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Teaching Multidisciplinary Engineering using Concepts and Technology of WSN

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Abstract— This paper discusses teaching and learning strategies of Wireless Sensor Networks technology in a new postgraduate subject run at the Faculty of Engineering and IT, University of Technology, Sydney. The aim is to present the role of using practice based and multidisciplinary methodologies in the context of new ICT technologies. This includes shared experiences, observations and common problems experienced in teaching new concepts and paradigms, standards, protocols and algorithms, embedded systems and sensor technologies. The theory of WSN is applied as a driver of system development for the group projects that students undertake in the subject.

Keywords: Wireless Sensor Networks, ICT, Teaching Multidisciplinary Engineering

I. BACKGROUND

The work presented in this paper aim to report on teaching and learning in a newly designed postgraduate 49227 Wireless Sensor Networks (WSN) subject at Faculty of Engineering and IT, University of Technology, Sydney.

In last 10 years, technology and applications of Wireless Sensor Networks have been the subject of intensive research and there has been a rapid growth of a wide range of engineering applications. For example, WSNs play a vital role in such areas as: environmental protection, agriculture, intelligent machines, smart buildings and factories, smart offices and cities, intelligent infrastructures and homes, smart hospitals and many more. The theory and concepts of WSN are now well defined, and there are many important applications related to system engineering, computing and telecommunication that, at present, are not covered in other subjects taught at UTS and other technical universities. Only recently, 6lowPAN has been proposing the use of IPv6 solutions in WSNs. IP in WSNs has been accepted not only as an extension of the conventional networks to the real world, but also as a solution to use well-known WSNs high-level protocols [2, 5], topologies and configurations (Fig. 1). These developments, as well as continuous progress being made in microelectronics, MEMS, sensors and embedded systems, are paving the way for WSNs to become a key factor in the future paradigm of the “Internet of things”.

WSN technology and applications span across computer engineering, telecommunication, computer science as well as biology and many other disciplines [3, 5, 7, 11]. The domain of WSN promotes multidisciplinary approaches to teaching and learning.

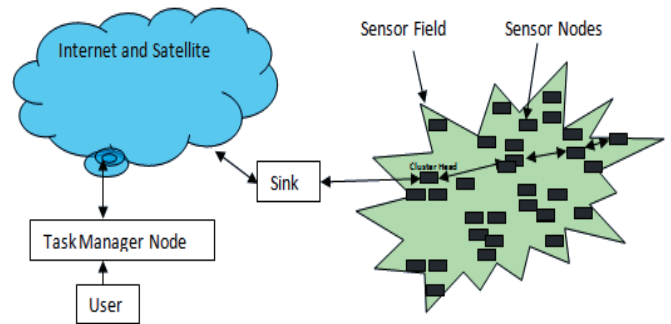


Figure 1: A typical topology WSN based infrastructure.

There is already a strong demand from industry for engineers and IT specialists with WSN skills. The area has the same potential for growth as the Internet in the mid-90's. With a strong emphasis on multidisciplinary skills, such as: information theory, signal processing, electronics, embedded systems, programming and computing algorithms, the newly designed WSN subject aims to prepare and position future engineering students to embrace industry and environmental challenges in the area of intelligent systems.

A. Rationale and motivation

The Wireless Sensor Networks subject is purposely designed to be highly technical and involving SOTA multidisciplinary methodologies, technologies and tools. The main goal is to extensively contribute to a wide range of graduate attributes for the ICT major program. Specifically, at the end of the WSN subject, the aim is to ensure that the students should be able to: understand and practice WSN principles, methods, protocols, algorithms, technology, and tools, as well as able to develop feasible WSN based solutions. While attending the course, the students are required to apply critical and analytic thinking to the planning, execution and evaluation of WSN analysis, design and system implementation. In the lab sessions students are trained to use automated tools to facilitate the WSN application development process. During lectures students are required to demonstrate creative thinking in the design of WSN based solutions that address a variety of multidisciplinary issues. During lectures, tutorials and lab sessions, students are required to communicate effectively to diverse audiences. The main student projects involve work in small teams, typically made up of 3 to 4 members.

II. TEACHING METHODOLOGY, TECHNOLOGY AND TOOLS

The postgraduate engineering program 49227 Wireless Sensor Networks subject covers both theoretical and practical aspects of engineering. The course runs in a block mode and consists of two parts. The first part includes formal lectures and lab sessions which cover both theoretical and practical aspects of the WSN domain. The second part involves laboratory group-work on Main Projects defined as a selected case study.

A. Formal Lectures

Theoretical components of the subject include both fundamentals and advanced aspects of the WSN such as:

- Background of the WSN and related technologies
- Key concepts, WSN components and architecture
- Enablers and inhibitors, typical applications,
- Advantages and Design Challenges of the WSN
 - Energy management
 - Ranging and Noise
 - Security
- Communication protocols, standards and topologies
- Sensors and sensing, actuators and control
- Computational algorithms
 - Deployment and configuration
 - Localisation, clustering, routing and detection
 - Tracking and data fusion
 - Autonomics and knowledge discovery
- OS hardware and software, middleware
- Case studies and advances of WSN

The 49227 subject's lectures have the following key objectives:

- To understand wireless sensor networks concepts, theoretical framework, methodologies, technology, applications and its multidisciplinary aspects.
- To develop an understanding of the WSN technology; this includes hardware, telecommunication and software components.
- To develop a prototype system to solve a case study.

B. Understanding the concept of WSN

- **Sensing** is a technique used to collect data about a physical object or process in a physical environment, including the occurrence of events (i.e., changes in state, such as presence of an obstacle, increase in barometric pressure, etc.).
- **Sensor** is an object that is performing sensing. For example, the human skin is equipped with billions of sensors that are able to capture information about temperature or humidity, from the environment; human eyes can obtain information about a presence of various objects, while human ears can intercept acoustic data (voices of other humans).

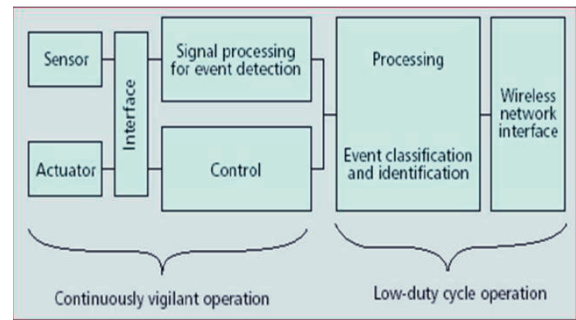


Figure 2: The architecture of the WSN mote.

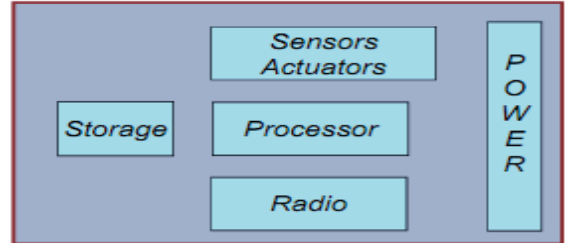


Figure 3: The main components of the WSN mote

- **A wireless sensor mote** (sensor node) can perform the following tasks: sensing, actuation, computing and storage of necessary data, power management, radio communication (Fig. 2 and Fig. 3). Typically, mote devices are integrated on a single or multiple boards, and packaged in a few cubic inches or even smaller size objects. With low-power circuits and networking technologies, a mote powered by 2 AA batteries only can operate for up to 2-3 years, in a low duty cycle working mode.

1) Definition of WSN, Components and WSN topologies

WSNs consist of a large number of wireless network devices called motes that can sense the surrounding areas, communicate the data collected from the monitored field (e.g. sensor nodes) and possibly execute controls of various electromechanical devices through wireless links.

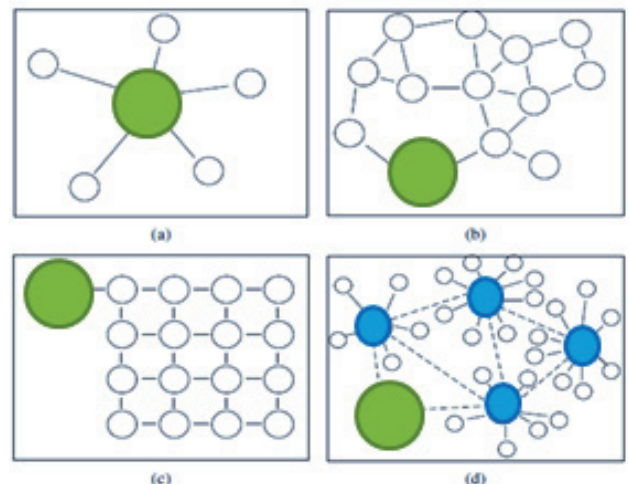


Figure 4: Various WSN deployment topologies: (a) single-hop star connection, (b) multi-hop mesh flat topology, (c) grid and (d) 2tier hierarchical cluster topologies.

The sensor data measurements (and controls) are transmitted through multiple hops communications to the sink nodes called Base Stations (BS) for further processing. The processes information can be used for local decision making or are passed to other interconnected networks. Figure 1 displays a typical architecture of the WSN infrastructure set-up. The sensor measurements include physical parameters such as: light, temperature, humidity, pressure, proximity, sound, presence and many other types. These measurements are communicated through wireless channels to the Base Station (BS) and then are used by different user application. The topology of WSN (Fig. 4) amplifies network traffic which poses various challenges related to the efficient use of limited resources and high bandwidth demand [8].

C. Lab Work in 49227 WSN Subject

The main aim of lab exercises is to introduce students to WSN embedded programming using Code Composer Studio and Workbench® for 8051 from IAR Systems with the MSP430

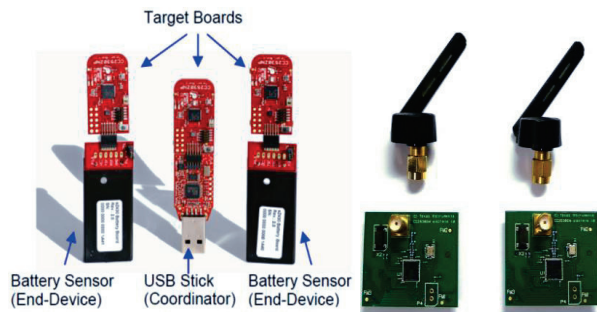


Figure 5: CC2530ZNP and CC2530EMK kits. Source [18]

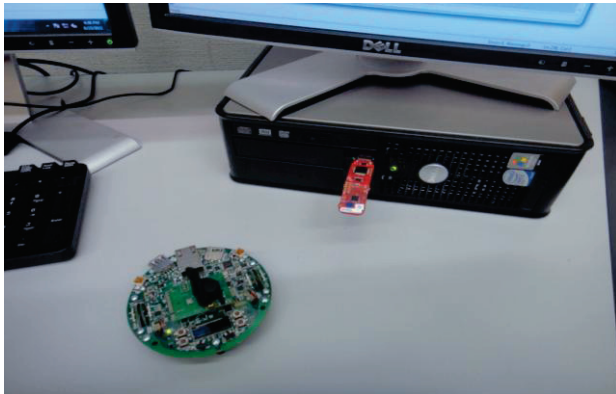


Figure 6: The Stellaris Evalbot and CC2530ZNP coordinator

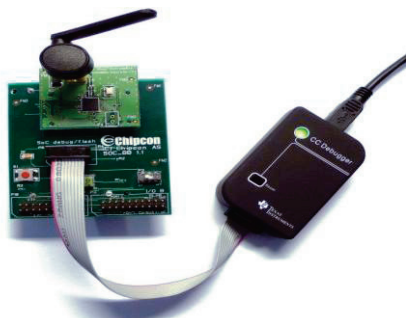


Figure 7: CC Debugger connected to a SoC Battery Board with a CC2530EM

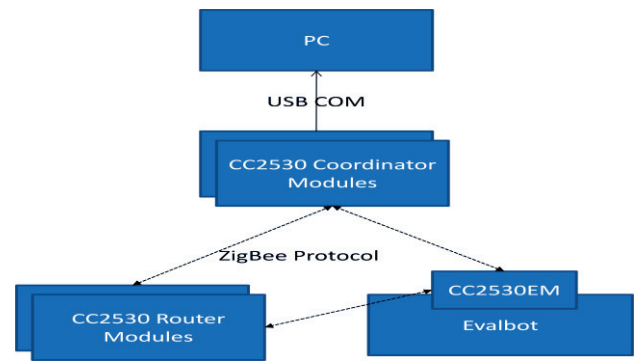


Figure 8: The hardware configuration of WSN system.

microcontroller as the target host. The CC2530 System-On-the-Chip (SOC) is the ZigBee Network Processor (Fig. 5), while the Stellaris® LM3S9B92 microcontroller (Fig. 6), based on the ARM® Cortex™ M3 can be used as a main controller (Fig. 8). While working with WSN kits, students learn to use other important tools such as:

- the TI CC Debugger (SWRU197C) (Fig. 7), that can be used to debug and program the flash of any of the RF System-on-Chip.
- the SmartRF™ Packet Sniffer that can be used to display and store RF packets captured with a listening RF HW node. The tool displays the captured packets and decodes the packet contents, depending on what protocol is actually running.
- The Flash Programmer application tool which can be used to program the flash (i.e. program Intel HEX files, read the contents of the flash and several other operations) of the CC2531 or CC2530.

1) Objectives:

After finishing various lab exercises the students shall be able to learn:

- What a simple ZigBee based sensor network is and how it can be used in practice;
- How to effectively use the Code Composer Studio IDE and other tools for programming and debugging WSN applications in combination with the industrial (TI) hardware platform;
- How to start a WSN project and develop the WSN firmware;
- Where to find the required resources for further study.

D. Assessment Components of 49227 WSN Subject

- **Written Report.** The written report assesses the student’s understanding of a WSN including what it is, how it works, as well as how a WSN can resolve problems in various areas. This assessment is to be completed individually.

Case Study. The Case Study requires students to work in groups in order to design, develop and program a WSN

for a particular application. The due dates for the Case Study deliverables are in the semester schedule that is contained in this document.

- **Practical Exam.** The practical exam focuses on the evaluation of a WSN application. Marks will be awarded based on the student’s ability to evaluate the strengths and flaws of the system. Other points of assessment include the student’s ability to overcome the various limitations of the system through ingenuity and understanding of the system. This assessment is to be completed individually.

E. Software Technologies and Tools

In 49227 WSN subject students are required to use modern software development IDE tools such as TI Code Composer (Fig. 9). For monitoring and diagnostics of the setup of CC2530ZNP WSN, an open source terminal emulator application called PuTTY [11] is used (Fig 10). The main project in the newly designed WSN subject involved development a proof of concept to use Wireless Sensor Network technology (CC2530 and Stellaris Evalbots [15, 16, 18]) to implement detection and localisation functions for a sensing system (Fig 2). Students are required to investigate and apply methods of detecting and reacting to potential environmental threats such bush fires or oil spills. For firmware and in some cases user applications students are required to use modern software development IDE tools. For firmware development, TI Code Composer [2] IDE framework is used. In the majority of cases, the students are able to design and develop a system with basic capabilities to perform the required functions, however, in some cases, not all initial functional requirements were realised in the scope of the assignment. The limitations were mostly time restrictions available and some deficiencies in expertise. These limitations did not, however, prevent students from getting tangible results.

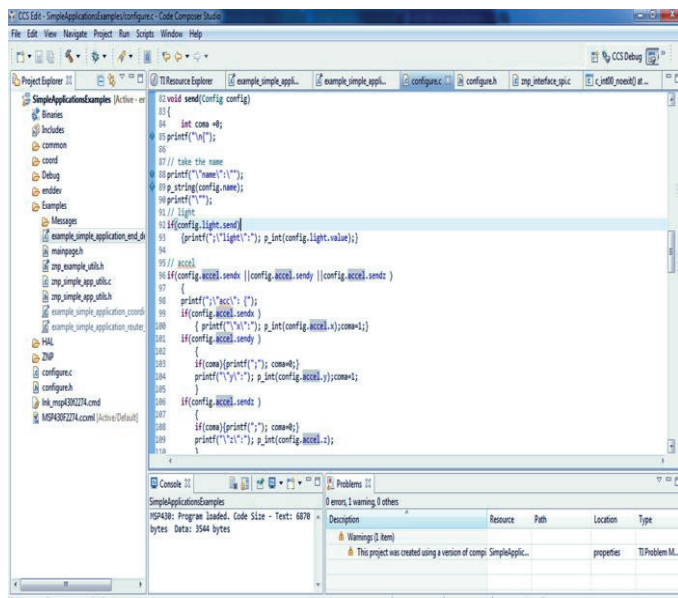


Figure 9: The TI Code Composer [22] IDE.

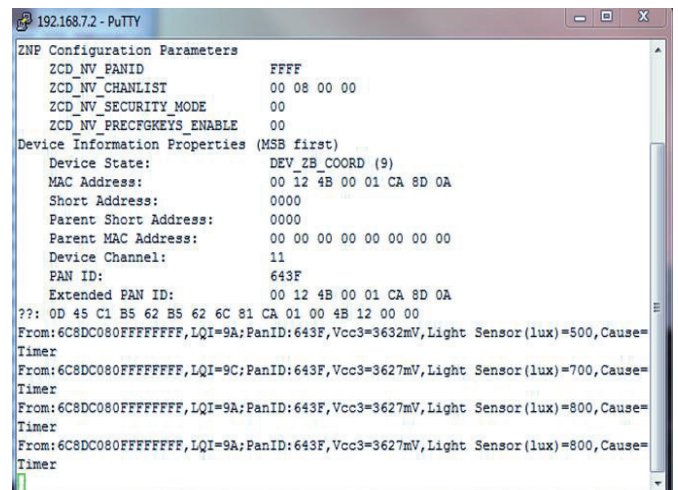


Figure 10: Monitoring sensor data in CC2530ZNP using PuTTY [24].

1) Stellaris LM3S9B92 Robotic Evaluation Board

The Stellaris® LM3S9B92 microcontroller (Fig 6.) is based on the ARM® Cortex™ M3 controller core operating at up to 80 MHz, with 256 kB, flash, 96 kBytes SRAM, a 32-ch DMA, 32-bit external peripheral interface, and ROM preloaded with the StellarisWare Driver library, Boot Loader, AES encryption lookup tables, and a cyclical redundancy check (CRC) function. The LM3S9B92 provides real-time industrial connectivity with a 10/100 Ethernet MAC/PHY, USB 2.0 full speed OTG/Host/Device, 2 CAN controllers, 2 SSI / SPI controllers, 2 I2C interfaces, an I2S interface, and 3 UARTs. The LM3S9B92 microcontroller includes such functions as: advanced motion control features, consisting of 8 motion-control PWM outputs with dead-band, two encoder inputs for position monitoring, and 4 fault protection inputs for the low-latency shutdown function.

F. System Architecture

The proposed architecture involves a variety of sensors connected to a Texas Instruments CC2530ZNP board attached to a battery board which broadcasts the local sensor environmental data over IEEE 8.2.15.4, ZigBee [21, 23] Protocol to a ZigBee network of routers (other CC2530ZNP boards) which include multiple coordinator nodes as well as the Stellaris Evalbot through the Texas Instruments CC2530EM board connected to the Evalbot’s EM socket. The Evalbot will receive the locally sensed data through the use of the sensors on its ADC and use this environmental and location/movement data parameters (i.e. temperature, light, humidity, motion, etc.) broadcast by nearby nodes and also the coordinator node(s) to calculate areas of a potential threat (i.e. high temperature) and then use the onboard motors, sonic and bumper sensor to navigate towards the hazardous (high temperature) areas to investigate whether a fire is present and then broadcast an alert over router nodes to a coordinator node ultimately reaching a computer. The CC2530ZNP board is designed to introduce students to the Zigbee Network Processor without a large amount of hardware and software setup required. This makes it ideal for developing quick

prototypes to test the design while using the protocol and on-board chip (CC2530) expected to be used in a final product.

III. THE MAIN PROJECT CASE STUDIES

A. Construction Vehicle Tracking using WSN Technology

This case study summarises the research and prototype work done by students as a part of the Main Project in 49227 WSN subject [6]. The proposed solution demonstrated how WSN technology could be used for detecting, tracking and analysing the motion of construction vehicles (e.g. bulldozers, excavators, cranes, trucks or passenger cars) on construction sites with high levels of vehicle traffic. This application facilitates the detection of construction vehicles as they move through a sensor network established across a construction site. The concept of target detection and tracking has become an increasingly important and prevalent application of WSN in recent years [2, 3, 8, 10]. The real advantage of WSN technology is that the network can be deployed ‘ad-hoc’ and operate unattended for a long time with little maintenance, without the need for any established infrastructure. This characteristic can be seen as especially advantageous for a construction equipment tracking application on the construction sites as these are often temporary and usually there is no pre-existing infrastructure. An application of this nature would also enable site management (the system’s end-users) to be aware of vehicle movements at any given time providing them with real-time detection allowing for greater control over levels of traffic in any given area on the construction site. Two main benefits foreseen as a result of implementing this proposed solution include a decrease in safety incidents and the ability to optimise construction operations through vehicle route management. The WSN would include the capability of sensing construction vehicles that come into close proximity with other vehicles. The network would handle this scenario by alerting the operators of the respective vehicles about people or equipment in the neighbourhood, as well as, sending messages to the Base Station (i.e. the GUI application used by the site management). Consequently, this process aims to improve awareness of safe working distances and blind spots at the construction sites. A flow-on effect would see an improvement in the safety of machine operators and other site personnel. The solution is an attractive proposition for large civil infrastructure organisations which manage projects in high-risk working environments. For site managers, it is important to be aware of all movements of operating vehicles for both fleet management purposes and to ensure optimum efficiencies, which can be achieved in terms of haul distances and fuel burn. The proposed WSN system would provide the real-time information required to assist the decision making process on a daily basis. For this application, the WSN would estimate and track a target vehicle based on the spatial differences of the target’s signal strength detected by sensors established at different locations within the construction site’s boundary. A localisation method, proposed by Malik [5], was adopted to see the network of ‘anchor’ sensors distributed in a triangular fashion (see Figure 1) that would follow a

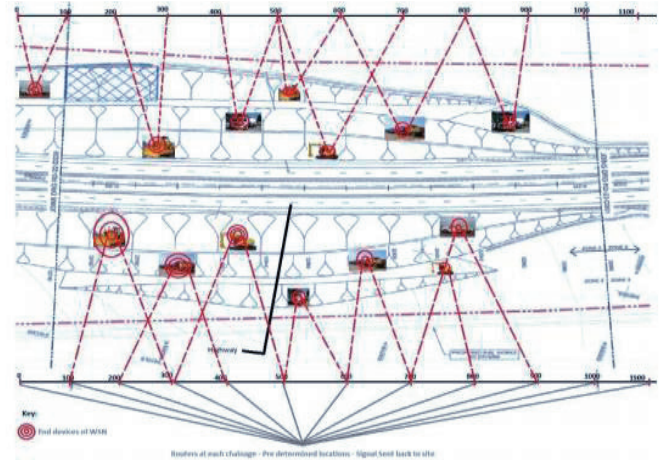


Figure 11: Vehicle tracking at a construction site using WSN technology [6].

localisation algorithm to determine the location of vehicles passing through the sensing field. Each anchor sensor would be aware of its physical location (pre-determined) and that of its neighbouring anchor sensors. The proposed methodology used for this application is known as the tri-lateration technique. The physical topology of a typical deployed WSN at the construction site is illustrated in Figure 11. WSN nodes that are equipped with various sensors and actuators would be mounted on construction vehicles and other specialised equipment and would be known as the ‘end-devices’. Along the boundaries of the construction site, anchor sensors would be placed in predefined locations to collect the data transmitted from the ‘end-devices’ (sources) and then relay it to the Base Station(s) and possibly smart gateways via a multi-hopping protocol. The predetermined location of these anchor devices will assist in the localisation of the tracked vehicles. The proposed prototype model of the WSN system was to demonstrate the basic functionality as described above. The *Texas Instruments CC2530 ZigBee Network Processor Mini Development Kit* was used to build a working prototype to represent a simplified model of the full system only. The kit’s ‘end-device’ is equipped with an accelerometer and a magneto-resistive sensor to capture motion data related to various construction vehicles in the real-time. The accelerometer data can be analysed and adjusted to output a velocity in a horizontal direction, while the magneto-resistive sensor was required to act as a digital compass, providing directional heading data. The combination of these two types of data outputs is to provide information to the Base station about the target vehicle’s direction and motion (acceleration). The localisation functionality was not implemented in the demonstrated prototype.

B. Water Well Monitoring System.

The prototype of Water Well Monitoring System (WWMS) aimed to effectively monitor and possibly manage the water level in water wells. This was achieved by measuring the distance from the ground level to the first appearance of water in a given well under observation. The initial solution was to calculate the depth was to base it on measuring the barometric pressure using WSN nodes.

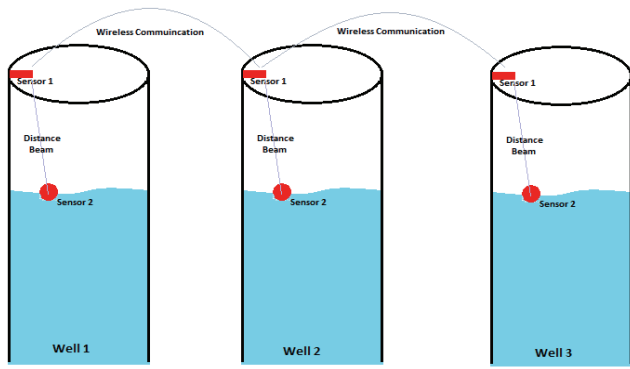


Figure 12: Water Well Monitoring System using WSN technology [1].

While developing the Water Well Monitoring System, it was assumed that the value of barometric pressure changes at varying altitudes. Thus, with simple calculations, the depth could be derived from the sensor readings of barometric pressure [11, 12]. This can be defined as the first step. In the second step, the sensor data are processed by an embedded microcontroller (MSP430). Finally, communication among motes surrounding the network of wells would use ZigBee protocol and a low power radio frequency telecommunication technology. Frequent forwarding of data could seriously affect the battery life thus the sensor motes would be required to transmit data at a low rates to limit power consumption, as the system is expected to be maintenance free for many years. Thus, power management should be given a priority as the readings are normally processed locally and the results of calculations are only forwarded to the next node. In WSN field, sensor reading received from sources are aggregated and passed to the sink, which will be located in the most well dense location, and would include a more sophisticated infrastructure. This could include a gateway that runs intelligent processes and provides an internet connection to allow monitoring to the whole system (Fig. 20). The state machine diagrams that demonstrate the system's behaviour are depicted in Figures 13 and 14. It was observed, that in order to improve the prototype of the Water Well Level Monitoring System (Fig. 12), some more specific sensors have to be used to meet the system requirements (see Table 1). The proposed choice of sensors, if integrated with CC2530 ZNK kit, would extend the functionality of the prototype of a simple system, that measures the water level only, to a more complete solution that would allow monitoring other aspects of the water well, such as: water's purity, toxicity, temperature, etc.

Table 1: Selection of sensors required for the project [1]

| Sensor | Input Range | Sensitivity | Accuracy |
|-------------|------------------------|----------------------|------------------------|
| Pressure | 50-120 KP | 10 P | + - 10% error margin |
| Temperature | -10 - 60 Degrees | 1 Degree Sensitivity | + -10% error margin |
| Water Level | 0 m to 100m | 1 cm Sensitivity | + - 25 cm error margin |
| Toxicity | Depends on Environment | Very Sensitive | Safe for human use |
| Humidity | 0-100% | 1% | + - 5% error margin |
| GPS | Max # of Satellites | Very Sensitive | 100% |

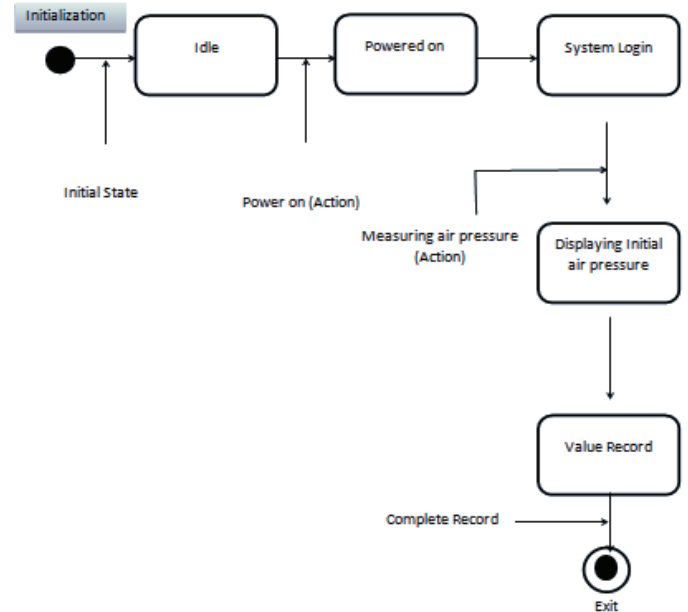


Figure 13: State chart diagram of receiving reference values from pressure sensors [1].

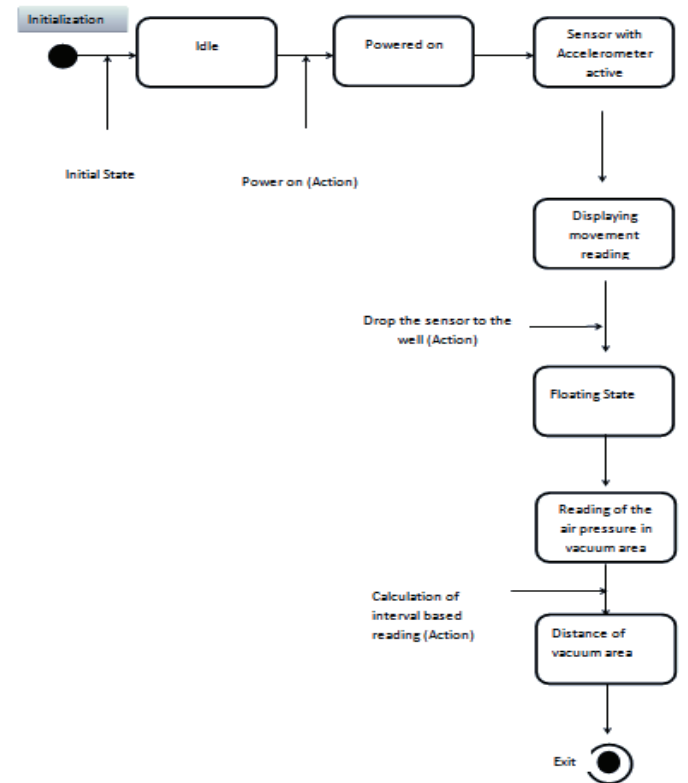


Figure 14: State Chart Diagram of Distance Calculation System [1].

IV. CONCLUSION

In majority of cases students were able to ascertain that they could set-up and configure Zigbee network with the CC2530 based motes, including coordinator and router nodes, as well as send and receive sensor readings over the network. While students in some cases were not able to test the theory behind

localisation using the signal strength of messages received from nodes, the theory has been thoroughly tested by some students which indicated it was feasible to implement these aspects in further iterations of prototypes, given more time or experience. The problems encountered also didn't prevent students from communicating with the Evalbot to develop a response vehicle that can respond to changes in the environment (i.e., temperature, humidity, light, etc.). Based on the results of various projects and the developed prototypes, there was enough evidence to suggest that work on system prototypes based on WSN technology was found to be a very fruitful and rewarding learning experience for all students. Most of the students appreciated the importance of WSN related research in Australia and worldwide, as it was observed that the WSN technology can be effectively used in a vast range of user applications.

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