Abstract—This paper presents a novel system to remotely control and reconfigure an heterogeneous underwater acoustic sensor network in scenarios with no direct access to all the underwater nodes after their deployment. The system uses the SUNSET framework to interact with and to operate the underwater network via single-hop and multi-hop acoustic transmissions. Users can remotely configure the underwater devices and the tests to run without the need to retrieve or bring to the surface the deployed nodes. The system allows the user to select different protocol stacks, protocol parameters and device behavior policies and to investigate the performance of several network configurations in an easy and fast way, avoiding that most of the experiment time is used to prepare the tests rather than to actually run the tests and collect the results. The presented mechanism has been successfully tested and validated during three in field campaigns, considering different underwater environments and communication devices. Our results show that the time to remotely control and reconfigure several batteries of tests for a variety of network configurations reduces to few tens of seconds, thus enhancing robustness and flexibility and significantly reducing the costs and logistic complexity of in field experiments.

Index Terms—Underwater acoustic networks, remote on line control, underwater network reconfiguration, SUNSET.

I. INTRODUCTION

The on-going enhancement in reliability and performance of underwater acoustic modems and mobile assets is opening a wide range of application scenarios, with increasing interests from both academia and industry [1]. Several solutions have been proposed in the past years for Underwater Acoustic Sensor Networks (UASNs) at all levels of the protocol stack and their performance has been evaluated by means of both simulations and in field tests. Simulations, however, can only capture a subset of the total environmental variability, providing an approximate and generally simplified model of the acoustic channel and its dynamics. At sea tests are therefore needed for a more accurate evaluation of the network performance and validation of the proposed solutions in real scenarios. In field experiments, however, introduce high costs and logistic complexity not only related to the deployment of the underwater network itself, but also to the execution of the experimental activities. When multiple protocol solutions and/or parameters have to be investigated, different node reconfigurations and tests have to be performed. If a fast direct link to all the deployed nodes is available (cable, radio connection or others) this can be easily done, otherwise for each test the nodes have to be recovered, reconfigured and redeployed, which in turn results in the need of long time, personnel and resources. Having a fast direct link to each of the nodes in the network is not easy and the constraints related to cable length, radio link coverage, etc. could significantly reduce the size of the area where the underwater network is deployed. The availability of a mechanism to acoustically configure and control the experiments in UASNs would allow to significantly reduce the costs and the logistic complexity for in field testing and to speed up the design and thorough validation of novel protocol stack solutions at sea.

A first solution addressing this problem has been presented in [2]. It uses acoustic links and a master/slave approach to reconfigure the experiments in the underwater network. A direct connection to the master node is required. Command messages are sent by the Master to instruct the other nodes on reconfiguring the experiment and start (stop) the test. The master node needs to specify in each control message the path that has to be followed by the packet to reach all the intended nodes. The final destination of each path has to be the master node itself to ensure that the transmitted commands have been received by all the addressed nodes. Although, this approach has been successfully tested in the Werbellin lake, near Berlin (Germany) [3], it could poorly perform in the presence of a high dynamic acoustic channel. The knowledge on the network connectivity could be not available in advance or it could be fast changing over time, even before the time needed by each control message to return back to the master node. Additionally, if a large network is considered, the path information could result in a large amount of data to be added to the packet and could not fit within a single acoustic message together with the information to set-up the experiment. Packet fragmentation could be necessary thus introducing additional overhead and delays. A more flexible mechanism is therefore needed.
In this paper we investigate a novel approach, based on the SUNSET framework [4], which overcomes the limitations described above and provides a more flexible tool to remotely control and reconfigure an heterogeneous underwater network in scenarios where there is no direct access to all the nodes in the network. This mechanism allows therefore to acoustically control and run several experiments in an easy and fast way. No master/slave approach is assumed and no preliminary information on the network status and connectivity are needed. The implemented mechanism permits to start/stop a given experiment and to monitor the status of each test thus ensuring a full control on the network nodes during the experimental activities. When starting a new test, the user can select different configuration settings, including: Protocol stack and related parameters; device policies; which node has to act as collection point (sink), if any; which nodes have to generate data; what traffic load has to be used, etc. The presented approach has been successfully tested under different environmental conditions and network configurations, considering different underwater nodes and communication devices. The collected results show the validity, robustness and flexibility of the proposed mechanism.

The rest of the paper is organized as follows. The SUNSET architecture is described in Section II. A detailed description of the proposed mechanism and its operations is provided in Section III. Section IV presents the different in field experiments conducted to validate the system and the collected results. Finally, Section V concludes the paper.

II. THE SUNSET ARCHITECTURE

The Sapienza University Networking framework for underwater Simulation, Emulation and real-life Testing (SUNSET) [4] is a novel solution developed to seamlessly simulate, emulate and test at sea communication protocols. It is based on the open source and well known network simulator ns-2 [5] (and its extension ns2-Miracle [6]) and it has been made freely available to the research community [7].

SUNSET provides a software development toolkit to implement and evaluate the performance of complete protocol stacks for underwater acoustic sensor networks by means of both simulation and in field tests. Using SUNSET, anyone can first test its protocol solution in a simulative environment (by means of the network simulator ns-2), which speeds up the development and debugging process (Figure 1a). It can then use the same networking protocols implementation in emulation and during at sea testing without any code re-writing, adopting real acoustic modems for data transmissions and additional external devices for sensing and navigation operations (Figure 1b).

The development of the entire protocol stack is independent from the communication devices giving the possibility to implement new protocol solutions in an easy and fast way. Developers and researchers can run tests changing either the selected protocols (MAC, routing, etc.) or some protocol parameters without any modification in the external devices code and, at the same time, can change the configuration parameters for the selected communication hardware without any modification in the actual protocol stack. Several routing, MAC and cross-layer solutions have already been implemented, including: CARP [8], TDMA, CSMA [9], Slotted CSMA, T-Lhoi [10], DACAP [11], Flooding-base solutions, an improved version of the routing solution presented in [12], etc.

When running simulations (Figure 1a), SUNSET can use different underwater acoustic channel models, such as empirical formulas [13] and Bellhop ray tracing [14] via the WOSS [15] interface. When running in emulation mode (Figure 1b), instead, real acoustic modems and additional devices are used. New modules and several drivers have been developed to allow a proper interaction with the external real hardware and to make transparent to the user the switch between a simulated underwater channel and the use of real acoustic modems. SUNSET has been interfaced with several
external devices: 1) Acoustic modems (WHOI Micro-Modem; Evologics modem, Kongsberg modem and Teledyne Benthos modem); 2) Sensing platforms (temperature, CO₂ and methane concentrations [16], ADCP); 3) Mobile vehicles (MARES AUV and ASV [17], eFolaga AUV). The designed architecture is flexible and open enough to allow the integration of whatever external device once Application Programming Interfaces (APIs) are provided to control its operations.

The time needed to design and implement the specific driver is very short and proportional to the complexity of the operations required by the specific hardware. Radio, optical and other type of communication devices can be interfaced to SUNSET as well. This provides the possibility to explore and take advantage of multiple communication interfaces available at a given node to improve the network performance and capability.

All the SUNSET modules and drivers have been extensively tested, validated and improved during several at sea campaigns conducted in the past three years. Moreover, when running in field tests, it has been successfully ported on small portable devices (Gumstix [18], IGEPv2 [19], PC104 and other ARM-based systems), thus allowing the user to embed it inside modem or AUV housings, making easier the deployment at sea. The additional delays introduced by SUNSET are in the order of milliseconds with an additional overhead per packet of just few bits for proper packet coding.

SUNSET provides therefore the networking and communication support to create an underwater heterogeneous network [20], [21] and to deliver data to the different underwater devices. It also provide the tools to remotely control and operate the underwater nodes via single-hop and multi-hop acoustic transmissions [16], [17], [22].

III. BACK-SEAT DRIVER

A. System Description

The implemented mechanism provides the support to remotely configure and control the experiments in an underwater network, considering scenarios where there is no direct access to all the nodes in the network after their deployment.

No master/slave approach is assumed and no preliminary information on the network status and connectivity are needed. The control information are delivered in the network using the networking and communication capabilities provided by SUNSET, which support the use of unicast, multicast and broadcast transmissions. Additional modules have been implemented allowing to remotely operate the underwater devices and control the tests to investigate. More specifically, as presented in Figure 2, one SUNSET instance is always active on the node running in “control mode”, with a control module, named back-seat driver, operating at the application layer. It provides the user all the tools to remotely control and reconfigure the experiments to run. Once the back-seat driver receives a control message, it extracts the user request and starts (stops) a second instance of SUNSET, running in “standard mode” according to the requested information. It replies also to the sender about the correct execution of the request. Each node can act as relay and forward the request/response messages to the other nodes in the network according to the protocol stack selected for the back-seat driver. The implemented back-seat driver allows also to monitor the status of each node in the network when running experiments, thus ensuring a full control on the on going test.

A direct access to at least one node in the network is required which is used to instruct all the other nodes. If multiple nodes with a direct access are available, the user can easily make use of some or all of them to interact with the underwater network and to monitor the node responses about status and correct configuration of the required test.

The protocol stack solution selected for the back-seat driver has to be configured before the network deployment and cannot be changed at run time. However, since the back-seat driver runs a SUNSET instance, all the different protocol stack solutions provided by the framework can be used, with the possibility to have also multiple protocols running at each layer if adaptive policies are considered. The solutions that best fit the user requirements can be therefore selected, according to the given scenario and the expected underwater channel conditions.

When selecting the back-seat driver protocol stack, we have to consider that each control message it transmits, to instruct and control all the nodes in the network (or a subset of them), is really important and has to be correctly delivered to the intended node(s). Robust solutions should be therefore preferred for this control mechanism even if they introduce a higher overhead. On the other hand, a limited amount of control messages should be transmitted in the channel to avoid possible interference with the running test.

In the implemented control architecture, the two SUNSET instances (control mode and standard mode) have to share the same acoustic device, unless two different modems are available at each node. Although the solution of having two modems is supported by our system it would result in higher
costs. We have therefore implemented an additional module, named “multiplexing layer”, which allows a correct interaction between the two SUNSET instances and the acoustic modem, as shown in Figure 2. The multiplexing layer receives the information from these two instances and allows that only one of them interacts with modem at a given time. Moreover, it is responsible to mark each data flow coming from the SUNSET instances as control flow or standard flow. When a message coming from the modem is received, i.e., reception of a data packet or response to a requested action, the multiplexing layer forwards it to the correct instance according to the information mark.

A TCP connection is used for the interaction between each SUNSET instance and the multiplexing layer, while different connections (serial line, TCP, etc.) can be used between the multiplexing layer and the acoustic modem, according to the specific modem requirements. The operations performed by the multiplexing layer could be also embedded at the modem level. In such a case, this layer can be removed and the two SUNSET instances can be directly connected to the acoustic modem using two different communication lines. An example of such a configuration is represented by the Evologics modem with Ethernet connection [23]. It provides the possibility to have multiple connections to the modem using several TCP streams with different port numbers and it also forwards the different data flows according to the used communication port.

B. Operational use

To avoid any possible interference between the control messages used to start a new test and the actual test transmissions, the user can decide to introduce at run time an arbitrary delay to the beginning of the requested test. In this way all the control information (request and response messages) to configure and start the experiment can be delivered in the network before the actual experiment begins. Moreover, when the user starts a new test an identification number is assigned to it (Run ID). This ID is then used to stop and monitor the ongoing test, and to ensure that all the intended nodes are running the same experiment. Each node that receives a request message checks whether it is the destination of the packet. If it is the case, it executes the requests and replies about the status of the action. Otherwise, it forwards the received request according to its routing policy. When a start request is received, each response message will contain one of the following status notifications: OK, if the experiment has been correctly started; ERROR, if an error occurred; RUNNING, if the requested test is already running at the node. If a node receives multiple requests to start the same experiment, due to the reception of duplicated packets, it only considers the first one and ignores the others. Similarly, when a node receives a request message to stop a given test, the response message will notify if the test has been correctly stopped, if it has been already stopped or if an error occurred. Additionally, in case of a status request, the receiving node will reply with a message containing the ID of the test currently running at the node, if any, or notifying that no experiment is currently on going.

To reduce the amount of information transmitted in the network by the back-seat driver, two different options are available when starting a new test: 1) The configuration settings for the experiment can be selected by the user, compressed (to reduce the size of the acoustic message) and then transmitted in water; 2) the information about the different experiments to run can be saved in a configuration file at each node and only the ID of the selected test is then transmitted in the network, allowing each node to identify what configuration has to be loaded from the file.

The first option requires larger messages to be transmitted in water but it allows the user to select all the parameters it is interested in at run time. The second option allows to reduce the message payload to the few bits needed to express the maximum value of the experiment ID, but it requires to pre-load all the settings for the different tests before the nodes are deployed. The user can, however, use both these options: Pre-loading the configuration information for the planned tests and then selecting at run time the additional configuration to investigate, based on the collected results and the observed underwater channel conditions.

Table I contains a complete list of all the settings currently supported by the back-seat driver mechanism. For both of the options described above, the user does not have to specify all the settings but only the ones it is interested in.

Table I: Test configuration settings

<table>
<thead>
<tr>
<th>Experiment parameters</th>
<th>Run ID</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sink ID, if any</td>
</tr>
<tr>
<td></td>
<td>Data sources</td>
</tr>
<tr>
<td></td>
<td>Traffic type (CBR - Poisson)</td>
</tr>
<tr>
<td></td>
<td>Traffic load (CBR period - λ)</td>
</tr>
<tr>
<td></td>
<td>Test start delay</td>
</tr>
<tr>
<td></td>
<td>Data packet length</td>
</tr>
<tr>
<td></td>
<td>Debug level</td>
</tr>
<tr>
<td></td>
<td>Collect statistics (Yes or No)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Protocol stack</th>
<th>Application layer(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Routing layer(s)</td>
</tr>
<tr>
<td></td>
<td>MAC layer(s)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Protocol parameters</th>
<th>Application: depending on the selected solution(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Routing: depending on the selected solution(s)</td>
</tr>
<tr>
<td></td>
<td>[static routes, probability of forwarding, etc.]</td>
</tr>
<tr>
<td></td>
<td>MAC: depending on the selected solution(s)</td>
</tr>
<tr>
<td></td>
<td>[back-off type (linear/exponential), use ACK or not,</td>
</tr>
<tr>
<td></td>
<td>maximum control message retry, maximum data</td>
</tr>
<tr>
<td></td>
<td>message retry, slot time for slotted solution, etc.]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Modem parameters (according to the modem)</th>
<th>Modem type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transmission power</td>
</tr>
<tr>
<td></td>
<td>Transmission mode</td>
</tr>
<tr>
<td></td>
<td>Message format</td>
</tr>
<tr>
<td></td>
<td>Others</td>
</tr>
</tbody>
</table>

It is useful to point out, however, that using the capability
provided by SUNSET to compress the transmitted information, the larger request message to configure and start a test, according to Table I, results in a packet payload shorter than 15 Bytes. This means that, even selecting all the settings at run time introduces limited overhead and that, according to the maximum packet length supported by the current acoustic modems, there is still a lot of space to include additional parameters to the configuration list.

IV. SYSTEM VALIDATION

The proposed approach has been successfully tested considering different environmental conditions (sea, lake and fjord environments) and network configurations, making use of different underwater nodes and communication devices. The back-seat driver mechanism has been used in three in field campaigns conducted during 2012: 1) The NATO CommsNet12 sea trial, carried out by the NATO Centre for Maritime Research and Experimentation (CMRE); 2) The Werbellin lake tests conducted in collaboration with Evologics GmbH; 3) The Oslofjord tests conducted within the EU FP 7 STREP project CLAM “CoLlAborative EMbedded Networks for Submarine Surveillance” [24].

The NATO CommsNet12 and Oslofjord tests have been performed under a collaboration between the University of Rome and CMRE and between the University of Rome and the CLAM project, respectively. The Werbellin lake tests instead have involved people from Evologics GmbH, University of Rome and WSENSE [25].

Table II shows the locations of the LOON nodes (M1, M2, M3 and M4), the location of the Gateway device (GW) and the other locations used to deploy the additional nodes on a temporary basis: WG, is the position where the WaveGlider was circling around during most of the routing experiments;

Figure 3: Pictures from the NATO Commsnet12 sea trial.
AUV1, AUV2 and AUV3 are the positions where the eFolagas were moored during the overnight experiments; Alliance is the position of the NRV Alliance, acting as sink for most of the routing tests. Figure 4 shows the operational area and locations of the different nodes and reference points.

Table II: Locations used during the sea trial

<table>
<thead>
<tr>
<th>ID</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>44°02′24.4″N</td>
<td>9°50′04.5″E</td>
<td>27.5m</td>
</tr>
<tr>
<td>M2</td>
<td>44°01′49″N</td>
<td>9°49′23″E</td>
<td>28.5m</td>
</tr>
<tr>
<td>M3</td>
<td>44°02′90.9″N</td>
<td>9°50′23.7″E</td>
<td>27.5m</td>
</tr>
<tr>
<td>M4</td>
<td>44°02′24.4″N</td>
<td>9°49′52.2″E</td>
<td>28m</td>
</tr>
<tr>
<td>GW</td>
<td>44°01′96.7″N</td>
<td>9°50′0.60″E</td>
<td>15m</td>
</tr>
<tr>
<td>WG</td>
<td>44°02′53.8″N</td>
<td>9°49′48.5″E</td>
<td>5m</td>
</tr>
<tr>
<td>AUV1</td>
<td>44°01′60.6″N</td>
<td>9°49′92.7″E</td>
<td>30m</td>
</tr>
<tr>
<td>AUV2</td>
<td>44°01′67.9″N</td>
<td>9°50′40.6″E</td>
<td>30m</td>
</tr>
<tr>
<td>AUV3</td>
<td>44°02′18.3″N</td>
<td>9°49′52.7″E</td>
<td>30m</td>
</tr>
<tr>
<td>Alliance</td>
<td>44°01′34.9″N</td>
<td>9°50′33.9″E</td>
<td>15m</td>
</tr>
</tbody>
</table>

The LOON was controlled by a Desktop PC on shore, for all the other nodes IGEPv2 [19] boards were used. SUNSET was installed on all the different devices and used to configure and run the different network protocols and to control the modem operations. The number of nodes involved in the different experiments was ranging from 4 to 11, including static and mobile nodes.

During the NATO CommsNet12 sea trial the implemented back-seat driver has been used to acoustically interact, instruct and configure all the nodes in the network for the investigation of several tests involving different routing protocols (flooding, an improved version of the routing solution presented in [12], and CARP [8]), MAC solutions (CSMA [9] and TDMA) and different parameter settings. The back-seat driver mechanism has allowed to run several tests without the need to retrieve, reconfigure and redeploy any of the nodes in the network when switching from one test to the other. Evologics acoustic modems S2C R 18/34 [23] with Ethernet connection were used for data transmissions. No multiplexing layer has been used during these experiments since the functionality of handling different incoming data flows was already provided by the Evologics modems.

The node on the NRV Alliance, which was cabled to the modem deployed on side of the ship, has been always used as control unit to instruct the other nodes in the network. Additionally, a radio connection to other nodes was available during the tests (LOON nodes, GW, WG) and these nodes have been used as additional points to transmit and receive the control messages. However, due to some power issues and bad radio connection, in most of the cases only the NRV Alliance and the Gateway (GW) buoy have been used to instruct the other nodes in the network via acoustic links.

The maximum number of hops traversed by the control messages has been 4 with a maximal distance among the nodes in the network of about 3km. The protocol stack selected for the back-seat driver (flooding and CSMA) has been really robust in delivering all the control messages to the intended receivers. In some cases few retransmissions have been triggered by the NRV Alliance and the GW nodes due to missing response messages from some of the other nodes, even if in most of the cases these nodes had already received the request messages and started the experiments. In all the considered tests the SUNSET back-seat driver mechanism has been able to reconfigure the network, start and stop each test in less than 20 seconds. A conservative initial delay of 50 seconds has been added to the beginning of each test to avoid any interference between back-seat driver messages and test messages.

During the NATO CommsNet12 sea trial, the main benefits of using the back-seat driver mechanism have been: 1) The possibility to easily operate a network composed by several underwater assets without the need to retrieve any of the devices; 2) The possibility to run multiple overnight tests investigating different protocol stacks and parameter configurations without the need of personnel at sea physically operating the nodes, which could have been difficult or even impossible. Everything has been done remotely from the NRV Alliance using acoustic links; 3) The possibility to save time and money avoiding the need of any intervention on the network after the deployment. All the operations to switch from one test to another have been remotely completed in few tens of seconds without the need of any personnel or the use of additional resources (rubber boats, ships, etc.)

B. Werbellin lake

Additional tests to validate the proposed back-seat driver mechanism and to evaluate its performance have been conducted at the end of October 2012 in the Werbellin Lake (Figure 5a), near Berlin, Germany.
Five moored Evologics acoustic modems S2C R 18/34 (WiSE and standard editions - Figure 5b) with Ethernet connection have been deployed in the lake according to Figure 6. The maximal depth for the deployed nodes was about 25 meters and the distance between each node and the next one in the sequence was ranging between 130m and 220m.

All the nodes were battery powered and SUNSET was installed inside the embedded developer sandbox available at each node. Node1 and Node5 were not able to directly communicate to each other. Node5 was able to communicate to Node3 and Node4 using a single-hop transmission and it experienced a really poor acoustic link to Node2. Node1 instead was able to directly communicate to Node2 and Node3 with almost no acoustic link to Node4.

The back-seat driver mechanism has been used to remotely instruct the entire network to start, stop and monitor several experiments investigating the performance of different routing solutions (two different flooding approaches) and different MAC protocols (CSMA [9], T-Lohi [10] and Slotted CSMA) when delivering data between Node1 and Node5. A direct access was available to Node1, connected to a PC on a small pier, and to Node5 cabled to a PC on board of a small boat. However, only Node5 (Figure 5c) has been used to acoustically instruct the other nodes in the network. Again, no multiplexing layer has been used since the needed functionality was already provided by the Evologics modem.

All the information have been delivered in the network using multi-hop transmissions with a maximum number of traversed hops equal to 3. In all the considered tests the SUNSET backseat driver mechanism has been able to reconfigure the nodes in the network, start and stop each test in less than 12 seconds. A conservative initial delay of 30 seconds has been added to the beginning of each test to avoid any interference with the started test.

During the Werbellin lake trial, a complete set of experiments has been investigated considering two different routing protocols, three MAC solutions and four traffic loads, resulting in a total of 24 different configurations. Each test lasted for about 12-15 minutes with almost six hours of continuous testing. The use of the back-seat driver mechanism has allowed to run all these tests in less than six hours in a network where several underwater nodes were deployed without any direct access to them. Only few tens of seconds have been needed between the stop of a test and the start of a new one. Without such a mechanism and with the need to retrieve, reconfigure and redeploy the nodes after each test, probably more than twelve hours (twice the time needed using the back-seat driver) would have been required to complete the same set of tests. Moreover, without the need to redeploy the nodes, no changes in the topology configuration have been introduced allowing for a more fair comparison of the performance of the different investigated protocols.

C. Oslofjord

Additional tests validating the use of the implemented back-seat driver have been conducted in the Oslofjord in front of Horten, Norway (Figure 7a) in November 2012. Four cNode Kongsberg modems [27] have been used (Figure 7b), three of
them deployed at a depth of 200m and the fourth one deployed on side of a ship moving on top of the other nodes, as depicted in Figure 8. The node on the ship has been used as the control point to instruct the other nodes in the network. Node2 and Node3 were quite close to each other (about 200m apart) while Node1 was deployed about 800m apart from Node2 and Node3. All nodes were battery powered and the ones deployed on the sea floor were equipped with acoustic releases for node recollection. Each of these nodes was also equipped with a floating collar to bring the nodes to the surface after the activation of the release, resulting in an overall weight for each node of more than 50 kg. Inside each node a Gumstix Overo embedded device [18] was installed and it was used to run the SUNSET framework and interact with the acoustic modem.

The purpose of the experiment has been to investigate the networking protocol solutions used within the CLAM project. The back-seat driver mechanism has been therefore used to remotely control and reconfigure the entire network, allowing to test different MAC (Underwater Polling [28] and CSMA [9]) and routing (SUN [3] and CARP [8]) solutions.

To interact with a cNode Kongsberg modem a serial line connection is required, meaning that the cNode does not support any multiplexing functionality. The implemented multiplexing layer has been therefore used to separate the control and standard flows of information and to regulate the interaction and message exchange between SUNSET and the modem.

During the different investigated tests, the back-seat driver has been also used to collect status information on the different modems and to activate the acoustic releases and bring the nodes to the surface at the end of the trial. To accomplish these tasks, an additional SUNSET module specifically designed for the cNode Kongsberg modem has been developed.

The back-site driver mechanism has provided again a robust and flexible solution for the interaction and reconfiguration of the network after its deployment, allowing to configure and start each test in less than 12 seconds.

This mechanism has been particularly useful during the Oslofjord tests because, given the weight of the nodes equipped with the floating collar, ship operations, personnel and time were needed to deploy and recollect each of these nodes. Without such a mechanism a big portion of the ship time and of the time reserved for the experimental activities would have been used to prepare the tests, i.e., retrieving, reconfiguring and redeploying the nodes, rather than to actually run the tests and collect the results. The use of the back-seat driver mechanism has allowed to remotely interact and operate the entire network in an easy and fast way, investigating the different tests without the need of any special operation when switching from one test to another. It has also allowed to significantly reduce the costs and logistic complexity of the conducted experiments.

V. CONCLUSIONS

We have described the implementation and use of a back-seat driver mechanism which allows to remotely control and reconfigure an underwater network without the need of a direct access to all the nodes after their deployment. This mechanism makes use of the networking and communication capabilities
provided by the SUNSET framework to address the different devices in the network, via single-hop and multi-hop acoustic transmissions. SUNSET has been extended allowing to acoustically control, configure and run several experiments of different complexities in an easy and fast way.

The presented back-seat driver is a really flexible solutions. It overcomes some of the limitations of the previously proposed system, reducing the amount of information needed to control the network and avoiding the need of any preliminary knowledge on the network status and connectivity.

The proposed system has been tested and evaluated during three different campaigns conducted in 2012, working with static and mobile nodes. Different computational platforms have been used to run the back-seat driver mechanism, considering various network topologies and deployments, and making use of different communication devices. The presented back-seat driver mechanism has been used to start, stop and monitor several experiments investigating the use of different MAC and routing protocols and of several parameters settings.

All the conducted tests have shown the reliability, robustness and efficiency of the proposed solution. In all the considered cases the back-seat driver has been able to remotely reconfigure all the nodes in the network in less than 20 seconds, instructing underwater nodes several hops apart, and covering areas of several kilometers. Moreover, given its open architecture, it provides the possibility to easily support the investigation of novel protocols and additional parameters configurations.

ACKNOWLEDGMENTS

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