On the Development of Energy-Efficient Communications for Marine Monitoring Deployments

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Abstract — **In this paper we present a novel architecture for enabling on-line communication with marine environment monitoring deployments. We rely on a set of communication technologies that range from IoT related low data rate communication standards to the widely adopted Wi-Fi and LTE protocols that are able to support bandwidth demanding applications. To achieve energy-efficient results we turn off all the power-hungry interfaces and peripherals, while maintaining a low-power interface active, dedicated to control the rest of the components. Finally, we present the installation of the developed system in the Vida oceanographic buoy, in Slovenia and evaluate our device in terms of power consumption.**

***Keywords*— Energy-Efficiency, Marine Monitoring, WSN.**

I. Introduction

The unleashed potential of the ocean ecosystem has raised the interest of the research community, towards understanding and exploiting the vast resources existing in the aquatic environment. Notably, oceans cover 71% of the globe, while most of its scale remains unexploited in several fields. Undeniably, it is urgent to understand and interpret the aquatic ecosystem, since it plays a significant role in several sectors, such us fisheries, oil, gas, seabed minerals, etc., and impacts every facet of our society in general.

To address this challenge, it is imperative to keep track of oceanic and coastal areas and assess how these regions are evolving. Towards this direction, scientists all over the globe deploy permanent observatory systems (buoys) in marine waters in order to acquire long-term environmental data in real-time. Along the same lines, some institutions [1] employ Autonomous Unmanned vehicles (AUVs) to perform underwater survey missions such as detecting submerged wrecks or mapping the structure of seafloor. Of course, AUVs also embed a vast number of environmental sensors to measure the concentration of different elements at various points. This need, is also highlighted by the fact that several initiatives [2], [3] aim at establishing Earth observation services, freely accessible and at a large scale.

Despite the recent technological advances and the need for real-time, in-situ monitoring the aforementioned observatory systems still present some inefficiencies. One key parameter of such systems is their backbone communication link, which is used for measurements offloading as well as for configuring the sensing setup. Typically, observatory systems exploit either WiFi or GSM technologies. The first is widely used when a system is deployed in a coastal zone, where it is likely to experience line-of-sight with a shore gateway, while the second one is mostly used in far-located systems. Both technologies are targeted at specific applications, while the latest protocols present improved features in terms of achievable throughput and power consumption.

To address this challenge we propose a novel architecture, employing several communication interfaces, divided into a set of low-power ones and a group of high-throughput ones. Our principle is to deactivate all power-hungry interfaces and peripherals when not required. For example, high-throughput interfaces are only activated for transferring large files, while the low-power interfaces remain active to wait for incoming requests dedicated to performing only lightweight tasks. Relying on this, we have developed an energy-efficient communication device that supports both low and high rate technologies. To evaluate our system we installed a stripped-down version in the Vida oceanographic buoy [4], in Piran, Slovenia.

The rest of the paper is organized as follows. Section II lists important requirements and considerations for the development of such system. Related work is discussed in section III, while system implementation and integration appear in IV. Finally, section V presents our evaluation measurements and section VII concludes the paper.

II. Key Parameters & Considerations

The nature of ocean observatory systems is characterized by intermittent connectivity, limited energy budget, and varying network conditions. To this end, we should thoroughly consider all the above when designing a communication system for marine monitoring.

Energy-Efficient Operation: Observatory systems typically harvest energy from ambient sources, since they operate unattended for long periods of time, without fixed power connection. Moreover, it is impractical or even unfeasible to visit and replace their batteries.

Even if possible, a power efficient system, would require less frequent battery substitutions, which would remarkably reduce the attendance cost of the system. This implies that the communication system must be power-efficient and drain as less power as possible. In our implementation we adopt some low-power protocols to ensure on-line communication with a

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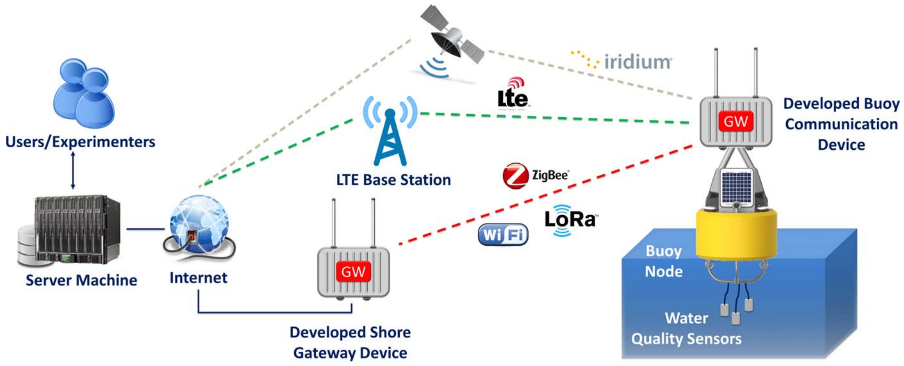

Figure 1: Proposed Marine Communication System Architecture

power-efficient profile and we employ high data rate ones to transfer large amounts of data only when truly required.

Reliable Connectivity: Marine monitoring systems are unlikely to have constant or reliable network connectivity, due to the unpredictable and sometimes harsh weather conditions or even because they might be deployed at a long distance from the shore. To this end, we exploit more than one wireless technologies, able to switch from one to another to ensure reliable connection with the observatory system in different conditions. For example, in windy conditions, WiFi signal presents a significant decrease when directional antennas are used. But in the same conditions the performance of cellular protocols is not affected greatly, thus, a sophisticated selection is required. Moreover, we employ delay-tolerant techniques to ensure that the acquired measurements are successfully transmitted to the shore even if they do in an asynchronous fashion.

III. RELATED WORK

There are numerous devices that aim at enabling wireless communication between marine sensing devices and the shore. In this work, we discuss some indicative examples since typically, off-the-shelf systems are used in such applications. The Manta Gateway [1] is a heterogeneous platform that embeds a wide variety of communication technologies, such as 3G, WiFi and underwater acoustics. It is mainly used to provide backbone network and remote access to moving AUVs. Along the same lines, the Meshlium gateway [5], integrates several wireless protocols, such as, 4G, WiFi, ZigBee, LoRa and BLE. It can be used in several Wireless Sensor Networks (WSNs) application scenarios as the backbone communication link. Both devices feature several wireless standards, but despite the fact that are powered over batteries they do not implement any energy-efficient mechanisms. Moreover, [6], [7] propose an acoustic backbone network, which undeniably presents several limitations both in terms of throughput and power consumption, while, [8] illustrates a new radio communication system that achieves long distances, but supports limited data rate.

IV. SYSTEM IMPLEMENTATION & INSTALLATION

In this section, we present the architecture of the proposed framework, and moreover, we discuss the development of the communication device. Lastly, we present the installation at the VIDA Buoy.

A. *System Architecture*

The overall system architecture is divided in two tiers, the shore-side components and the sea-side ones. The shore components are used to control the sea deployed nodes and to provide remote access to experimenters. The shore gateway node is deployed on the shore, having line-of-sight access with the deployed monitoring system, whilst the sea-side device is installed into the Buoy, interfaced with the sensors.

The principle of our system lies in the utilization of several communication protocols and the sophisticated employment of the appropriate one, for each different task. The supported technologies range from IoT-related communication standards, such as LoRa and ZigBee that support low data rates, to the widely adopted WiFi and LTE protocols able to support bandwidth demanding applications. Also, the Iridium interface is utilized to provide remote access to far-located deployments. Notably, IoT-like interfaces present low-power profiles but attain throughput of only a few kbps. However, their speed is adequate to support the needs of such deployments, since environmental sensors operate at low sampling frequencies, generating only a few Bytes per sample. On the contrary, WiFi and LTE are used to enable remote access and large file transfers. Fig. 1 illustrates the system architecture.

B. *System Implementation*

The communication device is composed of different hardware and electronic components, constituting a unified system. Fig. 2(a) illustrates the developed device.

Embedded Device: The core module is the BeagleBone Black Rev. C [9], which is a low-cost, embedded platform characterized by sufficient processing capabilities (1GHz with 512MB RAM), low-power consumption and several communication interfaces. All of the electronic components used are hosted on a custom-made printed circuit board (PCB) daughterboard mounted on top of the embedded host device. The embedded platform is responsible for the communication with the on-board environmental sensors and implements the software architecture for the communication system. Furthermore, the device locally caches the acquired measurements, prior to the offloading process.

Low-power microprocessor: The developed communication device is also equipped with a low-power ARM cortex-M4 microprocessor, the MK20DX128 [10], responsible for the power management of all the on-board components. In brief, the MK20DX128 remains always active and communicates directly with the IoT-like interface (LoRa

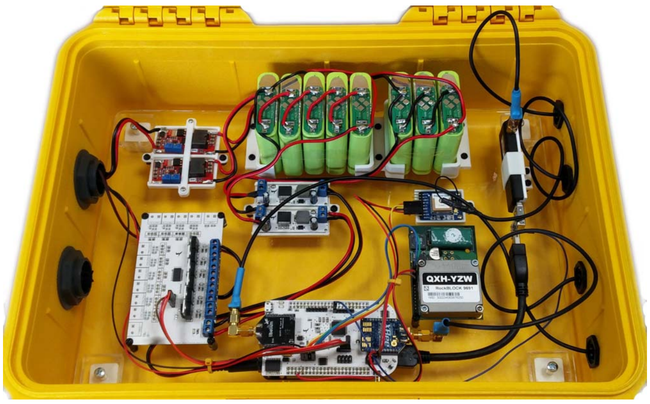

Fig. 2(a): Developed Buoy Communication Device

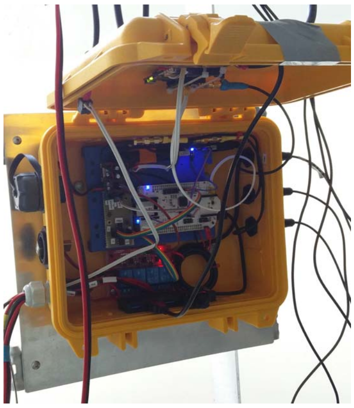

Fig. 2(b): Installed Buoy Device

Fig. 2(c): Installed Shore Device

or XBee) expecting incoming requests, in order to activate the required components. When it is requested to perform a sensing cycle, it awakes the BeagleBone and then acts as a bridge between the IoT interface and the BeagleBone, by forwarding all the incoming data. Of course, it can also activate the WiFi, the LTE or the Iridium interfaces when requested. After the completion of the sensing cycle, it instructs the BeagleBone and any other active component to enter sleep state. Moreover, the microprocessor periodically senses the battery voltage and reports the acquired value via the IoT interface. Notably, the MK20DX128 is configured to operate at 24MHz, draining roughly 12 mA, which is a reasonable consumption for such systems. Finally, the MK20DX128 can be set in a duty-cycled fashion, draining even less. In essence, it can be configured to enter sleep state, consuming just a few μA and use its internal timers to generate wake-up interrupts, in order to awake and check for any pending request(s).

XBee 868LP: The XBee S8 [11] is an IoT interface that can reach communication distances of up to 8.4 km. It operates in the 868 MHz ISM band and achieves up to 80 kbps transmission rate. It supports the establishment of ad-hoc networks towards creating a single network of several monitoring systems in a mesh topology. The communication with the MK20DX128 is realized through UART protocol.

LoRa: LoRa [12] is a recent ultra-long-range technology that can reach distances of up to 21 km, by exploiting spread spectrum modulation. It attains very low data rates from 0.3 kbps to 50 kbps, while consuming only a few mA when propagating and receiving frames. Notably, LoRa does not support ad-hoc topologies but only star networks. In our implementation we used the Semtech SX1272 chipset which communicates with the MK20DX128 via SPI.

WiFi: WiFi connectivity is enabled through the commercial Atheros 9271 chipset offering a wide range of supported channel bandwidths from 40 MHz down to 5 MHz, providing a compromise between achievable data rates and transmission range. It communicates with the BeagleBone through a USB port and supports the connection of an external antenna to achieve higher signal. It offers high speed features allowing transfers of large files and remote access.

LTE: LTE provides an alternative high bandwidth option, even in far locations where WiFi connectivity can no longer be maintained. We used the Huawei E392 USB Dongle that supports 2x2 MIMO with external antennas support, reaching up to 100 Mbps download and 50 Mbps upload speeds.

Iridium: We also equipped our device with the Iridium RockBLOCK Mk2 interface that is only used in extreme conditions when no other backbone networks are available.

Finally, communication with the environmental sensors is realized via a serial-to-USB module, connected to the BeagleBone and a GPS interface is used to provide measurement time-stamping and the geo-location of the system.

C. Power Switches

Some of the aforementioned modules feature a sleep state which they can enter in order to save energy, while some others do not. For instance, WiFi, LTE, Iridium and the on-board environmental sensors do not integrate such feature. To this end, we implemented custom circuits to entirely cut their power off when required. More specifically, for the USB dongles, we developed a USB extension board that features a power switch IC that intercepts the voltage rail. This IC is controlled by the MK20DX128 for turning the targeted modules on and off. Along the same lines, we employed power MOSFETs, used in a topology that forms a power switch, in order to control the operational state of the on-board sensors and peripherals. Notably, the quiescent current consumption of the power switch and MOSFET ICs is negligible and does not affect the overall power expenditure.

D. Installation

A stripped-down version of the developed communication system was successfully installed in the Vida oceanographic buoy [4], in Piran, Slovenia, which is operated by National Institution of Biology (NIB). Vida is equipped with various physical and chemical sensors constantly measuring relevant environmental parameters, serving as a proper laboratory in the ocean. The installed communication device features a LoRa interface as the low-rate link and an LTE one for high-throughput demanding applications. Moreover, the device interfaces with the WIZ probe [13], which is an in-situ nutrient probe. Also, it features several power MOSFETs to control the power of the WIZ probe and its filtration system (pumps). On the shore-side we have deployed a gateway communication device that acts as the LoRa backbone network. Notably, the shore-side gateway is located 3.7 km away from the Vida buoy. Fig. 2(b) and 2(c) illustrate the communication device deployed into the Buoy, and the gateway one, deployed at the NIB premises. The environmental measurements acquired by our system can be accessed at our web-based GUI [14].

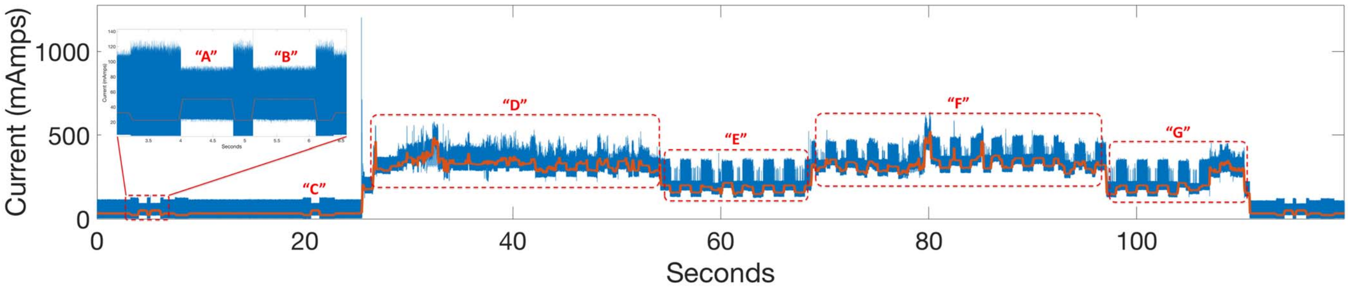

Figure 3: Power Consumption Profiling of the Developed Buoy Communication Device

TABLE I
POWER CONSUMPTION MEASUREMENTS OF DISCRETE COMPONENTS

Component	Sleep	Idle	Active
BeagleBone	-	160 mA	328 mA
MK20DX128	150 µA	-	14 mA (at 24 MHz)
XBee 868LP	1.7 µA	22 mA	45 mA (Tx), 33 mA (Rx)
LoRa	-	1.65 mA	41 mA (Tx), 11 mA (Rx)
WiFi	-	51 mA	101 mA (upload)
LTE	-	120 mA	109 mA (upload)
Iridium	20 µA	-	102 mA

V. EVALUATION

To characterize the power consumption profile of the developed communication system, we performed in-lab investigation, employing our high-end power consumption monitoring tool, developed in [15]. First, we measure the instantaneous power consumption per different component in the supported states, as illustrated in Table I. We can observe a huge difference between the high throughput interfaces and the low-power ones, both in idle and active states, which further highlights the urgency to turn them off when not in use. In Fig. 3 we plot the total power consumption draw of the installed device. At first, only the LoRa link is active, while at roughly the 26th second the BeagleBone is instructed to awake from sleep state. Notably, this is an artificial experiment aiming to illustrate the different states and power consumption levels of our device. Also, we plot, with red line, the average power consumption which gives us more clear observations.

We have marked the acknowledgement packet transmitted by the LoRa with “A”, after the reception of a battery voltage request, which is then followed by the data transmission, marked with “B”. Roughly at the 21st second LoRa receives a message instructing the activation of the BeagleBone, marked with “C”, which is realized after a short artificial delay. Frame “D” illustrates the drain of the BeagleBone in boot phase, while frame “E” shows its idle consumption. In turn, the device is instructed to turn on the LTE interface highlighted with “F”, while in “G” the BeagleBone is idle and then powers off completely.

Moreover, we calculated the energy consumption of our system required to perform one full analysis cycle. We estimated that for one cycle, our device must be in active state for roughly 76 seconds. In essence, it takes 38 seconds to initiate the WIZ probe and control the related pump systems and 38 more seconds after the completion of the cycle to acquire the measurements. This implies that the required energy per measurement cycle is roughly 101.4 J, which is quite a reasonable energy expenditure for such systems. Notably, our device drains 22 mA when in idle state, in which the BeagleBone is in sleep state and only the MK20DX128 and LoRa are awake. Finally, to note that the LoRa and the LTE links, presented stable network performance during the entire testing phase, not affected by the weather conditions.

VI. CONCLUSION

In this work, we introduced a novel communication architecture tailored to marine monitoring deployments. It features ultra-low power consumption profile, while also providing high throughput capabilities. Our work highlights the urgency to turn off the power-hungry interfaces and only maintain a low-power one to act as the primary communication link. After thorough experiments, we measured that the developed device only requires 102 J to perform one measurement cycle.

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