A Self-Sustaining Maritime Mesh Network

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***Abstract*—This paper proposes a self-sustaining maritime mesh network. The system consists of two components, energy harvesting buoys, and wireless mesh routers. The radios operate in the white space frequency band. The white space routers were designed and prototyped. A pair of these systems was used in a communication link in the Claytor Lake. An ocean-surface simulator is designed and used to predict the height of the buoys and ocean waves to assist the communication protocol to maintain connectivity. The measurement shows 2 Mbps UDP throughput at a radius of 5 km on the lake.**

I. Introduction

In spite of the extensive cellular and Wi-Fi wireless network coverages in the land, the maritime wireless communication is still in its primitive period. Users on the ocean cruise ships, vessels, and oil-rigs bases are in critical need of low-cost broadband connectivity. Currently, there are three types of maritime communication technologies. The first one, satellite communication, can provide services to the users in the static and mobile vessels. However, it suffers from a large latency, limited bandwidth, high installation cost, and expensive monthly service [1]-[2]. The MF, HF, or VHF ship-to-shore radios are narrowband and can only support voice communications [3]. The third type is undersea fiber as wire communication type imposes high deployment cost [4] and it is not practical for mobile basis. Therefore, these existing services cannot fully satisfy the essential requirements of ocean connectivity.

We propose a self-sustaining maritime wireless mesh network consisting of a compact, low-cost and maintenance-free energy-harvesting buoy as a wireless node (base station). The buoy generates energy for the base station to provide omnidirectional wireless coverage over several kilometers as shown in Fig.1. The plan is to design the buoy to be deployed simply by dropping it to the ocean from air or a boat. The buoy is anchored to the seabed and the antenna system can be designed to automatically deploy in response to a mechanical impact or electrical signal. The idea is to minimize the deployment cost of the network far below the cost of a terrestrial cellular system. Also with the help of multi-hop relaying mesh network, formed by these base stations, we can provide wireless broadband coverage for more than 100km offshore. TV white space band (470-698 MHz) has been chosen as the backhaul link for this network because of high data rate, broader coverage, and lower cost [5].

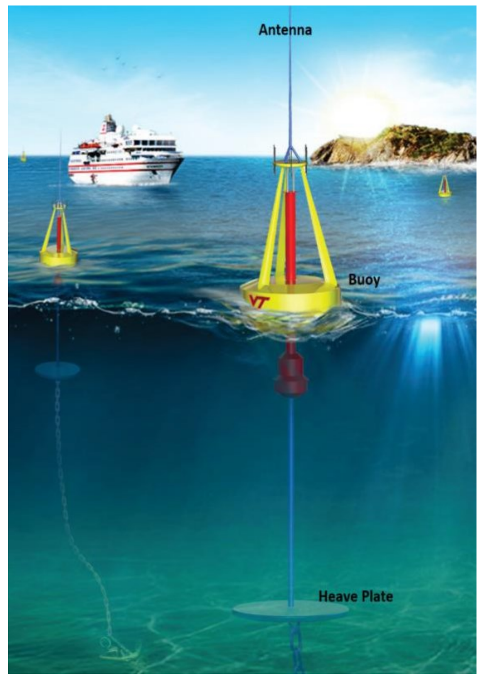

Fig. 1. Illustration of the energy harvesting maritime mesh network

II. White Space Router Implementation

We design and implement a low-cost low-power TV white space router prototype which contains seven components, the 2.4- GHz Wi-Fi router, RF front-end, PLL, microcontroller, sensor kit, a microcomputer with a camera, and antenna as shown in Fig.2. In the transmitter side, the output signal of the Wi-Fi router at 2.4 GHz is fed into the RF front-end. The signal is down-converted into a specific vacant white space band, then transmitted over the TV channel. In the receiver side, the RF front-end up-converts the received signal to the 2.4 GHz frequency band and after filtering delivers the signal to the Wi-Fi router. The microcontroller receives commands from the router to control the PLL for dynamic channel selection in TV band. The sensor kit includes GPS, an inertial measurement unit (accelerometer, gyroscope, and magnetometer), and barometric pressure sensors which send real-time data back to the router. The microcomputer (we used a Raspberry Pi) with camera continuously streams surveillance video to the router via Ethernet cable. As there is a weight limitation on the buoy for mounting antenna, the antenna is required to have a low weight.

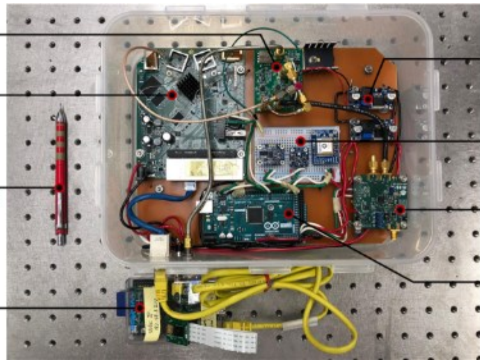

Fig. 2. White space router prototype

Accordingly, the sleeve dipole antenna was chosen due to its low-weight and simple structure.

The operating system was customized based on OpenWrt [6], which allows us to establish 802.11g mesh backhaul link between white space routers based on mac80211 framework embedded into the Linux kernel. The operating system provides interface for flexible channel bandwidth configurations (e.g. 5 MHz, 10 MHz, and 20 MHz), which can appropriately fit into TV channels with 6 MHz bandwidth.

III. Measurement Results

In order to confirm the long-distance ocean communication capability of our white space router, we perform link measurement on the field and use ocean-surface propagation simulation. We set up the equipment as shown in Fig.3, which two routers were put at a distance of 500 meters line-of-sight of each other. As allowed by white space spectrum database, TV channel 14 with center frequency 473 MHz and a 5 MHz bandwidth were chosen for link measurement. The two routers both transmit 25 dBm power via sleeve dipole antennas with 5 m height. In order to evaluate the link quality at different receiving signal strength, we put controllable attenuator before antennas to adjust the output signal power. Also, we designed a real-time monitoring system to display and log important data which includes receiving signal strength indicator (RSSI), modulation coding scheme (MCS), round-trip (RTT) delay, UDP throughput, packet error rate (PER), sensor data stream, and surveillance video stream.

The link quality results are shown in TABLE *I*. Our white space router can maintain a decent link quality with around 2 Mbps UDP throughput even when the receiving signal strength is as low as -85 dBm. According to the link quality results, the communication distance of the white space router on the ocean can be estimated by using two-ray ocean-surface path loss model, which has been demonstrated by measurements for WiMAX at 5.8 GHz on ocean [7]. For our experiment settings, in the case of transmitting signal with 30 dBm power, it can reach more than 5 km signal coverage with -85 dBm received signal strength and provide a communication link with around 2 Mbps UPD throughput.

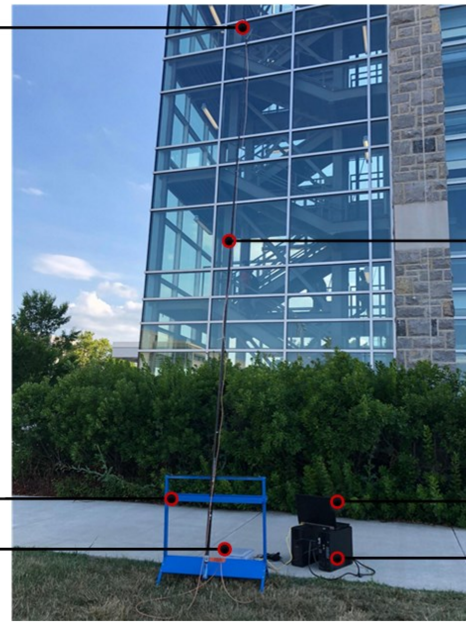

Fig. 3. Experiment setup for field measurements

TABLE I. LINK QUALITY RESULTS

RSSI (dBm)	> -68	$[-75, -85]$	< -87
MCS	64-QAM 3/4 or 2/3	QPSK 1/2 or BPSK 1/2	DSSS
UDP Throughput	3.14-5.22 Mbps	1.43-2.82 Mbps	11.8-23.5 Kbps
PER	0.044-0.25 %	0.24-1.5 %	33-50 %
RTT Delay (ms)	1.57	2.44	N/A

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