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NETWORKING CONSIDERATIONS FOR ACOUSTIC COMMUNICATION WITHIN MULTI-NODE UNDERWATER SENSOR NETWORKS

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Within the EU ACME project both communication and environmental impact experiments were performed for an acoustic underwater communication network in shallow water in coastal areas. Using the conclusions from these experiments some new approaches are suggested for future implementations of similar systems. A 'time-triggered' communication strategy is suggested to overcome the impact of long communication times associated with master to slave communication. The usage of an adaptive network controller/protocol is suggested to optimize the system performance under changing environmental conditions and marine mammal presence.

1. INTRODUCTION

Systems capable of monitoring the environment and/or to control equipments in underwater coastal areas are used more and more. Typically these systems comprise of sensors located on the sea floor or in the water and are linked to shore either by cable or via radio network from surface buoys. However it is often not possible to set surface buoys and sea floor cables because of associated cost, environmental conditions or shipping activities. In such conditions, the desired way to transfer data from sensors to end user or to remotely control underwater devices from shore is to use an underwater acoustic communication link.

The acoustical environment in coastal areas, especially in or near shipping lanes is difficult. It can be characterized by multi-path propagation, rapidly changing conditions (e.g. turning of the tide), high noise levels (e.g. ships) and absence of direct sound paths between two modems (due to placement on or near the seabed). Furthermore only limited power is available due to non-infinite battery life time. Last but not least these areas are frequently visited by marine mammals, so care must be taken that marine wildlife is not hindered by the continuous operation of these underwater sensor networks.

Within this set of system requirements a networking protocol has to be chosen which can not only configure such a multi-node underwater sensor network, but is most of all capable of periodically requesting sensor data from a wide variety of sensors in an efficient way without causing harm to marine wildlife.

2. SYSTEM ANALYSIS

Typical setups of an underwater network as described above include a single master unit and multiple slave units. The master unit is typically placed on a buoy, a ship or more likely a measurement pole. The slave units are typically placed within a frame on the seabed. See also *Fig.1*.

Fig.1: Example system with master unit (on measurement pole) and two slaves units (before deployment)

Depending on the layout of the slaves on the seabed it is possible to exchange information directly between master and slaves or to use some slaves as a relay in order to retransmit information which would otherwise not reach certain slaves ('hopping'). This allows communication when distances between master and slave become larger, when no direct paths are available due to the local bathymetry or to route information along paths which are less affected by noise and disturbances (shipping traffic). See also *Fig.2*.

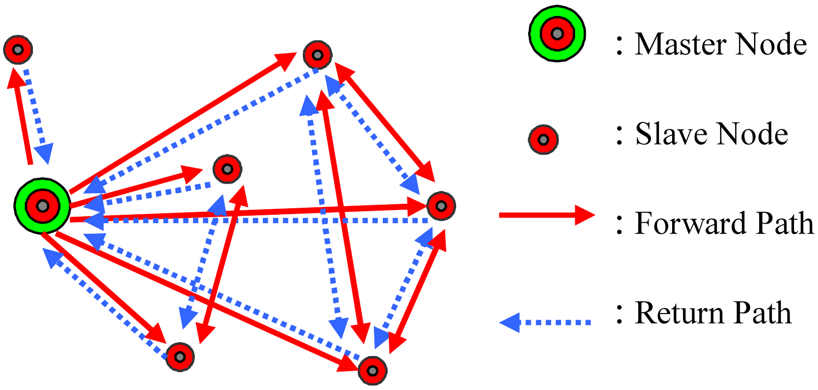

Fig.2: Example network topology

The communication between the nodes in such an underwater heavily depends on the different phases or states the system can be in (see also *Fig.3*):

- After deployment of the system (and later-on when environmental changes occur) an **identification** of the system has to be performed. In this state the propagation times between the nodes are estimated. Communication is limited to just a few bytes and only takes place at relatively long intervals.
- After that the system can enter a **configuration** state in which the parameters of the master and slaves will be set. This state will also be entered when an operator wants to change the working settings of the system. Communication uses blocks of data with mixed and variable lengths without having strict real-time restrictions.
- During normal working conditions the system is in the **operational** state in which the master requests sensor information from the slaves and the slaves return data to the master, either direct or via a relay node. Furthermore the master can tune the performance of the communication within the system by changing the power levels and to certain extend also the modulation types. Communication takes place at regular intervals and with mixed length but a-priori known data quantities.

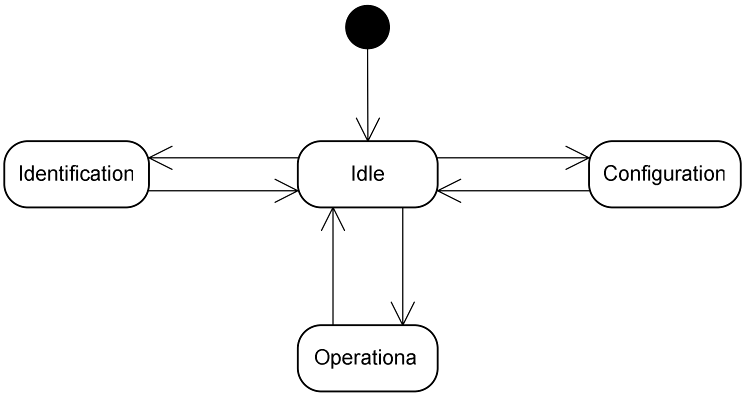

Fig.3: State diagram

3. ACME EXPERIMENTS

3.1. Introduction

ACME stands for ‘Acoustic Communication network for Monitoring of underwater Environment in coastal areas’ and was a European Project within the Energy, Environment and Sustainable Development Cluster of the 5th Framework Program of the European Commission. The project focused on the design of robust underwater communication and protocol algorithms for coastal areas, but also took the environmental impact of the acoustic data on marine animals into account. During the course of the project several sea trials were performed. Furthermore several experiments with marine animals were conducted in which the influence of underwater acoustic data communication sounds on the behaviour of harbour porpoises and seals was investigated.

3.2. Communication Experiments

The system used during one of the sea trial experiments in the Westerschelde (see also *Fig.4*) consisted of one master node mounted on a measurement pole near the shore line and three slave nodes located at the seafloor in or near the shipping lane in the Westerschelde near Hansweert (NL). The slave units consisted of a modem with an additional microcontroller running some network layer software and a data logger connected to one or more sensors. The master modem on the pole was connected via a cable connection to a computer running some dedicated network layer software which was capable to estimate the propagation times (identification state) and to generate messages to send/receive data to/from the slaves (configuration and operational state). This network layer software was furthermore capable to on-line tune the communication settings like modulation type and power level based on for example the success rate of the transmissions. This computer was connected to another computer running a combination of sensor controller and ARAM software. The main task of this computer was to configure the data loggers and to periodically request sensor data from the data loggers. Furthermore it took care of all interpolations and conversions necessary to make the raw sensor data available in a format suitable for storage in the main database of an existing measurement network (RMI). See also [1].

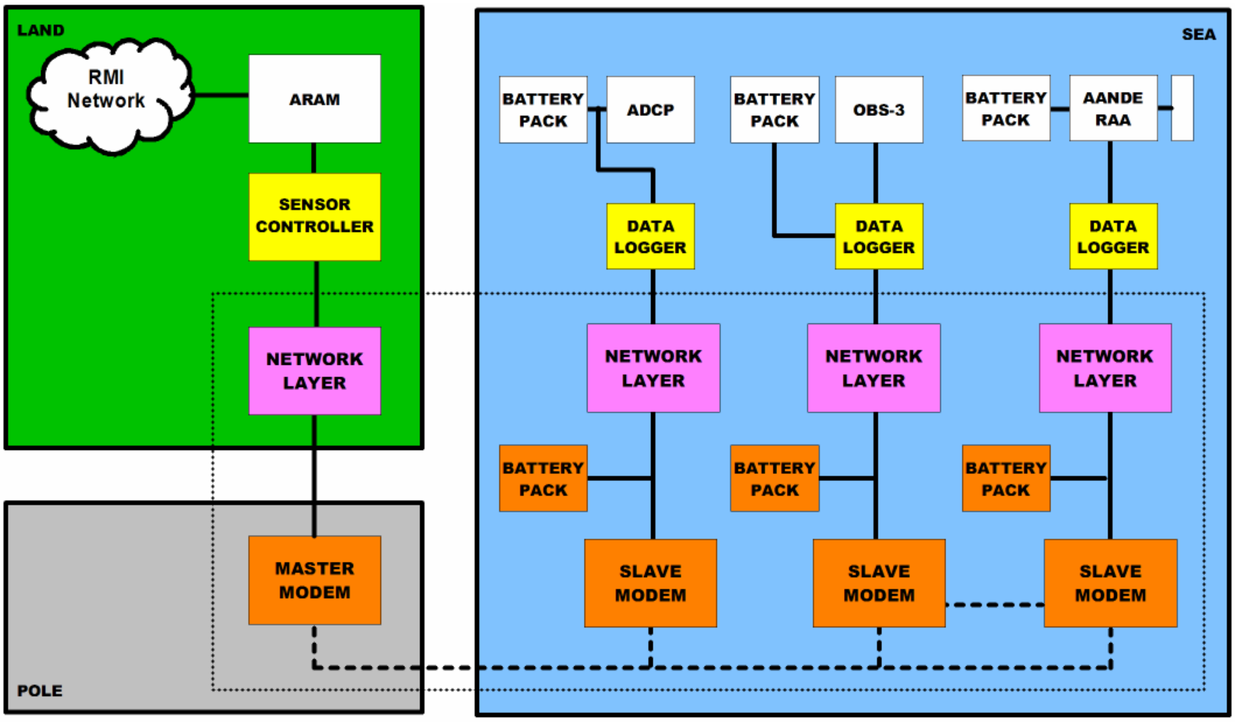

Fig.4: ACME system setup

The three slave units were deployed in a configuration as shown in *Fig.5*. Under normal conditions two slaves would always be reachable with a direct connection from the master on the pole near the shore line. Under ideal situations the third slave would also be reachable via a direct connection, however in less ideal situations the two other slaves could work as a relay for this slave. Furthermore a direct link between these two slaves would also be possible.

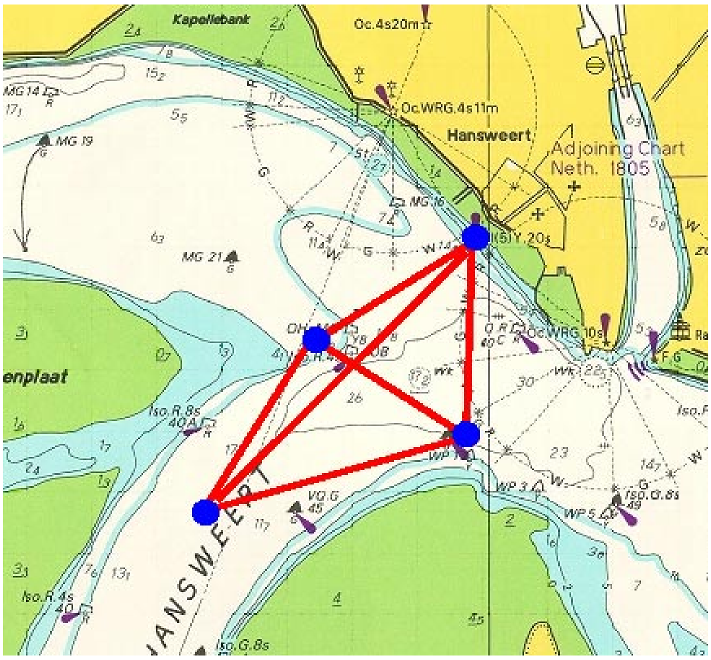

Fig.5: ACME network topology

Forward path communication was done using chirp modulation (5 bps); return path communication using MFSK, CDMA or HDR modulation (100-4000 bps). For chirp and MFSK the modems performed error detection/correction, for return path communication an additional CRC was added to network layer. See also [2].

The experiments in ACME showed that it is possible to operate a multi node underwater communication system with relay functionality. However also some short comings in the communication strategy were found and future improvements were identified:

- Although the data quantity from master to slave was very small compared to the data quantities from slave to master, the relative communication time was long due to the low communication speed available to master-slave communication. In non-relayed experiments up till 60% of the available bandwidth was used for master-slave communication and in relayed experiments this figure would even become worse.
- The concept of an adaptive control strategy in the network layer software (‘power and rate controller’) on the master node proofed to be a promising approach for the future. Although the current implementation was limited in the number of inputs (packet loss) and the number of set-points (modulation type and power level), it could easily be seen that more inputs and set-points could provide a better system performance (e.g. ship detection and dynamic routing).
- The modulation mechanisms implemented in the modems offered various error detection and correction mechanisms. However none of them would fulfil the requirements which would be applicable for future systems which would have to run continuously and reliably. A connection between the error detection mechanism in the modem and the adaptive controller in the network layer software could lead to better decisions when to change various set-points in the communication strategy.

3.3. Environmental Impact Experiments

Two kinds of experiments were conducted. The first experiments involved two harbour porpoises in a floating pen. The second experiments involved nine harbour seals in a pool. These marine mammals were subjected to a set of sounds, some of them typical for underwater acoustic data communication. The effect of each sound was judged by comparing the animals' positions and respiration rates during a test period with those during a baseline period. Each of the sounds could be made deterrent by increasing the amplitude of the sound.

- The animals reacted to the sounds by slightly increasing their respiration rates and/or by swimming away from the sounds. For harbour porpoises the level at which this happened was at 100 dB re 1 microPa near the animal and for harbour seals at 107 dB re 1 microPa. See also [3].
- In case an underwater acoustic data communication network starts to transmit loud sounds when an animal is close to the sound source, it could cause damage the hearing of the animal (e.g. 170 dB re 1 microPa for harbour porpoises). Therefore it is advised to slowly increase sound levels, thus allowing the animals time to swim away before sound levels dangerous to their hearing occur. See also [3].
- Discomfort zones (area around the sounds source that the animals are avoiding) for several source levels were calculated for each of these sounds using a propagation model for shallow water. See also [4] and [5]. Using these figures it is possible to determine source levels and network topology which protect the living patterns of marine mammals in those areas.

4. NEW APPROACH

An approach for a solution for the above mentioned issues is thought to be found in an adaptive networking protocol with 'time-triggered' communication strategies.

4.1. Time Triggered Communication

Time triggered communication is based on the periodic transmission of a reference message by a master (see also [6] and [7]). The reference message indicates the start of a so called 'basic cycle', in which the different slave responses are assigned to specific time windows. Based on the contents of the reference message, different basic cycles are possible, see *Fig.6*. The relationship between contents of reference message and location of time windows including which slave/relay units should be transmitting, which data should be send, which modulation type or power level should be used, etc. is all defined during the configuration phase of the system. This way a very short reference message is enough to fully define and start the different communication patterns during the operational phase.

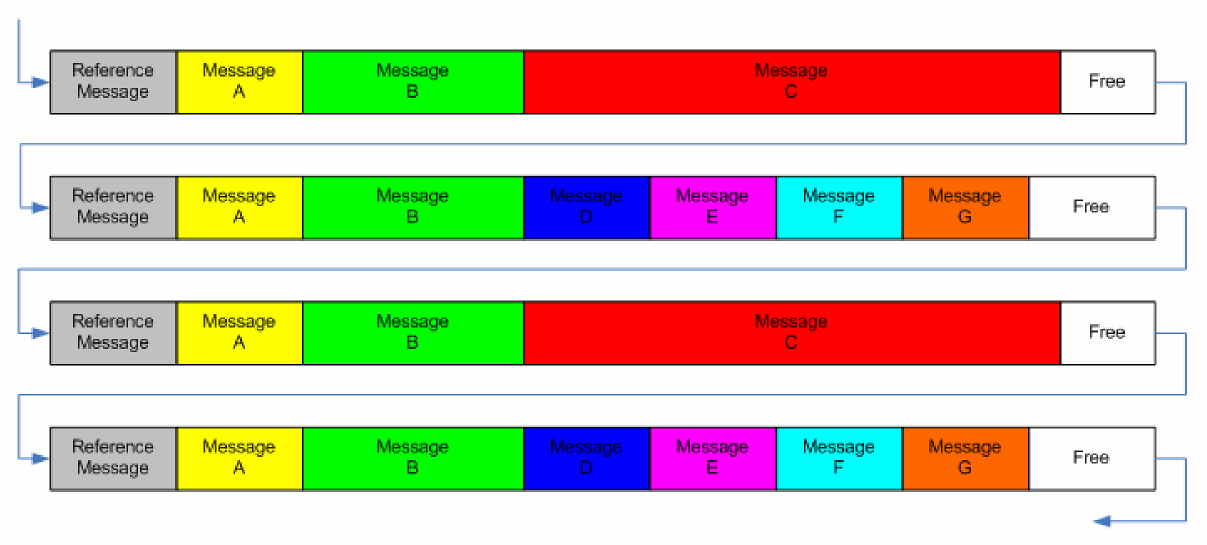

Fig. 6: Example of time triggered communication strategy with 2 basic cycles

4.2. Adaptive Controller

The task of the adaptive controller is to determine the optimal basic cycle to use. This decision is made based on a number of dynamic inputs like packet loss info and battery usage and some static inputs like topology, data quantities and sensor acquisition patterns. Some rules dealing with these inputs together with some rules regarding sea life protection (e.g. slowly increasing and maximum sound levels), estimated shipping traffic (e.g. based on radar information) and changing environmental conditions (e.g. tidal and weather information) determine which transmission powers, modulation types and relay options should be used and therefore be forwarded to the basic cycle selector. The setup of such an adaptive controller is shown in *Fig. 7*.

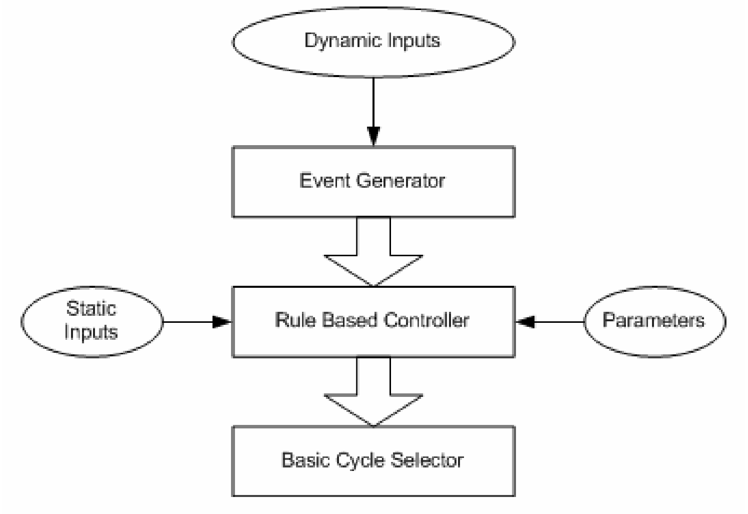

Fig. 7: Adaptive controller setup

5. CONCLUSIONS

Based on the outcomes of the communication and environmental impact experiments done in the EU ACME projects some lessons were learned on what to improve in current multi node underwater sensor networks using acoustic communication. The usage of an adaptive networking protocol with 'time-triggered' communication strategies looks to be a favourable approach to increase the effective available bandwidth for sensor data and limit transmission power levels to values not harmful to marine mammals.

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