# Adaptive multi-sensor biomimetics for unsupervised submarine hunt (AMBUSH) - First year review

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## Abstract

Underwater surveillance is inherently difficult because data transmission is limited and unpredictable when targets and sensors move around in the communication-opaque undersea environment. This report briefly describes this past year's research efforts finding inspiration in Nature's collaborative tasks, such as wolves hunting in packs, to advance undersea-surveillance. The research proposes an unsupervised surveillance concept maximizing target localization and sensor covertness. This research project leverages recent technological advances to address two unique undersea challenges: intermittent communications and dynamic environmental changes. This document also reviews the scientific objectives and engineering challenges pertaining to these research activities.

## Significance for defence and security

Military undersea-surveillance systems usually are wired, deployed overtly in friendly waters, and requiring a significant operator/analyst overhead. As a coalition member, the Royal Canadian Navy (RCN) is often tasked to patrol or secure strategic choke points with a small number of warships and away from friendly waters. These situations keep RCN personnel and assets within the reach of an opposing force, thus requiring a high-level of readiness over long periods of time.

Today's RCN sensors enable the collection of a massive amount of data, often analyzed offline. The RCN of tomorrow will dominate by making sense of that data in real-time.

To increase the RCN standoff distance, the proposed undersea-surveillance network could be deployed and operated in a covert manner thus enabling surveillance beyond friendly waters. Such a network will operate with minimal operator intervention while exploiting the changing undersea environment to its advantage. Other direct benefits of this research project are the reduction of submarine threat exposure, an increase in sensors' coverage, an acceleration of the first two stages of the observe-orient-decide-act (OODA) loop, the enabling of surveillance for choke points, confined areas and ice-covered areas, and the identification of countermeasures to render RCN submarines stealthier.

# Résumé

La surveillance sous-marine est intrinsèquement complexe dû au fait que la communication et la transmission de données sont restreintes et imprévisibles en présence de capteurs et de cibles faisant preuve de mobilité. Ce document présente une brève description de travaux de recherche effectués au cours de la dernière année et s'inspirant de diverses tâches de collaboration dans la nature, telle une meute de loups en chasse, pour l'avancement de la surveillance sous-marine. Ces travaux de recherche exploitent de récentes avancées technologiques tout en visant à compenser deux difficultés propres à l'environnement sous-marin, soit la présence de communications intermittentes et des changements environnementaux fréquents. Cette documentation rapporte également de façon brève les objectifs scientifiques ainsi que les défis technologiques associés à ces recherches.


# Importance pour la défense et la sécurité

Les systèmes militaires de surveillance sous-marine sont souvent câblés, installés à découvert en eaux territoriales, et requièrent la participation intensive d'un opérateur ou d'un analyste. En tant que membre d'une coalition, la Marine royale canadienne (MRC) est généralement mandatée pour patrouiller ou pour sécuriser des points stratégiques avec un nombre limité de plateformes navales en dehors des eaux territoriales. Ces situations maintiennent la Marine et son personnel à la portée d'une force de frappe ennemie, ce qui nécessite ainsi un niveau d'alerte élevé sur une longue période.

Les capteurs actuels de la Marine permettent l'acquisition massive de données habituellement analysées hors ligne. La Marine de demain qui saura interpréter ces données en temps réel aura un avantage décisif.

Afin d'accroître la distance de sécurité, le concept proposé de réseau de surveillance sous-marine pourra être déployé et exploité de manière furtive étendant ainsi la capacité de surveillance au-delà des eaux territoriales (points d'étranglement, zones confinées ou recouvertes par les glaces, etc.). Ce réseau fonctionnera également avec un minimum d'intervention de la part de l'opérateur tout en exploitant à son avantage les changements environnementaux sous-marins. Les recherches permettront en outre la réduction de l'exposition aux menaces sous-marines, l'augmentation de l'aire de surveillance, l'accélération de la boucle OODA «observe- orient-decide-act», de minimisation d'utilisation du personnel, et l'identification des contre-mesures rendant les sous-marins de la MRC plus furtifs.

# Acknowledgements

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# 1 Introduction

This document provides an overview of the work achieved in the first year of DRDC's Adaptive Multisensor Biomimetics for Unsupervised Submarine Hunt (AMBUSH) project that was funded by a Technology Investment Fund (TIF). The main objective of the AMBUSH project is to maximize the performance of persistent, undersea and wireless networked sensors towards unsupervised submarine localization. More information about the AMBUSH project can be found in [1].

## 1.1 Review of project objectives

The undersea networks discussed here will be deployed in shallow waters and continental shelf locations with potential ice cover. The proposed network will consist of a combination of wireless, intelligent, static sensory nodes and mobile sensory nodes, or autonomous underwater vehicles (AUV's), as illustrated in Figure 1. Static nodes will provide the permanent sensor barrier whereas mobile nodes will enable the exploration of new areas, a more complete analysis of the water column, and the creation of novel network-relay communication paths.

The main objective of the AMBUSH project is to maximize the performance of persistent, undersea and wireless networked sensors made of mobile and fixed nodes through distributed, adaptive and collaborative computation performing the following tasks:

- network discovery;
- network connectivity monitoring;
- target localization;
- adaptation to changing environmental conditions impacting the acoustic channel; and
- fast and opportunistic message routing.

*Distributed*, here means the sensor-network tasks are performed collectively using contributions from multiple nodes. In this setup, each undersea sensor must develop an awareness of its surroundings so that the sensor collective behaves like an intelligent entity performing the above tasks. Distributed paradigms are usually more robust to individual node failure than their centralized counterparts. *Adaptation* is a necessary feature enabling satisfactory unsupervised behaviour. Adaptation enables network nodes to tune their collective performance in response to the dynamically changing undersea environment, which strongly influences underwater acoustic detection and communication. Similar to the wolf-pack hunting strategy, *collaboration* among network nodes is believed to augment the success and the robustness of their mission.

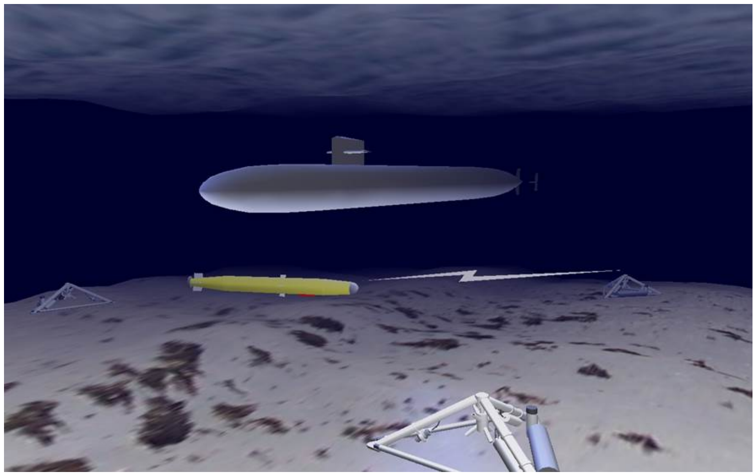

***Figure 1:*** *Mobile and static networked sensors localizing a submarine.*

## 1.2 Project approach

This project adopts a sequential approach comprised of theoretical studies and simulations followed by at-sea experiments. Theoretical studies incorporate undersea-communication features while addressing the above objectives. Most of these studies are pursued concurrently and independently to maximize overall project success. Simulations help prove concepts with fully-controlled conditions and mimic underwater network acoustic communications and detections. Simulations use sea-trial data and/or results to better mimic reality. Ultimately, the accuracy of simulations could be compared to sea-trial data.

The project execution relies on a combination of in-house, collaborative, and contracted work engaging DRDC, external contractors, and academic partners. To support the AMBUSH project, four research contracts were awarded on the following topics related to underwater acoustic sensor networks:

- network connectivity assessment (A.G. Aghdam at Concordia University);
- relaxation of distributed data aggregation (M. Rabbat at McGill University);
- robust and adaptive routing (E. Kranakis at Carleton University); and
- development of an acoustic propagation simulator for shallow water environments (Maritime Way Scientific).

Proposed solutions from these research contracts will be tested experimentally by purpose-built experimental equipment deployed in a real underwater environment. The planned experiments will involve relatively simple network nodes (Figure 2) whose main components are a Freewave radio, a strobe, a radar reflector, an antenna, a Global Positioning System

***Figure 2:*** *AMBUSH network node.*

(GPS), an acoustic modem, and a battery pack. By order of decreasing height one finds the antenna, radar reflector, and strobe in Figure 2 all mounted on a casing where the other components are located, except for the modem which is positioned much deeper under water. This basic, lightweight, and affordable node design has a relatively simple assembly and manual deployment. The design simplicity originates from the decision to *not* include any sensor or computational capability in the node itself. Instead, commands and queries will happen through radio communications as sketched in Figure 3.

Even though the computation capability is centralized at DRDC (ref. Figure 3), the computation will run each node's computational logic separately. The computational scheme will query each node to determine which one received the underwater acoustic message before determining the next message to send.

## 1.3 Results

Results from the DRDC work and all four research contracts listed in Section 1.2 are presented in the sections to follow. In [2], results from Carleton University on network routing are presented. Report [3] introduces the work on network connectivity assessment performed by the team at Concordia University. The authors of [4] discuss the progress made by the team at McGill University on distributed target-localization. The development of an underwater acoustic propagation simulator by Maritime Way Scientific is introduced in [5]. In Section 2, the main results are individually listed and summarized. Then, Section 3 interprets these results for their potential impact on the RCN.

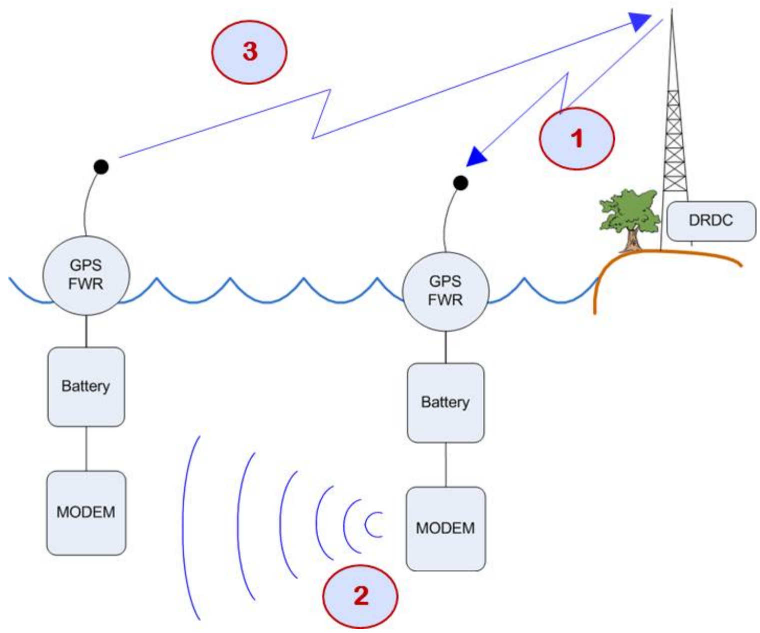


***Figure 3:*** *Command and query sequence between two nodes (Steps 1 through 3 describe a likely sequence for sending a specific message to a node, the underwater communication of that message from the node, and the report of a received message from another node.).*

# 2 Summary of results

This section summarizes key results from ten scientific publications. The presented results were selected based on their impact on the design and/or operation of the proposed network nodes. The results are grouped under two main topics: distributed computing and underwater acoustics. Technical details of the work may be found in the cited publications.

## 2.1 Distributed computing

The distributed computing category is further broken down in to sub-categories pertaining to various distributed computation schemes including *network discovery*, *network connectivity*, *routing*, and *target localization*.

- Network discovery [6]: This task amounts to discover which nodes are part of the network and what network links exist between those nodes.
  - ◇ A relatively simple network discovery scheme, not requiring *a priori* network knowledge, has been derived and tested in simulation. The proposed algorithms only require two user inputs and is more general than existing techniques.

- The technique assumes one-way broadcast communications and uses data intermissions to learn a network structure and to estimate node-to-node link probabilities.
- The study also demonstrated that for discovering network size and composition, broadcasting the estimates of the entire network structure becomes more important at low probabilities of received communications, which is the condition likely to prevail under water.

- Network connectivity [3, 7]: This task focuses on determining how well-connected the overall network is in a decentralized and distributed manner, *i.e.*, without a central node gathering data from all other nodes.
  - A novel measure to evaluate the connectivity of the network is proposed. The Weighted Vertex Connectivity (WVC) extends the classic vertex connectivity metric by capturing the probabilistic and time-varying nature of each node-to-node communication link. As a consequence, the new connectivity measure is well-suited to capture both slow and rapid acoustic channel variations observed in underwater acoustic communications.
  - There exists an important trade-off for estimating the network connectivity based on local data exchanges. The trade-off is between the convergence rate and the accuracy of the network connectivity estimate.

- Network simulation and routing [2, 8]: This task amounts to simulate underwater communication and derive mechanisms to route messages through the network as efficiently as possible.
  - The main focus of this work is about the software emulation of underwater acoustic wave propagation and software modulation and demodulation of underwater acoustic digital data signals in presence of mobility, with integration with other protocol layers.
  - A simulator for underwater communications was developed for sensor networks comprising mobile nodes. The physical layer is simulated through Matlab$^{TM}$ and the link and network layers through OMNeT++. The main advantages of this composite approach is that the OMNeT++ environment addresses fairly well the protocols placed in the link layer and above while Matlab$^{TM}$ provides the computational flexibility to provide an accurate physical layer description as well as many distinct modulation schemes like Phase Shift Keying (PSK), etc.
  - A location-free routing scheme was developed assuming the presence of a depth sensor in each node. The main advantage of this pressure-based sensing approach is that it is non-blocking in that messages are always guaranteed to move forward and toward the destination (also called "sink") node.

- Target localization [4, 9, 10]: This work focuses on performing the localization of a target in a distributed manner (*i.e.*, without centralizing all of the sensed information) and assuming underwater acoustic communications as the main data-exchange mechanism.
  - ◇ The authors have focused most of their efforts on distributed particle filtering and distributed Ensemble Kalman filtering.
  - ◇ The proposed Ensemble Kalman filter schemes clearly outperforms state-of-the-art non-linear distributed tracking alternatives despite a severe reduction in the number of scalars it is allowed to transmit. The number of transmitted scalar values describing filter particles varied between 1000, 500, and 200.

## 2.2 Underwater acoustics

The following results originate from [5];

- An underwater acoustic propagation simulator was put together using the BELLHOP ray tracer, Virtex and Matlab$^{TM}$. The BELLHOP ray tracer was modified to study the impact of water currents and ice cover on acoustic propagation.
- Simulations showed that the spread in time-of-arrivals is sensitive to the increase in partial ice cover. An increase in wind speed tends to make the response of the acoustic channel more scattered in terms of the structure of acoustic arrivals. This increased scattering of the acoustic arrivals originates from the increased roughness of the water surface, which in turns tend to scatter the acoustic energy. As expected, this effect decreases as the ice cover augments.

# 3 Interpretation of results

This section is an interpretation of the results presented in Section 2 with the goal of conveying their significance to future RCN underwater networked systems.

## 3.1 Distributed network discovery

The representation of an underwater sensor network by a Random Weighted Directed Graph proposed by the present author in [1, 6] is an innovative approach with many possibilities for future development. It allows considerations for time-varying acoustic propagation conditions, for instance. The other novel concept proposed by the present author is the use of time-based underwater acoustic broadcasts for communicating information through the network. The time-based approach was based on future expectations regarding the affordability of on-board atomic clocks which are capable of persistent deployments while guaranteeing a low clock drift. This broadcasting communication approach is unlike traditional hand-shaking and point-to-point communication protocols. Such a broadcast feature is advantageous from a covertness standpoint as only the broadcasting sensor node gives away its position. Moreover, it can be shown that broadcasting leads to faster information diffusion through the network and at a reduced energy cost. This last aspect is relevant to the RCN as most of its off-board sensors are powered by batteries.

The author developed and tested algorithms that could be readily used and implemented on off-board RCN sensors. The proposed technology is capable of discovering networks that are initially unknown. Moreover, the author evaluated the algorithms on underwater sensor networks subject to underwater communications whose probability of received message dynamically varies over time. Such a configuration attempted to duplicate slow-varying environmental changes (tides, seasons, etc.) impacting underwater communications. The proposed algorithms can also adapt to network node deletion (death) and addition (birth). This agility is of particular interest to the RCN as it may decide to add or remove sensor nodes based on the level of activity from an adversarial force. Similarly, this feature may be useful in other situation such as when environmental conditions may isolate certain nodes from the rest of the network or when a mobile node becomes out-of-reach due to its separation distance with the network. The developed algorithms only require an averaging time-horizon and sampling time inputs from the operator, which makes it relatively easy for an operator to enable such a network discovery feature.

One important lesson learned from this work is that any network structure estimation technique (including the one presented in [6]) will always lag the actual network structure. Even though the two operator inputs can be set to minimize this deficiency, it will not make it disappear. Another lesson learned is that it is beneficial for the network if each node transmits its own estimate of the perceived network structure despite the energy costs associated with it.

## 3.2 Distributed network connectivity

This work element focuses on the proposed representation of an underwater sensor network as a Random Weighted Directed Graph [1, 6] in order to develop a global (network-wide) connectivity metric based on local (node-to-node) communications only.

Many network functions such as data-aggregation, health-monitoring, message routing, etc. require explicit knowledge of the network structure (or size) and topology (i.e., how each node is connected to the rest of the network). Therefore, it is important to define a global connectivity measure and develop an efficient algorithm to monitor, and if possible control, this network connectivity on a frequent basis. Although there exists various schemes for connectivity assessment in the literature, such algorithms are not distributed over the network. In this research effort, the authors of [3, 7] introduced a novel connectivity metric, the Weighted Vertex Connectivity (WVC) measure which extends the classic notion of vertex connectivity to the more general case of random weighted directed graph (also commonly called “digraphs").

An important lesson learned for the application of the proposed algorithms is the trade-off between the algorithm convergence speed and the connectivity estimation accuracy through the selection of a learning parameter. Indeed, a faster learning rate leads to a larger variance of the connectivity estimation error and inversely, a slower learning rate generates smaller variance of the connectivity estimation error. Consequently, if the RCN intends to use such algorithms for estimating the network connectivity among multiple underwater sensor nodes (AUV’s, starfish cubes, etc.), convergence speed or accuracy of the network-connectivity estimation will need to be prioritized.

The results developed in this work can be used by the RCN to strengthen the performance of an underwater acoustic sensor network by identifying the relative contribution of each node-to-node link in the connectivity of the overall network. This in turn can help decide which communication link should be reinforced by either altering the variable acoustic modem features (bit rate, power, directionality if available, etc.) or the location of a mobile node such as an AUV.

## 3.3 Network simulation and routing

Given the RCN’s current budget constraints, it is advantageous to develop and test underwater communication protocols and signal modulation schemes as much as possible in a simulated environment. This effort focuses on a software emulation of underwater acoustic wave propagation and software modulation and demodulation of underwater acoustic digital data signals in the presence of node mobility, along with the integration of other protocol layers (ref. the Open Systems Interconnection (OSI) model standard in communication sciences). For underwater operations, (controlled or uncontrolled) mobility is relevant because there are underwater vehicles and environmental conditions causing displacement of drifting and moored sensors. The inclusion of mobility in the software emulation is critical to the RCN as it enables the mixing of AUV’s, drifting nodes, and moored nodes, thus covering all off-board sensor possibilities. The initial and simplified physical layer model (by Thorpe) takes into account attenuation, noise and their effect on a Phase Shift Keying (PSK) modulated signal.

Given most of the RCN’s off-board sensors are battery powered, underwater routing protocols must be designed to minimize energy consumption and nodes must appropriately manage their energy reserves. For that requirement, proactive routing protocols for ad hoc networks are not suitable for underwater communications as they require a constant exchange of control information to keep the routing information current. Most existing routing protocols for underwater sensor networks may lead to a *communication void* in that data packets may no longer be able to move forward and toward the sink node. Given that GPS signals cannot penetrate beyond 1-2 meters of water, *location-free* routing protocols are favored as they do not require that every node knows its own and the sink node geographical positions. The authors of [2, 8] proposed a novel location-free routing protocol guaranteeing the absence of a communication void. The new communication-void free routing protocol is particularly interesting for sensor networks located at different depths. The proposed approach considers the characteristics of the communication channel to rank the quality of various forward paths before selecting the next hop for packet forwarding. In case of a tie, the node related to the greatest path quality is selected and if the tie persists, then the lowest pressure node is selected. This routing strategy is loop-free and comprises a recovery mode activated when the network topology changes. The routing protocol was implemented and simulated in *ns*-3.

## 3.4 Distributed target localization

As target localization is a major objective of the AMBUSH project, the author provided an experimental dataset to the McGill University team. The data originates from sea-trial Q347 [10] and is a post-processed bearing-only (with time stamps and signal-to-noise ratios) version of the actual underwater acoustic data collected by sonobuoys in the presence of a controlled, towed, and active sound source. The data contains the typical level of bearing inaccuracies, noise, and clutter.

In the envisioned underwater sensor network described in [1], acoustic measurements are taken at each sensor node, and in order to obtain the best target-localization accuracy, the measurements must be processed jointly by the largest possible number of nodes that detected the same target. This requires communication among nodes even though robust underwater acoustic communication is challenging to achieve and energy-intensive. Consequently, transmitting all measurements to a central location becomes impractical. Instead, a distributed approach in which on-board microprocessors perform target tracking and share minimal and compact information content with neighboring nodes is proposed.

Most modern data-aggregation techniques (like consensus and gossip) have focused on the distributed averaging problem, where each node has an initial value and the objective is to reach a state where all nodes have the average of the initial values. Fewer publications considered the estimation and tracking of time-varying signals, typically in a Gaussian-noise framework, while minimizing the tracking error. The vast majority of consensus dynamical setups consider continuous-time dynamics which imply that nodes are in constant communication with their neighbors. There are also discrete-time versions of the consensus dynamics considered, however these also assume synchronous communication and updating.

Given that each node must acoustically communicate the output of its target-localization algorithm to other nodes through the unreliable and unpredictable underwater acoustic channel, a different class of algorithm called *broadcast gossip algorithms* seems more suitable from a data-transfer standpoint. In broadcast gossip, nodes periodically and asynchronously broadcast their current target-location estimate, and those other nodes who receive the message perform an update and aggregate the received information with their own local target-location estimate. Consequently, nodes do not need to know any characteristics of the network (size, or other structure-related parameters), and the algorithm is highly robust to changes in network size, topology, and other conditions, which is unlike other approaches (e.g., synchronous consensus and asynchronous pairwise randomized gossip).

Bearing-only measurements resulting from underwater acoustics are highly nonlinear, and the noise associated with such measurements is often characterized as having a Rician or Log-normal distribution. Thus, the above-mentioned methods are not likely to be well-suited for the problem at hand. Instead, this work focuses on the *particle filtering* technique which is a sequential Monte Carlo method for recursive state estimation. Particle filters represent uncertainty in the target state using a collection of weighted point masses (the particles), corresponding to a sub-sample of the state space. Although particle filters can be more computationally intensive than the Kalman family of filtering approaches, they can also provide significantly better tracking performance, especially when the target dynamics are non-linear and/or the measurement noise is non-Gaussian, which is the case of the current dataset. In *distributed particle filtering* approaches, each node runs a local particle filter. In order to update its state estimates, the measurements from different sensors need to be fused, and different approaches have been proposed to perform this task. For there to be any hope of the entire network converging to a common target location, the network should have strong connectivity, a topic covered in a previous section.

For the sake of benchmarking the particle filter approach, another filter, the Ensemble Kalman filter, was also evaluated on the same dataset and results were conveyed in [4, 9]. The main motivation for evaluating the Ensemble Kalman filter was due to its smaller data packet size to communicate to neighboring nodes compared to the number of particles in the particle filter, which could easily in the order of a few hundreds to a few thousands. It must be noted that to the knowledge of the authors of [4, 9, 10], this is the first time that decentralized particle filters have been carefully compared using experimental data.

This work resulted in numerous noteworthy observations potentially impacting future RCN off-board sensor technologies performing target localization. First, the impact of message reception probability on localization performance was evaluated and found to be nonlinear. Secondly, increased communications reduce both the mean time-averaged square error and the error variance. Third, there exists a trade-off when using distributed particle filtering in that a larger number of particles improves the tracking accuracy at the cost of potentially increasing communication cost if all particles need to be communicated. Fourth, when using bearing-only measurements, the co-linearity of measurements due to sensor location and similar sensor perspective make the localization problem more challenging. This observation highlights how important the sensor placement and the potential use of mobile nodes are to gain distinct bearing aspects with respect to the target. It must be also noted that estimating the underwater acoustic channel can help improve the accuracy of the target localization and help dissociate clutter from useful measurements as demonstrated in [10].

### 3.5 Underwater acoustics

Similar to previously-discussed computer simulations of a network, it is also advantageous to properly simulate the propagation of acoustic waves under water. Considering the relatively high frequencies of commercial acoustic modems, an acoustic ray tracing model like BELLHOP is appropriate. Given the underwater surveillance technology proposed by the AMBUSH project is most likely to be deployed at choke-points and in littoral waters, the project's intention is to modify BELLHOP to include the impact of water currents and ice cover (partial or complete).

From the work completed, it was found that even though water currents do not impact Doppler spread, simulations showed how a poor sampling of the water current profile can severely affect the resulting impulse response characterizing the acoustic channel. More precisely, the structure of the received acoustic wave form can be quite different due to various current profile samplings. It was also shown in simulations how water currents can destroy reciprocity, *i.e.*, propagation losses from $A$-to-$B$ does not equate those from $B$-to-$A$. This observation indicates a preferential direction for data flow in that energy requirements to communicate in one direction will be much less than the energy required for the opposite direction. In the presence of partial ice cover, severe spatial banding of acoustic energy may occur. Whereas increasing ice cover tends to increase the time-spread of the received wave form, the number of arrivals (or echoes) does not seem to be too impacted for a (randomly-distributed) ice cover exceeding 25%.

All of the above-mentioned modifications of the BELLHOP ray trace model provide new capabilities to the RCN for modelling the characteristics of shallow water acoustic communication channels. The next phase builds an infrastructure enabling the integration of real (analog) signals into the simulation path along with the capability to connect to and feed underwater acoustic modems.

## 4 Conclusion

This report summarizes DRDC's AMBUSH research efforts undertaken in the last year. The AMBUSH research project focuses on distributing intelligence and computation across a network of underwater mobile and fixed sensor nodes. Early theoretical and simulation results already provide bounds and limits about what may be practically feasible. Specifically designed network nodes were built to perform experiments. Next year, testing and validation of various algorithmic solutions in an underwater setting will take place. In particular, the following tests will be carried out:

- validating the impact of medium currents on acoustic propagation;

- evaluating the effect of acoustic modem setup in Bedford Basin;
- performing real-time network discovery and connectivity assessment over long periods; and
- testing in water the centralized/distributed Particle Filter target-localization.

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Underwater surveillance is inherently difficult because data transmission is limited and unpredictable when targets and sensors move around in the communication-opaque undersea environment. This report briefly describes this past year's research efforts finding inspiration in Nature's collaborative tasks, such as wolves hunting in packs, to advance undersea-surveillance. The research proposes an unsupervised surveillance concept maximizing target localization and sensor covertness. This research project leverages recent technological advances to address two unique undersea challenges: intermittent communications and dynamic environmental changes. This document also reviews the scientific objectives and engineering challenges pertaining to these research activities.

La surveillance sous-marine est intrinsèquement complexe dû au fait que la communication et la transmission de données sont restreintes et imprévisibles en présence de capteurs et de cibles faisant preuve de mobilité. Ce document présente une brève description de travaux de recherche effectués au cours de la dernière année et s'inspirant de diverses tâches de collaboration dans la nature, telle une meute de loups en chasse, pour l'avancement de la surveillance sous-marine. Ces travaux de recherche exploitent de récentes avancées techno-logiques tout en visant à compenser deux difficultés propres à l'environnement sous-marin, soit la présence de communications intermittentes et des changements environnementaux fréquents. Cette documentation rapporte également de façon brève les objectifs scienti-fiques ainsi que les défis technologiques associés à ces recherches.

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DRDC Scientific Report; Underwater sensor network, distributed sensing and intelligence, adaptive behaviour.