Communication Operations at THEMO: the Texas A&M - University of Haifa - Eastern Mediterranean Observatory

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***Abstract*—We introduce the communication operations of THEMO: the new Texas A&M - University of Haifa - Eastern Mediterranean Marine Observatory. THEMO includes moored sensors, surface sensors, and secondary moorings. In all cases, the data from the sensors is transferred in near real-time to a shore station where it is freely shared with the community. Variety of communication aids are used. These include underwater acoustic communications to connect the sensors onboard the secondary moorings with THEMO's surface platform, underwater inductive communication to connect the moored submerged sensors to the buoy's controller, and radio communication connecting the mooring to the shore station. After deployment of almost a year, our results show that the communication performance are reliable, and the data flows in all weather conditions. In this paper, we describe the mooring's communication applications, and share the details of the different communication components.**

***Index Terms*—Marine Observatories; THEMO; Submerged sensor; Underwater acoustic communication; inductive communications; Communication from marine buoys**

I. INTRODUCTION

EXploring the ever-changing sea environment is one of the great challenges of our time. The sea controls the heat balance of the earth, provides our food supply, and function as a biological pump that is a major part of the planet's food chain. Understanding how the sea responds to events like oil contamination and toxic algal bloom requires the development of a data baseline. The sea provides more than 70% of the resources for the global industry, yet its harsh environment makes it hard to explore. In particular, while information about the variability in the coastal and deep water ecosystems can be collected in sea experiments, these efforts provide only snap-shots of the marine environment. It is now clear that long-term marine exploration and climate monitoring requires obtaining sustained measurements of key ocean indicators from observing systems. With the advance of marine technology, a new era in marine exploration has started. One that includes stationary marine observatories for long-term data collection.

Recently, the discovery of natural gas off the coast of Israel has boosted the need for a high-end research facility to extend our knowledge of the Mediterranean Sea and for the development of marine technology. Following that, Israel has joined the effort of long-term marine exploration through *THEMO*: Texas A&M – University of Haifa – Eastern Mediterranean Observatory. THEMO is a joint effort of the University of Haifa and the Texas A&M University (see [1]). Stationed in the Levant Basin of the Mediterranean Sea, the observatory includes three mooring platforms in two locations: two *shallow* moorings at water depth of 125 m, and a *deep* mooring at water depth of 1500 m. The moorings' locations are marked in Fig. 1. The two shallow moorings are used interchangeably, such that continuous data collection is obtained while one of the moorings is serviced. On the contrary, the deep mooring is deployed continuously with short breaks for servicing.

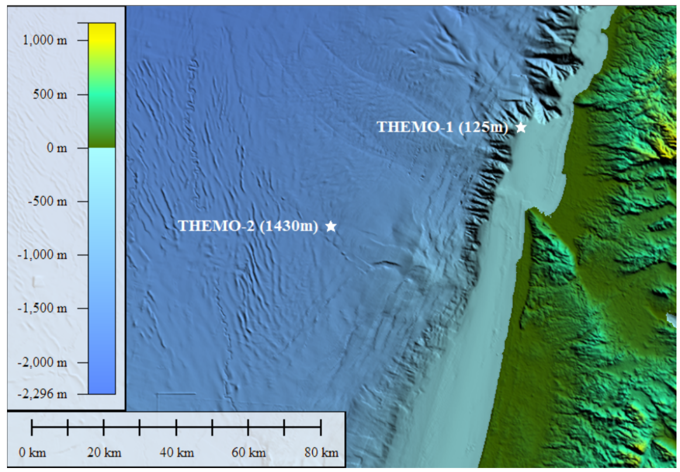

Fig. 1. Locations of the THEMO moorings.

THEMO is one of the few observatories world-wide that provides access to the collected data in near real-time [2], [3], [4], [5]. The location of the University of Haifa some 600 m above the sea level on top of Mt. Carmel and its proximity to the sea, provides the communication line-of-sight that is necessary for the data transmission from the shallow and deep moorings, whose range to the shore station is 30 km and 60 km, respectively. At the shore station, the data is processed for quality assurance, and is openly shared for view and download with the community from themo.haifa.ac.il. Besides data download, the two-way radio communication link allows the offshore servicing of the moorings. For more information on THEMO see [6].

A picture of the surface platform of one of the moorings is shown in Fig. 3. The diagram in Fig. 2 illustrates the structure of the shallow and deep moorings. More than 40

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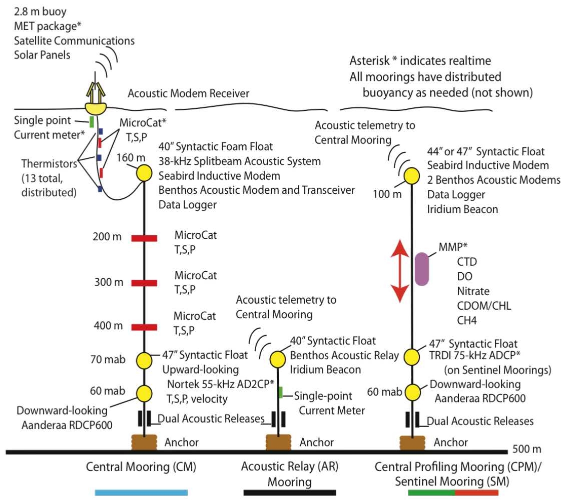

Fig. 2. Illustration of THEMO's structure.

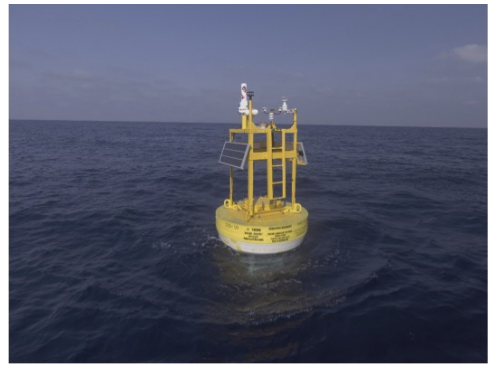

Fig. 3. Picture of the surface buoy of THEMO's shallow mooring.

sensors are used. These include various sensor types such as inductive temperature and pressure sensors, Fluorometer, Acoustic Doppler Current Profiler (ADCP), Conductivity-Density-Depth (CTD) measurements, and underwater acoustic sensors, to name a few. To avoid rotation, the mooring's cable is attached to an anchor and to the surface platform through swivels, and is kept roughly straight through a set of floaters. The surface platform includes three solar panels that charge 600 AH batteries, a splash proof housing for the mooring's electronics and controllers, and supports meteorological sensors as well as the radio communication to shore.

In this paper, we survey the communication operations of THEMO. These include the data transfer from the moored sensors, transmission of data from secondary moorings to the main mooring, high rate transmission of acoustic data from a submerged hub stationed on the mooring's cable, and the transmission of data from the surface platform to a shore station. To that end, a variety of communication aids are used. These include underwater inductive communication, Digital Subscriber Line (DSL) communication, acoustic communication, and radio communication. The hardware is integrated in house at the University of Haifa's underwater acoustic and navigation laboratory.

The structure of the rest of the paper is as follows. In Section II we list all data transfer operations. In Section III we give the specification of the communication components and show some communication results. Conclusion remarks are given in Section IV.

II. THEMO's Data Transfer Operations

THEMO's communication operations support four main data transfer tasks: 1) from the moored sensors, 2) from sensors onboard two secondary moorings, 3) acoustic data from a submerged hub, and 4) a combination of acoustic and optic communication from a near surface platform. The first three tasks are operational, while the fourth one is in design. In all cases, data processing including compression, packet handling, and automatic request control is handled by the communication provider.

A. *Communication Services to THEMO's Sensors*

THEMO includes several moored sensors at varying depth between surface to 90 m for the shallow mooring, and between surface to 500 m for the deep mooring. These sensors provide temperature measurements, tilt measurements (of the mooring's cable), Fluorometer, ADCP current meter, CTD, meteorological and wind velocity sensors, barometric pressure, air temperature and humidity, long wave irradiance measurements using an Eppley Labs Precision Infrared Radiometer (PIR), as well as short wave irradiance measurements.

The data transfer is a scheduled operation that is controlled by the surface platform's main processor. This scheduling table schedules the periodic operation of the sensors, the cycle of data collection, and can be altered from the shore station. Currently, data collection from all sensors is every 30min. For each sensor, this process include the transmission of a few kbits that represents the status of the sensor and its collected data as accumulated from the last data request.

B. *Data Transfer from Secondary Mooring Platforms*

Alongside the main mooring, the deep THEMO mooring supports two secondary moorings (SM) which are stationed about 500 m from the main mooring. These two secondary platforms are submerged at 100m of water, and are aimed to collect sediment samples and water current measurements (*SM-I*), and CTD measurements with fine depth resolution (*SM-II*). The result is a cluster of three moorings, with the main mooring serving as a sink to transfer the collected data to shore via its radio communication system. This design requires the data transfer from the two SMs to the main mooring. Since wired cables will tangle between free anchored moorings, this data transfer is based on underwater acoustic communication.

At SM-I, sediment samples are collected by a MClean Labs sediment trap. The transmitted data includes the status of the sediment trap, as well as the time elapsed between the exchange of the sediment trap's collection batteries to evaluate the sediments' flux. SM-I also includes a Nortek 55 kHz ADCP sensor that provides directional velocity measurements of the water current along the water column. The total sum of the data from the SM-I is on the order of 1 MB per day, and the data transfer is performed once per day. At SM-II, an inductive Mooring Mcklaren's Profiler (MMP) slowly moves between 100 m depth to the bottom at 1500 m while collecting measurements with fine resolution of 1 m. The MMP's data includes a CTD sensor to periodically measure the water temperature and salinity. The data is transferred to the main mooring each time the profiler reaches the 100 m depth mark, which is roughly every 12 hours.

C. Data Transfer from Submerged Hub

Both shallow and deep THEMO moorings include a structure referred to as a *submerged hub*. The hub is mounted on the mooring's cable at depth of 90 m (shallow mooring) and 500 m (deep moorings). The task of the main hub is to allow acoustic emissions such as the detection and classification of marine animals that often approach the mooring, and communication with autonomous underwater vehicles. Another example is the passive detection of sounds from sound producing marine mammals (e.g., Dolphins). Through THEMO's communication system, the operations of the hub are controlled from the shore station. This way, a full set of sea experiments can be planned from shore to be performed onboard the mooring. More details about the submerged hub can be found in [7].

The hub includes internal battery of large capacity of 2200 WH, a processing unit, and two EvoLogics 7-17kHz and 48-78kHz software defined modems. The unit is triggered and controlled by the main mooring surface platform's processing unit. The data transferred includes the transmission of script files to the submerged hub including operation commands, and the transmission of processing results from the hub to the surface platform. The former can be updated from the shore via the radio communication that allows direct SSH and FTP to the surface platform. The data flow from shore-to-hub is not high and includes the transmission of a few kB per operation. The data transfer from hub-to-shore includes the transmission of large acoustic files. For example, sound recordings detected to belong to marine mammals. This, in turn, involves a data flow of a few hundreds of MB per operation, to be transferred to shore in near real-time. To allow these high communication demands, the submerged hub is connected to the surface platform via DSL communication that also allows the charging of the hub from a surface vessel.

D. Data Transfer from Near-Surface Platform

As part of the European Union's Horizon 2020 research and innovation project SYMBIOSIS [8], THEMO supports the operation of a near-surface platform aimed for the detection, classification, and biomass estimation of pelagic fish from marine observatories. The SYMBIOSIS system is in its design stage, and the deployment is planned for 2019. The system includes three components: two clusters of six optical cameras each, stationed at depth of 20 m and 30 m, and a cluster of 12 acoustic transceivers stationed at a depth ranging between 20 m and 30 m. The system is controlled from a main unit, which includes the unit's power source and its processing units. The operation includes the transmission of short narrow-band and wideband signals, whose reflected reverberations are analyzed to detect the existence of six target pelagic fish. The data is further processed by the array of acoustic elements to estimate the bearing angle to the detected fish. Then, if range is sufficient, the corresponding optical cameras picture the fish, segment the image, and classify the fish type.

The data transfer from the SYMBIOSIS system to shore includes short acoustic files including the reflection from detected targets, as well as the transmission of segmented portions of optical images identified to include a target fish. The data is on the order of 200 kB per detection. The SYMBIOSIS unit is located below the surface platform. However, since THEMO already supports the wired-based data transfer from the sensors and from the submerged hub, due to mechanical limitations, the THEMO mooring cannot support additional cable transfer from deep to surface, this data transfer is performed through underwater acoustic communication.

III. Specifications of the Communication Components

A. Mooring-to-Buoy Slow Communications

To avoid the high cost of underwater cables and connectors, the data collected by the submerged sensors is transferred to the surface platform via inductive communication. To that end, each submerged sensor is equipped with a power-independent Soundnine ULTI Modem that is attached to the mooring's cable. This way, multiple sensors can be serviced in the form of a communication bus. From the submerged frame of the surface platform, another inductive ULTI Modem is deployed. This modem is connected directly to the buoy's processor, and allows direct connection to each sensor from the shore station. The communication to the sensors is two-way, and is initiated by the surface modem. The transmissions are 1200 baud rate half-duplex. The transmitted data from each sensor is on the order of one kB per 30 min.

B. Mooring-to-Buoy Fast Communications

The communication from the submerged hub [7] to the surface mooring is performed via a fast DSL link. We chose DSL since it allows cable transmission for more than the 100 m of regular Ethernet connection. At the hub side, the data transfer is controlled by a single raspberry pi 3 controller that is connected to a DSL switch. Upon operation, the controller pulls new tasks from the surface buoy's processor, executes the required tasks, and sends the results back to the buoy. Standard ssh TCP communication protocols are used.

C. Buoy-to-Shore Radio Communications

The communication from the surface platform to the shore station is based on a radio link, which is backed up by satellite communications. Cellular communication was also considered as a backup system for the shallow mooring but failed to show reliable reception. At its nominal usage, the buoy-to-shore link is required to transfer 5 MB/day from all sensors, and up to 2 GB/day in its maximal usage. Availability must be higher than 90% to support both the data transfer to shore and the telemetry transmissions from shore to manage of the mooring's operations via a secured ssh and ftp connection. Considering the rough weather conditions at sea, the robustness of the buoy-to-shore link is extremely important. Moreover, the limited power provided by the solar panels limits the power available for the communication system.

The biggest challenge in employing the radio communication is the fast rotation of the mooring's surface platform rotate on all three axises. These motions are hard to predict, and cannot be considered periodic. As a result, any system that relies on directional communication may fail. While a possible solution can be a system that self stabilize its orientation such as deployed on ships, due to limitations set by the structure of the surface buoy, heavy motorised stabilizing system is not an option. Considering this challenge, we tested two solutions for the radio communication. The first, based on the BATS system [9], involved a cluster of 5.8 GHz antennas and a digitally steering mechanism to continuously adapt the beam pattern of the system's radio antenna. The steering is performed according to the location from which the strongest signal from shore arrives. The system was proven on shore to accurately find the correct location with an error less than 2 degrees. However, due to the motion of the buoy, especially in the pitch and roll angles, the system could not track the relative location of the shore station fast enough, and communication availability was poor. The second solution is based on a MikroTik system [10] that includes an omni-directional 5.8 GHz antenna and is about half the size of the BATS system. At the cost of power consumption (0.8 Amp over 24 V, which is more than twice than the power consumption of BATS), an omni-directional antenna allows reception regardless of the motion of the surface buoy and the communication link becomes bi-directional stable. The performance of this system while operating at sea is shown in Fig. I. Since THEMO can supply the required power needs, the second solution was chosen.

TABLE I
AN EXAMPLE OF THE MOORING'S RF COMMUNICATION STATUS

Metric	Value
Rx rate	24Mbps
Tx/Rx CCQ	24/45 %
Uptime	08:25:30
Distance	31km
Tx/Rx signal strength	-78/-75 dBm
signal to noise	35 dB

Consisting of 66 cross-linked Low Earth Orbit Satellites and covering the entire planet, we chose the Iridium network for the satellite communications. The Iridium antenna covers a wide enough angle to manage the frequent motion of the buoy. However, its effective transmission rate is only about 100 Byte/sec, and two-way access is not easily possible. Operation requires subscription to an Iridium provider that charges per usage. We therefore use the satellite communications as a backup system. The switch from radio to satellite is done upon several failed communication attempts by the radio link.

At the shore side, the radio communication link is based on an 80 cm dish for the shallow mooring (roughly 30 km distance), and on a 120 cm dish for the deep mooring (roughly 60 km away). The satellite communications does not require a receiver on the shore side. Instead, it only requires connection to an Iridium server. However, since the Iridium connection is from an external provider, it's operation requires passing the university's firewall which caused some implications. To that end, we used a raw TCP socket. The data from the moorings flows to a server, where it is parsed, processed, analyzed for quality assurance, and placed on a database for download.

D. External Devices-to-Buoy Communications

The communication from the near-surface platform and from the two SMs to the main mooring is based on wireless underwater acoustics. This is mainly because of the difficulty and cost of deploying an underwater cable to connect the mooring platforms. The underwater acoustic communication used for the application of sending images and acoustic data from the near-surface platform to the surface one, is based on short-range high-rate transmissions. In particular, with the transmission of 20 segmented images of detected fish and one second of acoustic data, the required data flow is 200k Bps per detection. To accomplish this, we use the S2CR42/65 EvoLogics Modem (see [11]) — one near the acoustic/optic unit, and one mounted on the submerged frame of the mooring's surface platform. In both sides of the link, the modems connect to the processing units over an Ethernet link. The modem operates at the frequency range of 42-65 kHz, and allows a fast 31.2 kbps link over 300 m. We choose this modem due to its low power. The modem draws 2.5 mW in stand-by mode, and 5.5 W in transmission mode.

The link connecting the SMs to the main mooring is based on the ATN 925 Teledyne Benthos underwater acoustic modem [12]. This is a 2000 m rate modem and has an 380 WH internal battery. The modem uses a frequency range of 16-20 kHz, and its nominal baud rate is roughly 10kbps. This specification is suitable for the long-term deployment over the deep THEMO mooring. The modem supports the transmission of CTD data in a 1 m resolution collected by the profiler, which sums up to roughly 1 kBps per 12 hours.

IV. CONCLUSION

In this paper, we introduced the communication operations of the THEMO observatory. The data from the THEMO moorings is transmitted to a shore station in real-time every 30 min, and is freely shared for research purposes. The communication includes data transfer via a combination of underwater acoustic communication, inductive communication, DSL communication, and radio communication. We have described the detail design and motivation for each of the communication links. The variety of links makes THEMO a complex communication system that can operate in near real-time with high availability at harsh sea conditions.

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