IMPLEMENTATION OF IEEE 802.15.4 PROTOCOL STACK FOR LINUX.

by

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ABSTRACT

SANDEEP SIRPATIL. Implementation of IEEE 802.15.4 Protocol Stack for Linux. (Under the direction of DR. JAMES M. CONRAD)

The IEEE 802.15.4 is a new wireless standard introduced for low power, low cost wireless communication with moderate data rates. It is intended to be used in embedded applications for home/office automation, industrial control and sensor networks. In such applications there is generally a need for a master controller, which will be responsible for data acquisition and communicate with other systems. Linux is gaining popularity as an embedded operating system. There are many industrial controllers / data acquisition systems that use Linux as the operating system. These controllers could potentially be used as the master controller for the wireless network. This thesis work implements a subset features of IEEE 802.15.4 for Linux operating system and develop a modular expandable Linux platform for IEEE 802.15.4 wireless systems. The developed software stack is easily portable to other hardware platforms and operating systems. The system is intended to be useful on research of various aspects of IEEE 802.15.4 standard.

ACKNOWLEDGEMENTS

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I would like to express my sincere appreciation and thank my friends Gajendra Singh, Gurudatt Mysore, Michael Thomas and many others for their support throughout. I also want to thank the open source developer community for their efforts and dedication without which this work would not have been possible.

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LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
AES	Advanced Encryption Standard
ALU	Arithmetic and Logic Unit
API	Application Program Interface
ARM	Advanced RISC Machine
CC2420DB	CC2420 Development Board
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
CSMA-CA	Carrier Sense Multiple Access with Collision Avoidance
DHCP	Dynamic Host Configuration Protocol
DLL	Dynamic Link Library
DSSS	Direct Sequence Spread Spectrum
ext2	Extended File System
FCS	Frame Check Sequence
FFD	Full Function device
FIFO	First In First Out
GTS	Guaranteed Time Slots
HAL	Hardware Abstraction Layer
IDE	Integrated Drive Electronics
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
IF	Intermediate Frequency

IP	Internet Protocol
ISM	Industrial, Scientific, and Medical
ITU-T	Telecommunication Standardization Sector
JTAG	Joint Test Action Group
LAN	Local Area Network
LR-WPAN	Low-Rate Wireless Personal Area Networks
MAC	Medium Access Control Layer
MFR	MAC Footer
MHR	MAC Header
MIPS	Million Instructions Per Second
MMU	Memory Management Unit
MPDU	MAC Protocol Data Unit
NFS	Network File System
OHCI	Open Host Controller Interface
O-QPSK	Offset Quadrature Phase Shift Keying
PA	Power Amplifier
PAN	Personal Area Network
PC	Personal Computer
PDA	Personal Digital Assistant
PHY	Physical Layer
POSIX	Portable Operating System Interface
PPDU	PHY Protocol Data Unit
PSDU	PHY Service Data Unit

PWM	Pulse Width Modulation
RAM	Random Access Memory
RF	Radio Frequency
RFD	Reduced Function Device
RISC	Reduced Instruction Set Computer
RSSI	Received Signal Strength Indication
RTC	Real Time Counter
RXFIFO	Receive First In First Out
SAP	Service Access Points
SBC	Single Board Computer
SDRAM	Synchronous Dynamic RAM
SFD	Start of Frame Delimiter
SLIP	Serial Line IP
SPI	Serial Peripheral Interface
SRAM	Static Random Access Memory
SSH	Secure Shell
TXFIFO	Transmit First In First Out
UART	Universal Asynchronous Receiver/Transmitter
USART	Universal Synchronous Receiver Transmitter
USB	Universal Serial Bus
WPAN	Wireless Personal Area Network

CHAPTER1: INTRODUCTION

There has been tremendous growth in the field of wireless communication during the last decade. The wide acceptance of 802.11 standards for wireless local area network (WLAN) and cellular phone networks have proved that low cost wireless solutions are feasible and acceptable. There are many applications that require low cost, low data rate, low power and inexpensive solution to network within a small area thus requiring a low rate wireless personal area network (LR-WPAN). There are many proprietary solutions that address these needs, but they are expensive and incompatible between manufacturers. The IEEE 802.15.4 is a new standard for LR-WPAN providing a low cost and less complicated solution. The expected applications are home/office automation, industrial sensors and control, distributed sensor networks and environment monitoring [2].

The silicon implementation of the standard is inexpensive when compared to other proprietary solutions, as the standard is open and available to everyone. As a result the chip making companies compete to develop a better product at a lower cost. The cost of a wireless node is an important factor as some applications require large number of nodes.

The ZigBee alliance, an association of companies working together to develop ZigBee standard based products for monitoring and control, has led to the increased adoption of the IEEE 802.15.4 standard. The ZigBee standard defines upper layer that are built on the IEEE 802.15.4 standard. The aim of the ZigBee alliance is to replace every switchbox, electrical outlet and various sensors in a building by wireless nodes that communicate with each other even though manufactured by different manufacturers. This standard is being widely adopted by the industry and the numbers of products based on the standard are increasing exponentially. The ZigBee alliance is forecasting that in the next four to five years time, there could be 50 ZigBee devices per home and eventually as many as 150 [15].

1.1 Motivation

The IEEE 802.15.4 is a relatively new standard and thus attracts new research on its various aspects. Many universities are conducting research on the use of different routing protocols, efficient energy use and coexistence issues of IEEE 802.15.4 with other wireless technologies. The vast majority of applications will require the use of embedded devices. The embedded devices used in the IEEE 802.15.4 wireless nodes can range from a small battery-powered sensor to a large central controller with large processing power and data storage ability. The central controller can also provide user interface, connect with other wired/wireless networks and control other devices. These central controllers require an embedded operating system for their operation as they have to perform a variety of functions.

Linux is an open-source UNIX like kernel that can be freely distributed under the terms of GNU General Public License (GPL). Linux was specifically developed as an operating system for server/desktop environment. Currently there is a lot of interest among the open source community to customize Linux for embedded applications. Linux is growing as an embedded operating system of choice because of its advantages such as, no licensing fees, scalability, reliability, a large programmer base and community support [12]. According to a survey conducted by Venture Development Corporation, a technology research and marketing firm, Linux owned the highest percentage of new embedded-development projects of any operating system [13]. Linux is used in industrial controllers, network routers, commercial devices and home entertainment systems. These devices are expected to include IEEE 802.15.4 wireless functionality in the near future.

There are many commercial implementations of IEEE 802.15.4 and ZigBee stack. There are also a few community projects working on implementing an open source version of the IEEE 802.15.4 stack. The current statuses of these projects indicate that development has almost come to a stop [25, 26, 27]. The lack of a working open source implementation of the standard was a big motivation factor to develop one and also develop the setup as an embedded Linux wireless development platform.

1.2 Current Work

There are currently numerous research projects conducted in various aspects of IEEE 802.15.4 standard. A paper titled “On the use of IEEE 802.15.4 to enable wireless sensor networks in building automation” [2] provides an insight into the application of the standard and its effects on building maintenance, energy consumption, safety and security. An article “Home networking with ZigBee” [28] presents the comparison of Bluetooth, ZigBee, 802.11 and other proprietary solutions and shows that ZigBee will succeed where others failed in home networking.

The results of the work presented in a paper titled “Coexistence of IEEE 802.15.4 with other Systems in the 2.4 GHz –ISM –Band” [3] show that IEEE 802.15.4 can co exist with other networks , is robust and reliable even in the presence of some interference. Another paper titled “An Experiment on Performance Study of IEEE 802.15.4 Wireless Networks” [11] presents the results of an experiment conducted to evaluate the performance of various features such as, direct and indirect transmissions, CSMA-CA mechanism, data payload size and beacon enabled mode. The data throughput, delivery ratio and received signal strength were investigated as performance metrics. The results show that non beacon network has better raw data rates and utilization ratio as compared to beacon enabled networks.

The hardware board developed by Mr. Assad [29] is an inexpensive IEEE 802.15.4 evaluation board. Mr. Rai [30] used this setup in evaluating energy consumption in IEEE 802.15.4 communication. Their work very helpful as it is very important to determine energy consumption of wireless nodes as they are expected to operate for long time on small batteries.

A paper titled “Embedded Linux Outlook in PostPC Industry” [14] presents an analysis of embedded Linux in the industry, how it compares to other commercial embedded OS. The paper concludes with a forecast in growth of industry adoption of Linux and proposes standardization measures to sustain the growth. Linux is inherently a non real-time OS; there have been many efforts to add real-time functionality to Linux kernel. A paper titled “A Measurement-Based Analysis of the Responsiveness of the Linux Kernel” [31] presents experiments conducted on various non preemptible sections of the kernel code and quantified its effects on interrupt latency. The results show the user-space task do not influence the kernel’s response time to external interrupts. In general, many of the net applications, network device drivers, several file systems even under heavy fragmentation, do not represent source of unresponsiveness and thus, Linux can safely adopted in soft real time systems.

With kernel version 2.6.18, basic real-time support is now available in the main kernel source and thus improves the real time performance. With the growing advancements in Linux, it is projected to continue its growth as an embedded OS.

1.3 Completed Thesis work

The work started with an investigation of IEEE 802.15.4. It is gaining wide support from industry for its adoption and attracting new research in various aspects of it. Further investigation found no open source working implementation of IEEE 802.15.4 for Linux. With Linux gaining foothold in embedded operating systems mainly for it being open source and the number of devices using Linux is increasing everyday. Many of these devices will need to add IEEE 802.15.4 functionality to them and the current work is expected to be helpful in this regard.

Many single board computers were considered and evaluated for their performance, features, price and software support. A SBC with inadequate support from the manufacturer in the form of device drivers, kernel patches and operating system will require enormous individual effort. TS-7200 SBC was selected for its features, good support by the manufacturer and huge user community. The TS 7200 manufacturer supports Debian distribution, it is well recognized for its stability and component package management, it also has a large advanced user community. Debian version 3.0 ('woody') was installed on a 512MB compact flash and TS-7200's RedBoot boot loader was configured accordingly. Debian hosts development tools for large number of programming languages this adds to the adaptability of the setup to any system.

The CC2420DBK was selected to be used as IEEE 802.15.4 for its features and availability of development tools for it in the lab. The possible ways to interface CC2420 to the TS-7200 were (set of designs of system were) evaluated for their flexibility, modularity and complexity, and the system was designed to have a good balance of these attributes.

A subset of IEEE 802.15.4 protocol was implemented for Linux in C programming language. A test program was developed to use the stack and communicate with another IEEE 802.15.4 device. The setup is developed as an embedded wireless Linux platform.

The contribution of the work is to provide an open source GPL licensed IEEE 802.15.4 protocol stack and publish a paper on the work. The work also provides a test setup to evaluate standard on Linux operating system.

1.4 Organization of Thesis

The thesis report is divided into five chapters. Chapter 2 introduces the IEEE 802.15.4 protocol. It discusses various features, network topologies, communication mechanisms and layer of the protocol. Chapter 3 describes the hardware setup and the features of the individual components. Chapter 4 introduces the software component. It describes the software development environment, the Linux environment, the software stack developed and testing. Chapter 5 details results and conclusions and suggests future work.

CHAPTER2: INTRODUCTION TO IEEE 802.15.4

The IEEE 802.15 defines the Wireless Personal Area Network (WPAN). The Task Group 4 is working on defining a standard for low rate WPAN (LR-WPAN). The standard defines the physical (PHY) and medium access control (MAC) layer specifications.

The devices that take part in a LR-WPAN can be either a reduced function device (RFD) or full function device (FFD). The FFD can take one of the three roles, a personal area network (PAN) coordinator, a coordinator or a device. An FFD can communicate with other FFDs or RFDs, while an RFD can communicate only with an FFD. An RFD is intended for simple devices in the network, such as a light switch; which does not operate continuously or send large data and generally associates with a single FFD. Therefore an RFD can be implemented with very minimum resources. A WPAN consists of two or more devices within radio reach communicating on the same physical channel. A WPAN shall include at least one FFD operating as the PAN coordinator of the network [1].

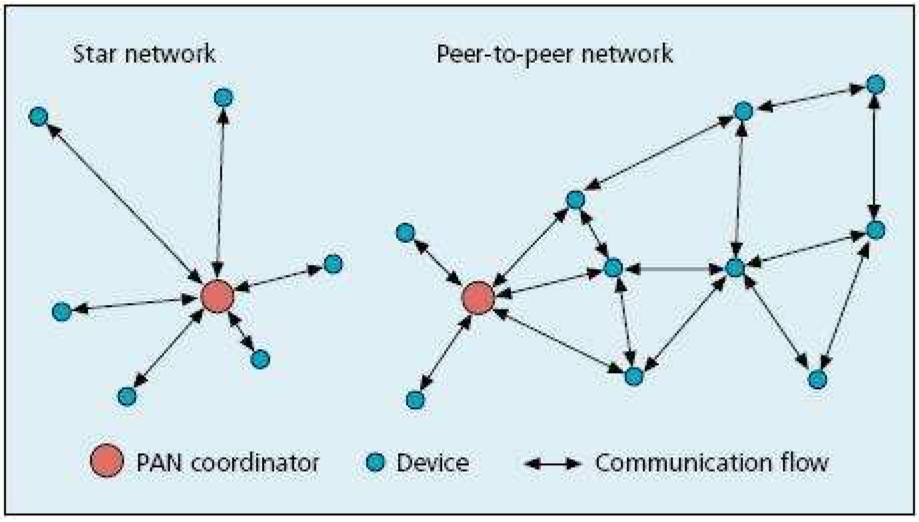

Figure 2.1: Star and peer-to-peer networks [4]

2.1 Network Topologies

A LR-PAN can be setup to operate in either of the two topologies; the star topology or the peer-to-peer topology. As shown in the Figure 2.1, the PAN coordinator forms the central node in the star topology. Every device in the network communicates with the central node. The PAN coordinator is used to initiate, terminate or route communication around the network. The PAN coordinator is the primary controller of the network. All devices generally have a 64 bit extended address. This address can be used or exchanged for a shorter address allocated by the PAN coordinator when the device associates with the PAN coordinator. The PAN coordinator may be powered by mains outlet, while the devices generally are battery powered. The applications of star topology are home automation, personal computer (PC) peripherals, toys and games.

The peer-to-peer topology allows any device to communicate with any other device within the radio reach, but requires a PAN coordinator to form the network. This topology allows formation of complex network configurations, such as mesh networking topology. This type of topology is useful in applications such as industrial control and monitoring, wireless sensor networks monitoring environment, inventory and tracking. This topology allows the network to be ad hoc, self organizing and self healing. A device may communicate with other devices out of its radio reach by routing the message through other devices.

2.2 Architecture

A set of layers is used to describe the architecture of the LR-PAN. Each layer is responsible for a logical part of the standard and offers services to the higher layers. The layout of layers is based on the open systems interconnection (OSI) seven-layer model.

An LR-WPAN device comprises of a PHY, which contains the radio frequency (RF) transceiver along with its low-level control mechanism and a MAC sublayer that provides access to the physical channel for all types of transfers [1].

Figure 2.2 illustrates the layer arrangement in the standard. The upper layers consists of network layer, which is responsible for network configuration and message routing, and application layer, which provides the intended functionality for the device. An IEEE 802.2 Type 1 logical link layer (LLC) can access the MAC sublayer through the service specific convergence sublayer (SSCS) [1]. The LR-WPAN architecture can be implemented in either an embedded device or as a device requiring support of an external device such as PC.

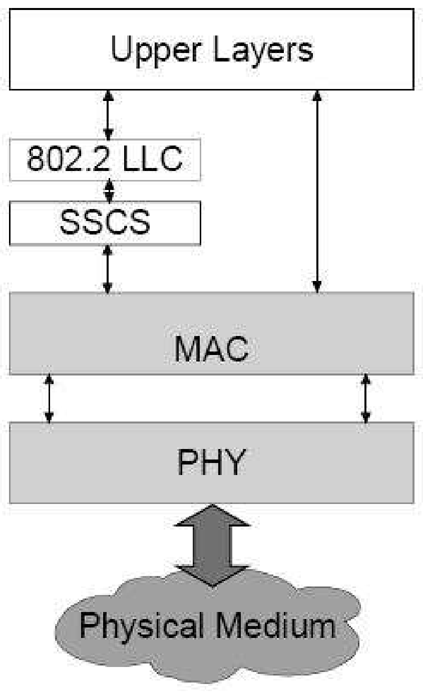

Figure 2.2: LR-WPAN device architecture [1]

2.3 PHY specification

The PHY layer is expected to provide two services: the PHY data service and PHY management service interfacing to the physical layer management entity (PLME). The PHY data service allows the transmission and reception of PHY protocol data units (PPDU) across the physical radio channel. The features of PHY are activation and deactivation of the radio transceiver, energy detection (ED), link quality indication, channel selection, clear channel assessment (CCA), transmission and reception of packets across the physical medium.

Table 2.1: Frequency bands and data rates [1]

PHY (MHz)	Frequency band (MHz)	Spreading parameters		Data parameters		
		Chip rate (kchip/s)	Modulation	Bit rate (kb/s)	Symbol rate (ksymbol/s)	Symbols
868/915	868–868.6	300	BPSK	20	20	Binary
	902–928	600	BPSK	40	40	Binary
2450	2400–2483.5	2000	O-QPSK	250	62.5	16-ary Orthogonal

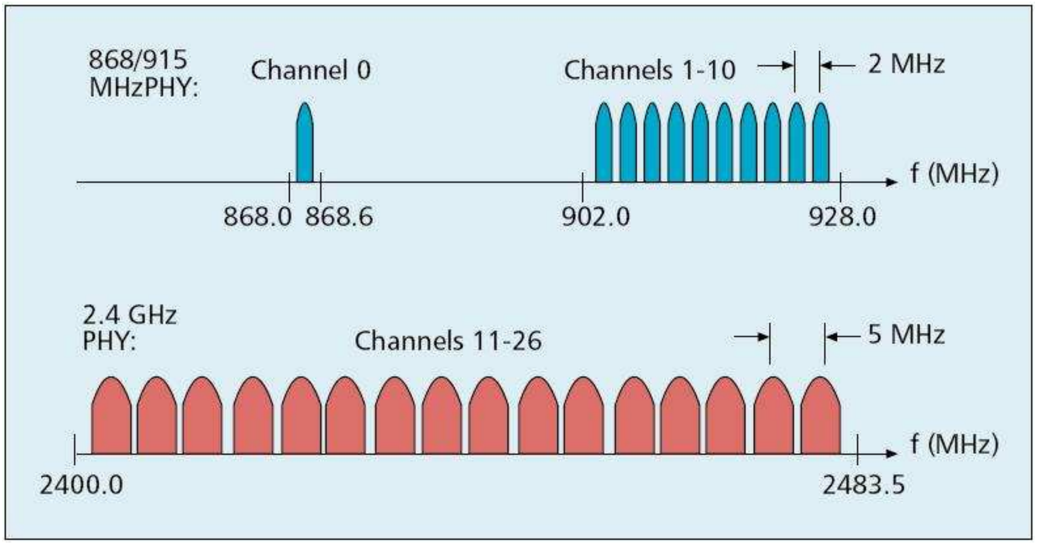

Figure 2.3: The channel structure in IEEE 802.15.4 [4]

The standard offers two PHY options which differ in frequency bands and data rate. The **Error! Reference source not found.** summarizes the frequency bands, modulation and spreading technique.

The standard defines 27 channels, numbered 0 to 26, across the three frequency bands, as illustrated in Figure 2.3. Sixteen channels are available in the 2450 MHz band, 10 in the 915 MHz band and 1 in 868 MHz band. The relation between the channel number and centre frequency is defined as:

F_c = 868.3 MHz for k = 0,   (k is the channel number)

$F_c = 906 + 2(k-1)$ MHz for $k = 1, 2, ..., 10$

$F_c = 2405 + 5(k-11)$ MHz for $k = 11, 12, …, 26$

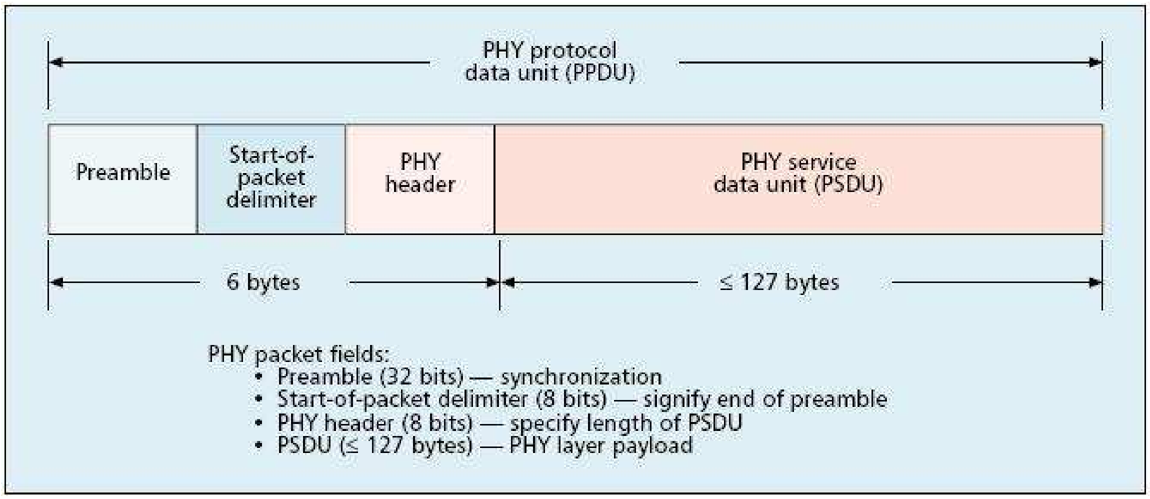
PHY protocol data unit (PPDU)
Preamble
Start-of-packet delimiter
PHY header
PHY service data unit (PSDU)
6 bytes
≤ 127 bytes
PHY packet fields:
• Preamble (32 bits) — synchronization
• Start-of-packet delimiter (8 bits) — signify end of preamble
• PHY header (8 bits) — specify length of PSDU
• PSDU (≤ 127 bytes) — PHY layer payload

Figure 2.4: The PHY packet structure [4]

Figure 2.4 illustrates a PPDU. Each PPDU contains a synchronization header (SHR), which consists of a preamble and start of packet delimiter (SFD), a PHY header (PHR) containing frame length information, and PHY payload or PHY service data unit (PSDU). The preamble field is used by the transceiver to obtain chip and symbol synchronization with an incoming message. The preamble field is composed of 32 binary zeros. The SFD is an 8 bit field indicating the end of preamble and start of packet data. The PHY header specifies the length of PSDU in bytes. The PSDU field is variable and carries the actual PHY packet. For all packet types of length five bytes or greater than seven bytes, the PSDU contains the MAC sublayer frame [4].

2.4 MAC sublayer specification

The MAC sublayer provides two services: the MAC data service and the MAC management service interfacing to the MAC sublayer management entity (MLME) service access point (SAP). The MAC data service enables the transmission and reception of MAC protocol data units (MPDU) across the PHY data service [1].

The features of the MAC sublayer are beacon management, channel access, guaranteed time slot (GTS) management, frame validation, association and disassociation.

2.4.1 MAC frame format

The MAC frame structure is designed to keep the complexity at a minimum while ensuring they are sufficiently robust to be transmitted on a noisy channel. The general format of a MAC frame is shown in the Figure 2.5.

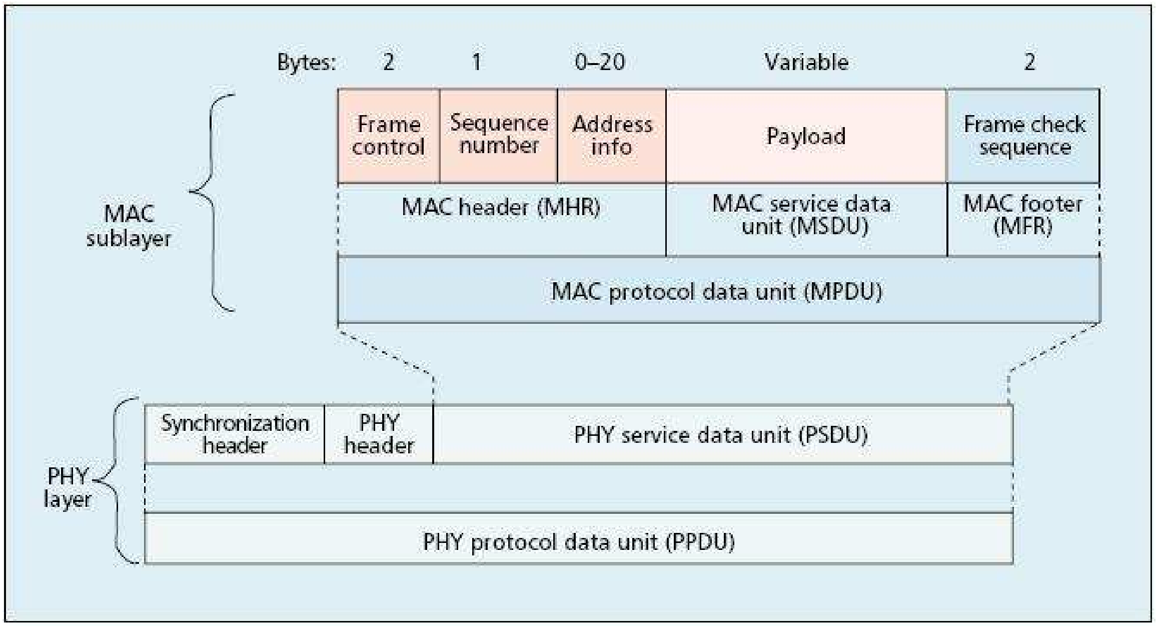

Figure 2.5: The format of a general MAC frame [4]

A MAC frame is composed of the MAC header (MHR), MAC service data unit (MSDU), and MAC footer (MFR). The first field of the header is the frame control field. It indicates the type of the MAC frame, specifies format of the address field, and controls acknowledgement. The address field is variable of length 0 to 20 bytes. Based on the frame type, the address field may contain source and destination addresses, no address or destination address. A short 8 bit device address or 64 bit IEEE device address may be used [4].

The payload is of variable length with a restriction of 127 bytes for the complete MAC frame. The data contained in payload is dependent on the frame type. The 802.15.4 MAC has four different frame types. These are the beacon frame, data frame, acknowledgement frame and MAC command frames which are used for MAC peer-to-peer communication.

The sequence number field is used to identify successful transmission of a frame when the received acknowledgment frame contains the same sequence number. The frame check sequence (FCS) is a 16 bit International Telecommunication Union – Telecommunication Standardization Sector (ITU-T) cyclic redundancy check (CRC) to ensure data integrity [1].

2.4.2 Superframe structure

The standard allows the optional use of a superframe structure illustrated in Figure 2.6. The superframe is sent by the coordinator bounded by network beacons. It is divided into 16 equally sized slots. A device can transmit at any time during the slot, but must finish before the next superframe beacon. The channel access during the time slots is contention based. For low latency applications or applications requiring specific data bandwidth, the PAN coordinator may dedicate portions of the active superframe to that application. These portions are called guaranteed time slots (GTS). The GTS form the contention free period (CFP), which always appear at the end of the contention access period (CAP). All contention based transactions must be complete before the CFP begins.

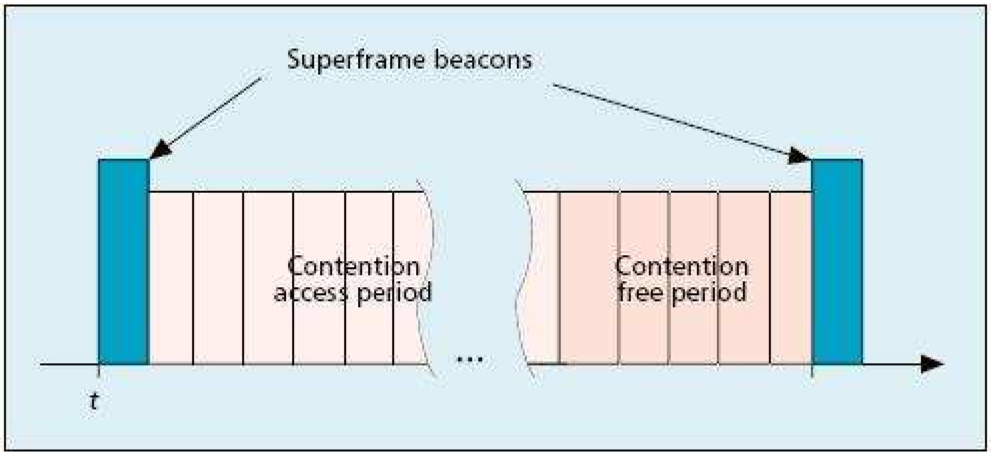

Figure 2.6: A MAC superframe structure [4]

2.4.3 Data transfer model

There are three types of data transfer transactions. The first one is the data transfer to a coordinator in which a device transmits the data. The second transaction is the data transfer from a coordinator to the device. The third transaction is the data transfer between the peer devices.

2.4.3.1 Data transfer to a coordinator

When a device needs to transfer data to a coordinator in a beacon enabled network, it listens for the beacon, when the device finds a beacon it synchronizes to the superframe structure. At an appropriate time it transmits data using slotted CSMA-CA to the coordinator. The coordinator may send an optional acknowledgement frame to complete the transaction. This sequence is summarized in Figure 2.7.

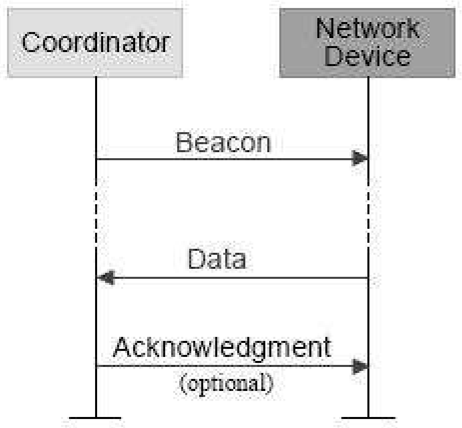

Figure 2.7: Communication to a coordinator in a beacon enabled network [1]

If the device is in a non-beacon enabled network, it transmits the data frame using an unslotted CSMA-CA, to the coordinator. The coordinator may acknowledge successful reception with an optional acknowledgment frame. The sequence is summarized in Figure 2.8.

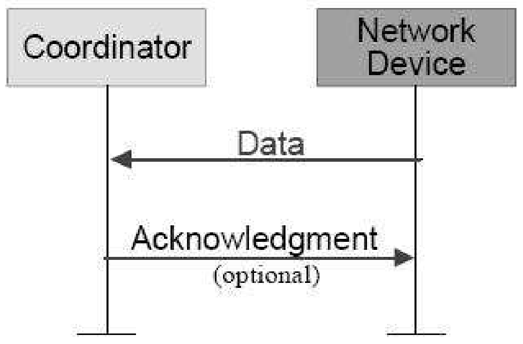

Figure 2.8: Communication to a coordinator in a non beacon enabled network [1]

2.4.3.2 Data transfer from coordinator

When the coordinator needs to transfer data to a device in a beacon enabled network, it indicates in the network beacon that data message is pending. The device periodically listens to the network beacon and if a message is pending, transmits a MAC command requesting the data using slotted CSMA-CA. The coordinator acknowledges the successful reception of the data request from the device by transmitting an optional acknowledgement frame. The requested data frame is then sent by the coordinator using slotted CSMA-CA. The device may send an optional acknowledgement frame. The coordinator will then remove the frame from its list of pending frames in the beacon. The sequence is summarized in Figure 2.9 [1].

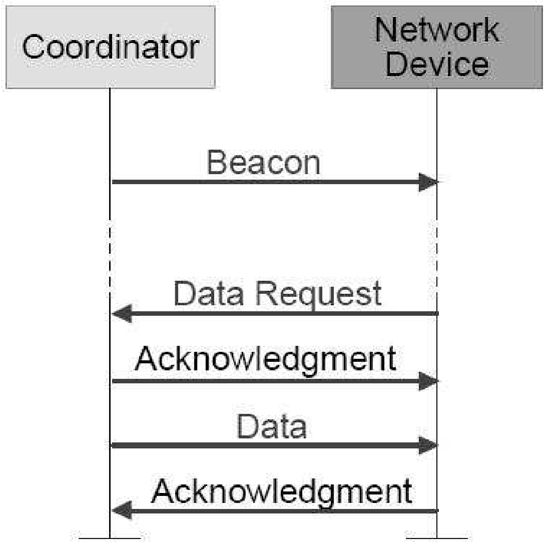

Figure 2.9: Communication from a coordinator in a beacon enabled network [1]

When the coordinator needs to transfer data to a device in a non beacon enabled network, it stores the data and waits for the device to make contact and request the data. The device will send a MAC command requesting the data using unslotted CSMA-CA. The coordinator may send an optional acknowledgement frame indicating successful reception of the request. If any data is pending, the coordinator transmits the data using unslotted CSMA-CA to the device, else it will send a zero length payload frame indicating there is no data available. The device acknowledges successful receptions with optional acknowledgement frame. The sequence is summarized in Figure 2.10.

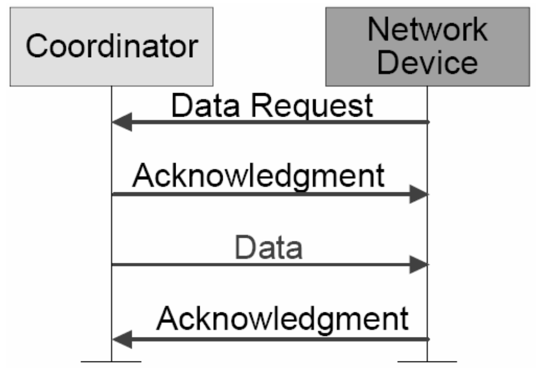

Figure 2.10: Communication from a coordinator in a non beacon enabled network [1]

2.4.3.3 Peer-to-peer data transfers

In a peer-to-peer network, every device may communicate with every other device within its radio reach. In order to achieve this effectively, the devices will need to either turn their receiver on continuously or synchronize with each other. In the former case, the devices can communicate using unslotted CSMA-CA. In the latter case, other synchronization measures have to be used. Description of such measures is left to the upper layers to decide and is beyond the scope of this standard.

2.4.4 CSMA-CA mechanism

The standard defines two types of channel access methods depending on the network configuration. Non beacon enabled networks use unslotted CSMA-CA method. The device wishing to transmit data will wait for a random period of time. If the channel is found idle, it shall transmit the data, else if the channel was found to be busy, the device waits for another random period of time before trying to access the channel again. Acknowledgment frames are sent without using CSMA-CA mechanism.

The beacon enabled networks use slotted CSMA-CA mechanism where the backoff slots are aligned with the start of the beacon transmission. A device wishing to transmit data during CAP, will locate the boundary of the next backoff slot and then wait for a random number of backoff slots. If the channel is busy, following this wait, the device waits for another random number of backoff slots before trying to access the channel again. If the channel is found idle, the device can begin transmitting on the next available slot. Acknowledgement and beacon frames are sent without using a CSMA-CA mechanism [1].

2.4.5 Security

The MAC sublayer provides a baseline security measures such as maintaining an access control list (ACL) and symmetric cryptography to protect transmitted frames. The higher layers determine when security is to be used at the MAC sublayer and provide all the necessary keying material to provide the security services.

This chapter provided a brief introduction to the IEEE 802.15.4 standard. For a complete specification, readers are advised to refer to the reference [1].

CHAPTER3: HARDWARE DESCRIPTION

3.1 System Architecture

The aim was to use the existing hardware in the lab, keeping the cost down yet maintaining modularity and expandability in the system. The CC2420 DBK is a demonstration kit from Chipcon consisting of a pair of CC2420DB boards, each containing a CC2420 IEEE 802.15.4 compliant RF transceiver and an Atmel ATmega128L microcontroller. This kit was considered for our familiarity with AVR microcontrollers and easy availability of JTAGICE mkII debugger for microcontroller.

There are dozens of small single board computers available which are capable of executing Linux on them varying is physical size, CPU speed and features. Our requirements were low cost, easily expandable, good support from the manufacturer and community. A number of SBC's were considered and TS-7200 from Technologic systems was selected.

3.2 CC2420 – RF Transceiver

Chipcon was one of the first companies to develop a silicon implementation of the standard in the form of CC2420 IC. The CC2420 is a true single-chip 2.4GHz IEEE 802.15.4 complaint RF transceiver designed for low power and low voltage applications. CC2420 includes a digital direct sequence spread spectrum base band modem providing a spreading gain of 9dB and an effective data rate of 250 kbps.

The CC2420 provides extensive hardware support for packet handling, data buffering, burst transmissions, data encryption, data authentication, clear channel assessment, link quality indication and packet timing information. These features reduce the load on the host controller and allow CC2420 to interface with low-cost microcontrollers. The CC2420 is designed as an SPI slave peripheral.

Figure 3.1 illustrates a simplified block diagram of CC2420, which features a low- intermediate frequency (IF) receiver. The received RF signal is amplified by the low-noise amplifier (LNA) and down converted in quadrature (I and Q) to the IF. At IF (2 MHz), the complex I/Q signal is filtered and amplified, and then digitized by the ADCs. Automatic gain control, final channel filtering, de-spreading, symbol correlation and byte synchronization are performed digitally. The SFD pin goes high when a start of frame delimiter has been detected. CC2420 buffers the incoming data in a 128 byte receive FIFO buffer. The user may read the FIFO through the SPI interface. CRC is verified in hardware while the RSSI and correlation values are appended to the frame. CCA is available on a pin in receive mode [6].

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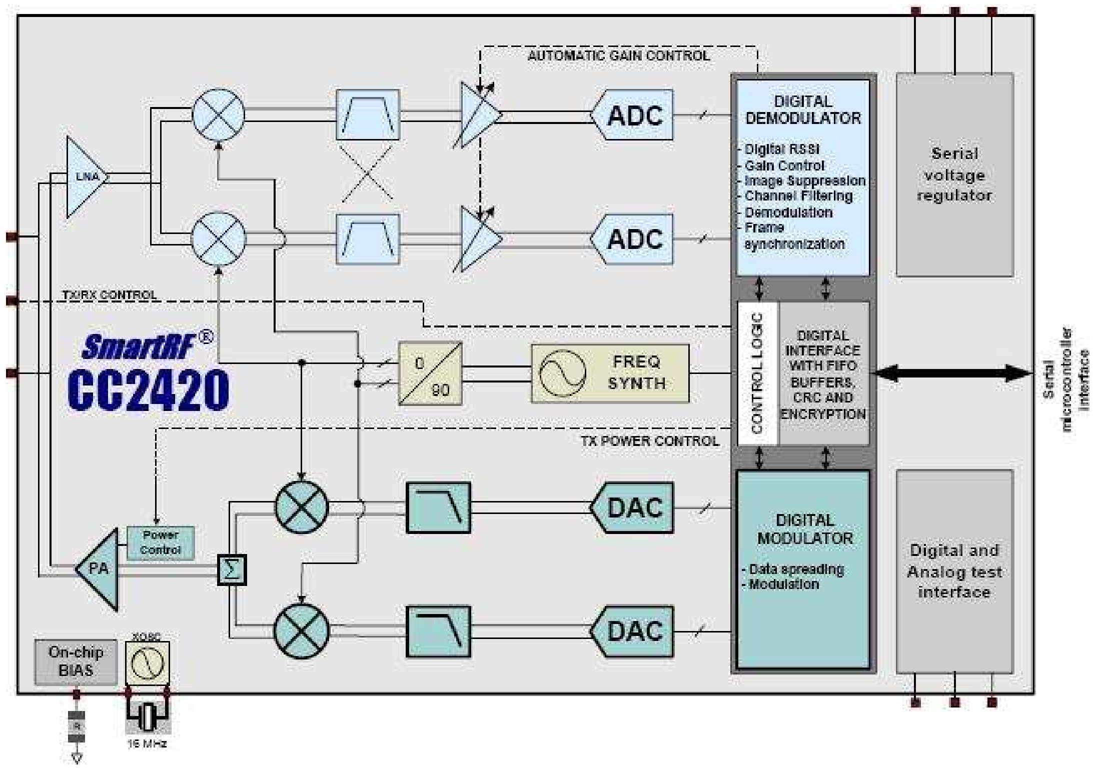


Figure 3.1: CC2420 simplified block diagram [6]

The CC2420 transmitter is based on direct up-conversion. The data is buffered in a 128 byte transmit FIFO (separate from the receive FIFO). The preamble and start-of-frame delimiter are generated by hardware. Each symbol (4 bits) is spread using the IEEE 802.15.4 spreading sequence to 32 chips and output to the digital-to-analog converters (DACs). An analog low-pass filter passes the signal to the quadrature (I and Q) up-conversion mixers. The RF signal is amplified in the power amplifier (PA) and fed to the antenna.

3.3 CC2420DBK – Demonstration Board Kit

The CC2420DBK Demonstration Board Kit includes two CC2420DB Demonstration Boards. These boards contain a CC2420 with necessary support components, an Atmel ATmega128L AVR microcontroller, 32 Kbytes external RAM, a PCB antenna, as well as a joystick, buttons and LED's that can be used to implement a visual user application interface. The demonstration board is also furnished with connectors for JTAG, ISP and direct access to CC2420 for expansion [5].

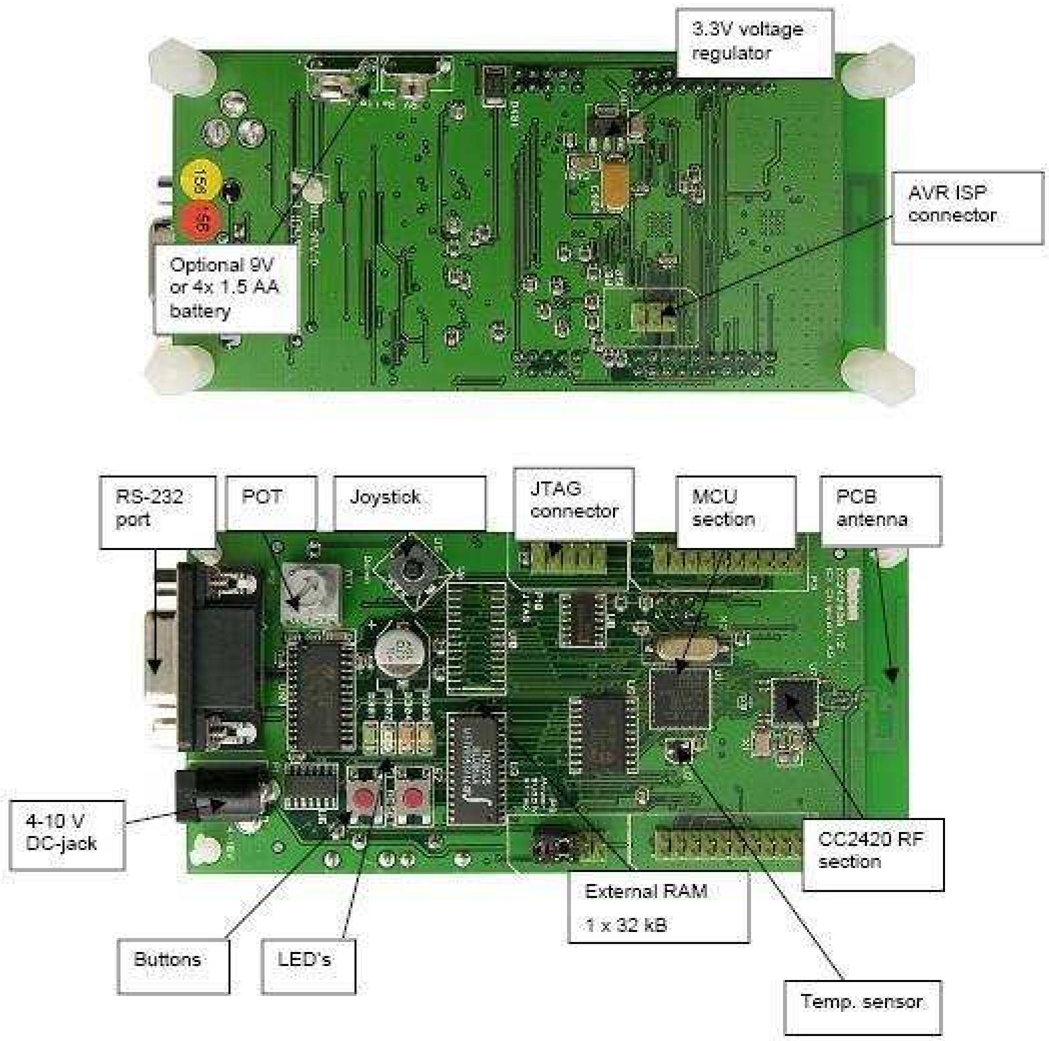


Figure 3.2: CC2420DB Overview [5]

Figure 3.2 illustrates the various features on the CC2420DB demonstration board. The board serves as a development platform. There is an onboard voltage regulator, which allows it to be powered by either a 9V battery for portability or a wall adaptor of 4-10V. It has a standard DB9 connector for RS232 communication with the microcontroller and headers for ISP and JTAG connections, which can be used to program the microcontroller and debug the application. The ATmega128L has the ability to interface an external RAM; the board contains a 32KB external RAM, which is quite sufficient for the program. The board also features a 5-way joystick, buttons and LED's. A small potentiometer is connected to the on-chip ADC of ATmega128L.

3.3.1 Atmel ATmega128L Overview

The ATmega128L is a low power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a clock cycle, the ATmega128L achieves throughputs approaching 1 MIPS per MHz. The AVR core combines a rich instruction set with 32 general-purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle [7].

The ATmega128L provides the following features:

- 128K bytes of in-system programmable Flash
- 4K bytes EEPROM
- 4K bytes SRAM
- Real Time Counter (RTC)
- 2 USART

- SPI port
- 8-channel, 10-bit ADC
- Two 8-bit Timer/Counters and two 16-bit Timer/Counters
- JTAG test interface

3.4 TS-7200 overview

The TS-7200 is a compact, full-featured single board computer (SBC. This board was selected based on its features and the manufacturer provided good support for Linux by providing precompiled Linux Kernel, Debian distribution and tool-chain. This board is small in size and priced economically.

TS-7200 is based on the Cirrus EP9302 ARM9 CPU. The EP9302 features an advanced 200 MHz processor design with a memory management unit (MMU) that allows support for high level operating systems such as Linux, Windows CE, and others [8]. As a general-purpose controller, it provides a standard set of peripherals on board. Figure 3.3 illustrates the hardware components on TS-7200 [8].

The features of TS-7200 are:

- 200 MHz ARM9 CPU with MMU
- 8 MB Strata Flash drive (16 MB Optional)
- 32 MB SDRAM (64 MB Optional)
- True Integrated Drive Electronics (IDE) Compact Flash socket
- 2 USB 2.0 OHCI ports (12 Mbit/s max)
- 2 serial ports (up to 230 Kbaud)
- 10/100 Ethernet port
- Watchdog Timer

- SPI bus interface
- PC/104 expansion bus

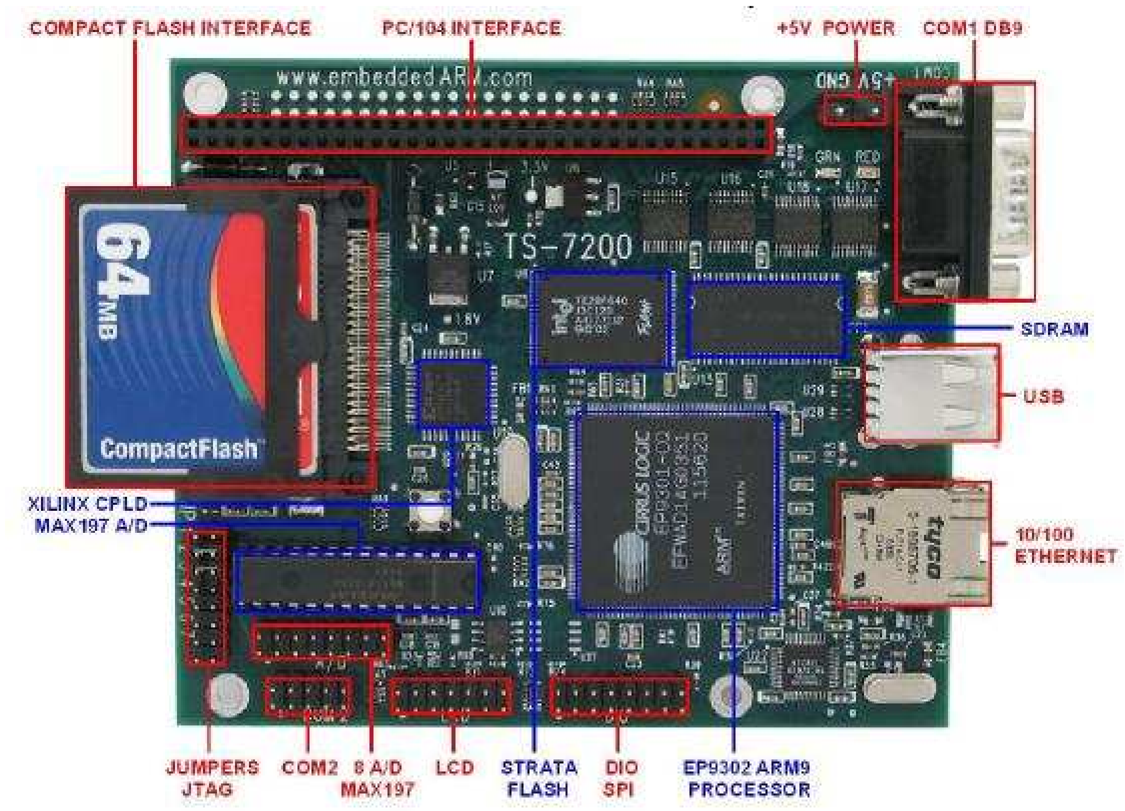


Figure 3.3: TS-7200 Hardware Components [8]

The TS-7200 features a true IDE compact Flash socket. A compact Flash card in the socket appears as a hard drive to the operating system. Compact Flash cards are available in a wide range of capacities. A 512 MB card is sufficient to install a customized version of Debian Linux distribution. The board also features USB and Ethernet ports which can be used to connect to other devices. This board serves right for a PAN coordinator as it is expected to be the master controller.

CHAPTER4: SOFTWARE DESCRIPTION

4.1 System Setup

The setup consists of the CC2420DBK, TS-7200, Desktop, Laptop, Router, and two JTAGICE mkII debuggers. Figure 4.1 illustrates the setup. The laptop, desktop and TS-7200 were connected to the router to form a local area network (LAN). The desktop computer is connected to one of the CC2420DB via JTAGICE mkII debugger. This setup forms one node of the wireless network. The other CC2420DB and TS-7200 connected via RS-232 form another node and this CC2420DB is connected to the Laptop via another JTAGICE mkII.

The router is the dynamic host configuration protocol (DHCP) server of the network. The DHCP server was configured to assign specific Internet Protocol (IP) addresses to the desktop, laptop and TS-7200 which were 192.168.100, 192.168.0.101 and 192.168.0.102 respectively.

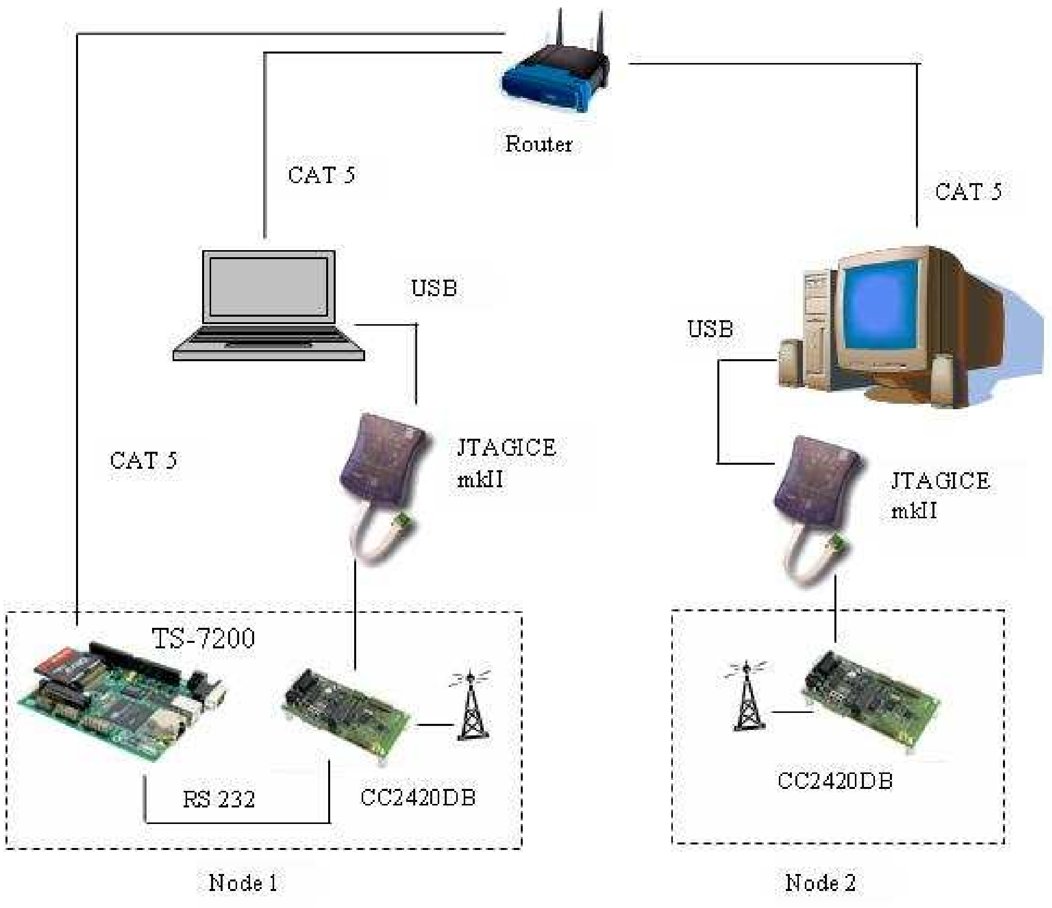


Figure 4.1: Setup overview

4.2 Atmel Development Environment

4.2.1 AVR Studio

AVR Studio is an Integrated Development Environment (IDE) for assembling and debugging AVR application in windows environment. It provides a project management tool, source file editor and chip simulator and interfaces with the JTAGICE mkII for downloading and debugging of applications. The AVR Studio also has a symbolic source level debugger, with features for Break Points, variables watch/ edit, single stepping. Additional features can be added through the use of plugins.

4.2.2 WinAVR

WinAVR is a suite of executable, open source software development tools for the Atmel AVR series of microcontrollers hosted in windows platform. The installation and usage instructions can be found in the user manual [24].

The software development tools include:

- Compilers
- Assemblers
- Linker
- Librarian
- File converters
- C Library
- Debugger
- In-Circuit Emulator software
- Many support utilities.

All the software for the ATmega128L microcontroller was developed using WinAVR tools version 20060421 and AVR Studio version 4.12b.

4.3 Linux Environment

The TS-7200 comes with TS-Linux embedded distribution installed in the on-board Flash memory. TS-Linux is a compact distribution, based on Busybox, ideal for small footprint. BusyBox combines tiny versions of many common Linux/UNIX utilities into a single small executable. A full featured Linux distribution can also be run on either the Network File System (NFS) root file system or installed on a large CompactFlash card.

The on-board Flash contains the TS-Linux kernel which is a standard kernel with patches to customize for this hardware. The version of the on-board kernel was ts-8. A newer version ts-10 based on standard kernel version 2.4.26 was available and the on-board Flash was updated with this version.

A 512MB CompactFlash card was formatted with the second extended file system (ext2) on a desktop running Linux via a USB – CompactFlash card reader. The customized Debian 3.0 (Woody) distribution available on Technologic system website was installed on the CompactFlash card. The configuration of the RedBoot bootloader was updated to specify the CompactFlash card file system as the root file system to the kernel.

There are many advantages of running a full featured Linux distribution where the associated tools, utilities, application and software development environment are available. The Debian distribution; as a default runs a secure shell (SSH) server. Any SSH client could be used to login into this Linux. PuTTY is one such client and is available as free software for many operating environment including windows. Its easy to install and configure [23]. A terminal over SSH was preferred over the standard terminal available on the serial port, as this terminal was found to be more stable and the applications were found to interact well with it.

4.3.1 Cygwin

Cygwin is a Linux-like environment for Windows. It consists of a Dynamic Link Library (DLL) named cygwin1.dll, which acts as an emulation layer providing substantial Portable Operating System Interface (POSIX) system call functionality, and a collection of tools, which provide a Linux look and feel. Many of the Linux applications are ported to execute in Cygwin environment [22].

An NFS server was installed in the Cygwin, the installation steps [17] by H. Sparks were found helpful. It was setup to run and export a local folder “/usr/Sandy”. The TS-7200 was configured to mount this folder at location “/mnt/laptop/” automatically on boot up by adding an entry in the “/etc/fstab” file. This setup would make the folder visible to both the systems, thus enabling file and application sharing. Additional installation and configuration information can be found in the Linux NFS how to [16].

Technologic Systems provides Linux programming tools (toolchain) for Cygwin environment. The toochain was installed on Cygwin, thus allowing Linux applications for TS-7200 to be built from the Cygwin environment. The Cygwin environment was preferred over natively building applications on TS-7200, since the laptop computer offered more computational resources.

4.4 Stack Overview

The software stack implementation is split into two parts, one part of the stack is implemented on the Linux side and the other part resides on the ATmega128L microcontroller. The Linux section implements the device independent higher level functionality of the stack. The device specific part is implemented on the ATmega128L. This allows for easy porting to new 802.15.4 RF transceivers.

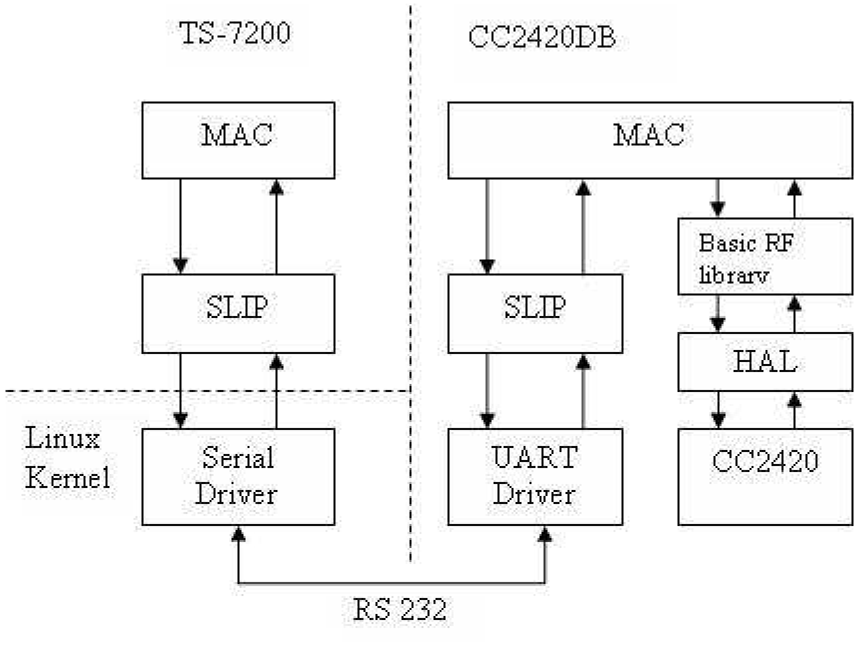
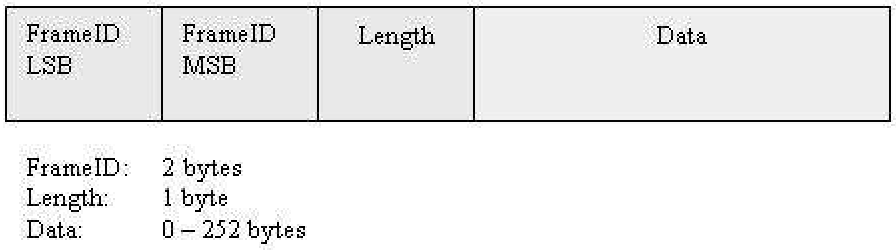


Figure 4.2: Software structure and data flow

4.4.1 Linux - Media Access control (MAC)

As illustrated in the Figure 4.2, the software is implemented in layers. The Media Access Control (MAC) layer is the top layer and it provides a set of functions to initialize, configure, control, send and receive packets of data over the radio. The MAC layer on the Linux side maintains the state and configuration of the node. It communicates with its counterpart on the microcontroller in the form of data packets.



FrameID LSB	FrameID MSB	Length	Data

FrameID:	2 bytes
Length:	1 byte
Data:	0 – 252 bytes

Figure 4.3: The structure of MAC packet

Figure 4.3 shows the structure of a MAC packet as composed of 3 fields. The first field, “FrameID” identifies the type of packet and is of 2 bytes in length. The next field is “Length”, a 1 byte field specifying the total length of the packet in bytes. The third field “Data”, is the actual data, its length varies based on the type of packet. The largest number for the “Length” field can be 255 and the header i.e. “FrameID” and “Length” fields take 3 bytes, consequently a maximum of 252 bytes is available for the “Data” field.

The MAC layer defines a function called MAC_Process(), which must be called often. This function receives packets from SLIP and processes them accordingly. It is best to place a call to this function in the infinite loop part of the software, if the software is multi-threaded a separate thread can be assigned to execute this function periodically.

4.4.2 Linux – Serial Line Internet Protocol (SLIP)

The SLIP was designed to encapsulate IP datagram and send it over serial lines. It encapsulates data to form frames so that the receiving end can differentiate the frames and provide the data to the upper layers. SLIP protocol defines two special characters: “END” (octal 300) and “ESC” (octal 333). To send a packet, a starting character of “END “is sent first, it is followed by the data in the packet. If a data byte is the same code as “END” character, a two byte sequence of “ESC” and octal 334 is sent instead. If it is the same as an “ESC” character, a two byte sequence of “ESC” and octal 335 is sent instead. After the entire data in the packet is sent, an “END” character is sent to end the frame [9]. SLIP encapsulation drops corrupted packets, thus ensuring that the MAC layer always receives a complete data packet. SLIP is a simple protocol and causes very less overhead.

4.4.3 Linux – Serial port

Serial port access in Linux is fairly simple and easy. Each serial port on the system is available as a “ttyS#” device file, # representing the port number, 0 for “COM1”, 1 for “COM2” and so on. These files are located under “/dev” directory. The configuration for the serial port is stored in a structure “termios” which is defined in the header file “termios.h”. The “COM2” of the TS-7200 is connected to the CC2420DB, which can be accessed by the device file “/dev/ttyAM1”. The serial port is configured for sending and receiving of raw data bytes. The data can be sent and received via write() and read() functions respectively. The reference [9], is a good guide for serial port programming in Linux.

4.4.4 ATmega128L – MAC

This layer complements the Linux’s MAC layer with implementation of device specific functionality. The MAC layer receives MAC frames from the SLIP layer and processes them. When a 802.15.4 packet is received, it is wrapped with MAC frame and sent to the Linux MAC layer through SLIP. This layer utilizes the sample code provided by Chipcon to communicate with CC2420. The current stack code expects the MAC_Process() function to be called in the infinite while loop of the microcontroller. This function checks for a new 802.15.4 packet, processes it, it then checks for any new frame in the SLIP layer to process.

The sample code consists of Hardware definition files, Hardware Abstraction Layer (HAL) and Basic RF Library. The Hardware definition files define macros to the registers in the microcontroller and CC2420, thus providing an easier way to access the hardware. To support program development, hardware abstraction layer presents with functions and macros to access most of the CC2420 and microcontroller resources. These functions and macros can be used without hardware specific knowledge. The Basic RF library provides simple function to send and receive 802.15.4 packets through CC2420.

4.4.5 ATmega128L – SLIP

The SLIP layer functionality is the same as in Linux's SLIP layer. It encapsulates every MAC frame being sent and unpacks every received frame and provides it to the MAC layer. The current implementation buffers a single MAC frame received.

4.4.6 ATmega128L – Serial driver

The serial driver provides an interrupt based buffered mechanism for transmitting and receiving data. It implements two circular buffers for transmission and reception. The data being transmitted is copied to the transmit buffer and the transmit interrupt is triggered. The transmit interrupt routine checks for an available data byte and copies it to the transmit data register, if the transmit data buffer is empty, it disables further interrupt triggers. When a byte of data is received in the microcontroller, it triggers the receive interrupt routine which copies the data byte to receive buffer.

4.5 MAC Communication

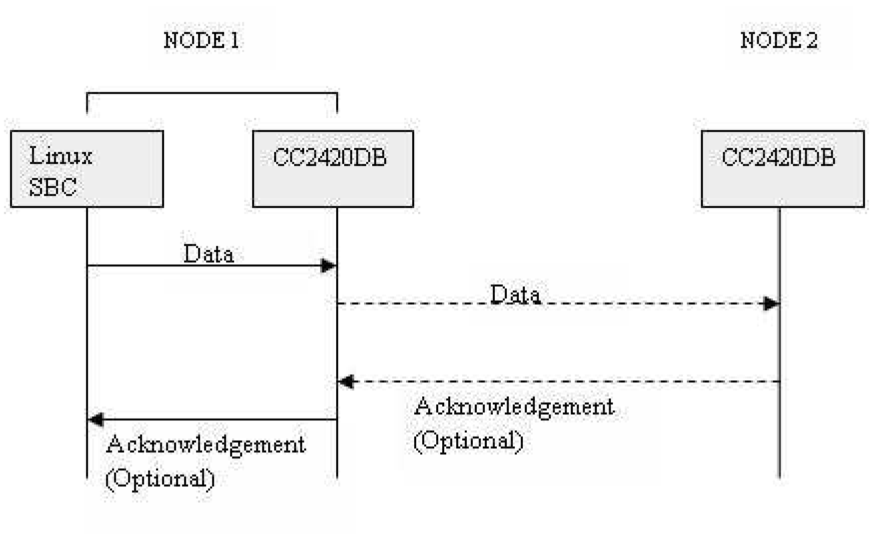


Figure 4.4: Packet Transmission Mechanism

Figure 4.4 illustrates the mechanism to send data from “Node 1” to “Node 2”. The data packed into a MAC frame and wrapped with SLIP is sent from the TS7200 to the CC2420DB. The microcontroller receives the frame and identifying as data to transmit, sends it to CC2420 for transmission over radio. If the acknowledgement option was set, the microcontroller waits for an acknowledgement from the other node before it times out, If it receives an valid acknowledgement it forwards it to the Linux MAC else it sends an transmission error.

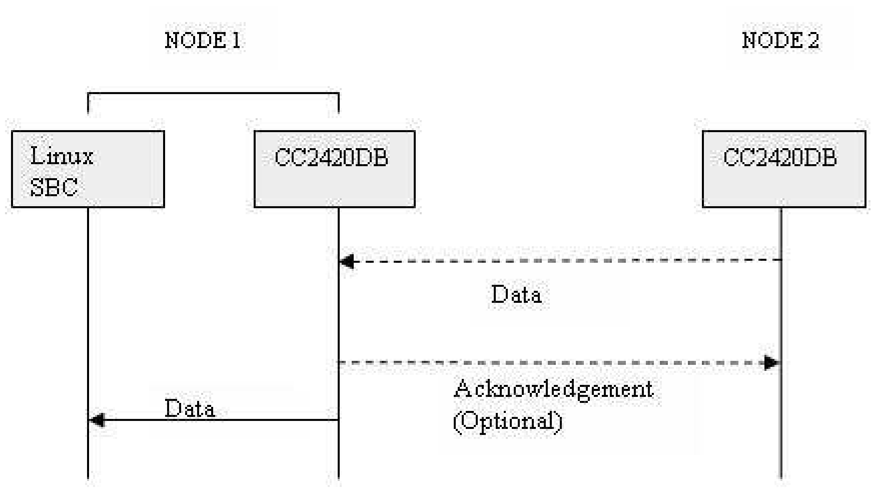


Figure 4.5: Packet receiving mechanism

Figure 4.5 illustrates the packet reception. The “Node 2” sends a data packet addressed to “Node 1”. Upon receiving it, the CC2420 interrupts the microcontroller. The microcontroller gets the data from CC2420 buffer, if the packet requested acknowledgement, it sends an acknowledgement to CC2420 for transmission. The microcontroller then encapsulates the data with a MAC frame and sends it to the Linux SBC.

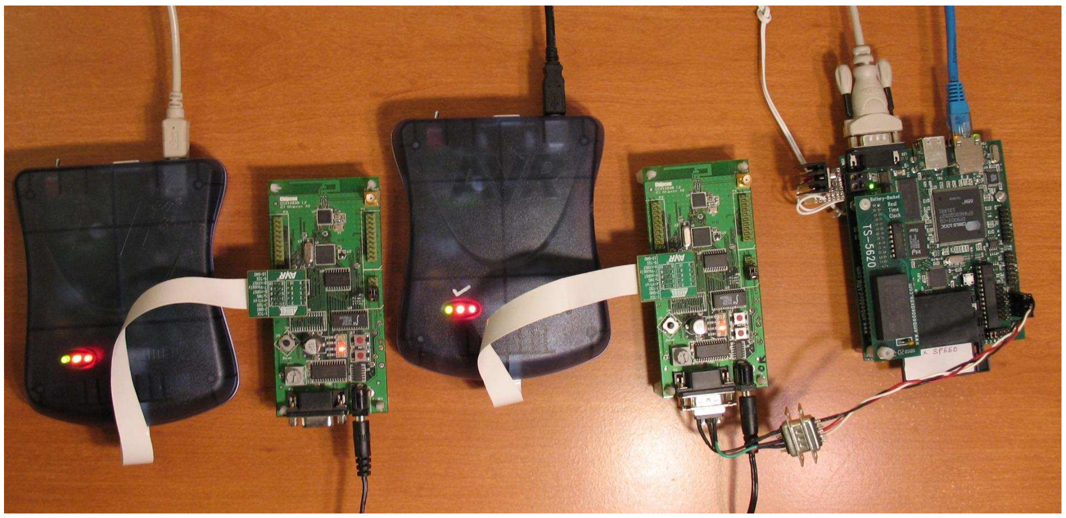
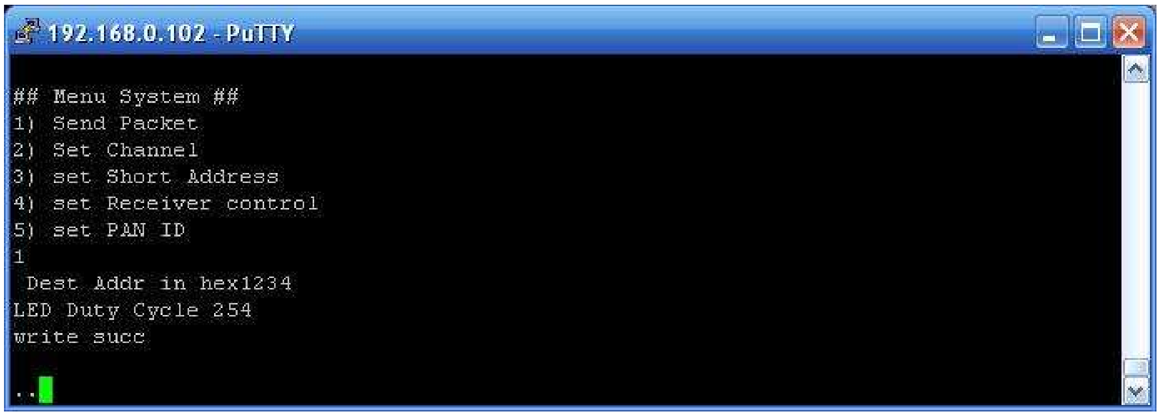


Figure 4.6: The test setup.

4.6 Setup for testing

The system was setup as described in the section 4.1 and illustrated in Figure 4.1. The sample demo program provided by Chipcon for CC2420DB was used in testing. The program establishes a point-to-point RF link between two CC2420DB nodes for communication using the 802.15.4 MAC frames. The program uses 0x2420 as the PAN ID of the nodes and uses channel 26. The short address of the node is selected based on the joystick position, if it was pressed down a short address of 0x1234 is selected else if moved in any direction an address of 0x5678 is selected for the node at startup. If the potentiometer is turned or the joystick centre button is held down, a data packet containing the potentiometer value is sent to the other node, which is used to control the Pulse Width Modulation (PWM) duty cycle thus effectively controlling the brightness of the Orange LED.

The standalone “Node 2” was programmed with the sample demo program. For the “Node 1”, a test program was written which would execute on the Linux SBC and use the stack to communicate with the “Node2”. The test program would perform the same functionality as the demo program, but uses user inputs for the PWM duty cycle and displays the contents on the received packets.

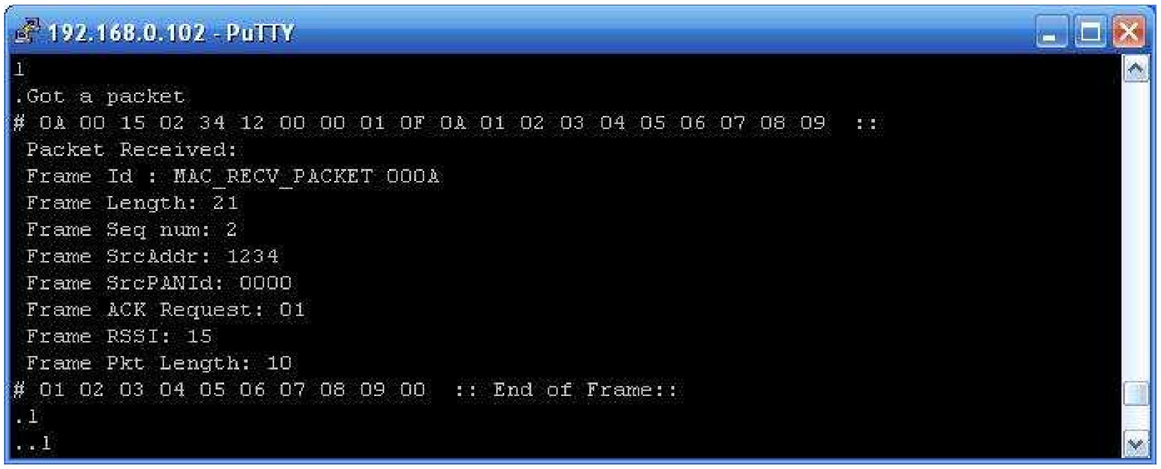


```
## Menu System ##
1) Send Packet
2) Set Channel
3) set Short Address
4) set Receiver control
5) set PAN ID
1
 Dest Addr in hex1234
LED Duty Cycle 254
write succ

..
```

Figure 4.7: Test program menu

Figure 4.7 shows the menu system of the test program. Menu option 1 sends a packet to “Node 2” with a user input value for the PWM duty cycle and the node address. Upon receiving the packet “Node 2” would update the PWM duty cycle value and can be noticed on the brightness of the LED. Other functions of the test program were tested similarly by making appropriate changes on the demo program of “Node 2”.



```
1
.Got a packet
# 0A 00 15 02 34 12 00 00 01 0F 0A 01 02 03 04 05 06 07 08 09  ::
 Packet Received:
 Frame Id : MAC_RECV_PACKET 000A
 Frame Length: 21
 Frame Seq num: 2
 Frame SrcAddr: 1234
 Frame SrcPANId: 0000
 Frame ACK Request: 01
 Frame RSSI: 15
 Frame Pkt Length: 10
# 01 02 03 04 05 06 07 08 09 00  :: End of Frame::
.1
..1
```

Figure 4.8: A received frame by test program

Figure 4.8 shows the contents of a received packet on “Node1” from “Node 2”. The test program displays the various fields associated with the packet received, it also displays the raw bytes of the packet.

CHAPTER5: CONCLUSION

The objectives of the thesis work has been achieved with the implementation of subset features of IEEE 802.15.4 features on a Linux SBC and demonstrate the use of such a controller in LR-PAN. The SBC with Linux setup and the development tools form the embedded Linux development system. The complete system with the hardware setup and the software stack can be used in the following ways.

- Serves as an embedded Linux development system with the development tools, other interfaces such as Ethernet and USB, and many applications.
- Can be used in investigating and developing upper layer protocols such as ZigBee.
- Evaluating various aspects of IEEE 802.15.4 protocol.
- As a tool in the study of co-existence of IEEE 802.15.4 with other wireless standards.
- As a packet logger/analyzer in IEEE 802.15.4 networks.
- As an educational tool in teaching LR-PAN and embedded Linux.
- As a valuable resource in the ongoing research of IEEE 802.15.4 at UNC Charlotte.

5.1 Future work

This thesis work can be extended in many ways. The stack can be enhanced with the support for beacon enabled networks. The current version lacks support for security features, which can be implemented.

The stack can be ported to operating systems such as Windows CE, which is another popular embedded operating system. As Windows CE is widely used in personal digital assistants and cell phones, IEEE 802.15.4 wireless functionality can be added to such devices.

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APPENDIX

ATmega128L code

```
/*******************************************************
*     File Name: MAC.h                                 *
*     Version:    0.1                                  *
*     Author:   Sandeep Sirpatil                       *
*     License: GNU General Public License...............*
*     Purpose: This file contains constansta for  MAC    *
*              and function prototypes                 *
*                                                      *
*******************************************************/

#ifndef MAC_H
#define MAC_H

// Define Frame IDs

#define MAC_SET_PAN_ID         1
#define MAC_GET_PAN_ID         2
#define MAC_SET_ADDR           3
#define MAC_GET_ADDR           4
#define MAC_SET_CHANNEL        5
#define MAC_GET_CHANNEL        6
#define MAC_SET_RECEIVER       7
#define MAC_GET_RECEIVER       8
#define MAC_XMIT_PACKET        9
#define MAC_RECV_PACKET       10
#define MAC_SET_ACK                 11
#define MAC_GET_ACK                 12


// FrameID + length + seqNum+SrcAdd+srcPanID+AckReq+Rssi+length
// 2      + 1         + 1        + 2    + 2       + 1    + 1  + 1 =
11
#define MAC_RECV_PKT_OVERHEAD  11

int MAC_Init();

int MAC_Process();


#endif // MAC_H

/************** END   ***********************************/
/*******************************************************
*     File Name:  MAC.c                                *
*     Version:    0.1                                  *
*     Author:   Sandeep Sirpatil                       *
*     License: GNU General Public License...............*
*     Purpose: This file implements the device specific  *
*               functionality of IEEE 802.15.4         *
*                                                      *
*******************************************************/
```

```
#include "include.h"
#include "SLIP.h"
#include "MAC.h"

#define SLIP_TX_BUF_SIZE  140
#define SLIP_RX_BUF_SIZE  140


// Structure for local copy of the received packet
// This RX Struct will get written into when a packet is received from
radio.
// This copy of the received packet should be used for further
processing.
volatile BASIC_RF_RX_INFO rf_rcv_info;
UINT8 rf_rx_buffer[BASIC_RF_MAX_PAYLOAD_SIZE];
volatile UINT8 received_newFrame;

UINT8 slip_TxBuff[SLIP_TX_BUF_SIZE];

UINT8 slip_RxBuff[SLIP_RX_BUF_SIZE];

 BASIC_RF_TX_INFO rf_Tx_Info;

UINT8 rf_Tx_Buffer[BASIC_RF_MAX_PAYLOAD_SIZE];


//extern volatile BASIC_RF_TX_INFO rf_Tx_Info;


// Initialize function
int MAC_Init(){
      rf_rcv_info.pPayload = rf_rx_buffer;
      rf_Tx_Info.pPayload = rf_Tx_Buffer;

      received_newFrame = FALSE;
      return 0;

}

// Primarily handles packets to be received by SLIP and transmitted via
radio.
// and handle packets received via radio to be sent over SLIP.

int mac_pr_ctr =0;
int MAC_Process(){
      UINT16 slipRxLength;
      int i=0;
      if(received_newFrame == TRUE){ // got a new frame from radio
            // Make a new SLIP frame and send it
            slip_TxBuff[0] = LOWER_BYTE(MAC_RECV_PACKET);
            slip_TxBuff[1] = UPPER_BYTE(MAC_RECV_PACKET);
            slip_TxBuff[2] = MAC_RECV_PKT_OVERHEAD +
rf_rcv_info.length;
            slip_TxBuff[3] = rf_rcv_info.seqNumber;
            slip_TxBuff[4] = LOWER_BYTE(rf_rcv_info.srcAddr);
            slip_TxBuff[5] = UPPER_BYTE(rf_rcv_info.srcAddr);
            slip_TxBuff[6] = LOWER_BYTE(rf_rcv_info.srcPanId);
            slip_TxBuff[7] = UPPER_BYTE(rf_rcv_info.srcPanId);
            slip_TxBuff[8] = rf_rcv_info.ackRequest;
            slip_TxBuff[9] = rf_rcv_info.rssi;
            slip_TxBuff[10] = rf_rcv_info.length;

            memcpy(
&slip_TxBuff[MAC_RECV_PKT_OVERHEAD],rf_rcv_info.pPayload,rf_rcv_info.le
ngth);

            //for (i=0; i< rf_rcv_info.length; i++){
            //    slip_TxBuff[MAC_RECV_PKT_OVERHEAD+i] =
rf_rcv_info.pPayload[i];
      //    }

            SLIP_Send(slip_TxBuff,
MAC_RECV_PKT_OVERHEAD+rf_rcv_info.length);
            mac_pr_ctr++;
            received_newFrame = FALSE; // clear flag

      }

      // check for new any frames received on SLIP and process them
      SLIP_process();
      if(   SLIP_getFrame(slip_RxBuff, &slipRxLength) ==0){
            // got a SLIP frame process it
                unsigned int frameId;
                  frameId = GET_INT(slip_RxBuff[1], slip_RxBuff[0]);

                  switch(frameId){
            case  MAC_SET_PAN_ID :{
                        UINT8 n;
                        UINT16 panid =
GET_INT(slip_RxBuff[4],slip_RxBuff[3]);
                        rfSettings.panId = panid;

                      halRfWaitForCrystalOscillator();
                        DISABLE_GLOBAL_INT();
                        //FASTSPI_WRITE_RAM_LE(&myAddr,
CC2420RAM_SHORTADDR, 2, n);
                  FASTSPI_WRITE_RAM_LE(&panid, CC2420RAM_PANID, 2, n);
                        ENABLE_GLOBAL_INT();
                        }
                  break;
              case MAC_GET_PAN_ID:
                  break;
              case MAC_SET_ADDR :{
                        UINT8 n;
                        UINT16 addr =
GET_INT(slip_RxBuff[4],slip_RxBuff[3]);
                        rfSettings.myAddr = addr;

                      halRfWaitForCrystalOscillator();
                        DISABLE_GLOBAL_INT();
                  FASTSPI_WRITE_RAM_LE(&addr, CC2420RAM_SHORTADDR, 2,
n);
                        ENABLE_GLOBAL_INT();
                        }
                  break;

              case MAC_GET_ADDR:
                  break;

              case MAC_SET_CHANNEL:
                        // check channel range 11-26 valid
                        if( 10 < slip_RxBuff[3] && slip_RxBuff[3] <27){
                        DISABLE_GLOBAL_INT();
                        // if on turn it off
                        if(rfSettings.receiveOn)
FASTSPI_STROBE(CC2420_SRFOFF);
                        halRfSetChannel(slip_RxBuff[3]);
                        if(rfSettings.receiveOn)
FASTSPI_STROBE(CC2420_SRXON);
                        ENABLE_GLOBAL_INT();
                        }
                  break;

              case MAC_GET_CHANNEL:

                  break;

              case MAC_SET_RECEIVER:
                        if(slip_RxBuff[3]==0){ // rx off
                              basicRfReceiveOff();
                              //DISABLE_GLOBAL_INT();
                              //FASTSPI_STROBE(CC2420_SRFOFF);
                              //ENABLE_GLOBAL_INT();
                        }else if(slip_RxBuff[3]==1){ // rx on
                              basicRfReceiveOn();
                              //DISABLE_GLOBAL_INT();
                              //FASTSPI_STROBE(CC2420_SRXON);
                              //ENABLE_GLOBAL_INT();
                        }

                  break;

              case MAC_GET_RECEIVER:
                  break;

              case MAC_XMIT_PACKET:{ // receive from slip and send it
via radio
                        rf_Tx_Info.destAddr =
GET_INT(slip_RxBuff[4],slip_RxBuff[3]);
                        rf_Tx_Info.ackRequest = slip_RxBuff[5];
                        rf_Tx_Info.length = slip_RxBuff[6];
                        memcpy(rf_Tx_Info.pPayload,
&slip_RxBuff[7],slip_RxBuff[6]);
                        //basicRfSendPacket( rf_Tx_Info);
                        if( basicRfSendPacket( &rf_Tx_Info) ){ //TODO:
return status via SLIP
                              TOGGLE_YLED();
                        }else{
                              TOGGLE_RLED();
                        }
                        }
                  break;

              case MAC_RECV_PACKET:
                        break;
            }

      }

      return 0;
}


UINT16 rx_cntr =0;

BASIC_RF_RX_INFO* basicRfReceivePacket(BASIC_RF_RX_INFO *pRRI) {
//    int i=0;
    // Adjust the led brightness
//    PWM0_SET_DUTY_CYCLE(pRRI->pPayload[0]);

    // Blink the green LED
//    SET_GLED();
//    halWait(10000);
//    CLR_GLED();
      rf_rcv_info.seqNumber = pRRI->seqNumber;
      rf_rcv_info.srcAddr = pRRI->srcAddr;
      rf_rcv_info.srcPanId = pRRI->srcPanId;
      rf_rcv_info.length = pRRI->length;

      rf_rcv_info.ackRequest = pRRI->ackRequest;
      rf_rcv_info.rssi = pRRI->rssi;
      memcpy(rf_rcv_info.pPayload, pRRI->pPayload, pRRI->length);

      received_newFrame = TRUE;
      TOGGLE_GLED();
      rx_cntr++;

//    for(i=0; i<pRRI->length;i++){
//          rf_rcv_info.pPayload[i]= pRRI->pPayload[i];
//    }


    // Continue using the (one and only) reception structure
    return pRRI;

} // basicRfReceivePacket


/************** END   ************************************/
```

```
/*********************************************************
*     File Name: SLIP.h                                  *
*     Version:    0.1                                    *
*     Author:   Sandeep Sirpatil                         *
*     License: GNU General Public License................*
*     Purpose: This file contains SLIP configuration     *
*               and function prototypes                  *
*                                                        *
*********************************************************/


#ifndef SLIP_H
#define SLIP_H




#define END             0300    /* indicates end of packet */
#define ESC             0333    /* indicates byte stuffing */
#define ESC_END         0334    /* ESC ESC_END means END data byte */
#define ESC_ESC         0335    /* ESC ESC_ESC means ESC data byte */

int SLIP_Init();

int SLIP_Send(unsigned char *buf, int length);

void SLIP_process();

int SLIP_getFrame(UINT8 *buf, UINT16 *size);



#endif // SLIP_H
/************** END   ************************************/



/*********************************************************
*     File Name: SLIP.c                                  *
*     Version:    0.1                                    *
*     Author:   Sandeep Sirpatil                         *
*     License: GNU General Public License................*
*     Purpose: This file implements SLIP layer and       *
*               uses UART layer as serial driver         *
*                                                        *
*********************************************************/


#include <include.h>
#include "USART.h"
#include "SLIP.h"

#define SLIP_TXBUF_SIZE  200
#define SLIP_RXBUF_SIZE  250

UINT8 slip_xmit_buf[SLIP_TXBUF_SIZE];
UINT8 rx_lastByte;
```

```
struct Slip_Rcv_Frame{
    UINT8 buffer[SLIP_RXBUF_SIZE];
    UINT16 length;
    UINT8 isEmpty;
    UINT8 writeFlag;
};

struct Slip_Rcv_Frame slip_rcv_frame;

int SLIP_Init(){
      slip_rcv_frame.isEmpty = TRUE;
      slip_rcv_frame.length = 0;
      slip_rcv_frame.writeFlag = FALSE;
      return 0;

}

int SLIP_Send(unsigned char *buf, int length){
      int idx=0;
      int i=0;

      slip_xmit_buf[idx] = END;
      idx++;

      for(i=0;i<length;i++){
            if(idx+2 >SLIP_TXBUF_SIZE){
                  return -1; // Buffer overflow
            }
            switch(buf[i]){
                  case END:
                        slip_xmit_buf[idx] = ESC;
                        idx++;
                        slip_xmit_buf[idx] = ESC_END;
                        idx++;
                        break;
                  case ESC:
                        slip_xmit_buf[idx] = ESC;
                        idx++;
                        slip_xmit_buf[idx] = ESC_ESC;
                        idx++;
                        break;
                  default:
                        slip_xmit_buf[idx] = buf[i];
                        idx++;
            }
      }

      slip_xmit_buf[idx] = END;
      idx++;

      return( USART1_Send( idx, slip_xmit_buf));

}

int SLIP_getFrame(UINT8 *buf, UINT16 *size){
      UINT16 i;
      // check the frame status
      if(slip_rcv_frame.isEmpty == FALSE){ // containe a new frame.
      // If new frame is available, copy the data and clear the
receiveframe
            for(i=0;i<slip_rcv_frame.length; i++){
                  buf[i] = slip_rcv_frame.buffer[i];
            }
            *size = slip_rcv_frame.length;
            slip_rcv_frame.isEmpty = TRUE;
            return 0;
      }else{      // If no new frame avialable retunr -1


      return -1;
      }

}


/* This function is to be called as many times as possible.
      It checks the receiveframe, if found empty, it tries to get data
from the
      USART layer and assemble a new frame.*/





void SLIP_process(){
      UINT8 ch;
      int moredata =1;

      if(slip_rcv_frame.isEmpty == TRUE){
          if(slip_rcv_frame.writeFlag == FALSE){ // beginning of a new
frame
              slip_rcv_frame.length = 0;
          }
          while(moredata == TRUE){ // a getdata flag
              if(USART1_Recv(&ch) ==0){ // if a byte is received then
process it

                  switch(ch){
                      case END:
                          if(slip_rcv_frame.writeFlag ==FALSE){ //start
of new frame
                              slip_rcv_frame.writeFlag = TRUE; //
indicate the write is in progress
                          }else{ // End of frame received.
                              slip_rcv_frame.isEmpty = FALSE; //
indicate a new frame is stored.
                                          slip_rcv_frame.writeFlag =
FALSE;
                              moredata = FALSE; // end the while loop
                          }
                          break;

                      case ESC:
                          rx_lastByte = ESC; // keep a record of it

                          break;

                      case ESC_END:
                          if(rx_lastByte == ESC){

slip_rcv_frame.buffer[slip_rcv_frame.length] = END;
                              slip_rcv_frame.length++;
                              rx_lastByte = 0;
                          }else{ // TODO: handle error
                          }
                          break;

                      case ESC_ESC:
                          if(rx_lastByte == ESC){

slip_rcv_frame.buffer[slip_rcv_frame.length] = ESC;
                              slip_rcv_frame.length++;
                              rx_lastByte = 0;
                          }else{ // TODO: handle error
                          }
                          break;

                      default:
                          slip_rcv_frame.buffer[slip_rcv_frame.length]
= ch;
                          slip_rcv_frame.length++;
                  }
              }else{ // no more data in Queue
              moredata = FALSE;
              }
          } // while
      }
}

/************** END   ***********************************/

/*********************************************************
*     File Name: USART.h                                 *
*     Version:    0.1                                    *
*     Author:   Sandeep Sirpatil                         *
*     License: GNU General Public License................*
*     Purpose: Provides varios configuration options for *
*               UART driver.                             *
*                                                        *
*********************************************************/

#ifndef USART_H
#define USART_H

//#define USART_2XMODE   1; // Puts USART in 2x mode. not preferred.

#ifdef USART_2XMODE

// (CPUCLOCK / 8*baud) -1
#define UART_BAUD_2K4           416
```

```
#define UART_BAUD_4K8           207
#define UART_BAUD_9K6           103
#define UART_BAUD_14K4          68
#define UART_BAUD_19K2          51
#define UART_BAUD_28K8          34
#define UART_BAUD_38K4          25
#define UART_BAUD_57K6          16
#define UART_BAUD_76K8          12
#define UART_BAUD_115K2         8
#define UART_BAUD_230K4         3
#define UART_BAUD_250K          3
#define UART_BAUD_500K          1
#define UART_BAUD_1M            0

#else
// (CPUCLOCK / 16*baud) -1
#define UART_BAUD_2K4           207
#define UART_BAUD_4K8           103
#define UART_BAUD_9K6           51
#define UART_BAUD_14K4          34
#define UART_BAUD_19K2          25
#define UART_BAUD_28K8          16
#define UART_BAUD_38K4          12
#define UART_BAUD_57K6          8
#define UART_BAUD_76K8          6
#define UART_BAUD_115K2         3
#define UART_BAUD_230K4         1
#define UART_BAUD_250K          1
#define UART_BAUD_500K          0
// #define UART_BAUD_1M            0 // not supported

#endif


#define XMIT_BUF_SIZE  250
#define RECV_BUF_SIZE  250



extern volatile  UINT8  uart_xmit_buf[XMIT_BUF_SIZE];
extern volatile  UINT8  uart_xmit_buf[RECV_BUF_SIZE];


UINT8 USART1_Send( UINT8, UINT8* );
UINT8 USART1_Init( UINT8 , UINT8, UINT8, UINT8);
UINT8 USART1_Recv(UINT8* );

#endif

/************** END   ***********************************/
```

```
/*********************************************************
*     File Name:  USART.c                                *
*     Version:    0.1                                    *
*     Author:   Sandeep Sirpatil                         *
*     License: GNU General Public License................*
*     Purpose:  A circular buffer device driver for UART *
*                                                        *
*                                                        *
*********************************************************/

#include <include.h>
#include "USART.h"

#define UART1_TX_INT_ENABLE()       do { UCSR1B |= BM(UDRIE1); } while
(0)
#define UART1_TX_INT_DISABLE()      do { UCSR1B &= ~BM(UDRIE1); } while
(0)


volatile  UINT8  uart_xmit_buf[XMIT_BUF_SIZE];
volatile  UINT8  uart_recv_buf[RECV_BUF_SIZE];
volatile  UINT16 uart_Recv_Ridx =0;
volatile  UINT16 uart_Recv_Widx =0;

volatile  UINT16 uart_Xmit_Ridx =0;
volatile  UINT16 uart_Xmit_Widx =0;


volatile  UINT16 txISRCntr =0;
volatile  UINT16 rxISRCntr =0;
volatile  UINT8  rxChar =0;

/* Initialize
UINT8 baud
UINT8 databits = Num of databits, generally 8
UINT8 stopbits = Num of stop bits, generally 1
UINT8 parity = 0-no parity, 1-even, 2- odd

*/

UINT8 USART1_Init( UINT8 baud, UINT8 databits, UINT8 stopbits, UINT8
parity ){


//INIT_UART1(UART_BAUDRATE_9K6,(UART_OPT_8_BITS_PER_CHAR||UART_OPT_ONE_
STOP_BIT||UART_OPT_NO_PARITY));
      // disable global int
      DISABLE_GLOBAL_INT();
      UBRR1H = (unsigned char) baud >>8;
      UBRR1L = baud;

      UCSR1A &= ~0x01; // Multi procesor disable
      UCSR1B = 0; // default state
      UCSR1C = 0x06; // default

      #ifdef USART_2XMODE
            UCSR1A |= BM(U2X1);
```

```
#else
      UCSR1A &= ~BM(U2X1);
#endif

switch(databits){
case 5:
            UCSR1C &= ~BM(UCSZ10);
            UCSR1C &= ~BM(UCSZ11);
            UCSR1B &= ~BM(UCSZ12);
            break;
case 6:
            UCSR1C |=  BM(UCSZ10);
            UCSR1C &= ~BM(UCSZ11);
            UCSR1B &= ~BM(UCSZ12);
            break;
case 7:
            UCSR1C &= ~BM(UCSZ10);
            UCSR1C |=  BM(UCSZ11);
            UCSR1B &= ~BM(UCSZ12);
            break;
case 8:
            UCSR1C |=  BM(UCSZ10);
            UCSR1C |=  BM(UCSZ11);
            UCSR1B &= ~BM(UCSZ12);
            break;
case 9:
            UCSR1C |=  BM(UCSZ10);
            UCSR1C |=  BM(UCSZ11);
            UCSR1B |=  BM(UCSZ12);
            break;
default:
            return -1;

}

if(stopbits ==1){
      UCSR1C &= ~BM(USBS1);
}else if (stopbits ==2){
      UCSR1C |= BM(USBS1);
}else{
      return -1;
}

if (parity ==0){
      UCSR1C &= ~BM(UPM11);
      UCSR1C &= ~BM(UPM10);

}else if (parity==1){ // even
      UCSR1C |=  BM(UPM11);
      UCSR1C &= ~BM(UPM10);

}else if (parity ==2){ // odd
      UCSR1C |=  BM(UPM11);
      UCSR1C |=  BM(UPM10);

}else{
      return -1;
```

```
        }

        UCSR1B |= (BM(RXEN1)|BM(RXCIE1)); // rx | int enable
        UCSR1B |= BM(TXEN1); //tx enable

        // Initialize
        ENABLE_GLOBAL_INT();
        return 0;


}

/* Starts the interrupts for transmission*/
void USART1_startTx(UINT8 ch){



}

/* send function*/
UINT8 USART1_Send( UINT8 numBytes, UINT8* arry){
        UINT16 i=0;
        UINT16 xmit_Widx =0;
        xmit_Widx = uart_Xmit_Widx; // local copy

        for (i=0;i<numBytes; i++){

                if(xmit_Widx+1 == uart_Xmit_Ridx ||( xmit_Widx+1 ==
XMIT_BUF_SIZE && !uart_Xmit_Ridx)){
                        return -1; // buffer full
                }
                uart_xmit_buf[xmit_Widx]= arry[i];
                xmit_Widx++;
                if(xmit_Widx == XMIT_BUF_SIZE) xmit_Widx = 0; // loop back

        }

        uart_Xmit_Widx = xmit_Widx; // restore the pointer
        // enable TX int
        UART1_TX_INT_ENABLE();
        return 0;
}



UINT8 USART1_Recv(UINT8 *ch){
        if(uart_Recv_Ridx == RECV_BUF_SIZE) uart_Recv_Ridx =0;
        if(uart_Recv_Ridx == uart_Recv_Widx){
                return -1;
        }else{
                uart_Recv_Ridx++;
                 *ch = uart_recv_buf[uart_Recv_Ridx-1];
                return 0;
        }
}
```

```
/* Interrupt routine for Receive  */
ISR(USART1_RX_vect){
      UINT8 ch;
      if(uart_Recv_Widx+1 == uart_Recv_Ridx ||(uart_Recv_Widx+1
==RECV_BUF_SIZE && !uart_Recv_Ridx)){
            // err cntr ++
            // dummy read ??
            ch = UDR1;
      }else{
            uart_recv_buf[uart_Recv_Widx] = UDR1;
            uart_Recv_Widx++;
            if(uart_Recv_Widx==RECV_BUF_SIZE ) uart_Recv_Widx=0;
      }


}

/* ISR for TX*/
ISR(USART1_UDRE_vect){
      txISRCntr++;

      if(uart_Xmit_Ridx == XMIT_BUF_SIZE)
            uart_Xmit_Ridx = 0; // loop  back
      if(uart_Xmit_Ridx == uart_Xmit_Widx){
            UART1_TX_INT_DISABLE();
      }else{
            uart_Xmit_Ridx++;
            UDR1 = uart_xmit_buf[uart_Xmit_Ridx-1];
      }

}

/************** END   ***********************************/

/************************************************************
*     File Name:  util.h                                    *
*     Version:    0.1                                       *
*     Author:   Sandeep Sirpatil                            *
*     License: GNU General Public License............... .*
*     Purpose: provides utility macros                      *
*                                                           *
*                                                           *
***********************************************************/


#ifndef UTIL_H
#define UTIL_H

#define LOWER_BYTE(x) ((unsigned char)(x & 0xFF))
#define UPPER_BYTE(x) ((unsigned char)((x & 0xFF00)>>8))


#define GET_INT(x,y)  ((((UINT8)x)<<8) |((UINT8)y))
#endif // UTIL_H

/************** END   ***********************************/
```

Linux Code:

```
/**********************************************************
*     File Name: main.c                                  *
*     Version:    0.1                                    *
*     Author:   Sandeep Sirpatil                         *
*     License: GNU General Public License................*
*     Purpose: Sample test application                   *
*                                                        *
*                                                        *
**********************************************************/
#include "include.h"
#include <errno.h>
void sig_catcher(int sig);

void menu();

int main(){
    unsigned char ch,rxBuf[50],txBuf[50];
    int rxLen =0;
    int rtn;

    txBuf[0] = 'A';
    txBuf[1] = 'B';
    txBuf[2] = ESC;
    txBuf[3] = 'D';
    txBuf[4] = 'E';
    txBuf[5] = 'F';

    if( signal(SIGINT,sig_catcher)== SIG_ERR){
        fprintf(stderr,"Sigset cannot set SIGINT");
    }




    SLIP_Init();
   // SLIP_Send(txBuf,6);

    while(1){
        SLIP_Process();
        rtn = SLIP_Recv(rxBuf,&rxLen);
        if(rtn ==0){
            fprintf(stderr,"Got a packet\n");
            printBuf(rxBuf,rxLen);
            printPacket(rxBuf,rxLen);
            clearBuf(rxBuf,rxLen);
        }
        if(rxBuf[0] =='X')
            break;
        ch = getchar();
        if(ch =='z'){
            SLIP_Send(txBuf,6);
        }else if(ch=='m'){
            menu();
        }else if(ch =='a'){
```

```
        int duty;
            fprintf(stderr,"inside");
            txBuf[0]= LOWER_BYTE(MAC_XMIT_PACKET);
            txBuf[1]= UPPER_BYTE(MAC_XMIT_PACKET);
            txBuf[2]= 17; // length
            txBuf[3]= 0x34;
            txBuf[4]= 0x12;
            txBuf[5]=TRUE; // ack request
            txBuf[6]=10;
            //duty = getchar();
            //duty = getchar();
            //fprintf(stderr," before Errno %d %d",errno,rtn);
            scanf("%d",&duty);
            //rtn = fscanf(stdin, "Duty cycle %d",&duty);
            //fprintf(stderr,"Errno %d %d",errno,rtn);
            txBuf[7]=LOWER_BYTE(duty);
           // txBuf[7]=0xDE;

            SLIP_Send(txBuf,17);

        }
        fprintf(stderr,".");
        sleep(1);

    }

    SLIP_Term();


return 0;
}


void sig_catcher(int sig){
        fprintf(stderr,"SIG caught");
        SLIP_Term();

        exit(EXIT_FAILURE);
        perror("SIGINT: port closed and exit.");
}

void menu(){
    unsigned char txBuf[50];
    int menu;
    fprintf(stderr,"\n## Menu System ##\n");
    fprintf(stderr, "1) Send Packet \n");
    fprintf(stderr,"2) Set Channel \n");
    fprintf(stderr,"3) set Short Address\n");
    fprintf(stderr,"4) set Receiver control \n");
    fprintf(stderr,"5) set PAN ID \n");
    scanf("%d",&menu);
    switch(menu){
        case 1:{
            int add=0,duty;
            txBuf[0]= LOWER_BYTE(MAC_XMIT_PACKET);
            txBuf[1]= UPPER_BYTE(MAC_XMIT_PACKET);
            txBuf[2]= 17; // length
            txBuf[3]= 0x34;
            txBuf[4]= 0x12;
            txBuf[5]=TRUE; // ack request
            txBuf[6]=10;
            fprintf(stderr," Dest Addr in hex");
            scanf("%X",&add);
            if(add!=0){
                txBuf[3] =LOWER_BYTE(add);
                txBuf[4] =UPPER_BYTE(add);
            }
            fprintf(stderr,"LED Duty Cycle ");
            scanf("%d",&duty);
            txBuf[7]=LOWER_BYTE(duty);
            SLIP_Send(txBuf,17);
            fprintf(stderr,"\n");
            }break;
        case 2:{
            int chnl =0;
            txBuf[0]= LOWER_BYTE(MAC_SET_CHANNEL);
            txBuf[1]= UPPER_BYTE(MAC_SET_CHANNEL);
            txBuf[2]= 4; // length
            fprintf(stderr,"\nChannel range 11-26 :");
            scanf("%d",&chnl);
            while((chnl < 11 )|| (chnl > 26)){
                fprintf(stderr,"\nIncorrect Channel");
                scanf("%d",&chnl);
            }
            txBuf[3] = LOWER_BYTE(chnl);
            SLIP_Send(txBuf,4);

            }break;
        case 3:{
            int addr;
            txBuf[0]=LOWER_BYTE(MAC_SET_ADDR);
            txBuf[1]=UPPER_BYTE(MAC_SET_ADDR);
            txBuf[2]=5;
            fprintf(stderr,"\nNode address in Hex:");
            scanf("%X",&addr);
            txBuf[3] = LOWER_BYTE(addr);
            txBuf[4] = UPPER_BYTE(addr);
            SLIP_Send(txBuf,5);
            }break;
        case 4:{
            int rxCntrl;
            txBuf[0]=LOWER_BYTE(MAC_SET_RECEIVER);
            txBuf[1]=UPPER_BYTE(MAC_SET_RECEIVER);
            txBuf[2]=4;
            fprintf(stderr,"\nReceiver control 1-On, 0-Off");
            scanf("%d",&rxCntrl);
            while((rxCntrl!=0) &&(rxCntrl!=1)){
                fprintf(stderr,"\nIncorrect:");
                scanf("%d",&rxCntrl);
            }
            txBuf[3]=LOWER_BYTE(rxCntrl);
            SLIP_Send(txBuf,4);
            }break;
        case 5:{
```

```
            int panId;
            txBuf[0]=LOWER_BYTE(MAC_SET_PAN_ID);
            txBuf[1]=UPPER_BYTE(MAC_SET_PAN_ID);
            txBuf[2]=5;
            fprintf(stderr,"\nSet PanID in HEx ");
            scanf("%X",&panId);
            txBuf[3]=LOWER_BYTE(panId);
            txBuf[4]=UPPER_BYTE(panId);
            SLIP_Send(txBuf,5);
            }break;
        default:
            fprintf(stderr,"Incorrect choice");
    }

}
/************** END   ***********************************/

/*********************************************************
*     File Name: MAC.h                                  *
*     Version:    0.1                                   *
*     Author:   Sandeep Sirpatil                        *
*     License: GNU General Public License................*
*     Purpose: This file contains constants for  MAC     *
*               and function prototypes                 *
*                                                       *
*********************************************************/

#ifndef MAC_H
#define MAC_H

#define MAC_SET_PAN_ID         1
#define MAC_GET_PAN_ID         2
#define MAC_SET_ADDR           3
#define MAC_GET_ADDR           4
#define MAC_SET_CHANNEL        5
#define MAC_GET_CHANNEL        6
#define MAC_SET_RECEIVER       7
#define MAC_GET_RECEIVER       8
#define MAC_XMIT_PACKET        9
#define MAC_RECV_PACKET       10
#define MAC_SET_ACK                 11
#define MAC_GET_ACK                 12


// FrameID + length + seqNum+SrcAdd+srcPanID+AckReq+Rssi+length
// 2      + 1          + 1         + 2    + 2        + 1    + 1  + 1 =
11
#define MAC_RECV_PKT_OVERHEAD  11

#endif //MAC_H

/************** END   ***********************************/
```

```
/********************************************************
*     File Name: SLIP.h                                 *
*     Version:    0.1                                   *
*     Author:   Sandeep Sirpatil                        *
*     License: GNU General Public License................*
*     Purpose: This file contains SLIP configuration    *
*              and function prototypes                  *
*                                                       *
********************************************************/
#ifndef SLIP_H
#define SLIP_H


/* SLIP definitions */
#define END             0300    /* indicates end of packet  0xC0 */
#define ESC             0333    /* indicates byte stuffing  0xDB */
#define ESC_END         0334    /* ESC ESC_END means END data byte 0xDC
*/
#define ESC_ESC         0335    /* ESC ESC_ESC means ESC data byte 0xDD
*/


#define SLIP_TX_BUFF_SIZE 250
#define SLIP_RX_BUFF_SIZE 500
#define FRAME_SIZE  250

/* Serial port definitions */
#define BAUD_RATE  B9600

//#define BAUD_RATE  B57600
//#define BAUD_RATE  B115200
//#define BAUD_RATE  B230400


#define PORT    "/dev/ttyAM1"

/* Function declerations*/
int SLIP_Init();
int SLIP_Term();

int SLIP_Process();
int SLIP_Send(unsigned char *buf, int len);
int SLIP_Recv(unsigned char *buf,int *length);

#endif //SLIP_H
/************** END   ***********************************/

/********************************************************
*     File Name: SLIP.c                                 *
*     Version:    0.1                                   *
*     Author:   Sandeep Sirpatil                        *
*     License: GNU General Public License................*
*     Purpose: This file implements SLIP Layer          *
*                                                       *
*                                                       *
********************************************************/
/* The file contains the code to interface to the serial port
```

```
and send and receive SLIP frames*/

#include "include.h"

// Receive Circular buffer
static int rx_rdIdx =0;
static int rx_wrIdx = 0;
static unsigned char rx_buffer[SLIP_RX_BUFF_SIZE];
static unsigned char rx_lastByte;
struct rxFrame{
    unsigned char buffer[FRAME_SIZE];
    int length;
    int isEmpty;
    int writeFlag;
    };

struct rxFrame rx_frame;
struct termios oldconfig, newconfig;
int fd;

/* Function definitions of local functions */
int port_Open();
int port_Close();
int rx_putByte( char c);
int rx_getByte(unsigned char *c);


int SLIP_Init(){
    rx_frame.isEmpty = TRUE;
    rx_frame.writeFlag = FALSE;
    rx_frame.length =0;
    fd = 0;
    return (port_Open());

}

int SLIP_Term(){
     return (port_Close());


}



int port_Open(){
    int ret;
    /* O_NOCTTY - this is not the controlling terminal program else
Cntr-C will close process */
    /* O_NDELAY or O_NONBLOCK  - Do not care abt DCD line status and
non blocking read*/
    //fd = open("/dev/ttyAM1", O_RDWR | O_NOCTTY | O_NDELAY);
    fd = open(PORT, O_RDWR | O_NOCTTY | O_NDELAY);
    if(fd == -1){
        return -1; // port open failed
    }
    tcgetattr(fd, &oldconfig); // save the old config
    tcgetattr(fd, &newconfig);
    // Set the port speed parameters
    cfsetispeed(&newconfig, BAUD_RATE);
    cfsetospeed(&newconfig, BAUD_RATE);
    // 8N1
    newconfig.c_cflag &= ~PARENB;
    newconfig.c_cflag &= ~CSTOPB;
    newconfig.c_cflag &= ~CSIZE;
    newconfig.c_cflag |= CS8;
    newconfig.c_cflag &= ~CRTSCTS; // No Flow control
    newconfig.c_cflag |= (CLOCAL | CREAD); // local line no ownew
change and enable receiver
    // set line parameters for raw input; ie no processing
    newconfig.c_lflag &= ~(ICANON |ECHO|ECHOE| ISIG);

    // Input flags
    newconfig.c_iflag &= ~(IXON|IXOFF |IXANY);

    // Output flags
    newconfig.c_oflag &= ~OPOST; // raw output
    // set the new options to the port
    ret = tcsetattr(fd, TCSANOW, &newconfig);

    return 0;
}

int port_Close(){
    //restore old port settinngs
    if(fd!=0 && fd!=-1){
        tcsetattr(fd, TCSANOW, &oldconfig);
        close(fd);
        fprintf(stderr,"Port closed\n");
        return 0; // test
    }
    return -1;
}


/* Max packet size is about 150 bytes
    sends a packet through the serial port frammed in slip protocol
    */
int SLIP_Send(unsigned char *buf, int len){
    unsigned char slipBuff[SLIP_TX_BUFF_SIZE];
    int idx=0;
    int i;
     /* send an initial END character to flush out any data that may
      * have accumulated in the receiver due to line noise
      */
    slipBuff[idx] = END;
    idx++;

    for( i =0; i<len ;i++){

        if(idx+2 > SLIP_TX_BUFF_SIZE){
            return -1; // buffer overflow
        }
        switch(buf[i]){
            // data equals END, then send ESC followed by END
            case END:
                slipBuff[idx] = ESC;
                idx++;
                slipBuff[idx] = ESC_END;
                idx++;
                break;
             case ESC:
                slipBuff[idx] = ESC;
                idx++;
                slipBuff[idx] = ESC_ESC;
                idx++;
                break;
             default:
                slipBuff[idx] = buf[i];
                idx++;

        }

    }
    slipBuff[idx] = END; // end of frame
    idx++;
    //printBuf(slipBuff,10); // debug
    if(idx == write(fd,slipBuff,idx)){
        fprintf(stderr,"write succ\n");
        return 0; // write success

    }else {
        return -1; // write failure
    }
}

int SLIP_Recv(unsigned char *buf,int *length){
    int i;
    if(rx_frame.isEmpty ==FALSE){
        for(i=0;i<rx_frame.length;i++){
            buf[i] = rx_frame.buffer[i];
        }
        *length = rx_frame.length;
        rx_frame.isEmpty = TRUE;

    }else{
        return -1; // no new frame
    }
    return 0;
}
/* Serial receive Queue management functions */

int rx_putByte( char c){
    if(rx_wrIdx+1 ==rx_rdIdx || (rx_wrIdx+1 == SLIP_RX_BUFF_SIZE &&
!rx_rdIdx)) {
        return -1; // Queue full
    }
    rx_buffer[rx_wrIdx] = c;
    rx_wrIdx++;
    if(rx_wrIdx ==SLIP_RX_BUFF_SIZE){
        rx_wrIdx =0;
    }
    return 0;
}

int rx_getByte(unsigned char *c){
    if(rx_rdIdx == SLIP_RX_BUFF_SIZE){
         rx_rdIdx = 0; // reset it
    }
    if(rx_rdIdx == rx_wrIdx){
        return -1; // Queue empty
    }
    rx_rdIdx++;
    *c = rx_buffer[rx_rdIdx -1];
    return 0;
}


// Should be called periodically to process the input buffer
int SLIP_Process(){
    unsigned char buffer[50],ch;
    int rtn=0, i=0;
    int moredata = 1;



    rtn = read(fd, &buffer, 50);
    //printf("Slip read return %d ",rtn);
    //fprintf(stderr,"f-Slip read return  ");
    if(rtn >0){
        for(i=0; i<rtn; i++){
            rx_putByte(buffer[i]);
            // TODO: need to take care of Queue full  condition
        }
    }
    // check the current frame status, if empty, load new frame

    if(rx_frame.isEmpty == TRUE){
        if(rx_frame.writeFlag == FALSE){ // beginning of a new frame
            rx_frame.length = 0;
        }
        while(moredata == TRUE){ // a getdata flag
            if(rx_getByte(&ch) ==0){ // if a byte is received then
process it
                switch(ch){
                    case END:
                        if(rx_frame.writeFlag ==FALSE){ //start of new
frame
                            rx_frame.writeFlag = TRUE; // indicate the
write is in progress
                        }else{ // End of frame received.
                            rx_frame.isEmpty = FALSE; // indicate a new
frame is stored.
                            rx_frame.writeFlag = FALSE;
                            moredata = FALSE; // end the while loop
                            //fprintf(stderr,"slip got a frame\n");
                        }
                        break;
                    case ESC:
                        rx_lastByte = ESC; // keep a record of it

                        break;

                    case ESC_END:
                        if(rx_lastByte == ESC){
                            rx_frame.buffer[rx_frame.length] = END;
                            rx_frame.length++;
                            rx_lastByte = 0;
                        }else{ // TODO: handle error
                        }
                        break;
                    case ESC_ESC:
                        if(rx_lastByte == ESC){
                            rx_frame.buffer[rx_frame.length] = ESC;
                            rx_frame.length++;
                            rx_lastByte = 0;
                        }else{ // TODO: handle error
                        }
                        break;
                    default:
                        rx_frame.buffer[rx_frame.length] = ch;
                        rx_frame.length++;
                }
            }else{ // no more data in Queue
            moredata = FALSE;
            }
        } // while
    }

    return 0;
}

/************** END   ************************************/

/*********************************************************
*     File Name:  util.h                                *
*     Version:    0.1                                   *
*     Author:   Sandeep Sirpatil                        *
*     License: GNU General Public License................*
*     Purpose: This file contains utility macros        *
*              and function prototypes                  *
*                                                       *
********************************************************/
#ifndef UTIL_H
#define UTIL_H

#define LOWER_BYTE(x) ((unsigned char)(x & 0xFF))
#define UPPER_BYTE(x) ((unsigned char)((x & 0xFF00)>>8))

// x- MSB y-LSB
#define GET_INT(x,y)  ((((unsigned char)x)<<8) |((unsigned char)y))
void printBuf(unsigned char *buf, int len);
void clearBuf(unsigned char *buf, int len);
void printPacket(unsigned char *buf, int len);
#endif

/************** END   ***********************************/

/* *****************************************************
*     File Name:  SLIP.h                               *
*     Version:    0.1                                  *
*     Author:   Sandeep Sirpatil                       *
*     License: GNU General Public License................*
*     Purpose: This file utility functions             *
*                                                      *
*                                                      *
*******************************************************/

#include "include.h"

/* Printf the contenets of buffer in Hex to stderr*/
void printBuf(unsigned char *buf, int len){
    int i;
    fprintf(stderr,"# ");
    for(i=0; i<len; i++){
        fprintf(stderr,"%02X ", buf[i]);
    }
    fprintf(stderr," ::");
}

void clearBuf(unsigned char *buf, int len){
    int i=0;
    for(i=0;i<len;i++){
        buf[i] = 0;
    }
}

void printPacket(unsigned char *buf, int len){
    unsigned int frameId;
    frameId = GET_INT(buf[1], buf[0]);
    switch(frameId){
        case  MAC_SET_PAN_ID :
            break;
        case MAC_GET_PAN_ID:
            break;
        case MAC_SET_ADDR :
            break;

        case MAC_GET_ADDR:
            break;
        case MAC_SET_CHANNEL:
            break;
        case MAC_GET_CHANNEL:
            break;
        case MAC_SET_RECEIVER:
            break;
        case MAC_GET_RECEIVER:
            break;
        case MAC_XMIT_PACKET:
            break;
        case MAC_RECV_PACKET:
            fprintf(stderr,"\n Packet Received:\n");
            fprintf(stderr," Frame Id : MAC_RECV_PACKET
%04X\n",frameId);
            fprintf(stderr," Frame Length: %u\n",buf[2]);
            fprintf(stderr," Frame Seq num: %u\n",buf[3]);
            fprintf(stderr," Frame SrcAddr:
%04X\n",GET_INT(buf[5],buf[4]));
            fprintf(stderr," Frame SrcPANId:
%04X\n",GET_INT(buf[7],buf[6]));
            fprintf(stderr," Frame ACK Request: %02X\n", buf[8]);
            fprintf(stderr," Frame RSSI: %d\n", buf[9]);
            fprintf(stderr," Frame Pkt Length: %u\n",buf[10]);
            printBuf(&buf[11],buf[10]);
            fprintf(stderr," End of Frame::\n");

            break;
        case MAC_SET_ACK:
            break;
        case MAC_GET_ACK:
            break;
        default:
            fprintf(stderr," Case fail in func \"printPacket\" \n");

    }
}

/************** END   ***********************************/
/*******************************************************
*     File Name:  include.h                            *
*     Version:    0.1                                  *
*     Author:   Sandeep Sirpatil                       *
*     License: GNU General Public License..............*
*     Purpose: A general include file for the whole    *
*             application                              *
*                                                      *
*******************************************************/
#ifndef INCLUDE_H
#define INCLUDE_H
// general definitions used in the stack
#include <sys/types.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <termios.h>
#include <stdio.h>
#include <signal.h>

#include <unistd.h>
#include <stdlib.h>
#include <errno.h>

#include "util.h"
#include "SLIP.h"
#include "MAC.h"
```

```
#ifndef TRUE
#define TRUE 1
#endif

#ifndef FALSE
#define FALSE 0
#endif


#endif // INCLUDE_H

/************** END   ************************************/
```