Product development at Kongsberg Maritime related to underwater sensor networks

Thor S. Husøy; Frank R. Knudsen; Bjørn Gjelstad; Arne Furdal
Kongsberg Maritime
Strandpromenaden 50
NO-3183 Horten, Norway
+47 33 03 41 00 (switchboard)
{thor.husoy,frank.reier.knudsen,bjorn.gjelstad,arne.furdal}@kongsberg.com

ABSTRACT
This paper presents selected product development activities in Kongsberg Maritime related to underwater sensor network nodes. Nodes include tethered fixed seabed nodes, easy deployable wireless nodes, catch monitoring for commercial fishery and Autonomous Underwater Vehicles (AUV). Sensors interfaced to the different nodes are touched upon, including scientific echo sounders. Further, the communication capabilities of the nodes are discussed with emphasis on wireless acoustic communication including PHY, MAC and network layer capabilities of the cNODE.

Keywords
Underwater Sensor Network; AUV; Acoustic Communication; Echo Sounder; cNODE; Catch Monitoring System; Autonomous Underwater Vehicle

1. INTRODUCTION
Underwater sensor network research has attracted quite some interest over the last years. Research challenges typically are derived from how to efficiently get sufficient spatial and temporal sampling of whatever phenomena are to be observed. Research includes subjects such as underwater acoustic communication and networking, low power embedded electronics, but also on the sensor side for e.g. efficient detection of hydrocarbons. Proposed strategies at one side span from networks composed of disposable low cost fixed or drifting nodes, via more sophisticated solutions with gliders or AUVs, to very expensive cabled networks with a wide range of sensors [1]-[3]. The diversity of strategies reflects that the optimal or preferred solution all depends on the application, and that there is no single solution or silver bullet to serve them all. Kongsberg Maritime (KM) is doing product development to meet the needs of some of the applications including environmental monitoring, and is currently involved in collaborative projects with customers, research institutes and universities [4]-[6].

A generic sensor network is depicted in Figure 1 with the different platforms or components of the network. The structure of this paper is in section 2 to firstly introduce the network nodes in this context, including a dedicated section to AUV in section 3. Node platforms for commercial fishery e.g. catch monitoring are given in section 4, while section 5 introduces examples of sensors suitable for integration in a sensor network. Finally recent development of the communication capabilities of the cNODE is discussed in section 6, before a summary is given in section 7.

2. NETWORK NODE PLATFORMS
KM Subsea is developing a number of platforms that currently are, or in the near future can act as, sensor nodes. In the following is an overview of these platforms.

2.1 cNODE
The cNODE® is developed to be a battery powered easy to install seabed component of the sensor network. In its basic form it is a self contained unit with the possibility of integrated or external sensors. The cNODE communicates using wireless acoustics to other cNODEs or compatible surface units. It comes in a wide range of physical layouts and configurations including the cNODE Research model [7] and the cNODE Mini model in Figure 2. cNODE Research contains a Gumstix embedded Linux computer for open application development. The larger models come with the option of a release mechanism and floating collar enabling easy deployment and retrieval of the node: The node is deployed using a little weight as anchor that on retrieval is dropped using an acoustic release command causing the unit to float to the surface. First developed depth rating for the cNODE was a 4000 m aluminum version followed by a 7000 m stainless steel version.

The battery capacity of the cNODE depends on the model; with the largest model cNODE Maxi having a capacity of 1840 Wh. Expected autonomy varies greatly with the sensor configuration and the amount of data to be transmitted. The cNODE Maxi has a quiescent lifetime of 2.5 years. Optionally the cNODE can also be powered externally via cabled infrastructure or from separate external battery packs in outside containers.
cNODE compatible units include the cPAP® transceivers developed as a network gateway for retrieving sensor data from the cNODEs or together forming a transparent link for outside users. The cPAP transceivers are developed in two versions which of the cPAP Subsea transceiver (Figure 2a) are designed for integration with remote operated vehicles and, while the cPAP Portable transceiver (Figure 2b) is designed for rugged operation on deck of a surface vessel or on a small open vessel like a RHIB. cPAP Portable transceiver is a self contained unit with a panel PC in a hard cover suitcase complete with batteries to be combined with a separate dunking transducer to be lowered over board.

The cNODE was originally developed as a positioning transponder for the HiPAP® acoustic positioning systems. As a sensor node it is still compatible with the HiPAP system, offering positioning precisions down to centimeter range. Both the cPAP and HiPAP systems are controlled with the APOS operator station software continuously being developed for new functionality. Latest additions to the software include sensor data logger functions, both topside and subsea, whereof the sensor log rate and duration can be controlled from the surface, and data in specified time intervals can be retrieved.

A common sensor interface board is developed for cNODE for all external and internal sensors. The interface board has functions for controlling the power supply to individual sensors for maximum power efficiency, making sensors powered only for the duration of the measurements. All data are further logged on the boards SD-card through the subsea data log function enabling post analysis of sensor data.

2.2 TETHERED NODES

Environmental monitoring in daily offshore operations is becoming increasingly important where oil and gas fields or renewable energy sites must be monitored throughout their life cycles. Impacts on the local ecosystem and oil and gas leaks are critical issues.

KM Subsea is developing a node for permanent sea floor installation that can interface several sensors monitoring both marine life and leaks of oil and gas. Communication to surface is primarily via cable, but the solution must also be able to operate autonomously at sites without any infrastructure. The solution intends to interface any third-party sensor satisfying the SIIS (Subsea Instruments Interface Standard) and will involve both internal and external sensors. Examples of internal sensors are echo sounders and ADCP (Acoustic Doppler Current Profiler) while external sensors are simpler, typically measuring turbidity (water clarity) and physical parameters. The cNODE interfacing simple sensors can act as satellites to the subsea node to increase areal coverage. These capabilities are under development and will be qualified in a joint on-going development program with Statoil and KONGSBERG for use in Integrated Environmental Monitoring systems.

2.3 GATEWAY BUOY

The Gateway buoy (Figure 3) can be used in conjunction with the AUV to provide the operator with the ability to remotely track, monitor, command, and interact with the vehicle while it is underway. This allows operators to maintain communication with the vehicle, and share information with all interested parties,
whether they’re in the vicinity, or around the world. The buoy includes GPS receiver, Iridium satellite modem and modem for acoustic communication.

Further development will let the buoy also serve as a link to other kind of subsea network nodes.

3. AUTONOMOUS UNDERWATER VEHICLES
In an underwater sensor network AUVs will operate as mobile sensor nodes. The AUV is a modular and flexible sensor platform capable of doing simultaneous recording of data from a wide range of sensors. An example of this is shown in Figure 4. The graphs present recorded data from a CH₄ sensor mounted on a HUGIN® AUV moving at a speed of 4 knots over a subsea area with seepages.

The AUVs can be sent out for routine surveys or as a result of e.g. detections by other sensor nodes in the network. During the survey the AUV can communicate with other subsea nodes, surface buoys and vessels.

AUVs may also have other roles like doing data harvesting from permanently or temporarily isolated nodes and record data for change detection with respect to subsea infrastructure and biota.

![Figure 2](image)

**Figure 2** a) cNODE Research with release mechanism, b) cNODE Mini with floating collar, c) cPAP Subsea transceiver and (d) cPAP Portable transceiver

![Figure 3](image)

**Figure 3** Gateway Buoy for remote AUV tracking, communication and navigation

![Figure 4](image)

**Figure 4** Leakage detection with CH₄ sniffer

4. CATCH MONITORING SYSTEMS
The trawl is one type of fishing gear where catch monitoring has a long history. Critical to the successful operation of a trawl is knowledge about its depth in the water, the distance between the trawl doors, height above the bottom, trawl opening, bottom contact and filling. KM Subsea has a whole family of sensors to provide real time information about these variables. Recent advances in our catch monitoring technology (Figure 5) involves acoustic scanning of the trawl opening and camera observations inside the trawl enabling active exclusion of fish below the legal minimum size or protected species.
5. SENSORS
KM Subsea has a long tradition as a supplier of echo sounders to the scientific market including ocean observatories. An echo sounder will collect information from the whole water column and offer quantitative data on plankton, fish and marine mammals. Echo sounders are also used to map bottom habitats like coral reefs. Additional active acoustic instruments like multibeam sonars, side scan sonars and synthetic aperture sonars provide better volumetric and areal coverage than echo sounders and produce camera-like images of both the water column and sea floor that are easy to interpret (Figure 5).

To obtain a full understanding of the ecosystem, active acoustic instruments must be supplemented with data from other sensors. The ADCP is important for mapping of water currents and their stratification in the water column. CTD (Conductivity, Temperature, and Depth) profiles are mandatory for interpretation of both biological and acoustic data. Underwater construction work or drilling for oil can release particles into the water that can affect marine life. Simple turbidity (water clarity) sensors measure such particles in water. Fluorometers are similar sensors that have proven useful for measuring both oil contamination and organic compounds. Natural seeps of gas (methane and carbon dioxide) can be monitored with both active acoustic instruments and dissolved gas sensors. A major challenge is to distinguish gas from natural and human sources. Hydrophones are important for mapping natural background sounds as well as sound produced by human activities like ship traffic and pile driving. Cameras are often used together with active acoustic sensors for target identification. Relevant platforms for environmental sensors are permanent nodes at the sea floor, AUVs, ROVs and gliders in addition to the traditional surface vessels.

6. cNODE NETWORK COMMUNICATION
The acoustic communication protocol of the cNODE, called Cymbal®, is developed as the main wireless carrier of subsea data.

Table 1, cNODE example transport formats and their capacity

<table>
<thead>
<tr>
<th>TF</th>
<th>Capacity [Bytes]</th>
<th>Burst rate [bit/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48</td>
<td>200</td>
</tr>
<tr>
<td>2</td>
<td>118</td>
<td>470</td>
</tr>
<tr>
<td>3*</td>
<td>229</td>
<td>1710</td>
</tr>
</tbody>
</table>

* Developed together with FOI, Swedish Defence Research Agency.

6.1 PHY
The physical layer capabilities of the protocol is based on direct sequence spread spectrum (DSSS) signaling with a variable spreading factor. Unit spreading rate can be selected resulting in ordinary quadrature phase shift keying (QPSK). Several transport formats or transmission speeds have been developed (up to 32 can be defined) of which three examples are presented in Table 1. These transport formats were used in the UAN project [8]. The physical layer use Viterbi- and Turbo equalizer with ½ and 1/3 rate forward error correcting coding. Demonstrated ranges have been up to 3000 m vertically and up to 3800 m horizontal for the 20-30 kHz band. The roadmap includes a 10-15 kHz band and enhanced range capabilities.

6.2 MAC NETWORK
The cNODE has been developed with two approaches for network communication. The first was used in the UAN project where a complete network layer was implemented on the CPU of the cNODE. Later a second approach has been adapted by running the test framework SUNSET [9] on the Gumstix open platform. Both approaches are currently available for cNODE.

The network layer implemented in the CPU is a light weight system designed for energy efficiency in low and medium traffic situations [10]. Demonstration was carried out in the Trondheim fjord in 2011 with a five node network, whereof two mobile glider/AUVs. The routing of the network starts with an automatic
network discovery phase, and this process can be repeated locally around moving nodes for mobility support.

The medium access strategy is hybrid with pure Aloha in the network discovery phase, combined with CSMA/CA and RTS/CTS option for long messages. IP/UDP end to end communication has been demonstrated with header compression running on an embedded Linux computer reducing header size from 40 Bytes to 3-5 Bytes at its minimum.

6.3 APPLICATION
Several sensors have been integrated with cNODE at the application level. Typical applications so far include polling of sensor data from a centralized surface unit like the HiPAP system. Sensor data include sea current, temperature, pressure and inclinometer. The roadmap for cNODE sensor integration include Doppler velocity log (DVL), heading sensors, CO2, vibration sensor, altimeter and motion reference unit (MRU).

The road map for the cNODE Research model include developing an Application Program Interface for more efficient use of the communication capabilities and facilitating third party open application development on the Gumstix.

7. SUMMARY
Product development activities in Kongsberg Maritime related to underwater sensor networks involve a wide range of node platforms.

The easy deployable seabed platform cNODE is being developed for further sensor integration and enhanced acoustic communication capabilities. Work is focused on physical layer, but also MAC/Network layer as well as the application layer. A development project together with Statoil is establishing a SIIS compatible cabled seabed platform for a wide range of environmental sensors. The seabed platform is also designed for autonomous operation in areas where no cabled infrastructure is available.

AUVs are developed as mobile nodes for underwater sensor networks. The AUVs are integrated with a large set of sensor whereof one example is a CH₄ sniffer for leakage detection from the seabed. Gateway buoys are integrated with AUV operation and further work will let the surface buoy also communicate with other kinds of subsea equipment.

Active acoustic sensors, as single and multi beam echo sounders, side scan sonars and synthetic aperture sonars, are developed both for monitoring of the water volume as well as the seabed. Integration of a wide range of sensors is being done at the different platforms including examples like APCR, CTD, cameras, chemical sniffers and turbidity sensors.

In addition to the above mentioned development activities, more specific sensor networks are developed for catch monitoring systems for trawls.

Development work at KM Subsea is partly performed in collaborative projects together with customers, research institutions and universities.

8. ACKNOWLEDGEMENTS
Writing of this article has been supported in part by the European Commission under the 7th Framework Programme (grant agreement no. 258359 – CLAM).

9. REFERENCES