Management of Surveillance Underwater Acoustic Networks

Michel Barbeau(✉), Zach Renaud, and Wenqian Wang

School of Computer Science, Carleton University Ottawa, Ontario K1S 5B6, Canada
barbeau@scs.carleton.ca, {ZachRenaud,wenqianwang}@cmail.carleton.ca

Abstract. A Surveillance Underwater Acoustic Network (SUAN) is a sensor network specialized in the detection of sea surface or subsurface physical intruders, e.g., seagoing vessels. Network management provides the ability to remotely monitor and update the state of SUAN nodes. It is a crucial feature because of the difficulty of physical access once they have been deployed in sea or underwater. We explore three network management approaches: out-of-band, in-band and bio-inspired. Out-of-band management assumes the availability of high-speed wireless channels for the transport of management messages. The acoustic bandwidth of the SUANs is not directly used. In-band management uses the low date rate and short range underwater acoustic communication paths. Network management traffic is mixed together with data traffic. The bio-inspired approach does not require management traffic. Learning-by-imitation is used to transfer the settings node-to-node. It is useful in cases where it is really hard to convey information using messages because of harsh conditions.

Keywords: Surveillance underwater acoustic network · Sensor network · Sensor network management · Underwater acoustic communications · Network management · Routing · Bio-inspired network management

1 Introduction

A Surveillance Underwater Acoustic Network (SUAN) is a sensor network specialized in the detection of sea surface or subsurface physical intruders. Physical intruders are seagoing vessels. They are detected using acoustic and magnetic sensors. Transgressors produce acoustic noise and magnetic perturbations. The acoustic detection range is in the order of kilometers. The magnetic detection range is in the order of a fraction of a kilometer. When a presence is detected, alarms are produced. They are forwarded to a sink. SUANs involve deployment of underwater sensors, communication nodes and gateway buoys, playing the roles of sinks. Acoustic waves are used for underwater communications.

Once they are deployed in sea or underwater, physical access to SUAN nodes becomes difficult or literately impossible. Network management provides the ability to remotely monitor and update the state of nodes. It comprises getters

Y. Zhou and T. Kunz (Eds.): ADHOCNETS 2016, LNICST 184, pp. 3–14, 2017.
DOI: 10.1007/978-3-319-51204-4_1

(e.g., data rate selection), setters (e.g., interface shutdown) and data models of managed information. It aims at automation and scalability. Classical network management approaches include remote login, Web interface, management protocol, such as Simple Network Management Protocol (SNMP) [10], and software-defined network.

We have explored out-of and in-band SUAN management. Out-of-band management assumes the availability of high-speed wireless channels for the transport of messages. The acoustic bandwidth of the SUANs is not directly used. Gateway buoys have this capability. To reach seabed sensors, in-band management is required. The acoustic bandwidth of the SUANs is used, that is, the low data rate and short range underwater acoustic communication paths. Management and data traffic are mixed together.

Our out-of and in-band network management work is integrated in our GNU Radio [1] Location-free Link State Routing (LLSR) protocol implementation [6, 7, 27, 33]. For out-of-band management, we use the popular and well supported SNMP. In every node, an agent, in conjunction with a translation and state management layer, handles incoming requests that retrieve or modify the state of variables. The state of a node can be accessed and modified through a myriad of available client side tools. On the hand, SNMP is a protocol designed for the Internet. It generates too much overhead with respect to the capacity of underwater communication channels.

For in-band management, there are two main issues. Firstly, given the low bandwidth of underwater acoustic paths, management messages need to be small. Secondly, in sensor networks, the flow of traffic is optimized for the sensor-to-sink direction. Management messages are expected to flow in the opposite direction. We create small management messages. We leverage the protocol elements of LLSR and augment it with a simple strategy for the transport of management traffic from sinks to sensors.

There are instances where underwater communications are very difficult. Solely few bytes can be exchanged. For such cases, we investigate a non-classical approach. We propose bio-inspired SUAN management. Every node learns its settings by imitating its neighbors. That approach does not generate traffic overhead.

Background and related work are reviewed in Sect. 2. Out-of-band, in-band and bio-inspired SUAN management are respectively discussed further in Sects. 3, 4 and 5. We conclude with Sect. 6.

2 Background and Related Work

The SUAN concept has been defined by Benmohamed et al. [8], Otnes et al. [25] and Rice et al. [28]. According to Otnes et al. [25], the architecture of a SUAN consists of seabed sensors, communication nodes and gateway buoys. In a SUAN, at least one gateway plays the role of sink. It forwards data, collected by sensors and relayed by communication nodes, to a fusion center. Underwater communications (sensors to communication nodes to gateways) are done using acoustic waves. Gateway-to-fusion center communications are done using electromagnetic waves. With respect to underwater communications, low data rates (in hundreds or thousands bits per second) and short ranges (e.g., 1000 m) are assumed. Small message payloads (e.g., 300 bytes) and small message rates (e.g., lower than one message per second per sensor) are also assumed. Intruder detection strategies that favor low traffic generation are desirable. Hence, issues specific to SUANs include the design of light weight communication protocols and placement of detection data processing functions (e.g., local processing of alarms in sensors versus global processing in fusion centers). The data fusion aspect is investigated in Braca et al. [9]. Underwater communication performance taking into account the various impairments is studied in Huang et al. [17]. The work comprises simulation and sea trial results. The main observation is that bit and packet error rates can be very high, even over short distances.

SUANs use underwater acoustic waves, a mechanical phenomenon. In contrast, terrestrial and space wireless communications are based on an electromagnetic phenomenon. Hence, acoustic waves are generated, propagate and are detected according to rules that differ from the ones of electromagnetic waves. Acoustic waves are produced by mechanical vibrations, a vibrator. Because of the elasticity of water, the resulting acoustic pressure propagates undersea. The detection of the acoustic pressure is done using a hydrophone.

Our research activities comprise an experimental facet. We adopted a software-defined approach. It is ideal for the academic environment because of its open character, flexibility and possibility to software-define low level protocols, i.e., at the physical and link layers. Modems, and accompanying protocols, are implemented in software using GNU Radio. They run in the Linux environment on a mini PC. To interface with the acoustic world, a recording studio-quality sound card is used. The vibrator and hydrophone plug in. In lieu of vibrator, the strength of the signal is raised with an audio power amplifier. It feeds a portable underwater speaker. Both the hydrophone and speaker have long cables that allow operation in depths. Other hardware options are described in the software-defined underwater communication projects of Demirors et al. [12] and Dol et al. [13].

The design of link layer and network layer communication protocols specific to SUANs has been investigated. MAC protocol performance issues are discussed in Otnes et al. [25] and Guerra et al. [16]. In particular, the time correlation between messages from different sensors and their impact in medium access are studied. MAC protocol and power control issues are addressed by Karlidere and Cayirci [19]. The DFLOOD routing protocol for SUANs has been defined by Otnes and Haavik [24], with improvements by Komulainen and Nilsson [21] and simulation work by Austad [4]. Security and clustering are discussed by Islam et al. [18]. The design of jamming resistant routing is investigated by Goetz et al. [15]. A delay tolerant network approach is introduced by Azad et al. [5]. Much of the protocols in commercial hardware are proprietary and vendor specific. JANUS is multiple-access acoustic protocol being standardized by the North Atlantic Treaty Organization (NATO) [2]. The physical layer uses

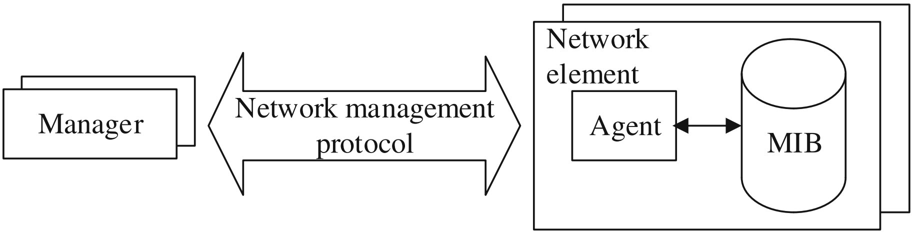

Fig. 1. Generic network management architecture.

frequency hopping transmission and binary frequency shift keying modulation. The link layer follows the carrier sense multiple access with collision avoidance protocol.

Figure 1 shows a generic architecture that most of the network management systems actualize in one way or another. Left side, there is one or several *managers* on which management applications are running. Right side, there are managed *network elements*. On each of them is running a server called the *agent*. The managers and agent communicate together using a *network management protocol*. The protocol is used to transport get and set requests, from the managers to the agents, as well as responses and alarms, in the reverse direction. In each network element there are manageable resources. Each of them is abstracted as a *managed object*. They are all collectively represented in a structure called the *Management Information Base* (MIB). A MIB is a collection of identified managed objects, i.e., constants and variables. They have standard formats. Hence, they look the same across different network elements. A manager controls a network element by inspecting and updating managed objects, using the management protocol. An agent may spontaneously notify a manager when a managed object reaches a condition by sending an alarm.

SNMP [10] is a well established Internet management framework, following the model of Fig. 1. For out-of-band SUAN management purposes, that is, sink node management, the use of SNMP is a good choice. One reason is the availability of a large base of SNMP software tools. For the aim of in-band SUAN management, i.e., submersed nodes, use of SNMP faces the problem of limited underwater acoustic bandwidth. Indeed, SNMP messages are not short. SNMP involves three layers of encapsulation (UDP, IP and data link). These three layers prefix each SNMP message with at least 50 bytes $(16 + 20 + 14)$ of headers. The size of a SNMP message is variable. Depending on the version and exact operation being performed, a SNMP message easily consists of a few tens of bytes.

To the best of our knowledge, the management of SUANs has received little attention in the scientific literature. On the other hand, the management of wireless sensor networks has been a research topic [11,14,23,30]. Hereafter, two examples are reviewed. Management Architecture for Wireless Sensor Network (MANNA), by Ruiz et al. [29], is a policy-based system. It collects information, maps it into a network model, executes management functions and provides management services. The policies define management functions that are executed when conditions are met. Management is done by analyzing and updating the MIBs through the MANNA protocol. The sensor nodes are organized into clusters. Each node sends its status to its cluster head. The head is responsible for executing local management functions. It aggregates management data received from sensor nodes, which is forwarded to a base station. Several cluster heads, in a hierarchical architecture, can work together to achieve global network management.

The Sensor Network Management System (SNMS), by Tolle and Culler [32], is an interactive tool for monitoring the health of sensor networks. It has two main functions: query-based health data collection and event logging. Query functions retrieve and oversee the parameters of each node. The event-driven logging function set the parameters of the nodes. The nodes report data according to the values of dynamically configured thresholds. SNMS supports collection and dissemination of traffic patterns.

3 Out-of-Band Network Management

We investigated out-of-band management of SUANs [27]. For the purpose of compatibility with our work on software-defined communications and LLSR [7], it has been implemented in the GNU Radio environment. Given a communication application, a GNU Radio component is embedded to support remote management. A Python based SNMP agent is used above the NET-SNMP library in conjunction with a translation and state management layer to handle requests that retrieve or modify the state of variables within LLSR. SNMP requires the presence of a MIB in order to handle communication between a managed application and an agent. Creating this object database is a crucial task for adding SNMP support where none currently exists. The strength of this approach is that the state of LLSR can be remotely accessed and modified using off-the-shelf client side tools. The downside is the amount of traffic overhead that is required.

4 In-Band Network Management

LLSR forwards packets, produced by sensor nodes and relayed by communication nodes, in the direction of the sink. It is a routing model typical of sensor networks. For the purposes of forwarding, the next hop is selected according to a link-state metric. The sink announces its presence using broadcast beacon packets. Each of them contains the sink address, a hop count (zero, initially) and a numerical value reflecting the quality of the path to it, which for instance may be a degree of redundancy. Near surface underwater nodes, that are the sink one-hop neighbors, receive these beacon packets. They store the three items of information extracted from beacon packets into a neighbor node table. These nodes are now considered connected to the sink. In turn, they produce beacon packets. This procedure is performed repeatedly, hop-by-hop, until leaf sensor nodes are reached and become also connected to the sink through the communication nodes. When the network is fully connected, each node periodically broadcasts beacon packets. Network connectivity is maintained. From its neighbor node table, each node selects a next hop node, for packet forwarding.

To integrate in-band network management into LLSR, the sink node becomes responsible of forwarding management messages down to sensors and collecting the management data they produce. Each node has a SNMP-inspired agent to handle the management requests. There is also a MIB mapping abstract managed objects to actual resources. LLSR has been extended with four main protocol elements. Firstly, the management messages that are generated by the sink node reach their destination using network flooding. Secondly, the delivery of management packets to their final destination is confirmed. In third place, management response messages may be returned to the sink. Finally, management messages are authenticated and integrity checked.

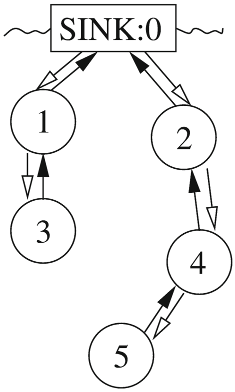

Fig. 2. Data packet forwarding.

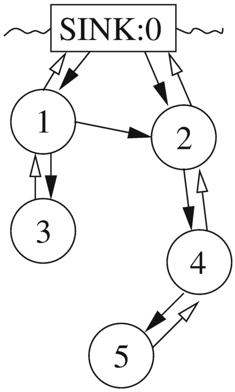

Fig. 3. Management message forwarding.

Figure 2 illustrates the flow of data traffic. Black-end arrows indicate data packets. Their sources are sensors, node 5in this example. Figure 3 shows the flow of management traffic. Black end arrows indicate management messages. Their source is the sink. In both figures, white-end arrows are acknowledgments. For data traffic, the data collected by each node is forwarded upward to the sink (node 0). For management message routing, Fig. 3 illustrates network flooding. Each node repeats once every management packet it receives. In Fig. 3, nodes 0 and 1 both deliver the same management message to node 2. At node 2, when it is received for the first time, the message number and arrival time are recorded in a table. An acknowledgment is sent to node 0. When the same management message is received for the second time, a table lookup performed by message number succeeds. The management message is ignored.

Fig. 4. Management packet structure.

In each node, there is an agent for handling management messages. The agent has a MIB for mapping abstract managed objects to network parameters. The handling of a management message results into a response upward forwarded to the sink. The management packet structure is shown in Fig. 4. Each field is one byte, for a total of nine bytes. Management messages are short because of the low data rate of acoustic communications. `PROTO ID` is the identifier of the management protocol. `PKT SRC` is the address of the sender. `MGMT TRACK` is the tracking number of the management packet. `MGMT ORG` is the address of the management message origin sink. `DEST` is the address of the destination node. The default of field `VALUE` is zero. It is used to store a value accompanying a set operation. `OPT` indicates the type of management operation: a set (1) or a get (0). `OID` is the identifier of the managed object on which the operation is performed. `HASH VALUE` is an authentication field. The sink node shares a unique secret key with each network node. It is used to generate the value of the authentication field.

5 Bio-inspired Network Management

The use of the bio-inspired approach for distributed decision making in wireless networks has been discussed by Barbarossa and Scutari [3]. Hereafter, we use the approach for SUAN management purposes. With respect to out-of or in-band management, the bio-inspired approach does not generate traffic overhead. We leverage *learning-by-imitation*. It is used in robotics [22,31]. In the context of SUANs, a managed node acquires and updates its configuration by observing and replicating the behavior of other nodes. The network configuration parameters are transferred node-to-node without the use of network management messages.

Learning-by-imitation makes sense in networks in general because nodes must consistently apply a similar behavior. Epitomes are protocol elements such as the transmit probability and request-clear to send exchange in data link multiple access with collision avoidance.

Learning-by-imitation involves a teacher-observer relation. Figures 5 and 6 illustrate two possibilities. In both figures, an arrow represents a teacher-observer relationship, which is enabled when two nodes are within communication range. In Fig. 5, it is address-based. Each node has a numerical address. Node zero is the sink. There is a teacher-observer relationship when the address of the former is lower than the one of the latter. In Fig. 6, it is according to depth. There is a teacher-observer relationship when the depth of the former is lower than the one of the latter. Depth information needs to be available. Each node needs the ability to determine its depth and to learn the depths of neighbors. Note the

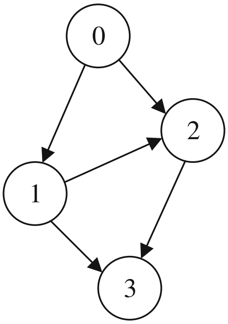

Fig. 5. Teacher-observer relation by address.

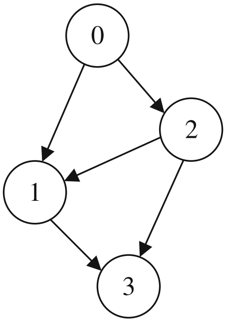

Fig. 6. Teacher-observer relation by depth.

inversion of the relationship between nodes one and two. In both cases, the goal is to establish a teacher-observer relation tree rooted at the sink. Establishment of a hierarchy is a typical animal behavior.

Figure 7 shows an example. It is about the beacon broadcast period. It is a parameter of LLSR. During the SUAN operation, the teacher periodically sends beacons. An observer collects traffic traces of the teacher. The observer measures beacon-to-beacon time differences. In Fig. 7, the x axis represents observation points. The y axis represents time values, in seconds. For each point, the actual period applied by the teacher is shown as a diamond, in seconds. For the first 20 points, the actual beacon period is one second. For the next 20 points, it is three seconds. For the last 20 points, it is two seconds. Because of various factors, such as processing time, the observations are noisy. In this example, zero mean white Gaussian noise and a signal-to-noise ratio of 22 dB are assumed. The noisy observations are shown as hollow circles. The observer uses the theory of system identification to estimate the value of the parameter from the observations [20]. System identification is about the construction of mathematical models of dynamic systems using collected observations. More particularly, on-line estimation algorithms have the ability to determine the parameters in reaction to the availability of data during the operation of a system. In Fig. 7, it is a problem of *time-varying parameter tracking*. The *recursive least-squares* algorithm is used [20]. The estimate resulting from each observation point is shown as a filled circle. The observer uses the current estimate to set the value of its own beacon broadcast period.

For comparison purposes, Fig. 7 plots as yellow circles the calculation of beacon periods from observations using a moving average equation. Figure 8 shows the Root Mean Square Error (RMS), as a function of the observation point, of the estimates using the recursive least-squares algorithm (diamonds) and moving average (circles). The RMS of the former is always substantially better than the one of the latter.

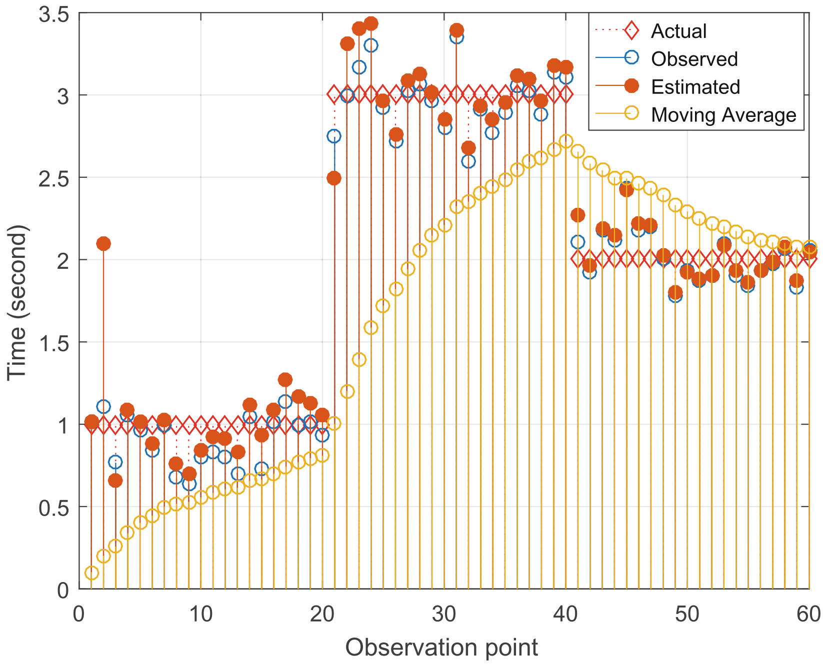

Fig. 7. Time-varying parameter tracking using the recursive least squares algorithm. (Color figure online)

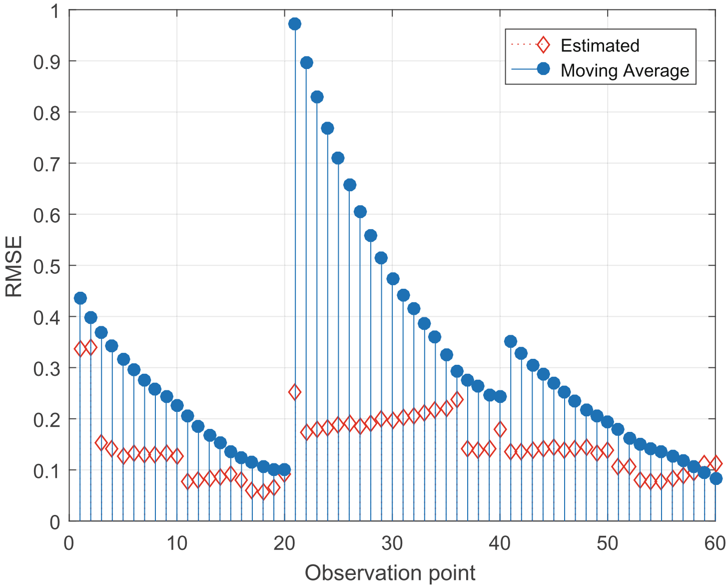

Fig. 8. Root mean square error (RMSE).

6 Conclusion

SUAN is an emerging area. It has been present in the literature only for a few years. Most of the projects, that have been published, discuss deployments of handful numbers of nodes. Much larger systems are expected in the future, as the technology will be perfected. The Internet type of communication protocols work solely for elements of SUANs with classical wireless access. SUAN specific protocols are required for submerged node communications. Interoperability between components from different sources is desirable. However, little standardization work has been accomplished so far.

Building SUANs is an important problem. Planning mechanisms enabling fine tuning their operation after their deployment is equally important. Physical access to SUAN elements may become very challenging as they may have to be recovered from the seabed. We have explored out-of-band, in-band and bio-inspired SUAN management. Out-of-band management is applicable to nodes that are directly accessible over a wireless channel, i.e., gateway buoys which are not entirely submersed. The approach leverages the vast amount of available SNMP tools. The work essentially amounts to defining and implementing a MIB, which we have demonstrated for the LLSR protocol. The disadvantage is the high traffic overhead for this context. For submersed communication nodes and sensors, we have developed an in-band management approach. The underwater acoustic bandwidth is used and shared with normal data traffic. Because of the low data rates and unreliable links, a light weight solution is highly desirable. Another aspect of the problem is the fact that the nature of the traffic in sensor networks is asymmetric, sensor to sinks. Sensor network routing protocols are designed for that traffic model. The solution we propose comprises short messages and leverages the protocol elements defined in the host routing protocol, which is LLSR in the example discussed in this paper. Our ideas have bee implemented, simulated and tested [6,7,27,33]. We have established the foundations of bio-inspired SUAN management. Nodes adopt the behavior of neighbors higher in a hierarchy. They learn and imitate their behavior. No management traffic required. Further work is needed to find strategies for learning the settings for various kinds of managed objects.

References

1. GNU radio - the free and open software radio ecosystem. gnuradio.org. Accessed June 2016
2. JANUS wiki. www.januswiki.org. Accessed June 2016
3. Abdolee, R., Champagne, B., Sayed, A.H.: Diffusion adaptation over multi-agent networks with wireless link impairments. IEEE Trans. Mob. Comput. **15**(6), 1362–1376 (2016)
4. Austad, H.: Simulation of subsea communication network. Master's thesis, University of Oslo, Department of Informatics, Norway (2003)
5. Azad, S., Casari, P., Zorzi, M.: Coastal patrol and surveillance networks using AUVs and delay-tolerant networking. In: OCEANS, pp. 1–8, May 2012

6. Barbeau, M.: Location-free Link State Routing (LLSR) implementation for GNU Radio (2016). http://www.github.com/michelbarbeau/gr-llsr.git. Accessed Apr 2016
7. Barbeau, M., Blouin, S., Cervera, G., Garcia-Alfaro, J., Kranakis, E.: Location-free link state routing for underwater acoustic sensor networks. In: 28th Annual IEEE Canadian Conference on Electrical and Computer Engineering (CCECE), Halifax, Nova Scotia, Canada, May 2015
8. Benmohamed, L., Chimento, P., Doshi, B., Henrick, B., Wang, I.J.: Sensor network design for underwater surveillance. In: IEEE Military Communications Conference (MILCOM), pp. 1–7, October 2006
9. Braca, P., Goldhahn, R., Ferri, G., LePage, K.: Distributed information fusion in multistatic sensor networks for underwater surveillance. IEEE Sens. J. **16**(11), 4003–4014 (2016)
10. Case, J., Fedor, M., Schoffstall, M., Davin, J.: Simple network management protocol (SNMP), RFC 1157. rfc-editor.org/rfc/rfc1157.txt
11. de Oliveira, B.T., Margi, C.B., Gabriel, L.B.: TinySDN: enabling multiple controllers for software-defined wireless sensor networks. In: IEEE Latin-America Conference on Communications (LATINCOM), pp. 1–6, November 2014
12. Demirors, E., Sklivanitis, G., Melodia, T., Batalama, S.N., Pados, D.A.: Software-defined underwater acoustic networks: toward a high-rate real-time reconfigurable modem. IEEE Commun. Mag. **53**(11), 64–71 (2015)
13. Dol, H., Casari, P., van der Zwan, T.: Software-defined open-architecture modems: historical review and the NILUS approach. In: Underwater Communications and Networking (UComms), pp. 1–5, September 2014
14. de Gante, A., Aslan, M., Matrawy, A.: Smart wireless sensor network management based on software-defined networking. In: 27th Biennial Symposium on Communications (QBSC), pp. 71–75, June 2014
15. Goetz, M., Azad, S., Casari, P., Nissen, I., Zorzi, M.: Jamming-resistant multi-path routing for reliable intruder detection in underwater networks. In: Proceedings of the Sixth ACM International Workshop on Underwater Networks (WUWNet), p. 10 (2011). Observation of strains. Infect Dis. Ther. **3**(1), pp. 35–43, pp. 1–10. ACM, New York, NY, USA
16. Guerra, F., Casari, P., Zorzi, M.: MAC protocols for monitoring and event detection in underwater networks employing a FH-BFSK physical layer. In: Proceedings of IACM UAM (2009)
17. Huang, J., Barbeau, M., Blouin, S., Hamm, C., Taillefer, M.: Simulation and modeling of hydro acoustic communication channels with wide band attenuation and ambient noise. Int. J. Parallel, Emergent Distrib. Syst. dx.doi.org/10.1080/17445760.2016.1169420 (2016)
18. Islam, M.R., Azad, S., Morshed, M.M.: A secure communication suite for cluster-based underwater surveillance networks. In: International Conference on Electrical Engineering and Information Communication Technology (ICEEICT), pp. 1–5, April 2014
19. Karlidere, T., Cayirci, E.: A MAC protocol for tactical underwater surveillance networks. In: IEEE Military Communications Conference (MILCOM), pp. 1–7, October 2006
20. Keesman, K.J.: System Identification - An Introduction. Springer, London (2001)
21. Komulainen, A., Nilsson, J.: Capacity improvements for reduced flooding using distance to sink information in underwater networks. In: Underwater Communications and Networking (UComms), pp. 1–5, September 2014

22. Lopes, M., Santos-Victor, J.: A developmental roadmap for learning by imitation in robots. IEEE Trans. Syst. Man Cybern. Part B Cybern. **37**(2), 308–321 (2007)
23. Luo, T., Tan, H.P., Quek, T.Q.S.: Sensor OpenFlow: enabling software-defined wireless sensor networks. IEEE Commun. Lett. **16**(11), 1896–1899 (2012)
24. Otnes, R., Haavik, S.: Duplicate reduction with adaptive backoff for a flooding-based underwater network protocol. In: OCEANS - Bergen, 2013 MTS/IEEE, pp. 1–6, June 2013
25. Otnes, R., Voldhaug, J.E., Haavik, S.: On communication requirements in underwater surveillance networks. In: OCEANS 2008 - MTS/IEEE Kobe Techno-Ocean, pp. 1–7, April 2008
26. Porter, M.B.: The KRAKEN normal mode program (draft). http://www.oalib.hlsresearch.com/Modes/AcousticsToolbox/manual/kraken.html. Accessed 20 Apr 2015
27. Renaud, Z.: Network management for software defined radio applications. Honours project report, School of Computer Science, Carleton University. http://www.github.com/michelbarbeau/gr-llsr/blob/master/docs/ZachRenaud.pdf. Accessed Apr 2016
28. Rice, J., Wilson, G., Barlett, M., Smith, J., Chen, T., Fletcher, C., Creber, B., Rasheed, Z., Taylor, G., Haering, N.: Maritime surveillance in the intracoastal waterway using networked underwater acoustic sensors integrated with a regional command center. In: International Waterside Security Conference (WSS), pp. 1–6, November 2010
29. Ruiz, L.B., Nogueira, J.M., Loureiro, A.A.F.: MANNA: a management architecture for wireless sensor networks. IEEE Commun. Mag. **41**(2), 116–125 (2003)
30. Sayyed, R., Kundu, S., Warty, C., Nema, S.: Resource optimization using software defined networking for smart grid wireless sensor network. In: 3rd International Conference on Eco-friendly Computing and Communication Systems (ICECCS), pp. 200–205, December 2014
31. Schaal, S.: Is imitation learning the route to humanoid robots? Trends Cogn. Sci. **3**(6), 233–242 (1999)
32. Tolle, G., Culler, D.: Design of an application-cooperative management system for wireless sensor networks. In: Proceeedings of the Second European Workshop on Wireless Sensor Network, pp. 121–132, January 2005
33. Wang, W.: Performance management of hydroacoustic surveillance networks. Master of computer science project report, school of computer science, Carleton University. http://www.github.com/michelbarbeau/gr-llsr/blob/master/docs/WenqianWang.pdf. Accessed June 2016