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Information technology – Underwater Acoustic Sensor Network (UWASN) – Part 3: Entities and interfaces

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FOREWORD

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International Standard ISO/IEC 30140-3 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.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

Water covers approximately 71 % of the surface of the Earth. Modern technologies introduce new methods to monitor the body 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 architectural perspective of UWASNs. However, the ISO/IEC 30140 series is an application agnostic standard. Thus, the 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 can 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 3: Entities and interfaces

1 Scope

This part of ISO/IEC 30140 specifies the various entities in UWASNs. Moreover, it describes the interfaces between different physical and functional entities.

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*

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

4 Abbreviated terms

A/C	analog-to-digital converter
CLM	cross layer management
I^2C	inter integrated circuit
IP	Internet protocol
MLDE	MAC layer data entity
MLME	MAC layer management entity
NLDE	network layer data entity
NLME	network layer management entity
PLDE	physical layer data entity
PLME	physical layer management entity
PWM	pulse width modulation
QoS	quality of service
SAP	service access point
SCI	serial communication interface
SPI	serial peripheral interface

USV	underwater surface vehicle
UUV	unmanned underwater vehicle
UWA-APS	underwater application layer
UWA-BUN	underwater bundle layer
UWA-CH	underwater acoustic cluster head
UWA-DL	underwater datalink layer
UWA-DTN	underwater delay tolerant network
UWA-DTN-GW	underwater DTN gateway
UWA-FN	underwater acoustic fundamental network
UWA-GW	underwater acoustic gateway
UWA-NWK	underwater network layer
UWA-PHY	underwater physical layer
UWA-SNode	underwater acoustic sensor node
UWASN	underwater acoustic sensor network
UWA-UN	underwater acoustic united network

5 Overview

The purpose of this document is to provide basic information about and high-level models for the various entities and interfaces that comprise an UWASN. Entities can be roughly categorized into two classes, physical and functional. An underwater sensor node is a physical entity that contains many sensors. A functional entity represents a certain task that can be carried out on one or more types of physical entities. Routing and authentication are examples of functional entities. More often than not, functional entities are pieces of code that run on physical entities.

UWASN physical entities are categorized into three groups, namely underwater domain physical entities, network domain physical entities, and application domain physical entities. Examples of such physical entities include sensors and actuators, surface gateways, relay nodes, cluster head and user, access and backbone networks, etc. Similarly, more detailed models have been provided for functional entities such as environmental monitoring, disaster prevention, aquafarm monitoring, data forwarding, persistent storage, network coding, data processing, privacy management, self-localization, group management/clustering, collaborative information processing, and device management. A more detailed model can include an input-output relationship for what the entity does, some features of the entity that characterize its capabilities, and a taxonomy of various ways in which the entity can be implemented.

6 UWASN entities

6.1 UWASN physical entities

6.1.1 General

Physical entities comprise hardware, devices and/or components. UWASN physical entities can be divided into three categories:

- UWASN domain physical entities;
- network domain physical entities;
- application domain physical entities.

6.1.2 UWASN domain physical entities

Underwater domain physical entities exist in the seabed. These include underwater moving and fixed gateways (UWA-GWs), underwater acoustic sensor nodes (UWA-SNodes), underwater acoustic cluster heads (UWA-CHs), fouling cleaner, acoustic modem, node reclamation, UUV, etc.

Table 1 shows the UWASN domain physical entities and corresponding examples.

Table 1 – UWASN domain physical entities

Entities		Examples
Surface domain	UWA-GW UWA-DTN-GW	– Moving gateway (ships) – Fixed gateway (buoys), etc. – USV
Controlling domain	UWA-CH	– Ad-hoc UWA-SNode
	Relay node	– UUV, etc.
Sensing domain	UWA-SNode	– Sensors – Acoustic tag – UUV

UWA-GW: UWA-GWs facilitate communication between underwater sensor networks and the Internet. The surface gateway receives underwater related data from sensor nodes (relay node, UWA-CHs or UWA-SNodes) and transmits the data to the monitoring centre via wireless communication channels. In general, UWA-GWs are moving or fixed nodes. For example, a buoy is a fixed gateway, and ships and UUVs are the moving gateways. UWA-SNodes transmit packets to the nearest gateway rather than using a long path.

UWA-CH: UWA-CHs receive information from all cluster sensor nodes and transmit information to the relay node or directly to the surface gateway.

Relay node: Relay nodes transfer underwater data from UWA-SNodes to UWA-GWs.

UWA-SNode: UWA-SNodes, such as acoustic tags, UUVs, and sensors, collect data from water and transmit the data to the UWA-CH, relay nodes, or UWA-GW.

6.1.3 Network domain physical entities

The network domain entities comprise access networks and backbone networks. An access network provides connectivity between the backbone network and underwater domain physical entities.

Table 2 shows the network domain physical entities and corresponding examples.

Table 2 – Network domain physical entities

Entities	Examples
Access network	Wi-Fi®[a], 3G / 4G, Ethernet, and ZigBee®[a]
Backbone network	Internet, and Intranet

[a] 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.

Access network: Access networks provide connectivity between the Internet and the surface gateway.

Backbone network: The Internet is the most widely used backbone network.

6.1.4 Application domain physical entities

Users are considered application domain entities. Users can connect to the UWASN for accessing of scientific, military, business, and aqua applications.

User: The user can visualize information produced by an UWASN. The applications of UWASN include environmental monitoring, assisted navigation, disaster prevention, and locating intruder submarines.

6.2 UWASN functional entities

6.2.1 General

Typically, the sensor node architecture comprises six functional layers, as shown in Figure 1:

- UWA-APS;
- UWA-BUN;
- UWA-NWK;
- UWA-DL;
- UWA-PHY;
- UWA-Cross layer.

Sensor nodes and gateways can have similar layers; however, the modules in each layer can differ. For example, sensor nodes can integrate different sensors but gateways do not have sensing capability.

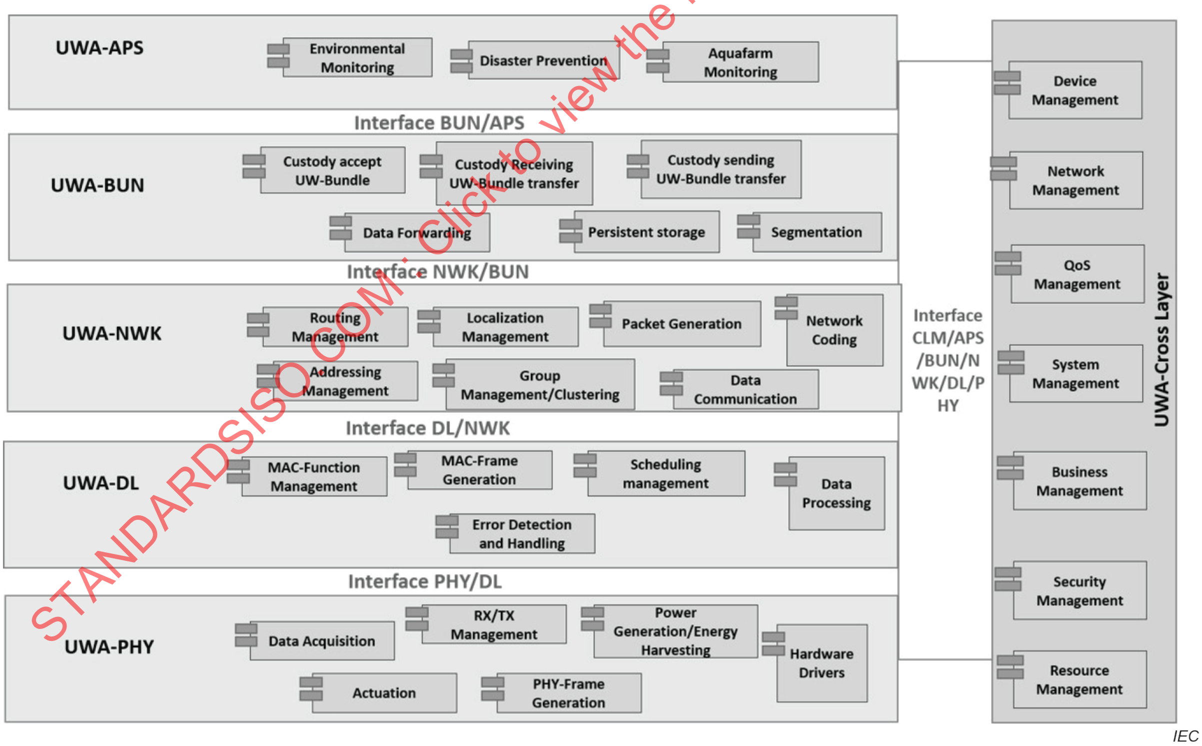

Figure 1 – Interfaces between UWASN functional layers and functional entities

Communication between functional modules in layers is implemented by the interface between the layers (Figure 1). The following interfaces are defined.

- The BUN / APS interface is between the UWA-BUN and the UWA-APS.
- The NWK / BUN interface is between the UWA-NWK and the UWA-BUN.

- The DL / NWK interface is between the UWA-DL and the UWA-NWK.
- The PHY / DL interface is between the UWA-PHY and the UWA-DL.
- The CLM / APS/BUN/NWK/DL/PHY interface is between the cross layer management and the UWA-APS, UWA-BUN, UWA-NWK, UWA-DL and UWA-PHY.

6.2.2 UWA-APS entities

The UWA-APS layer provides application processes to exchange data and contains different scientific, business, civilian, aqua and military application functionalities such as environmental monitoring, disaster prevention, aquafarm monitoring, fish farming, assisted navigation, intruder submarine detection, and ocean bottom imaging and mapping.

6.2.3 UWA-BUN entities

The UWA-BUN layer carries bundles between the UWA-APS and UWA-NWK layers. These bundles are transmitted using a store-and-forward approach.

1) Custody accept UWA-Bundle: This is sent by a candidate custodian after accepting the custody transfer of the underwater bundle.
2) Segmentation: The UWA-BUN layer divides a bundle into smaller segments to maximize the probability that each can be delivered to the destination correctly.
3) Data forwarding: After receiving an underwater bundle from a source node, these bundles are forwarded to the destination node via intermediate nodes.
4) Convergence layer adapter: In each of the corresponding protocols, functions required to carry UWA-DTN protocol data units or UWA-Bundles are provided by protocol-specific convergence layer adapters.
5) Persistent storage: After receiving the data, the UWA-BUN layer stores the data until a connection is established.

6.2.4 UWA-NWK entities

The UWA-NWK layer is an intermediary system that performs routing functions between the underwater devices.

1) Network management: This manages the network topology, routing table, configuration information, network performance, and reconfigures network information. Manages algorithms and protocols to detect and handle disconnections due to failure.
2) Routing management: This manages the different routing algorithms based on underwater communication. It is required to manage routing algorithms for intermittent connectivity of acoustic channels.
3) Localization management: This manages different localization technologies and algorithms to identify the location of underwater sensor nodes in underwater communication.
4) Packet generation: This generates packets according to underwater properties such as low bandwidth, and data rate.
5) Network coding: This improves throughput and provides redundancy for error recovery.
6) Group management/Clustering: This manages the cluster based network for underwater communication. Clustering provides parallel processing, load balancing between underwater sensor nodes, and fault tolerance.
7) Address management: Each underwater sensor node has a unique IP address. Address management manages the mechanisms for binding IP addresses to MAC addresses.
8) Integration management: This manages the mechanisms for integration of UUVs in the UWASN and enables communication among sensor nodes and UUVs.

6.2.5 UWA-DL entities

The UWA-DL layer provides a channel to access control mechanisms between various underwater devices. It is also responsible for detecting and possibly correcting errors that can occur in the UWA-PHY layer.

1) MAC-Function management: MAC-Function management maintains time synchronization between underwater devices, channel scanning, and power management.
2) Error detection and handling: The UWA-DL layer manages technologies for handling and detecting errors.
3) Scheduling management: This manages scheduling techniques for energy saving and controlling communication between underwater sensor nodes by assigning time slots.
4) MAC-Frame generation: MAC-Frame generation can increase network efficiency by using optimum frame length.
5) Time synchronization management: Time synchronization management is responsible for synchronization between underwater devices.

6.2.6 UWA-PHY entities

The UWA-PHY layer establishes, maintains, and releases connections to transfer bits for underwater transmission.

1) Actuation: The actuator is responsible for controlling UWA-SNodes.
2) Energy harvesting: This manages energy mechanisms in UWASN.
3) PHY-Frame generation: The PHY frame generation process comprises random bit generation for the encoding, modulation, and mapping of equivalent transmission channels.
4) Hardware drivers: This manages power efficient transducer hardware drivers for underwater wireless acoustic communication.
5) Acoustic modem: These are inexpensive transmitter/receiver devices for underwater communication.
6) Modulation scheme management: This manages simple modulation schemes to reduce the need for synchronization and energy cost.

6.2.7 UWA-Cross layer entities

1) Device management: This manages devices in the sensing domain, including power, system parameters, identification, and embedded software/firmware programs in device.
2) QoS management: This manages the services provided by underwater sensor nodes and underwater gateways including service registration, service discovery, service description, service analysis, and service processing queue.
3) Security management: This manages the security of communication and data, including authentication, authorization, encryption, and key management.
4) Time synchronization management: The time synchronization management synchronizes different communication nodes to handle delay tolerant applications.
5) Power management: This minimizes energy consumption using sleep modes and power control between underwater devices.
6) Localization management: This provides absolute or relative localization information to UWA-SNodes.
7) Routing management: These services determine the shortest route from a source to a destination to avoid network congestion.
8) Error and flow control management: These services are responsible for error correction and communication flow.

7 UWASN interfaces

7.1 Overview

UWASN comprise interconnected (wireless or wired) and spatially distributed underwater sensor nodes to sense, process, transfer, and provide information.

An interface is shared between two interactive entities or layers; thus the interface definition depends on the entities or layers on both sides. An interface can be described in physical and functional forms. The purpose of developing generic and generalized definitions for UWASN interfaces is to promote interoperability among layers within a sensor node, between sensor nodes, and other entities. Defining a set of standard interfaces for UWASN is one of the most efficient approaches to achieve interoperability between terrestrial and underwater sensor networks.

This document describes common interfaces that should be considered when building UWASN infrastructures. Figure 2 shows an overview of interfaces enabling underwater sensor network services along with interfaces between functional layers in a sensor node and interfaces between physical entities.

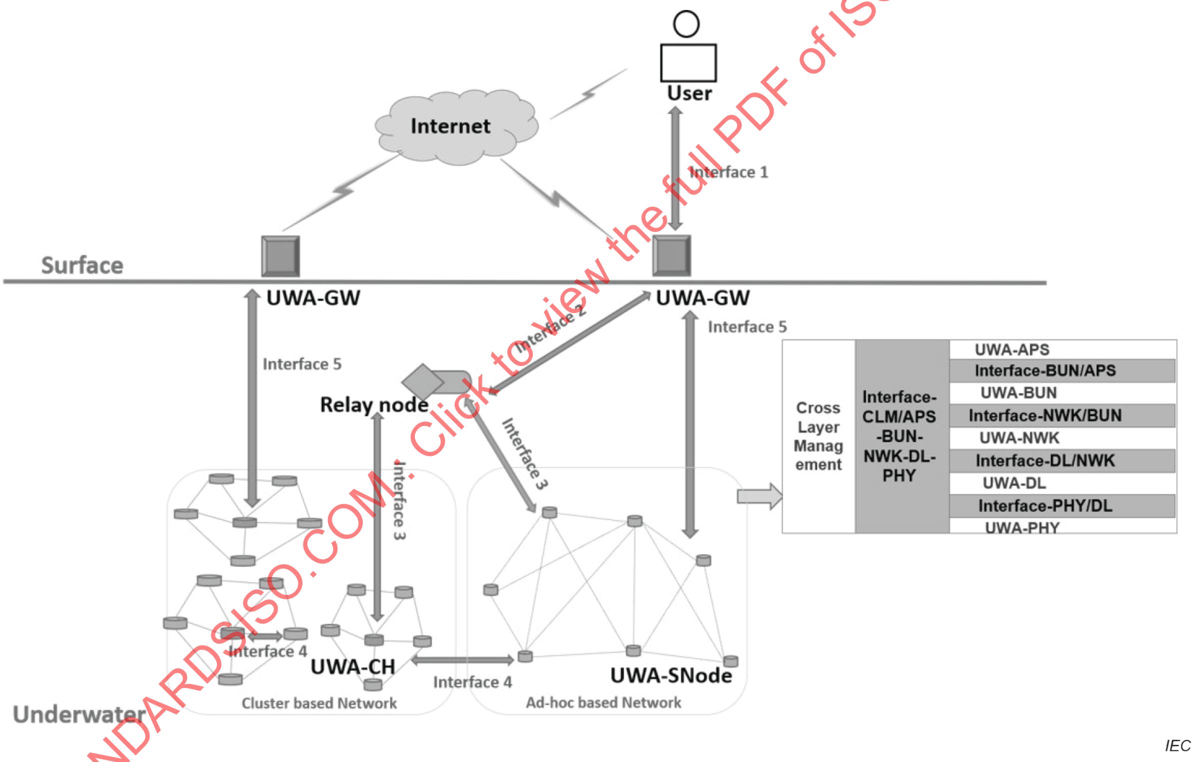

Figure 2 – Overview of interfaces enabling UWASN services

7.2 Interfaces between UWASN physical entities

7.2.1 Overview

Interfaces between physical entities are shown in Figure 3.

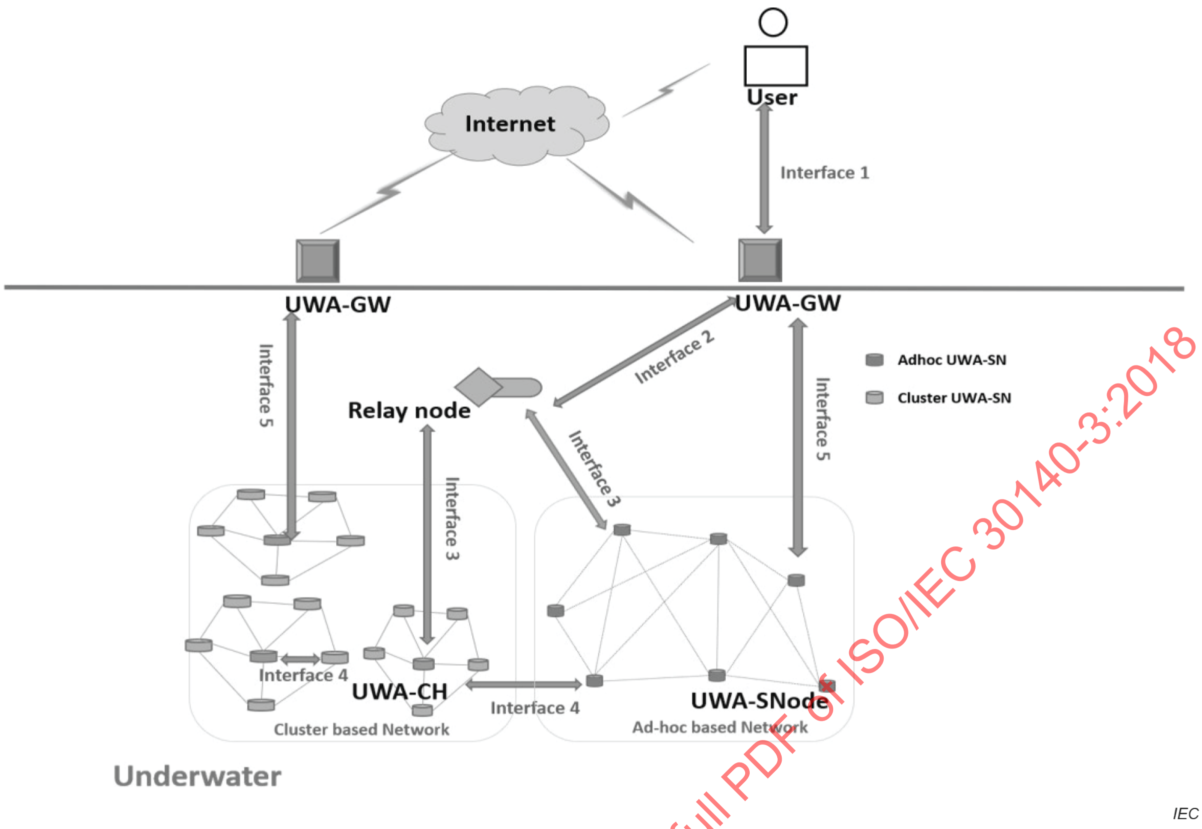

Figure 3 – Interfaces between physical entities

Figure 3 shows five interfaces between entities that enable underwater sensor network services and applications.

1) Interface 1 is between the user and the surface gateway. The user sends a request to the surface gateway to obtain the required information. The user communicates with the surface gateway through the Internet.
2) Interface 2 is between the surface gateway and relay node. Sensor data are exchanged via this interface.
3) Interface 3 is between relay node and the cluster head. This interface deals with control information, network topology, and underwater data exchange mechanism.
4) Interface 4 is between the underwater sensor nodes. Sensor nodes exchange network topology information, control information and sensor data via this interface.
5) Interface 5 is between a sensor node and the surface gateway. The user stays on the surface and directly accesses sensor data from the underwater sensor nodes through the gateway.

Figure 4 shows the functional view point of interfaces between the different physical entities. It is an important issue for transfer data reduction of Internet packets to UWASN.

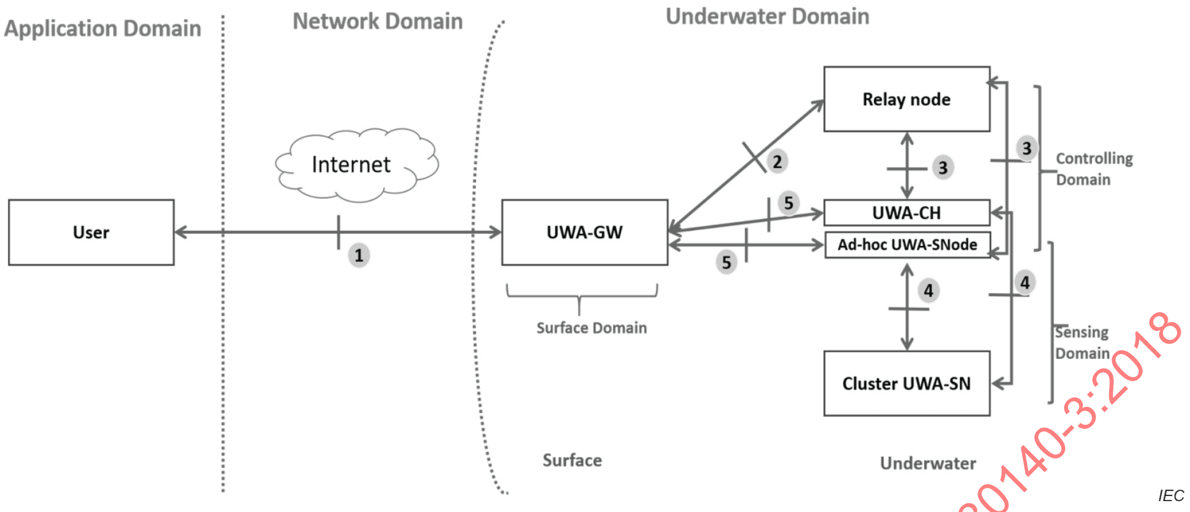

Figure 4 – Functional view of interfaces between the physical entities

7.2.2 Interface 1 – User / UWA-GW

Interface 1 is between the user and the surface gateway. The user sends a request to the gateway through this interface to obtain the underwater information, such as temperature, salinity, pH, current, turbidity, and oxygen levels. The gateway sends processed data or the requested information back to the user through this interface. Different users can interact with this interface through the Internet.

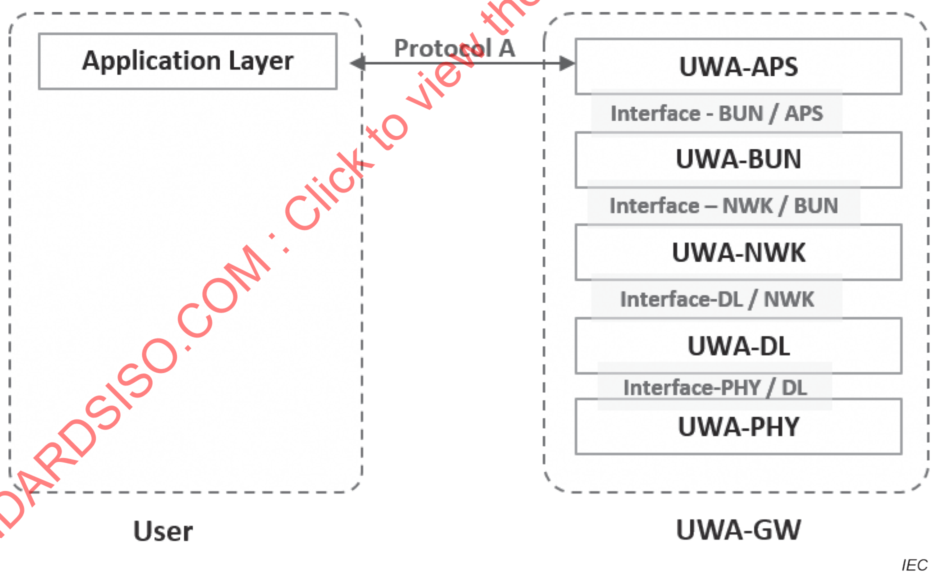

Figure 5 – Information exchange via interface 1

The message exchange mechanism in the application layer between the user and gateway is defined by protocol A, as shown in Figure 5.

The provisions for defining interface 1 are as follows:

- Interface 1 is mandatory in UWASN according to architecture and logical perspective.
- The message exchange mechanism and data format in the application layer (protocol A) between the user and gateway should be developed for interface 1 to enable UWASN applications, as shown in Figure 5.

For example, when a user wants to obtain the current water temperature, the user sends a request from the application layer to the application layer of the gateway through this interface. The surface gateway acquires the sensor data from the UWA-SNodes and sends the current temperature data from the application layer to the user's application layer. Message exchange mechanisms differ in the various functional modules of the layers.

7.2.3 Interface 2 – UWA-GW / Relay node

Interface 2 is between the underwater surface gateway and the relay node. The surface gateway passes the user requests to a relay node through this interface. The relay node sends processed data or the requested information to the gateways through this interface.

The message exchange mechanisms between the network layers, datalink layers, and physical layers of the gateway and relay node are defined by protocol N, protocol D and protocol P, respectively, as shown in Figure 6.

The provisions for defining interface 2 are as follows.

- From a communication perspective, interface 2 is mandatory in underwater sensor networks according to the overall architecture of the sensor network.
- The message exchange mechanism and message format used in the UWA-NWK, UWA-DL and UWA-PHY layers of the relay node and the gateway should be developed on the basis of the application requirements.

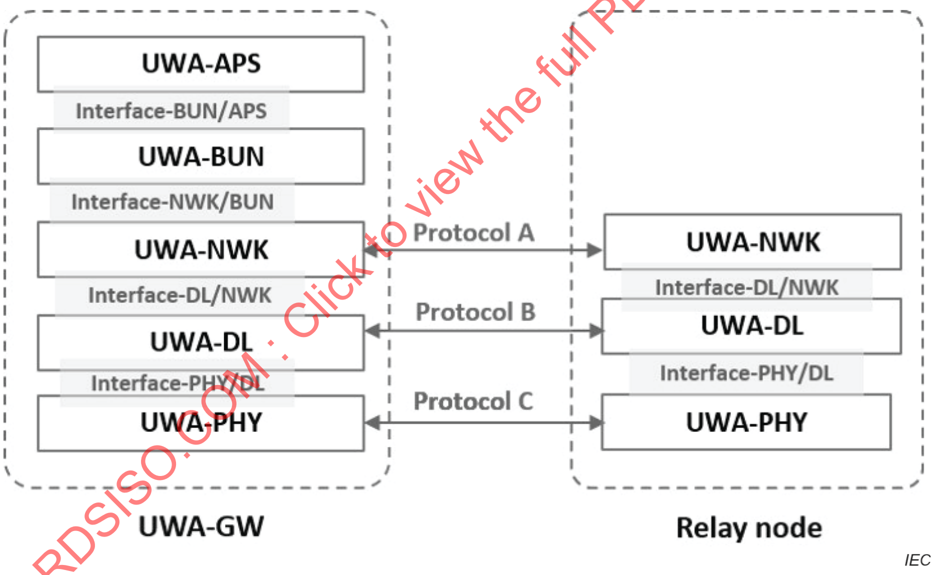

Figure 6 – Information exchange between different layers via interface 2

7.2.4 Interface 3 – Relay node / UWA-SNode

Interface 3 is between a relay node and an underwater sensor node. This interface is used for data collection and control. The relay nodes access underwater environmental data from UWA-SNodes through this interface. The message exchange mechanism between the UWA-NWK, UWA-DL and UWA-PHY layers of the relay and sensor nodes are defined by protocol N, protocol D, and protocol P, respectively, as shown in Figure 7.

The provisions for defining interface 3 are as follows.

- Interface 3 is mandatory in cluster and ad-hoc-based sensor networks according to the overall architecture and communication perspective.

- The message exchange mechanism and message format used in the UWA-NWK, UWA-DL, and UWA-PHY layers of the relay node and sensor nodes should be developed based on application requirements.

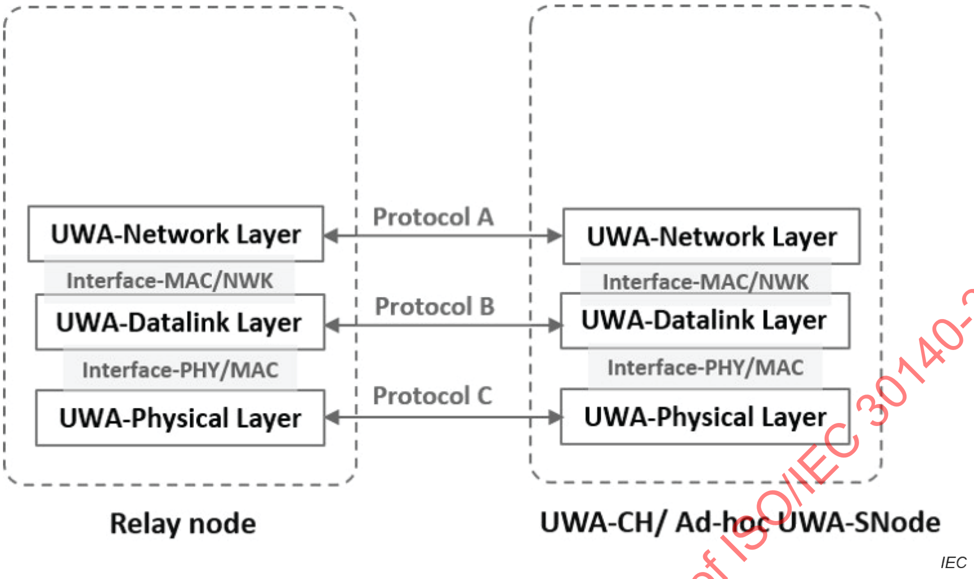

Figure 7 – Information exchange in different layers via interface 3

7.2.5 Interface 4 – Between UWA-SNodes

Interface 4 is between the underwater sensor nodes. Sensor nodes exchange network topology information, control information, and sensor data via this interface. The message exchange mechanism between the network layers, datalink layers, and physical layers of the sensor nodes are defined by protocol N, protocol D, and protocol P, respectively, as shown in Figure 8.

The provisions of defining interface 4 are as follows.

- Interface 4 is optional for ad-hoc-based sensor networks but mandatory for cluster based sensor network.
- The message exchange mechanism and message format in the UWA-NWK, UWA-DL, and UWA-PHY layers between the sensor nodes should be developed based on application requirements.

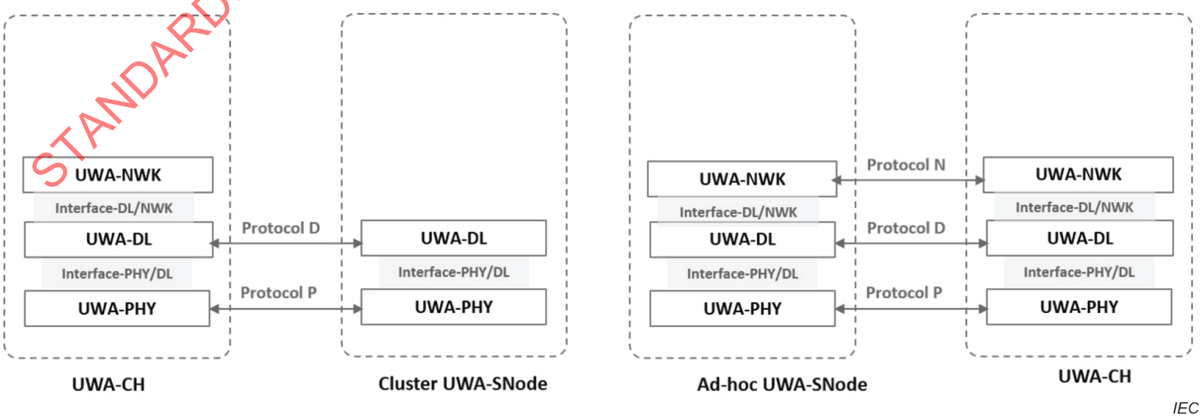

Figure 8 – Information exchange in different layers via interface 4

7.2.6 Interface 5 – UWA-SNode / UWA-GW

Interface 5 is between the underwater sensor nodes and the surface gateway. The surface gateway passes the user requests to a sensor node through this interface. The sensor node sends the processed data or requested information to the gateways through this interface without using a relay node.

The message exchange mechanism in the datalink and physical layers between the gateway and the sensor node are defined by protocol D and protocol P, as shown in Figure 9.

The provisions of defining interface 5 are as follows.

- Interface 5 is optional in underwater sensor networks according to the overall architecture of sensor network from a communication perspective.
- The message exchange mechanism and message format used in the data link layer and physical layer between the sensor node and the gateway should be developed based on application requirements.

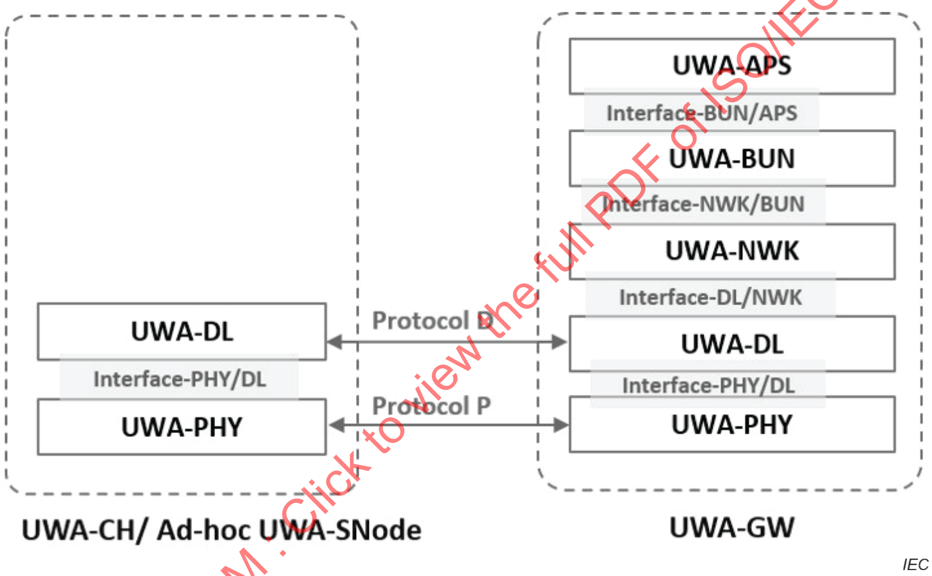

Figure 9 – Information exchange in different layers via interface 5

7.3 Interfaces between UWASN functional entities

7.3.1 Interface – UWA-PHY / DL

The UWA-PHY / DL interface is between the physical layer and datalink layer that contains the physical hardware (acoustic modem) and the logical software components of a sensor node. Through this interface, the functional modules in the physical layer interact with the datalink layer.

The UWA-PHY layer includes a processor, acoustic modem, memory, communication devices, power supplies, and other hardware. This interface allows datalink layer to access and utilize sensor node hardware. In general, A/C, SPI, SCI, I^{2}C, and PWM interfaces are used in underwater acoustic communication.

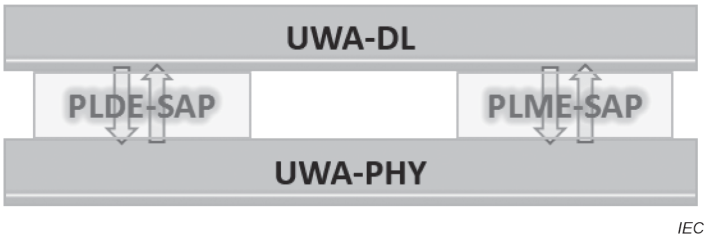

Figure 10 – Service access point provided by the UWA-PHY / DL

The UWA-PHY layer provides two types of service access points (SAP) to the UWA-DL layer. Two SAPs are shown in Figure 10. The functional entities in the UWA-DL layer access data from the UWA-PHY layer (underwater sensor data) by the PLDE-SAP, and the UWA-DL layer manages hardware in the UWA-PHY layer (actuator, and hardware drivers) using the PLME-SAP.

7.3.2 Interface – UWA-DL / NWK

The UWA-DL / NWK interface is between the UWA-DL and the UWA-NWK layers as shown in Figure 11. Using this interface, functional modules in the UWA-DL layer interact with the UWA-NWK layer. The UWA-DL layer provides error checking, flow control, acknowledgments, and retransmission. UWA-DL layer protocols reply to service requests by the UWA-NWK layer. These protocols supply service requests to the UWA-PHY layer using the data and management entity SAPs.

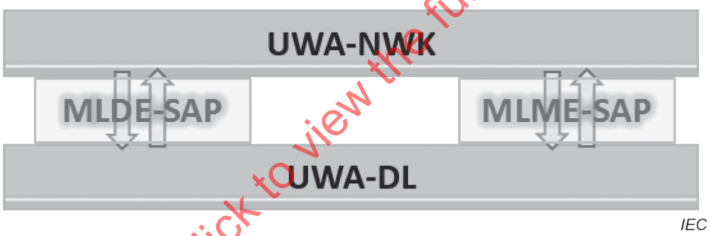

Figure 11 – Service access point provided by the UWA-DL / NWK

7.3.3 Interface – UWA-NWK / BUN

The UWA-NWK / BUN interface is between the UWA-NWK and the UWA-BUN layers. Using this interface, functional modules in the UWA-NWK layer interact with the UWA-BUN layer.

The UWA-NWK layer provides routing management, localization, address management, group management, and clustering network coding functional modules. The UWA-BUN layer accesses UWA-NWK layer functional modules through the data and management entity SAPs. Figure 12 shows the service access point provided by the UWA-NWK/BUN interface.

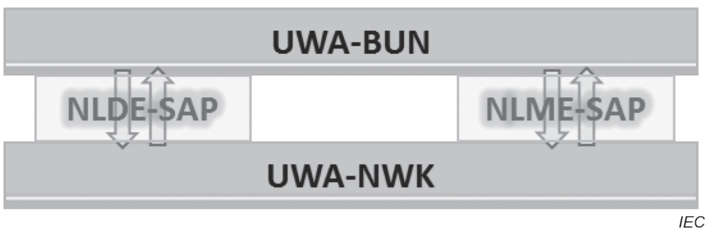

Figure 12 – Service access point provided by the UWA-NWK / BUN