EMBEDDED TCP/IP IN SENSOR NODES (SENSORNETS)

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To my beloved husband for his support and understanding

To my 'little baby' for not giving any problem

To my dearest mother, father and family for their encouragement and blessing

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ABSTRACT

A sensor network is a group of sensor nodes (sensor) which are connected and communicate each other. Sensor node has the ability to sense environmental data such as humidity, light, weight, and temperature, and has been ported with embedded TCP/IP protocol to perform the networking. A sensor node is equipped with a small microcontroller, a radio transceiver, and an energy source. Sensors are constrained in terms of memory and processing power because of their limited physical size and cost. These constraints have been considered too limiting for physical size sensor to be able to use the TCP/IP protocols. This project was carried out to develop two sensor nodes that able to sense the temperature value, to embed the TCP/IP stack into the sensor nodes, and to apply the SLIP protocol into the TCP/IP stack. One will be the transmitter node while the other is the receiver node. The programming was developed with WinAVR, an AVR-GCC development tools and the hex code was ported using AVRISP connector. Finally, the transmission of data between sensor nodes is measured and result is compared between wired and wireless data.

ABSTRAK

Rangkaian pengesan ialah sekumpulan nod-nod pengesan (pengesan) yang saling berhubungan dan berkomunikasi antara satu sama lain. Nod pengesan mempunyai kebolehan untuk mengesan data daripada persekitaran seperti kelembapan, cahaya, berat dan suhu, dan ia juga dilengkapi dengan protokol *TCP/IP* terbenam untuk perangkaian. Setiap nod pengesan dilengkapi dengan mikro-pengawal yang kecil, gabungan pemancar dan penerima, dan satu sumber tenaga. Nod-nod pengesan ini terikat dari segi ingatan dan kuasa pemprosesan disebabkan oleh kos dan saiz fizikal yang terhad. Ciri-ciri ini telah dipertimbangkan amat terhad bagi saiz fizikal nod pengesan untuk berupaya menggunakan protokol *TCP/IP*. Projek ini telah untuk dijalankan untuk membangunkan dua modul nod pengesan yang berupaya untuk mengesan nilai suhu, untuk memprogramkan tindanan *TCP/IP* ke dalam nod pengesan dan mengaplikasikan protokol *SLIP* kedalam tindanan *TCP/IP* tersebut. Satu nod sebagai nod pemancar manakala satu lagi nod sebagai nod penerima. Pengaturcaraan dibangunkan dengan WinAVR, sebuah perkakasan pembangunan *AVR-GCC* dan kod perenambelasan diprogramkan melalui penghubung *AVRISP*. Akhir sekali, penghantaran data di antara nod-nod pengesan ditentukan dan keputusan di antara data dengan wayar dan tanpa wayar dibandingkan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADC	Analog to Digital Conversion
AM	Amplitude Modulation
ARP	Address Resolution Protocol
AVR-GCC	AVR- GNU Compiler Collection
AVR RISC	AVR Reduced Instruction Set Computer
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
DTN	Delay Tolerant Network
EEPROM	Electrically Erasable Programmable Read Only Memory
FTP	File Transfer Protocol
GPRS	Global Packet Radio Service
HTTP	HyperText Transfer Protoco
ICMP	Internet Control Message Protocol
ISP	In-Circuit Serial Programmable
KB	Kilo Byte
LWIP	Light Weight Internet Protocol
LSB	Least Significant Bit
MHz	Megahertz
MSB	Most Significant Bit
OS	Operating System
PPP	Point-to-Point Protocol
RAM	Random Access Memory
RF	Radio Frequency
Rx	Receiver

SLIP	Serial Line Interface Protocol
SMTP	Simple Mail Transport Protocol
SN	Sensor Network
SRAM	Static Random Access Memory
TCP/IP	Transmisson Control Protocol/ Internet Protocol
Tx	Transmitter
UDP	User Datagram Protocol
USART	Universal Synchronous Asynchronous Receiver Transmitter

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

1.1 Overview

Today, most network infrastructures use the Internet Protocol (IP) as its base technology. It is of particular interest to look how sensor networks can be connected to IP network infrastructures (TCP/IP) and methods to interconnect and embed TCP/IP protocol into the sensor device. By directly employ the TCP/IP suite as the communication protocol in the sensor network enable the integration of the sensor network and TCP/IP network. There have been a number of research and development efforts at all levels of development and usage of sensor networks, including applications, operating systems, architectures, middleware, integrated circuit, and system. Sensor network based on TCP/IP has the advantage of being able to directly communicate with an infrastructure consisting either of a wired IP network or of IP-based wireless technology.

1.2 Introduction to Sensor Networks

A sensor network consists of many spatially distributed sensor nodes (sensors) which are used to monitor or detect phenomena at different locations, such as temperature changes or pollutant levels. Sensor networks enable information gathering, information processing, and reliable monitoring of a variety of environments for both civil and military applications. These sensor nodes can be spread out in hard accessible areas depends on the application fields. A sensor node combines the abilities to compute, communicate and sense [J.Bluementhal *et al.*, 2002].

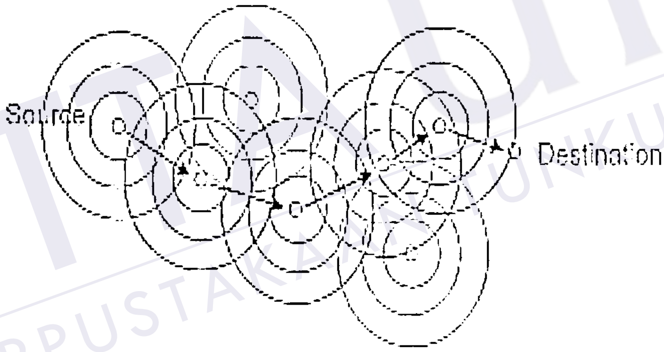

Figure 1.1 Sensor Network Structure

Applications of sensor networks can be found in such diverse areas as wild-life habitat monitoring, forest fire detection, alarm systems, medicine, and monitoring of volcanic eruptions. Communication can be performed using medium such as wireless, optic or acoustic. For nodes with a far distance range from the source node to the destination, traffic is forwarded by other intermediate nodes.

The development of sensor nodes was influenced by the increasing of the device complexity, high performance of wireless networking technologies, combination of digital signal processing and sensor data acquisition, the advances in the development of micro-electromechanical systems (MEMS) and the availability of high performance development tools. [J.Blumenthal *et al.*, 2002]:

1.3 Problem Statement

This project was developed because of:

i) Limited resources such as size of memory and processing power is said to be the limiting criteria for a sensor node to run the TCP/IP protocol. This project was run in an 8-bit processor with 8KB flash memory, 512 Bytes of SRAM to proof that porting TCP/IP stack is not a problem into the device itself.

ii) uIP is a small TCP/IP stack developed for small size microcontroller. Because of this, we tried to embed the uIP into the AVR ATmega8535 which has the limited size of memory.

iii) Data need to be transmitted and received at a specific time. We also need to work on specific device driver that used in the project. The project was carried out to see the performance of data transmission according to the time/period specified in the uIP codes and device driver.

(4) Normally IP works with Ethernet interface. In this project, the uIP code has been modified to be used with SLIP protocol. We try to observe the transmission of data by using the RF transceiver and direct wire interface at the physical layer.

1.4 Objectives

The objectives of this project are as follows:

i) To develop sensor nodes that able to do sensing, processing and networking. Temperature data from a specific area is collected by one sensor node (defined as transmitter node) before it is transmitted to the other sensor node (defined as receiver node).

ii) To embed the uIP, a TCP/IP stack protocol into sensor nodes. This is done as to make sure the data can be transmitted and received at specific time. The IP address for each node and the periodic transmission of data is determined in the uIP stack.

iii) To develop sensor networking (between sensor nodes) using SLIP protocol. By using SLIP protocol, data can be transmitted more flexibly with wired or through the wireless link such as RF.

1.5 Scope of Project

The scopes of work for this project are:

- Developing the sensor nodes which implemented TCP/IP protocol using:
  - Processor : AVR microcontroller
  - Sensor type: Temperature sensor
  - Communication link: direct wire, RF transmitter and receiver module

- Frequency involved: 433 MHz
- TCP/IP Protocol: uIP stack

- Programming the microcontroller using C/C++, and then compile the source codes using GNU tools, WinAVR (AVR-GCC).

- Convert the data collected by the analog temperature sensor into digital representation (A/D Conversion).

- Build the AVRISP connector to program the INTEL hex code into the AVR microcontroller.

- Write a device driver for target's network device in uIP (serial), and configure the uIP codes to be used in the sensor device.

- Embed uIP, a TCP/IP functions into the sensor nodes. This is done to perform a networking between both sensor nodes.

1.6 Thesis Outline

This thesis comprises of five chapters. The first chapter briefly overviews the background of sensor network and sensor nodes, objectives and scope of this project.

Chapter 2 deals with the previous research and development of sensor nodes (a.k.a sensor) and its application in sensor networks. The design architecture, development of sensors, and problem comprises in the development are presented in this chapter.

This is followed by Chapter 3 which presents the software and hardware development for each of sensor nodes. This chapter described those resources used and the development steps of both transmitter and receiver node, such as hardware parts used, block diagram, and schematic circuits. In software development, AVR-GCC and its development tools is discussed. This tool is used to ease the microcontroller and application programming as it consists of cross-compiler, linker, object files, etc.

Chapter 4 discusses the simulation results. Here, the ADC data for temperature value is analyzed. The performance of the data transmission between transmitter node and receiver node as seen in the oscilloscope for both wired and wireless is compared. For the comparison purposes, data observed at several temperature value has been captured and being analyzed.

Finally, Chapter 5 summarizes the works undertaken. Recommendations for future work of this project are presented at the end of the chapter.

CHAPTER II

SENSOR NODES ARCHITECTURE

2.1 Introduction

Wireless sensor network is an information gathering paradigm based on the collective efforts of many small wireless sensor nodes. The sensor nodes were equipped with one or more sensors, a short-range radio transceiver, a small microcontroller, and a power supply [A.Dunkels *et al*., 2004]. With the success of the Internet, the TCP/IP protocol suite has become a global standard for communication. Therefore, it is interesting to connect the sensornets to TCP/IP networks. For an embedded system, being able to run TCP/IP suite makes it possible to connect the system directly to an intranet or internet [A.Dunkels, J.Alonso, T.Voigt, 2004].

Data transport in a TCP/IP sensor network is done using the two main transport protocols in the TCP/IP stack: the best-effort UDP and the reliable byte-stream TCP. This chapter reviewed the previous and recent works of sensor network and some of them were used in the sensor nodes development in this project.

J.Hill (2001) had discussed the new direction in wireless system design, extending wireless connectivity to small, low-cost embedded devices for a wide range of applications. The comparisons between conventional and current wireless design was also analyzed. Wider range of applications was introduced in the paper such as inventory asset tracking, roadside traffic pattern and open parking spot detection, individual plant monitoring for precision agriculture, habitat monitoring in nature preserves, and advanced building security and automation.

2.2 Sensor Nodes (Sensornets)

A sensor application contains the readout of a sensor as well as the local storage of data. It has full access to the hardware and is able to access the operating system directly. The sensor application provides essential basic functions of the local sensor node, which may be used by the node application. The application field of sensor node was determined by the processor performance, transmission range, radio sensitivity, communication module, power consumption, weight and size [J. Blumenthal *et al.*, 2002]. For examples, the processor performance could be compared in terms of the power consumption, memory size, fast re-programmability, A/D channels and operating supply voltage.

A smart sensor network consists of a huge number of small sensors that spread across a geographical area. Each sensor has wireless communication capability and sufficient intelligence for signal processing and networking of the data (MANET, 1999). Sensor nodes development such as UCLA's WINS, Berkeley's Smart Dust, WebS and PicoRadio was a well-known research activity in the field of sensor networks (A.Dunkels *et al,* 2004).

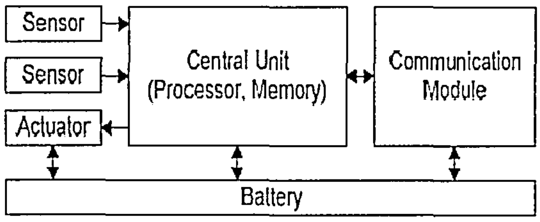

Figure 2.1 Structure of Sensor Node

A sensor node combines the abilities to compute, communicate and sense. The structure of sensor nodes discussed in [J. Blumenthal *et al.*, 2002] was shown in Figure 2.1. For instance, the development of *motes*, *mica motes*, and Commercial-off-the-Shelf Dust (COTS Dust) can be differentiated between each other by the above criteria: processor, sensors chosen, and the communication module. At UC Berkeley, researches had developed small sensor devices called motes, and operating systems called TinyOS, which was especially running on them.

2.3 Sensor Network Developments and Limitations

Sensor networks consist of a huge number of small sensor nodes, which communicate wirelessly. These sensor nodes can be spread out in hard accessible areas by what new applications fields can be pointed out. In most ad hoc sensor networks, some areas of the network have higher packet forwarding loads than other areas. For example, in a network where the nodes are uniformly distributed in space, the nodes near the center of the network will tend to carry a higher load when the network routing protocol prefers shortest-path routes.

Sensor networks based on TCP/IP have the advantage of being able to directly communicate with wired IP network or IP-based wireless technology [A.Dunkels, J.Alonso, T.Voigt, 2004]. Further research had been carried out such as extending the sensor networks into a wireless ad hoc network and analyzed the routing protocol and aggregation of the data.

Sensor networks have to be self-organizing. A node has to autonomously set-up an operating network infrastructure by interaction with its neighboring nodes. Traditional wired networks are usually based on the client-server-principle. However, communication in sensor networks should be event-based. In large sensor networks, packets have to be routed from data sources to data sinks over intermediate nodes. That means, besides the measurement task, all nodes had to perform additional tasks to maintain network integrity [J. Blumenthal *et al.*, 2002]. The cooperative processing of tasks should lead to more precise results and new application fields. Sensor networks required security mechanisms that were adaptive to environmental conditions which depend on network application and environmental conditions. Furthermore, all algorithms and protocols must be energy optimized such as implemented the OS for sensor nodes with a low-power task-scheduling.

Sensor networks are limited in external bandwidth, i.e. how much data can be delivered to an outside system by the sensor networks. In many cases the externally available bandwidth is a small fraction of the aggregate internal bandwidth [S.Madden *et al.*, 2001]. Thus computing aggregates in-network is also attractive from a network performance and longevity standpoint: extracting all data over all time from all sensors will consume large amounts of time and power as each individual sensor's data is independently routed through the network.

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