Demo: Leveraging Underwater Backscatter for Long-Term Environmental Sensing

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Abstract

This demo presents BlueTag, a permanently deployed underwater sensor system based on backscatter communication. BlueTag is a battery-powered CTD (conductivity, temperature, depth) sensor that transmits measurements every 15 minutes to a remote base station via underwater backscatter. The base station archives these measurements and publishes them online. Unlike prior underwater backscatter systems limited to short-term laboratory experiments, BlueTag has been deployed in the Charles River in Boston, MA since July 9th, 2025, marking the first long-term underwater backscatter deployment of its kind to sense meaningful environmental data. Live data from this deployment is available publicly at https://sk-exp-server.mit.edu/.

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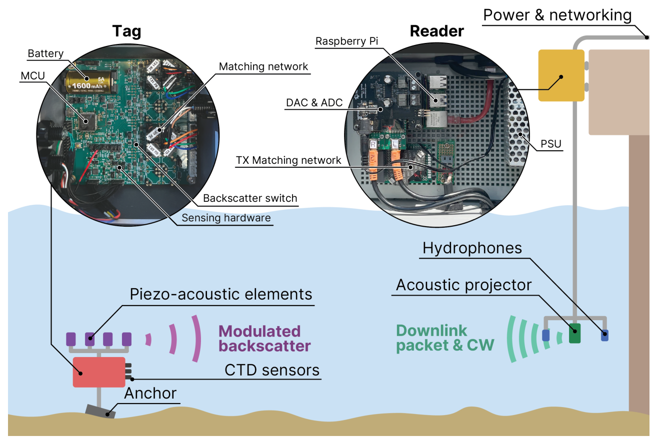

Figure 1: Overview of BlueTag. The reader transmits a polling downlink to the tag, followed by a tone. The tag wakes up after receiving the request and uses backscatter to modulate its Van-Atta array of piezo elements according to captured data from its CTD sensors. The reader decodes the sensor data from the uplink packet and stores it.

1 Introduction

Environmental monitoring of Earth's bodies of water–such as rivers, lakes, estuaries, and oceans–is critical to understanding the impact of pollution and human activity on the climate. Recently, increased research attention has been paid to underwater wireless sensor networks that have the potential to provide rich environmental data of these water bodies over a wide area [6, 7, 14]. Such systems could generate data with high spatiotemporal resolution at lower deployment cost to improve climate models, support disaster response, model runoff pollution in urban areas, or provide early warning systems for complex environmental hazards such as harmful algal blooms [1, 4, 10].

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Underwater backscatter is an example of such a system that enables wireless underwater networking at orders of magnitude lower power than traditional acoustic modems [5]. It operates by reflecting or absorbing incoming sound waves rather than generating them itself. Because of this, devices that communicate via underwater backscatter can last far longer on a single battery charge, vastly reducing the maintenance overhead associated with device retrieval and battery replacement. However, today's underwater backscatter systems largely remain research curiosities; their deployment lengths are mostly limited to a few hours (during experimentation), and their implementation often requires complex testing infrastructure and experimental setups.

This demo presents BlueTag, a permanently-deployed, acoustically-wireless conductivity, temperature and depth sensor (CTD). Shown in Fig. 1, BlueTag is a fully-submerged, battery-powered device that offloads its sensor measurements to a remote base station every 15 minutes. The base station saves these measurements to a database and displays them on a publicly-available website. BlueTag represents the first underwater backscatter system to be deployed for more than 24 hours, and the first underwater backscatter system to collect repeated, *in-situ* data from a real underwater environment. We measured the average current consumption of BlueTag to be 90 μA, indicating that it can last for more than two years with the included 1600 mAh battery.

2 System Overview

Our system is comprised of two main components: a submerged tag and a surface-mounted reader. The reader is connected to grid power and networking infrastructure, while the tag is battery-powered. Every 15 minutes, the tag (based on an STM32U535 microcontroller) collects water data using its on-board CTD sensors. To retrieve the data, the reader sends a downlink command containing the tag's unique address, and the tag responds by backscattering a packet with the sensor readings.

Most of the time, BlueTag remains in a low-power sleep state to conserve energy. At scheduled intervals, the tag enters a sensing state where conductivity, temperature, depth and battery voltage are measured. Finally, in the data transmission state, data is off-loaded to the reader. Every 15 minutes, the RTC wakes the tag to sample sensor data, store it in a circular buffer, and return to sleep. To decode downlink commands, we leverage a staged wake-up mechanism using an AS3933 IC [11], a low-frequency pattern detector. Using its carrier-detection capability, it produces an interrupt and wakes the MCU when the downlink signal is detected. Once awake, the tag enters a listening phase to decode the downlink command whose bits are encoded with up- and down-chirps. If the address and CRC match, the tag encodes the most recent sensor readings into a packet, using a 1/5-rate polar code to preserve data integrity. BlueTag remains active for under 10 seconds per 15-minute cycle, enabling an average current consumption of only 90 µA.

We measure temperature with a commercially available I^2C temperature sensor from Blue Robotics based on the TSYS01, which provides an accuracy of 0.1 °C [3]. Pressure is measured with a Keller 10L-10 bar, supporting depths of up to 100 m and an accuracy of 25 mbar (corresponding to roughly 25 cm of water depth) [9]. Conductivity sensing is realized via the LFS1107 that can sense between 0.1 and 10 mS/cm [13].

The reader illustrated in Fig. 2a consists of an acoustic projector and two hydrophones that receive the backscatter signal. A Raspberry Pi 5 in conjunction with a DAC+ADC daughterboard from HiFiBerry provides compute and transmit/receive capabilities respectively [2, 8]. The reader decodes the backscatter packet with a polar decoder and a standard two-channel decision-feedback equalizer (DFE) commonly used in underwater acoustic systems [12]. If the backscatter packet successfully decodes, the sensor values are unpacked and saved to a database.

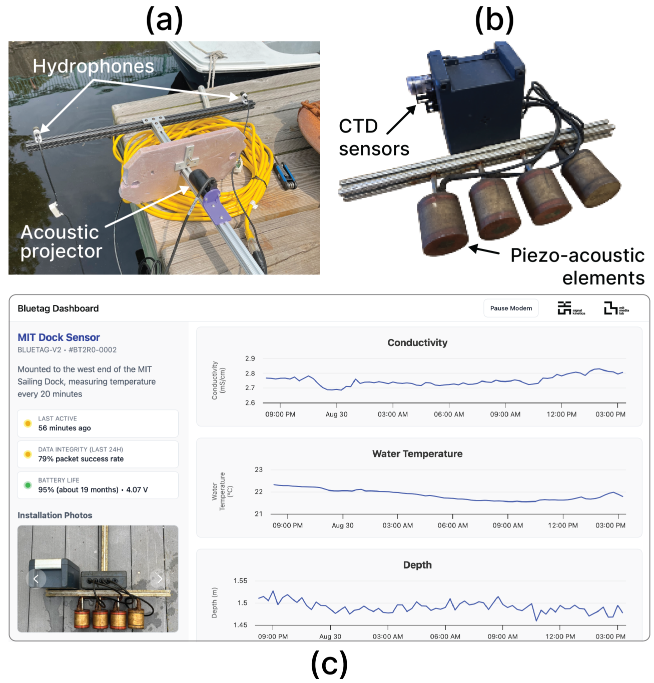

Figure 2: BlueTag Deployment. The reader, shown in (a), is mounted to a dock inside a weather-proof box. Its acoustic projector and hydrophones extend into the water below on an aluminum boom. The tag, shown in (b), is fully submerged underwater. The cylindrical transducers are visibly biofouled. Data from the tag is decoded by the reader and presented via a web-app, which is shown in (c). It displays time series of various water and system metrics.

3 Demo Setup

Our system has been deployed with temperature sensing in the Charles River since July 9th, 2025, and with conductivity, temperature, and depth sensing since August 5th, 2025. Shown in Fig. 2(a), the reader is mounted to the side of a wooden dock inside of a weather-proof box, with grid power and networking cables laid to it. An aluminum boom extends from the reader into the water, containing the acoustic projector and two hydrophones. The tag, seen in Fig. 2(b), is anchored to the bottom of the river, 46 m away, floating about 2 m above the river bed.

For our demo, we will present live data from the Charles River in an interactive web-app, shown in Fig. 2(c). Users will be able to see historical and live data as it is produced from the real-world deployment. Our sensor will be operating with an increased duty cycle, producing new sensor readings every few minutes. Public access to the dashboard of live data will be provided. Videos will show the tag and reader's installation in the river.

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