Ultra-Wideband Underwater Backscatter via Piezoelectric Metamaterials

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This paper presents *U²B* that enables wideband backscatter for underwater networking.

Motivation. Underwater backscatter was motivated by a high-power consumption problem of point-to-point underwater communication (and thus battery and cost problem). However, the state-of-the-art underwater backscatter system has very limited throughput and supporting distance. In underwater systems, the piezoelectric transducers are commonly used, which are activated for communication at their resonance frequency. This property enables the underwater communication or backscattering through making vibration at a certain frequency with narrowband, but limits the bandwidths (and thus throughputs), since they are inactive at frequencies other than the resonance frequency.

Core Idea. *U²B* enables 'ultra-wideband' communication using a novel metamaterial-inspired transducer. First, the paper introduces a naïve approach to solve the problem, using multiple piezo devices together, each at different frequency, but pointed out that this method will cause many practical issues such as costly designs and directionality. Instead, the paper suggests a multi-layer design consisting of only two piezoelectric layers at different resonance frequencies and a passive polymer in the middle to enable and thus make use of middle frequencies between two resonance frequencies (i.e., wideband property). Using this wideband feature, along with higher throughput (that is naturally coming from the wideband system), the paper also introduces a technique for self-interference cancelation. The evaluation shows that the proposed system achieves 5 times more throughput (20 kbps) and 6 times more communication range (62 m), compared to the previous system introduced in 2019.

There were interesting discussions on the paper during the class.

1. **Underwater Applications enabled by High Data Rate:** More clear and straightforward examples of underwater applications that are achievable by high bandwidth must be helpful. The paper mentioned submerged datacenters at the beginning, but one pointed out that a different medium might be required to satisfy throughput to support underwater datacenters. Regarding this, many possible applications such as videos and images are discussed. Since many readers are not familiar with the ocean field, we believe that some introductions on available underwater applications depending on available throughputs must be helpful to appreciate the paper contributions even further (maybe these are available in the previous papers).
2. **Feasibility of Design beyond Double Layers:** Since the double-layered design (i.e., two piezoelectric layers) was able to enable the wideband system, the feasibility of multi-layer design beyond the double layers that might improve the performance further was discussed. When assuming the same frequency gaps between layers as one in *U²B*, even wider bandwidth seems available, while denser gaps between layers (but not quite close to avoid the directionality issue), more points of high SNRs seems available. Since wider

bandwidths and/or higher SNRs can improve throughput, this approach sounds interesting, though each node will become a bit more costly (expected trade-off).

3. **Issues caused by Locations of the Projector (sender) and Hydrophone (receiver):** While the backscatter nodes (U^2B nodes) are underwater, it seems that the sender and receiver need to be near shores since they assume relatively high power. This location requirement might limit the applications, especially considering current available communication distance (less than 100 m).
4. **Unclear Design Details:** We found some parts of the design descriptions in the paper somewhat unclear, when assuming one tries to re-implement the system (maybe this is because we have missed something in the paper, or we lack backgrounds). There were some questions on design details such as **Q1:** Is it a true wideband system, where the transducer can react to many frequencies simultaneously (if yes, how?) and **Q2:** How does the system send a downlink command to instruct a certain node in many-nodes scenario?

More interesting discussions were made during the class including a chance of enabling underwater MIMO communications. We found that the field, approaches/methods used, and achieved performance advances intriguing and promising.