UDT 2023 – Underwater acoustic wireless network for diving operations

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Abstract — An underwater acoustic wireless network provides significant operational and safety benefits to diving operations. In the military context, the potential exists to expand this network to include other assets in the underwater battlespace to deliver a level of domain awareness until now only seen in the surface and air environments. In the commercial sector the predominant use of umbilicals makes communication with the surface or other divers less reliant on a wireless network, however the benefits of all effectors (divers or ROVs and UUVs) being tracked within one network offers benefits in safety and efficiency. The objective of the network is to provide enhanced situational awareness, communications and positional information between divers, their safety craft or delivery vehicle and their destination. Situational Awareness for the diving supervisor includes location and depth of the divers plus other telemetry data such as cylinder pressures, oxygen content of the breathing loop of any other biometric data required by a customer. The core technology for the diver network has been in commercial use for decades: Ultra-Short Baseline (USBL) tracking technology delivers reliable high positional accuracy. The inclusion of GNSS and divers' depth data refine these positions to 3-5% of slant range but is not essential for reliable operation of the network which means the system can operate in a GPS denied environment. Encryption of the signals and choice of transmission protocols have been selected to reduce the probability of intercept and exploitation. This means that the tactical and safety benefits of the system outweigh the operational risks of detection against most adversaries.

1 The challenge

1.1 Definition of terms.

In the context of this paper communication means the transmission of information. In basic terms communication can be subdivided into sharing tracking data (position, depth, heading, speed) and telemetry (mission specific information, for example: a diver's gas cylinder pressures; start or completion of a task; or biometric data of the diver themselves).

1.2 User requirements.

For a diver and their supervisor, reliability is the most important element of communications. Incomplete or incoherent voice messages reduce efficiency at best and at worst impart greater risk into an already unforgiving operating environment. For a surface supplied diver, whose umbilical and diving helmet easily contain a hard-wired voice communication solution, there is no reason to consider more complex technology to solve what appears a simple problem. The diver can speak freely according to need albeit not aided in terms of location.

However, simple voice communications rarely satisfy the requirements of modern military diving operations. The underwater domain has changed. It is more congested, occupied by more autonomous systems and subject to additional technical requirements such as: low probability of intercept (LPI) of secure (encrypted) communications; resilience to GNSS denial; and increased operating ranges. For military diving the predominant use of rebreather life support equipment means the use of a bite mouthpiece interferes with clear speech. Where tactical requirements prevent the use of a full-face mask there is no option to speak past the mouthpiece at all; itself a bad practice on a rebreather: in effect, current products for voice communications present more problems than they solve.

In designing a solution, a fundamental truth must never be overlooked or compromised: the user must be assisted by the technology. The technology must enhance operational capability and/or safety, militate against human error and not add to an operator's cognitive loading: the information flow must be near-real time, autonomous and unambiguous.

Meanwhile the demand for miniaturisation continues, as space in a dive boat is limited. Divers, their personal equipment, ancillaries (tools to execute the task) and rescue/medical equipment must be accommodated. Diving communications equipment must be ruggedised and easy to use, while being low cost, low size, low weight and needing minimal power.

2 Creating the acoustic underwater wireless network

2.1 Problem.

Shallow water is the most challenging environment for acoustic positioning and data transfer (telemetry). Unlike in deep water, problems such as multipath from the sea surface, refraction due to large sound velocity differentials and aerated water play a major role. All affect the performance of a robust underwater wireless network.

The properties of the acoustic signals are critical. Digital signals are necessary to allow signal processing techniques to be used to resolve interference and provide error correction ability. Phase Shift Keying (PSK) has become the de-facto standard encoding method for through-water acoustic signals. Digital bits are phase-shifts of a carrier frequency, either by half a wavelength or by a quarter wavelength (BPSK/QPSK).

The fundamental trade-off for either positioning or telemetry signals is detectability versus data rate. BT (Bandwidth Time) Product is the common measure of this. A higher BT value essentially means more time/energy between phase shifts (bits), meaning the signals are easier to detect. However, this comes at the cost of data rate and as such effective bit rate or throughput is not used to describe system effectiveness in shallow water.

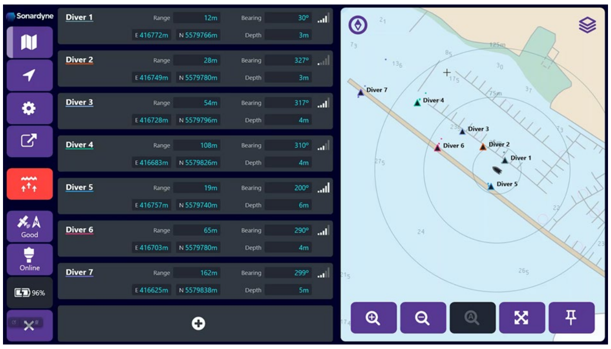

Fig. 1 - USBL technology is used to position and exchange telemetry with dive teams

For Shallow water tracing and communication systems, both detectability and robust, efficient data transfer are equally important. Sonardyne's proven Wideband 2+ (WB2+) address set is used for the positioning signals, which are appended with telemetry payloads. The WB2+ navigation signals have twice the acoustic energy of the WB2 signals more commonly used in deep water oil and gas operations. When available, GNSS input provides a navigation function to enable the use of electronic chart overlays. When GNSS input is denied the USBL system operates accurately as a relative positioning network.

The appended telemetry uses a new scheme which supports variable packet sizes and adjustable BT values, allowing an application to maximise performance for a given environment. All telemetry transfers are error checked to prevent corruption and incorrect decode – this is crucial when the data consists of dive rebreather diagnostics, messages, and alarms.

This new scheme was developed as an iterative development on pre-existing deep-water waveforms which have lower BT and are designed to optimise for battery life, robustness and precision in ideal conditions. During repeated testing with end users the deep-water waveform performance did not meet the exceptional robustness (accuracy & availability) required to transmit key information in shallow water regions.

Consequently, key technical challenges and requirements were identified during early development and trialling in Plymouth (UK):

- Improve the robustness of acoustic waveform to environmental parameters
- Increase the detectability of acoustic waveform
- Increase the sensitivity (ability to detect) of all hardware used in shallow environments
- Simplified operation of system

2.2 Solution

Forcys' technology partner Sonardyne worked directly with diving equipment manufacturers [1] [2] to enable a dive supervisor on the surface to view the same diagnostics that are available to a diver, via BT64 optimised telemetry packets. The system supports simultaneous telemetry updates from up to 8 divers (Fig. 6), responding to a common interrogation signal. To this end the system optimises: power levels; BT; sound velocity variations via measured temperature & pre-set salinity; acoustic gain; and uses TDMA to schedule and eliminate the possibility of signal clashes within the water column.

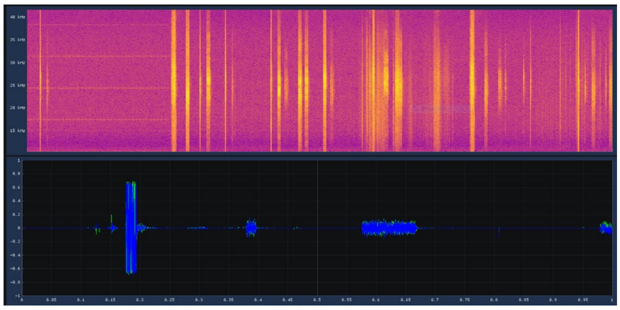

Fig. 2 - Sonardyne digital signal

The use of short transmission packets from the transponders also minimises the diver's noise exposure. Transmit power is lower than typical USBL transponders, while still supporting >1.5km range (Fig. 5 & Fig. 6). Carrier frequencies are ~24kHz: beyond audible limits for humans.

The results presented in the next section follow those presented by Neasham et al. [3]. (Fig. 3) who examined receive success percentage of all detected packets across different BT and the performance gains delivered by an Adaptive Receiver (AR) compared to their standard Reference Chain (RC). These results highlight the improvements in decode success by increasing BT over a 1.3km range (vessel – Waypoint 3) in the same body of water in Plymouth (UK). The results presented by Neasham et al. [3] utilise the AR used in the DiveTrack results presented in Section 2.3.

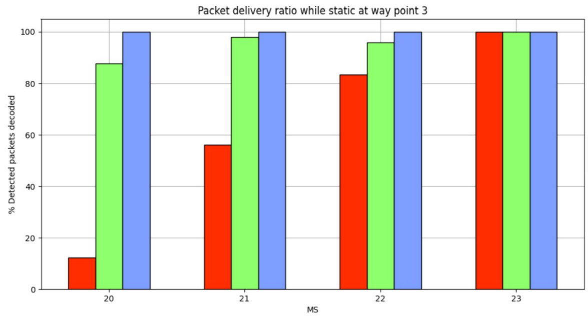

Fig. 3 - Packet delivery rates for 24kHz static signals in Plymouth Sound (red trace RC, green trace AR, blue trace 6-channel AR, BT16,32,64,128 left to right) [3]

2.3 Results

Two datasets are presented in Figs 5 and 6 from Plymouth UK, one an estuarine river environment ~10m max depth (River Tamar, Devonport) and one from a sheltered coastal area ~30m max depth (Cawsand Bay). These representative trial areas are used regularly for acoustic waveform testing [3]. Note that the maximum range for River Tamar results is limited by the depth beneath the hull to which the vessel can operate safely rather than acoustic performance.

For these trials, the USBL system was deployed from Sonardyne's trial and support vessel *Echo Explorer*. Transponders and dive computers were deployed at a depth of 2-6m, the support vessel opened from the transponders before returning, to simulate how an expeditionary dive team might swim away from a vessel and return at depths typically <6m. The consistency of range results indicates a telemetry and tracking link which is well optimised and robust to previously mentioned environmental factors.

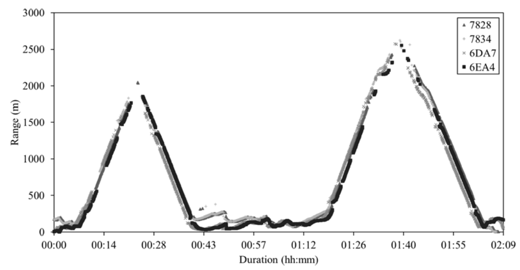

Fig. 4 - Cawsand Bay range results (~30m)

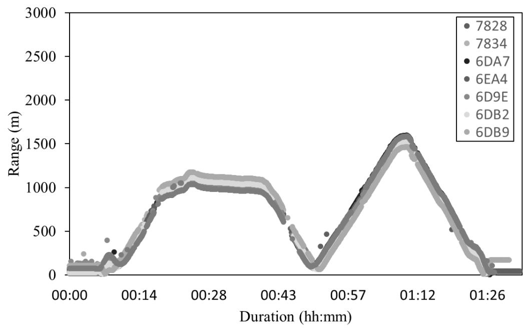

Fig. 5 - River Tamar range results (~10m)

2.4 Engineering

The transceiver and transponder were designed for the challenging shallow water environment from the outset. This started with mechanical design which ensures build quality and physical tolerance of the piezo-ceramic transducers used in the USBL array. It is essential that the array is built to tight tolerances that are stable in all environments.

Next in the chain comes the analogue electronics which is designed to ensure fidelity of the received signal along with reducing inter-element crosstalk and consistency. Both factors are critical when measuring phase differences which are at the heart of the USBL positioning. Finally, and most importantly, the signal processing carried out on the received signals was designed to adaptively change from one sample to the next. This mitigates fading, multipath and interference to provide robust communications and positioning.

The hardware development also included future capability to support the emerging Phorcys underwater acoustic waveform [4] [5]. This will provide encryption and bespoke customer address sets in the future, to enhance operational security [5].

3 Application

Diver tracking and communications have the potential to improve operational efficiency and diver safety. The solution discussed in this paper has focused on the diving operation.

While operating depths offshore have increased, performance of USBL in the more complex shallow water environment, has benefitted most from optimisation and new digital signal processing methods. A shallow water optimised system provides tangible tactical benefits for military operations and strengthens the equipment and operating safety case for the dive. The cognitive loading and opportunity for human errors in information exchange are greatly reduced. With a reliable, consistently accurate and simple to use system diving is safer, more efficient, and more flexible.

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Speaker Biography

Justin Hains MBE served in the Royal Navy for 28 years as a Mine Warfare and Clearance Diving Officer, with specialist experience in anti-submarine and surface warfare. He commanded a bomb-disposal unit, two minehunters and the Standing NATO Mine Countermeasures Group 2 before managing the Royal Navy's mine-warfare, diving, and bomb disposal capabilities in Navy Headquarters, where he also advised the UK MOD Capability Sponsor for defence-wide diving safety.