Deploying a Wireless Sensor Network for Oceanography using ZigBee

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***Abstract*—** We recently developed new offshore observation system using USN buoy, widely used to measure the directional properties of ocean wave, seawater temperature, UV light, longitude and latitude of the buoy using GPS module. This paper also documents the development and implementation of a buoy network for acquisition of data of base station with buoys. The major phases of the project include specification of the network, physical construction of network nodes, software development for control of nodes, and testing of network performance. We described some of the practical issues involved in designing, building and deploying a buoy network for oceanographic monitoring. The paper explains some of the design decisions and their consequences, and some of the lessons learned from a first lesson network trial at sea.

***Index Terms*—** Ubiquitous Sensor Network (USN), Global Positioning System (GPS)

I. INTRODUCTION

In recent years, wireless communication and electronics have encountered many breakthroughs. Advances in digital signal processing, miniaturization of electronic circuitry, low-cost and low-power sensors have prompted the emergence of buoy network.

Most of the monitoring and data logging system for hazardous industrial areas are wired systems that are link to a central monitor system. Although these systems are critical for proper functioning of an industrial plant, they have some drawbacks. Since these systems are hard-wired, they are non portable and the cost of upgrading or adding devices to the system is significant high. Hence, there arises the need for a portable, low-cost and reliable system for monitoring and data logging. This system also needs to accommodate new devices with the least configuration required.

This paper outlines the development and implementation of a wireless network which can be used in monitoring the ambient temperature, wave height, UV light, wind properties and etc. Unlike the most existing systems, the wireless buoy network will provide more flexibility at affordable cost. The buoy was desired to monitor the environmental conditions at different locations; as a result the need for several sensors was taken into account. The networking of the buoy was an important issue because the structure of the wireless buoy network is determined by how the buoys are networked. The implemented wireless buoy network consisting of the ZigBee modem operating at 2.4GHz IEEE 802.15.4 compliant was also implemented and tested.

The developed new offshore observation system which does not need seabed maintenance human works and which can be installed in any sea area without water depth limitation. The buoy has the potential to be used in many applications to conduct meteorological and oceanographic measurement along the pre-programmed transect. The buoy has the ability to monitor ocean wave height, check current location of the buoys with GPS, seawater temperature and battery voltage monitor.

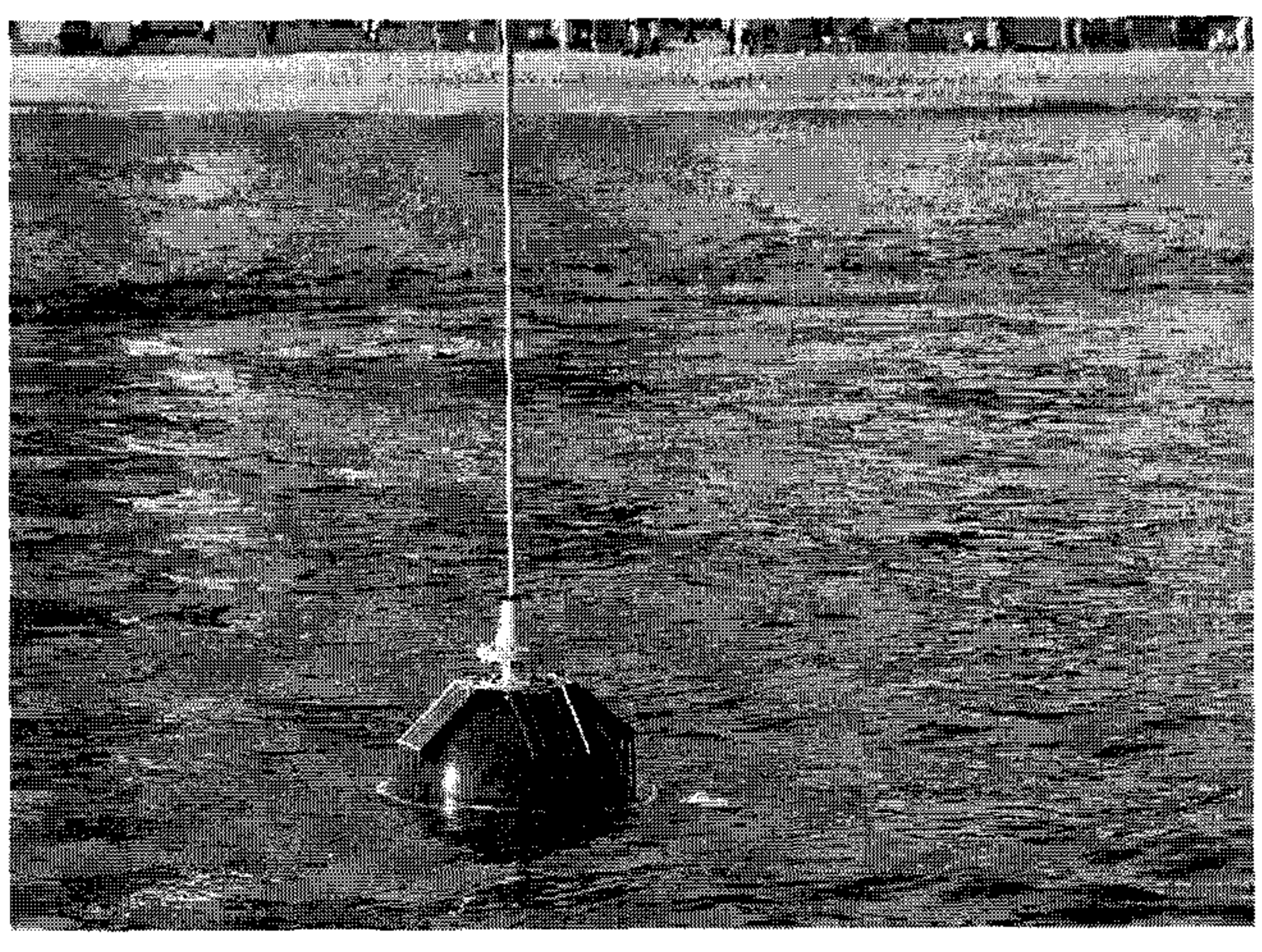

Fig. 1: A typical USN buoy with standard sensor suit.

II. Buoy System Description

A. Communication Network

In this paper, we required communication in a point-to-point or a point-to-multipoint configuration. The base station is set to be a central coordinator while the another 4 buoys are configured as multiple remote nodes connecting back to this base station as shown in Fig. 2.

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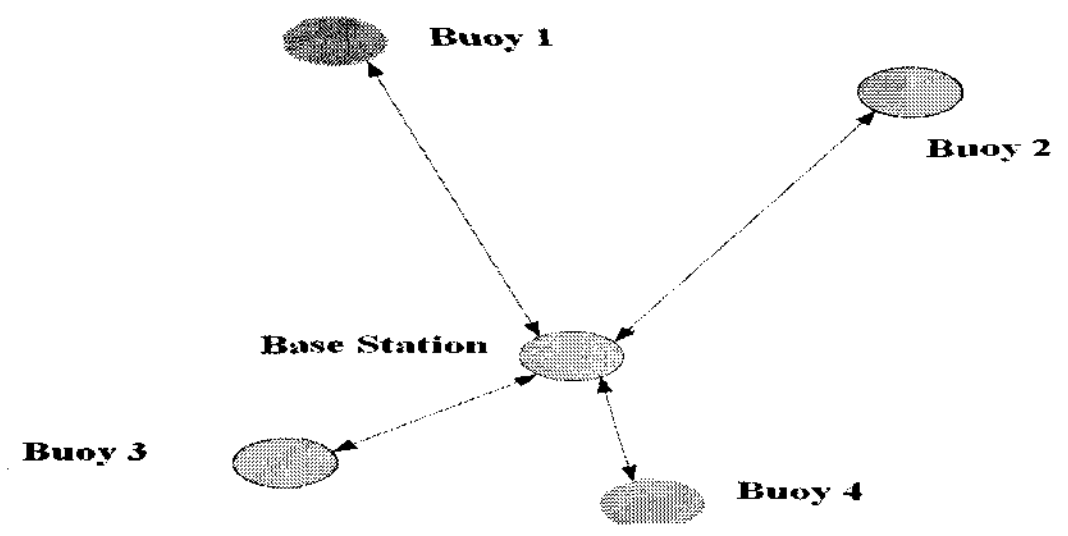

Fig. 2: Network route of the system

The MaxStream's XBee-PRO PKG-R RF modem can be set up to operate in a point-to-multipoint. This application strictly needs to communicate in point to multipoint fashion, the ZigBee modem will be able to handle all the communications between nodes and will be simpler to implement than trying to use a module with ZigBee firmware to accomplish the same goal.

ZigBee technology is a low data rate, low power consumption, low cost and its wireless networking protocol targeted towards automation and remote control applications. It is expected to provide low power connectivity for equipment that needs battery life as long as several months to several years but does not require data transfer rate as high as those enable by Bluetooth. In addition, ZigBee can be implemented in mesh networks larger than is possible with Bluetooth. Zigbee compliant wireless devices are expected to transmit 1200 meters, depending on the RF environment and the power output consumption required for a given application. ZigBee sits below Bluetooth in terms of data rate. The RF data rate of our Buoy ZigBee is 250Kbps at 2.4GHz. ZigBee uses a basic master-slave configuration suited to static star networks of many infrequently used devices that talk via small data packet. It allows up to 254 nodes. [1]

	ZigBee & 802.15.4	GSM/GPRS CDMA	802.11	Bluetooth
Focus Application	Monitoring and Control	Wide area voice and data	High-speed internet	Device connectivity
Battery Life	Years	1 week	1 week	weeks
Bandwidth	250kbps	up to 128k	11Mbps	720kbps
Typical Range (meters)	100+	Several Km	50-100	10-100
Advantages	Low power, Cost	existing infrastructure	Speed, Ubiquity	Convenience

Fig. 3: Specification of Communication Sensor with each type of modem.

The lower data rate of the ZigBee devices allows for better sensitivity and range, but of course offers fewer throughputs. The primary advantage of ZigBee lies in its ability to offer low power and extended battery life. Another advantage of using ZigBee, it can be stored the previous data into ZigBee buffer when the ZigBee change into sleep mode without any data loss. Each of the buoy has one ZigBee modem with configured a specific slave address. The base station is configured as master with its own address.

B. *Prototype Design*

The buoy electronic system was designed to be power-efficient, self-contained and programmable for different application. Care has been taken to balance the power consumption and the performance requirement because the buoy is integrated in a stand-alone system that is battery operated. For this application, a dedicated control board, based on an 8-bit lower power CMOS ATMEGA32 microcontroller has been developed.

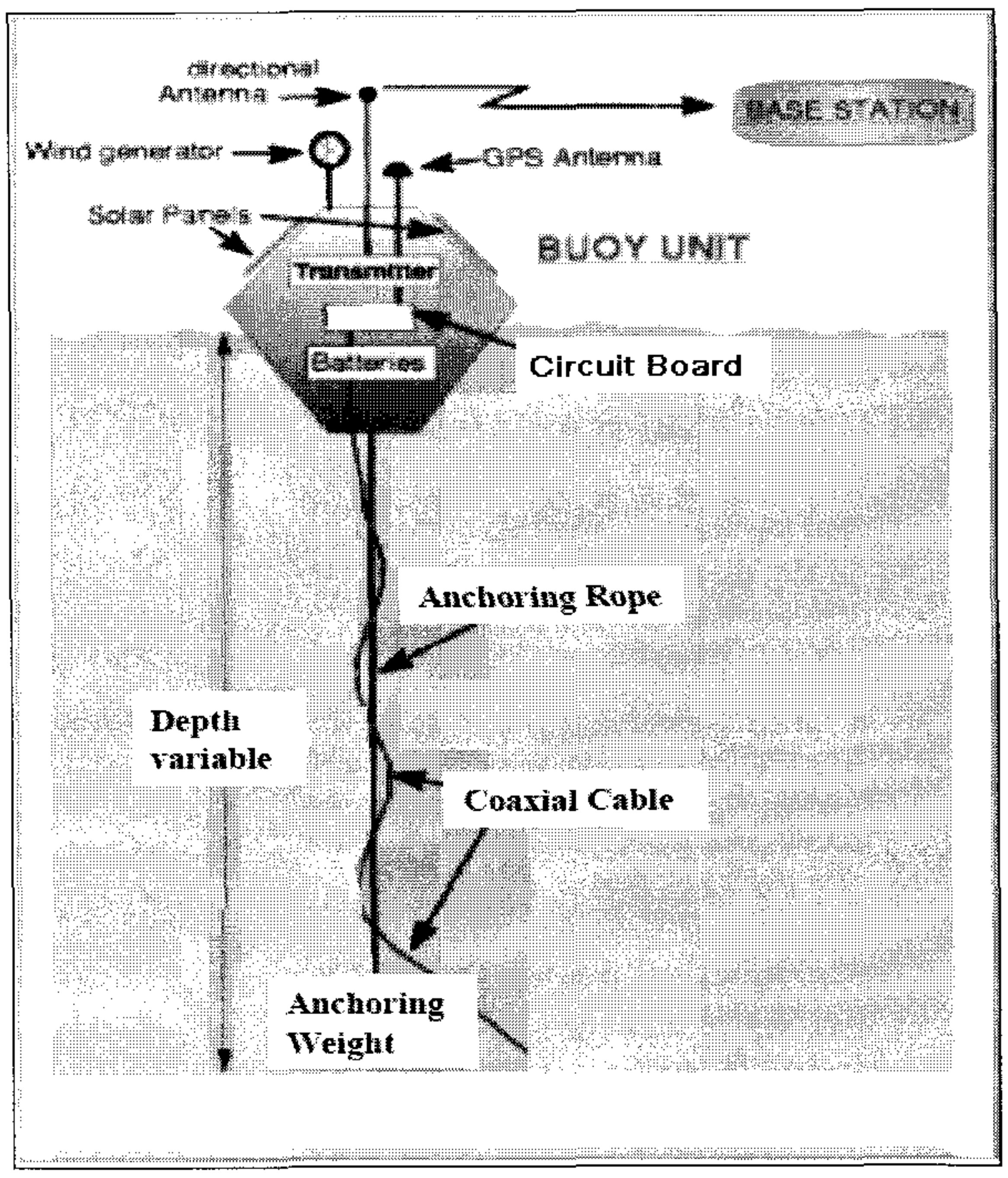

Fig. 4: Element of Buoy Configuration

In the Fig. 4, we present schematically the principal components in the buoy and the transmission possibilities from the buoy to base station. The buoy is anchored by a wire rope and an anchor-weight of 500KG in a fixed position at the seafloor. The hardware design structure is similar for 4 buoys. The power supply of the buoy is provided by six 12V sealed rechargeable batteries that are recharged by 4 solar panels of 40W each. A GPS module provides continuous timing and current location for the buoy [2]. The wave height sensor provides current wave properties in ocean. The temperature sensor is added on to provide us real time weather temperature. The control board has 5 interface circuits to measure, with 12-bit resolution ADC, the electrical currents of the different electromechanical devices. Two other ADCs are used to acquire the air temperature and the battery voltage level. Using two software of USART, microcontroller performs as a buffer to collect the data from wave height sensor and GPS value. The control board receives simple command strings from ZigBee and sends the measured values using a standard serial link via ZigBee modem to base station.

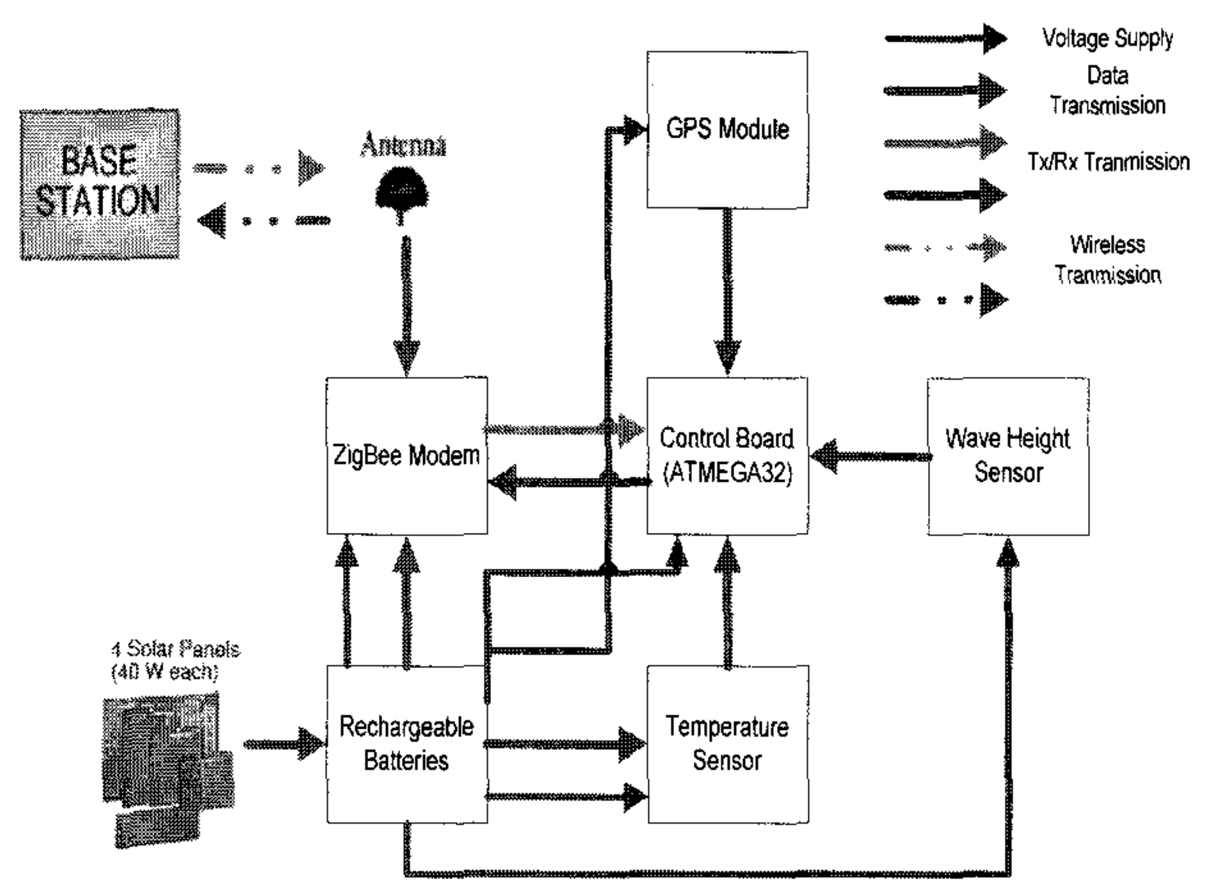

Fig. 5: Block Diagram of the Buoy module and its data communication

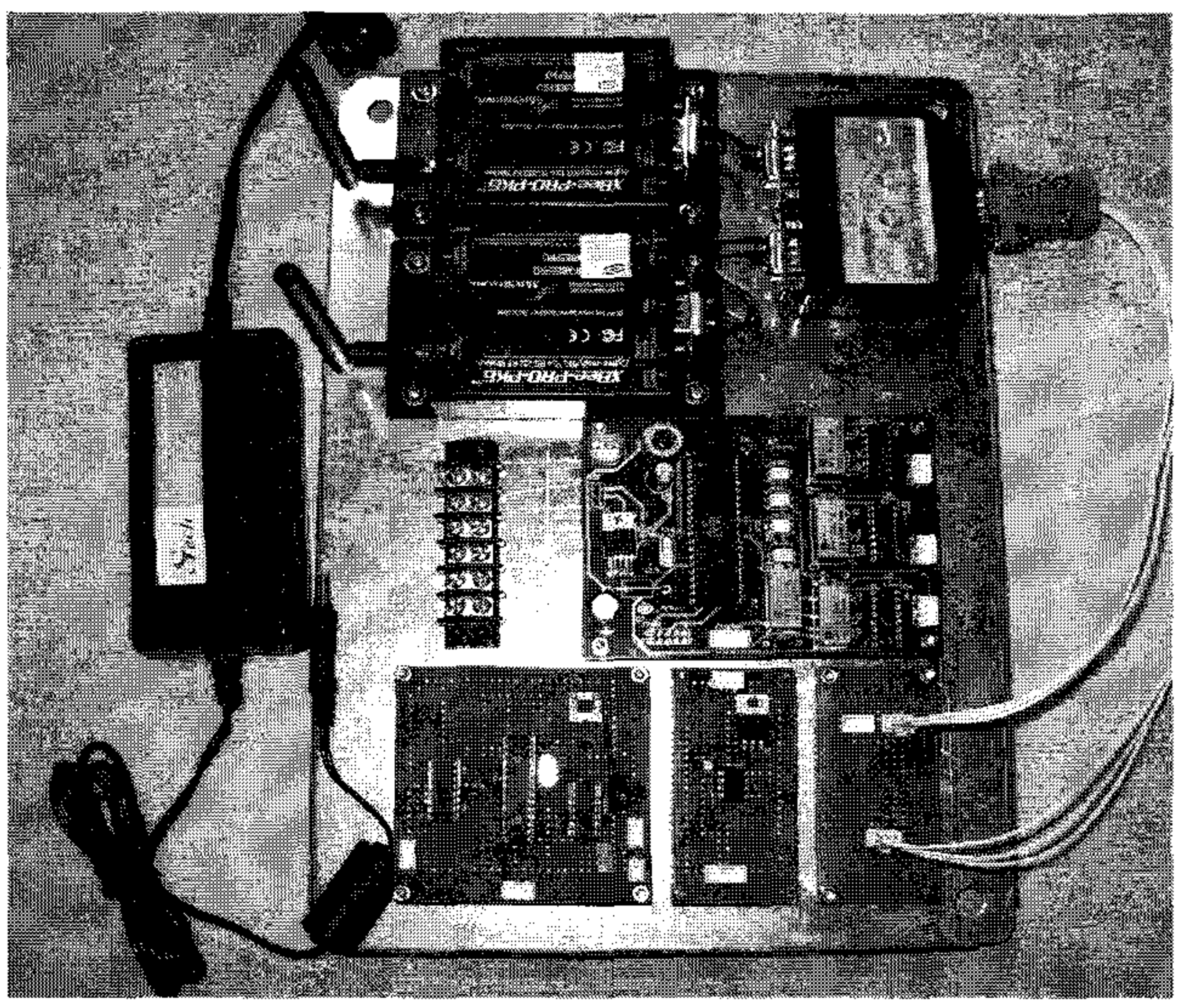

Fig. 6: Complete Buoy Electronic System

The base station as indicated in Fig. 7 consists of the Airmar ultrasonic weather station instrument, UV sensor, ZigBee Modem, RF antenna and PC with internet connection. This gives us the possibility to download data continuously and to communicate with the buoy via RF link between the base station and the ZigBee installed in the buoy. The Airmar Ultrasonic WeatherStation Instrument detects instantaneous changes in the weather. We used all-in-one weather sensor that calculates apparent wind speed and direction, air temperature and relative humidity at the base station. In the base station, we are using PC to check and monitor all the data reading from 4 buoys and base station.

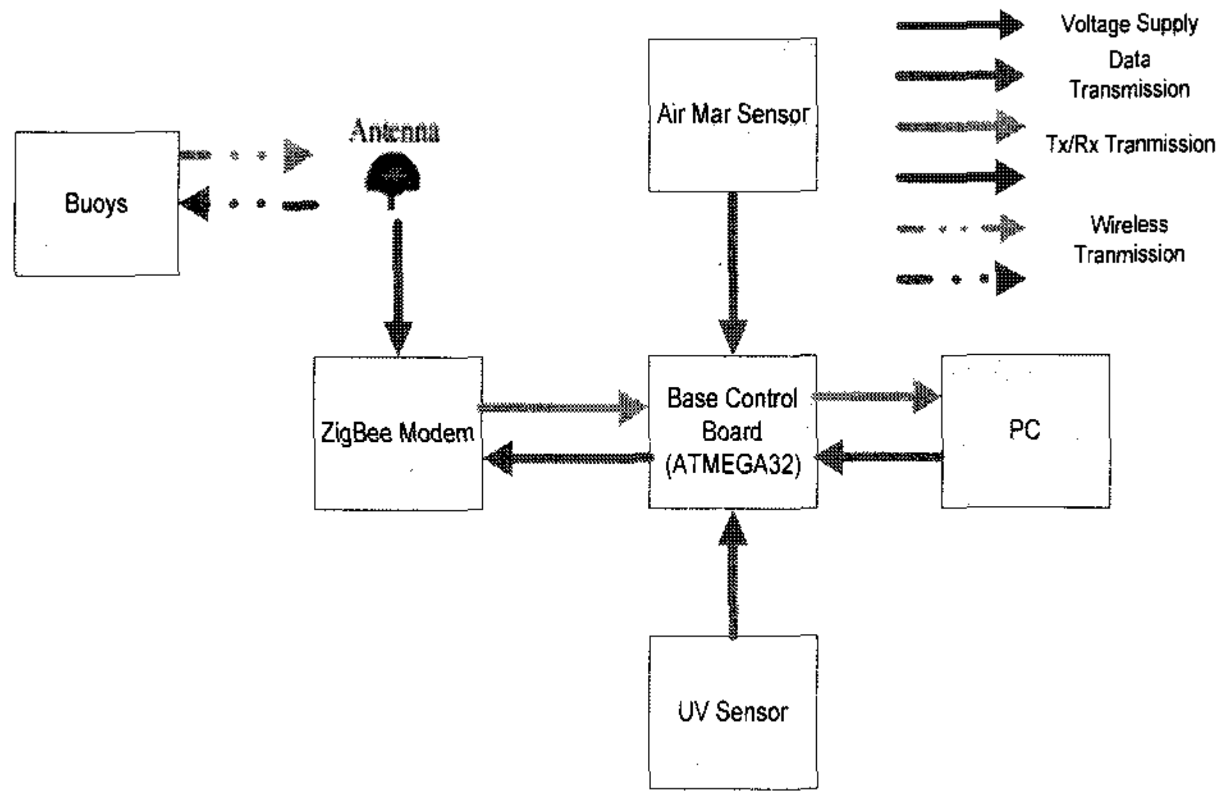

Fig. 7: Block Diagram of the complete system indicating also the elements consist in the base station.

C. *Algorithm Overview*

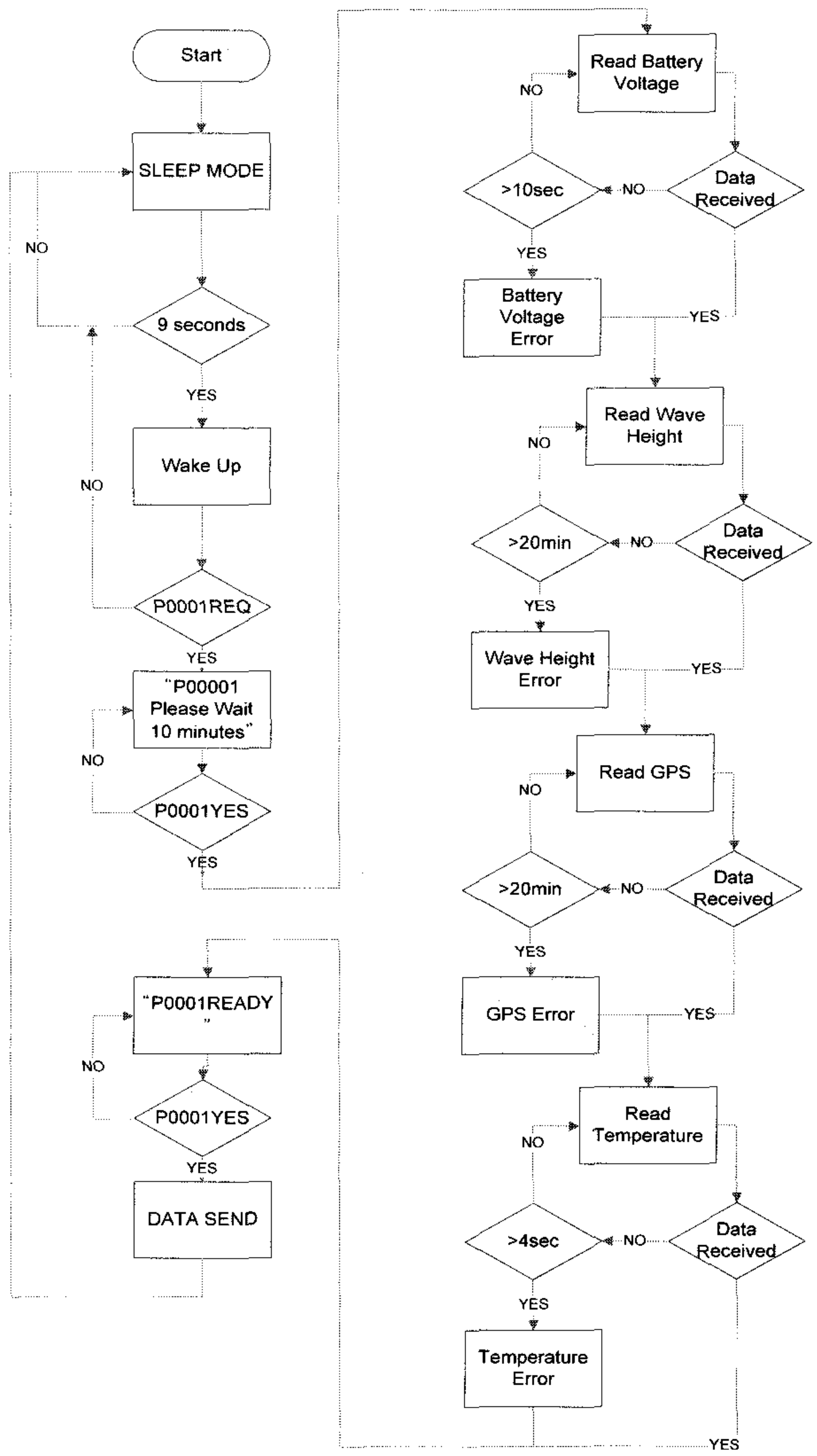

Fig. 8: The complete flow chart of the buoy

A host computer attached to the base station was required to interface the data received to the user. Firstly the base station will be sending the specific address that assigned to each buoy to request data from buoy. The specific buoy will send an acknowledgement to the base station as the wireless communication connection is established. With 10 minutes waiting time is required for buoy initialize all the variables, wave height calculation, and sensor device. The buoy will send an acknowledgement to base station and start reading voltage level, collecting wave height, GPS and current sea water temperature. The given specific addresses of each buoy are used to distinguish on the base station computer. Each ZigBee modem in each buoy is given a distinct node id when programmed.

III. Observation Results

This section is not intended for a detailed reporting of scientific results obtained during at sea testing but simply to give an overview of the overall performance of the communication between the Buoy with the base station.

A. Implementation and Testing of ZigBee Wireless Network

The first system trial took place over 2 weeks. This trial was the first time the buoy and base station had been linked by wireless network. The base station acted as the master, sending request to the buoy when ZigBee indicated availability in response. We conducted the testing with two types of different coaxial cables as antenna for base station. We run first testing with coaxial cable RG-305. We discovered that there are some failures of receiving data from the buoy. The buoys are sending a string of data to base station every hour. After all, we changed the coaxial cable to RG-365. The result of both experiment are shown in Fig. 9.

	Buoy 1 (P00001)	Buoy 2 (P00002)	Buoy 3 (P00003)	Buoy 4 (P00004)
RG-305	>5 (Bad)	<5	<5	>5 (Bad)
RG-365	<5	<5	<5	<5

Fig. 9 Average experimental results of the failure data transmission packet collect from base station in a day.

From the Fig.9, the main reason causing bad data transmission when using RG-305 is the cable itself has high impedance which is 75ohm. Meanwhile, the RG-365 has lower impedance compare to RG-305 which is 50ohm. In the experiment, we considered the buoys have failure transmission as if the base station fails to receive more than 5 data packet in a day. It is desirable to transfer as much power as possible from ZigBee modem to antenna. To ensure this happens, the ZigBee and antenna impedances should be matched, and the transmission line used to connect the two should have equal characteristic impedance as well.

The Fig.10 below shows the comparison RG-305 and RG365 of total number data packet received in base station. From the graph, we could obtain that the best distance between base station and buoys using RG-365 is 4.4Km which we able to receive 1024 packets data. In other words, we requested 1024 data packets from base station, the buoy received the command and transmit data information back to base station without any failure. Meanwhile, while the antenna cable changed to RG-305, the best transmission length is only can reach maximum 2Km. The transmission goes weak beyond the 2Km. In addition, using RG-305 cable, we could not receive 1024 data packets while we are requested from base station. In fact, we received only 950 data packets. Due to loss data packet transmission, we decided to change from RG-305 to RG-365 to increase the transmission reliability. As a conclusion, we stated that the reliability of the transmission signal strength of RG-365 is better than RG-305.

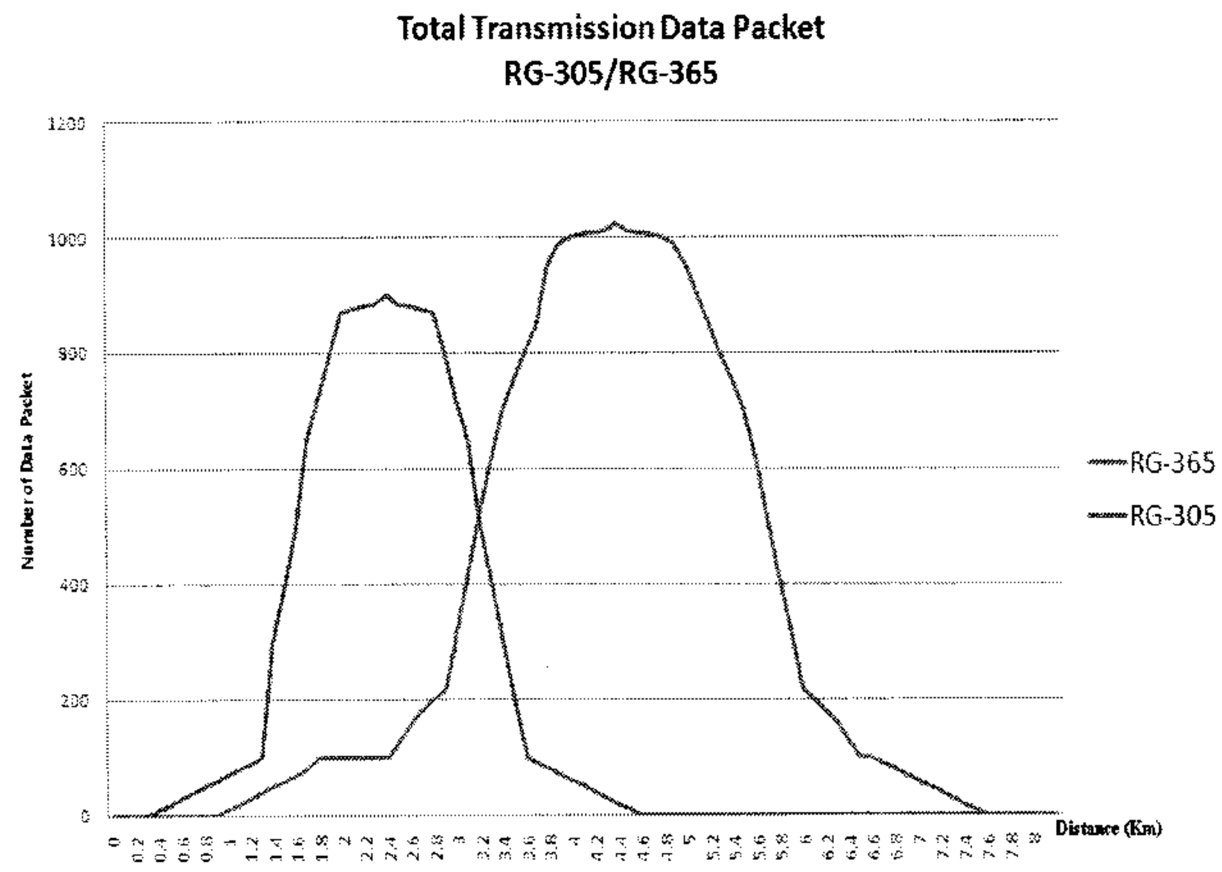

Fig. 10 Total Transmission Data packet for RG-305 and RG-365 antenna cable

In this RF transmission, the impedance between two stations will cause a portion of the signal power traveling from the ZigBee to Antenna to be reflected back to the base station. The magnitude of the mismatch will determine the portion of the power that keeps traveling down the cable towards the antenna and the portion that get reflected back to the ZigBee.

B. Buoy and Base Station Communication – Data & Network Analysis

During the development of the buoys network experiments were carried out beside the beach. The first network trial it was decided to experiment base station with a single buoy. This experiment was designed particularly to produce an accurate characterization of network settings for the oceanic environment. The focus was on single hop link behaviour as the appropriate first step in understanding the challenges that sea conditions create for networking. Tools, instrument and Hyperterminal programs were deployed to record receiving data. An example of unprocessed data of buoys recorded at base station is shown in

The command P0000x refers to the Buoy ID that assigned individually. The REQ command sends from the base station to request the data from the buoys. Once the wireless network is established between two sides, the buoy will send a command wireless link connected to the base station.

P00001,2008/01/04,07:14:36,35.09578,129.09582,10.62, 0.0,13.6,n,n,n,n,n,n

<BuoyID><Date><Time><GPS Longtitude and Latitude><Seawater Temperature><Wave height><Battery Voltage>

<n><n><n><n><n><n>

n – Reserved for special purpose

Fig. 11 Experimental of 1 sample data sent by buoy 1 captured in Base Station

The Fig.11 show that the 1 sample data packet of buoy with ID P00001 that we received in base station. In the whole string, the user in base station able to check the current data, time and the location of the each buoy. The GPS module provides longitude and latitude of the buoy. Technically, seawater temperature and the battery voltage of the buoy will not change significantly. During this experiment, we obtained the seawater temperature is about 10.62°C~ 10.7°C. Meanwhile, the low power consumption of the circuit board consideration has been added early of this project, the voltage batteries in the buoy are automatically rechargeable by solar panel. The voltage level of this sample buoy data is 13.6V.

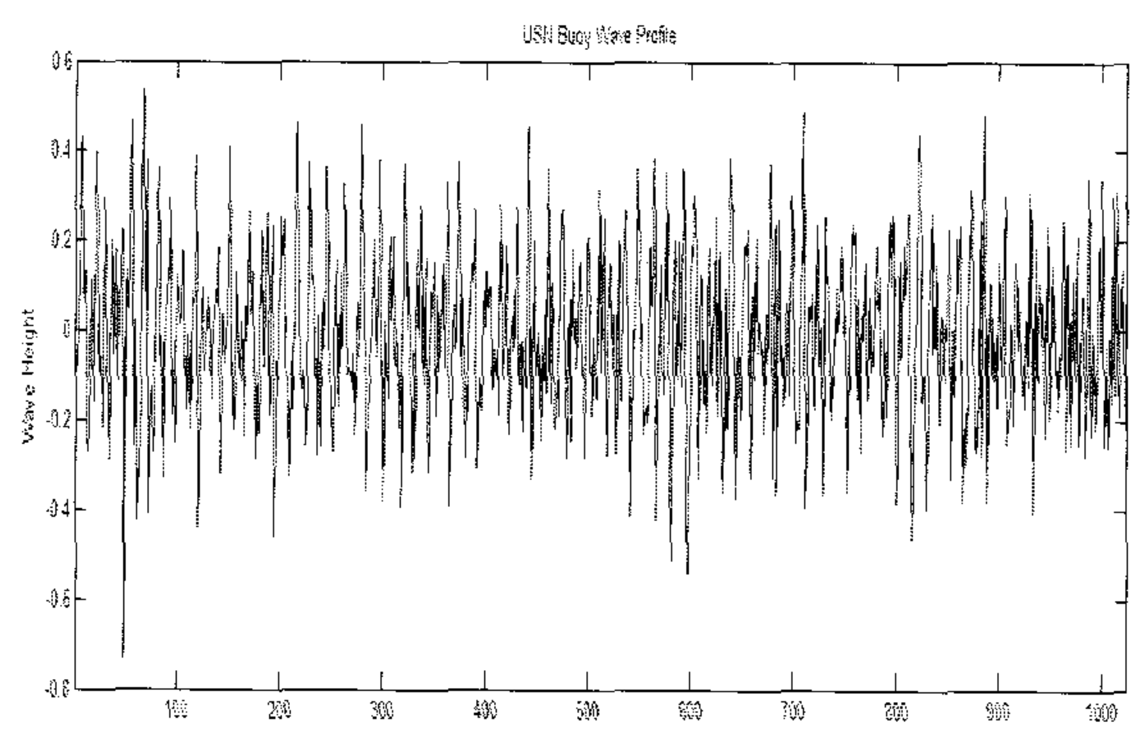

Fig. 12 USN buoy 1024 samples wave height vs. wave count

Fig. 12 shown that we have used 1024 wave counts of measured wave heights in a given position of sea corresponding to 1024 sequential hours which is 42 days to train the ZigBee Wireless Network reliability. From the graph observation, the maximum wave height is 0.55m. In general the sensor modules behaved as expected. The independence of sensor and ZigBee modules enabled the wireless networking side of the experiment to be unaffected by the sensor module failure.

IV. CONCLUSION

The project objectives were successfully achieved. The data was effectively retrieved through a wireless RF link from buoy to base station interfaced to the user. The reliability of the wireless buoy network was demonstrated in the case. The behavior of the wireless buoy network in the presence of the other wireless network was studied and it was found that wireless buoy network demonstrate reasonable immunity against radio frequency interference, hence increasing reliability. Such network can be used environmental monitoring of highly hazardous industrial areas that requires minimum human interaction. [13],[14],[15]

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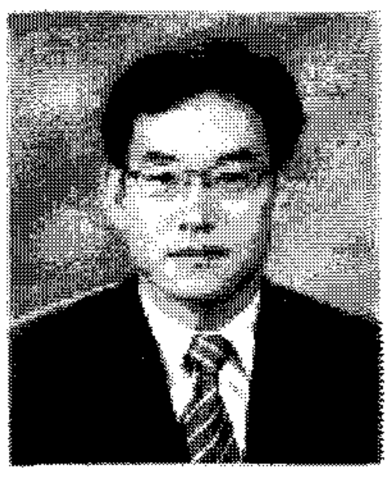

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