	8-bit integer	Integer
INT16	16-bit integer	Integer
INT32	32-bit integer	Integer
INT64	64-bit integer	Integer
INT8U	8-bit unsigned integer	Unsigned
INT16U	16-bit unsigned integer	Unsigned
INT24U	24-bit unsigned integer, used for Timestamp	Unsigned
INT32U	32-bit unsigned integer	Unsigned
FLOAT32	Floating point value, IEEE 754	Floating-point
ENUMERATED	Ordered sequence of values	Integer
CODED ENUM	Ordered sequence of values	Bit-string
OCTET STRING	Maximal length must be defined	Octet-string
VISIBLE STRING	Maximal length must be defined	Visible-string
UNICODE STRING	Maximal length must be defined	MMS
Currency	3-char international currency code, ISO 4217	
Common ACSI Data Types		
Name	**Data Type / Description**	**MMS data type**
Object Name	VISIBLE STRING 64	n/a
ObjectReference	VISIBLE STRING 129	MMS address
PHYCOMADDR	Physical Communication Address	Addr-PRI-VID-APPID
ARRAY	Array 0 .. m OF p	MMS array
ServiceError	ENUMERATED	MMS messages
EntryID	OCTET STRING	MMS octet string
Packed List	Sequence of types	MMS bit-string
TimeStamp	UTC time stamp since 1970-01-01: sec, frac, quality	MMS string
EntryTime	GMT time since 1984-01-01	Binary-time
TriggerConditions	Packed list of BOOLEANS	bitstring
ReasonCode (ReasonForInclusion)	Packed list of BOOLEANS	bitstring

Appendix E: Mapping IEC 61850 objects and services to MMS

The following table shows ASCI objects and services defined by IEC 61850-7-2 and their mapping to MMS service according to IEC 61850-8-1 [6].

IEC 61850 Object	IEC 61850 Services	MMS Object	MMS Services	MMS Value
Server	GetServerDirectory	Virtual Manufacturing Device (VMD)	FileDirectory	4
Association	Associate		initiate	1
	Abort		abort	2
	Release		Conclude	3
Logical Device	GetLogicalDeviceDirectory	Domain	GetNameList	5
Logical Node	GetLogicalNodeDirectory	Named Variable	GetNameList	55
	GetAllDataValues		Read	6
Data	GetDataValues	Named Variable	Read	7
	SetDataValues		Write	8
	GetDataDirectory		GetVariableAccessAttributes	9
	GetDataDefinition		GetVariableAccessAttributes	10
Data Set	GetDataSetValues	Named Variable List	Read	11
	SetDataSetValues		Write	12
	CreateDataSet		DefineNamedVariableList	13
	DeleteDataSet		DeleteNamedVariableList	14
	GetDataSetDirectory		GetNameVariableListAttributes	15
Setting-Group-Control-Block	SelectActiveSG	Named Variable	Read	16
	SelectEditSG		Read	17
	SetEditSGValue		Write	18
	ConfirmEditSGValues			19
	GetEditSGValue		Read	20
	GetSGCBValues		Read	21
Report-Control-Block	Report	Named Variable	InformationReport	22
	GetBRCBValues		Read	23
	SetBRCBValues		Write	24
	GetURCBValues		Read	25
	SetURCBValues		Write	26
Log		Journal		
Log-Control-Block	GetLCBValues	Named Variable	Read	27
	SetLCBValues		Write	28
	QueryLogByTime		ReadJournal	29
	QueryLogAfter		ReadJournal	30
	GetLogStatusValues		GetJournalStatus	31
GOOSE-Control-Block	GetGoCBValues	Named Variable	Read	33
	SetGoCBValues		Write	34
	SendGOOSEMessage		Write	32
	GetGoReference			35
	GetGOOSEElementNumber			36
GSSE-Control-Block	GetGsCBValue	Named Variable		
	SetGsCBValue			
Control	Select	Named Variable	Read	43
	SelectWithValue		Write	44
	Cancel		Write	45
	Operate		Write	46
	CommandTermination		InformationReport	47
	TimeActivatedOperate		InformationReport	48
Files	GetFile	Files	FileOpen/FileRead/FileClose	49
	SetFile		ObtainFile	50
	DeleteFile		FileDelete	51
	GetFileAttributeValues		FileDirectory	52

Appendix F: Application protocol specification for GOOSE

This part describe ASN.1 definition of GOOSE and GSE messages as defined by IEC 61850-8-1, Annex A [6].

```
IEC 61850-8-1 Specific Protocol ::= CHOICE {
        mngtPdu   [APPLICATION 0]   IMPLICIT   MngtPdu,
        goosePdu  [APPLICATION 1]   IMPLICIT   IECGoosePdu,
        …
}
MngtPdu ::= SEQUENCE {
        StateID     [0]     IMPLICIT INTEGER,
        Security    [3]     ANY OPTIONAL, -- reserved for future definition
        CHOICE      {       requests    [1]     IMPLICIT    MngtRequests,
                            responses   [2]     IMPLICIT    MngtResponses
                    }
}
MngtRequests ::= CHOICE {
        getGoReference              [1]     IMPLICIT    GetReferenceRequestPdu,
        getGOOSEElementNumber       [2]     IMPLICIT    GetElementRequestPdu,
        getGsReference              [3]     IMPLICIT    GetReferenceRequestPdu,
        getGSSEDataOffset           [4]     IMPLICIT    GetElementRequestPdu,
        getMsvReference             [5]     IMPLICIT    GetReferenceRequestPdu,
        getMSVElementNumber         [6]     IMPLICIT    GetElementRequestPdu,
        getUsvReference             [7]     IMPLICIT    GetReferenceRequestPdu,
        getUSVElementNumber         [8]     IMPLICIT    GetElementRequestPdu,
        …
}
MngtResponses ::= CHOICE {
        gseMngtNotSupported         [0]     IMPLICIT NULL, # deprecated in the revision
        getGoReference              [1]     IMPLICIT    MngtResponsePdu,
        getGOOSEElementNumber       [2]     IMPLICIT    MngtResponsePdu,
        getGsReference              [3]     IMPLICIT    MngtResponsePdu,
        getGSSEDataOffset           [4]     IMPLICIT    MngtResponsePdu,
        getMsvReference             [5]     IMPLICIT    MngtResponsePdu,
        getMSVElementNumber         [6]     IMPLICIT    MngtResponsePdu,
        getUsvReference             [7]     IMPLICIT    MngtResponsePdu,
        getUSVElementNumber         [8]     IMPLICIT    MngtResponsePdu,
        …
}
GetReferenceRequestPdu ::= SEQUENCE {
        ident                   [0]     IMPLICIT    VISIBLE-STRING,
                                                    -- size shall support up to 129 octets
        offset                  [1]     IMPLICIT    SEQUENCE OF INTEGER,
        …
}

GetElementRequestPdu ::= SEQUENCE {
        ident                   [0]     IMPLICIT    VISIBLE-STRING,
                                                    -- size shall support up to 129 octets
        references              [1]     IMPLICIT    SEQUENCE OF VISIBLE-STRING,
        …
}
```

```
MngtResponsePdu ::= SEQUENCE {
        ident                   [0]     IMPLICIT    VISIBLE-STRING,     - - echos the value of the request
        confRev                 [1]     IMPLICIT    INTEGER OPTIONAL,
        CHOICE {
                                responsePositive    [2]     IMPLICIT SEQUENCE {
                                                    datSet  [0]     IMPLICIT VISIBLE-STRING OPTIONAL,
                                                    result  [1]     IMPLICIT    SEQUENC     OF
RequestResults
                                },
                                responseNegative    [3]     IMPLICIT GlbErrors
        },
        …
}

RequestResults::= CHOICE {
        offset                  [0]     IMPLICIT INTEGER,
        reference               [1]     IMPLICIT VISIBLE-STRING,
                                            -- Formerly IA5STRING,
        error                   [2]     IMPLICIT ErrorReason
}

GlbErrors ::= INTEGER {
        other                           (0),
        unknownControlBlock             (1),
        responseTooLarge                (2),
        controlBlockConfigurationError  (3),
        …
}

ErrorReason ::= INTEGER {
        other                           (0),
        notFound                        (1),
        …
}

IECGoosePdu ::= SEQUENCE {
        gocbRef             [0]     IMPLICIT    VISIBLE-STRING,
        timeAllowedtoLive   [1]     IMPLICIT    INTEGER,
        datSet              [2]     IMPLICIT    VISIBLE-STRING,
        goID                [3]     IMPLICIT    VISIBLE-STRING OPTIONAL,
        t                   [4]     IMPLICIT    UtcTime,
        stNum               [5]     IMPLICIT    INTEGER,
        sqNum               [6]     IMPLICIT    INTEGER,
        simulation          [7]     IMPLICIT    BOOLEAN DEFAULT FALSE,
        confRev             [8]     IMPLICIT    INTEGER,
        ndsCom              [9]     IMPLICIT    BOOLEAN DEFAULT FALSE,
        numDatSetEntries    [10]    IMPLICIT    INTEGER,
        allData             [11]    IMPLICIT    SEQUENCE OF Data,
}
```

UtcTime ::= OCTET STRING(8) representing the elapsed number of whose seconds since GMT midnight January 1, 1900, see CCIR Recommendation 460-4 (1986).

Appendix G: ASN.1 and BER Encoding

Abstract Syntax Notation 1 (ASN.1, defined by ITU-T X.680) specifies the following categories of data types [see also 7]:

- Primitive data types (universal class 00)
  - BOOLEAN – universal class tag 1
  - INTEGER – universal class tag 2
  - BIT STRINT – universal class tag 3
  - OCTET STRING – universal class tag 4
  - NULL – universal class tag 5
  - OBJECT IDENTIFIER – universal class tag 6
  - ObjectDescriptor – universal class tag 7
  - EXTERNAL – universal class tag 8
  - REAL – universal class tag 9
  - ENUMERATED – universal class tag 10
  - UTF8String – universal class tag 12
  - NumericString – universal class tag 18
  - PrintableString – universal class tag 19
  - IA5String – universal class tag
  - UTCTime – universal class tag 23
  - GeneralizedTime – universal class tag 24
  - GraphicString – universal class tag 25
  - VisibleString – universal class tag 26
  - GeneralString – universal class tag 27
  - UniversalString – universal class tag 28
  - CHARACTER STRING – universal tag 29
- Application-wide data types (class 01)
  - Not standardized but defined by each application. For GOOSE, see Appendix F.
- Constructor data types
  - SEQUENCE, SEQUENCE OF – universal class tag 16
  - SET, SET OF – universal class tag 17
  - CHOICE
  - SELECTION
  - ANY

Basic Encoding Rules (BER, standard ITU-T X.690) defines transfer syntax of ASN.1 data structures transmitted between applications. BER describes a method how to encode values of ANS.1 data as a string of octets. It encodes an ASN.1 value as a triplet TLV (type-length-value) that includes an identifier of the data type, length of the value, and the value itself, see the following figure.

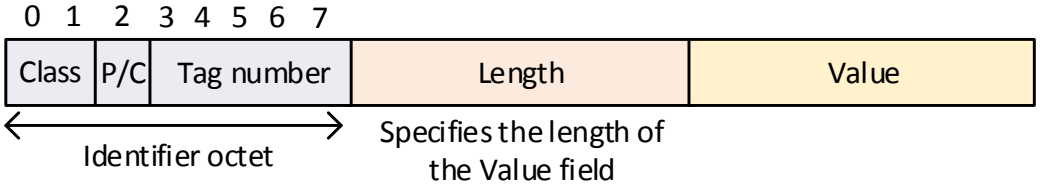
- *Type* (or identifier) is one-byte value that indicates the ASN.1 type, see below.
- *Length* indicates the length of the actual value representation.

- *Value* represents the value of ASN.1 type as a string of octets. For constructed types the value can be an embedded TLV triplet.

Example 1: sequence 41 02 3F 22 (hex)

- Type 41 = 0100 0001 (binary) denotes class 01 (application), primitive type (0) and the application tag is 1 (00001), see below. Application tag 1 in SNMP is Counter32 data type.
- 02 gives the length of the data, e.g., 2 bytes.
- 3F 22 is the value of the variable of type Counter 32. The value is 16,162 in decimal.

The *identifier* specifies the ASN.1 data type, the class of the type, and the method of encoding, see the following figure:



- *The first two bits* determine the class of the ASN.1 data type:
  - Universal (00) - universal data types (primitive or constructive) are given by the standard,
  - Application (01),
  - Context-specific (10),
  - Private (11).
- *The third bit* describes the encoding method: primitive (0) or constructed (1) form.
  - If set to 1, constructed data types as SEQUENCE, SET, CHOICE, etc. are used. It also means that another TLV triplet is embedded as a value.
- *The last five bits* identify the data type. This is called a tag. Universal data type tags are listed above. Application, context-specific and private tags are defined by the application.

The *length* can be encoding in three forms:

- *short definite length* (primitive form): 1 byte value if the MSB is 0, i.e., for length 0-127 B
- *long definite length* (primitive form): the first byte (without leading 1) represents the length of the length field, that is, the number of octets necessary for encoding the length.
- *indefinite length* (constructed form): the first byte 1000 0000 indicates this form, the next octets represent the value of the length, and two zero octets (0x 00 00) are added after the encoding the value.

Example 2: sequence *61 81 83 80 1f 53* … (hex)

- Type 61 (0110 0001 in binary) is an identifier octet which describes the application class (01), in the constructed (1) form with data type 1. Application type 01 means *goosePDU* (see Appendix F).
- Length 81 83 is an extended length field where 0x81 (1000 0001) describes the long definite form of the length with 1 octet and 0x83 is the length value, that is, 131 bytes.
- Type 80 (1000 0000) starts an embedded TLV triplet which is of the context-specific class (10), primitive form (0) and the type is 0 which is *gocbRef* (see Appendix F).

- Length 1f is the length of the VISIBLE STRING in the *gocbRef* field.

Encoding BIT STRING value
The encoding form of BIT STRING value can be primitive or constructed.

In the primitive form, the string is cut up in octets and a leading octet is added so that the number of bits left unused at the end could be identified by an integer between 0 and 7. If this octet is 0, it means that all bits are used.

For example, BIT STRING 1011 0111 0101 1 (13 bits) will be aligned to two octets (16 bits), e.g., 1011 0111 0101 1000, thus three zero bits are left added to align the bit string to octets. BER encoding will be *0000 0011* 1011 0111 0101 1000, where the first octet (italic) represents the number of left added zero bits (3) and two following octets represent the bit string without three last zero bits. For further details, see [8].

The *EXTERNAL* type

EXTERNAL data type is the first type that enabled the user to change the presentation context. It models values that are external to the current specification in the sense that they are defined with another abstract syntax or encoded with a transfer syntax different from that of the active presentation context. The component *direct-reference* identifies the data type syntax. The component *indirect-reference* is an integer that references one of the presentation contexts that were negotiated. The *data-value-descriptor* is a string that describes the abstract syntax of the data but it is not used in practice. For embedding the value in the *encoding* component, the item *single-ASN1-type* is chosen if the abstract syntax is an ASN.1 type and if the data are encoded with the same transfer syntax as the active presentation context.

```
EXTERNAL ::=      [UNIVERSAL 8]    IMPLICIT SEQUENCE {
        direct-reference           OBJECT IDENTIFIER        OPTIONAL,
        indirect-reference         INTEGER                  OPTIONAL,
        data-value-descriptor      ObjectDescriptor         OPTIONAL,
        encoding                   CHOICE {
                        single-ASN1-type        [0]     ANY,
                        octet-aligned           [1]     IMPLICIT        OCTET STRING,
                        arbitrary               [2]     IMPLICIT        BIT STRING
                }
}
```

The type *EXTERNAL* is used, for example, in the PDUs of the Association Control Service Element (ACSE) invoked by all the applications that use the OSI stack, see Appendix H.

Appendix H: ACSE APDU

The abstract syntax of ACSE APDUs is specified by standard X.227 [] and expressed using ASN.1. MMS uses only two ACSE APDUs: AARQ (Association Request APDU) and AARE (Association Response APDU) which encapsulates MMS Initiate Request and MMS Initiate Response, respectively.

```
AARQ-apdu ::= [APPLICATION 0] IMPLICIT SEQUENCE {     --- APPLICATION 0 = 60H = 96
        protocol-version                [0]     IMPLICIT BIT STRING { version 1(0)} DEFAULT {version 1},
        application-context-name        [1]     Application-context-name,
        called-AP-title                 [2]     AP-title OPTIONAL,
        called-AE-qualifier             [3]     AE-qualifier OPTIONAL,
        called-AP-invocation-id         [4]     AP-invocation-identifier OPTIONAL,
        called-AE-invocation-ide        [5]     AE-invocation-identifier OPTIONAL,
        calling-AP-title                [6]     AP-title OPTIONAL,
        calling-AE-quantifier           [7]     AE-qualifier OPTIONAL,
        calling-AP-invocation-id        [8]     AP-invocation-identifier OPTIONAL,
        calling-AE-invocation-id        [9]     AE-invocation-identifier OPTIONAL,
        sender-acse-requirements        [10]    IMPLICIT ACSE-requirements OPTIONAL,
        mechanism-name                  [11]    IMPLICIT Mechanism-name OPTIONAL,
        calling-authentication-value    [12]    EXPLICIT Authentication-value OPTIONAL,
        application-context-name-list   [13]    IMPLICIT Application-context-name-list OPTIONAL,
        implementation-information      [29]    IMPLICIT    Implementation-data OPTIONAL,
        user-information                [30]    IMPLICIT    Association-information OPTIONAL
}

AARE-apdu ::= [APPLICATION 1] IMPLICIT SEQUENCE {     --- APPLICATION 1 = 61H = 97
        protocol-version                [0]     IMPLICIT BIT STRING {version 1(0)} DEFAULT {version 1},
        application-context-name        [1]     Application-context-name,
        result                          [2]     Association-result,
        result-source-diagnostic        [3]     Associate-source-diagnostic,
        responding-AP-title             [4]     AP-title OPTIONAL,
        responding-AE-qualifier         [5]     AE-qualifier OPTIONAL,
        responding-AP-invocation-id     [6]     AP-invocation-identifier OPTIONAL,
        responding-AE-invocation-id     [7]     AE-invocation-identifier OPTIONAL,
        responder-acse-requirements     [8]     IMPLICIT ACSE-requirement OPTIONAL,
        mechanism-name                  [9]     IMPLICIT Mechanism-name OPTIONAL,
        responding-authentication-value [10]    EXPLICIT Authentication-value OPTIONAL,
        application-context-name-list   [11]    IMPLICIT Application-context-name-list OPTIONAL,
        implementation-information      [29]    IMPLICIT Implementation-data OPTIONAL,
        user-information                [30]    IMPLICIT Association-information OPTIONAL
}

RLRQ-apdu ::= [APPLICATION 2] IMPLICIT SEQUENCE {     --- APPLICATION 2 = 62H = 98
        reason                          [0]     IMPLICIT Release-request-reason OPTIONAL,
        user-information                [30]    IMPLICIT Association-information OPTIONAL
}

RLRE-apdu ::= [APPLICATION 3] IMPLICIT SEQUENCE {     --- APPLICATION 3 = 63H = 99
        reason                          [0]     IMPLICIT Release=response-reason OPTIONAL,
        user-information                [30]    IMPLICIT Association-information OPTIONAL
}
```

```
ACSE-requirements     ::= BIT STRING {
        authentication                  (0),
        application-context-negotiation (1),
}

Application-context-name-list ::= SEQUENCE OF Application-context-name
Application-context-name ::= OBJECT IDENTIFIER
Implementation-data ::= GraphicString
Association-information ::= SEQUENCE OF EXTERNAL  -- See Appendix G for EXTERNAL data type

Mechanism-name ::= OBJECT IDENTIFIER

Association-result ::= INTEGER {
        accepted                (0),
        rejected-permanent      (1),
        rejected-transient      (2)
}

Associate-source-diagnostic ::= CHOICE {
        acse-service-user       [1]     INTEGER {
                null                                                    (0),
                no-reason-given                                         (1),
                application-context-name-not-supported                  (2),
                calling-AP-title-not-recognized                         (3),
                calling-AP-invocation-identifier-not-recognized         (4),
                calling-AE-qualifier-not-recognized                     (5),
                calling-AE-invocation-identifier-not-recognized         (6),
                called-AP-title-not-recognized                          (7),
                called-AP-invocation-identifier-not-recognized          (8),
                called-AE-qualifier-not-recognized                      (9),
                called-AE-invocation-identifier-not-recognized          (10),
                authentication-mechanism-name-not-recognized            (11),
                authentication-mechanism-name-required                  (12),
                authentication-failure                                  (13),
                authentication-required                                 (14)
        }
        acse-service-provider  [2]      INTEGER {
                null                            (0),
                no-reason-given                 (1),
                no-common-acse-version          (2)
        }
}
```

Appendix I: Format of Presentation Protocol Data Units (PPDUs)

Standard ISO/IEC 8823-1 or ITU-T X.226 defines several types of Presentation Protocol Data Units (PPDUs). MMS employs only three types: CP PPDU (Connect Presentation), CPA PPDU (Connect Presentation Accept), and CPC-type which transmit user data only.

```
CP-type ::= SET {
        mode-selector                   [0]     IMPLICIT    Mode-selector,
        normal-mode-parameters          [2]     IMPLICIT    SEQUENCE {
                protocol-version                    [0] IMPLICIT Protocol-version DEFAULT {version-1},
                calling-presentation-selector       [1] IMPLICIT Calling-presentation-selector OPTIONAL,
                called-presentation-selector        [2] IMPLICIT Called-presentation-selector OPTIONAL,
                presentation-context-definition-list [4] IMPLICIT Presentation-context-definition-list
OPTIONAL,
                default-context-name                [6] IMPLICIT Default-context-name OPTIONAL,
                presentation-requirements           [8] IMPLICIT Presentation-requirements OPTIONAL,
                user-session-requirements           [9] IMPLICIT User-session-requirements OPTIONAL
                user-data               User-data   OPTIONAL
        } OPTIONAL
}
CPA-PPDU ::= SET {
        mode-selector                   [0]     IMPLICIT    Mode-selector,
        normal-mode-parameters          [2]     IMPLICIT SEQUENCE {
                protocol-version                        [0] IMPLICIT Protocol-version DEFAULT {version 1},
                responding-presentation-selector        [3] IMPLICIT Responding-presentation-selector
                                                            OPTIONAL,
                presentation-context-definition-result-list [5] IMPLICIT
                                                        Presentation-context-definition-result-list OPTIONAL,
                presentation-requirements               [8] IMPLICIT Presentation-requirements OPTIONAL,
                user-session-requirements               [9] IMPLICIT User-session-requirements OPTIONAL,
                user-data               User-data   OPTIONAL
        } OPTIONAL
}
CPC-type ::= User-data
Mode-selector ::= SET {
        mode-value          [0]         IMPLICIT    INTEGER {
                            x410-1984-mode          (0),
                            normal-mode             (1)
        }
}
Protocol-version ::= BIT STRING {
        version-1           (0)
}
Calling-presentation-selector ::= Presentation-selector

Called-presentation-selector ::= Presentation-selector

Presentation-context-definition-list ::= Context-list

Context-list ::= SEQUENCE OF SEQUENCE {
        presentation-context-identifier     Presentation-context-identifier,
        abstract-syntax-name                Abstract-syntax-name,
        transfer-syntax-name-list           SEQUENCE OF         Transfer-syntax-name
```

```
}
Default-Default-context-name ::= SEQUENCE {
        abstract-syntax-name        [0]     IMPLICIT    Abstract-syntax-name,
        transfer-syntax-name        [1]     IMPLICIT    Transfer-syntax-name
}
Presentation-requirements ::= BIT STRING {
        context-management  (0),
        restoration         (1)
}
User-session-requirements ::= BIT STRING {
        half-duplex                 (0),
        duplex                      (1),
        expedited-data              (2),
        minor-synchronize           (3),
        major-synchronize           (4),
        resynchronize               (5),
        activity-management         (6),
        negotiated-release          (7),
        capability-data             (8),
        exceptions                  (9),
        typed-data                  (10),
        symmetric-synchronize       (11),
        data-separation             (12)
}
User-data ::= CHOICE {
        simply-encoded-data         [APPLICATION 0]     IMPLICIT    Simply-encoded-data,
        fully-encoded-data          [APPLICATION 1]     IMPLICIT    Fully-encoded-data
}
Responding-presentation-selector ::= Presentation-selector

Presentation-context-identifier-list ::= SEQUENCE OF SEQUENCE {
        presentation-context-identifier    Presentation-context-identifier,
        transfer-syntax-name               Transfer-syntax-name
}
Presentation-selector               ::= OCTET STRING
Presentation-context-identifier     ::= INTEGER
Transfer-syntax-name                ::= OBJECT IDENTIFIER
Abstract-syntax-name                ::= OBJECT IDENTIFIER
Simply-encoded-data                 ::= OCTET STRING
Fully-encoded-data                  ::= SEQUENCE OF PDV-list

PDV-list ::= SEQUENCE {
        transfer-syntax-name            Transfer-syntax-name            OPTIONAL,
        presentation-context-identifier Presentation-context-identifier,
        presentation-data-values        CHOICE {
                        single-ASN1-type    [0]     ABSTRACT-SYNTAX.&Type (CONSTRAINED BY{
                                                    -- Type corresponding to presentation context identifier --}
),
                        octet-aligned       [1]     IMPLICIT    OCTET STRING,
                        arbitrary           [2]     IMPLICIT    BIT STRING
        }
}
```

Appendix J: Format of MMS Protocol Data Units

This part describes PDUs used to operate the MMS protocol as specified in standard ISO 9506-2:2003 [9]. There are fourteen types of PDUs in MMS. The most frequent PDUs are *initiate-Request*, *initiate-Response*, *confirmed-Request*, *confirmed-Response*, *conclude-Request*, *conclude-Response*, *and unconfirmed-PDU*. The format of MMS PDUs is described using ASN.1 notation and encoded using Basic Encoding Rules (BER) for transmission, see Appendix G. The electronical version is here[4].

```
MMSpdu ::= CHOICE {
        confirmed-RequestPDU        [0]     IMPLICIT    Confirmed-RequestPDU,       -- 0xa0
        confirmed-ResponsePDU       [1]     IMPLICIT    Confirmed-ResponsePDU,      -- 0xa1
        confirmed-ErrorPDU          [2]     IMPLICIT    Confirmed-ErrorPDU,         -- 0xa2
        unconfirmed-PDU             [3]     IMPLICIT    Unconfirmed-PDU,            -- 0xa3
        rejectPDU                   [4]     IMPLICIT    RejectPDU,                  -- 0xa4
        cancel-RequestPDU           [5]     IMPLICIT    Cancel-RequestPDU,          -- 0xa5
        cancel-ResponsePDU          [6]     IMPLICIT    Cancel-ResponsePDU,         -- 0xa6
        cancel-ErrorPDU             [7]     IMPLICIT    Cancel-ErrorPDU,            -- 0xa7
        initiate-RequestPDU         [8]     IMPLICIT    Initiate-RequestPDU,        -- 0xa8
        initiate-ResponsePDU        [9]     IMPLICIT    Initiate-ResponsePDU,       -- 0xa9
        initiate-ErrorPDU           [10]    IMPLICIT    Initiate-ErrorPDU,          -- 0xaa
        conclude-RequestPDU         [11]    IMPLICIT    Conclude-RequestPDU,        -- 0xab
        conclude-ResponsePDU        [12]    IMPLICIT    Conclude-ResponsePDU,       -- 0xac
        conclude-ErrorPDU           [13]    IMPLICIT    Conclude-ErrorPDU           -- 0xad
}

Confirmed-RequestPDU ::= SEQUENCE {
        invokeID                Unsigned32,
        listOfModifiers         SEQUENCE OF Modifier        OPTIONAL,
        service                 ConfirmedServiceRequest,
        service-ext             [79]    Request-Detail OPTIONAL
}

Confirmed-ResponsePDU ::= SEQUENCE {
        invokeID                Unsigned32,
        service                 ConfirmedServiceResponse,
        service-ext             [79]    Response-Detail OPTIONAL
}

Confirmed-ErrorPDU ::= SEQUENCE {
        invokeID                [0]     IMPLICIT    Unsigned32,
        modifierPosition        [1]     IMPLICIT    Unsigned32          OPTIONAL,
        serviceError            [2]     IMPLICIT    ServiceError
}

Unconfirmed-PDU ::= SEQUENCE {
        service     UnconfirmedService,
        service-ext             [79]    Unconfirmed-Detail  OPTIONAL
}
```

[4] See https://www.nettedautomation.com/standardization/ISO/TC184/SC5/WG2/mms_syntax/index.html [July 2018]

```
RejectPDU ::= SEQUENCE {
        originalInvokeID        [0]     IMPLICIT    Unsigned32          OPTIONAL,
        rejectReason            CHOICE {
                confirmed-requestPDU            [1]     IMPLICIT INTEGER {
                        other                                   (0),
                        unrecognized-service                    (1),
                        unrecognized-modifier                   (2),
                        invalid-invokeID                        (3),
                        invalid-argument                        (4),
                        invalid-modifier                        (5),
                        max-serv-outstanding-exceeded           (6),
                        max-recursion-exceeded                  (8),
                        value-out-of-range                      (9)
                }
                confirmed-responsePDU           [2]     IMPLICIT INTEGER {
                        other                                   (0),
                        unrecognized-service                    (1),
                        invalid-invokeID                        (2),
                        invalid-result                          (3),
                        max-recursion-exceeded                  (5),
                        value-out-of-range                      (6)
                }
                confirmed-errorPDU              [3]     IMPLICIT INTEGER {
                        other                                   (0),
                        unrecognized-service                    (1),
                        invalid-invokeID                        (2),
                        invalid-serviceError                    (3),
                        value-out-of-range                      (4)
                }
                unconfirmedPDU                  [4]     IMPLICIT INTEGER {
                        other                                   (0),
                        unrecognized-service                    (1),
                        invalid-argument                        (2),
                        max-recursion-exceeded                  (3),
                        value-out-of-range                      (4)
                }
                pdu-error                       [5]     IMPLICIT INTEGER {
                        unknown-pdu-type                        (0),
                        invalid-pdu                             (1),
                        illegal-acse-mapping                    (2)
                }
                cancel-requestPDU               [6]     IMPLICIT INTEGER {
                        other                                   (0),
                        invalid-invokeID                        (1)
                }
                cancel-responsePDU              [7]     IMPLICIT INTEGER {
                        other                                   (0),
                        invalid-invokeID                        (1)
                }
                cancel-errorPDU                 [8]     IMPLICIT INTEGER {
                        other                                   (0),
```

```
                                    invalid-invokeID                (1),
                                    invalid-serviceError            (2),
                                    value-out-of-range              (3)
                        }
                        conclude-requestPDU         [9]     IMPLICIT INTEGER {
                                    other                           (0),
                                    invalid-argument                (1)
                        }
                        conclude-responsePDU        [10]    IMPLICIT INTEGER {
                                    other                           (0),
                                    invalid-result                  (1)
                        }
                        conclude-errorPDU           [11]    IMPLICIT INTEGER {
                                    other                           (0),
                                    invalid-serviceError            (1),
                                    value-out-of-range              (2)
                        }
            }
}
Cancel-RequestPDU ::= Unsigned32 – originalInvokeID

Cancel-ResponsePDU ::= Unsigned32 -- originalInvokeID

Cancel-ErrorPDU ::= SEQUENCE {
            originalInvokeID    [0]     IMPLICIT    Unsigned32,
            serviceError        [1]     IMPLICIT    ServiceError
}
Initiate-RequestPDU ::= SEQUENCE {
            localDetailCalling                          [0]     IMPLICIT    Integer32   OPTIONAL,
            proposedMaxServOutstandingCalling           [1]     IMPLICIT    Integer16,
            proposedMaxServOutstandingCalled            [2]     IMPLICIT    Integer16,
            proposedDataStructureNestingLevel           [3]     IMPLICIT    Integer8    OPTIONAL,
            initRequestDetail                           [4]     IMPLICIT    SEQUENCE {
                        proposedVersionNumber           [0]     IMPLICIT    Integer16,
                        proposedParameterCBB            [1]     IMPLICIT ParameterSupportOptions,
                        servicesSupportedCalling        [2]     IMPLICIT    ServiceSupportOptions ,
                        additionalSupportedCalling      [3]     IMPLICIT
            AdditionalSupportOptions
                        additionalCbbSupportedCalling   [4]     IMPLICIT    AdditionalCBBOptions,
                        privilegeClassIdentityCalling   [5]     IMPLICIT    VisibleString
            }
}
Initiate-ResponsePDU ::= SEQUENCE {
            localDetailCalled                           [0]     IMPLICIT    Integer32   OPTIONAL,
            negotiatedMaxServOutstandingCalling         [1]     IMPLICIT    Integer16,
            negotiatedMaxServOutstandingCalled          [2]     IMPLICIT    Integer16,
            negotiatedDataStructureNestingLevel         [3]     IMPLICIT    Integer8    OPTIONAL,
            initResponseDetail                          [4]     IMPLICIT    SEQUENCE {
                        negotiatedVersionNumber         [0]     IMPLICIT    Integer16,
                        negotiatedParameterCBB          [1]     IMPLICIT ParameterSupportOptions,
                        servicesSupportedCalled         [2]     IMPLICIT    ServiceSupportOptions,
                        additionalSupportedCalled       [3]     IMPLICIT
            AdditionalSupportOptions
```

```
                additionalCbbSupportedCalled    [4]     IMPLICIT    AdditionalCBBOptions,
                privilegeClassIdentityCalled    [5]     IMPLICIT    VisibleString
        }
}
Initiate-ErrorPDU ::= ServiceError

Conclude-RequestPDU ::= NULL

Conclude-ResponsePDU ::= NULL

Conclude-ErrorPDU ::= ServiceError

UnconfirmedService ::= CHOICE {
        informationReport               [0]     IMPLICIT    InformationReport
        unsolicitedStatus               [1]     IMPLICIT    UnsolicitedStatus
        eventNotification               [2]     IMPLICIT    EventNotification
}
InformationReport ::= SEQUENCE {
        variableAccessSpecification     VariableAccessSpecification,
        listOfAccessResult              [0]     IMPLICIT SEQUENCE OF AccessResult
}

ConfirmedServiceRequest ::= CHOICE {
        status                          [0]     IMPLICIT    Status-Request
        getNameList                     [1]     IMPLICIT    GetNameList-Request
        identify                        [2]     IMPLICIT    Identify-Request
        rename                          [3]     IMPLICIT    Rename-Request
        read                            [4]     IMPLICIT    Read-Request
        write                           [5]     IMPLICIT    Write-Request
        getVariableAccessAttributes     [6]     GetVariableAccessAttributes-Request
        defineNamedVariable             [7]     IMPLICIT    DefineNamedVariable-Request
        defineScatteredAccess           [8]     IMPLICIT    DefineScatteredAccess-Request
        getScatteredAccessAttributes    [9]     GetScatteredAccessAttributes-Request
        deleteVariableAccess            [10]    IMPLICIT    DeleteVariableAccess-Request
        defineNamedVariableList         [11]    IMPLICIT    DefineNamedVariableList-Request
        getNamedVariableListAttributes  [12]    GetNamedVariableListAttributes-Request
        deleteNamedVariableList         [13]    IMPLICIT    DeleteNamedVariableList-Request
        defineNamedType                 [14]    IMPLICIT    DefineNamedType-Request
        getNamedTypeAttributes          [15]    GetNamedTypeAttributes-Request
        deleteNamedType                 [16]    IMPLICIT    DeleteNamedType-Request
        input                           [17]    IMPLICIT    Input-Request
        output                          [18]    IMPLICIT    Output-Request
        takeControl                     [19]    IMPLICIT    TakeControl-Request
        relinquishControl               [20]    IMPLICIT    RelinquishControl-Request
        defineSemaphore                 [21]    IMPLICIT    DefineSemaphore-Request
        deleteSemaphore                 [22]    DeleteSemaphore-Request
        reportSemaphoreStatus           [23]    ReportSemaphoreStatus-Request
        reportPoolSemaphoreStatus       [24]    IMPLICIT    ReportPoolSemaphoreStatus-Request
        reportSemaphoreEntryStatus      [25]    IMPLICIT    ReportSemaphoreEntryStatus-Request
        initiateDownloadSequence        [26]    IMPLICIT    InitiateDownloadSequence-Request,
        downloadSegment                 [27]    IMPLICIT    DownloadSegment-Request,
        terminateDownloadSequence       [28]    IMPLICIT    TerminateDownloadSequence-Request
        initiateUploadSequence          [29]    IMPLICIT    InitiateUploadSequence-Request,
```

uploadSegment	[30]	IMPLICIT UploadSegment-Request,
terminateUploadSequence	[31]	IMPLICIT TerminateUploadSequence-Request
requestDomainDownload	[32]	IMPLICIT RequestDomainDownload-Request
requestDomainUpload	[33]	IMPLICIT RequestDomainUpload-Request
loadDomainContent	[34]	IMPLICIT LoadDomainContent-Request
storeDomainContent	[35]	IMPLICIT StoreDomainContent-Request
deleteDomain	[36]	IMPLICIT DeleteDomain-Request
getDomainAttributes	[37]	IMPLICIT GetDomainAttributes-Request
createProgramInvocation	[38]	IMPLICIT CreateProgramInvocation-Request
deleteProgramInvocation	[39]	IMPLICIT DeleteProgramInvocation-Request
start	[40]	IMPLICIT Start-Request
stop	[41]	IMPLICIT Stop-Request
resume	[42]	IMPLICIT Resume-Request
reset	[43]	IMPLICIT Reset-Request
kill	[44]	IMPLICIT Kill-Request
getProgramInvocationAttributes	[45]	IMPLICIT GetProgramInvocationAttributes-Request
obtainFile	[46]	IMPLICIT ObtainFile-Request
defineEventCondition	[47]	IMPLICIT DefineEventCondition-Request
deleteEventCondition	[48]	DeleteEventCondition-Request
getEventConditionAttributes	[49]	GetEventConditionAttributes-Request
reportEventConditionStatus	[50]	ReportEventConditionStatus-Request
alterEventConditionMonitoring	[51]	IMPLICIT AlterEventConditionMonitoring-Request
triggerEvent	[52]	IMPLICIT TriggerEvent-Request
defineEventAction	[53]	IMPLICIT DefineEventAction-Request
deleteEventAction	[54]	DeleteEventAction-Request
getEventActionAttributes	[55]	GetEventActionAttributes-Request
reportEventActionStatus	[56]	ReportEventActionStatus-Request
defineEventEnrollment	[57]	IMPLICIT DefineEventEnrollment-Request
deleteEventEnrollment	[58]	DeleteEventEnrollment-Request
alterEventEnrollment	[59]	IMPLICIT AlterEventEnrollment-Request
reportEventEnrollmentStatus	[60]	ReportEventEnrollmentStatus-Request
getEventEnrollmentAttributes	[61]	IMPLICIT GetEventEnrollmentAttributes-Request
acknowledgeEventNotification	[62]	IMPLICIT AcknowledgeEventNotification-Request
getAlarmSummary	[63]	IMPLICIT GetAlarmSummary-Request
getAlarmEnrollmentSummary	[64]	IMPLICIT GetAlarmEnrollmentSummary-Request
readJournal	[65]	IMPLICIT ReadJournal-Request
writeJournal	[66]	IMPLICIT WriteJournal-Request
initializeJournal	[67]	IMPLICIT InitializeJournal-Request
reportJournalStatus	[68]	ReportJournalStatus-Request
createJournal	[69]	IMPLICIT CreateJournal-Request
deleteJournal	[70]	IMPLICIT DeleteJournal-Request
getCapabilityList	[71]	IMPLICIT GetCapabilityList-Request
fileOpen	[72]	IMPLICIT FileOpen-Request
fileRead	[73]	IMPLICIT FileRead-Request
fileClose	[74]	IMPLICIT FileClose-Request
fileRename	[75]	IMPLICIT FileRename-Request
fileDelete	[76]	IMPLICIT FileDelete-Request
fileDirectory	[77]	IMPLICIT FileDirectory-Request
additionalService	[78]	AdditionalService-Request
getDataExchangeAttributes	[80]	GetDataExchangeAttributes-Request
exchangeData	[81]	IMPLICIT ExchangeData-Request
defineAccessControlList	[82]	IMPLICIT DefineAccessControlList-Request
getAccessControlListAttributes	[83]	GetAccessControlListAttributes-Request

```
        reportAccessControlledObjects   [84]    IMPLICIT    ReportAccessControlledObjects-Request
        deleteAccessControlList         [85]    IMPLICIT    DeleteAccessControlList-Request
        changeAccessControl             [86]    IMPLICIT    ChangeAccessControl-Request
}
ConfirmedServiceResponse ::= CHOICE {
        status                          [0]     IMPLICIT    Status-Response,
        getNameList                     [1]     IMPLICIT    GetNameList-Response,
        identify                        [2]     IMPLICIT    Identify-Response,
        rename                          [3]     IMPLICIT    Rename-Response,
        read                            [4]     IMPLICIT    Read-Response,
        write                           [5]     IMPLICIT    Write-Response,
        getVariableAccessAttributes     [6]     IMPLICIT    GetVariableAccessAttributes-Response,
        defineNamedVariable             [7]     IMPLICIT    DefineNamedVariable-Response
        defineScatteredAccess           [8]     IMPLICIT    DefineScatteredAccess-Response,
        getScatteredAccessAttributes    [9]     IMPLICIT    GetScatteredAccessAttributes-Response,
        deleteVariableAccess            [10]    IMPLICIT    DeleteVariableAccess-Response,
        defineNamedVariableList         [11]    IMPLICIT    DefineNamedVariableList-Response,
        getNamedVariableListAttributes  [12]    IMPLICIT    GetNamedVariableListAttributes-Response,
        deleteNamedVariableList         [13]    IMPLICIT    DeleteNamedVariableList-Response,
        defineNamedType                 [14]    IMPLICIT    DefineNamedType-Response,
        getNamedTypeAttributes          [15]    IMPLICIT    GetNamedTypeAttributes-Response,
        deleteNamedType                 [16]    IMPLICIT    DeleteNamedType-Response,
        input                           [17]    IMPLICIT    Input-Response,
        output                          [18]    IMPLICIT    Output-Response,
        takeControl                     [19]    TakeControl-Response,
        relinquishControl               [20]    IMPLICIT    RelinquishControl-Response,
        defineSemaphore                 [21]    IMPLICIT    DefineSemaphore-Response,
        deleteSemaphore                 [22]    IMPLICIT    DeleteSemaphore-Response,
        reportSemaphoreStatus           [23]    IMPLICIT    ReportSemaphoreStatus-Response,
        reportPoolSemaphoreStatus       [24]    IMPLICIT    ReportPoolSemaphoreStatus-Response,
        reportSemaphoreEntryStatus      [25]    IMPLICIT    ReportSemaphoreEntryStatus-Response,
        initiateDownloadSequence        [26]    IMPLICIT    InitiateDownloadSequence-Response,
        downloadSegment                 [27]    IMPLICIT    DownloadSegment-Response,
        terminateDownloadSequence       [28]    IMPLICIT    TerminateDownloadSequence-Response,
        initiateUploadSequence          [29]    IMPLICIT    InitiateUploadSequence-Response,
        uploadSegment                   [30]    IMPLICIT    UploadSegment-Response,
        terminateUploadSequence         [31]    IMPLICIT    TerminateUploadSequence-Response,
        requestDomainDownload           [32]    IMPLICIT    RequestDomainDownload-Response,
        requestDomainUpload             [33]    IMPLICIT    RequestDomainUpload-Response,
        loadDomainContent               [34]    IMPLICIT    LoadDomainContent-Response,
        storeDomainContent              [35]    IMPLICIT    StoreDomainContent-Response,
        deleteDomain                    [36]    IMPLICIT    DeleteDomain-Response,
        getDomainAttributes             [37]    IMPLICIT    GetDomainAttributes-Response,
        createProgramInvocation         [38]    IMPLICIT    CreateProgramInvocation-Response,
        deleteProgramInvocation         [39]    IMPLICIT    DeleteProgramInvocation-Response,
        start                           [40]    IMPLICIT    Start-Response,
        stop                            [41]    IMPLICIT    Stop-Response,
        resume                          [42]    IMPLICIT    Resume-Response,
        reset                           [43]    IMPLICIT    Reset-Response,
        kill                            [44]    IMPLICIT    Kill-Response,
        getProgramInvocationAttributes  [45]    IMPLICIT    GetProgramInvocationAttributes-Response,
        obtainFile                      [46]    IMPLICIT    ObtainFile-Response,
        defineEventCondition            [47]    IMPLICIT    DefineEventCondition-Response,
```

```
        deleteEventCondition                [48]    IMPLICIT    DeleteEventCondition-Response,
        getEventConditionAttributes         [49]    IMPLICIT    GetEventConditionAttributes-Response,
        reportEventConditionStatus          [50]    IMPLICIT    ReportEventConditionStatus-Response,
        alterEventConditionMonitoring       [51]    IMPLICIT    AlterEventConditionMonitoring-Response,
        triggerEvent                        [52]    IMPLICIT    TriggerEvent-Response,
        defineEventAction                   [53]    IMPLICIT    DefineEventAction-Response,
        deleteEventAction                   [54]    IMPLICIT    DeleteEventAction-Response,
        getEventActionAttributes            [55]    IMPLICIT    GetEventActionAttributes-Response,
        reportEventActionStatus             [56]    IMPLICIT    ReportEventActionStatus-Response,
        defineEventEnrollment               [57]    IMPLICIT    DefineEventEnrollment-Response,
        deleteEventEnrollment               [58]    IMPLICIT    DeleteEventEnrollment-Response,
        alterEventEnrollment                [59]    IMPLICIT    AlterEventEnrollment-Response,
        reportEventEnrollmentStatus         [60]    IMPLICIT    ReportEventEnrollmentStatus-Response,
        getEventEnrollmentAttributes        [61]    IMPLICIT    GetEventEnrollmentAttributes-Response,
        acknowledgeEventNotification        [62]    IMPLICIT    AcknowledgeEventNotification-Response,
        getAlarmSummary                     [63]    IMPLICIT    GetAlarmSummary-Response,
        getAlarmEnrollmentSummary           [64]    IMPLICIT    GetAlarmEnrollmentSummary-Response,
        readJournal                         [65]    IMPLICIT    ReadJournal-Response,
        writeJournal                        [66]    IMPLICIT    WriteJournal-Response,
        initializeJournal                   [67]    IMPLICIT    InitializeJournal-Response,
        reportJournalStatus                 [68]    IMPLICIT    ReportJournalStatus-Response,
        createJournal                       [69]    IMPLICIT    CreateJournal-Response,
        deleteJournal                       [70]    IMPLICIT    DeleteJournal-Response,
        getCapabilityList                   [71]    IMPLICIT    GetCapabilityList-Response,
        fileOpen                            [72]    IMPLICIT    FileOpen-Response,
        fileRead                            [73]    IMPLICIT    FileRead-Response,
        fileClose                           [74]    IMPLICIT    FileClose-Response,
        fileRename                          [75]    IMPLICIT    FileRename-Response,
        fileDelete                          [76]    IMPLICIT    FileDelete-Response,
        fileDirectory                       [77]    IMPLICIT    FileDirectory-Response,
        additionalService                   [78]    AdditionalService-Response,
        getDataExchangeAttributes           [80]    GetDataExchangeAttributes-Response,
        exchangeData                        [81]    IMPLICIT    ExchangeData-Response,
        defineAccessControlList             [82]    IMPLICIT    DefineAccessControlList-Response,
        getAccessControlListAttributes      [83]    IMPLICIT    GetAccessControlListAttributes-Response,
        reportAccessControlledObjects       [84]    IMPLICIT    ReportAccessControlledObjects-Response,
        deleteAccessControlList             [85]    IMPLICIT    DeleteAccessControlList-Response,
        changeAccessControl                 [86]    IMPLICIT    ChangeAccessControl-Response,
        reconfigureProgramInvocation        [87]    IMPLICIT    ReconfigureProgramInvocation-Response
}

GetNameList-Request ::= SEQUENCE {
        objectClass                         [0]     ObjectClass,
        objectScope                         [1]     CHOICE {
                        vmdSpecific         [0]     IMPLICIT    NULL,       -- whole VMD
                        domainSpecific      [1]     IMPLICIT    Identifier, -- only domain (log.
node)
                        aaSpecific          [2]     IMPLICIT    NULL        -- application association
                                            },
        continueAfter                       [2]     IMPLICIT    Identifier  OPTIONAL
}
ObjectClass ::= CHOICE {
        basicObjectClass                    [0]     IMPLICIT    INTEGER {
```

```
                                        namedVariable               (0),
                                        scatteredAccess             (1),
                                        namedVariableList           (2),
                                        namedType                   (3),
                                        semaphore                   (4),
                                        eventCondition              (5),
                                        eventAction                 (6),
                                        eventEnrollment             (7),
                                        journal                     (8),
                                        domain                      (9),
                                        programInvocation           (10),
                                        operatorStation             (11),
                                        dataExchange                (12),
                                        accessControlList           (13),
                                }
        csObjectClass           [1]     IMPLICIT    INTEGER {
                                        eventConditionList          (0),
                                        unitControl                 (1)
                                }
}

GetNameList-Response ::= SEQUENCE {
        listOfIdentifier        [0]     IMPLICIT    SEQUENCE OF     Identifier,
        moreFollows             [1]     IMPLICIT    BOOLEAN         DEFAULT    TRUE
}

Identifier ::= UTF8String (SIZE(1..maxIdentifier))

maxIdentifier INTEGER ::= 32

Read-Request ::= SEQUENCE {
        specificationWithResult     [0]     IMPLICIT    BOOLEAN   DEFAULT   FALSE,
        variableAccessSpecification [1]     VariableAccessSpecification
}

Read-Response ::= SEQUENCE {
        variableAccessSpecification [0]     VariableAccessSpecification     OPTIONAL,
        listOfAccessResult          [1]     IMPLICIT    SEQUENCE OF AccessResult
}

VariableAccessSpecification ::= CHOICE {
        listOfVariable          [0]     IMPLICIT    SEQUENCE OF SEQUENCE {
                                variableSpecification   VariableSpecification,
                                alternateAccess         [5] IMPLICIT AlternateAccess OPTIONAL
                                }
        variableListName        [1]     ObjectName
}

VariableSpecification ::= CHOICE {
        name                    [0]     ObjectName,
        address                 [1]     Address,
        variableDescription     [2]     IMPLICIT    SEQUENCE {
                                        address             Address,
```

```
                                        typeSpecification       TypeSpecification
                                    },
            scatteredAccessDescription  [3]     IMPLICIT    ScatteredAccessDescription,
            invalidated                 [4]     IMPLICIT    NULL
}

GetVariableAccessAttributes-Request ::= CHOICE {
            name                        [0]     ObjectName,
            address                     [1]     Address
}

ObjectName ::= CHOICE {
            vmd-specific                [0]     IMPLICIT    Identifier,
            domain-specific             [1]     IMPLICIT    SEQUENCE {
                                        domainID    Identifier,
                                        itemID      Identifier
                                        },
            aa-specific                 [2]     IMPLICIT    Identifier
}

GetVariableAccessAttributes-Response ::= SEQUENCE {
            mmsDeletable                [0]     IMPLICIT    BOOLEAN,
            address                     [1]     Address     OPTIONAL,
            typeDescription             [2]     TypeDescription,
            accessControlList           [3]     CHOICE {
                                                    basic BasicIdentifier,
                                                    extended ExtendedIdentifier
                                                } OPTIONAL,
            meaning                     [4]     ObjectName OPTIONAL
}

Address ::= CHOICE {
            numericAddress              [0]     IMPLICIT    Unsigned32,
            symbolicAddress             [1]     MMSString,
            unconstrainedAddress        [2]     IMPLICIT    OCTET STRING
}

AccessResult ::= CHOICE {
            failure                     [0]     IMPLICIT    DataAccessError,
            success                     Data
}

TypeDescription ::= CHOICE {
            array                       [1]     IMPLICIT    SEQUENCE {
                                        packed              [0]     IMPLICIT BOOLEAN DEFAULT FALSE,
                                        numberOfElements    [1]     IMPLICIT Unsigned32,
                                        elementType         [2]     TypeSpecification
                                        },
            structure                   [2]     IMPLICIT    SEQUENCE {
                                        packed              [0]     IMPLICIT BOOLEAN DEFAULT FALSE,
                                        components          [1]     IMPLICIT SEQUENCE OF SEQUENCE {
                                                componentName       [0] IMPLICIT Identifier OPTIONAL,
                                                componentType       [1] TypeSpecification
```

```
                                                }
                                        },
        boolean                 [3]     IMPLICIT    NULL,       -- BOOLEAN
        bit-string              [4]     IMPLICIT    Integer32, -- BIT-STRING
        integer                 [5]     IMPLICIT    Unsigned8, -- INTEGER
        unsigned                [6]     IMPLICIT    Unsigned8, -- UNSIGNED
        floating-point          [7]     IMPLICIT    SEQUENCE {
                                                        format-width        Unsigned8,
                                                        exponent-width      Unsigned8
                                                    },
        octet-string            [9]     IMPLICIT    Integer32
        visible-string          [10]    IMPLICIT    Integer32,
        generalized-time        [11]    IMPLICIT    NULL,
        binary-time             [12]    IMPLICIT    BOOLEAN,
        bcd                     [13]    IMPLICIT    Unsigned8,
        objId                   [15]    IMPLICIT    NULL,
        mMSString               [16]    Integer32
}

TypeSpecification ::= CHOICE {
        typeName                [0]     ObjectName,
        typeDescription                 TypeDescription
}

Data ::= CHOICE {
        array                   [1]     IMPLICIT    SEQUENCE OF Data,
        structure               [2]     IMPLICIT    SEQUENCE OF Data,
        boolean                 [3]     IMPLICIT    BOOLEAN,
        bit-string              [4]     IMPLICIT    BIT STRING,
        integer                 [5]     IMPLICIT    INTEGER,
        unsigned                [6]     IMPLICIT    INTEGER, -- shall not be negative
        floating-point          [7]     IMPLICIT    FloatingPoint,
        octet-string            [9]     IMPLICIT    OCTET STRING,
        visible-string          [10]    IMPLICIT    VisibleString,
        generalized-time        [11]    IMPLICIT    GeneralizedTime,
        binary-time             [12]    IMPLICIT    TimeOfDay,
        bcd                     [13]    IMPLICIT    INTEGER, -- shall not be negative
        booleanArray            [14]    IMPLICIT    BIT STRING,
        objId                   [15]    IMPLICIT    OBJECT IDENTIFIER,
        mMSString               [16]    IMPLICIT    MMSString
}

TimeOfDay ::= OCTET STRING (SIZE(4|6))   -- a relative day since January 1, 1984.

DataAccessError ::= INTEGER {
        object-invalidated              (0),
        hardware-fault                  (1),
        temporarily-unavailable         (2),
        object-access-denied            (3),
        object-undefined                (4),
        invalid-address                 (5),
        type-unsupported                (6),
        type-inconsistent               (7),
```

```
        object-attribute-inconsistent   (8),
        object-access-unsupported       (9),
        object-non-existent             (10),
        object-value-invalid            (11)
}
ServiceSupportOptions ::= BIT STRING {
        status                          (0),
        getNameList                     (1),
        identify                        (2),
        rename                          (3),
        read                            (4),
        write                           (5),
        getVariableAccessAttributes     (6),
        defineNamedVariable             (7),
        defineScatteredAccess           (8),
        getScatteredAccessAttributes    (9),
        deleteVariableAccess            (10),
        defineNamedVariableList         (11),
        getNamedVariableListAttributes  (12),
        deleteNamedVariableList         (13),
        defineNamedType                 (14),
        getNamedTypeAttributes          (15),
        deleteNamedType                 (16),
        input                           (17),
        output                          (18),
        takeControl                     (19),
        relinquishControl               (20),
        defineSemaphore                 (21),
        deleteSemaphore                 (22),
        reportSemaphoreStatus           (23),
        reportPoolSemaphoreStatus       (24),
        reportSemaphoreEntryStatus      (25),
        initiateDownloadSequence        (26),
        downloadSegment                 (27),
        terminateDownloadSequence       (28),
        initiateUploadSequence          (29),
        uploadSegment                   (30),
        terminateUploadSequence         (31),
        requestDomainDownload           (32),
        requestDomainUpload             (33),
        loadDomainContent               (34),
        storeDomainContent              (35),
        deleteDomain                    (36),
        getDomainAttributes             (37),
        createProgramInvocation         (38),
        deleteProgramInvocation         (39),
        start                           (40),
        stop                            (41),
        resume                          (42),
        reset                           (43),
        kill                            (44),
        getProgramInvocationAttributes  (45),
        obtainFile                      (46),
```

```
        defineEventCondition            (47),
        deleteEventCondition            (48),
        getEventConditionAttributes     (49),
        reportEventConditionStatus      (50),
        alterEventConditionMonitoring   (51),
        triggerEvent                    (52),
        defineEventAction               (53),
        deleteEventAction               (54),
        getEventActionAttributes        (55),
        reportEventActionStatus         (56),
        defineEventEnrollment           (57),
        deleteEventEnrollment           (58),
        alterEventEnrollment            (59),
        reportEventEnrollmentStatus     (60),
        getEventEnrollmentAttributes    (61),
        acknowledgeEventNotification    (62),
        getAlarmSummary                 (63),
        getAlarmEnrollmentSummary       (64),
        readJournal                     (65),
        writeJournal                    (66),
        initializeJournal               (67),
        reportJournalStatus             (68),
        createJournal                   (69),
        deleteJournal                   (70),
        getCapabilityList               (71),
        fileOpen                        (72),
        fileRead                        (73),
        fileClose                       (74),
        fileRename                      (75),
        fileDelete                      (76),
        fileDirectory                   (77),
        unsolicitedStatus               (78),
        informationReport               (79),
        eventNotification               (80),
        attachToEventCondition          (81),
        attachToSemaphore               (82),
        conclude                        (83),
        cancel                          (84),
        getDataExchangeAttributes       (85),   -- shall not appear in minor version one
        exchangeData                    (86),   -- shall not appear in minor version one
        defineAccessControlList         (87),   -- shall not appear in minor version one
        getAccessControlListAttributes  (88),   -- shall not appear in minor version one
        reportAccessControlledObjects   (89),   -- shall not appear in minor version one
        deleteAccessControlList         (90),   -- shall not appear in minor version one
        alterAccessControl              (91),   -- shall not appear in minor version one
        reconfigureProgramInvocation    (92)    -- shall not appear in minor version one
}

ParameterSupportOptions ::= BIT STRING {
        str1                            (0),    -- array support
        str2                            (1),    -- structure support
        vnam                            (2),    -- named variable support
        valt                            (3),    -- alternate access support
```

```
        vadr                    (4),    -- unnamed variable support
        vsca                    (5),    -- scattered access support
        tpy                     (6),    -- third party operations support
        vlis                    (7),    -- named variable list support
        cei                     (10),   -- condition event support
        aco                     (11),
        sem                     (12),
        csr                     (13),
        csnc                    (14),
        csplc                   (15),
        cspi                    (16)
}

AdditionalSupportOptions ::= BIT STRING {
        vMDStop                         (0),
        vMDReset                        (1),
        select                          (2),
        alterProgramInvocationAttributes (3),
        initiateUnitControlLoad         (4),
        unitControlLoadSegment          (5),
        unitControlUpload               (6),
        startUnitControl                (7),
        stopUnitControl                 (8),
        createUnitControl               (9),
        addToUnitControl                (10),
        removeFromUnitControl           (11),
        getUnitControlAttributes        (12),
        loadUnitControlFromFile         (13),
        storeUnitControlToFile          (14),
        deleteUnitControl               (15),
        defineEventConditionList        (16),
        deleteEventConditionList        (17),
        addEventConditionListReference  (18),
        removeEventConditionListReference (19),
         getEventConditionListAttributes (20),
        reportEventConditionListStatus  (21),
        alterEventConditionListMonitoring (22)
}
```