EMBEDDED TCP/IP IN SENSOR NODES (SENSORNETS)

WARSUZARINA BINTI MAT JUBADI

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical-Electronics & Telecommunications)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

NOVEMBER, 2005

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

ACKNOWLEDGEMENT

First of all, I am greatly indebted to ALLAH SWT on His blessing to make this project successful.

I would like to express my gratitude to honourable Professor Dr. Norsheila Bt. Fisal, my supervisor of Master's project. During the research, she inspired me with motivations, guidance, encouragement and assistance which finally led me to the completion of this project.

A very big appreciation goes to Mr. David Armstrong; an active members in AVR-GCC mailing list, and also to Mr. Dennis Kuschel, the developer of my-CPU who guide and assist me without any doubt through the emails. They have guided me a lot through the compiling of the embedded TCP/IP stack, the biggest part of this project.

I would also dedicate my appreciation to my husband, my little baby, my parents and family, and my friends who helped me directly or indirectly help me in this project. I am grateful to Kolej Universiti Teknologi Tun Hussein Onn (KUiTTHO), for supporting me in the form of a scholarship and study leave. Guidance, co-operation and encouragement from all people above are appreciated by me in sincere.

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].

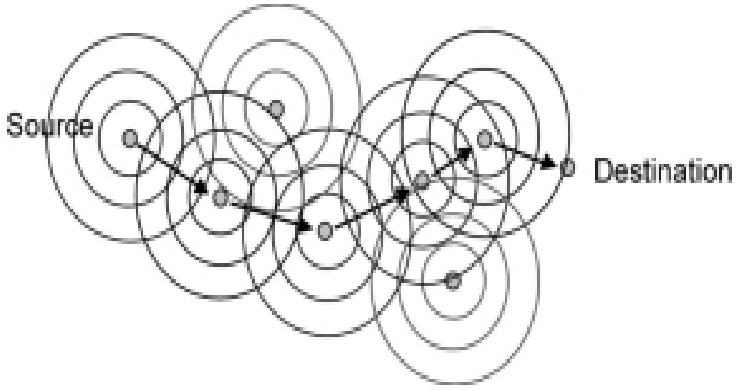

Figure 1.1 Sensor Network Structure

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.

REFERENCES

1. Jones, M. Tim (2002). *TCP/IP Application Layer Protocols for Embedded Systems*. Charles River Media, Inc.

2. A. Dunkels (May 2003). F*ull TCP/IP for 8-bit architectures.* In MOBISYS`03, San Francisco, California. **URL**: *http://dunkels.com/adam/uip*

3. A. Dunkels (January 2002). *uIP – A Free Small TCP/IP Stack.* Technical paper.

4. S. Hollar (2000). *COTS Dust.* Master Thesis, University of California, Berkeley.

5. A.Dunkels, J.Alonso, T.Voigt (2004). *Making TCP/IP Viable for Wireless Sensor Networks.* EWSN.

6. A.Dunkels, B.Grönvall, M.Johansson, K.Mayer, F.Oldewurtel, O.Raivio, J.Riihijärvi (2004). *Reconfigurable Ubiquitous Networked Embedded Systems.* Sixth Framework Programme Priority 2 “Information Society Technologies”.

7. Dr. K.V.K.K. Prasad, V. Gupta, A. Dass, A. Verma, Dreamtech Software Team (2002). *Programming for Embedded Systems: Cracking the Code.* Wiley Publishing, Inc.

8. J. Hill, R. Szewczyk, A. Woo, S. Hollar, D. Culler, and K. Pister (November 2000). *System Architecture Directions for Networked Sensors*. In Proceedings of the 9th International Conference on Architectural Support for Programming Languages and Operating Systems.

9. Forouzan, Behrouz A. with Sophia Chung Fegan (2003). *TCP/IP Protocol Suite.* 2nd Edition, McGraw-Hill Higher Education.

10. A. Dunkels, T. Voigt, J. Alonso, H. Ritter, and J. Schiller (February 2004). *Connecting Wireless Sensornets with TCP/IP Networks.* In WWIC2004.

11. D. Culler, D. Estrin and M. Srivastava (August 2004). *Overview of Sensor Networks.* IEEE Computer. Vol. 37. No. 8. Pp. 41-49.

12. James Martin, Joe Leben (1994). *TCP/IP Networking : Architecture, Administration and Programming.* Prentice Hall.

13. Srisathapornphat, C.Jaikaeo, C.Chien (2000). *Sensor Information Networking Architecture.* Chung Shen International Workshops on Parallel Processing. Page 23-30.

14. C. L. Stephens (April 2002). *TCP/IP - An Introduction for 8 & 16 bit Microcontroller Engineers.* Computer Solution Ltd. Version 1.0.

15. Sohrabi, J. Gao, V. Ailawadhi, and G. J. Pottie (October 2000). *Protocols for Self-Organization of a Wireless Sensor Network.* IEEE Personal Comm.

16. S. Meguerdichian, F. Koushanfar, M. Potkonjak, M. Srivastava (April 2001). *Coverage Problems in Wireless Add-Hoc Sensor Networks.* Proceedings of IEEE INFOCOM. Vol. 3. Pp.1380-1387.

17. M. Tubaishat, S. Madria (2003). *Sensor Network : An Overview*. IEEE Potentials.

18. C. C. Yee and S. P. Kumar (August 2003). *Sensor Networks: Evolution, Opportunities, and Challenges.* IEEE Proceedings. Vol. 91. No. 8. pp. 1247-1256.

19. A.Ahmed and M. R. Eskicioglu (June 2004). *Current Researches on Sensor Networks.* Technical Report TR-01-06/04. Telecommunication Research Labs, Winnipeg, Manitoba, Canada.

20. J. Agre and L. Clare (May 2000). *An Integrated Architecture for Cooperative Sensing and Networks. Computer*, vol. 33. pp. 106-108.

21. Douglas E.Comer, David L.Stevens (1999). *Internetworking with TCP/IP Vol II: Design, Implementation, and Internals.* 3rd edition. Prentice Hall.

22. Gharavi, H. Kumar, S.P. (August 2003). *Special issue on Sensor Networks and Applications*. National Institute of Standards Technology (NIST); Proceedings of the IEEE. Vol 91. Page 1151-1153.

23. S.Kumar, F.Zhao, and D.Shepherd (March 2002). *Special Issue on Collaborative Signal and Information Processing in Microsensor Networks. IEEE Signal Processing Mag.* Vol. 19. Pp. 13-85.

24. J. Blumenthal, M.Handy, F. Golatowski, M. Haase, D.Timmermann (2002). *Wireless Sensor Networks – New Challenges in Software Engineering.* University of Rostock, Germany.

25. Nollet, T.Marescaux, D.Verkest, Jean-Yves Mignolet, S.Vernalde (June 2004). *Memory and Network Optimization in Embedded Designs: Operating-System Controlled Network on Chip.* Proceedings of the 41st annual conference on Design automation.

26. K. Chandran *et al*, (February 2001). *A Feedback Based Scheme for Improving TCP Performance in Ad Hoc Networks.* IEEE Personal Communication Systems (PCS) Magazine Special issue on Ad Hoc Networks. Volume 8. Pp. 34-39.

27. Hong X.; Xu K.; Gerla M. (July/August 2002). *Scalable Routing Protocols for Mobile Ad Hoc Networks.* IEEE Network.

28. A. Hamidian (January 2003). *A Study of Internet Connectivity for Mobile Ad Hoc Networks in NS 2.* Master's thesis.

29. C. H. Yih and D. B. Johnson (March 2004). *Exploiting MAC Layer Information in Higher Layer Protocols in Multihop Wireless Ad Hoc Networks*. Proceedings of the 24th International Conference on Distributed Computing Systems (ICDCS 2004). Pp. 301-310. IEEE.

30. A. Dunkels, *The uIP TCP/IP Stack for Embedded Microcontroller*. Web page. Visited 2004-12-10. URL: http://www.sics.se/~adam/uip/

31. IETF MANET Working Group. *Mobile Ad Hoc Networks (MANET) Charter*. URL: http://www.ietf.org/html.charters/manet-charter.html.

32. H. Kipp. *Embedded Ethernet Board*. Web page. Visited 2004-12-10. URL: http://www.ethernut.de/en/

33. ATMEL corporation Website, URL: http://www.Atmel.com

34. GNU groups, AVR-GCC mailing list, URL: http://www.avrfreaks.com

35. A. Dunkels, *The Contiki Operating System*. Web page. Visited 2004-12-10. URL: http://www.sics.se/~adam/contiki/