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INTERNATIONAL STANDARD

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Information technology – Underwater acoustic sensor network (UWASN) – Part 2: Reference architecture

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INFORMATION TECHNOLOGY – UNDERWATER ACOUSTIC SENSOR NETWORK (UWASN) –

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FOREWORD

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International Standard ISO/IEC 30140-2 was prepared by subcommittee 41: Internet of Things and related technologies, of ISO/IEC joint technical committee 1: Information technology.

The list of all currently available parts of the ISO/IEC 30140 series, under the general title *Information technology – Underwater acoustic sensor network (UWASN)*, can be found on the IEC and ISO websites.

This International Standard has been approved by vote of the member bodies, and the voting results may be obtained from the address given on the second title page.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Water covers approximately 71 % of the Earth's surface. Modern technologies introduce new methods to monitor the bodies of water, for example, pollution monitoring and detection. Underwater data-gathering techniques require exploring the water environment, which can be most effectively performed by underwater acoustic sensor networks (UWASNs). Applications developed for the UWASNs can record underwater climate, detect and control water pollution, monitor marine biology, discover natural resources, detect pipeline leakages, monitor and locate underwater intruders, perform strategic surveillance, and so on.

The ISO/IEC 30140 series provides general requirements, reference architecture (RA) including the entity models and high-level interface guidelines supporting interoperability among UWASNs in order to provide the essential UWASN construction information to help and guide architects, developers and implementers of UWASNs.

Additionally, the ISO/IEC 30140 series provides high-level functional models related to underwater sensor nodes and relationships among the nodes to construct the architectural perspective of UWASNs. However, the ISO/IEC 30140 series is an application agnostic standard. Thus, ISO/IEC 30140 series specifies neither any type of communication waveforms for use in UWASNs nor any underwater acoustic communication frequencies. Specifying communication waveforms and/or frequencies are the responsibility of architects, developers and implementers.[1]

Acoustical data communication in sensor networks necessitates the introduction of acoustical signals that overlap biologically important frequency bands into the subject environment. These signals may conflict with regional, national or international noise exposure regulations. Implementers of acoustical communication networks should consult the relevant regulatory agencies prior to designing and deployment of these systems to ensure compliance with regulations and avoid conflicts with the agencies.

The purpose of the ISO/IEC 30140 series is to provide general requirements, guidance and facilitation in order for the users of the ISO/IEC 30140 series to design and develop the target UWASNs for their applications and services.

The ISO/IEC 30140 series comprises four parts as shown below.

- Part 1 provides a general overview and requirements of the UWASN reference architecture.
- Part 2 provides reference architecture models for UWASN.
- Part 3 provides descriptions for the entities and interfaces of the UWASN reference architecture.
- Part 4 provides information on interoperability requirements among the entities within a UWASN and among various UWASNs.

1 Architects, developers and implementers need to be aware of the submarine emergency frequency band, near and below 12 kHz, and it is recommended to provide a provision for such submarine emergency band in their UWASN design and applications.

INFORMATION TECHNOLOGY – UNDERWATER ACOUSTIC SENSOR NETWORK (UWASN) –

Part 2: Reference architecture

1 Scope

This part of ISO/IEC 30140 provides a UWASN conceptual model by identifying and defining three domains (application domain, network domain and UWASN domain).

It also provides UWASN reference architecture multiple views consistent with the requirements defined in ISO/IEC 30140-1:

a) UWASN systems reference architecture;

b) UWASN communication reference architecture;

c) UWASN information reference architecture.

For each view, related physical and functional entities are described.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 29182-2, *Information technology – Sensor networks: Sensor Network Reference Architecture (SNRA) – Part 2: Vocabulary and terminology*

ISO/IEC 30140-1, *Information technology – Underwater acoustic sensor network (UWASN) – Part 1: Overview and requirements*[2]

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 29182-2 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

[2] Under preparation. Stage at time of publication: ISO/IEC FDIS 30140-1:2017.

4 Abbreviated terms

2D	two-dimensional
3D	three-dimensional
3G	third generation
4G	fourth generation
A/D	analog-to-digital converter
AODV	ad hoc on demand distance vector
APS IB	application layer information base
APSDE	application layer data entity
APSME	application layer management entity
ASK	amplitude shift keying
AUV	autonomous underwater vehicle
BLDE	bundle layer data entity
BLME	bundle layer management entity
BUN IB	bundle layer information base
CDMA	code division multiple access
CLA	convergence layer adapter
CM	communication module
CPU	central processing unit
CRA	communication reference architecture
CSMA	carrier sense multiple access
D/A	digital-to-analog converter
DB	database
DG	distance group
DSDV	destination-sequenced distance vector routing
DSR	dynamic source routing
DTN	delay and disruption tolerant network
HAL	hardware abstraction layer
FSK	frequency shift keying
GFG	greedy-face-greedy
GPRS	general packet radio service
HAL	hardware layer
IB	information base
I^2C	inter-integrated circuit
IP	Internet protocol
IRA	information reference architecture
kbps	kilobits per second
LAN	local area network
MAC IB	datalink layer information base
MAC	media access control
MCU	microcontroller unit
MFSK	multiple frequency shift keying

MIMO	multi-input multi-output
MLDE	MAC layer data entity
MLME	MAC layer management entity
MM	micro controller module
MSDU	mac service data unit
NLDE	network layer data entity
NLME	network layer management entity
NWK IB	network layer information base
OFDM	orthogonal frequency division multiplexing
OLSR	optimized link state routing
OS	operating system
PC	personal computer
PDU	protocol data unit
PHY IB	physical layer information base
PIT	passive integrated transponder
PLDE	physical layer data entity
PLME	physical layer management entity
PSK	phase shift keying
PTKF	partial topology knowledge forwarding
PWM	pulse width modulation
QAM	quadrature amplitude modulation
QoS	quality of service
RA	reference architecture
REST	representational state transfer
RF	radio frequency
RFID	radio-frequency identification
ROV	remotely operated underwater vehicle
SAP	service access point
SCI	serial communication interface
SDV	switched digital video
SIM	sensor interface module
SIMO	single-input multi-output
SISO	single-input single-output
SM	service module
SPI	serial peripheral interface
SRA	system reference architecture
TDMA	time division multiple access
UART	universal asynchronous receiver/transmitter
UUV	unmanned underwater vehicle
UWA-APS	underwater application layer
UWA-BUN	underwater bundle layer
UWA-CH	underwater acoustic cluster head
UWA-EUN	underwater acoustic extend united network

UWA-FN	underwater acoustic fundamental network
UWA-GW	underwater acoustic gateway
UWA-DL	underwater datalink layer
UWA-NWK	underwater network layer
UWA-PHY	underwater physical layer
UWASN	underwater acoustic sensor network
UWA-SNode	underwater acoustic sensor node
UWA-UN	underwater acoustic united network
WAN	wide area network
Wi-Fi	wireless fidelity

5 Purpose of UWASN reference architecture (UWASN RA)

This document provides reference architecture views consistent with the requirements which are defined in ISO/IEC 30140-1.

A UWASN reference architecture (UWASN RA) is a generalized architecture sharing one or more common domains of several end systems, giving direction downward and requiring compliance upward. In other words, the developer can reuse entities and elements in the reference architecture that fit the developers' application or target architecture. In addition, the UWASN reference architecture provides standards and guidelines for building a specific architecture for underwater environment.

The combination of these architecture perspectives and views forms a comprehensive architectural description of a UWASN system. Reference architecture perspectives and views are to:

a) specify how UWASNs operate;
b) specify systems of equipment and flows of information which support UWASNs;
c) specify technical rules and guidelines which allow these systems to interoperate.

UWASN RA provides the rules and guidance for developing and presenting the architecture descriptions.

This document provides multiple views of the technical architecture of UWASN:

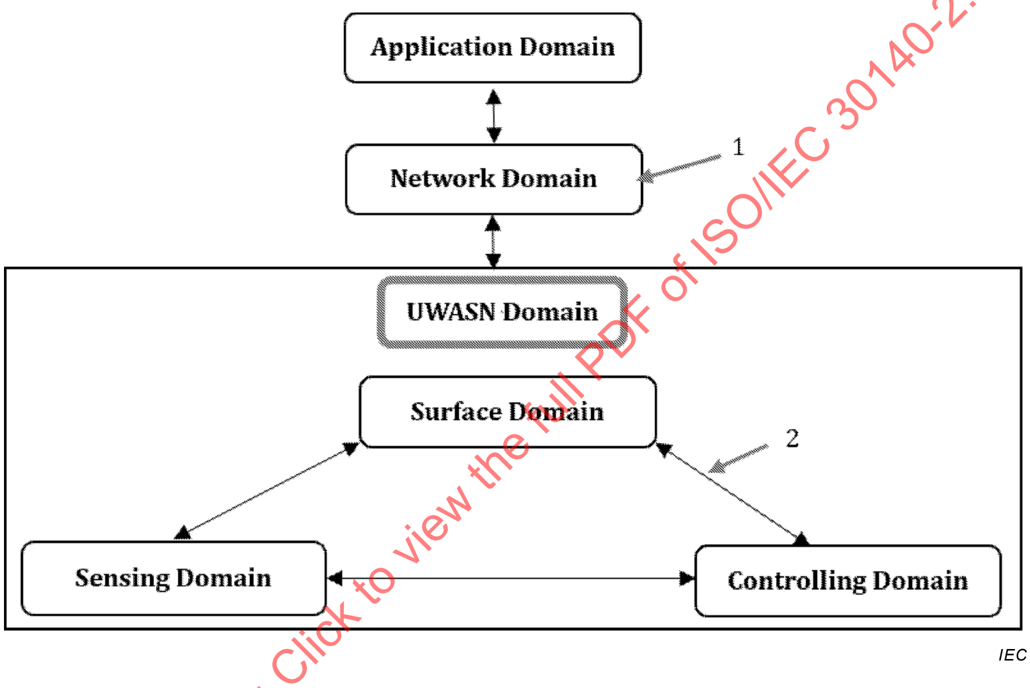
1) overview of UWASN reference architecture;
2) UWASN systems reference architecture;
3) UWASN communication reference architecture;
4) UWASN information reference architecture.

The UWASN supports development of interacting architectures. UWASN defines the multiple perspectives of UWASN reference architecture and multiple views of the technical architecture. All views are made up of sets of architecture data elements. The UWASN defines relationship between architectural views and the data elements.

6 UWASN conceptual model

The UWASN conceptual model shown in Figure 1 depicts the common domains that are identified in various UWASN systems and each of the presented domains. In this document, the UWASN reference architecture is described using the domains shown in Figure 1 and this conceptual model is extended to develop the three UWASN reference architectures which describe common entities and interfaces in each domain for various UWASN systems applications and services.

The UWASN RA describes the key technology that enables "a UWASN system". In most UWASN systems, there are three main technologies involved: system technology, communication technology and information technology. The UWASN reference architecture views are described and focused on these three technologies, resulting in the architecture views mentioned.



Key

1 domain

2 two-way communication link, interface for data/information and/or physical interface

Figure 1 – UWASN system conceptual model

The conceptual model describes the UWASN system in terms of the key domains which are common to the deployed UWASN systems. These domains are identified and defined.

a) Application domain

The application domain includes many types of application users connected to a UWASN system. These are scientific, military, business and aquatic applications. The application users make use of underwater sensor data for monitoring the environment, providing tsunami warnings, etc.

b) Network domain

The network domain can be realized using LAN, WAN and/or backbone networks. This domain provides data/information links between the application domain and UWASN domain. This domain uses RF communication, satellite or optical communication.

c) UWASN domain

This domain is related to the underwater environment, which includes surface domain, sensing domain, and controlling domain. These three domains are described below.

1) Surface domain

In the UWASN system, ships, surface buoys and UUVs may be used as underwater gateways. These gateways gather data from underwater sensor nodes using acoustic communication links and transfer to the backbone network using, e.g. satellite communication or CDMA.

2) Sensing domain

In the UWASN system, the sensing domain is used for sensing the underwater environment using various types of sensors, e.g. temperature, pressure and imaging sensors. The sensing domain can directly communicate with the surface domain in the case of ad-hoc networks.

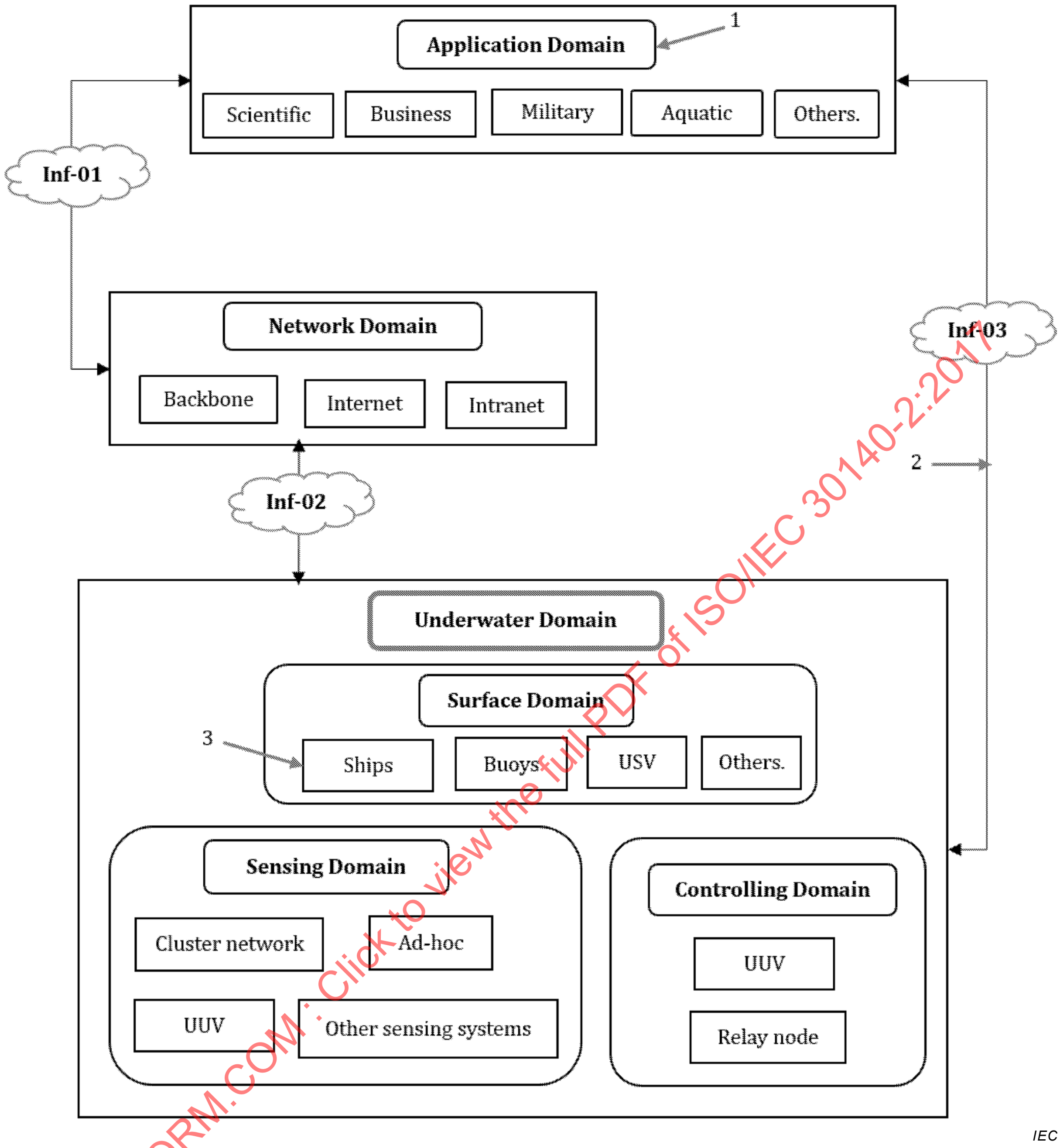
3) Controlling domain

In the UWASN system, the controlling domain is used for communication between the sensing domain and the surface domain. Intermediate nodes, such as AUVs and relay nodes, are used to gather data from the sensing domain and transform to surface domain with the help of acoustic communication.

7 Configuration of UWASN RA – Systems reference architecture (SRA)

7.1 General

The UWASN systems reference architecture is shown in Figure 2, along with all the entities involved and the interfaces among them. The entity and interface descriptions are presented in Table 1.



Key

1 domain

2 two-way communication link, interface for data/information and/or physical interface

3 entity

Figure 2 – UWASN systems reference architecture

Table 1 – UWASN systems reference architecture

UWASN domains	Domain entities
Network domain	Backbone Internet Intranet

<table>
<tr><td colspan="2">Application domain</td><td>Scientific
Business
Military
Aquatic
Civilian
Others (e.g. Sports)</td></tr>
<tr><td colspan="2">Underwater domain</td><td>Surface domain
– Ships
– Buoys
– USV (unmanned surface vehicle)
– Others [e.g. anti-submarine warfare (ASW) helicopters]
Sensing domain
– UUV
– Other sensing systems
Controlling domain
– Relay node
– UUV</td></tr>
<tr><td colspan="2">Interfaces (between entities)</td><td>Description</td></tr>
<tr><td>Application domain</td><td>Network domain</td><td>Inf-01: The interface between application domain and network domain.</td></tr>
<tr><td>Network domain</td><td>Underwater domain</td><td>Inf-02: The interface between network domain and underwater domain.</td></tr>
<tr><td>Underwater domain</td><td>Application domain</td><td>Inf-03: The interface between underwater domain and application domain.</td></tr>
</table>

7.2 System-level physical entities

7.2.1 Overview

The purpose of this subclause is to provide not only basic information but also high-level model descriptions for various UWASN entities identified in 7.1. Entities can be categorized into two types: physical and functional.

Physical entities are hardware entities, which are actual, tangible devices and/or components, such as underwater sensor nodes, underwater gateways, AUVs, relay nodes and access and backbone network devices.

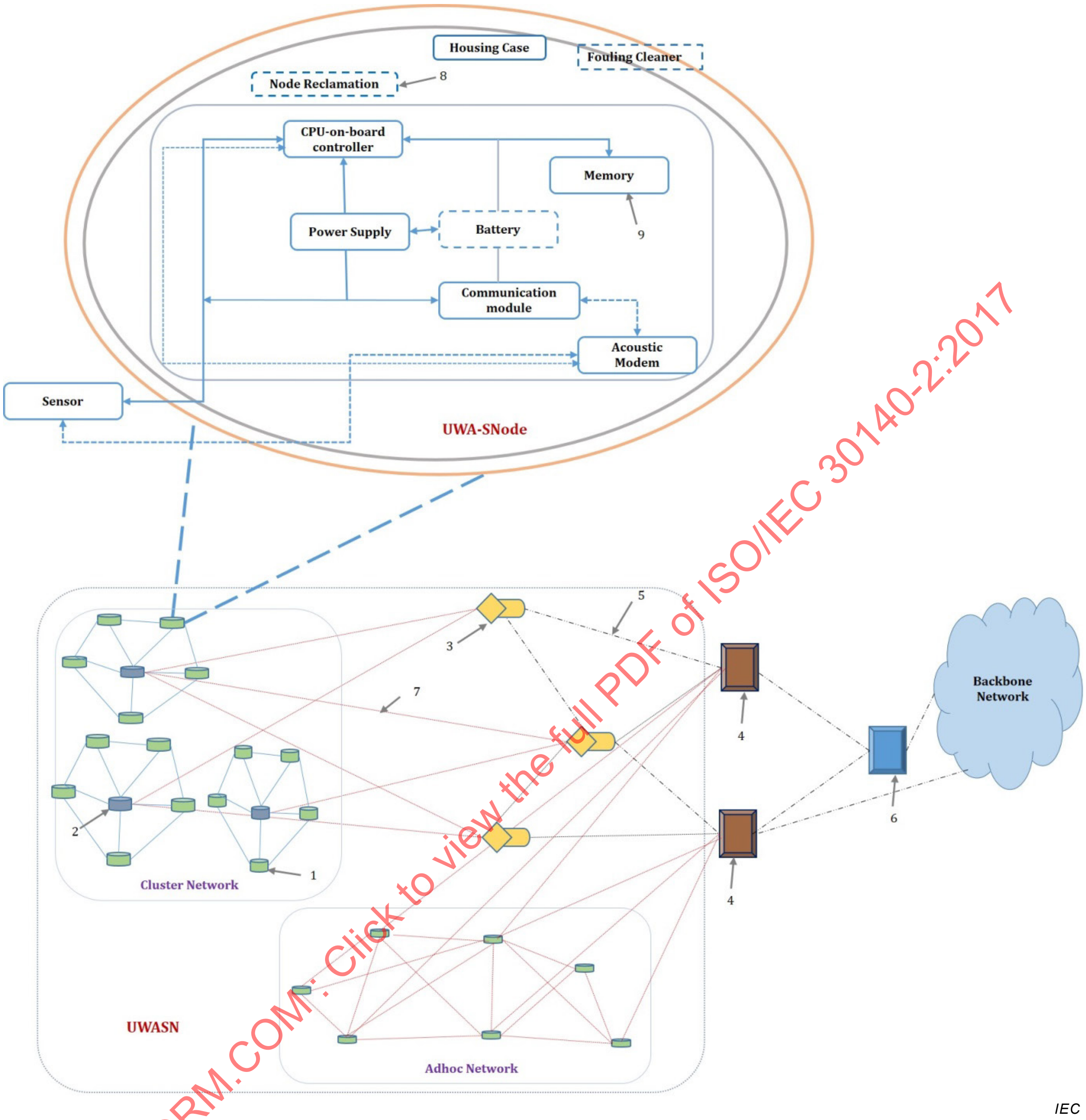
A functional entity represents a certain task that can be carried out on one or more physical entities, for example, the sensing of underwater data, transceiver management, access control management, network management and data forwarding. Figure 3 and Figure 4 show all the entities modelled in this document.

Each entity model presented in this document is a description of the function and/or role of that entity.

7.2.2 Physical entities

7.2.2.1 General

Figure 3 shows the physical entities that form an underwater acoustic sensor network and how the entities are interconnected.



Key

1	UWA-SNode	6	access network
2	UWA-CH	7	acoustic link
3	UUV	8	optional
4	UWA-GW	9	mandatory
5	communication path		

Figure 3 – Physical entities of a UWASN

Figure 4 describes the internal architecture of UWA-SNode and this architecture includes:

a) CPU-on-board controller: This contains a CPU or controller interfaced with a UWA-SNode via sensor interface circuitry. A microcontroller module obtains information from the UWA-SNode and then

   1) saves the information in the on-board memory;

   2) processes the information; and

   3) by controlling the acoustic modem, forwards the information to a new UWA-SNode. An operating system (OS) is optional here.

b) Memory: A storage device is a memory unit which can be embedded in a sensor node or located outside of the node. The memory unit stores various event data collected by the node, e.g. measurements and processed data (if an on-the-node processing is performed).

c) Sensor: A sensor or sensing element is a measuring device of external environment of a certain phenomenology. Typically, this device converts physical parameters into a measureable electrical signal. Depending on the type of a sensing device, the device can measure acoustics, seismic waves or vibration, magnetic fields, various light spectra (visual, infrared, etc.), electromagnetic fields (e.g. radio frequencies), temperature, pressure, motion, contaminants, etc. Depending on the complexity and technology implemented in the sensor, the sensor can measure one-dimensional, two-dimensional and three-dimensional signals along with time tagging.

d) Communication module: A communication unit is an essential component of a sensor node. This communication unit provides either a wired or wireless data link which is used to transmit the data collected by the sensor or sensing element and any processed data if available, in non-real time or in real time. In case of non-real time data transmission, some type of storage device is required.

e) Power supply: A sensor node requires a power supply. If a sensor node is physically connected via a wire, it typically does not require an on-board power supply, e.g. batteries. In the case of a wireless sensor node, a battery is required. Power management for a sensor node is essential and power management utility firmware may be hosted in the CPU, especially for the sensor nodes located remotely and operating wirelessly. The power supply is a critical element for powering a sensor node; therefore, it is also critical for powering an entire sensor network. This becomes even more critical for a wireless, geographically dispersed sensor network. A battery power supply is typical. The power supply greatly depends on the type of sensor and the sensor node functions. Power management on remote sensors is of great importance to the functionality of a UWA-SNode. The remoteness of a UWA-SNode dictates the power supply capacity and power usage management. The required frequency of inter-nodal communications also dictates how the power should be managed.

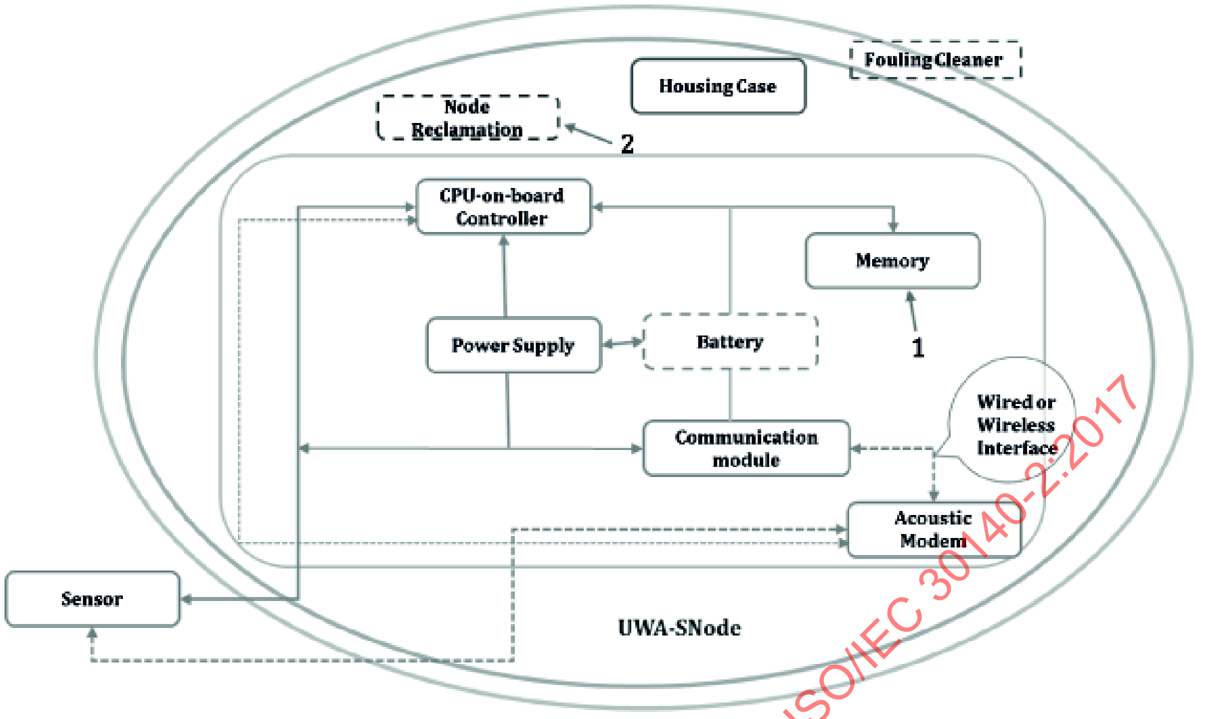
f) Acoustic modem: It is used to transmit and receive underwater data. It works like a telephone modem, which transmits the data with the help of a telephone line. It converts the digital data to acoustic signals and these signals are converted back to digital data at the receiver acoustic modem. These modems can be used for underwater monitoring and data logging, UUV command and control, underwater telemetry, diver communications and other applications wanting underwater wireless communications.

g) Node reclamation: Node replacement is also known as node reclamation. For more information, refer to ISO/IEC 30140-1:–[3].

h) Housing case: Housing integrity must be suitable for operation at the required working depth. Water proofing is one of the requirements for the UWA-SNode. For more information, refer to ISO/IEC 30140-1.

i) Fouling cleaner: It is optional for UWA-SNodes to have timely cleaning to resist fouling and corrosion because such issues may cause UWA-SNodes to fail.

[3] Under preparation. Stage at time of publication: ISO/IEC FDIS 30140-1:2017.



Key

1 mandatory

2 optional

Figure 4 – Physical architecture of underwater sensor node

7.2.2.2 Underwater acoustic sensor node (UWA-SNode)

Underwater acoustic sensor technology can be used in all the environments. Novel types of UWA-SNode can improve the range of environmental parameters for which information is collected.

In a cluster-based UWASN, the cluster head (UWA-CH) receives data from UWA-SNodes and transmits it to the UWA-CH of other clusters until data reach the UWA-GW. UWA-CH performs data aggregation on the sensor data it receives and then sends it to the UWA-GW. The cluster head will process the data of the cluster nodes. To perform effective communication and clustering of the nodes in the network, it is important to maintain the tracking of the nodes. The underwater cluster head improves network operation life and a network with an underwater cluster head provides more reliable and better communication connectivity. The underwater cluster head contains similar modules to the underwater sensor node, except that the cluster head has data gathering, filtering and compression managers.

In an ad-hoc network, each sensor node is a fully functional device that can sense and communicate with sensor nodes. A cluster-based network sensor node is either a reduced function device or a fully functional device. The reduced function devices only have communication functionality, whereas the fully functional devices are either UWA-SNodes or UWA-CHs and have sensing and communicating capabilities. In cluster-based networks, developers use the reduced function devices to reduce costs, energy consumption, etc.

The UWA-SNode architecture is presented in Figure 5.

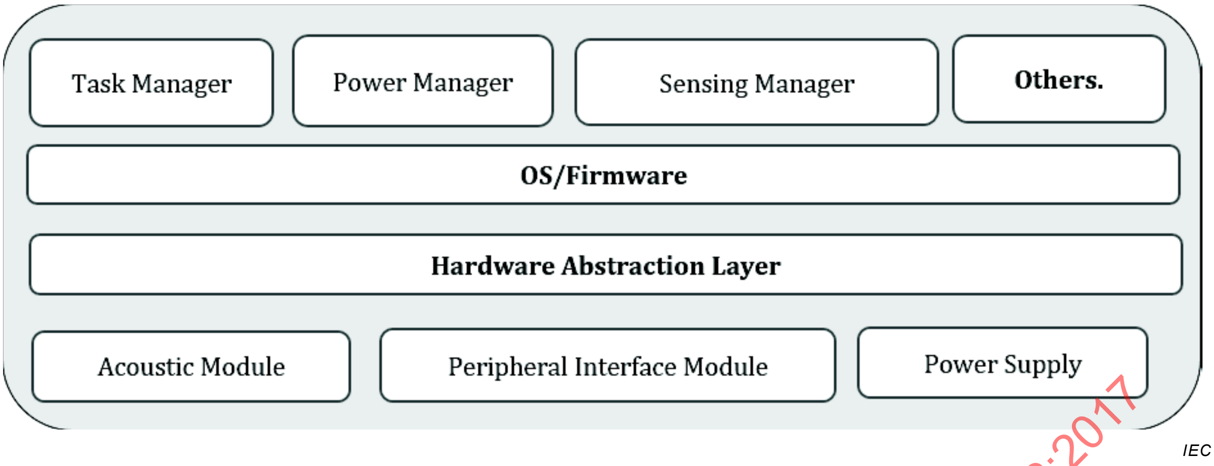


Figure 5 – Underwater sensor node (UWA-SNode) architecture

a) Task manager: The task manager provides information about the management system. It also performs network and communication management.

b) Power manager: The power manager manages the power supply to nodes and peripherals.

c) Sensing manager: The sensing manager processes the data received from various sensors.

d) Acoustic module: The acoustic module uses sound waves to transfer the data from a source device to a destination device.

e) Peripheral interface module: The peripheral interface module manages underwater data acquisition peripherals (e.g. actuators, underwater cameras, underwater sensors, etc.).

f) Power supply: The power supply module supplies power to underwater nodes.

g) Others: UWA-CH nodes receive the data from various underwater sensor nodes. UWA-CH filters and compresses the data and sends the filtered/compressed data to the final underwater gateway through the acoustic communication. Routing is performed by the UWA-CH and ad-hoc UWA-SNodes.

7.2.2.3 Underwater gateway (UWA-GW & UWA-DTN-GW)

7.2.2.3.1 General

The underwater gateway basically performs communication relay between the base station and the UWASN. The UWA-GW obtains underwater sensor information from relay nodes (or the UWA-CH and UWA-SNodes) and transmits it to the monitoring centre via wireless communication channels.

Underwater gateway communicates with two heterogeneous networks: RF based and acoustic based. The DTN (delay and disruption-tolerant networks) gateway is used for communication between heterogeneous communication networks.

7.2.2.3.2 UWA-GW architecture

Underwater gateway contains similar modules like those of the underwater sensor node. The RF module is added additionally to the UWA-GW. The architecture is shown in Figure 6. The RF module transfers the data to the surface or receives control commands from a ground station.

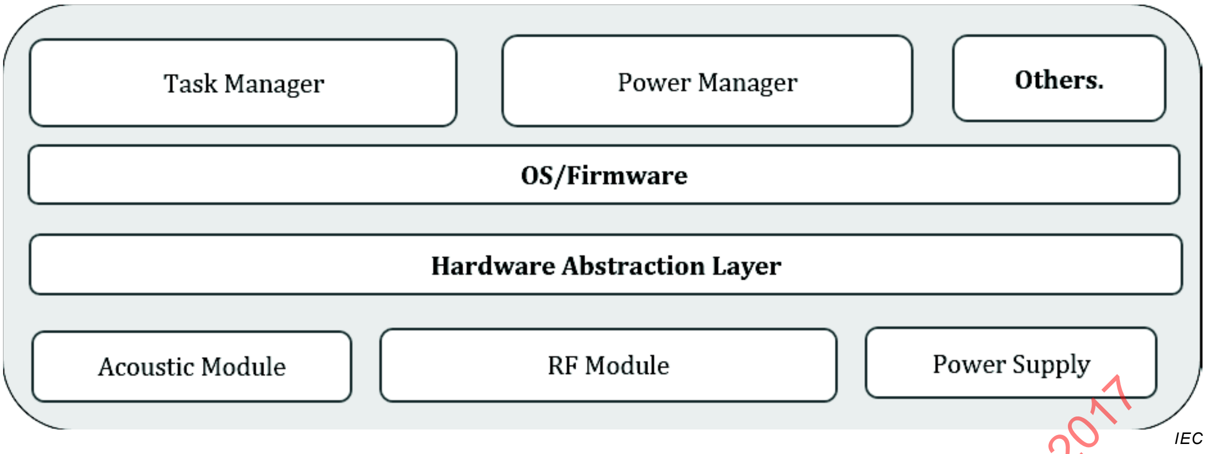


Figure 6 – Underwater gateway architecture

7.2.2.4 Housing case

In an underwater device, an expensive acoustic modem is needed for transmitting and receiving data. Hence, a strong waterproof housing case is needed against high water pressure and it can also prevent failures and corrosion.

7.2.2.5 Fouling cleaner

Fouling can be caused by marine wildlife, such as weeds, zebra mussels, algae, and barnacles becoming attached to a stationary underwater entity. In a UWASN, avoiding fouling is important because the attachment of marine wildlife to a membrane might limit or change the membrane's vibration characteristics [1][4].

7.2.2.6 Acoustic modem

Acoustic modems allow for wireless communication in water. Acoustic modems are used in real-time systems where information must be collected periodically.

As compared with radio communication, underwater acoustic communication is moderately slow. Not only is the communication speed slow but there are also complications with acoustic signal propagation because of boundary effects (multipath and delay-Doppler spreading). Acoustic modem producers use numerous methods to handle the above complications, i.e. signal data packaging, processing and coding schemes. These methods support the guarantee of reliable communication and at the receiver end, they detect bit loss and/or repair the lost bits of data. Not all producers use the same method.

7.2.2.7 Unmanned underwater vehicles (UUV)

7.2.2.7.1 General

AUV should be considered as one of the UUVs. Detailed explanation of AUV is given in 7.2.2.7.2.

7.2.2.7.2 Autonomous underwater vehicle (AUV)

These can be used to complete underwater operations such as detective work and the mapping of rocks, immersed wrecks and obstructions that may cause navigation risks. AUVs can autonomously conduct inspection operations and reach specified locations. Data collected by AUVs during critical missions can be downloaded and processed. Different kinds of sensors can be attached to AUVs and these can work without the use of cables, tethers or remote controls. AUVs can make multiple missions to monitor different environments, oceanography and water resources. AUVs are used to improve the capabilities of UWASNs in

[4] Numbers in square brackets refer to the Bibliography.

many ways. The integration of AUVs and UWA-SNodes can be networked with coordination algorithms.

a) Adaptive spatial sampling: This comprises control procedures that command AUVs to move to required locations. The adaptive sampling method has been used in innovative observation operations.

b) Self-configuration: This contains management methods for automatically identifying connectivity gaps due to node failure; it can then request AUV intervention. AUVs restore connectivity by deploying additional relay or sensor nodes.

7.2.2.7.3 UUV architecture

In Figure 7, the routing manager collects information from UWA-SNodes and send it to the gateway. It also provides the navigation path information for the UUV. The positioning manager performs the function of propulsion.

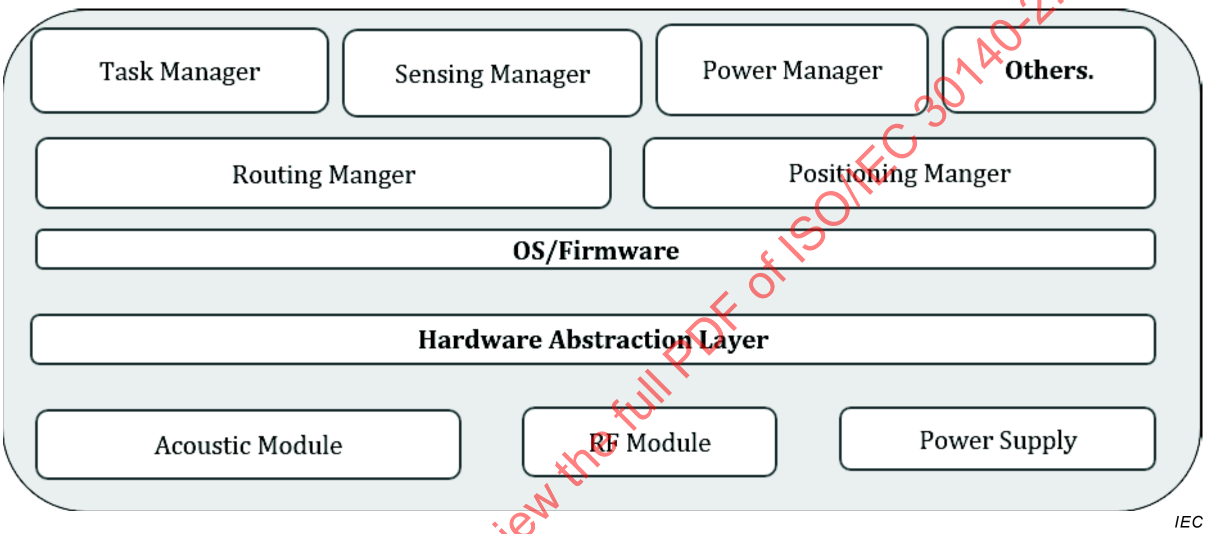


Figure 7 – Unmanned underwater vehicle architecture

7.2.2.8 Access network

An access network provides the connectivity between the backbone network and underwater gateway in the UWASN. Examples of access networks include Wi-Fi® networks, cellular networks (such as 3G/4G wireless), Ethernet, ZigBee® and CDMA and satellite communication.[5]

7.2.2.9 Backbone network

The most obvious backbone network is the Internet. Another example would be an Intranet, in which the data from the sensors are consumed “locally” and not accessed by other networks. In general, a backbone network provides connectivity among a large number of potentially geographically dispersed communicating entities. It is typically wired, although wireless backbone networks may also be used.

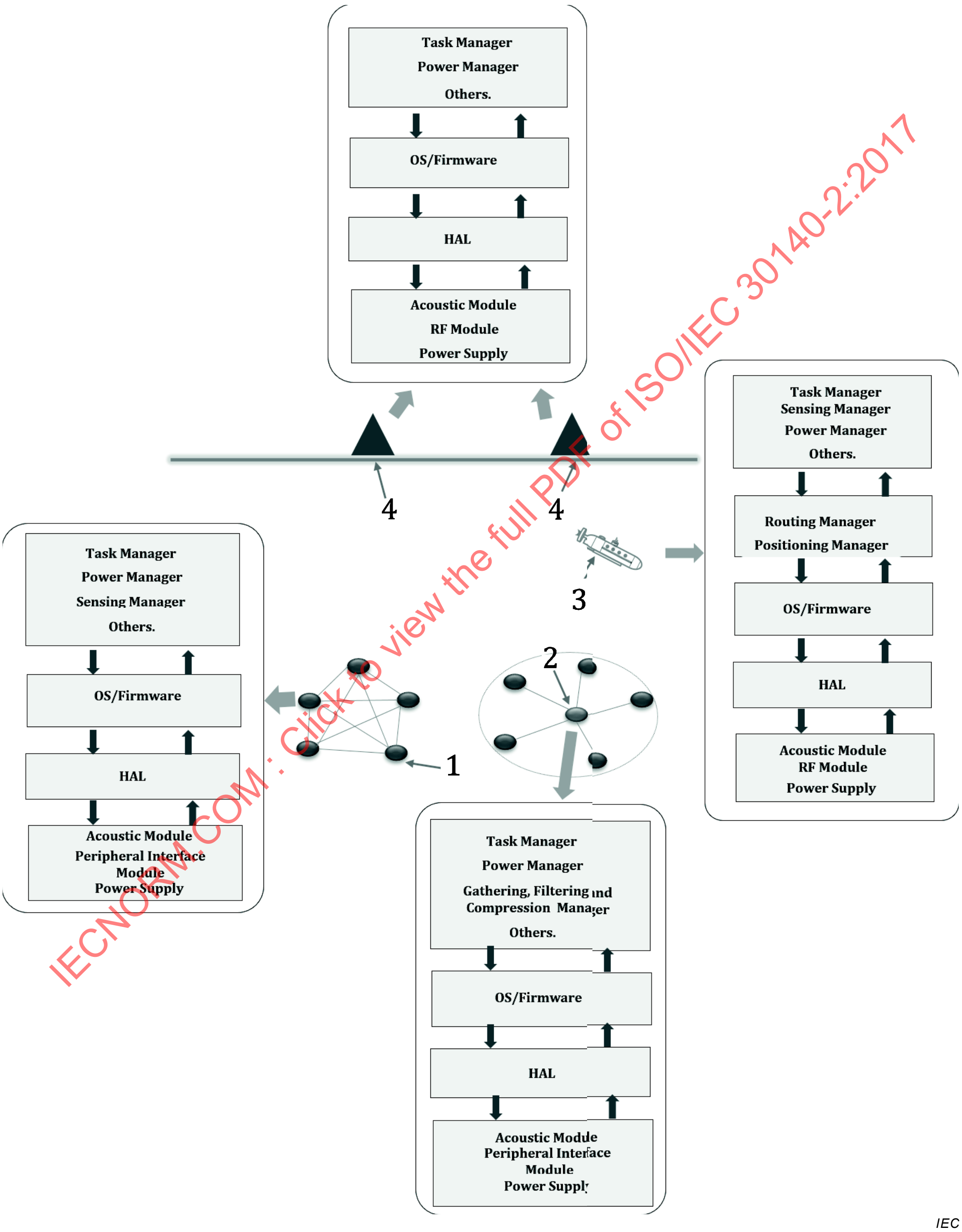
7.2.2.10 User

These are the entities that ultimately consume the high level information provided by UWASN. Sensor network applications, such as environmental monitoring and battlefield command and control, run on the user machines. The user may have the capability to visualize the information produced by UWASN applications.

5 ZigBee and Wi-Fi are registered trademarks of ZigBee Alliance and Wi-Fi Alliance, respectively. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC.

7.3 High-level SRA view

The UWASN device reference architecture is shown in Figure 8. The underwater device architecture mainly contains four underwater devices, an underwater acoustic sensor node (UWA-SNode), an underwater acoustic cluster head (UWA-CH), UUVs and an underwater gateway (UWA-GW & UWA-DTN-GW). Each device has its own functional architecture. Detailed information for each device is given in 7.2.2.



Key

1	UWA-SNode	3	UUV
2	UWA-CH	4	UWA-GW

Figure 8 – Underwater device architecture

7.4 SRA from system service view

The reference architecture is described using a set of entities that make up the UWASN. Each UWASN consists of a sensing domain, a controlling domain and a surface domain presented in Figure 1. Figure 9 presents the services provided by the UWASN. The arrows in this figure represent the interfaces that should allow seamless interoperations and interoperability between the services.

The interoperability of the UWASN includes five types of services: user service, network service, UWASN data processing services, data gathering/sending service and sensor service. Figure 10 illustrates the key entities involved in the services.

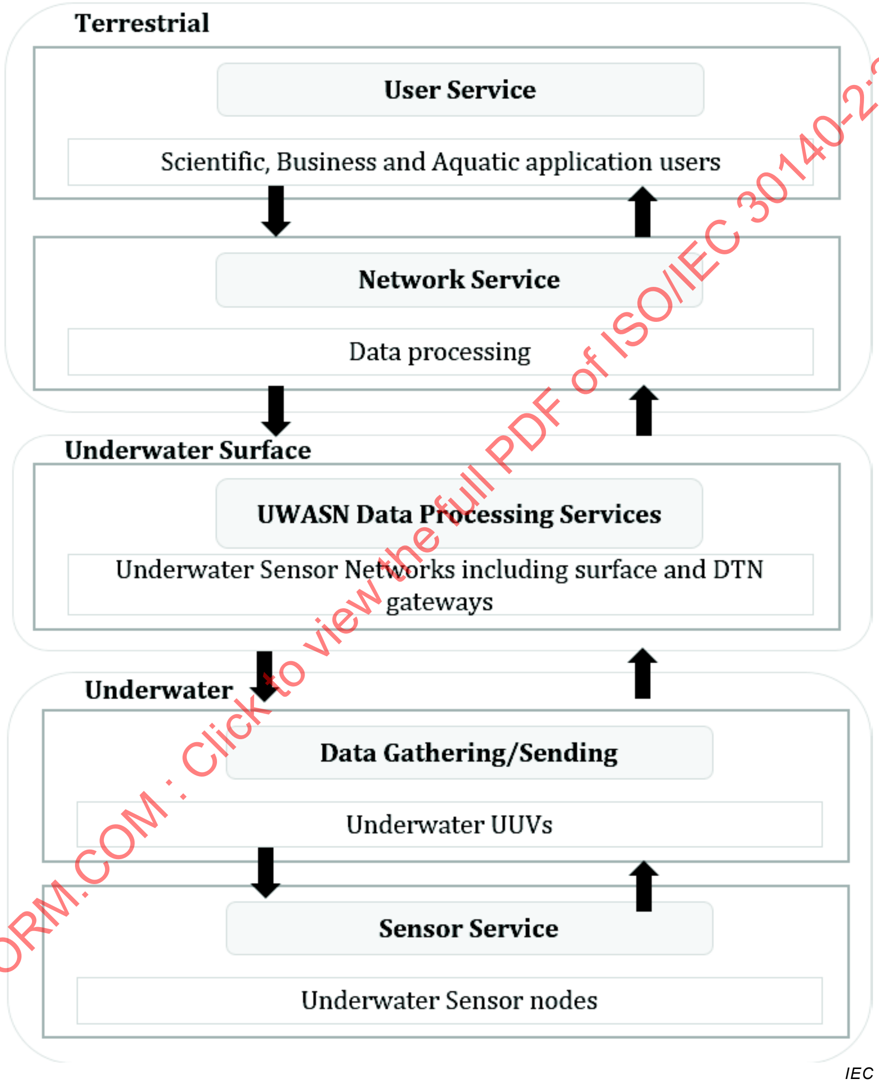
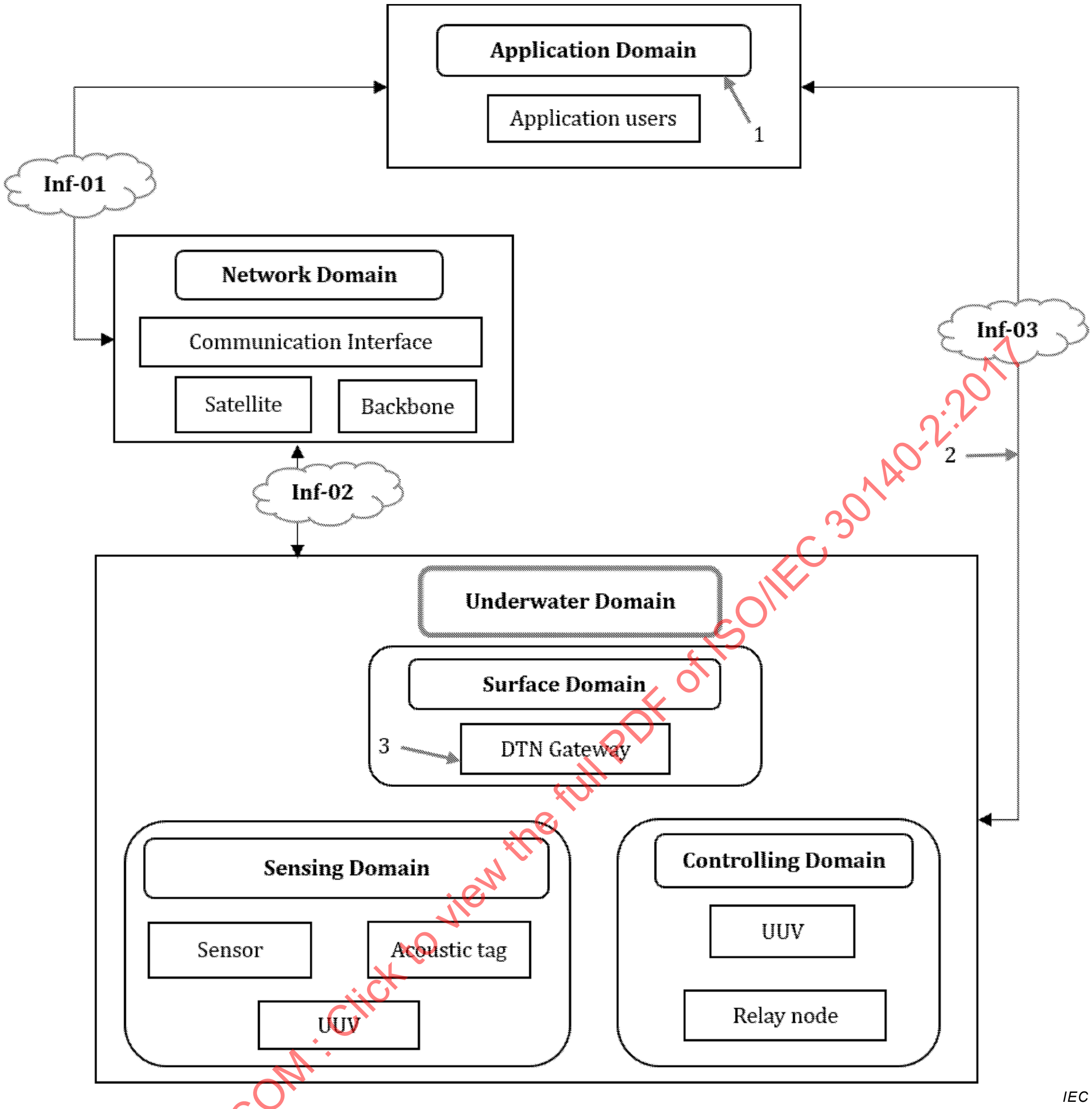


Figure 9 – Graphical representation of the interoperable UWASN RA from a service point of view

8 Configuration of UWASN RA – Communication reference architecture (CRA)

8.1 High-level CRA view

In Figure 10, UWASN CRA is shown along with all the entities involved and the interfaces among them. The entity descriptions are presented in Table 2.



Key

1 domain

2 two-way communication link, interface for data/information and/or physical interface

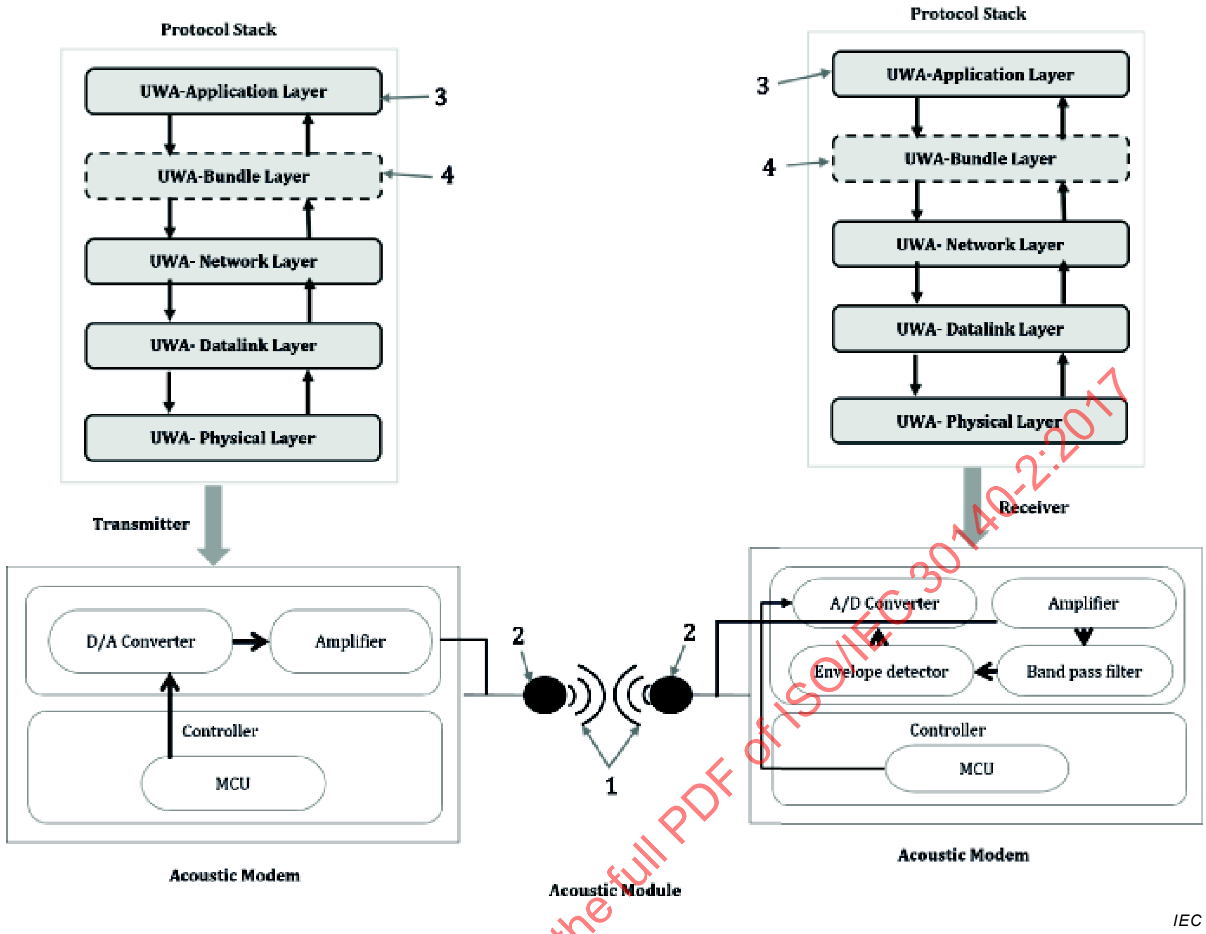
3 entity

Figure 10 – UWASN communication reference architecture

Table 2 – UWASN communication reference architecture (UWASN CRA)

<table>
<tr><th colspan="2">UWASN domains</th><th>Domain entities</th></tr>
<tr><td colspan="2">Network domain</td><td>Backbone
Satellite</td></tr>
<tr><td colspan="2">Application domain</td><td>Application users</td></tr>
<tr><td colspan="2">Underwater domain</td><td>Surface domain
– DTN gateway
Sensing domain
– Sensor
– Tags (acoustic, PIT)
– UUV
Controlling domain
– Relay node
– UUV</td></tr>
<tr><td colspan="2">Interfaces (between entities)</td><td>Description</td></tr>
<tr><td>Application domain</td><td>Network domain</td><td>Inf-01: The interface between application domain and network domain.</td></tr>
<tr><td>Network domain</td><td>Underwater domain</td><td>Inf-02: The interface between network domain and underwater domain.</td></tr>
<tr><td>Underwater domain</td><td>Application domain</td><td>Inf-03: The interface between underwater domain and application domain.</td></tr>
</table>

UWASN acoustic communication architecture is shown in Figure 11. Underwater devices communicate with each other by using acoustic waveforms. Each underwater device's communication unit has an acoustic module as shown in Figure 11. The transmitter and receiver use the same protocol stack for communication.



Key

1 acoustic link

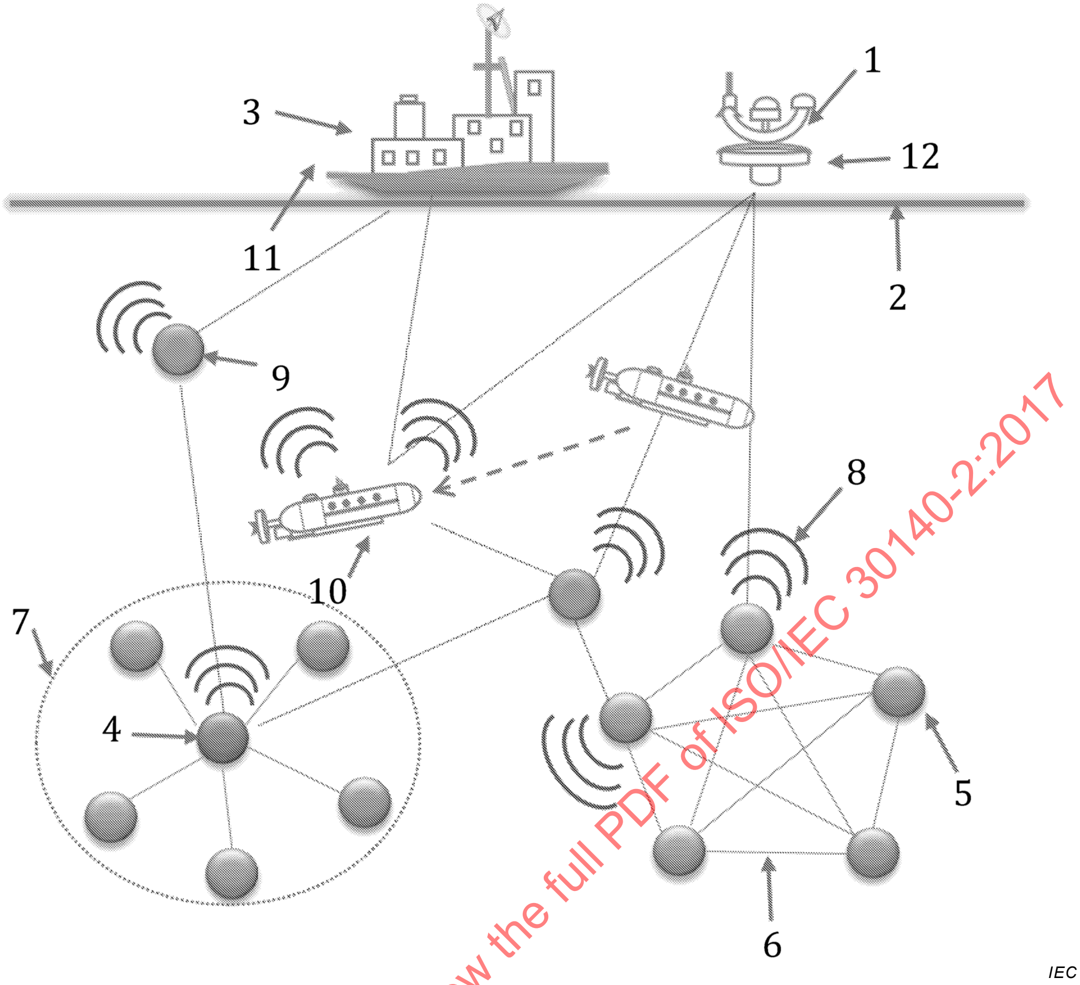
2 transducer

3 mandatory

4 optional

Figure 11 – Underwater acoustic communication architecture

UWASN architecture is shown in Figure 12. UWASN architecture is designed by combining underwater device architecture and underwater acoustic communication architecture.



Key

1	UWA-DTN-GW	7	cluster
2	surface	8	acoustic
3	UWA-GW	9	relay node
4	UWA-CH	10	UUV
5	UWA-SNode	11	moving gateway
6	ad-hoc network	12	fixed gateway

Figure 12 – Underwater acoustic sensor network architecture

8.2 CRA from network connectivity view

8.2.1 UWA-Physical layer

Features of the UWA-Physical (UWA-PHY) layer are the operating frequency band, the sound wave intensity, the modulation scheme and the channel coding. The UWA-PHY layer acts as the interface between the UWA-Datalink layer physical acoustic channel using acoustic hardware and firmware. The UWA-PHY layer should contain PLME. To invoke layer management functions, PLME offers layer management service interfaces. Further, it maintains a managed objects database relating to the UWA-PHY layer. This kind of database is termed a physical layer information base (PHY IB). The UWA-PHY layer offers two kinds of service, which is accessed by a service access point (SAP): the UWA-PHY layer management service, which is accessed through PLME-SAP; and the UWA-PHY layer data service which is accessed by the PLDE's SAP (PLDE-SAP)[2]. See Figure 13.

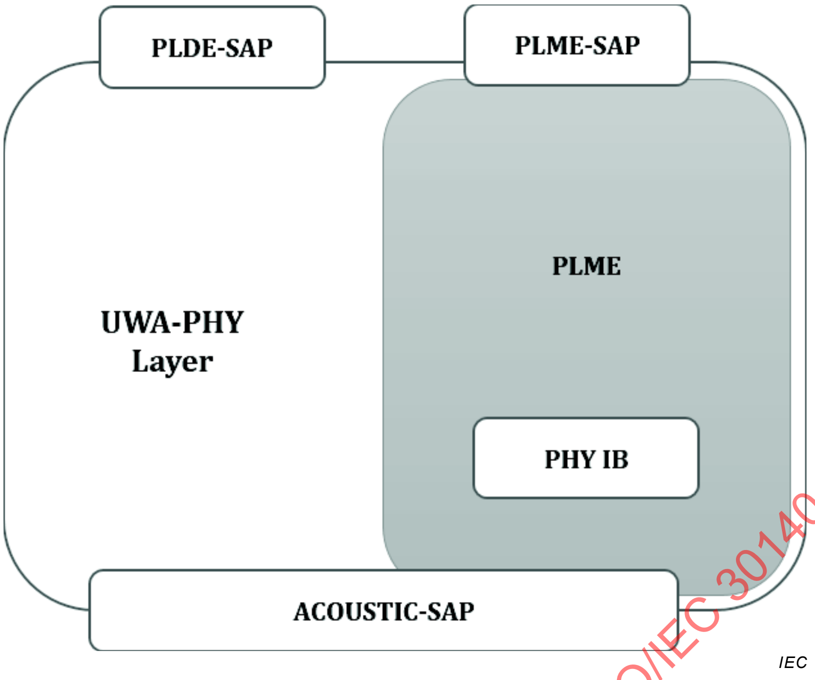


Figure 13 – UWA-PHY layer reference model

8.2.2 UWA-Datalink layer

The UWA-Datalink (UWA-DL) layer is accountable for underwater connection and acoustic channel management. The UWA-DL layer should contain MLME. To invoke layer management functions, MLME offers service interfaces. Moreover, it maintains a database for managing objects relating to the UWA-DL layer. This kind of database is termed as MAC IB. The UWA-DL layer offers two kinds of service, which are accessed by SAP: the MAC data service, which is accessed with the assistance of MLDE-SAP; and the management service retrieved through MLME-SAP. The UWA-DL layer has benefits such as time synchronization, channel management, beacon management, frame-based transmission of ACK, network combination and separation[3]. See Figure 14.

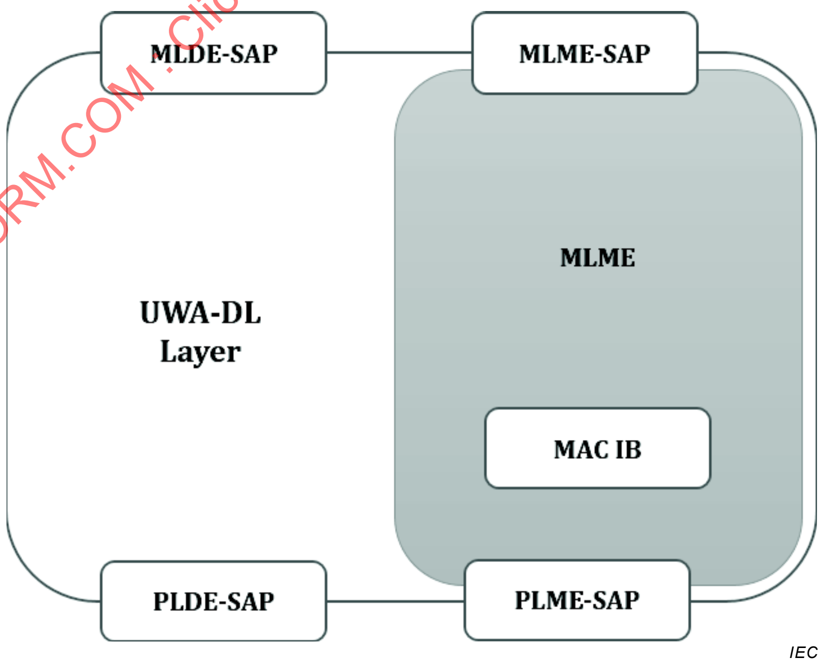


Figure 14 – UWA-DL layer reference model

8.2.3 UWA-Network layer

The UWA-Network (UWA-NWK) layer provides an appropriate service interface between the UWA-Data link layer and UWA-Bundle layer. The UWA-NWK layer theoretically should contain NLME and data entity known as NLDE. MLDE-SAP and the UWA-NWK layer provide a data transfer and addressing service through NLDE-SAP and management services by NLME-SAP and MLME-SAP. NLME performs administrative tasks using the NLDE. The NLME also maintains an information database (NWK IB) for the UWA-NWK layer. See Figure 15.

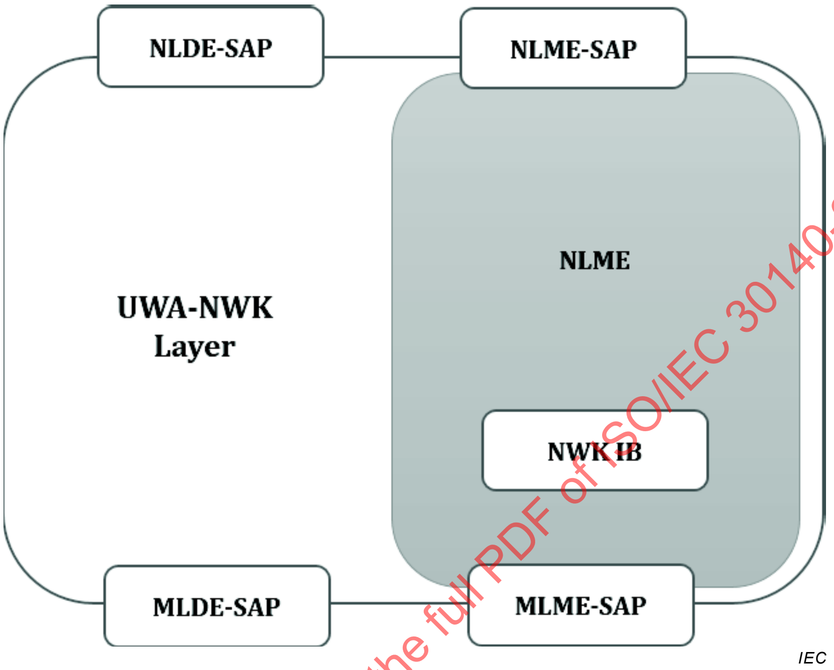


Figure 15 – UWA-NWK layer reference model

The UWA-NWK layer responsible for defining paths between UWA-SNode and UWA-GW. Long propagation delays should be addressed by this layer.

8.2.4 UWA-Bundle layer

The UWA-Bundle (UWA-BUN) layer transforms data units into one or more PDUs termed as “bundles” or “bundle layer” or “underwater bundle,” which are forwarded by UWA-SNodes. The idea is to bundle “underwater bundle layers” so that information essential for data transfer can be packed together, reducing the amount of round-trip connections especially while a round-trip period is more. Bundles contain an initiating timestamp, a useful pointer, service assignment and total length. The UWA-BUN layer helps routing and scheduling decisions.

The UWA-BUN layer provides an appropriate service interface between the UWA-NWK layer and UWA-APS layer. The UWA-BUN layer should contain bundle layer management entity (BLME) and data entity termed the bundle layer data entity (BLDE). The UWA-BLDE-SAP provides bundle transformation service through the BLDE. The BLME performs administrative tasks using the BLDE. The BLME also maintains the database (BUN IB) for the UWA-BUN layer. A bundle information base (BUN IB) is used for store and forward communication routing [3][4]. See Figure 16.

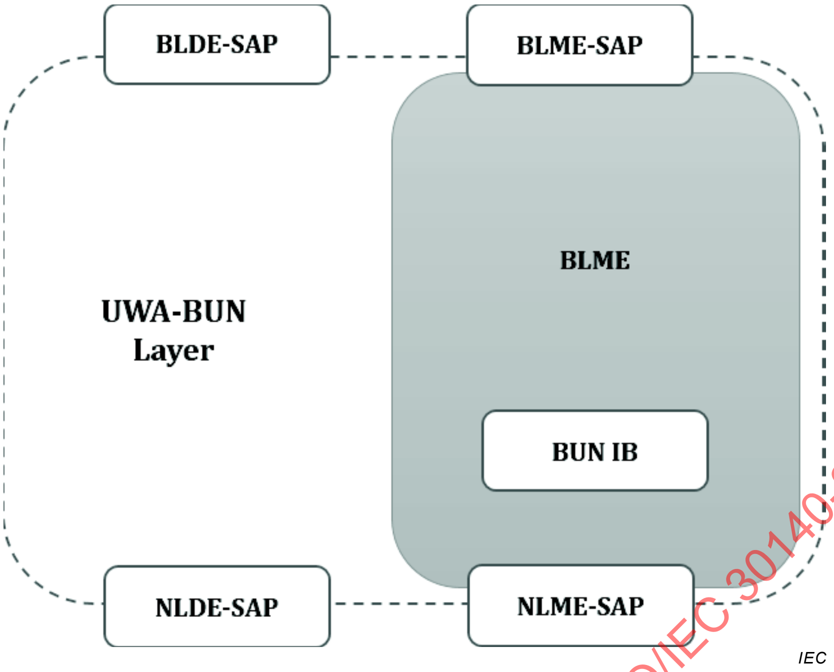


Figure 16 – UWA-Bundle layer reference model

8.2.5 UWA-Application layer

The application support sublayer provides an interface between the UWA-Bundle layer and the UWA-Application layer or UWA-Network layer and the UWA-Application layer via the overall service set. These services are management service (APSME) and data service (APSDE). The APSDE provides the data transmission service with the help of APSDE-SAP, which preserves the managed objects database termed APS IB [3][5]. See Figure 17.

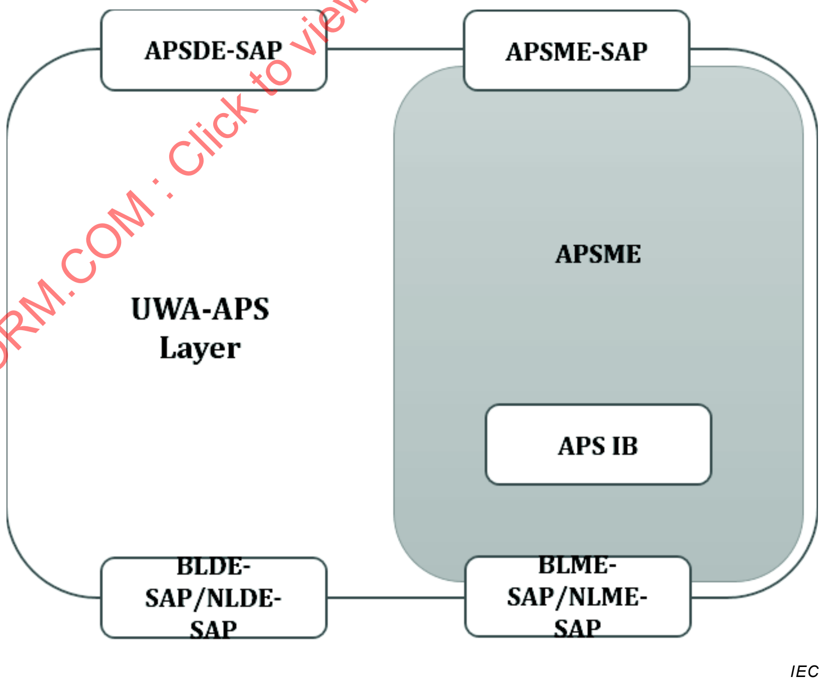


Figure 17 – UWA-APS layer reference model

The purposes of the application layer are to:

a) offer network management protocol which creates software and hardware information of lower layers apparent to management applications;
b) offer language for enquiring UWASN;
c) allow tasks and announce data and events.

8.2.6 Functional modules

From the point of view of the underwater device's architecture, there are four kinds of modules. Modules can communicate with one another with the help of peripheral interfaces using the sensor interface module.

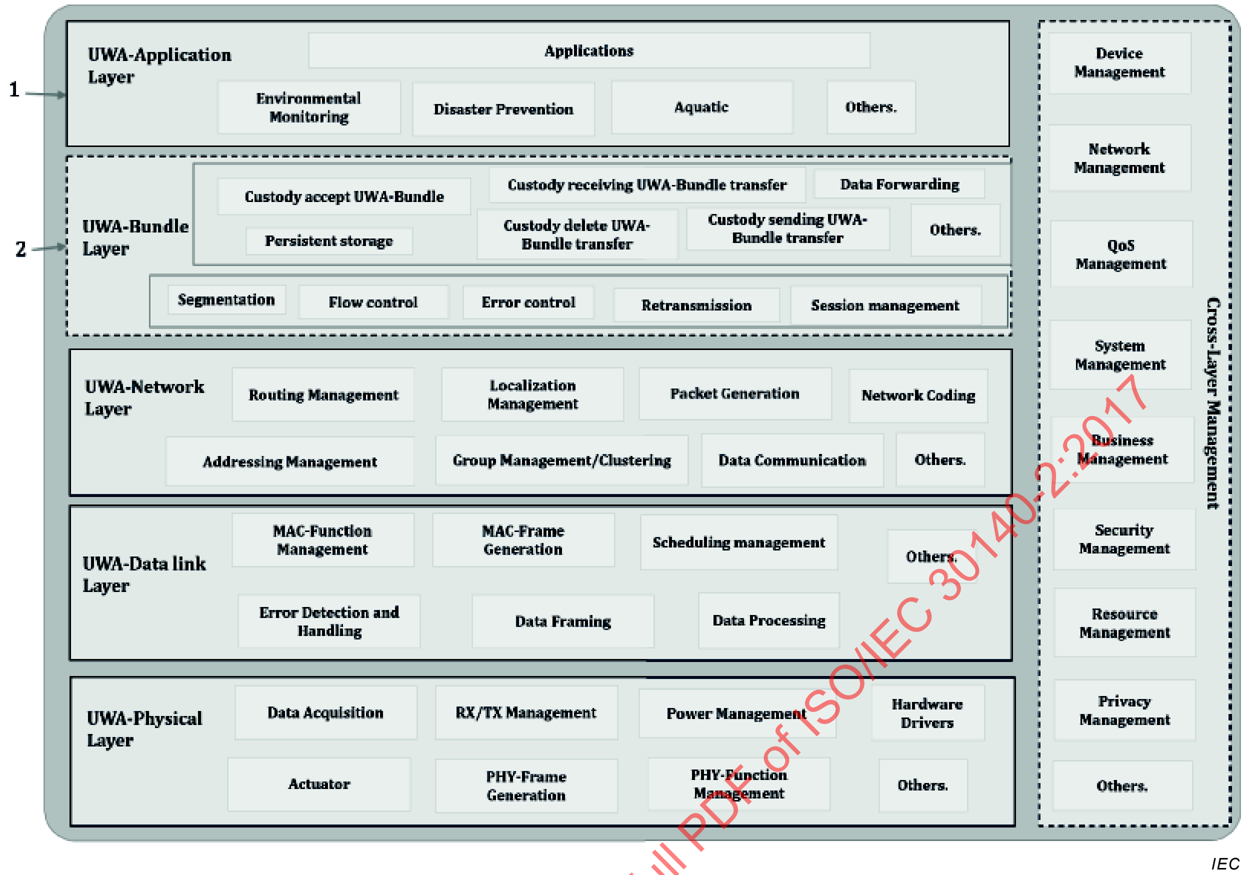
a) **Service module**: This supports different services provided to the underwater device. For example, the task manager is for managing the tasks, the power manager is for controlling power and the compression manager is for data handling.
b) **Microcontroller module**: This contains a CPU or controller interfaced with a UWA-SNode via sensor interface circuitry. The microcontroller module obtains information by UWA-SNode and saves information in the on-board memory, processes the information and by controlling the acoustic modem, forwards the information to a new UWA-SNode [5].
c) **Sensor interface module**: This supports the different peripheral interfaces for communication between the modules.
d) **Communication module**: This supports the different communication technologies such as acoustic, CDMA and RF. For example, an underwater sensor node can use acoustic communication and an underwater surface gateway can use RF communication and/or cellular communication.

8.2.7 Essential concept of functional entities

The UWASN communication system is divided into five layers, each with unique functionalities as follows.

a) The UWA-Application layer provides application processes to exchange data. This layer contains different application-related functionalities, for example, environmental monitoring, disaster prevention and aquatic applications.
b) The UWA-Bundle layer carries the bundles between the application and network layers. These bundles transmit using the store-and-forward approach. This performs data segmentation for energy saving.
c) The UWA-Network layer is an intermediate system that is commonly referred to as the "router". It is used to perform the layer routing, localization, packet generation and addressing the management of the communication between underwater devices.
d) The UWA-Data link layer provides channel access control mechanisms between several underwater devices. It is also responsible for finding and correcting errors that might occur at the UWA-PHY [6].
e) The UWA-Physical layer establishes, maintains and releases physical connections for the transfer of bits in an underwater transmission medium.

Figure 18 shows the functional entities and their related functionalities that form an underwater acoustic sensor network.



Key

1 mandatory

2 optional

Figure 18 – Functional entities of UWASN

Table 3 gives descriptions of the functional entities.

Table 3 – Functional model and descriptions in UWASN

Functional entities	Description
Actuators	An actuator contains a propulsion module which is responsible for moving or controlling an underwater sensor node.
Power management	Manages the energy management mechanisms for energy saving in underwater wireless acoustic sensor network.
Hardware drivers	Manage power-efficient transducer hardware drivers for underwater wireless acoustic communication.
PHY-frame generation	The PHY frame consists of encoding and modulation methods [3].
Error detection and handling	The UWA-MAC sublayer manages the technologies for handling and detecting errors.
MAC-function management	MAC function management is responsible for maintaining time synchronization between underwater devices, channel scanning and power management.
MAC-frame generation	The MAC processes MAC frame, MSDU and MMDU. A MAC frame encompasses the MAC header, MSDU, MAC footer and integrity check value.
Scheduling management	Manages the scheduling techniques for energy saving and controls communication between underwater sensor nodes by assigning time slots.
Data processing	Uses data/signal processing algorithms to extract requested or useful information from sensor data and metadata. The information extraction algorithms include collaborative information processing (e.g. data fusion, feature extraction, data aggregation and data presentation).

Functional entities	Description
Routing management	Manages the different routing algorithms for underwater communication.
Localization management	Manages the different localization technologies for identifying the location of underwater sensor nodes in underwater communication.
Packet generation	The UWA-Network layer generates the packets according to underwater properties such as limited bandwidth and data rate.
Group management/ clustering	Manages the cluster-based network for underwater communication. Clustering is used for parallel processing, load balancing between underwater sensor nodes and fault tolerance.
Network coding	UWASN uses the network coding concept for improving the throughput and providing the redundancy for error recovery.
Addressing management	Underwater sensor nodes have unique addresses. Addressing management manages the mechanisms for binding the unique address with a MAC address.
Custody accept UWA-bundle	Sent by a candidate custodian after accepting the custody transfer of the underwater bundle.
Segmentation	The UWA-Bundle layer divides the bundle into smaller segments to maximize the probability that each one can be delivered to the correct destination.
Data forwarding	After receiving the underwater bundle from the source node, this forwards this bundle to the destination node with the help of intermediate nodes.
Custody receiving UWA-bundle transfer	After receiving the bundle, this sends it to the destination node via custody transfer.
Persistent storage	After receiving the data, the UWA-Bundle layer stores the data until the connection is reestablished (if the communication link to the next hop is not available).
Custody delete bundle transfer	Deletes an underwater bundle when the time is expired.
Convergence layer adapter (CLA)	CLAs carry UWA-DTN protocol data units (called UWA-Bundles).
Flow control	For controlling data flow between neighbouring layers.
Error control	Checks the errors between the underwater terminal devices.
Retransmission	Provides retransmission mechanism for lost packets.
Session management	Session management allows to establish and manage sessions between the underwater devices.
Device management	Manages devices in the sensing domain, including power, system parameter, identification and embedded software/firmware programs in devices.
Network management	Manages the network topology, routing table, configuration information, performance and reconfigures network information.
Power management	Power management is responsible for minimizing the energy usage, for example, sleep modes and control power usage between the underwater devices.
Time sync management	Time sync management is responsible for synchronization between underwater devices, for example synchronization of sleep modes, 3D topology optimization and data aggregation.
Service management	Manages the services provided by underwater sensor nodes and underwater gateways including service registration, service discovery, service description, service analysis and service processing queue.
Security management	Manages the security of communication and data, including authentication, authorization, encryption and key management.
Applications	Different application users use underwater sensor data for various purposes.
Others	Others is for extended functionality of each layer.

Table 4 shows how they are related to each other.