THE FUTURE OF UNDERWATER WIRELESS

And how we are building it

SUBNERO

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We live in a hyper-connected world where we take wireless networking technology for granted. However, the same cannot be said in the case of 70% of our planet – our oceans. We know frighteningly very little about our oceans, considering the impact they have on our lives. True heterogeneous networks, like the ones we have on land, do not exist in the underwater domain today.

At Subnero, we believe we are at the cusp of a technological revolution that enables us to deploy smart underwater networks. By leveraging the latest trends in wireless networking (e.g. software-defined edge computing) and technological advancements both at the software level (e.g. machine learning) and hardware level (e.g. GPGPUs[1]), our technology, products, and solutions enable us to offer reliable, performant and smart underwater wireless networks for communication, navigation, monitoring, and sensing.

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In this whitepaper, we take a dive into some applications, challenges, and how we, at Subnero, are addressing them to build true heterogeneous underwater networks.

[1] General Purpose Graphics Processing Unit, https://en.wikipedia.org/wiki/General-purpose_computing_on_graphics_processing_units

So, who needs an underwater wireless network?

Subsea tasks such as inspection, survey, monitoring, repair, and maintenance of underwater assets and structures have been traditionally conducted by divers. Due to the hazardous nature of these tasks, divers are being gradually replaced by remotely operated vehicles (ROVs) or autonomous underwater vehicles (AUVs). However, ROVs have tethers, which make operations complicated, and the majority of AUVs are designed for long range survey missions, and therefore are unsuitable for inspection tasks that need hovering capabilities. This has given rise to two key trends in this space. The first trend is the rise in the use of underwater sensors for monitoring of large areas over long durations, to augment expensive inspections using vehicles or divers (e.g. Acoustic Doppler Current Profilers – ADCPs). The next trend is the drive towards tetherless ROVs, known as hybrid or hovering underwater vehicles (HUVs), that rely primarily on supervised autonomy.

In both of these cases, the key limiting factor is the lack of reliable, performant underwater wireless technology – not just point-to-point links, but a communication network. Such a network will enhance the operational efficiency, providing larger coverage and reduction in the cost of deployment and management, much like how IoT is driving innovation on the land today.

Subnero's WNC series of smart devices with their powerful computing hardware and a developer-friendly software framework with ML and artificial intelligence (AI) support are uniquely positioned to leverage the edge computing paradigm to its full potential.

"Transmit Less": A New Paradigm

Due to physical constraints associated with acoustic systems, they will always be limited in their data-carrying capacity, as compared with terrestrial wireless systems. While we continue to develop faster underwater wireless technologies to meet application demands, one has to balance this with reduction in the quantity of data to be transferred to a centralized location for a scalable approach. This is a major driver for the move towards edge computing.

The case for Smart Underwater Networks powered by Edge Computing

Acoustic transmissions come at a premium both in terms of bandwidth utilization and the power consumption. Combined with Machine Learning (ML) techniques, edge computing[2] can enable techniques such as content-aware data analysis, prioritization, classification, model fitting etc. to be performed at the edge. This ensures optimum link utilization and power saving by transmitting only the essential information within a fraction of time. Subnero's WNC[3] series of smart devices with their powerful computing hardware and a developer-friendly software framework with ML and artificial intelligence (AI) support are

[2] https://www.marketsandmarkets.com/Market-Reports/edge-computing-market-133384090.html
[3] WNC: Wireless Networked Communications

uniquely positioned to leverage the edge computing paradigm to its full potential.

Holy Trinity: Data Rate, Range, and Reliability

The first step in building any communication network is to have robust and reliable point-to-point (p2p) links. Due to the rapid absorption of electromagnetic waves underwater, acoustics is the prominent technology used for building wireless links underwater. However, underwater acoustics has to address many challenges such as long latency, limited information carrying capacity and challenging environmental conditions. In spite of this, acoustic communication systems have been an essential part of many subsea operations. These systems were primarily envisioned as a replacement for cables to provide low-rate wireless communications traditionally. To contrast this, many emerging applications require wireless systems with higher data carrying capacity over shorter distances with smart power management and scheduling capabilities.

The devil is in the details

Data rate, communication range, link reliability or bit error rate, power consumption etc. are some of the most common parameters that vendors use to advertise their devices. While these numbers are achievable under the right environmental conditions, they alone do not tell the whole story. Since the underwater communication channel conditions vary over time and geographies, the actual performance differs from the specifications.

We think the most important factor is a device's ability to be configured easily to adapt to different environmental conditions to provide the best performance. The ability to make such adjustments during an operation in the field is a key factor that sets our devices apart from the rest.

To address the varying needs of different industries, most acoustic modems (providing p2p links) in the market currently are either optimized for data rate or reliability or communication range, along with a focus on low power consumption and a small form factor. This approach has led to the need for multiple acoustic devices from different vendors. This adds to the complexity and cost of the end-user system. The problem gets compounded when a system that is designed for one use case (e.g. deep cold waters around Europe) is expected to perform equally well while deployed in a different environment (e.g.

Image credits: pch.vector - www.freepik.com shallow warm waters around southeast Asia).

All of these challenges present a large barrier to the development of devices to provide performant underwater p2p wireless links to form a strong foundation on top of which one can build underwater networks.

Let us build networks underwater!

Subnero's story started when a group of researchers at the Acoustic Research Laboratory[4] (ARL), Singapore dreamed of building underwater networks using acoustic modems. More than a decade and multiple R&D iterations later, they demonstrated the Unet modem powered by the UnetStack[5], outperforming many benchmarks in the harshest of the environments.

Subnero's WNC line of smart underwater acoustic modems, powered by UnetStack are at the forefront of today's underwater wireless communication technology. They provide **best-in-class performance** and dynamic in-field configurability, are fully **software-defined** for customizability, flexibility, extensibility, and **edge computing** and **network -ready** out-of-the-box.

Best-in-class Performance

The M25M series of smart modems can easily be configured to provide the best performance in different environmental conditions. For example, when optimized for communication range, they can achieve more than 4 km with 80 bps in shallow waters. When optimized for data rate, they have demonstrated up to 15 kbps at shorter ranges. When optimized for both, they can provide 2 kbps at more than 2 km in some of the most challenging waters. More importantly, a user can choose where on the performance curve the devices need to be operating at any point during a deployment.

The performance that far surpasses our competition is due to the plethora of the novel communication schemes running in our devices to address various challenges associated with underwater acoustics such as long latency[6], low bandwidth[7], and noisy environments[8].

Software-Defined Design powered by an Edge Computing-ready Hardware Platform

All our devices are powered by UnetStack, which is a software-defined in-water network stack. UnetStack offers customization at many levels and cross-layer integration that is critical in low bandwidth wireless networks.

[4] https://arl.nus.edu.sg/

[5] M. Chitre, R. Bhatnagar, and W.-S. Soh, "UnetStack: an agent-based software stack and simulator for underwater networks," in Proceedings of OCEANS 2014 MTS/IEEE, (St. John's, Canada), September 2014.

[6] P. Anjangi and M. Chitre, "Experimental Demonstration of Super-TDMA: A MAC Protocol Exploiting Large Propagation Delays in Underwater Acoustic Networks," in Underwater Communications Networking (Ucomms 2016), (Lerici, Italy), September 2016. (Invited).

[7] M. Chitre, A. Mahmood, and M. Armand, "Coherent communications in snapping-shrimp dominated ambient noise environments," in Acoustics 2012 Hong Kong Conference and Exhibition, vol. 131, p. 3277, May 2012. (Invited).

[8] A. Mahmood, M. Chitre, and V. Hari, "Locally optimal inspired detection in snapping shrimp noise," IEEE Journal of Oceanic Engineering, vol. 42, no. 4, pp. 1049–1062, 2017.

In addition to the various network stack functionalities, It provides a modern web-based user interface (UI), programmable dashboards, various libraries for data analysis, scientific programming, ML and has a built-in network simulator. The data flowing through the modems can be subjected to various analyses (e.g. content-aware data / image / video compression, prioritization, etc.) by leveraging the ML and GPGPU computing capabilities in the modem to ensure optimum link utilization.

Built around a single board computer featuring a multi-core ARM CPU with an integrated GPU, the Digital Module (DM) is the processing center that makes such powerful edge computing possible. It also runs various software signal processors through which the signals are "passed through" to provide the best performance to the user.

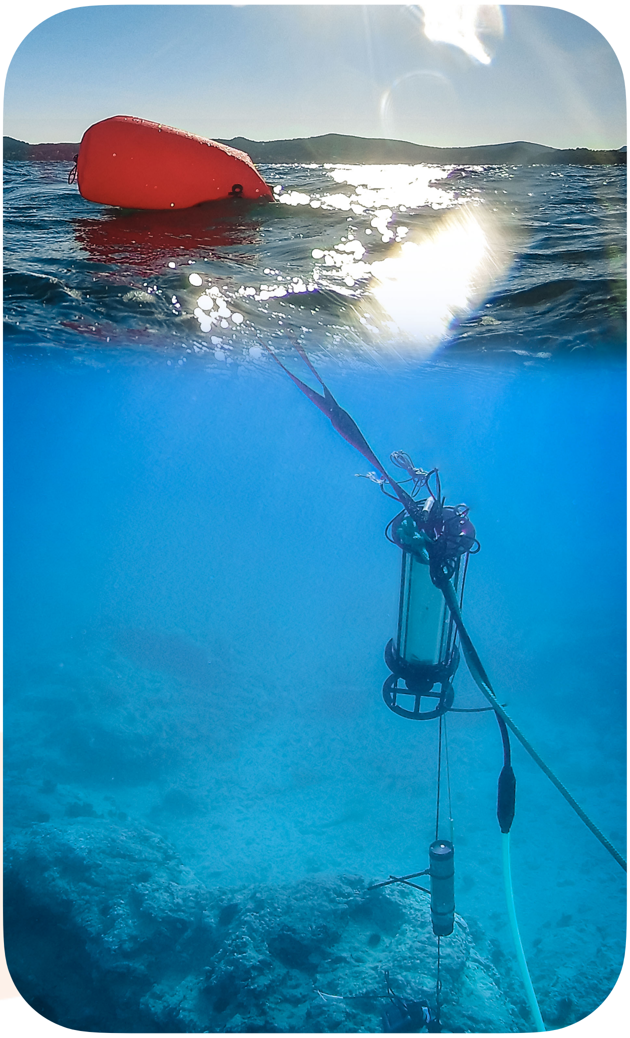
It is this seamless integration of the software-defined design, advanced algorithms and a powerful hardware platform that makes our smart modems a flexible computing device with an acoustic communication interface, similar to the smartphones of today.

What does it mean to a user?

To begin with, our devices provide different classes of communication links (including power control) optimized for robustness (e.g. telemetry) or data rate (e.g. sensor data)[9]. Users can choose different links depending on the payload at any time.

All devices that run UnetStack provide an intuitive and unified user interface. Software updates and new features are available at regular intervals to ensure that the devices are secure and have a long life time. Users can easily configure Subnero devices to avoid interference with third party devices[10] or to interoperate with them by emulating them. This in turn makes our devices not "just an acoustic modem", but a single device that can perform multiple functions simultaneously, e.g. communication, localization, data logging.

Acoustic researchers can get direct access to the raw signals for both transmission and reception. They can build their own signal processing techniques that run in the device using the multiple computer languages (e.g. Java, Python, Julia, Matlab, JavaScript etc.). Once developed and tested using the Unet Simulator[11], they can simply be copied to run on the Subnero modems.



There is no free lunch!

Supporting cutting-edge algorithms in the software requires computing elements that are powerful enough to crunch the numbers in real-time. This tends to consume more power as compared to a hardware-defined platform. By continuously optimizing our hardware design and leveraging the latest semiconductor technology which is driven by the need for extremely low power consumption, we are able to support extremely low power modes with our Gen4 hardware platform running UnetStack4. Such innovations in both software and hardware enable us to address new use cases with each update of our devices.

The Subnero Advantage

- **Best-in-class performance**
- **Software-Defined Open Architecture Modem**
- **Versatile, edge computing-ready hardware**
- **Dynamic, in-field user configurability**
- **Designed for networking at its core**
- **End-to-end connectivity with terrestrial networks**
- **Networked localization capabilities**

'N' in WNC: Advanced Networking and Localization at the Edge

Development of robust point-to-point links was only the first step in getting closer to

[9] https://unetstack.net/handbook/unet-handbook.html#_unetstack_basics
[10] https://blog.unetstack.net/frequency-band-control-in-unetstack
[11] https://unetstack.net/handbook/unet-handbook_writing_simulation_scripts.html

our dream of building underwater networks. In addition to the high performance physical layer, our devices also include a complete implementation of a network stack (as part of UnetStack) much like the TCP/IP[12] stack that powers today's Internet. Out-of-the-box, users can operate multiple devices in the same deployment area simultaneously without interference with each other, thanks to the datalink and MAC protocols. They can automatically form networks supporting multi-hop links, both above and below water surface, with relaying and routing functionalities to support end-to-end connections.

Conclusion

True wireless networks are possible only with a strong foundation that is a combination of robust point-to-point wireless technology as well as a flexible platform to customize and extend it. **Subnero Underwater Network (SUN)**[13] built using our WNC product line extends terrestrial networks underwater by providing best-in-class performance, unparalleled flexibility using software-defined approach on an edge computing platform as well as end-to-end connectivity out-of-the box, for innovative and reliable solutions for applications such as underwater IoT and autonomous subsea inspections.

[12] https://en.wikipedia.org/wiki/Internet_protocol_suite
[13] https://www.youtube.com/watch?v=ZoeZ4rdEjSY

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SUBNERO

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www.subnero.com
sales@subnero.com
+65 9819 9552
@subnero

SUBNERO

Subnero Pte. Ltd.
1003 Bukit Merah Central
#04-05
Singapore 159836