REDUCING POWER CONSUMPTION IN WIRELESS SENSORS NETWORKS

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For their love and support, I thank my family.

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ABSTRACT

The emerging field of wireless sensor networks combines sensing, computation, and communication into a single tiny device. Through advanced mesh networking protocols, these devices form a sea of connectivity that uses any possible communication path by hopping data from one node to another in search of its destination. While the capabilities of any single device are minimal, the collection of hundreds of sensors offers major new technological possibilities. Examples of usage scenarios for these devices are real-time tracking and security monitoring, issues that will be studied in this thesis. In fact, this thesis is mainly concerned with the analysis of a wireless sensor network used to track hostile mobile devices in a remote environment. The key evaluation metrics for such systems are the operational lifetime, response time and temporal consistency. These issues are studied in this thesis and a compromise is found to optimize all the system requirements and parameters.

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LIST OF ABREVIATIONS

WSN	Wireless Sensor network
STEM	Sparse Topology Energy Management
MERL	Mitsubishi Electric Research Laboratories
IP	Internet Protocol
DSR	Dynamic Source Routing
UWB	Ultra-Wide Band
GPS	Global Positioning System

Chapter 1

Introduction and Problem Definition

1.1 Sensors

Sensors are small machines that can sense their environment, and report what they have sensed. Such devices are found in many applications and systems, and can come under many brands such as Motorola, Termometric Corporation, and Oksolar.

Sensors can be used to measure temperature, relative humidity, pressure, vibration, speed of Vehicles… As an example consider the Fire Alert: The Fire Alert function is used to notify the central unit that there is a fire at the present location of the requesting sensor. When the fire sensor is triggered, a signal is sent to the central unit. This signal is specific to the sensor transmitting it so the central unit will know where a fire is taking place. The central unit will then send a signal for the rest of the installed alarms to sound after it receives the fire signal

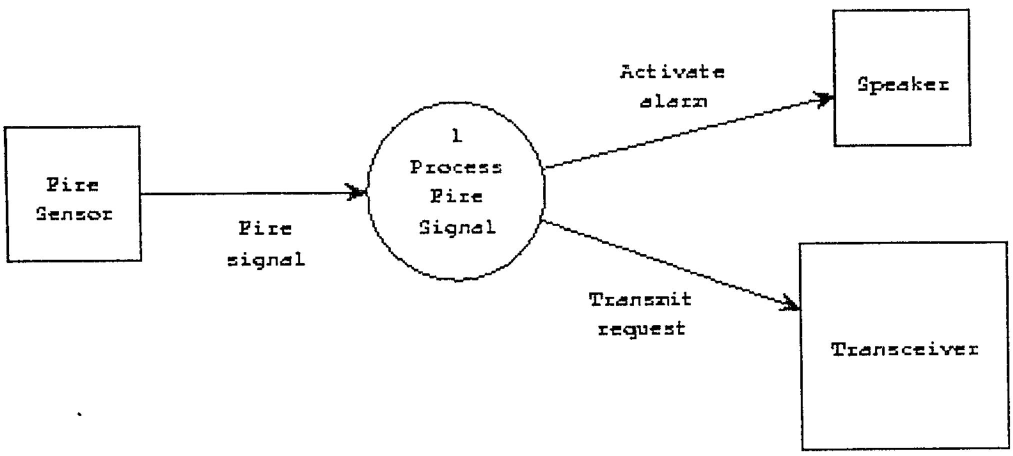


Figure 1.1 Data Flow Diagram of Fire Alert function

There are several types of sensors in the market; our main concern here is to discuss Wireless sensors, such sensors are given in appendix A1.

1.2 Wireless sensor networks

Wireless sensors networks applications fall into three main application classes namely: environmental data collection, security monitoring, and sensor node tracking. This thesis tackles the subject of security monitoring in particular it studies the survey of an environment with cameras. Usually such networks are designed and used for special military applications, for example; survey of any zone of interest or a battlefield.

Wireless Sensors Networks are designed to be self-organizing in the sense of establishing and maintaining their own network without the need for specialist operators. Long periods of autonomous operations in remote environments will need battery or other renewable energy sources. In order to prolong battery life, all node hardware and software functions need to be designed to **consume minimal power**. In general, a node will spend energy on local processing of sensor data to produce compressed information in order to reduce communications. These network systems are intended to support large numbers of such nodes to cover large geographic areas.

An optimum design can be accomplished by determining the best sensors for particular applications, constructing low power signal processing algorithms and using robust and low power network protocols.

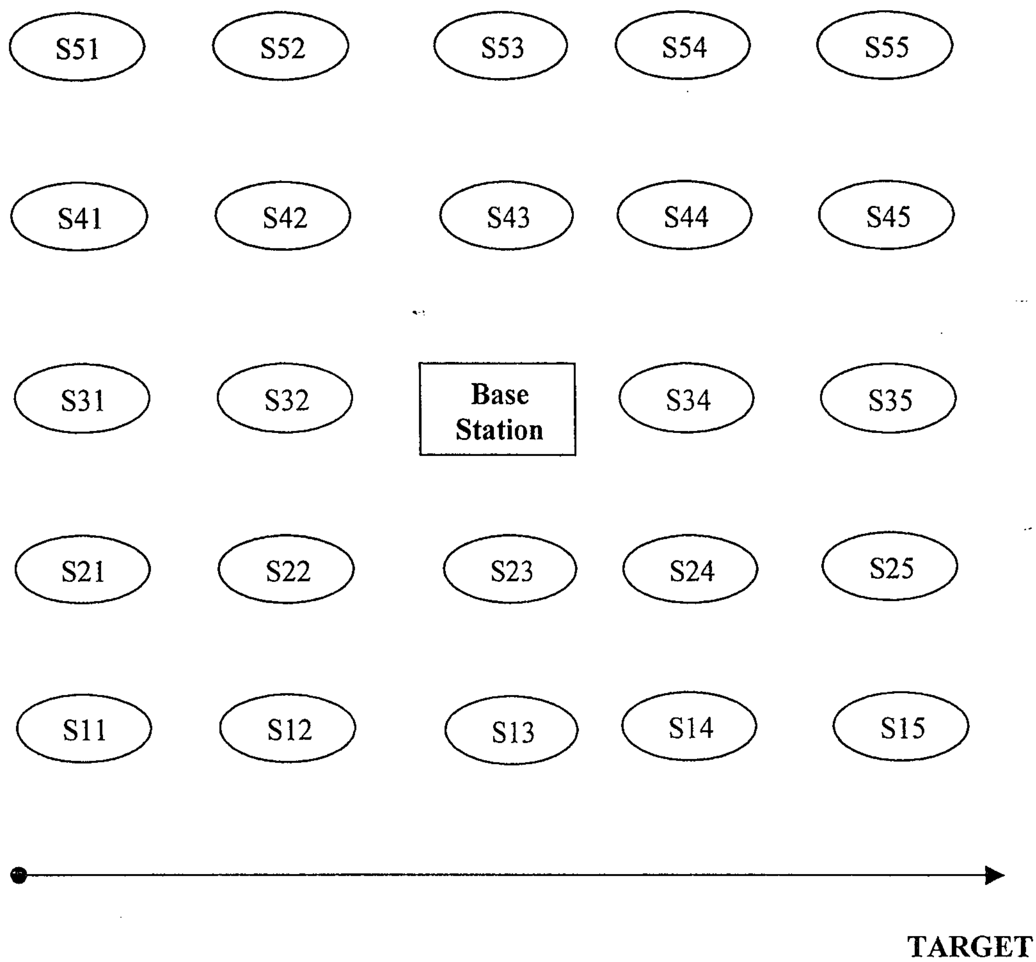
1.3 System requirements

Wireless sensor networks for security monitoring are composed of sensor nodes that are placed at different locations throughout an environment to continually monitor and detect an anomaly in the system. Each node has to frequently check the status of its sensor but it only has to transmit a data report when there is a security violation. The immediate and reliable communication of alarm messages is the primary system requirement. Additionally, it is essential that it is confirmed that each node is still present and functioning. If a node were to be down, it would represent a security violation that should be reported. For security monitoring applications, the network must be configured so that nodes are responsible for confirming the status of each other. Hence an acknowledged communication system is a must here.

The majority of the energy consumption in a security network is spent on meeting the strict delay requirements associated with the signaling of an alarm when a security violation occurs. Once detected, a security violation must be communicated to the base station immediately. The latency of the data communication across the network to the base station has a critical impact on application performance. In fact, alarm situations should be reported within seconds of detection. This means that network nodes must be able to respond quickly to requests from their neighbors to forward data. Response time analysis is a major issue of this research.

1.4 Problem Definition

As mentioned earlier we analyze in this thesis the problem of monitoring an environment using wireless sensor networks with the use of cameras. Each node in the network takes pictures of its surrounding area, compresses each image using JPEG compression, and transmits the data to its parent in the network. While each leaf node only transmits its own images, a parent node must also transmit the images of all of its descendents. Hence, a high-level node with many children, grandchildren and great-grandchildren is responsible for transmitting a large amount of data. The nodes closest to the base station (and highest in the routing tree), will have the most data to transmit and will quickly exhaust their available energy. After the highest-level nodes have been depleted, useful information can no longer reach the base station.



Figures1.2 Example of a set of sensors around a Base Station

So the Problem here is to develop a procedure that could save the power consumed in the nodes and enable the information to reach the central controller before the mobile target reaches its destination. We will assume that our system consists of a wireless distributed micro sensor network where every communicating node incorporates the following:

- One or more sensors for measuring the environment.
- A processing capability in order to process the sensor data into "high value" information and to accomplish local control.
- Special routing schemes optimized for minimal power consumption.
- A radio transceiver to communicate information to/from neighboring nodes.

- Each sensor has limited radio range and is only capable to communicate with neighboring nodes
- A sensor consumes about one unit of power per day if it is self-functioning, one unit of power if it is processing data, two units of power if it is transmitting and two units of power if it is receiving.

1.5 Research objectives

The key evaluation metrics of wireless sensor networks for mobile target tracking are lifetime, response time, temporal accuracy and effective sampling rate. The main objective of this research is to propose an optimum strategy that can find a compromise among all these constraints.

Lifetime

A Critical parameter in our system is the expected lifetime. The goal of our design is to have nodes placed out in the field, unattended, for months or years. The most significant factor in determining lifetime of a given energy supply is radio power consumption. In a wireless sensor node the radio consumes a vast majority of the system energy. This power consumption can be reduced through decreasing the transmission output power or through decreasing the radio duty cycle where a sensor is put to sleep for a good proportion of its operational time.

Response Time

Particularly in our system, system response time is a critical performance metric. An alarm must be signaled immediately when an intrusion is detected. Despite low power operation, nodes must be capable of having immediate messages communicated across the network as quickly as possible. The ability to have low response time conflicts with the techniques used to increase network lifetime. Network lifetime can be increased by having nodes "on" for brief periods of time. If a node only turns "on" once in a while to transmit and receive data, it would be impossible to meet the application requirements for response time of a security system. A compromise will be found here to meet both requirements.

Temporal Accuracy

In our system, samples from multiple nodes must be cross-correlated in time in order to determine the nature of phenomenon being monitored. The necessary accuracy of this correlation mechanism will depend on the rate of propagation of the phenomenon being monitored.

Effective Sample Rate

In addition to the sample rate of a single sensor, we must consider here the impact of the multi-hop networking architecture since in a data collection tree, a node must handle the data of all of its descendents. If each child transmits a single sensor reading and a node has a total of 10 descendants, then it will be forced to transmit 10 times as much data. Additionally, it must be capable of receiving those 10 readings in a single sample period. This multiplicative increase in data communication has a significant effect on system requirements. A maximum bit rates of 250 Kbps (a typical value for a given channel in wireless sensor networks) will impact the effective per-node sample rate of the complete system.

One mechanism for increasing the effective sample rate is to use in-network processing. Various forms of compression can be used to reduce the communication bandwidth required while maintaining the same effective sampling rate. Additionally local storage can be used to collect and store data for short periods of time. In-network data processing can be used to determine when a critical event has occurred and automatically trigger data transmission. The data can then be relayed over the multi-hop network as bandwidth allows.

1.6 Approach

Our main objective is to design a system that allows useful information to reach the base station before the parent sensors exhaust their available energy. This is done by designing a proper control of the system that ensures that the peak power is rarely required. An essential capability of the wireless sensors devices is that they can be put into idle or sleep modes under low-level software control to increase the system operational lifetime.

Our main interest in this thesis is to find a possible solution for the problem of surveying a battlefield. For military applications these low-cost, integrated wireless sensor nodes can be rapidly deployed by air over remote regions to monitor vehicles and personnel movements, and to relay the findings back to the command center on a real-time basis. This problem will be solved by taking into consideration, the arrival rate of the vehicles, the speed of the vehicles, the data processing rate of the sensors, the data transmission rate between neighboring sensors, the data transmission power consumption, the data receiving power consumption, and the data processing power consumption.

In particular we are trying to find in this thesis how much a parent sensor must wait after receiving data from several child sensors before it decides to transmit it to the grandparent sensors. We are trying here to conserve power consumption and minimize response time while taking into consideration the speed of the moving target.

In other words, we aim to find from how many child sensors should a parent sensor collect data before forwarding it to a higher level, knowing that transmission and reception consume more energy than processing and having to fulfill all the real-time constraints of the system. We mean by Real-time constraint the temporal consistency i.e. the information should quickly reach the base station before the vehicle reach its target, otherwise the information will be obsolete.

1.7 Thesis Organization

This thesis is composed of four chapters. In chapter two we will present an overview of what has been proposed in the literature as procedures, protocols and improved hardware devices to reduce nodes power consumption. In chapter three, we will present our own approach to reduce power consumption while taking into consideration all the other constraints in the system. Finally Chapter 4 gives a summary of the main results and provides possible extension of the current research.

CHAPTER 2

Background and Motivation

2.1 Introduction

Wireless Sensor Networks is fairly another unsolved area of work. Sometimes called also Distributed micro-sensor networks, built from collections of nodes each having the ability to sense their environment, process the raw sensor data in cooperation with other neighboring nodes into information and then communicate that information to end users.

In most envisioned applications, wireless communications are the most practical means of interconnection, eliminating the inter-node cabling. Long periods of autonomous operations in remote environments will need battery or other renewable energy sources.

In order to prolong battery life, all node hardware and software functions need to be designed to consume minimal power. Such networks are finding applications in both the military and commercial arenas, and several researches have been done to improve and prolong the system lifetime.

Before giving the detailed description of our work in chapter three, a description of the existing and previous work is given next in this chapter.

2.2 Location –centric computing

The location-centric computing approach [4] is based on the observation that detection, location, and tracking requires collaboration among devices in a certain area or region and not among an arbitrarily specified set of devices. In this approach, a device ceases (begins) to participate in an ongoing collaboration if it leaves (enters) the corresponding defining region.

To efficiently support this approach "Parameswaran Ramanathan et al" proposed a network application programmers interface called UW-API. In UW-API, geographic regions play the role of a node in the traditional network interface. In particular, the nodes/devices are not individually addressable in UW-API. Instead, the programmer creates entities called *regions*, which are then addressable in the communication primitives.

A region in UW-API represents a rectangular geographic area [4]. It is assumed that each device is aware of its geographic location and the regions to which it belongs. Within each region, an area is designated as a *manager sub-region*. Devices in a region participate in the information exchange and collaboration signal processing activities of that region.

In addition to primitives for creating and deleting regions, UW-API has primitives for sending task and information to regions, receiving task and information from regions, and aggregating information within a region. These primitives are supported by an underlying location-aware routing scheme called UW-routing. The routing scheme is bandwidth efficient in delivering information from one region to another.

2.3 STEM (Sparse Topology Energy Management).

The goal by STEM is that the communication protocols must be designed such that the energy consumed by the radio is as small as possible.

In STEM, they optimize power consumption by taking into consideration the radio characteristics and the time to transition from one mode to another

The protocol in [1] is as follows. Each node is assumed to be equipped with two radio transceivers – one for data transfer and one for control. Let us suppose that a node A has sensed an event and wants to transfer some data to node B (which is an intermediate node on the path to a base station). Prior to the data transfer, the link between A and B must be established, i.e node A must wake-up node B as shown in Figure 2.1.

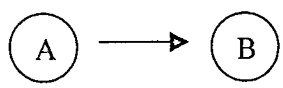


Figure 2.1. Node A wants to wake up node B [1].

As the whole concept is reducing power consumption, the STEM protocol does the following: during the period when a node is only in the monitoring state and does not have any data to transmit or receive, the data radio is in sleep mode until a link to a neighboring node is activated through a control message exchange between the node and one of its neighbors. The control radio of a node sleeps most of the time and wakes up periodically in order to listen to possible requests from neighboring nodes.

Node A transmits a series of beacons, and node B alternates between sleep and receive modes, until one of the beacons is captured by node B, upon which B sends an ACK back to A. This completes the link setup process. Note that there is no synchronization assumed between node A and node B.

2.4 The Dynamic Source Routing protocol (DSR)

Mobile users will want to communicate in situations in which no fixed wired infrastructure because it may not be physically possible to provide the necessary infrastructure or because the expediency of the situation does not permit its installation as the case of a the battlefield. For example, a group of emergency rescue workers may need to be quickly deployed after an earthquake or flood. In such situations, a collection of mobile hosts with wireless network interfaces may form a temporary network without the aid of any established infrastructure or centralized administration. This type of wireless network is known as an *ad hoc network.*

If only two hosts, located closely together, are involved in the ad hoc network, no real routing protocol or routing decisions are necessary [5]. In many ad hoc networks, though, two hosts that want to communicate may not be within wireless transmission range of each other, but could communicate if other host between them also participating in the ad hoc network are willing to forward packets for them. For example, if mobile host *C* is not within the range of host *A*'s wireless transmitter and If *A* and *C* wish to exchange packets, they may in this case use the services of host *B* to forward packets for them, since *B* is within the range of *A* and *C*. Here is the need of a routing protocol to manage the whole situation.

The Dynamic Source Routing protocol (DSR) [5] is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes. DSR allows the network to be completely self-organizing and self-configuring, without the need for any existing network infrastructure or administration.

The protocol is composed of the two main mechanisms of "Route Discovery" and "Route Maintenance" [5], which work together to allow nodes to discover and maintain routes to arbitrary destinations in the ad hoc network.

All aspects of the protocol operate entirely on-demand, allowing the routing packet overhead of DSR to scale automatically to only that needed to react to changes in the routes currently in use.

Dynamic source routing protocol offers a number of potential advantages over conventional routing protocols [5] specially that battery power is conserved on the mobile hosts, by not sending the advertisements used by conventional routing protocols and by not needing to receive them since a host could otherwise reduce its power usage by putting itself into "sleep" or "stand by" mode when not busy with other tasks.

2.5 Mitsubishi Electric Research Laboratories (MERL)

MERL [8] is currently working on several technologies that are suitable for wireless sensor networks specially investigating network protocols that help conserve node battery power. Their technique incorporates a node's energy into the cost metric that is computed when determining what route to send packets on. By avoiding nodes that have little reserve battery power the overall lifetime of the network can be extended. This technique has been used to modify the Dynamic Source Routing (DSR) protocol.

In addition to their work on network algorithms, MERL has extensive experience in Ultra-Wide Band (UWB) radio technology [9]. This has considerable promise in that it can reduce the cost of radio communications.

In UWB a series of short baseband pulses are used to communicate information, because communication occurs with baseband pulses no RF components are needed in the receiver, which reduces transceiver cost. Additionally, because of the signal's large bandwidth individual many multipath components are resolvable, this aids in UWB's ability to locate devices [9].

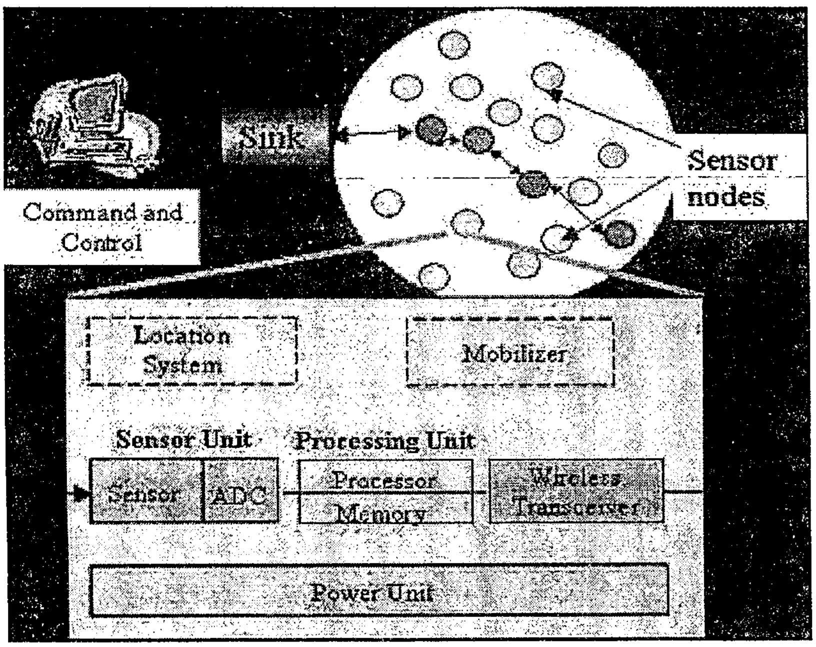


Figure 2.2 MERL wireless sensor network [8]

2.6 Prototype wireless sensor node, "AWAIRS I".

According to the UCLA/Rockwell Science Center Team [7], a sensor node will spend energy on data local processing to produce compressed information in order to reduce communications in a wireless Sensor network. These network systems are intended to support large numbers of such nodes to cover large geographic areas.

The UCLA/Rockwell Science Center team has developed a prototype wireless sensor node, "AWAIRS I," as a development platform to examine many of the issues relating to their design, deployment and usage.

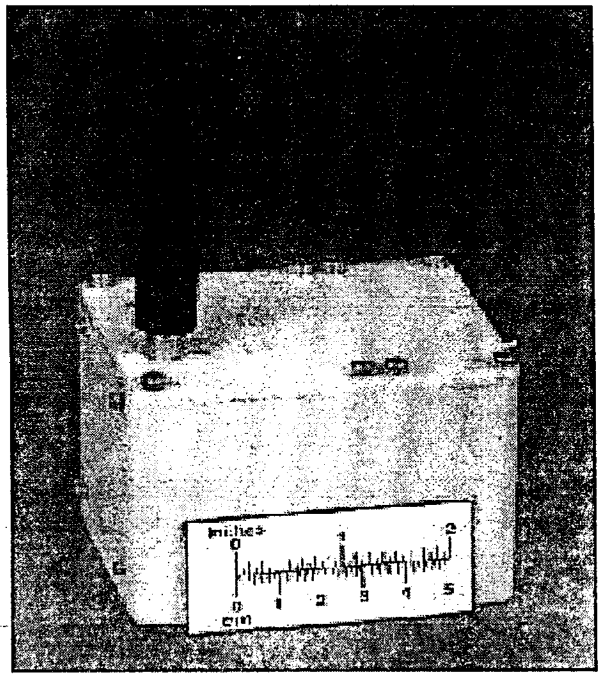


Figure 2.3 Prototype wireless sensor node, "AWAIRS I," [2]

As these networks are designed for low power, embedded signal processing is performed to reduce communication requirements. The sensor nodes are supporting experiments in multihop data communication protocols, dynamic cooperative signal processing and distributed resource management.

The new nodes have a processor, radio; power supply and sensors (seismic, magnetic, acoustic) [2] and they have developed software for the basic communication protocols, and signal processing applications.

2.7 Battery power for wireless sensors

Among the work done to manage power consumption in wireless sensor networks is the development of Batteries specially designed for Wireless sensors. Hybrid lithium batteries are a reliable way to power sensors that require high current pulses to transmit their data.

High current pulse power, combined with low background currents, is typically required when the sensor has three (or more) operating modes [10]:

- Sleep or standby, where battery power consumption ranges from nil to a low background current in the micro amp range.
- Measurement or interrogation, where the unit may require power in the range of a few hundred milliamps.
- Transmission, where the unit may require a few amps before power-down and return to an energy-saving sleep or standby status.

Lithium batteries are the preferred choice for most remote sensing applications because they have the highest specific energy (energy per unit weight) and energy density (energy per unit volume) of all battery types.

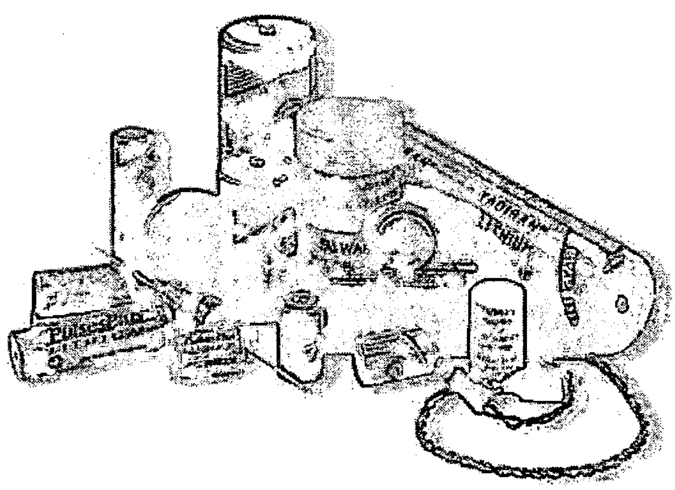


Figure 2.4 Lithium batteries for remote sensing applications.

Bobbin-type lithium thionyl chloride batteries have extremely low self-discharge, enabling them to last up to 20 years in extreme environmental conditions [10].

Lithium cells, all of which use a nonaqueous electrolyte, have nominal open-current voltages of 1.8–3.9 V. They also feature operating temperature ranges of –55°C to 85°C, and some can work at up to 150°C [10].

2.8 Motivation.

Several studies have been done to reduce the power consumption in a wireless sensor network. However very little research tackles the issue of the data propagation and its impact on the intermediate nodes power consumption. That is why we have decided to solve this problem in this thesis. In chapter 3 next, we will present our system in details. In particular we will describe its topology and the way the sensors are distributed. Also we will analyze the issues of power consumption and response time.

CHAPTER 3

Reducing Power consumption

3.1 Introduction

First, in this chapter (section 3.2) we will present the specifications and the assumption taken in our research.

In order to reduce the power consumption in our system we propose in this chapter (section 3.3) to put some of the sensor nodes to sleep ("off" status) and then after a certain fixed period of time to awake them ("on" status).

Also in this chapter (section 3.4), we distribute our sensor nodes into circular levels, where all the levels contain the same number of sensors. In Particular, in section 3.4 we will describe in details the positions of the sensors used, in addition to the mathematical aspect of their Topography.

Section 3.5 describes the routing technique that we have used and finally section 3.6 presents our simulation results.

3.2 Sensor's Specifications

The sensor nodes in wireless sensor networks have a limited energy supply that usually cannot be renewed (due the environmental conditions). As the energy consumption in sensor nodes is dominated by the radio transmission/reception, communication protocols must be designed for economy in radio communications, i.e we must find a way to reduce radio operations and if possible reduce the radio use (transmission and reception).

Thus, the lifetime of a network is constrained by the amount of energy that is spent by the sensor nodes in performing their operation of sensing, processing, and transmitting data to other nodes or to the control centers, or receiving data from other sensors or from the control centers. And as we have mentioned before, the power consumption in sensor nodes is dominated by the radio transmission/reception circuitry. Hence, the communication algorithms must be designed such that the energy consumed by the radio is as small as possible.

Sensor nodes are generally equipped with short-range radios that have various characteristics including

- Data rate of 250 kbps (e.g. Zigbee standard for wireless sensor networks)
- Power consumption in transmit mode
- Power consumption in Receive mode
- Power consumption in process mode
- Time to switch from one mode to another

These parameters can have significant effects on the performance of communication protocols in low energy sensor networks

In our system we will use a sensor with the following specification:

A Radio range of 5 m (Zigbee specifies this range between 1 to 100 m). In this case, a sensor can sense anything that moves in a distance of 5 meter around it.

Now, if a Sensor node detects 1kg of iron, it will process the data captured and sends it in a Data Packet.

But, if the sensor detects more than 1kg of iron then it will process the data captured and sends it in a picture {graphic packet} (this is done for surveillance reason).

The time needed to process a packet in a sensor is given by:

- Processing time of data type packet is 0.01 s
- Processing time of graphic type (picture) Packet is 0.1 s

The time taken by the Radio transmission of a data type packet between one node and another is 0.01s. While the time taken by the Radio transmission of a Graphic type packet between one node and another is 0.1s

Finally, different amount of energies are consumed by a given sensor, depending on its mode of operation. This is explained in the following table:

		Mode		
		Process	Transmit	Receive
Type of Data	Data	10 mw	20 mw	20 mw
	Picture	50 mw	100 mw	100 mw

3.3 Physical design

In our design, we will assume that the Wireless sensor network we are analyzing is composed of a large number of small sensor nodes and one "base station" the main job of this base station is to process the data received from the sensor nodes and to take necessary control actions.

In order to increase the longevity of our network and to save energy in the nodes we adopt the following:

First, at the network topology level, the routing tree should be transformed to reduce power consumption; especially at the level of the highest nodes. In the routing Data compression can be parameterized for different data qualities and compression tree.

Second, parents could use Processing Techniques to aggregate Data from their children into a single Data or could use filtering to selectively forward only interesting Data.

Third, Some sensors in a particular neighborhood (especially at the level of the highest nodes in the routing tree) can remain "off" mode, meanwhile other sensors at the same level are "on" mode, until the base station commands a group of nodes to switch their mode (or by using internal time scheduling, already in the sensor's memory).

Fourth, increase the density of sensors that are near the base station.

So as we can notice from what is specified above, an important part of the concept behind our design this is a topological and logical concept. Of course we need to take into consideration all the criteria mentioned and specially the radio range of the used sensors.

The networks we are designing here are typically used for monitoring and surveillance functions. A sensor node collects data from its environment, and then the data is processed by the node and broadcast to the base station.

The data transmission phase involves sending the data through other sensor nodes that act as intermediate nodes in a multi-hop network.

3.4 System design and Geographical aspect

We will divide the area of interest (surveyed area) into sub areas (we will call them Windows), each sub area or window is an essential part of the whole network, each window is totally independent (specially in terms of power) from the other windows and every window have its own base-station.

So each window contains a set of sensors. These sensors (of the same window) can easily communicate with their parent sensors following a special algorithm that we will discuss later. So each child must transmits data to its parent in the network until this data reaches the base station

Each Window can easily communicate with its neighboring window through their base stations till arriving to the central Base station.

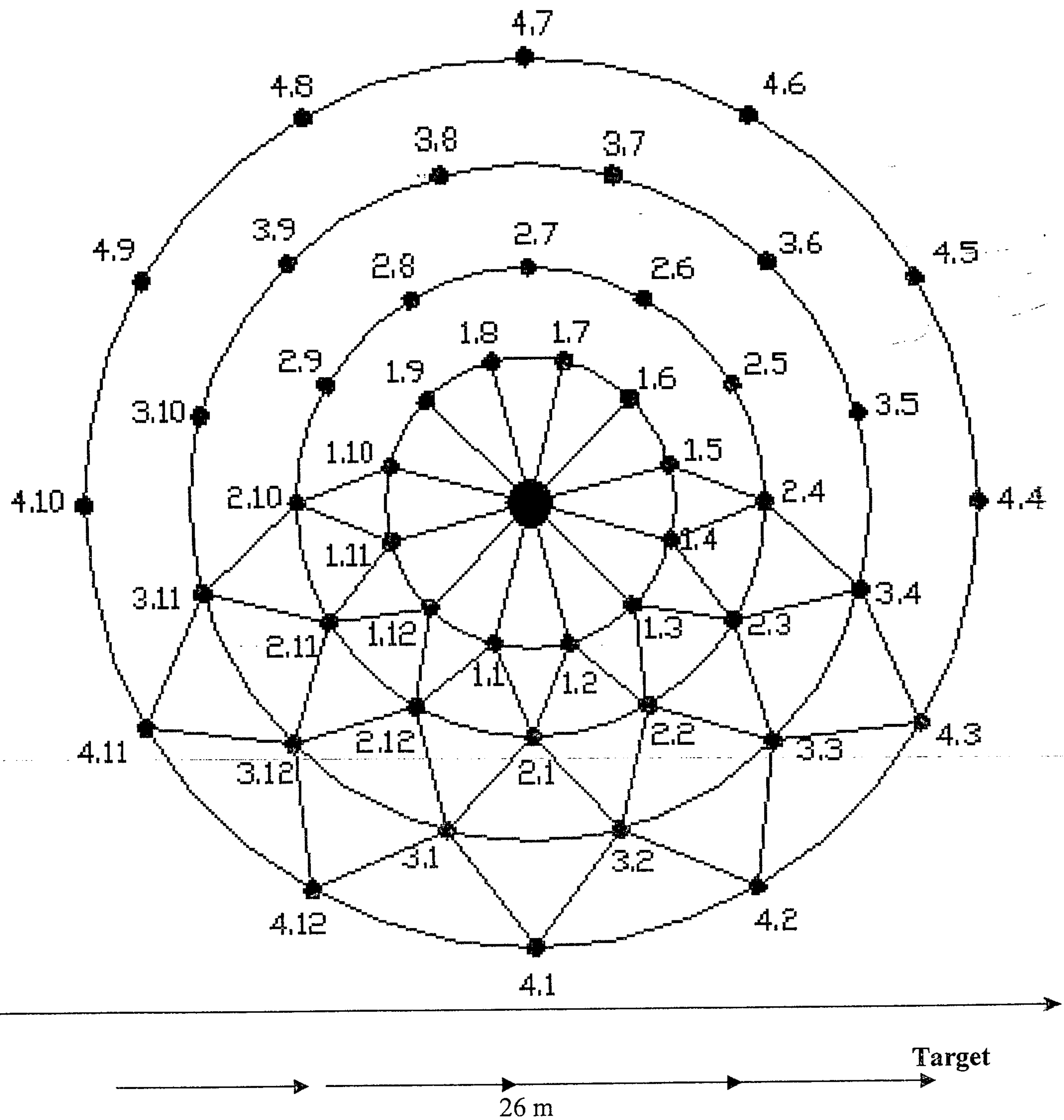


Figure 3.1 Window of nodes where the center represents the Base station

As explained earlier, the radio range of every sensor is 5 m. we shall consider that the distance between 2 Sensors of level 4 is 6.75 m. Therefore, 2 neighboring sensors of level 4 will not interview with each others.

3.4.1 System design and mathematical aspect:

The system is designed in such a way that a sensor of a given level n can only communicate with 2 sensors on level n-1, (respecting the radio range), where n is decreasing when we approach the base station.

Next we calculate the radius of the different levels of sensors.

The distance between a sensor of a level two and the 2 sensors that this sensor can communicate with on a prior level should be smaller than the maximum range R=5. We assume that R_1 which is the radius of the first level is equal to R i.e 5 m we have:

$$\sqrt{(R_2 - R_1 \cos \pi / n)^2 + R_1^2 \sin^2 \pi / n} < R_1$$

$$\Rightarrow R_1^2 + R_2^2 - 2R_1R_2 \cos\pi / n < R_1^2$$

$$\boxed{\Rightarrow R_2 < 2R_1 \cos\pi / n}$$

The same for the third and fourth circles:

$$\boxed{R_2^2 + R_3^2 - 2R_2R_3 \cos\pi / n < R_1^2}$$

$$\boxed{R_3^2 + R_4^2 - 2R_3R_4 \cos\pi / n < R_1^2}$$

For example:

Sensor 2.1 can only communicate with sensors 1.1 and 1.2

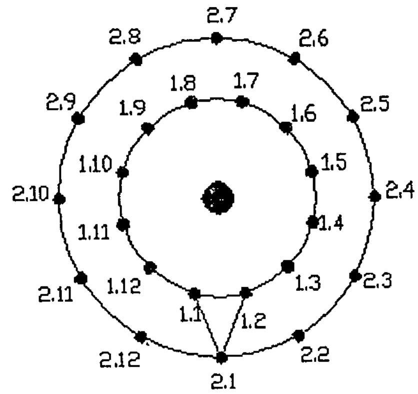


Figure 3 2 Distance between a sensor of level 2 and the 2 sensors of level 1 that this sensor can communicate with

Now, since we plan to switch off a sensor if its direct neighbors is on the Distance between 2 even sensors or between 2 odd sensors on the same circle should be larger than the radio range i.e larger than R_1

This gives:

$2 R_1 \sin (2 \Pi / n) > R_1 \Rightarrow \sin (2 \Pi / n) > 0.5$

$2 R_2 \sin (2 \Pi / n) > R_1 \Rightarrow R_2 > R_1 / 2 \sin (2 \Pi / n)$

$2 R_3 \sin (2 \Pi / n) > R_1 \Rightarrow R_3 > R_1 / 2 \sin (2 \Pi / n)$

$2 R_4 \sin (2 \Pi / n) > R_1 \Rightarrow R_4 > R_1 / 2 \sin (2 \Pi / n)$

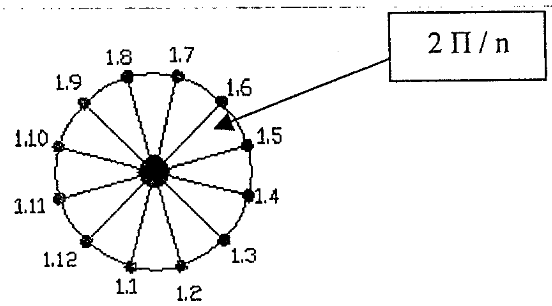


Figure 3.3 Nodes of the same level

The above conditions are fulfilled when n = 12

So a given window is made of the following n numbers of sensors and one base station.

- We have 4 levels of sensors where every level is represented by a circle

- The number of sensors on each level is 12 (see figure 3.1)
- The radius of the first level, R_1 is equal to the maximum radio range, i.e $R_1 = 5m$.

The previous calculations gave us the following values for the radius of the different levels. We have:

- The radius of the second level, $R_2 = 9$ m.
- The radius of the third level, $R_3 = 12$ m.
- The radius of the fourth level, $R_4 = 13$ m.

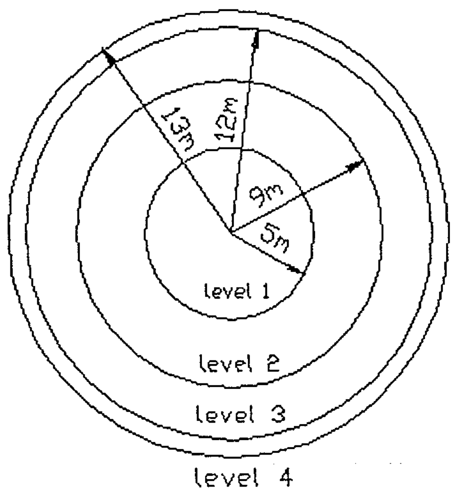


Figure 3.4 Distance between the levels

3.5 Routing technique and system analysis

We shall consider that sensors of the same level can be either "On" or "Off" states. Also we shall consider that odd labeled sensors (of the same level n) are "on" simultaneously and "off" simultaneously, even labeled sensors (of the same level n) are "on" simultaneously and "off" simultaneously.

Additionally, while odd labeled sensors of the same level are "on", all the even labeled sensors of the same level are "off".

The nodes of levels 3, 2, and 1 change their mode of operation (i.e switch between "on" and "off") every 1 s, except the sensors of the forth level, they are always "on" because they are monitoring the ground.

When a sensor node sends data to a higher-level sensor the "On" sensor will catch the signal and must transmit it to its parent until this message reaches the base station.

When a sensor receives a signal it must send back an acknowledgment to the sender node immediately, if the acknowledgment is not received, that means that the destination sensor didn't receive anything, and the sender sensor must retransmit its data again.

3.5.1 Communication tree

The following tree describes which sensor communicates to which other sensors in the system.

Please note that all the sensors of level 1 can directly communicate with the Base Station since the base station is within their range of radio coverage.

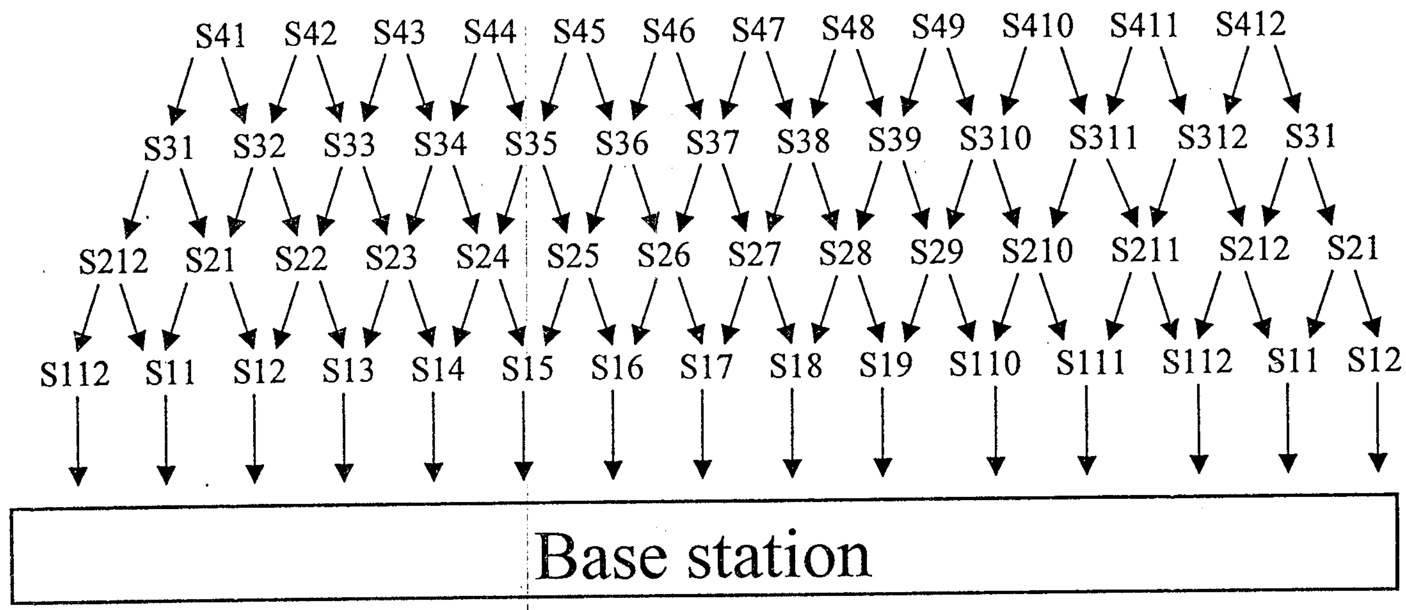


Figure 3.5 Communication tree

3.5.2 System response time

In this paragraph we calculate the system response time i.e the speed of propagation of the data through the network to reach the base station.

The total time taken by the data to arrive to the base station is given by:

$$T_{Total} = T_{Total\ processing} + T_{Total\ communication}$$

Now if we consider that the data will not be processed by the intermediate nodes, and these nodes will only relay these messages to their parents {packet with Priority header}. In this case we have:

$$T_{Total} = T_{Processing\,(level4)} + 4 * T_{Communication(one\ level\ to\ another)}$$

As numerical example we have:

Data Packet type, $T_{Total} = 0.01 + (4 * 0.01) = 0.05\,s$

Graphic Packet type, $T_{Total} = 0.1 + (0.1 * 4) = 0.5\,s$

Now we assume a level 4 sensor captures a target moving at a low speed. In order to save energy, a level 3 node will wait for less than 1 sec (before status switch) to check if it receives the same information from another node of level 4, before forwarding these messages into one single message instead of two.

In that case the Time taken by the data to arrive to the Base station is given by:

$$T_{Total} = T_{Processing\,(level4)} + T_{Processing(level3)} + \text{waiting time} + 4 * T_{Communication(one\ level\ to\ another)}$$

i.e in the case of a data packet type, we have:

$T_{Total} = 0.01 + 0.01 + 1 + 4 * 0.01 = 1.06\,s$ (Max time)

While in the case of a graphic packet type, we have:

$T_{Total} = 0.1 + 0.1 + 1 + 4 * 0.1 = 1.6\,s$ (Max time)

Please note that the packet will wait at most 1 s in the third level sensor. Hence the time can varies actually between 0.05 s and 1.06 s for a data packet type, and between 0.5 s and 1.6 s for a graphic packet type.

3.5.3 Consumed energy in the network

The amount of energy consumed by a Forth level node is:

$$\mathbf{E}_{\mathbf{Level4}} = \mathbf{E}_{\mathbf{Process}} + \mathbf{E}_{\mathbf{Transmission}} + \mathbf{E}_{\mathbf{receive ack}}$$

Numerical examples:

In case of data, $\mathbf{E}_{\mathbf{Level4}} = 10 + 20 + 20 = 50$ mw

In case of graphic, $\mathbf{E}_{\mathbf{Level4}} = 50 + 100 + 20 = 170$ mw

The amount of energy consumed by a third level node is:

$$\mathbf{E}_{\mathbf{Level3}} = \mathbf{E}_{\mathbf{receive packet}} + \mathbf{E}_{\mathbf{send ack}} + \mathbf{E}_{\mathbf{send packet}} + \mathbf{E}_{\mathbf{receive ack}}$$

Numerical examples:

In case of data, $\mathbf{E}_{\mathbf{Level3}} = 20 + 20 + 20 + 20 = 80$ mw

In case of graphic, $\mathbf{E}_{\mathbf{Level3}} = 100 + 20 + 100 + 20 = 220$ mw

This is the same for the Second level, i.e Energy consumed is equal to 80 mw in case of data packet and 220 mw in case of graphic packet.

For the first level, it is also 80 mw in case of data packet and 220 mw in case of graphic packet.

Hence, the total amount of energy consumed by a packet while crossing the network to the Base Station is:

$$\mathbf{E}_{\mathbf{total}} = \mathbf{E}_{\mathbf{level4}} + \mathbf{E}_{\mathbf{level3}} + \mathbf{E}_{\mathbf{level2}} + \mathbf{E}_{\mathbf{level1}}$$

In case of data packet, we have: $50 + 80 + 80 + 80 = 290$ mw

In case of graphic packet, we have: $170 + 220 + 220 + 220 = 830$ mw

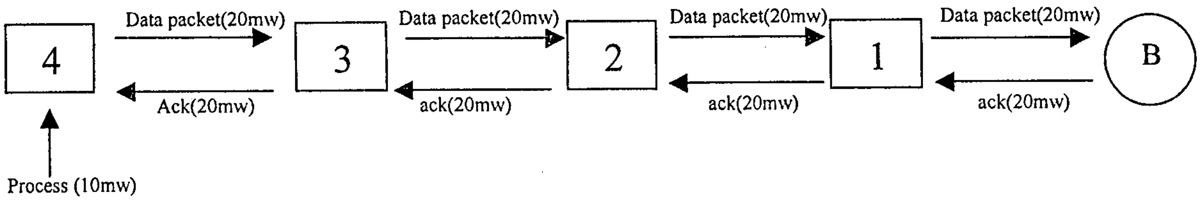


Figure 3.6 Energy consumed by a data packet while crossing the network to the Base Station

Please note, this is applicable if the speed of the captured target is considerably high and hence no processing is done at intermediate nodes.

Low speed vehicles

Now consider the case when the speed of the captured vehicle is very low. In this case processing will be done at level 3. This means a level 3 node will combine several packets to form a new one.

- First assume that a level 3 combines two packets, in this case we have:

$$
\begin{aligned}
E_{Total} = {} & 2 * (E_{Process} + E_{Transmission} + E_{receive\,ack})_{level4} + \\
& 2 * (E_{receive\,packet} + E_{send\,ack} + E_{Process})_{level3} + E_{send\,packet} + E_{receive\,ack} \\
& + (E_{receive\,packet} + E_{send\,ack} + E_{send\,packet} + E_{receive\,ack})_{level2} + \\
& (E_{receive\,packet} + E_{send\,ack} + E_{send\,packet} + E_{receive\,ack})_{level1}
\end{aligned}
$$

Numerical examples:

In case of data type: $E_{Total} = 2 * (10 + 20 + 20) +$

$$
\begin{aligned}
& 2 * (20 + 20 + 10) + 20 + 20 + \\
& 20 + 20 + 20 + 20 + \\
& 20 + 20 + 20 + 20 + \\
= {} & 400 \text{ mw}
\end{aligned}
$$

In case of graphic type: $E_{Total} = 2 * (50 + 100 + 20) +$

$$
\begin{aligned}
& 2 * (100 + 20 + 50) + 100 + 20 + \\
& 100 + 20 + 100 + 20 + \\
& 100 + 20 + 100 + 20 + \\
= {} & 1280 \text{ mw}
\end{aligned}
$$

- Second, assume that a level 3 combines 3 packets, in this case we have:

$$E_{Total} = 3 * (E_{Process} + E_{Transmission} + E_{receive\,ack})_{level4} +$$
$$3 * (E_{receive\,packet} + E_{send\,ack} + E_{Process})_{level3} + E_{send\,packet} + E_{receive\,ack}$$
$$+ (E_{receive\,packet} + E_{send\,ack} + E_{send\,packet} + E_{receive\,ack})_{level2} +$$
$$(E_{receive\,packet} + E_{send\,ack} + E_{send\,packet} + E_{receive\,ack})_{level1}$$

Numerical example:

In case of data type: $E_{Total} = 3 * (10 + 20 + 20) +$
$$3 * (20 + 20 + 10) + 20 + 20 +$$
$$20 + 20 + 20 + 20 +$$
$$20 + 20 + 20 + 20 +$$
$$= 500 \text{ mw}$$

In case of graphic type: $E_{Total} = 3 * (50 + 100 + 20) +$
$$3 * (100 + 20 + 50) + 100 + 20 +$$
$$100 + 20 + 100 + 20 +$$
$$100 + 20 + 100 + 20 +$$
$$= 1620 \text{ mw}$$

Now let us summarize the numerical results in the following 2 tables:

Data type

	No 3rd level Process	3rd level Process	Energy gain
1 data packet	290 mw	290 mw	0 mw
2 data packet	580 mw	400 mw	180 mw
3 data packet	870 mw	500 mw	370 mw

Graphic type

	No 3rd level Process	3rd level Process	Energy gain
1 Graphic packet	830 mw	830 mw	0 mw
2 Graphic packet	1660 mw	1280 mw	380 mw
3 Graphic packet	2490 mw	1620 mw	870 mw

3.5.4 Timing and distance constraints

A given sensor in our system can sense anything within a range of 5 m. Then the distance to the Red Zone is 18 m, and the distance to the target is 36 m

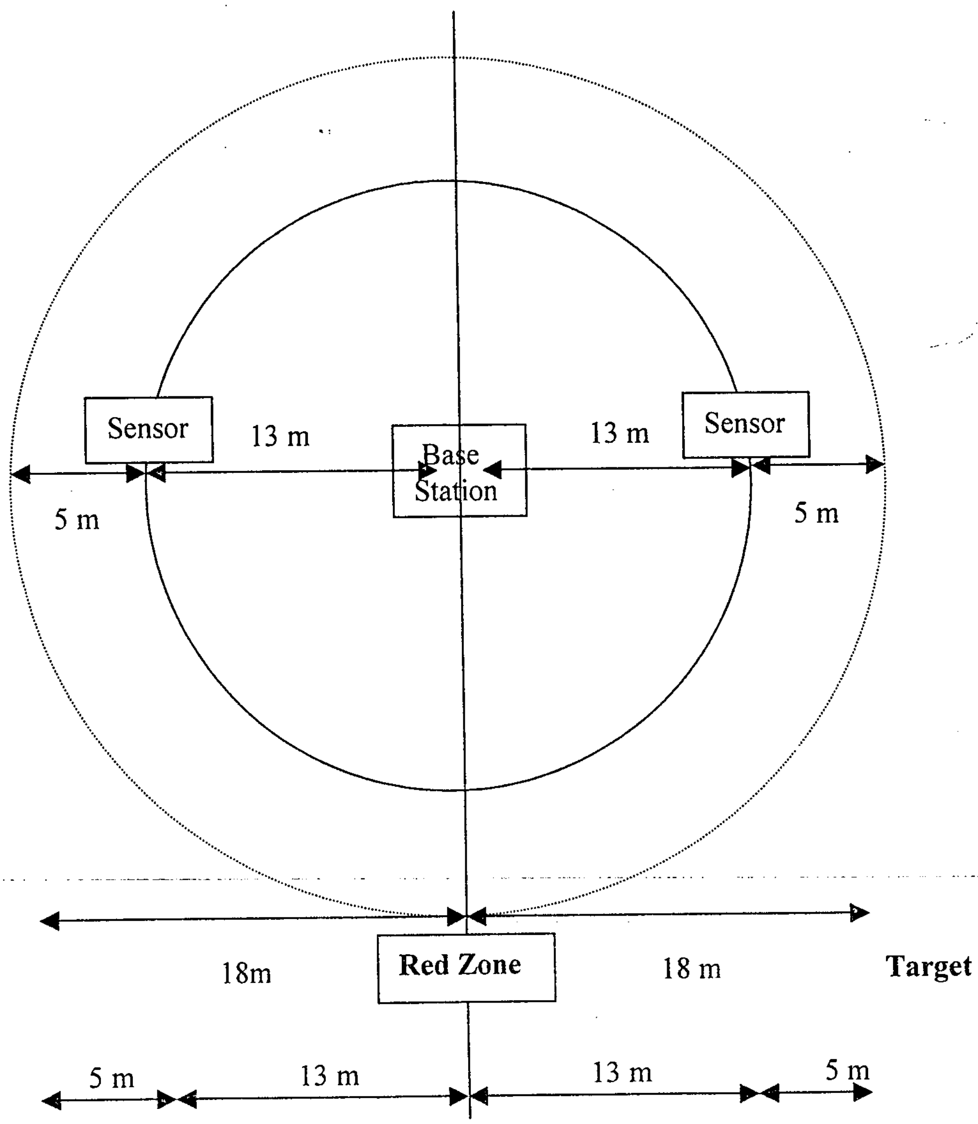


Figure 3.7 The Red Zone and the Target

If a vehicle has a speed of 60km/h i.e 16.66m/s then it needs 1.08 s to reach the Red Zone (16.66m/s = d/t = 18/t $\Rightarrow$ t = 1.08 s). And it needs 2.16 s to reach the target (16.66m/s = 36/t $\Rightarrow$ t = 2.16s)

So if we vary the speed of the vehicle we will have the following numerical values:

	Speed of the vehicle			
	60 km/h	50 km/h	40km/h	30 km/h
Time to reach the red zone	1.08 s	1.29 s	1.62 s	2.16 s
Time to reach the target	2.16 s	2.59 s	3.24 s	4.32 s

Hence, the speed of the captured vehicle is the criteria upon which we will decide to forward directly the data to the base station or to make a 3rd level processing. In fact we will consider the critical time, the time to reach the red Zone.

Therefore, the following algorithm will be used:

If data type
If the speed of the vehicle < 60 km/h
Then 3rd level process
3rd level process: the data must wait for maybe another data packet for 1 sec in node level 3
Otherwise NO 3rd level process: packet directly forwarded to the base Station
End if
End it

If graphic type

If the speed of the vehicle < 40 km/h

Then 3rd level process

3rd level process: the data must wait for maybe another graphic packet for 1 sec in node level 3

Otherwise NO 3rd level process: packet directly forwarded to the base station

End if

End if

3.6 Simulation Results

The results are shown below in form of charts.

A major result we can see here: we managed to save a good percentage of the energy especially when a "level 3" processing is done. However, when his is done, the system response time becomes larger because of the extra waiting time in the nodes.

Chart 3.1 - Energy consumed by transmission of data packets

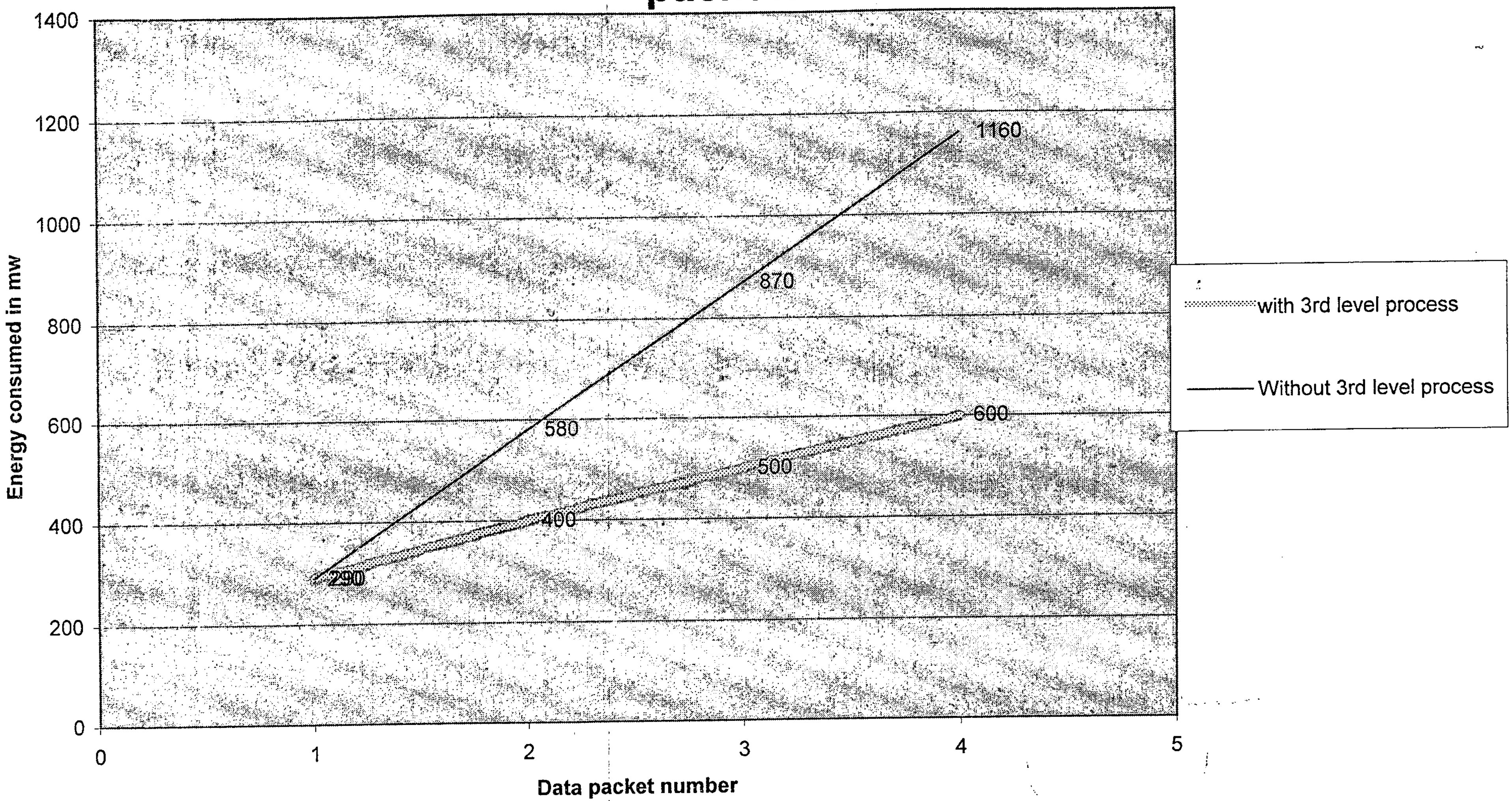


Chart 3.2 - Energy conserved by transmission of Data Packets with 3rd level process

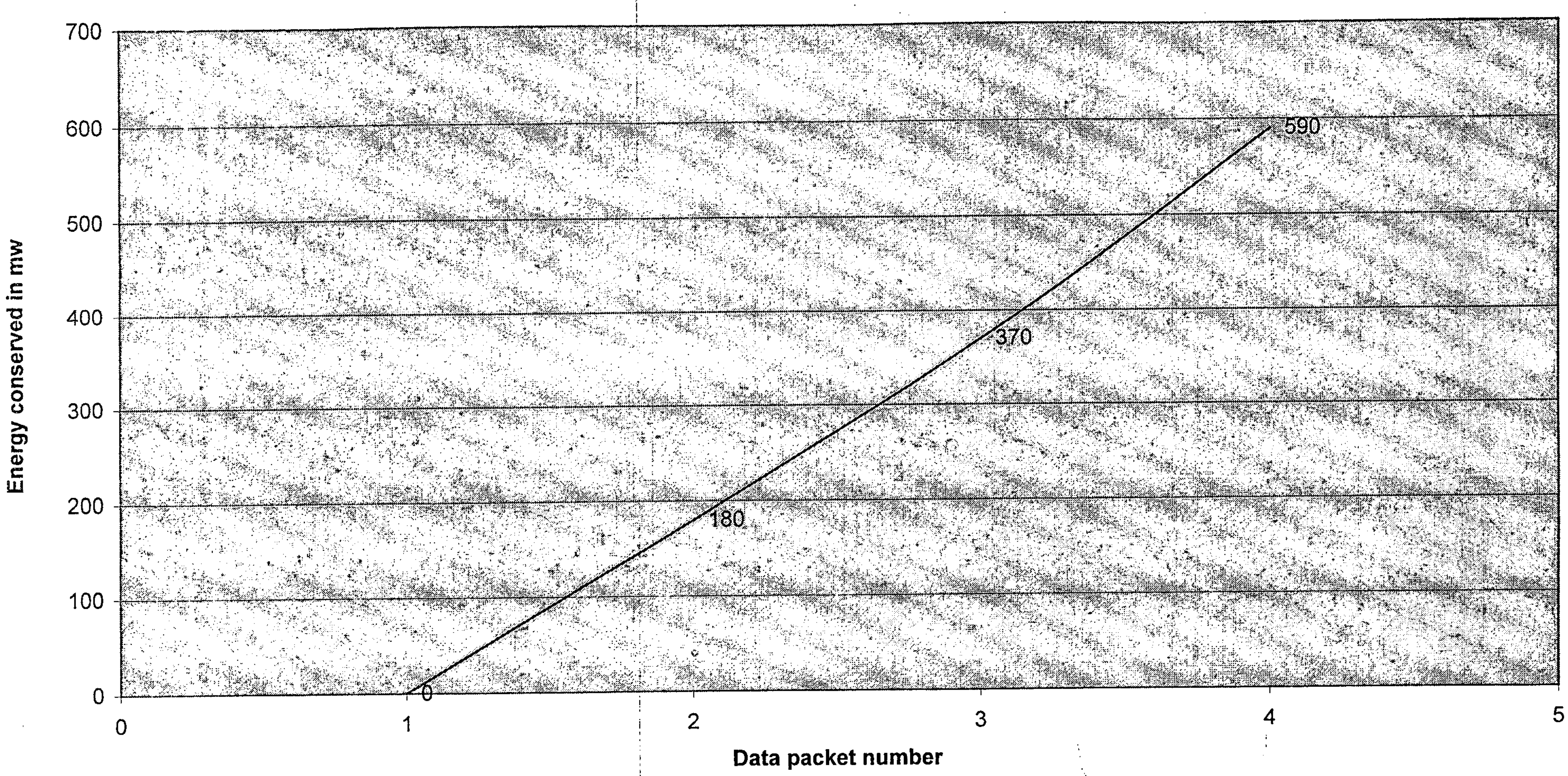


Chart 3.3 - Energy consumed by transmission of Graphic packets

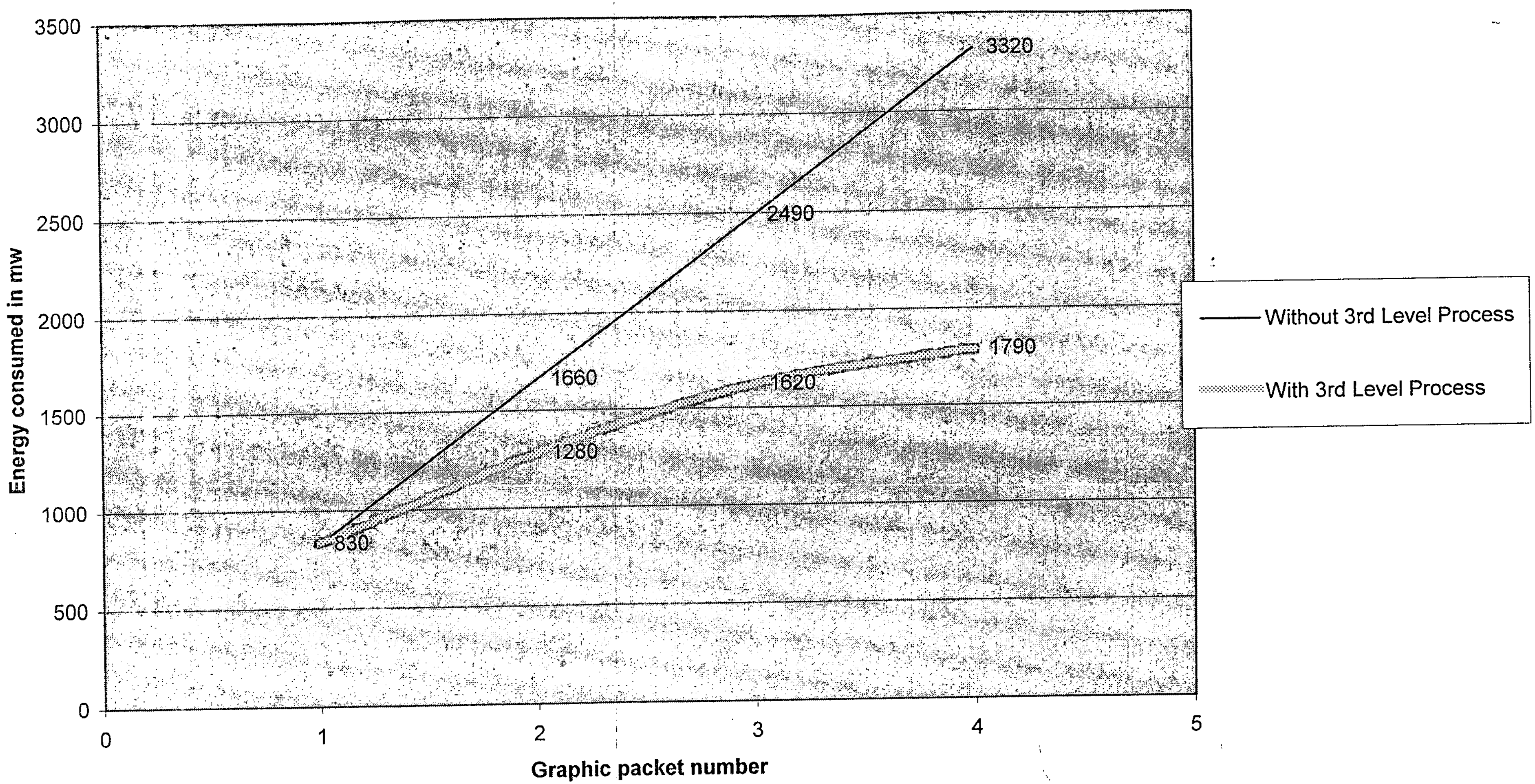


Chart 3.4 - Energy conserved by transmission of Graphic packets with 3rd level process

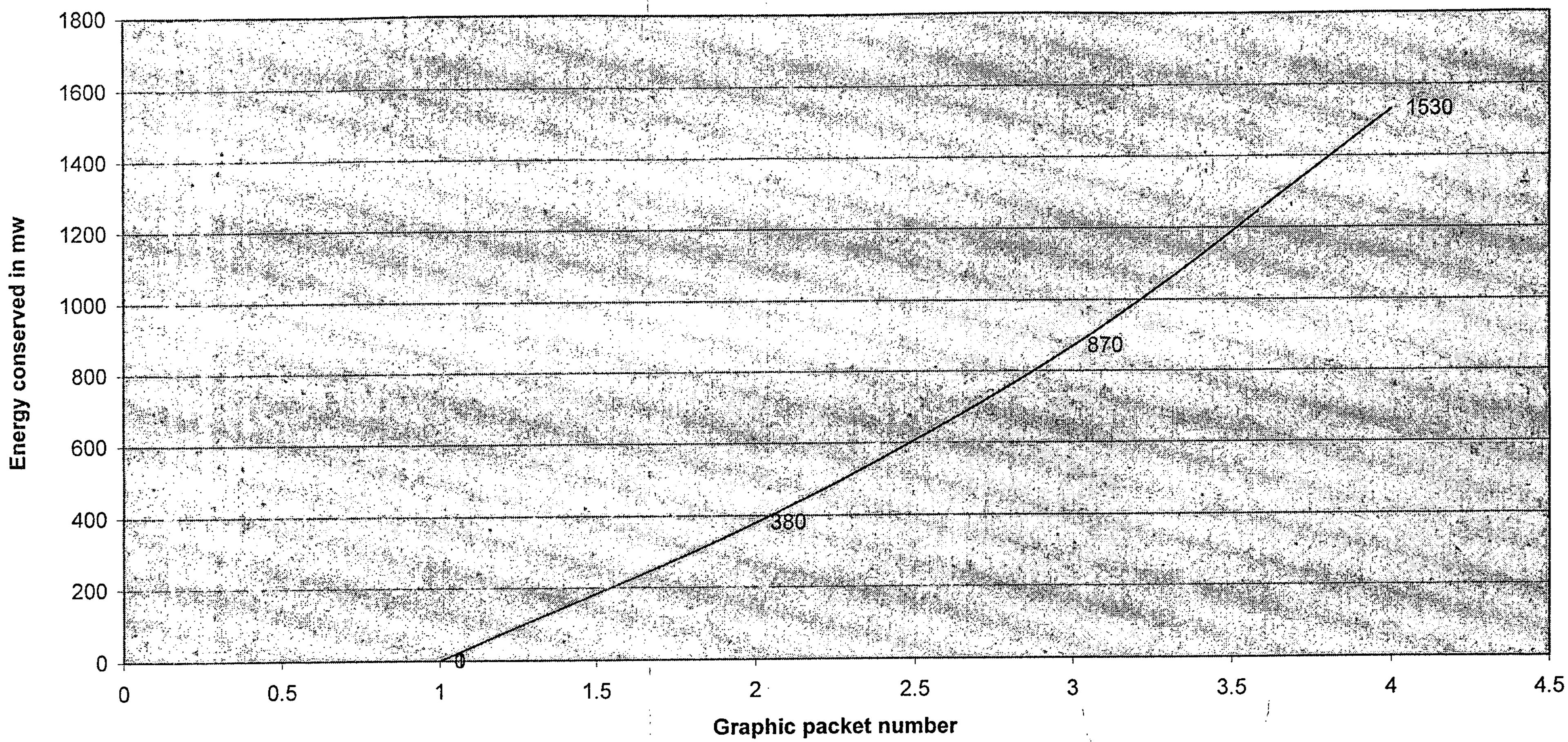
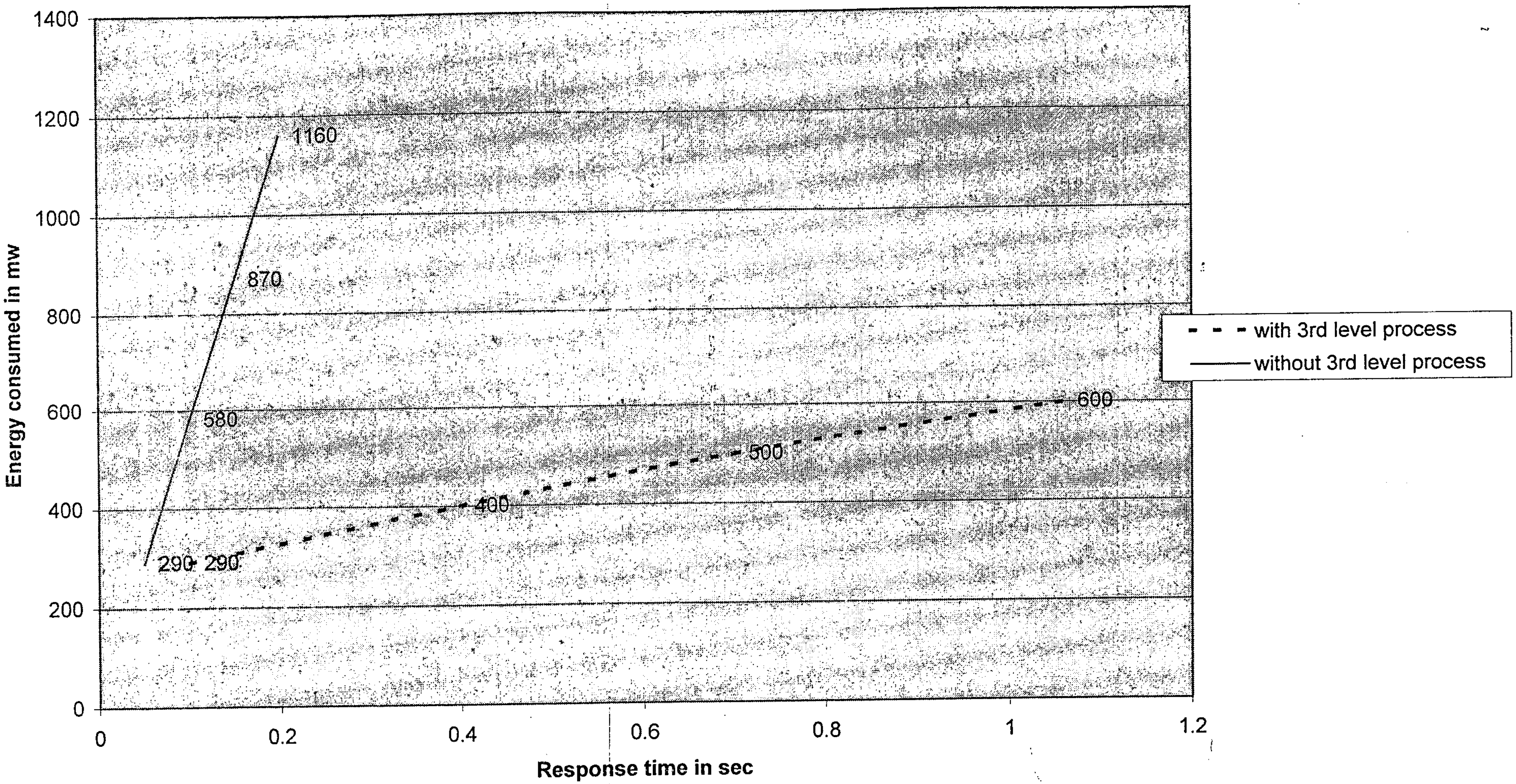


Chart 3.5 - Energy consumed vs. response time



Chapter 4

Summary and future work

4.1 Summary

This thesis proposes a new technique that can be used to reduce power consumption in a Wireless Sensor Network and hence it can increase the lifetime of the sensor nodes. This is done by using a combination of a special routing technique together with a well designed circular topology of sensors.

In fact, to ensure that the packets transmitted are only received by two sensor nodes at a parent level a circular topology distribution is used, where these only two sensor nodes are in the range of the sender node. Moreover, between these two receiver sensors, one of them can receive the information because only one of them can be "ON" (while the other sensor at a given time is "OFF").

Distribution of ON and OFF nodes will affect also the overall performance of the system; a distribution method was discussed in chapter 3 where odd labeled nodes of the same level are "ON" simultaneously (or "OFF" simultaneously). This is the same for even labeled nodes.

Besides that, a suggested processing technique can be applied at the third level of sensors. This method is optional and depends on the speed of the monitored vehicles.

Simulation results proved the efficiency of our proposed methods. This combination of the specialized circular topology with ON/OFF sensor nodes and a possible extra processing at level 3 lead to a decrease in the amount of consumed energy in the system. However our proposal method could increase the system response time. So in the case of slow moving targets our system could be very efficient (this is the case of tanks, and any heavy moving targets or soldiers)

4.2 Future work

In our system packets are sent to an ON/OFF network of sensors, therefore the packets are only received by the "ON" sensors. Another method can be adopted by keeping the sender sensor decides which should be its receiving sensor. The decision can be done after analyzing the Power reserve of its neighboring nodes. This could result in an increase in the lifetime of the system.

Also, in our approach we have considered that the speed to the target vehicle is constant while captured by the sensors. As mentioned earlier, our system is designed to monitor a battlefield where usually the speed of soldiers cannot exceed the 40 km/h and the speed of the tanks cannot exceed 70km/h. But if the speed of the vehicle is not constant and increasing then the time constraints must be reconsidered and maybe another approach will be needed.

Appendix A1

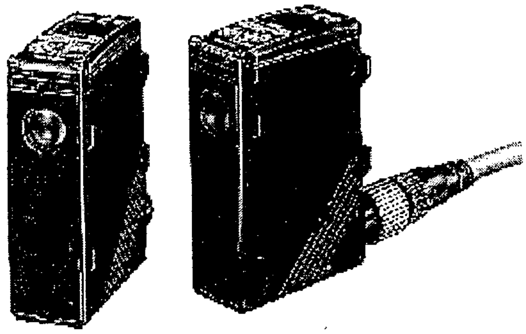
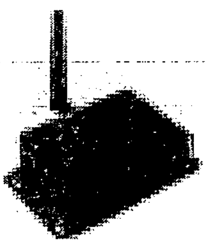


Figure A1 Color Mark Sensor detects yellow-on-white and other difficult color combinations [6]



Sensor Counter/Temperature
418 MHz Digital Counter and Temperature Sensor
The Point Sensor Counter/Temperature wireless transmitter is a battery operated digital counter and temperature sensor with a microprocessor controlled 418 MHz.

Main Features
32-Bit unique ID with 24-bit Digital Counter, 13-bit Temperature, digital input status
Switch for installation and service mode indication
Broad operating temperature range
Up to 600-foot range
Transmission rates from 10 to 240 seconds
Up to 100 transmitters can coexist
Battery lasts from 5 to 10 years
Very small (1.3" X 2.1" X .6") ABS Enclosure
Complies with part 15 of the FCC rules
Water resistant coating on PCB
CRC-16 checked Status, ID, temperature and counter data
Internal Loop antenna

Figure A2 Sensor Counter/Temperature [6]

Appendix A2

"AWAIRS 1" Hardware design.

The hardware in each micro-sensor node uses an open, modular design that allows incorporation of a range of sensors. And it consists of a stack of base circuits comprising the processor, radio and power supply, which are coupled with the desired sensors [2].

Figure 2.3 is a **standard battlefield node**. From the top down the boards are [2]:

- Acoustic Sensor.
- DCT Digital Spread Spectrum Radio module.
- StrongARM Processor module.
- Multiple voltage Power Supply module.
- Seismic Sensor module.
- Mark 4 Products Geophone (seismic sensor).
- 2 standard 9V batteries.

The basic hardware block diagram given the Figure below shows the connectivity and power distribution between the major modules within the system.

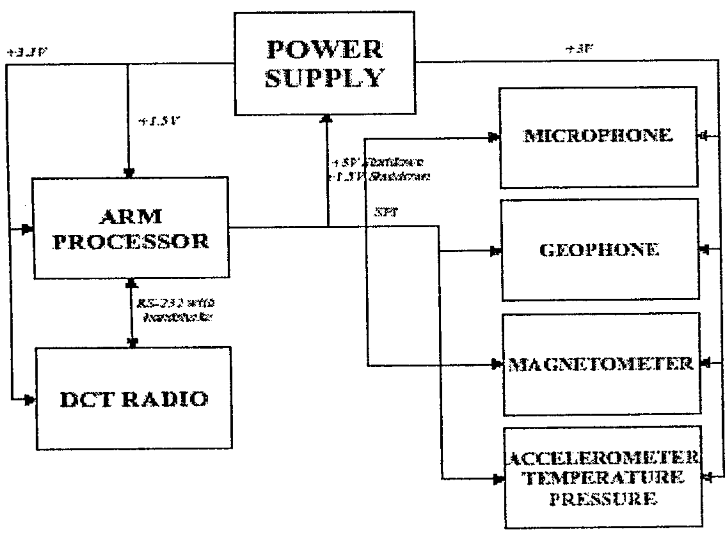


Figure A3 Connectivity and power distribution between the major modules within the system [2].

The tables below summarize the hardware specifications for the modules developed.

Processor Module [2]

Processor	Intel StrongARM 1100 @ 133 MHz, 150 MIPS
Power Dissipation	Max: <300 mW, Typical: < 200 mW, Idle: < 40 mW, Sleep: < 0.8 mW
Memory	128 KB SRAM, 1 MB FLASH memory
GPIO	26 lines
Radio Interface	3 wire RS-232
Sensor Interface	4 wire SPI and USB
External Interface	JTAG, USB, and RS-232

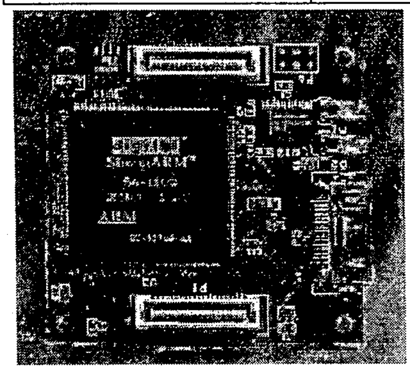
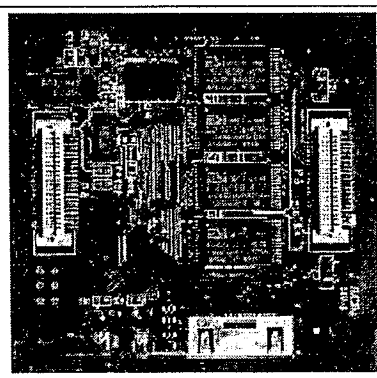



Figure A4 Processor Module Circuit Boards (Front and Back) [2]

Integrated Radio Module [2]

Modem	Conexant RDSSS9M spread spectrum
Data Rate	100 Kbps
RF Power	1 mW, 10 mW, 100 mW
Range	> 100 meters at 100 mW
Frequency	ISM band, 902-928 MH, divided into 40 channels
Controller	Controller Embedded 65C02 microcontroller with 32 KB SRAM and 1 MB bootable FLASH memory
Other	4 bit ADC for battery voltage monitoring

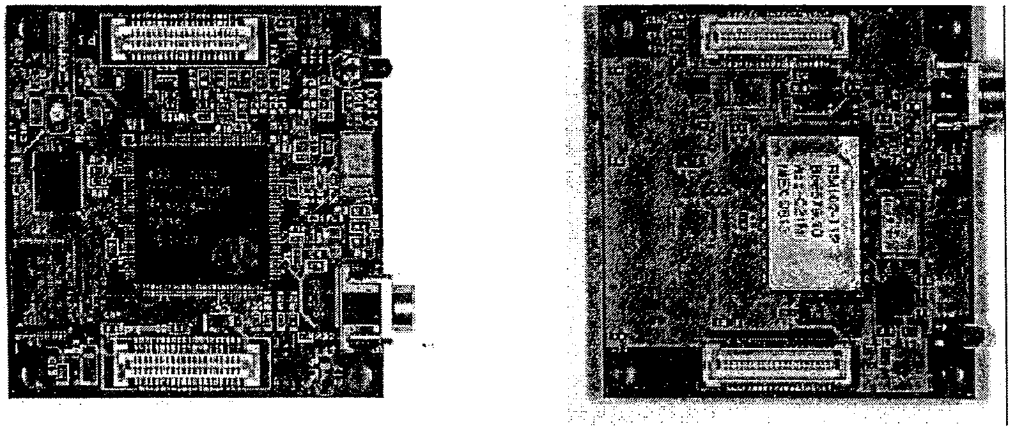


Figure A5 DCT Radio Module [2]

Power Supply Module [2]

Input Voltage	4-15 V
Output Voltages / max Current	1.5 V / 160 mA; 3.0 V / 20 mA; 3.3 V / 300mA

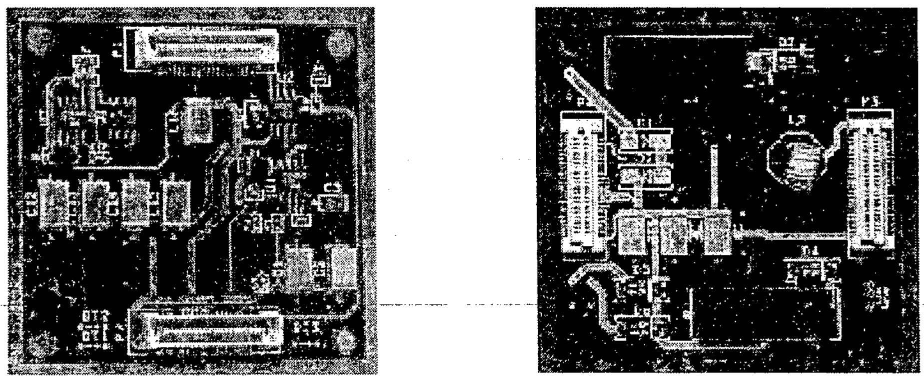


Figure A.6 Power Supply Module [2]

Sensor Modules [2]

Seismic	Mark IV geophone
Acoustic	Knowles BL1785 microphone, 4 Hz –2 KHz (in design stage)
Magnetometer	Honeywell HMC1001, sensitivity = 1 lb of iron at 6 feet (in prototype test)
Accelerometer, Temp, Pressure	20 KHz accel. Sampling bandwidth, combined with temperature and pressure sensor

Other Sensors.

Acoustic Sensor. The acoustic sensor board employs a miniature microphone such as a Knowles BL1785 microphone element with a low-end cutoff frequency of only 4Hz. The maximum frequency of interest for acoustic sensor applications has been selected as 2kHz [2].

Magnetometer. A magnetometer module has been fabricated and is being under tested as part of a related Army Research Laboratory program. It has a 10 Hz bandwidth and employs the Honeywell HMC1001. The rated sensitivity of this sensor is 27 μgauss so that it can detect 1 pound of iron at 6 feet [2].

Appendix A3

Simulation

```
#End Region
    Dim CommunicationTable As New SortedList
    Dim NetworkEnergy As New SortedList
    Dim route As String = ""

    Class EnergyStructure
        Public Node As String
        Public Energy As Integer
    End Class

    Class CommunicationStucture
        Public Sender As String
        Public FirstReceiver As String
        Public SecondReceiver As String
        Public FirtReceiverStatus As Boolean
        Public SecondReceiverStatus As Boolean
    End Class

    Private Sub FillEnergyTable(ByVal Amount As Integer)
        Dim node As New CommunicationStucture
        Dim i As Integer
        For i = 0 To CommunicationTable.Count - 1
            node = CType(CommunicationTable.GetByIndex(i), CommunicationStucture)
            NetworkEnergy.Add(node.Sender, Amount)

        Next
    End Sub

    Private Sub FillCommunicationTable()
```

```
Dim Node As New CommunicationStucture
Node = New CommunicationStucture
Node.Sender = "41"
Node.FirstReceiver = "31"
Node.SecondReceiver = "32"
Node.FirtReceiverStatus = True
Node.SecondReceiverStatus = False

CommunicationTable.Add("41", Node)
Node = New CommunicationStucture
Node.Sender = "42"
Node.FirstReceiver = "32"
Node.SecondReceiver = "33"
Node.FirtReceiverStatus = False
Node.SecondReceiverStatus = True

CommunicationTable.Add("42", Node)
Node = New CommunicationStucture
Node.Sender = "43"
Node.FirstReceiver = "33"
Node.SecondReceiver = "34"
Node.FirtReceiverStatus = True
Node.SecondReceiverStatus = False

CommunicationTable.Add("43", Node)
Node = New CommunicationStucture
Node.Sender = "44"
Node.FirstReceiver = "34"
Node.SecondReceiver = "35"
Node.FirtReceiverStatus = False
Node.SecondReceiverStatus = True
```

```
CommunicationTable.Add("44", Node)
Node = New CommunicationStucture
Node.Sender = "45"
Node.FirstReceiver = "35"
Node.SecondReceiver = "36"
Node.FirtReceiverStatus = True
Node.SecondReceiverStatus = False

CommunicationTable.Add("45", Node)
Node = New CommunicationStucture
Node.Sender = "46"
Node.FirstReceiver = "36"
Node.SecondReceiver = "37"
Node.FirtReceiverStatus = False
Node.SecondReceiver = True

CommunicationTable.Add("46", Node)
Node = New CommunicationStucture
Node.Sender = "47"
Node.FirstReceiver = "37"
Node.SecondReceiver = "38"
Node.FirtReceiverStatus = True
Node.SecondReceiverStatus = False

CommunicationTable.Add("47", Node)
Node = New CommunicationStucture
Node.Sender = "48"
Node.FirstReceiver = "38"
Node.SecondReceiver = "39"
Node.FirtReceiverStatus = False
Node.SecondReceiverStatus = True

CommunicationTable.Add("48", Node)
Node = New CommunicationStucture
```

```
Node.Sender = "49"
Node.FirstReceiver = "39"
Node.SecondReceiver = "310"
Node.FirtReceiverStatus = True
Node.SecondReceiverStatus = False

CommunicationTable.Add("49", Node)
Node = New CommunicationStucture
Node.Sender = "410"
Node.FirstReceiver = "310"
Node.SecondReceiver = "311"
Node.FirtReceiverStatus = False
Node.SecondReceiverStatus = True

CommunicationTable.Add("410", Node)
Node = New CommunicationStucture
Node.Sender = "411"
Node.FirstReceiver = "311"
Node.SecondReceiver = "312"
Node.FirtReceiverStatus = True
Node.SecondReceiverStatus = False

CommunicationTable.Add("411", Node)
Node = New CommunicationStucture
Node.Sender = "412"
Node.FirstReceiver = "312"
Node.SecondReceiver = "31"
Node.FirtReceiverStatus = False
Node.SecondReceiverStatus = True

CommunicationTable.Add("412", Node)
Node = New CommunicationStucture
Node.Sender = "31"
Node.FirstReceiver = "212"
```

```
        Node.SecondReceiver = "21"
        Node.FirtReceiverStatus = True
        Node.SecondReceiverStatus = False
        CommunicationTable.Add("31", Node)
```

{And the same for all the other level}

Example of a level 1:

```
        CommunicationTable.Add("11", Node)
        Node = New CommunicationStucture
        Node.Sender = "12"
        Node.FirstReceiver = "0"
        Node.SecondReceiver = "0"
        Node.FirtReceiverStatus = True
        Node.SecondReceiverStatus = True
.
.
.
    End Sub

Private Function NextNode(ByVal vl As String) As String
        Dim temp As CommunicationStucture
        temp = CommunicationTable.Item(vl)
        If temp.FirtReceiverStatus = True Then
                NetworkEnergy.Item(vl) = NetworkEnergy.Item(vl) - 1
          Return temp.FirstReceiver
        Else
          NetworkEnergy.Item(vl) = NetworkEnergy.Item(vl) - 1
          Return temp.SecondReceiver
        End If

    End Function
```

```
Private Sub Form1_Load(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Load
    FillCommunicationTable()

End Sub


Private Sub Timer1_Tick(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Timer1.Tick

    Dim node As New CommunicationStucture

    Dim i As Integer
    For i = 0 To CommunicationTable.Count - 1
        node = CType(CommunicationTable.GetByIndex(i), CommunicationStucture)

        If node.SecondReceiverStatus = True Then
            node.SecondReceiverStatus = False
            node.FirtReceiverStatus = True
        Else
            node.SecondReceiverStatus = True
            node.FirtReceiverStatus = False
        End If
    Next
End Sub
Private Function FindDiff() As Integer
    Dim Diff As TimeSpan
    Dim NbrMS As Double

    Dim dte1 As New DateTime(1999, 12, 1, 1, txt_A_min.Text, txt_a_sec.Text,
txt_a_ms.Text)
    Dim dte2 As New DateTime(1999, 12, 1, 1, txt_b_min.Text, txt_b_sec.Text,
txt_b_ms.Text)
```

```
Diff = dte1.Subtract(dte2)

NbrMS = Math.Abs(Diff.Days * 24 * 60 * 60 * 1000)
NbrMS = NbrMS + Math.Abs(Diff.Hours * 60 * 60 * 1000)
NbrMS = NbrMS + Math.Abs(Diff.Minutes * 60 * 1000)

NbrMS = NbrMS + Math.Abs(Diff.Seconds * 1000)
NbrMS = NbrMS + Math.Abs(Diff.Milliseconds)


End Function

Private Sub Button2_Click(ByVal sender As System.Object, _
ByVal e As System.EventArgs) Handles Button2.Click
   Application.Exit()
End Sub


Private Sub Button1_Click(ByVal sender As System.Object, _
ByVal e As System.EventArgs) Handles Button1.Click

   If FindDiff() < 1000 And ComboBox1.SelectedIndex = 0 _
   And ComboBox2.SelectedIndex = 0 And NumericUpDown1.Value _
   < 60 And NumericUpDown3.Value < 60 Then
      MsgBox("Energy consumed = 400 and energy save = 180")
   End If

   If FindDiff() < 1000 And ComboBox1.SelectedIndex = 1 _
        And ComboBox2.SelectedIndex = 1 And NumericUpDown1.Value _
        < 40 And NumericUpDown3.Value < 40 Then
      MsgBox("Energy consumed = 1280 and energy saved = 380")
   End If
   If FindDiff() < 1000 And ComboBox1.SelectedIndex = 0 _
            And ComboBox2.SelectedIndex = 0 And NumericUpDown1.Value _
```

```
            < 60 And NumericUpDown3.Value > 60 Then
    MsgBox("Energy consumed = 580 and energy saved = 0")
  End If
  If FindDiff() < 1000 And ComboBox1.SelectedIndex = 0 _
            And ComboBox2.SelectedIndex = 0 And NumericUpDown1.Value
_
            > 60 And NumericUpDown3.Value < 60 Then
    MsgBox("Energy consumed = 580 and energy saved = 0")
  End If
  If FindDiff() < 1000 And ComboBox1.SelectedIndex = 0 _
                And ComboBox2.SelectedIndex = 0 And
NumericUpDown1.Value _
                > 60 And NumericUpDown3.Value > 60 Then
    MsgBox("Energy consumed = 580 and energy saved = 0")
  End If
  If FindDiff() < 1000 And ComboBox1.SelectedIndex = 1 _
        And ComboBox2.SelectedIndex = 1 And NumericUpDown1.Value _
        < 40 And NumericUpDown3.Value > 40 Then
    MsgBox("Energy consumed = 1660 and energy saved = 0")
  End If
  If FindDiff() < 1000 And ComboBox1.SelectedIndex = 1 _
      And ComboBox2.SelectedIndex = 1 And NumericUpDown1.Value _
      > 40 And NumericUpDown3.Value < 40 Then
    MsgBox("Energy consumed = 1660 and energy saved = 0")
  End If
  If FindDiff() < 1000 And ComboBox1.SelectedIndex = 0 _
  And ComboBox2.SelectedIndex = 1 And NumericUpDown1.Value _
    < 60 And NumericUpDown3.Value < 40 Then
    MsgBox("Energy consumed = 1120 and energy saved = 0")
  End If
  If FindDiff() < 1000 And ComboBox1.SelectedIndex = 1 _
  And ComboBox2.SelectedIndex = 1 And NumericUpDown1.Value _
   > 60 And NumericUpDown3.Value < 40 Then
    MsgBox("Energy consumed = 1120 and energy saved = 0")
```

```
        End If
        If FindDiff() < 1000 And ComboBox1.SelectedIndex = 1 _
          And ComboBox2.SelectedIndex = 0 Then
          MsgBox("Energy consumed = 1120 and energy saved = 0")
        End If
        If FindDiff() > 1000 And ComboBox1.SelectedIndex = 0 _
                 And ComboBox2.SelectedIndex = 0 Then
          MsgBox("Energy consumed = 580 and energy saved = 0")
        End If
        If FindDiff() > 1000 And ComboBox1.SelectedIndex = 1 _
             And ComboBox2.SelectedIndex = 1 Then
          MsgBox("Energy consumed = 1660 and energy saved = 0")
        End If
    End Sub

    Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button3.Click
        route = ""
        Dim res As String = TextBox1.Text
        While res <> "0" And res <> "-1"
          res = NextNode(res)
          route = route & "  " & res
        End While
        MsgBox(route)
    End Sub
End Class
```

Bibliography

[1] - 'Franchun J', 'Hardware-Aware communication protocols in low energy wireless sensor networks', 'www.seas.gwu.edu/~hchoi/publication/wireless/milcom.pdf', 'October 2003'.

[2] - 'Jonathan R', 'Development Platform for Self-Organizing Wireless Sensor Networks','www.ee.ucla.edu/~pottie/papers/3713-34NoFigs.pdf', 'April 1999'.

[3] - 'Niggemeyer C', 'Dynamic source routing protocol', 'http://gauge.upb.de/pgmanet/seminar/dsr2.pdf', '2003'.

[4] - 'Parameswaran R', 'Collaborative sensor signal processing for target detection, localization and tracking', 'www.ece.wisc.edu/~sensit/publications/army02.ppt', 'December 2002

[5] – 'Robin L', 'Dynamic Source Routing in Ad Hoc Wireless Networks', 'http://list.cs.brown.edu/pipermail/cs295-1/Week-of-Mon-20021021/000110.html', 'Wed, 23 Oct 2002'.

[6] - 'GeneralCommunication.com' 'http://www.generalcommunications.com/gc/wireless_sensors/'

[7] - 'http://www.janet.ucla.edu/awairs/'

[8] – 'Mitsubichi Electric Research Laboratories', 'www.merl.com'

[9]- 'Mitsubichi Electric Research Laboratories', 'www.merl.com/areas/networks.php'

[10]-. 'www.the-powersource.com/**tadiran**1.html'