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Distributed Underwater Sensor Networks CFMETR Field Trial Spring 2018

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Abstract

This quick-look trial report contains a record of the trial's success with achieving the planned objectives and initial analysis of data. In particular, the impact of the changes to the body format and array structures on the deployment, recovery, and data performance are discussed. The success of the communications and the implementation of the new DFLOOD protocol, along with results from timing synchronization, power usage, node stability, and new data processing algorithms are presented.

Significance for defence and security

The Distributed Underwater Sensor Network (DUSN) nodes and their on-board processing are a research level implementation of a persistent autonomous underwater surveillance sensor. The DUSN nodes are designed to be interoperable and collaborative with Norwegian and Swedish sensor nodes that implement similar underwater communication and messaging protocols.

DUSN nodes and similar devices will very soon have direct defence application in choke point surveillance, such as in the Arctic Archipelago, and in harbour protection. Larger autonomous arrays based on the same technology will provide long-range surveillance capabilities. These systems minimize both the number of required operators and provide detection performance independent of the operator.

Résumé

Le présent bref rapport d’essai présente un compte rendu du succès de l’essai sur le plan de l’atteinte des objectifs prévus et de l’analyse initiale des données. Nous discutons notamment de l’effet des changements apportés au format du corps et au réseau sur le déploiement, la récupération et le rendement des données. Le succès des communications et la mise en œuvre du nouveau protocole DFLOOD, ainsi que les résultats de la synchronisation temporelle, l’utilisation de l’énergie, la stabilité des nœuds et les nouveaux algorithmes de traitement des données sont présentés.

Importance pour la défense et la sécurité

Les nœuds DUSN avec leur capacité imbriquée de traitement représentent la réalisation pour la recherche d’un capteur de surveillance sous-marine autonome et persistant. Ils sont conçus pour être interopérables et collaboratifs avec les nœuds de capteurs norvégiens et suédois qui mettent en œuvre des protocoles semblables de communication et de messagerie sous-marin.

Acknowledgements

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1 Introduction

A field trial in support of the Force Anti-Submarine Warfare (FASW) project, Work Breakdown Element 3 (01ca03), Autonomous Networked Sensor Systems (ANSS), was conducted at the Canadian Forces Maritime Experimental Test Ranges (CFMETR) during the period April 19 to May 4, 2018.

This field trial was an engineering test and data collection opportunity in direct support of the ANSS-related international agreement known as Distributed Underwater Sensor Networks (DUSN), which is a tri-lateral agreement with participants from Norway, Sweden, and Canada [1].

The trial also supports the objectives of the Canadian Arctic Underwater Sentinel Experimentation (CAUSE) project (99ab), which is a component of the DRDC All Domain Situational awareness program.

At present, the DUSN nodes operate as passive sonars that listen to the radiated noise from vessels. Despite the passive mode of operation, the DUSN nodes are 24-bit high-dynamic range receivers that will recover from acoustic signal overload within one to two data sample periods. They are therefore very well suited to active sonar applications. Active sonar algorithms are not included in the ANSS project work element; however, the DRDC Rapidly Deployable Systems Array Technology has been applied to active system such the Arctic Passive/Active Detection System (APADS). The APADS are passive and active sonars in a combined package with the capability of sharing data and synchronizing deployed nodes distributed globally; thus are a step toward providing collaborative monostatic, bi-static, multistatic sonar capabilities. Active sonar operating modes can be downloaded into DUSN nodes when desired.

The Canadian DUSN sensor nodes have recently undergone a major physical redesign that has resulted in a slightly heavier, but sturdier, and more compact package. In addition, the battery pack size has been doubled and the deployment and recovery of the devices has been greatly simplified [2].

This field trial was the first at-sea field test of the new design and is a dry-run for our future activities in the second international DUSN sea trial that is scheduled to occur in September 2018 near Stockholm, Sweden.

2 Objectives

The objectives of the CFMETR field trial are listed in the field trial plan, Reference [2]. They are:

- Assess the ease of deployment and recovery of the newly developed sensor nodes,

- Test interoperability amongst the nodes,
- Test remote control operation of the nodes,
- Collect acoustic data on vessels and targets of opportunity,
- Collect acoustic data on cooperative vessels and targets,
- Collect environmental data,
- Collect ambient noise data,
- Test node endurance and power consumption,
- Test GPS-based time synchronization of acoustic data recordings,
- Investigate automated operations of two gateway buoys,
- Test the networking protocol, and
- Test a towed acoustic source.

3 Trial location

The field trial was conducted on the CFMETR property, in the surrounding waters, and at a rented property overlooking the main deployment area.

CFMETR provides excellent support for these field trials. They provide office and working spaces, access to various boats and equipment, along with at sea support in terms of area control, environmental data collection, 3D position sensing, and personnel.

The Control Station on the elevated rental property provides a clear view of the operations area, see Fig. 1, and has room for antennae to support our data collection and network controls.

4 Personnel

The trial involved 17 personnel, all but one of which was from DRDC Atlantic. Dr. Michel Barbeau of Carleton University was the sole non-DRDC staff member. The Chief Scientist for the trial was Dr. Stephane Blouin. One DRDC staff member attended periodically and was not identified on the trial plan. This participant was Maj Dugald Thomson who is based in Victoria, BC, and who has recently become the new Air Liaison Officer for DRDC – Atlantic Research Centre.

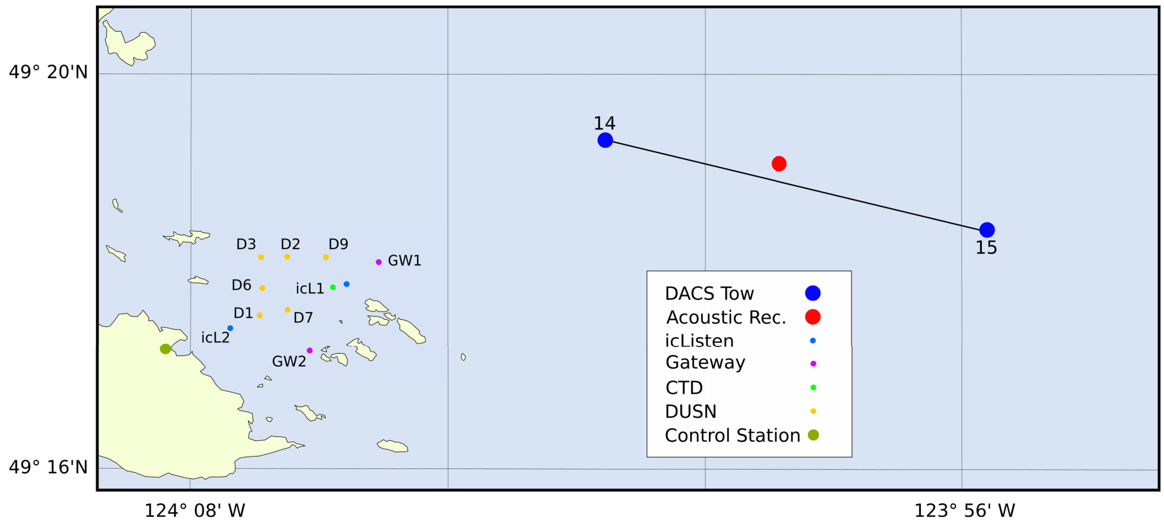


Figure 1: *The operating area for the trial. The legend shows the different types of sensors that were deployed, the Control Station location, and the track for the projector.*

5 Equipment

In this section of the report we describe the major components of trial equipment and how they are configured for operations in the CFMETR environment. For the nominal configuration of the deployable gear (nodes, gateways, etc.) we shall refer to the Trial Plan, Annex D. Standard Operation Procedures—DUSN nodes and small gear [2].

5.1 DUSN nodes

The first DUSN nodes were formatted as a cylinder similar in concept to a large sonobuoy. Unfortunately, the cylinders were large and unwieldy. They were also heavy, but remained flimsy and subject to damage during deployment and recovery. Due to these problems, the DUSN nodes were redesigned into a flattened cube shape made of PVC plastic pipes. The DUSN nodes used in this trial are the second generation models.

These second generation models allowed for an additional battery canister to improve duration, reduced stresses on the vertical line array (VLA), and provide an improved drop-and-go deployment scheme.

A significant change was also made to the directional sub-array (DSA), which was originally a tri-axial crossed dipole with centre hydrophone (seven hydrophones total). The umbrella-like DSA support structure was delicate and difficult to package and use. The new design for the DSA is a seven-element planar array, where six hydrophones are uniformly spaced on a circle of approximately 0.314 m radius and a seventh hydrophone is located at the centre. Figure 2 is a top down view of the DUSN node showing the DSA hydrophone placement.

The DSA is operated with an on-board selected beamformer (one of: conventional, minimum variance distortionless response, phase gradient, super-directive beamformers). The response of the beamformer is dependent on the beamforming algorithm chosen. The conventional beamformer is rarely employed because of the wide beams that result and the resulting requirement for high signal-to-noise ratios to adequately distinguish signal arrival bearings. The other beamforming choices all have varying degrees of constraint in frequency based on the array dimensions. Generally, we can operate the beamforming from approximately 10–1100 Hz. Higher frequency broadband signals could employ time-difference-of-arrival techniques for bearing estimation, but we do not currently use this method.

The VLA sub-array remains as it was in the first version of the DUSN nodes; however, the spacing between the DSA and VLA now precludes the centre phone of the DSA being a 10^{th} element of the VLA.

The VLA hydrophones are spaced 4 m apart with a nominal 1500 m/s design frequency of 187.5 Hz. However, we employ a 95% design rule in our array spacing, which means the nominal design frequency is actually 178 Hz. By reducing the hydrophone spacing slightly we can discriminate between the up and down looking endfire directions. Also, most of our system deployments are in the Arctic, and soon, in the Baltic Sea, where the sound speed tends to be lower than 1500 m/s. The lowered sound-speed, results in a lower design frequency that is actually closer to 170 Hz.

This field trial was the first full sea test of the new DUSN design. Several one-day sea tests were conducted previously in Bedford Basin to ensure that the new design was practical. Figure 3 shows one of the new design DUSN nodes being lowered by a CFMETR Torpedo Sound Range Vessel (TSRV) just prior to deployment release.

Six DUSN nodes were deployed during the trial. Of these, five were stand-alone nodes where the mooring configuration is as shown in Fig. 4. The sixth node was deployed with a high-bandwidth WiFi gateway buoy that allows for real-time data recovery and direct control. The mooring configuration for this buoy is shown in Fig. 5.

Each node was deployed to position the sub-surface float of the VLA sub-array at a depth of 20 m and the depth of the planar hydrophone array at 62 m. This constraint required adjustments to the line lengths in the table within Fig. 4 as water depths at the selected locations were not accurately known *a priori*.

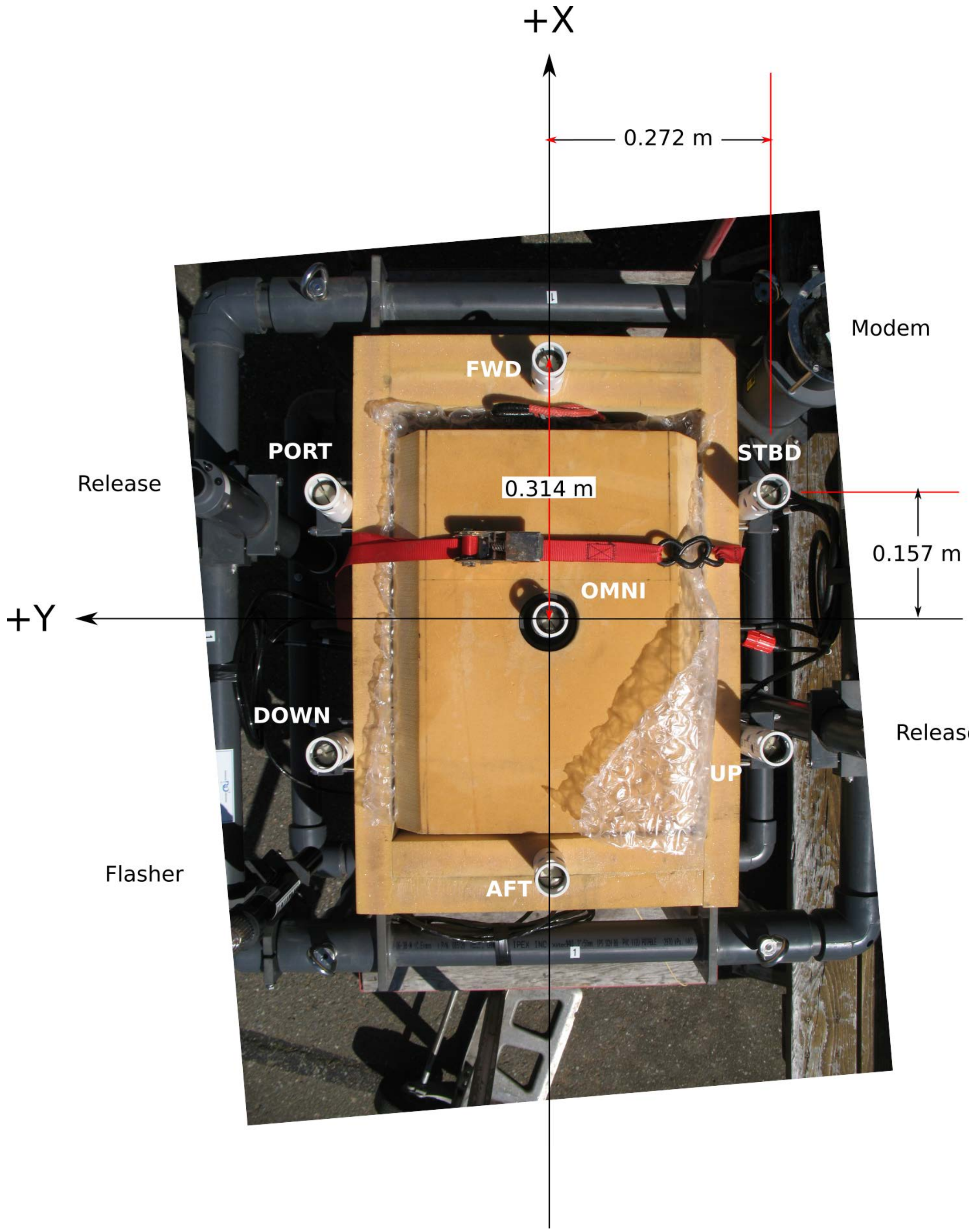


Figure 2: *A top-down view of a DUSN node showing the layout of the DSA sub-array. The hydrophones are labelled: FWD, AFT, PORT, STBD, UP, DOWN, and OMNI. These hydrophone names are a legacy from the original tri-axial crossed dipole array design in the first DUSN.*

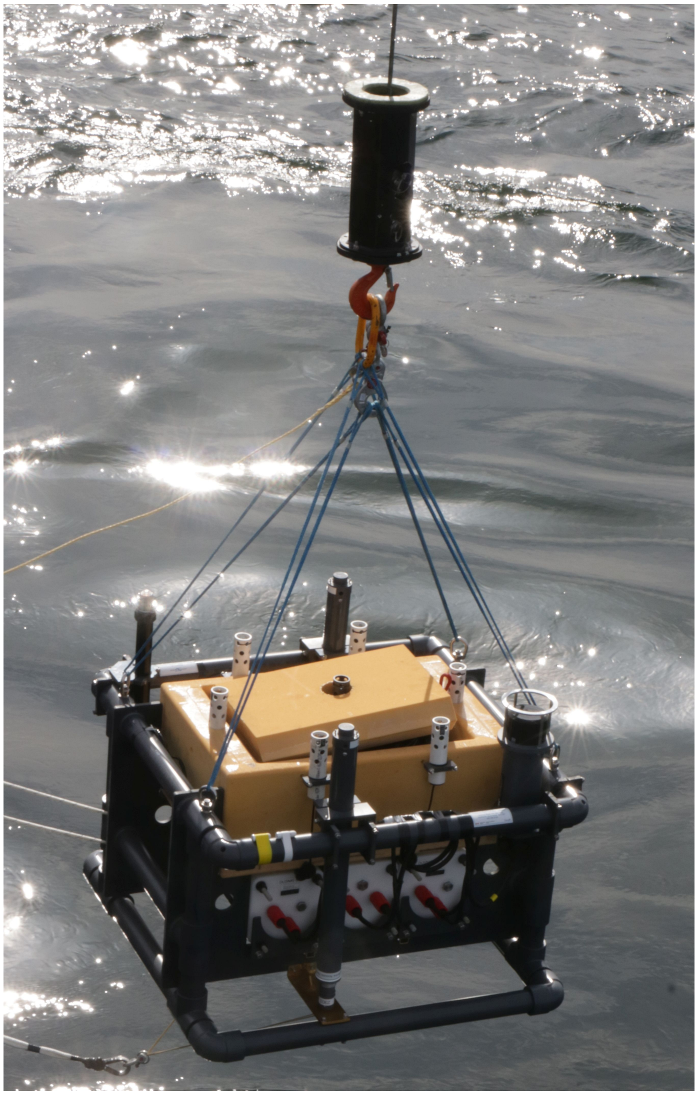


Figure 3: *A DUSN node being lowered to the water surface just prior to deployment.*

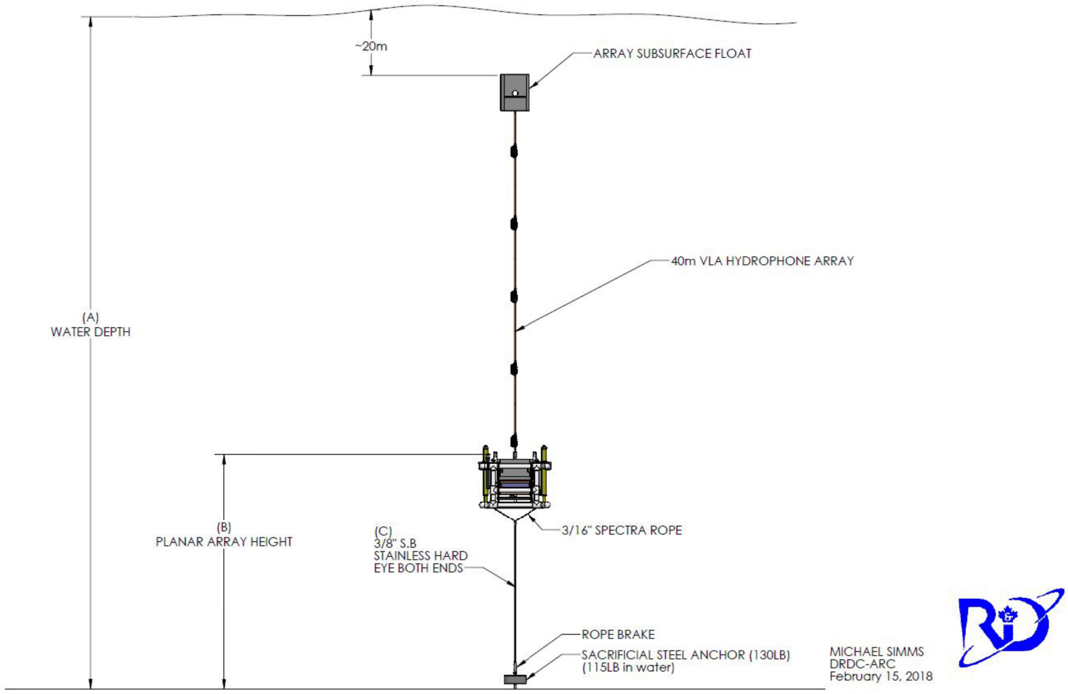


Figure 4: *The configuration of the DUSN node mooring system. The DUSN nodes are capable of resting on the sea floor, but are generally suspended in the water column.*

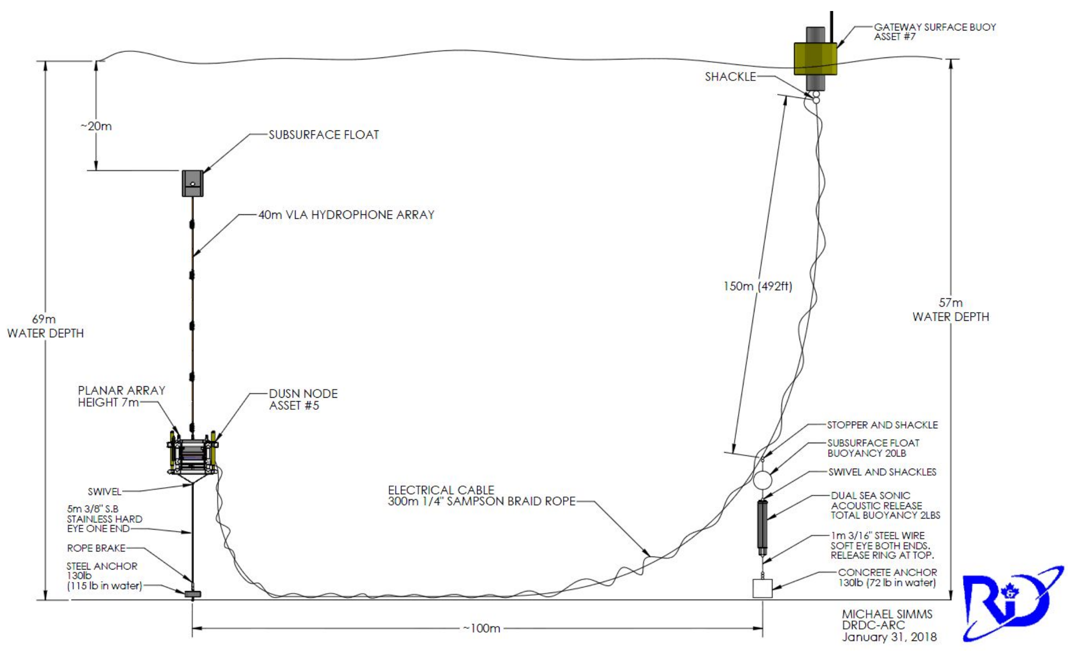


Figure 5: *The configuration of the DUSN node mooring system with a wide bandwidth WiFi gateway bouy tethered to the device.*

5.2 System Test Bed

The System Test Bed (STB) is a DRDC sonar signal processing environment that has been widely applied within DRDC and licensed for use by industy. STB provides real-time passive/active sonar signal processing and display. It also provides tactical displays and planning capabilities.

STB is high extensible and in addition to the already mentioned tasks, it has been integrated with the control our Rapidly Deployable Systems Array Technology (RDSAT) sonars and networks (DUSN and Northern Watch), and is currently in the design stages for the Drifting Arctic Monitoring System (DAMS) and the Digital Acoustic Surveillance Array (DASA) currently under construction.

In the current field experiment, the STB was used to achieve the following tasks

- To act as a primary sonar signal processor and tactical information display,
- Collect GPS signals from Sikanni and Stikine tow vessels,
- Receive and record AIS data from nearby vessels,
- Communicate with two gateway buoys to send NILUS [3] commands and status checks through acoustic modems,
- Transfer commands and data to/from the high-speed surface buoy, and
- Run automated tests of the DFLOOD [4] networking protocol,

The STB was located at the Control Station and is shown in Figure 6.

5.3 Gateway buoys

There were three types of gateway buoys deployed during this trial and they consisted of:

- Two gateway buoys (GW1, GW2) equipped with a float, an acoustic modem, a radio, and a GPS as shown in Figure 7,
- One gateway buoy connected by an electrical cable directly to a DUSN node equipped with a float and a wide-bandwidth WiFi radio, and
- One gateway buoy connected to an icListen acoustic recorder [5] and equipped with a float and a radio.

Antennae enabling RF communications with all gateway buoys were installed at the Control Station with receivers feeding data into the STB.

The mooring configuration of the gateway buoys (GW1, GW2) is provided in Fig. 8. Line lengths were adjusted to suit the water depth at the mooring locations.

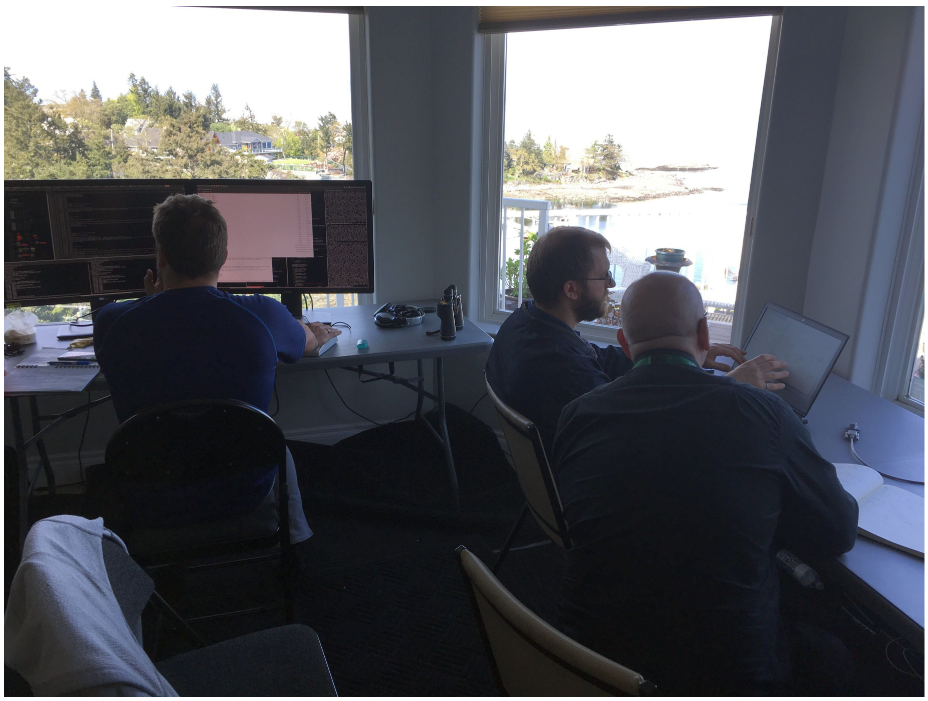


Figure 6: *The System Test Bed is a configurable sonar processing system. The STB now provides user control of DUSN nodes, supports DUSN DFLOOD and NILUS protocols, and is able to display tactical and sonar data from the network.*

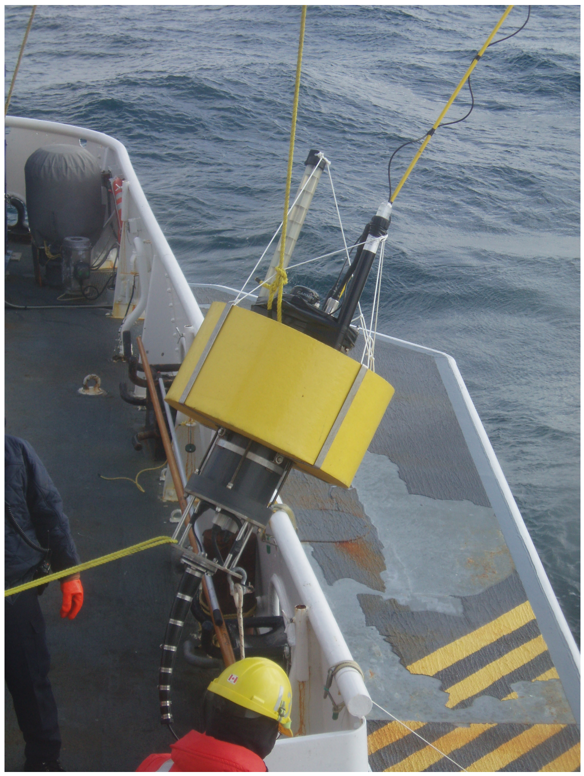


Figure 7: *The gateway buoy surface float. Two gateways of this type were employed in this field trial.*

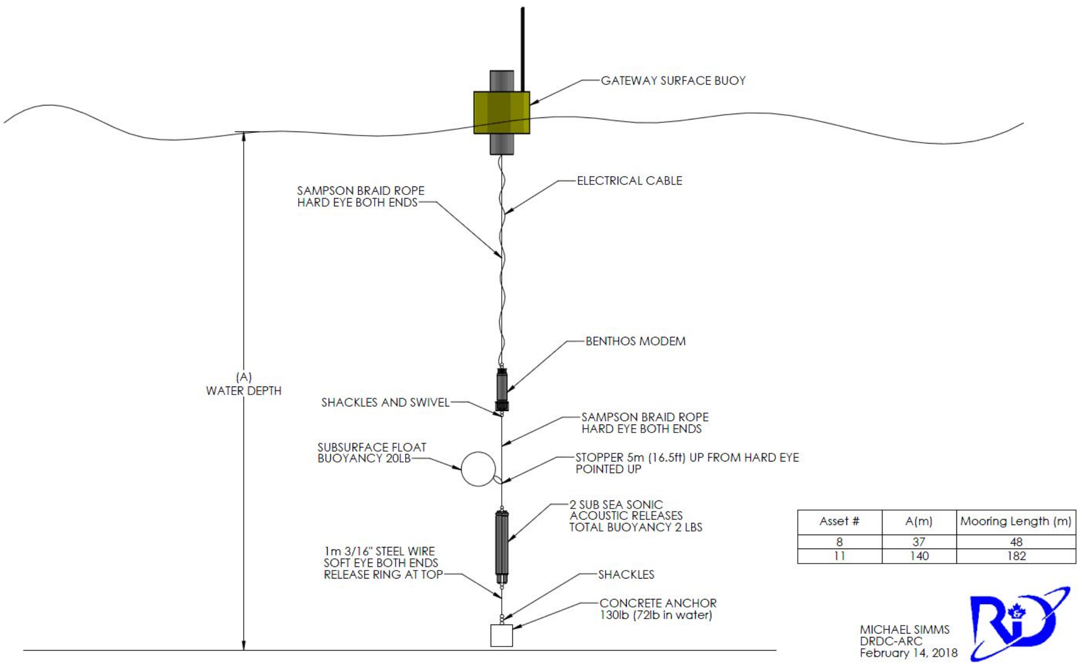


Figure 8: *Configuration of the digital radio gateway buoy mooring system.*

5.4 icListen

There were two configurations for the iCListen acoustic recorders [5] used in this field trial:

- A single mooring-line-and-anchor configuration with a subsurface float without any communication. Refer to Fig. 9 for details of the mooring.
- A double mooring-line-and-anchor configuration with a surface float and a radio to issue commands and support real-time data inquiries.

An iCListen unit is shown in Figure 10. One of the icListens was employed in a commandable mode with an attached radio and the other in stand-alone mode with a 16-bit recording quality.

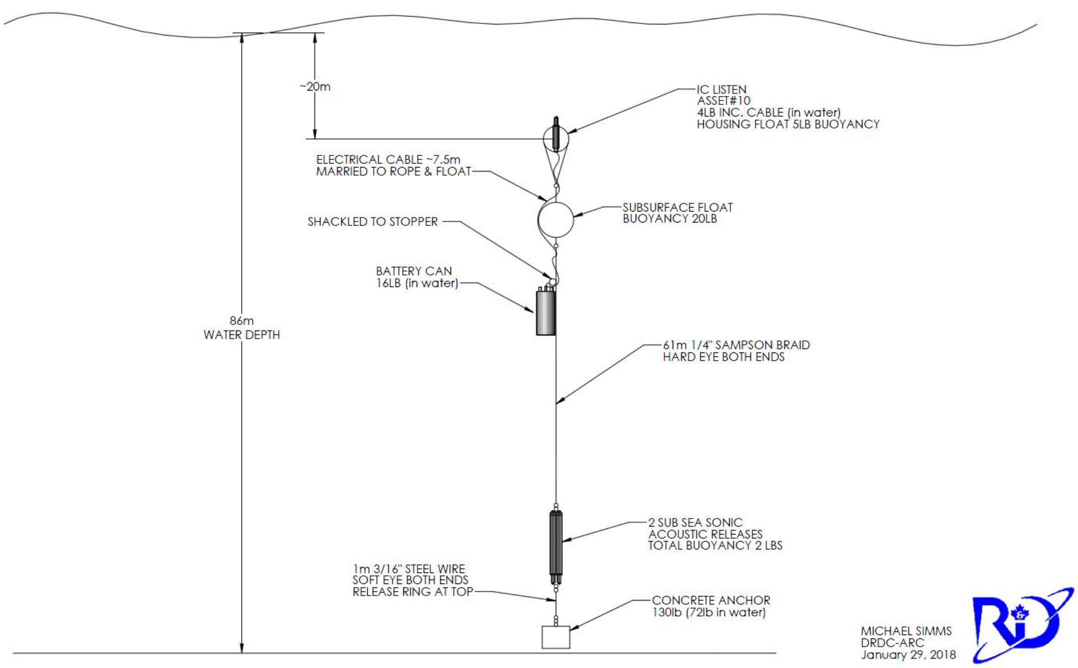


Figure 9: *The mooring configuration for the icListen hydrophone without the gateway buoy.*

Figure 10: *The icListen hydrophone.*

5.5 Deployable Acoustic Calibration System projector

The Deployable Acoustic Calibration System (DACS) projector was obtained from military stores and transfered to DRDC. This projector was purchased many years ago and had been unused for as long as 30 years.

DRDC has undertaken the rebuild of the supporting monitoring and power amplifier systems. The large compensated ring-shell transducer was calibrated at Seneca Lake without the tow body and electronics packages. The result of the ring-shell calibration is shown in Fig. 11.

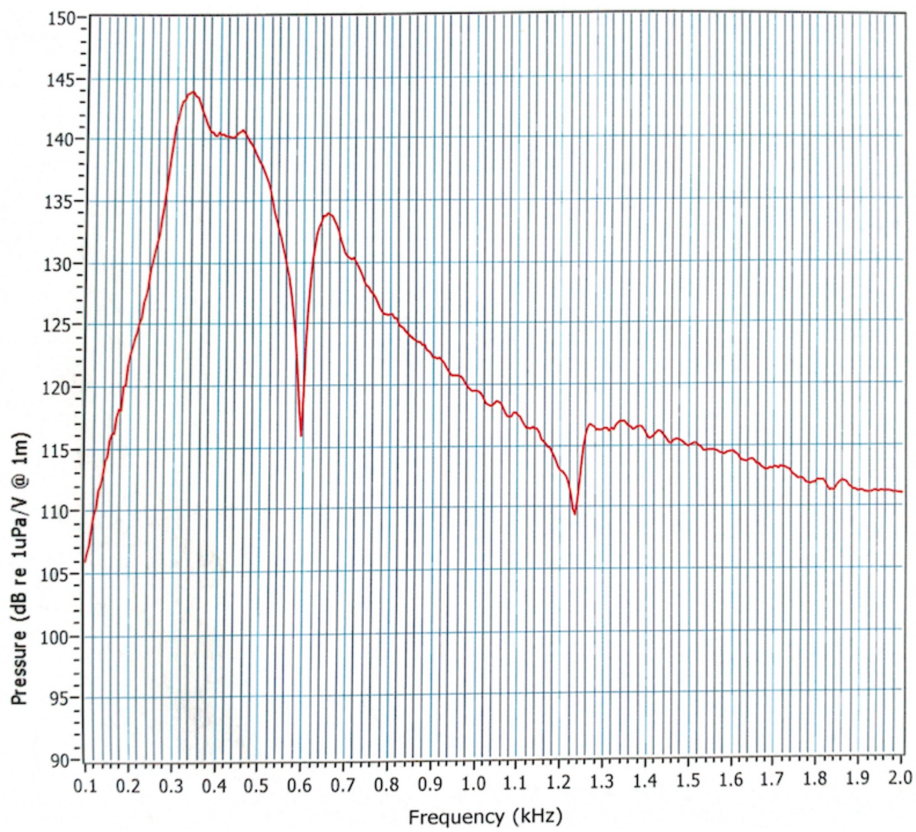


Figure 11: *The transmitting voltage response (TVR) of the bare ring-shell transducer.*

In general, the rebuilt DACS promises to be a very useful low-frequency UW acoustic source. A photo of the DACS on the deck of the CFAV STIKINE is shown in Fig. 12.

5.6 Sonobuoys

Sonobuoys of the AN/SSQ-53F(GPS) type and of various lots (01/14 and 01/09) were used to provide additional acoustic monitoring locations for the MR219 projector tows and the

Figure 12: *The rebuilt DACS acoustic projector.*

DACS projector tows. Typical settings were 8-hour lifetime and 30 m depth (setting d1). Typically, each MR219 tow-day required the use of five sonobuoys and each DACS tow-day required two sonobuoys. All sonobuoys deployed in the Ballenas area were recovered.

A total of 18 sonobuoys were used throughout the entire trial. One defective sonobuoy was found in the 01/09 lot.

5.7 Star:Oddi CTD

A conductivity-temperature-depth (CTD) profiler recording system was made using 21 Star:Oddi CTD modules. Figure 13 shows a Star:Oddi capsule-like sensor-recorder and a matching receptacle with spring clamp that is used to build the profiler.

The Star:Oddi capsules were positioned on a mooring line covering depths 5–105 m from a surface float.

5.8 CFMETR equipment

5.8.1 Vessels

Four vessels were used throughout the trial. Those vessels are:

- CFAV Torpedo Sound Range Vessel (TSRV) Stikine (613) as shown in Figure 14,
- Sister ship CFAV TSRV Sikanni (611),

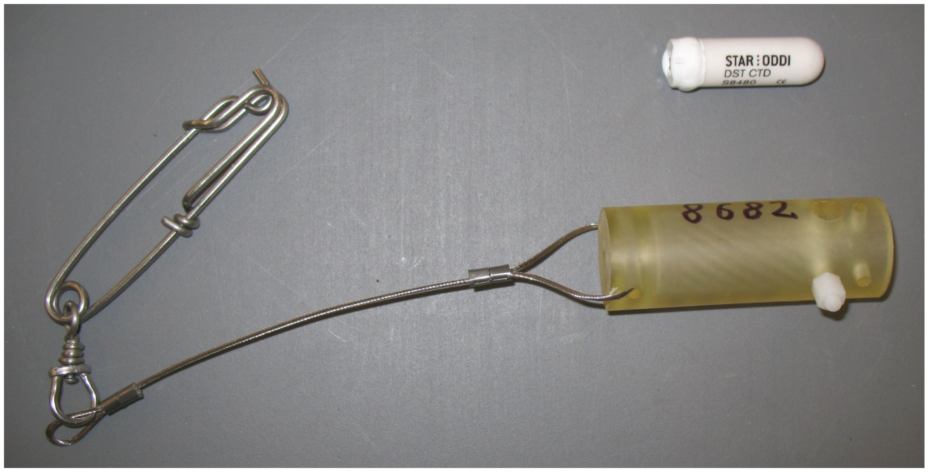


Figure 13: *The photograph shows the small Star:Oddi CTD sensor at top-right, a plastic container for the sensor is shown below the sensor and a spring-clip used to grab a support cable is shown on the right.*

- CFAV Egret YAG 680 as shown in Fig. 15, and
- A workboat shown in Fig. 16.

The TSRV were used to tow the acoustic projectors (DACS and MR219). Stikine towed DACS and Sikanni towed MR219. Stikine also helped recover sonobouys and it deployed all DUSN nodes. The workboat was used to deploy, recover, and inspect small gear. YAG 680 was utilized for: (i) acoustic localization, (ii) recover sonobuoys, and (iii) taxi people.

Figure 14: *CFAV Stikine (613) one of the two TSRV (Torpedo Sound Range Vessel) employed at CFMETR.*

Figure 15: *The "YAG 680" a small general purpose boat employed at CFMETR.*

Figure 16: *The workboat is a small general purpose open boat employed at CFMETR.*

5.8.2 MR219 projector

The MR219 projector is a small moving-coil device with pressure compensation provided by a pressurized reservoir behind the coil. The projector is shown in Fig. 17. The moving coil and air canister form the lower part of the projector, while the top is made of plate material and forms a tow depressor to help maintain depth under tow.

The MR219 is capable of producing source levels up to approximately 170 dB//1 μPa @ 1 m in the nominal frequency band of 50–1200 Hz. The projector normally operates from TSRV SIKANNI.

This projector has been a reliable device, but care must be exercised with towing as it has been observed to change depth suddenly and approach near the surface in a cross-current.

Figure 17: *The MR219 projector is a small, compensated moving-coil projector.*

6 Results

6.1 DUSN nodes

This section provides a summary of our experiences with the DUSN nodes and the UW network. It also provides a glimpse of the on-board signal processing and the developments that are nearly ready for inclusion.

6.1.1 Deployment and recovery

Deployment and recovery of the initial cylindrical format body for the DUSN nodes was found to be difficult. There was considerable risk of damage to the relatively fragile cylindrical body, especially during the recovery.

The length of the cylinder also required deployment to be from larger vessels where there was sufficient handling space and lifting room. In addition, the deployment of the arrays from within the tight confines of the cylinder turned out to be problematic as did the umbrella-like structure used for the directional array.

The DUSN node body format was modified for this field trial. The new format is a flattened cube made from PVC tubing and plates. Figure 3 shows the tubular structure and a box that contains the VLA made from pressure resistant glass bead foam. The box also provides an integral floatation.

The new format resulted in a significant change to the directional array component. This version has six hydrophones arranged on a circle with a seventh hydrophone at the centre. The hydrophones are fixed in position and no complicated mechanism is required to provide the planar aperture.

The VLA was slightly altered by the new format in that the VLA no longer shares one of the directional array elements. The resulting VLA now has only nine hydrophones versus the 10 available previously.

The new body format is about 23 kg heavier, but more rugged and has excess buoyancy to make the system float when released from the anchor. An extra canister for batteries is included in the new design with the result that system endurance has doubled. The weight of this canister is the main reason for the increase in the system weight.

The drop-and-go deployment of the DUSNs makes it possible to deploy many nodes in a day. Typically, at CFMETR where the distance between nodes varies from roughly 0.5–1.25 km, it was possible to position the ship, place the node at the surface, release it, and confirm deployment all in an average time of 40 minutes.

The procedure for deployment is to lower the node to the surface as shown in process in Fig. 3, confirm the location, and pull the release cord (yellow line in photo). The blue lifting cord then pulls completely free as the node begins to sink. The VLA sub-surface float pulls the array clear of the floatation box as the node sinks and it eventually disappears under the surface as the VLA comes under tension. Typically, this final stage of deployment took about 45 seconds for the conditions at CFMETR.

Each DUSN node mooring was adjusted for the water depth at the deployment site. The length of the mooring cable (C in Fig. 4) was adjusted to position the array sub-surface float at approximately 20 m from the surface. This also positions the DSA at 62-m depth. Table 1 provides details of the water depth, mooring line length, and the resulting DSA depth for this field trial.

The recovery process begins by activating the node's acoustic releases. Once the node's acoustic releases are triggered, the anchor is dropped and both the VLA sub-surface float and DUSN body come to the surface. The fact that the main body is buoyant greatly aids in the recovery process.

Typically, at CFMETR where the main recovery vessel is very high-sided, a workboat was used to begin the recovery process. When the node has surfaced, a boat hook is used to snag the VLA float. The VLA is then pulled aboard the workboat and the node body temporarily secured to the boat's side. The VLA connectors are cleaned, dried, and released, freeing the VLA from the node body completely. Dummy plugs are used to protect the connectors on both the VLA and body.

The lifting bridle is then attached to the node and the node is released from the workboat. The bridle is used to tow the node under the recovery vessel crane hook. Control lines are attached to the node to control sway when the node is lifted. The workboat then releases the node and backs away as the node is lifted from the water. Recovery required an average time of 30 minutes.

Recovery of the new format nodes was also improved over past experience; however, a few minor refinements are still required to lower risk of damage. The node body floats, but is very low in the water. Good conditions are needed to successfully get at the VLA connectors.

Table 1: *Water depth (m), mooring line length (m), and DSA depth (m) for each of the DUSN nodes ID 1–3, 6, 7, and 9. The sub-surface float of each node is at a depth of approximately 20 m, and the DSA at a depth of 62 m.*

DUSN ID	Water Depth	Mooring Length	DSA Depth
1	69	5	62
2	144	81	61
3	86	22	62
6	137	73	62
7	78	14	62
9	153	89	62

Another issue requiring refinement is using the lifting bridle to tow the node. The nodes have a small righting moment and when towed they roll over on their sides. The large open VLA box then provides significant drag and instability to the tow. As a result the bridle has an opportunity to tangle in the modem, flasher, and acoustic releases, all of which project like posts from the body. One of the plastic mounting brackets for the modem were broken from stresses applied by the tangled lifting bridle during a tow. A second bracket was broken when a wave pushed the DUSN under the side of the workboat. As a result of these breakages we now tow the DUSN by the recovery bridal, which is longer.

In summary, both the deployment and recovery were greatly improved and sped up by the new cubic format of the DUSN nodes. Smaller vessels can be employed and the deployment and recovery time is greatly reduced. Minor improvements to procedure and hardware are needed to reduce risk of damage during node recovery.

6.1.2 Node interoperability and remote control

The results in this sub-section cover two objectives of the field trial: interoperability amongst the nodes and remote control of the nodes. To a large extent both of these objectives require a stable and robust UW acoustic communications network.

In order to improve the network robustness, manual tests were conducted and the modem transmit rate (bps) and transmit power settings were adjusted on a modem-by-modem basis. Table 2 details the settings for the modems in the network.

In this network, nodes DUSN3 and DUSN6 were the least robust communicators (the 300 bps setting is unusually low and was used to assist nodes 3 and 6 in receiving messages). Table 2 reflects this difficulty.

The reason for the poor communication link with these two nodes is not known at this time, and it is likely to never be known for certain what the primary cause was. All of the DUSN

Table 2: *Manually determined optimum modem baud rate and power settings.*

Modem ID	Transmit Rate (bps)	Power Setting
1	300	8 (max)
2	300	8
3	300	8
6	140	8
7	300	8
9	300	8
18 (GW2)	800	6
19 (GW1)	600	6

nodes were deployed so that the DSA array (and modem) were at a depth of 62 m. This common depth should generally assist in acoustic communications between nodes.

If we look ahead to Figs. 24 and 25 we can see that the underwater sound-speed profile measured at the CTD string location (green dot in Fig. 1) is complicated with several weak channels. The modems are in the channel at 62 m depth. Since the variations measured are only on the order of 1 m/s, it is unlikely that we can explain the DUSN3 and DUSN6 communication difficulties on the profile, unless there is a change in the water mass at their locations, and this seems unlikely as nodes DUSN1, DUSN2, and DUSN7 are adjacent to DUSN3 and DUSN6 and had no communication issues.

UW acoustic networks are highly variable in performance. Noise, tides, inter-symbol interference from reflected arrivals, poor acoustic paths from the existing sound-speed profile are all typical causes of difficulty and everyone of them has been an issue for us in the past. It is likely that the issue for DUSN3 and DUSN6 is a result of multipath from a reflector (bathymetry variation) that causes sporadic symbol decoding problems.

The Teledyne Benthos modems [6] have eight power settings with a source level maximum of 185 dB//1μPa @ 1 m (Setting 8). Each power setting changes the source level by 3 dB. In this network, the maximum power was used for the nodes closest to DUSN3 and DUSN6 and the transmit rates were limited to 300 bps in order to help the *weakest* nodes *hear* the transmitted signals. The gateway nodes (GW1 and GW2) were more distant and it was expected that communications to DUSN3 and DUSN6 would be accomplished with at least one intermediate hop. The gateway nodes are operating with more typical baud rate and power settings.

Communications within the network have not proven to be robust at all times. Our early indications are that this is an acoustically noisy environment and the UW acoustic link success rate is lower at times of high noise. In particular, TSRV operations in and around the DUSN nodes have been sufficiently loud that UW communication success may be reduced to zero.

One of our standard checks on the UW network operation is the ability to query the inter-modem range. Modem range requests were issued from both gateway modems at intervals. Direct responses, as required by the ranging operation, were typically difficult when DUSN6 was involved. Often requiring two or three attempts to obtain a range estimate. The vast majority of modems returned ranges to either gateway on the first attempt, indicating a usable acoustic path and proper operation of the devices.

Ranging between GW1 and GW2 directly was often impossible; however, these modems are well separated in our network (see Fig. 1) and the acoustic path crosses through very shallow water.

At present, we are unable to range between any pair of modems in the network. This is a limitation of the current firmware and the next software update has already implemented this capability. We will update the modem firmware following this field trial.

Periodic testing of the network connectivity between gateway nodes to DUSN nodes has been automated. This testing was run at intervals to assess communication link success rates. At night the success rates from each gateway to all DUSN nodes were between 91–92%. During the day when ambient noise and area activity was higher, the success rates were generally less. In the case of DUSN3 and DUSN6, sometimes much less.

Issuing commands to transfer a new configuration file to the DUSN while deployed requires good communications due to the lengthy configuration file that must be transfered. We tried several times to update DUSN3, but communications with this buoy were poor and it took a number of retries and a considerable length of time to transfer the file.

We decided to try the other DUSN nodes and this file transfer was found to be much easier to carry out. In the end, new configuration files were transfered to all nodes. Commands were then sent to cause each node to re-boot and use the new configuration file. This was successful and the nodes became far more responsive to target presence as the updated file dealt with some software bugs that had been identified.

6.1.3 Node endurance and power

The new format of the DUSN nodes allowed for a second battery canister to be added with the result that the endurance of the nodes is doubled over the initial system design.

The batteries for the DUSN nodes are each composed of 60 Duracel alkaline D-cells. The cells are arranged in five layers, each with 12 cells in series. Thus, the open circuit voltage of the batteries will vary from $\sim$19.2 V when fresh to $\sim$13 V when exhausted. Each battery will have a nominal 75 A-H capacity at 20°C.

A third separate battery is included in each DUSN node for the purpose of running the Telesonar modems. These independent batteries are built in the same manner as the other batteries, but they have only two layers.

The voltages of each of the DUSN node batteries were recorded before deployment and after recovery. This information is tabulated in Table 3. Each of the batteries is observed to have a fresh open-circuit voltage as predicted. The open-circuit voltage after 8 to 10 days of operations varied depending on total usage and demand. The voltage measured under load post recovery does not include the VLA. This array will draw $<$500 mW and will cause the post recovery voltages to be lower than those reported in the table.

Dependent on processing load and frequency of message generation, we estimate the typical endurance of the nodes to be 10–12 days of continuous operation in water temperatures of 8–9°C.

Asset	Canister	Pre (OC)	Pre (load)	Post (OC)	Post (load)	Pre date	Post date	# days
DUSN 2	2 bat 1	19.35		15.55	15.28	April 24	May 1	8
	2 bat 2	19.37		15.59	15.28			
	benthos	19.17		16.97				
DUSN 1	1 bat 1	19.39	18.81	14.96	14.47	April 24	May 1	8
	1 bat 2	19.39	18.81	15	14.47			
	benthos	19.16		16.97				
	RF buoy	29		21.85				
DUSN 3	3 bat 1	19.39	18.99	15.48	15.1	April 24	May 1	8
	3 bat 2	19.41	18.99	15.48	15.1			
	benthos	19.14		16.94				
DUSN 6	6 bat 1	19.36		15.4	15.07	April 24	May 3	10
	6 bat 2	19.39		15.34	15.07			
	benthos	19.12		17.06				
DUSN 7	4 bat 1	19.2	18.59	14.72	14.3	April 24	May 2	9
	4 bat 2	19.37	18.59	14.75	14.3			
	benthos	19.11		16.85				
DUSN 9	5 bat 1	19.46		15.48	15.21	April 24	May 2	9
	5 bat 2	19.4		15.51	15.21			
	benthos	18.69		16.88				
RF 11 primary		27.5		22.98		April 22	May 2	11
RF 12 second.		26.6		22.18		April 22	May 2	11

Table 3: *Pre/post deployment battery voltages. Voltages were measured open-circuit (OC) and/or with a load (VLA not connected).*

6.1.4 Time synchronization

DUSN nodes are equipped with a CSAC (chip-scale atomic clock) whose oscillator needs to be disciplined in order to synchronize with a time standard (usually GPS) and keep accurate time over long periods. In order to enforce a common time amongst all DUSN nodes, a PTU (pulse-time unit) with a GPS receiver is used. As shown in Figure 18, up to three DUSN nodes can be connected simultaneously to our PTU to push the pulse-per-second conditioning signals to the CSACs for synchronization.

The CSAC employed in the DUSN nodes is a Microsemi (part number: 090-02984-001) with a TAU=1 s stability of 3x10^{-10}. Power consumption of this clock is less than 120 mW. A well conditioned CSAC should therefore have a maximum drift about 26 μs/day or on average less than 0.01 s/year. While this is incredible accuracy it is far less than is required for coherent processing amongst distributed sensors. This shortcoming begs the question of

Figure 18: *Up to three DUSN nodes can be synchronized simultaneously using the PTU in the lower right (white box).*

whether or not a less expensive clock could be employed as up to three orders of magnitude less accuracy could be tolerated for contact messages.

Disciplining the CSAC for maximum accuracy requires a significant length of time; however, highly accurate timing can be achieved in 20 minutes, but it isn't clear exactly how accurate at this time.

Upon recovery of DUSN1, 160 hours after deployment, indications are that the time had drifted 2 ns, which is a much smaller drift than the maximum. This measurement of drift is very uncertain. We are not confident that it is accurate; however, the clear indication is that the drift is small.

6.1.5 Orientation calibration

The orientation nodes used in the the DUSN sensors contain tri-axial accelerometers and magnetometers in order to determine the orientation of the DUSN frame with respect to gravity and magnetic north, respectively.

The orientation nodes require calibration prior to each usage in order to determine the DUSN frame orientation angles with respect to vertical and magnetic north. Unfortunately, this is not a simple process as it requires rotating the node in a horizontal plane and then rotating the node about a horizontal axis and then around the vertical axis.

At this point in time, we do not have suitable node handling gear to conduct the calibration process accurately. During this trial we carried out a simplified process using available materials, which included a moving cart and a magnetic compass, see Fig. 19.

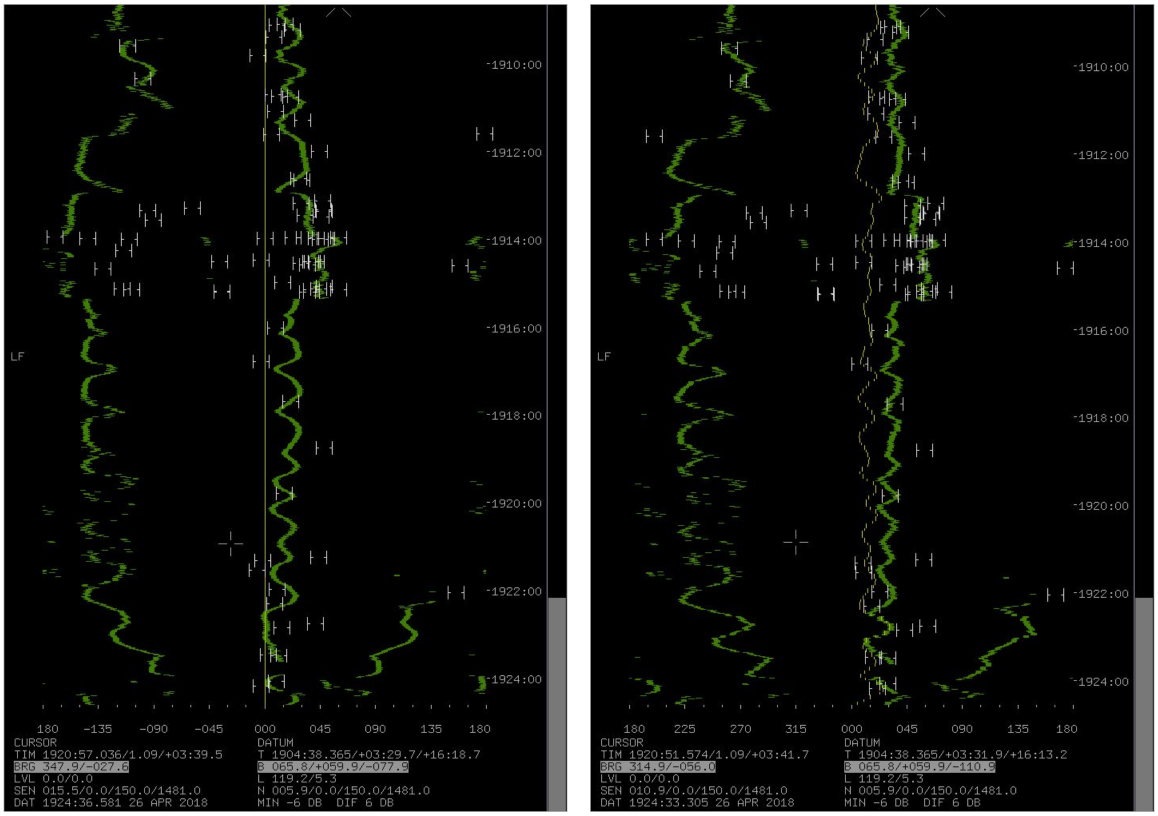
Figure 19: *An approximate calibration process was carried out for each DUSN node using available equipment. Note the compass rose on the ground to the left of the cart.*

Following the field trial, we will put some effort into building a calibration jig to move and rotate the DUSN node more easily and without the impact of magnetic materials.

6.1.6 Node physical stability

Referring to Fig. 4 it will be apparent that the DUSN nodes are free to move in a current. Therefore it is important to accurately know the orientation of the DUSN in real-time. Refer to Section 6.1.5 for details on the orientation calibration.

Both the DUSN node on-board processing and the STB are capable of providing bearing stabilization against motion. Figure 20 shows a bearing-vs.-time plot processed by the STB.



(a) *Without DUSN node motion compensation.* ***(b)*** *With DUSN node motion compensation.*

Figure 20: *Sonar Test Bed bearing vs. time plot.*

This figure was produced with the aid of a conventional 2D beamformer employing 12 beam directions. Part (a) shows the unstabilized beam direction results, while part (b) shows the bearing stabilized results. In each part of the figure, the yellow line shows the node bearing. For part (a) this bearing is assumed constant and the target bearing shows the node rotations on top of the slower bearing change of the acoustic source, while in part (b) the node bearing is measured and used to correct the target contact bearing.

In both figures the green traces denote acoustic sources. The central trace is the acoustic target of direct interest, while the traces to the left and right are caused by a second acoustic source in the area. The short trace on the right is an aliased image of the real source bearing on the left.

The STB stabilization procedure should result in a greatly reduced bearing variation on a short time scale; however, it is observed that the node rotation is poorly compensated for. The stabilization process does reduce the extent of the bearing deviation, but it does not eliminate it. Further work will be required to improve this result.

From our quick-look analysis, the STB bearing compensation does not appear to work as well as the on-board DUSN beamformer bearing compensation; however, the STB and the on-board processing are generally working with very different averaging times. The STB typically shows bearing estimates for a short time interval, while the on-board processing uses a much longer interval. The on-board processing also uses a bearing histogram approach, which provides considerable smoothing of the bearing estimate. Compare the stability of Figs. 20b and 22a. Further data processing and correlation with orientation data will be required to evaluate and improve the bearing stabilization. (*Author note: It has recently been discovered that there is a software bug in the orientation system that results in a variable delay in the bearing measurement and time associated with that measurement. The STB results are most affected by this error due to the short averaging time used in the real-time display. A fix of the error is being developed as this document is published.*)

This initial deployment with the DUSN nodes has shown that the motion under the influence of a current is more than desired. Our plans are to add a thin, curved plastic sheet to the "bow" and a rudder to the 'stern' of the DUSN frames in an attempt to stabilize and limit the motion.

6.1.7 Beamformer testing

Prior to deployment only one of our in-node beamforming algorithms was functional. This beamformer is the Minimum Variance Distortionless Response (MVDR) beamformer. The conventional beamformer and the phase-gradient beamformer were fixed after deployment, they were not enabled within the deployed DUSN nodes.

Testing of the MVDR beamformer implementation was required in order to be sure that the bearings determined were accurate. The pre-deployment testing was accomplished in air, by reducing the frequency of interest to match the physical dimensions of the DSA and by resetting the medium phase velocity to that of air.

A loudspeaker, amplifier, and tone generator were employed to produce a stable signal source.

Both the signal source and the DUSN node were moved to an open outdoor area and an operator connected a terminal to the DUSN node to receive the target detection bearing messages generated. Figure 21 shows the DUSN, signal source, and operator during a test measurement.

The results of the in air testing are only approximate. There are interfering noise sources and reflections from the pavement and buildings that produce a multi-path arrival. By walking around the signal source the existence of standing waves is easily heard. Despite this, the results of the testing were sufficient to show that the DUSN was indeed tracking the location of the signal source.

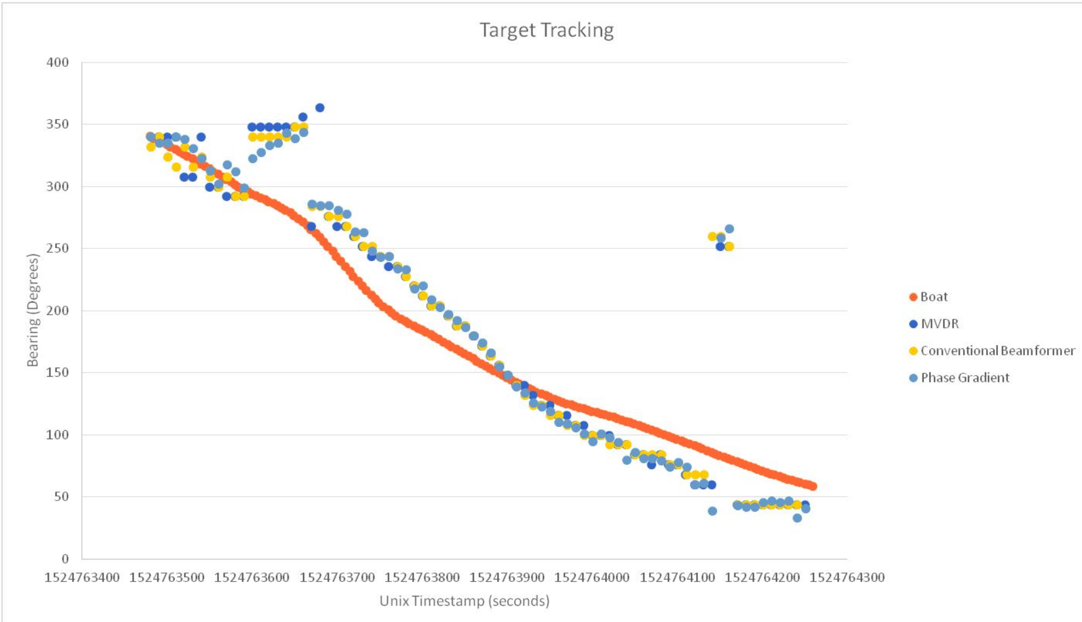
An example of the UW bearing track capability using the MVDR beamformer of the DUSN 1 node is given in Fig. 22a. In this example, the TSRV Sikanni is transiting through the

Figure 21: *A loudspeaker is used to generate a tone, while the DUSN node captures and processes data to determine the bearing of the acoustic arrival.*

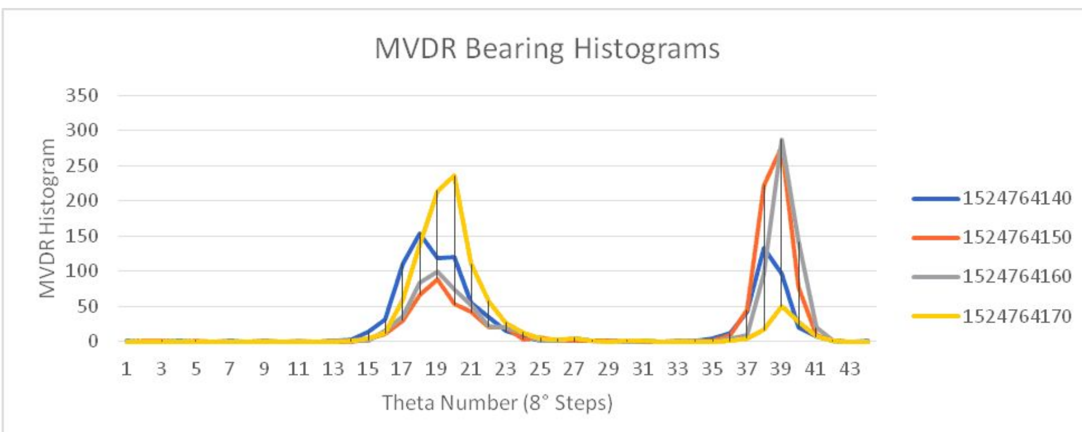
field of sensors and a second noise source, likely the YAG680, is also present. Figure 22a shows the bearing history of the Sikanni as it transits past DUSN 1.

It is worth noting that the DUSN software compensates the bearings for DUSN rotation by using the on-board orientation sensor that was calibrated prior to deployment (see Section 6.1.5). The resulting bearing estimates are smooth and without jitter caused by device rotation.

The DUSN nodes partition the azimuthal plane into 8° regions and count the number of bearings in each region to produce a histogram of bearing contacts over a short interval of time. Figure 22b is a plot of the significant bearing arrivals over a 30-second interval. In this case, there are two acoustic noise sources operating in the area.



(a) *A 1000-second snippet of data was processed to provide bearing estimates using broadband (50–1050 Hz) signals. The ship bearing vs. time estimates for MVDR, phase-gradient, and conventional are compared against the actual bearings of the ship.*



(b) *Two targets appear at separated bearings and times.*

Figure 22: *Bearing estimation example for the TSRV Sikanni transit.*

6.1.8 Bearing clustering

Not yet implemented in the DUSN nodes is a refinement of the bearing histogram approach employing a clustering technique described in Reference [7]. Simulation code to implement this clustering method was developed during the trial.

Figure 23 shows a simulation of two -10 dB SNR signal arrivals at bearings of -30° and 100° that has been processed by the new algorithm. Figure 23a shows a sonogram of the two weak arrivals with a broadband source. Figure 23b shows the bearing histogram and a smoothed histogram result. Figure 23c shows the initial bearing clusters and Fig. 23d shows the final result. The size of the balls in the last two sub-figures is related to the magnitude of the count of the observed bearings. The two arrival angles are accurately obtained, but a third arrival with fewer observed bearings (smaller ball in plot) is also found. In both the histogram method and the clustering method a threshold is applied to limit the number of detected bearings.

The clustering method shows great promise and appears to outperform the straight-forward histogram, but at the cost of higher processing requirements. Future work will be to compare performance of these methods with real data.

6.1.9 Configuration files

DUSN operation is controlled by a large number of parameters stored in a configuration file. Much of the effort during the trial was to understand the parameters and their effects.

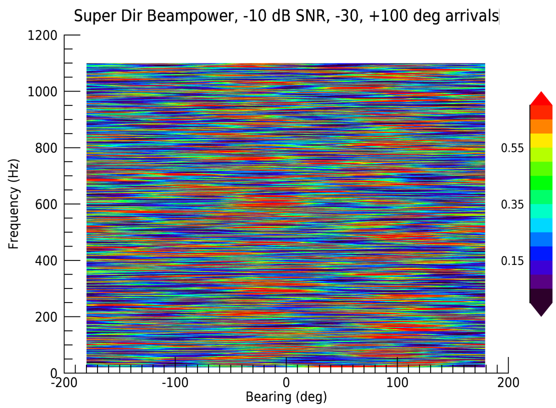
Annex A provides a tabular listing of the configuration parameters, a brief description of the parameter, and the values used in this trial.

6.2 Communications

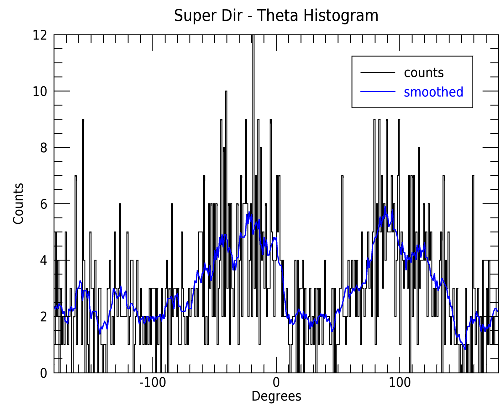
6.2.1 DFLOOD testing and NILUS messages

The DFLOOD networking protocol described in [4] is meant to reduce the number or re-transmissions when a node tries to reach a destination node through the network. This protocol was implemented for the first time in Norway on Teledyne Benthos modems [8] this past Fall (2017). The implementation involved modems connected to computers and three Norwegian NILUS sensor nodes (note that the name NILUS is used for both the message protocol and the sensor nodes). In the present trial, all six DUSN nodes were running the DFLOOD protocol on their embedded processors, which is currently the largest underwater network over which the protocol has so far been tested.

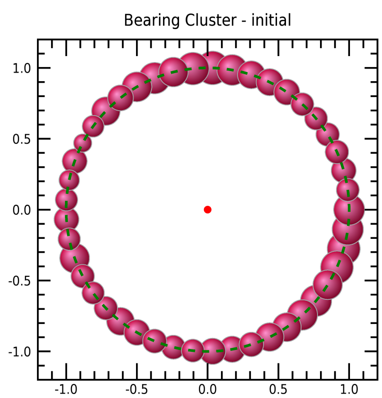
Tables 4, 5, and 6 summarize the results from an overnight series of tests during which multiple messages were sent through the network via two gateway buoys (named GW1 and GW2 here). The “Out” column gives the count of messages sent out from a gateway buoy and the “In” column reports the count of messages returning to the gateway buoy from



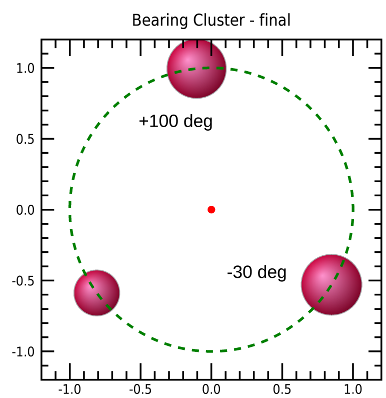
(a) *Sonogram of the simulated arrival directions estimated by super-directive beamforming.*



(b) *Histogram of bearings in one-degree bins.*



(c) *Initial bearing cluster estimates.*



(d) *Final bearing cluster estimates.*

Figure 23: *Processing stages in the new bearing clustering algorithm.*

destination node. As shown in Table 4, the overall counts for all messages result in a 97% success rate.

Table 4: *DFLOOD April 27 2018 overnight test. Modem source level setting 8.*

Gateway	DUSN #	Out	In
GW1	1	26	26
GW1	2	22	22
GW1	3	24	24
GW1	6	24	22
GW1	7	24	24
GW1	9	22	22
GW2	1	26	26
GW2	2	24	24
GW2	3	24	24
GW2	6	24	18
GW2	7	24	24
GW2	9	22	22
TOTAL		**286**	**278**

Table 5 is a similar test conducted on April 30 with a reduced modem source level, the overall counts for all messages result in a 88% success rate. Similarly, Table 6 provides the results for yet another test on May 2. This time, half of the DUSN nodes had been recovered enforcing a different network topology. The success rate was 100% in this instance.

It is difficult to compare the results from these tables because different acoustic source levels were employed. In fact, during the trial we discovered that the modems can change their levels autonomously, a behaviour confirmed by the manufacturer, but previously unknown by DRDC. Further clarification on this behaviour is needed, but it is at least partly related to the battery condition.

NILUS messages were used to send commands to various nodes during the trial. These commands included requests for ranges and status checks. The nodes also use NILUS messages to send target detection and target bearing history data to other nodes and to the operator.

6.3 Ambient noise collection and environmental data

Ambient noise data was collected by the six DUSN nodes; however, this data has not been processed as of yet to provide ambient noise levels for the region. The nodes each recorded 8–10 days worth of continuous data.

Two icListens were also deployed for the purpose of recording acoustic data and ambient noise. These hydrophones appear to have recorded data, but they have a DC offset and the voltage range of the signals appears to be less than expected. Unfortunately, we cannot

Table 5: *DFLOOD April 30 2018 overnight test. Modem source level setting 5.*

Gateway	**DUSN #**	**Out**	**In**
GW1	1	15	15
GW1	2	15	14
GW1	3	15	13
GW1	6	15	13
GW1	7	15	15
GW1	9	15	15
GW2	1	15	14
GW2	2	15	11
GW2	3	15	11
GW2	6	15	10
GW2	7	15	15
GW2	9	15	13
TOTAL		**180**	**159**

trust this data for calibrated measurements. All three of our icListen hydrophones need to be serviced and/or replaced.

The Star:Oddi data logging string deployed at 49.2973N, 124.0966W recorded the underwater temperature variation from 23 April, 2340 UTC to 30 April, 1623 UTC. This data is presented in Figs. 24 and 25.

Table 6: *DFLOOD May 2 2018 overnight test. Modem source level setting 7.*

Gateway	**DUSN #**	**Out**	**In**
GW1	1	recovered	recovered
GW1	2	recovered	recovered
GW1	3	recovered	recovered
GW1	6	10	10
GW1	7	10	10
GW1	9	9	9
GW2	1	recovered	recovered
GW2	2	recovered	recovered
GW2	3	recovered	recovered
GW2	6	10	10
GW2	7	9	9
GW2	9	9	9
TOTAL		**57**	**57**

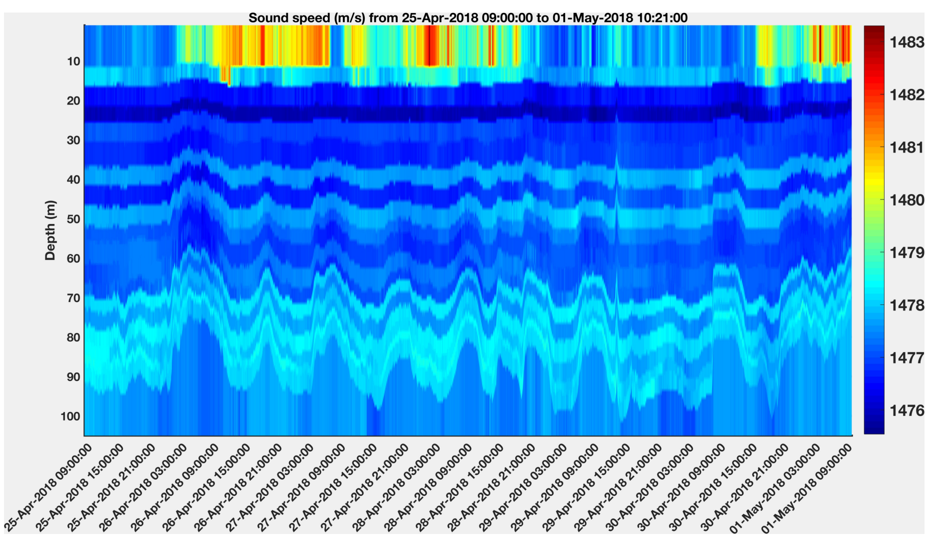


Figure 24: *The interpolated CTD information from the StarOddi sensors converted to sound-speed.*

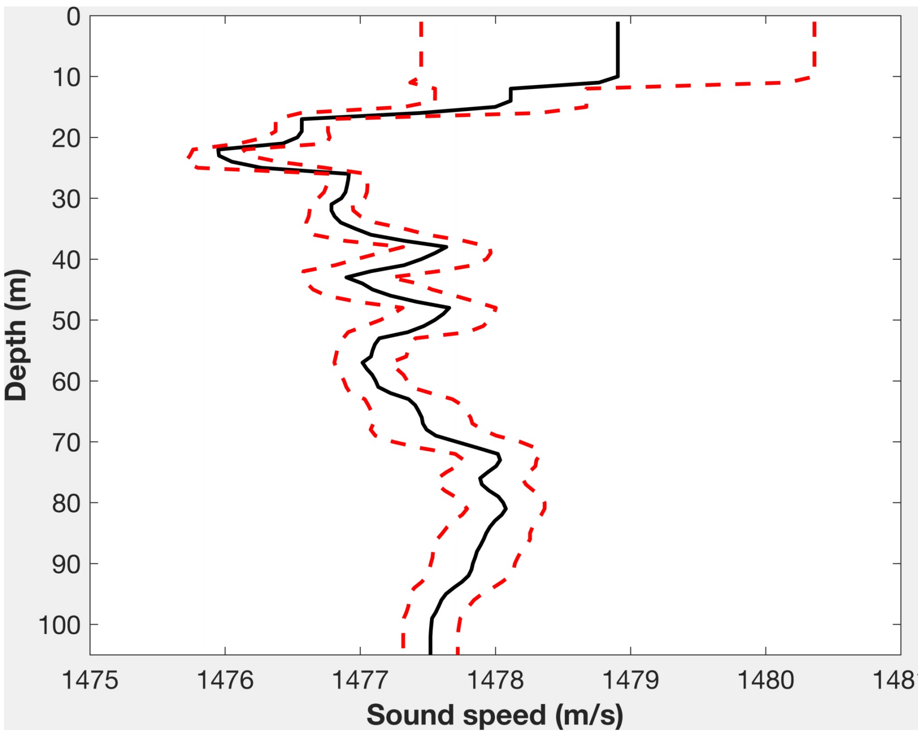


Figure 25: *The estimated sound-speed vs. depth with error bounds obtained from the StarOddi CTD sensor string.*

6.4 Vessel data collection

Many pleasure, fishing, and industrial boats operate in the CFMETR area. The DUSN data recordings are known to contain many transits of different vessels passing through the region. These are in addition to the range vessels that operated on both free-play and pre-arranged tracks.

AIS data were recorded continuously to aid in later vessel track reconstruction.

6.5 Gateway buoys

All of the gateway buoys refered to in Section 5.3 were deployed and operated as planned.

The only issue found with a gateway buoy was with the high-bandwidth link to DUSN 1, which failed on 27 April. The cause of this failure was a physical disconnection of the cable to the processor while still underwater. We do not know how this happened. The retaining collar was completely free of the connector and the connector was dangling. It is a mystery how this was possible, even if the retaining collar was never fully tightened. Several people claim to have checked the collar prior to deployment.

6.6 DACS projector

Extensive towing and projector level tests were conducted during the field trial to ensure that the system is fully functional. A large part of these tests was the collection of data to be used to determine the actual source level capabilities of the complete DACS system.

Unfortunately, as of this document's publication, the data has not been released to DRDC by CFMETR. Similarly, we have not been able to use the DRDC Calibration Barge as it is under-going refit. Also due to the limited water depth, calibration at the barge is restricted to frequencies 200 Hz and above. Therefore, we can only estimate source levels based on the TVR and measured applied voltages.

Notionally, it appears that the DACS system can reach source levels in the range of 185–195 dB in the band 200–1000 Hz, except possibly near 600 Hz where there is a deep notch in the transducer response. More work is required to fully determine the system capabilities.

The DACS projector tests were generally very successful. It has qualitatively proven itself to be a useful acoustic source. Data from the projector was recorded by CFMETR and is subject to inspection and editting prior to release. Acoustic performance analysis of the projector will thus be carried out at a later date as will some direct source level measurements at the Calibration Barge once it is fully accessible.

7 Conclusions

This was a highly successful trial. Essentially all of our pre-trial objectives were succesfully achieved.

The new body format for the DUSN nodes has resulted in far easier deployment and recovery, which can be managed even from small vessels. The deployment and recovery can be further improved by small changes to the hardware and process.

The new body format has resulted in instability of the body in a current. A light-weight nose cone and rudder are expected to overcome this azimuthal wandering. Tests with new components are expected to be conducted in the near future with the aid of flow tank.

Motion of the body was anticipated prior to testing and software to compensate for the body motion was developed. Our initial results show that some compensation is being applied, but it appears that the motion effects are not being adequately suppressed. Further development and analysis of the data is required.

We also found, not unexpectedly, that our pre-deployment calibration of node orientation sensor requires additional effort and hardware support. As discussed the entire node is required to be rotated through several perpendicular axes to achieve calibration. This is not easy to do with a large heavy object in the absence of magnetic materials.

Initial results from the DSA show that the planar array is capable and will likely meet our requirements. The VLA has not yet been analyzed adequately; however, we do expect some fine tuning of the sub-surface float buoyancy may be required. It may also be necessary to reduce VLA strumming and calibrate the in-line orientation sensors.

Remote control and interoperability between the nodes was tested and exercised. The capability is dependent on the interfering noise sources present, but it has been successfully demonstrated under typical conditions.

The objectives of data collection (environmental and vessels) have been successfully met. Almost 52 node-days of data recordings were collected with many planned and free-play vessel events included in the data.

Node endurance has been proven to be on the order of 10–12 days, with 12 days the likely endurance without constant system testing and queries in progress as is the case during an engineering trial.

While the objective of understanding the time synchronization of the nodes has not been fully met, it has been shown that we can synchronize the nodes and that they remain synchronized after more than a week in the water. We need to do more work to understand how long it takes to synchronize the nodes to a specified accuracy and to ensure our later measurement of time drift is accurate.

The question of the requirement for an atomic clock has also been raised. Considerable cost and power savings can be made by employing a less accurate clock. Coherent processing of data recorded on distributed nodes is an interesting, but likely unnecessary requirement and it appears that even with the CSAC, time drift could be sufficient to prevent coherent processing for all but the lowest frequencies after a relatively short interval of time.

Scripts were successfully used to automate operations of the gateway buoys and collect repetitive test data without the need for operator interaction.

The initial results from the DFLOOD implementation were extremely encouraging. All features were successfully demonstrated and we are now in a position to integrate our nodes with the Norwegian nodes in our next collaborative sea trial.

The refurbished DACS projector was operated for many hours and appears to be a valuable contribution to our low-frequency test gear. Small software upgrades were identified to make it a user friendly system.

In addition to the pre-trial objectives we also successfully implemented new and modified algorithms on the nodes, identified software bugs, and developed a scripted version of a new bearing estimation scheme. Another significant development was the delivery, by Omnitech, of a DUSN node simulation environment where we can set operating parameters and observe the DUSN node operation with real or simulated data.

Annexes B and C are provided below to list remaining work identified to do and lessons learned during the trial.

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Annex A Configuration Files

This annex consists of a multi-part table that lists all of the DUSN node configuration parameters. The tables provide the organizational structure of the parameters, a brief description of the parameter, and the value that was employed for the CFMETR 2018 field trial.

Table A.1: *Configuration file—Part 1*

PARAMETER	**DESCRIPTION**	**DEFAULT**
[CUBE]		
id	Platform and NILUS ID (should match the frame #)	node dependent
acoustic_msg	Acoustic autonomous state 0: communication will only occur when prompted externally 1: internally-generated messages will be transmitted	1
sample_rate	sampling rate (sample/sec.)	30000
battery_max_v	Maximum battery voltage when fully charged	18
battery_min_v	Minimum battery voltage when considered 0% charged	13
magnetic_declination	The angle (decimal degree value) between the magnetic and geographic meridians. True North is West of magnetic North	location dependent (16.4 at CFMETR)
bearing_bias	Additional configuration value for compass bearing compensation	0
compass_orientation	Orientation node mounting orientation	5
broadcast_addr	acoustic modem address to perform broadcasts (not P2P)	192.168.1.255
[GAINS]		
hyd	Hydrophone gain in dB (VLA and DIFAR) set on startup (options are 40, 60, 80)	60
[ON_START]		
wd_en	If enabled, the CPU will restart if the main application is unresponsive for more than 18 seconds (options are 0=debug and 1=deployment)	1
[HS_LOG]		
filesize	Maximum number of seconds in a single log file	600
prefix	Prefix to the log file name	hs_data
log_folder	Folder to save log files in	/mnt/log
log_en	If enabled platform will log all data (options are 0=disabled and 1=enabled)	1
sentinel_log_en	sentinel_log_en is only relevant if log_en is disabled If enabled and log_en is disabled, platform will only log data in between sentinel target detected, and target lost If enabled and log_en is enabled, all data is collected	0

Table A.2: Configuration file—Part 2

proc_en	If enabled the platform will send data to the respective algorithms (options are 0 and 1)	1 (to delete)
tcp_en	If enabled the platform will offer the respective data on a TCP server (options are 0 and 1)	1
[DEVICES]		
modem	Device handle of the modem	/dev/ttyS2
[DEBUG]		
msg_vebosity	Maximum message level that will be output to the system log (99 ensures that all debugging messages are logged)	99
[HS_PROCESSING]		
max_track_msg track_always	Number of bearings to accumulate before sending	30
	a target track message. A new NILUS track message will be sent after sentinel target lost condition or each time this number of bearings have been calculated	
num_sentinels	The number of different sentinels to run on the high speed data stream	1
tx_target_lost_only	1 = ignore "max_track_msg" and only transmit track messages on sentinel target lost	1
[SENTINEL], [SENTINEL1] [SENTINEL2] . . . [SENTINELn]	Settings under "SENTINEL", configure the "default" settings that apply to all other sentinel instances If more than one sentinel is set to run under "num_sentinels", then the additional settings are read from the SENTINEL1 through SENTINEL(N). Only the delta parameter need to be configured for each instance when using multiple sentinels	
enable	If enabled, sentinel will search for targets in high speed data if "proc_en" is also enabled in [HS_LOG]	1
domain	Determines the domain that sentinel searches for targets (options are "time" and "freq")	freq
max_target_time	Maximum number of seconds that the sentinel detector will hold a target for	N/A

Table A.3: *Configuration file—Part 3*

blanking_period	Time (second) interval following the start of a modem transmission	60
[SENTINEL_TIME]	(not used at CFMETR 2018)	
chan	The data channel one which to run the sentinel	N/A
ratio_thres	Ratio of short average to long average that triggers a detect	N/A
neg_rate_thres	Negative rate of the long average that triggers target lost	N/A
time_to_detect	Time in seconds that sentinel will average before searching for a target	N/A
noise_alpha	Alpha value for the long exponential average	N/A
sig_alpha	Alpha value for the short exponential average	N/A
[SENTINEL_FREQ]		
chan	The data channel one which to run the sentinel	3
dB_target_detect	short-term exp. Filter dB excess over the long-term exp. Filter before calling it a “target detection”	5
dB_target_lost	short-term exp. Filter dB excess over the long-term exp. Filter before calling it a “target loss”	0
num_fft_aves	Number of FFT’s being averaged	22
fft_ave_overlap	Overlap between successive FFT’s	2
fft_points	Number of points in FFT	30000
freq_high	Upper frequency limit (Hz) for sentinel to search	1050
freq_low	Lower frequency limit (Hz) for sentinel to search	50
bins_over_thres	Number of bins that have detected a target to trigger an overall target detection	300
bins_over_thres_loss	(Maximum or minimum?) Number of bins that have a “target detect” to trigger an overall target loss	100
time_to_detect	Time (seconds) for sentinel to average before searching for target	10
noise_alpha	Alpha value for the long exponential average	0.97
sig_alpha	Alpha value for the short exponential average	0.6
[STUPiDMVDR]		
enable	If enabled mvdr will calculate direction of target after sentinel triggers a target detected	1
is_continuous	If enabled, mvdr will calculate target bearings between target detected and target lost, otherwise, only 1 bearing will be calculated (0: off, 1: on)	1

Table A.4: *Configuration file—Part 4*

fft_points	Number of points in FFT	30000
fft_overlap	Number of FFT points to overalp	15000
freq_high	Upper frequency limit to look for targets	1050
freq_low	Lower frequency limit to look for targets	50
num_averages	Number of FFTs to average in solution	20
sound_speed	Speed of sound (m/s) in water at depth	1479
num_theta	Number of horizontal angle slices to search	45
[**DIFAR_XPOS**]		
x	Positive X hydrophone x position	0.3135
y	Positive X hydrophone y position	0
z	Positive X hydrophone z position	0
[**DIFAR_XNEG**]		
x	Negative X hydrophone x position	-0.3135
y	Negative X hydrophone y position	0
z	Negative X hydrophone z position	0
[**DIFAR_YPOS**]		
x	Positive Y hydrophone x position	0.1568
y	Positive Y hydrophone y position	-0.2715
z	Positive Y hydrophone z position	0
[**DIFAR_YNEG**]		
x	Negative Y hydrophone x position	0.1568
y	Negative Y hydrophone y position	0.2715
z	Negative Y hydrophone z position	0
[**DIFAR_ZPOS**]		
x	Positive Z hydrophone x position	-0.1568
	Positive Z hydrophone y position	-0.2715
z	Positive Z hydrophone z position	0
[**DIFAR_ZNEG**]		
x	Negative Z hydrophone x position	-0.1568
y	Negative Z hydrophone y position	0.2715
z	Negative Z hydrophone z position	0

Table A.5: *Configuration file—Part 5*

[DIAG_LOG]		
enable	If enabled, the diagnostic logger will log data	1
log_file	File to save log file	/root/log/diaglog.csv
log_period	Interval in seconds between log entries	5
[PHASEGRAD]	(not tested at CFMETR)	
fft_size	size of fft used in calculation	2048
overlap	0 or 1, where 0 is no time domain sample overlap and 1 is 50% sampling overlap in FFT calculation	1
snr_threshold		
min_bearing_freq	the lower frequency (Hz) to use in the bearing calculation histogram	100
max_bearing_freq	the upper frequency (Hz) to use in the bearing calculation histogram	500
histogram_resolution	the resolution used for bins in the bearing histogram. This value should be set large enough to account for target shift and calculation errors, but narrow enough to give the desired target bearing resolution.	5
[DFLOOD]		
enable	true = route modem comms through DFLOOD, false = peer-to-peer comms	true
defaultTxID	Default ID to send automatically generated messages to	19 (or GW1)
address	Local DFLOOD address, should match DUSN frame # and NILUS ID	node dependent
forwardPacketBufferSize Tm	size of the forward packet buffer in # of packets Delay after last buffered packet that a new packet is inserted if buffering APP-packets	8 5
T0	Maximum delay before a packet is retransmitted	60
T1	Additional delay when a copy of a buffered packet is received	20
Nf	Forwarding cancel packet threshold	2.5
usePacketBufferThreshold	Whether or not to buffer packets coming from application layer before sending. If false, packets from application are sent immediately	false
numPacketsBufferedThreshold	Maximum number of packets from application layer that can be buffered, if buffering is used	0
considerHopcounter	If false, “ttl” and “maxHops” is ignored	true

Table A.6: *Configuration file—Part 6*

sendAckStop	If true, destination node sends an ACK-STOP message when a packet is received to stop other neighbours to retransmit the same packet	true
useSinkPackets	Set to true to use destination node packet extension	false
forward__sink__packet__buffer__size	Size of forward sink packet buffer [number of packets]	4
isSink	If true, node is a sink and periodically transmits sink packets	false
sinkPktInterval	Period with which new sink packets are generated	300
sinkBackoffLow	Low backoff time used in sink packet relay	10
sinkBackoffHigh	High backoff time used in sink packet relay	40
sinkBackoffSpread	Maximum additional spread of sink back off times, to avoid collisions	10
routeRobustnessFactor	Controls the paths, besides the shortest, which are used for data forwarding when sink packets are used	2
maxHops	The maximum value used for TTL (time to live)	15
nofRetransmissions	Number of additional copies which are scheduled	1
retransmissionDelay	Delay used for additional copies: [0.5 *retransmissionDelay, retransmissionDelay]	120
historyCleanUpInterval	Interval at which the entire packet history is searched through and purged of old items	300
historyHoldTime	The time old packets are kept in the packet history	1000
debug	Debugging flag, if enabled, DFLOOD outputs packet activity	true

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Annex B To-do list

Tasks to accomplish as soon as possible (some of which must happen before the Sweden trial in Fall 2018):

1. Electronics and electrical:
    - Add depth sensor and digitally record its reading on each DUSN node.
    - Add a voltage sensor on the battery packs and digitally record values in the node. Make the values accessible by NILUS query.
    - Install a GPS on the high-bandwidth data link buoy.
2. Software:
    - Upgrade to the newest NILUS message format.
    - Implement conventional, super-directive, and phase-gradient beamformers in the node firmware.
    - Code the bearing clustering algorithm for inclusion in the node firmware.
    - Code DFLOOD in a simulated environment to aid in the testing of the selected parameters.
    - Analyze node bearing bias with the data from a vessel running circles around nodes.
    - Test changing node ID via NILUS messaging.
3. Analysis:
    - Investigate CPU usage during different states.
    - Look at DUSN frame motion with respect to tidal flow, etc.
    - Assess behaviour and character of each hydrophone's data. Identify potential issues as many hydrophones are subject to failure in this build.
    - Validate the orientation correction on bearing estimates.
    - Gather and analyze Cast-Away CTD data and buoy GPS data.
4. Tests:
    - Test various sampling rate option and compare long-term power consumption on the nodes.
    - Investigate reason for high-bandwidth link failure.
5. Hardware:
    - Identify with Teledyne when modems autonomously alter their source level.
    - Upgrade the acoustic modem firmware to the latest version.
    - Obtain manufacturer information for retrieving CSAC drift time upon recovery.

6. Mechanical:
   - Build a bracket to hold the orientation sensor in a fixed position for each node.
   - Build sturdier brackets for the acoustic modem.
   - Manufacture new brackets to replace those that were fractured/damaged during recovery.
   - Build a magnetic material free jig for calibrating the DUSN frame orientation sensor by rotating the entire node about several axes.
   - Fiberglass all VLA boxes.
   - Investigate the necessity of a stabilization system (bow and rudder) on DUSN frames.
   - Add handles to surface buoys to facilitate their recovery.

Tasks to complete at a later time:

- Devise a new anchor in which the rope could be embedded.
- Analyze VLA data for matched-field processing and Lloyd's mirror inversion.
- Attempt frequency-only target tracking.
- Calibrate VLA and DSA at the Calibration Acoustic Barge.
- Procure a multi-axis Helmholtz magnetic field system for improved orientation sensor calibration.
- Deconflict frequency band and line-of-sight with radios prior to deployment.

Annex C Lessons learned

- Check NTP server configuration to speed up CSAC sychronization.
- Automate node localization through scripted operation of the network acoustic gateway modems.
- Investigate possibility of orientation calibration prior to shipping equipment to field site. This may not be technically feasible.
- make sure separation distance between node location and recovery vessels is large enough to avoid impact on the node release
- Ensure critical information is immediately communicated to log-keeper and double-check your information with main log record prior to trying to use it. For example, release code numbers.
- Clarify CFMETR vessel usage limitations and over-time requirements ahead of time.
- Always include the light-weight BATS acoustic source in the field kit.
- Three people are needed for modem ranging on a boat.
- Record weather conditions (especially wind).
- Configuration file of NTP server must be checked to enable CSAC disciplining. This was a significant issue during the trial and took a lot of time to find the cause.

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This quick-look trial report contains a record of the trial's success with achieving the planned objectives and initial analysis of data. In particular, the impact of the changes to the body format and array structures on the deployment, recovery, and data performance are discussed. The success of the communications and the implementation of the new DFLOOD protocol, along with results from timing synchronization, power usage, node stability, and new data processing algorithms are presented.

Le présent bref rapport d'essai présente un compte rendu du succès de l'essai sur le plan de l'atteinte des objectifs prévus et de l'analyse initiale des données. Nous discutons notamment de l'effet des changements apportés au format du corps et au réseau sur le déploiement, la récupération et le rendement des données. Le succès des communications et la mise en œuvre du nouveau protocole DFLOOD, ainsi que les résultats de la synchronisation temporelle, l'utilisation de l'énergie, la stabilité des nœuds et les nouveaux algorithmes de traitement des données sont présentés.