Implementation of WiFiRe MAC protocol

Ranging, Registration and Packet classifier modules

A thesis submitted in partial fulfillment of
the requirements for the degree of

Master of Technology

by

Madalapu Ranjith Kumar
(Roll No. 05329R08)

Under the guidance of
Prof. Sridhar Iyer
and
Prof. Anirudha Sahoo

DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY–BOMBAY
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Dissertation Approval Sheet

This is to certify that the dissertation entitled

Implementation of WiFiRe MAC protocol

by

Madalapu Ranjith Kumar

(Roll no. 05329R08)

is approved for the degree of **Master of Technology**.

____

Prof. Sridhar Iyer

(Supervisor)

____

Prof. Anirudha Sahoo

(Co-Supervisor)

____

Prof. Varsha Apte

(Internal Examiner)

____

Dr. Vijay Raisinghani

(External Examiner)

____

Prof. T.K. Biswal

(Chairperson)

Date: ______________

Place: ______________

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

CERTIFICATE OF COURSE WORK

This is to certify that **Mr. Madalapu Ranjith Kumar** was admitted to the candidacy of the M.Tech. Degree and has successfully completed all the courses required for the M.Tech. Programme. The details of the course work done are given below.

Sr.No.	Course No.	Course Name	Credits
		Semester 1 (Jul – Nov 2005)	
1.	HS699	Communication and Presentation Skills (P/NP)	4
2.	IT601	Mobile Computing	6
3.	IT605	Computer Networks	6
4.	IT619	IT Foundation Lab	8
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6.	CS681	Performance Analysys of Computer Systems and Network	6
7.	IT620	New Trends in Information Technology	6
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10.	IT628	Information Technology Project Management	6
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Abstract

WiFiRe is an extension of the existing WiFi protocol for providing broadband access for rural areas. It provides good bandwidth at ow cost by making use of licence free spectrum at 2.4GHz band and also cost effective chipsets of WiFi (PHY). It mainly replaces the MAC of existing WiFi (802.11b) with a MAC of WiMAX (802.16). It follows Time Division Duplex-Multi Sector TDM (TDD-MSTDM) which uses same channel for both UL (up-link) and DL (down-link). It has star topology, and divides whole area into sectors; each sector has one base station (BS) with sectorized antenna, each village has one subscriber terminal (ST) with directional antenna and a System (S) located at fiber Point-of-Presence (PoP), which controls the whole network. WiFiRe has one single MAC for all sectors (PHY) in the System, which helps to co-ordinate the medium access.

Design of WiFiRe MAC was started last year and emulation over Ethernet was proposed. We implemented most of the functionalities for single sector WiFiRe MAC. Implementation is done using C sockets and it allows user to test basic MAC functions such as connection establishment, packet flow and header construction, in absence of WiFiRe hardware. Our code can be easily ported onto hardware. Our implementation supports various kind of applications like HTTP, FTP, VoIP etc. for Single BS, multiple Subscriber Terminals (ST) and their clients. Challenges encountered in implementation and their solutions are covered as well.

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Abbreviations and Notations

ARP :	Address Resolution Protocol
BE :	Best Efforts
BS :	Base Station
BSID :	Base Station Identification
BWA :	Broadband Wireless Access
CID :	Connection Identifier
CRC :	Cyclic Redundancy Code
CS :	Carrier Sense
CSMA :	Carrier Sense Multiple Access
DCF :	Distributed Co-ordination Function
DCID :	Data Connection Identifier
DBPSK :	Differential Binary Phase Shift Keying
DL :	Down Link
DL-MAP :	Down Link Slot Allocation Map
DLL :	Data Link Layer
DQPSK :	Differential Quadratic Phase Shift Keying
DSA :	Dynamic Service Addtion
DSSS :	Direct Sequence Spread Spectrum
DL-TB :	Down Link Transport Block
FTP :	File Transfer Protocol
GPC :	Grant Per Connection
GPSF :	Grant Per Service Flow Type
GPST :	Grant Per Subscriber Terminal

HTTP :	Hyper Text Transfer Protocol
ID :	Identifier
IP :	Internet Protocol
LAN :	Local Area Network
LoS :	Line of Sight
MAC :	Medium Access Control layer
MTU :	Maximum Transmission Unit
NIC :	Network Interface Card
nrtPS :	Non-real Time Polling Service
PCF :	Point Co-ordination Function
PDU :	Protocol Data Unit
PHY :	Physical Layer
PoP :	Point of Presence
PS :	Physical Slot
QoS :	Quality of Service
rtPS :	Real Time Polling Service
RF :	Radio Frequency
Rx :	Reception
S :	System
SAP :	Service Access Point
SDU :	Service Data Unit
SF :	Service Flow
SS :	Subscriber Station
ST :	Subscriber Terminal
TCP :	Transmission Control Protocol
TDD :	Time Division Duplex
TDM :	Time Division Multiplex
TDMA :	Time Division Multiple Access
Tx :	Transmission
UDP :	User Datagram Protocol
UE :	User Equipment
UGS :	Unsolicited Grant Service

UL :	Up Link
UL-MAP :	Up Link Slot Allocation Map
UL-TB :	Up Link Transport Block
URL :	Universal Resource Locater
VoIP :	Voice over IP
WAN :	Wide Area Network
WiFi :	Wireless Fidelity
WiFiRe :	Wireless Fidelity for Rural Extension
WiMAX :	Worldwide Interoperability for Microwave Access

Chapter 1

Introduction and Motivation

Now-a-days the use of Internet and mobile communication has grown to a large extent such that it became mandatory for daily usage of life. The statistics in India show that there are more than 100 million mobile users in India [as per June 10th, 2005], which show its importance in daily routine. Major population in India resides in remote areas where access to communication technologies like telephony, Internet etc., are difficult to provide. Broadband Wireless Access (BWA) is the best way to meet escalating business demand for rapid Internet connection and integrated data, voice and video services. But deployment of BWA (WiMAX) compatible devices is much complex and costlier. Rural areas are sparsely populated and their distance varies in few kilometers, unlike urban areas. Installation of more base stations will probably not solve this problem, which also costs more.

Wireless Fidelity - Rural Extension (WiFiRe)[1] introduces the concept of wireless communication over WiFi IEEE 802.11b physical layer (PHY)[16] and WiMAX IEEE 802.16 MAC layer[17]. 802.11b PHY has better availability of low cost chip sets which can operate on unlicensed 2.4GHz frequency band and WiMAX has potential to communicate over larger distances of 30-40km range. In India, almost every rural area has land line connection, but mobile communication and broadband are difficult to deploy using land line. We believe, WiFiRe is the one of the good solution to achieve this goal at affordable cost. WiFiRe supports maximum of 25Mbps data rate, includes both UL and DL, and two parallel transmissions by opposite sectors.

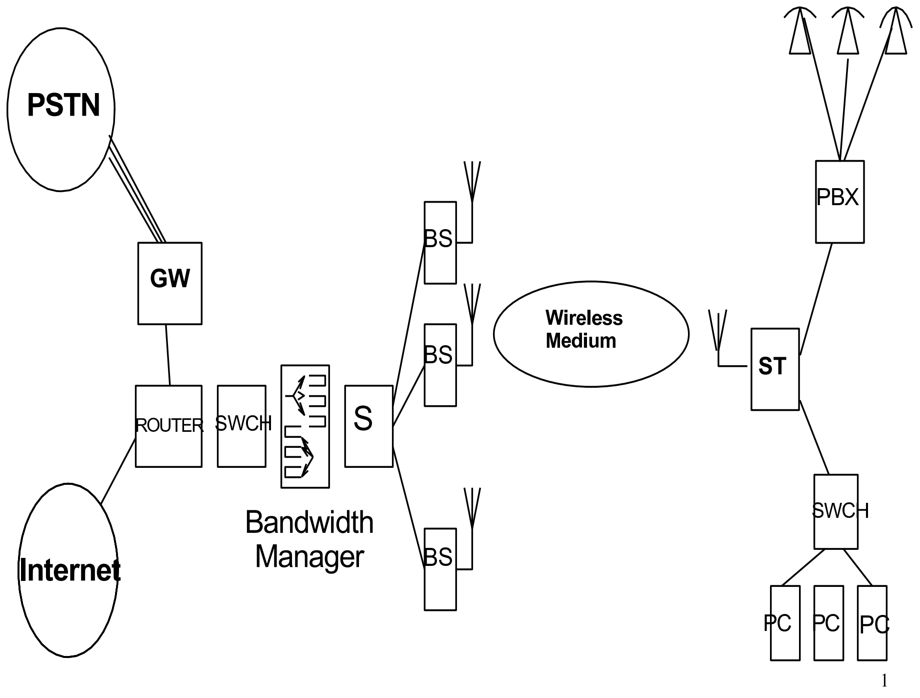


Figure 1.1: WiFiRe system architecture[1]

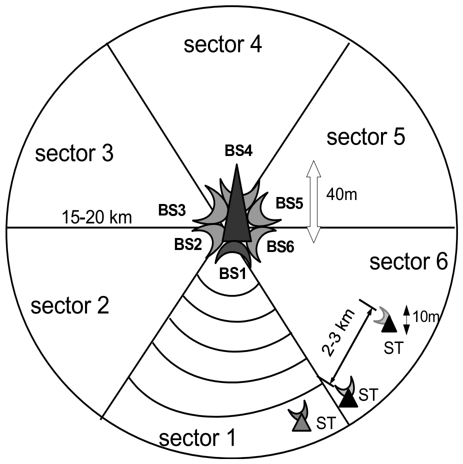


Figure 1.2: WiFiRe system architecture, Multi-sector system

1.1 Architecture

WiFiRe uses a star topology network as shown in above Figure 1.1 and Figure 1.2, in which System (S) is located at fiber Point-of-Presence (PoP) on top of 40m tower and is connected to set of Base Stations (BS) which is equivalent to number of sectors in the System. Each BS is connected to sectorized antenna through which a Subscriber Terminal (ST) is communicated. Each village holds one ST with 10m directional antenna directing to BS. Each ST differ by 2-

3km and all Clients under same ST are connected through LAN. All BS in the System use same WiFi channel for communication with respected STs, so transmission by one BS may interfere with adjacent sectors. For avoiding interference between two BSs, only opposite sectors should communicate parallel. WiFiRe follows TDD-MSTDM approach to communicate with in the System. Sectorization of coverage area while using the same frequency channel for all sectors is a key feature in WiFiRe.

1.2 Motivation

There are alternatives present for broadband wireless access but most of them are not cost effective. WiMAX-d (IEEE 802.16d), can provide an alternate solution as it has got high gain and a good spectral efficiency, which can carry 80Mbps over-the-air per base station with a 20MHz allocation[17]. The main drawback is, deployment requires complex and costly hardware that is not available easily. WiFi (IEEE 802.11b) can provide for short distance communication of about few meters but not for long distances. In 802.11 based networks, contention algorithms such as Distributed Coordination Function (DCF) mechanism does not provide any delay guarantees and are more distributed in nature, while the Point Coordination Function (PCF) mechanism is efficient only for small number of nodes[16]. 802.11 based Mesh Network, where it doesn't use the existing CSMA/CA technology, instead uses 2-phase TDMA based protocol. But the problem with 802.11b MAC is its non capability of providing any Quality of Service (QoS) except PCF. The outdoor long-distance use of 802.11 requires a revisit to the protocols at various layers of the OSI stack, as well as various system design issues. And finally, our Mobile cellular technologies cannot provide broadband services with high bandwidth. The concept of *WiFiRe* seems to be good solution for this scenario and can satisfy bandwidth need at proper price that suits rural people.

1.3 Problem statement

The main problem that we are focusing here is to replace the MAC layer of the existing WiFi protocol which is of low cost and easily available PHY chipset with WiMAX like MAC which have capable of long range communication. In India our protocol works because there are very few high buildings in the terrain for several kilometers, we can achieve good Line-of-

Sight (LoS). WiFi has increased tremendously and it has got the benefit of last-hop wireless solution in almost all the networks. Basically 802.11 has been designed for indoor operations but because of its low cost of PHY it is now being taken into consideration for extending to rural environment.

WiFiRe is promoted by CEWiT India[1] and the project is spread across IIT Bombay, IIT Madras and IISc Bangalore. This project is divided into three major parts each part is handled by different group. Design of MAC, PHY fabrication and Scheduler are taken care by IITB, IITM and IISc respectively.

This project started last year by WiFiRe team at IIT Bombay [4][5]. The team has done theoretical study of protocol, suggested some of the important changes in WiFiRe draft which helped during the actual implementation. They have also implemented testbed prototype for emulation which include single ST and BS machines.

Scope of this thesis is to implement MAC specification for the WiFiRe single sector which includes several modules related to MAC like beaconing, connection management (Ranging or Registration), handling different CIDs, building frame, basic scheduling, buffer and memory management, packet encapsulation, packet classification and also supporting documents which help in further development of the protocol. Primary goal is to provide VoIP (Voice Over IP) and web connectivity with in a single sector having one BS, multiple ST's in it and multiple Clients under each ST.

WiFiRe MAC team work is divided in two parts as shown in Figure 1.3. Modules which are developed by Janak [2] are in grey color while modules developed by Ranjith (me) are in white color. In this report, we discuss all the modules shown in white color. All modules integrate with each other and make complete WiFiRe MAC prototype.

1.4 Thesis Outline

The outline of thesis is as follows:

Chapter 2 explains some similar projects which are working to provide long-range communication by using off-the-shelf 802.11 chipset. Detail description of protocol to be implemented is explained in chapter 3. Chapter 4 describes overview of implementation of WiFiRe,

[1]The Center of Excellence in Wireless Technology (CEWiT) is an independent research organization set up by the Ministry of Information Technology, Government of India (MIT) in partnership with industry.

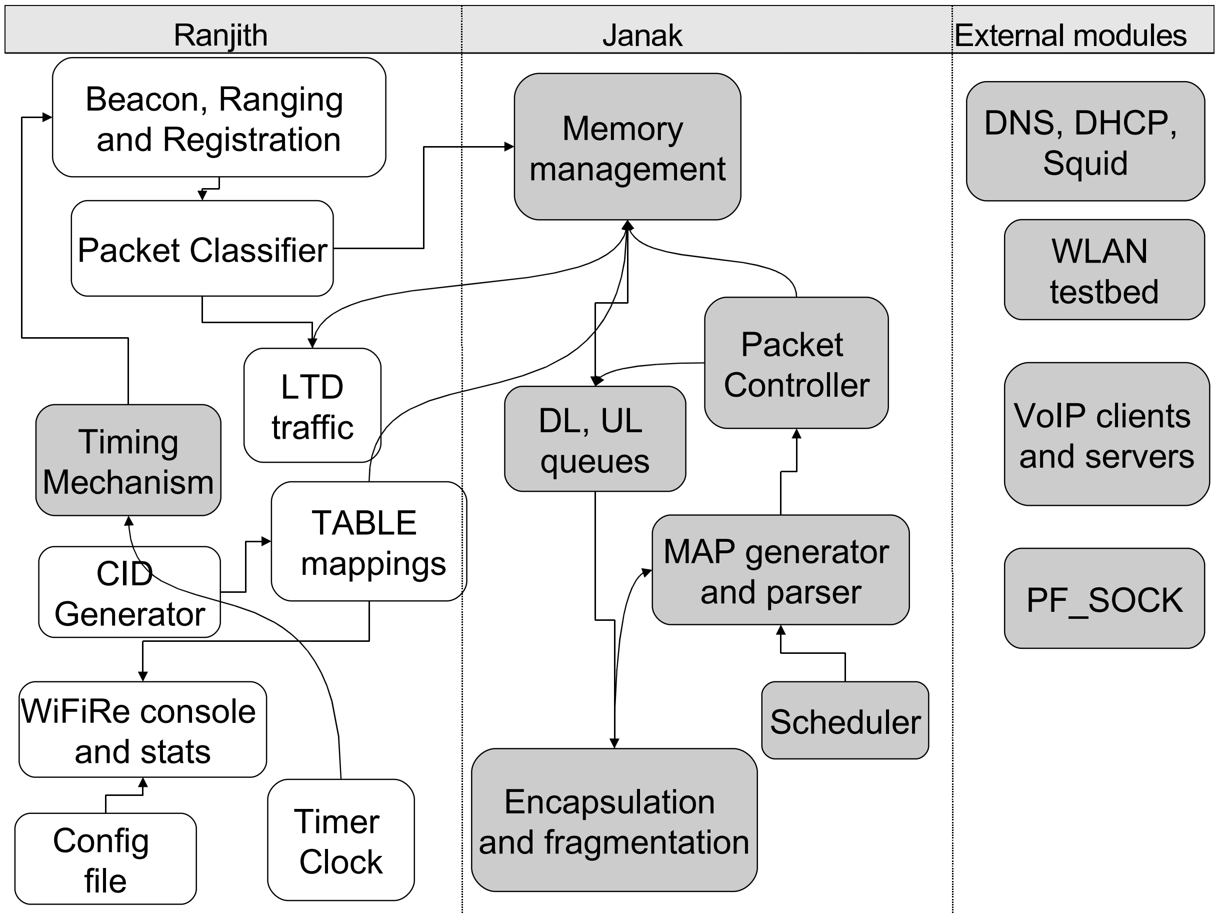


Figure 1.3: Division of work, WiFiRe MAC modules

while chapter 5 talks about my contribution to the project.

Problems encountered during implementation of the project and their corresponding solutions are being presented in Chapter 6. In chapter 7 we would be finally concluding and recommendations for future work are provided.

Chapter 2

Literature Survey

This chapter covers related work of WiFiRe MAC layer protocol which includes some of the other similar projects working for long-range communication by using 802.11 chipset, overview of WiMAX [17] and WiFi [16].

2.1 Long Range WiFi projects

This section is dealt with introduction of few projects which are going on in India as well as all over the world, in similar area for providing long-range communication by using off-the-shell 802.11 chipset.

Digital Gangetic Plains (DGP) project

Digital Gangetic Plains (DGP) project is started with the aim of providing low cost long range communications for covering low-density rural areas by using 802.11 chipset at IIT Kanpur[12]. DGP main goals are (a) Quantify 802.11 performance in outdoor (b) Range extension and (c) Cost reduction. This project has a testbed consisting of multi-hop directional 802.11 links, testbed span up to 80 km long. 8 hops are located in the testbed with maximum distance between point-to-point link is about 38km. Most of the long distance links are over flat terrain which helps to solve LoS problem. Each hop is located on tower of length about 40m. Each hop includes off-the-shelf parabolic grid antennas for directional gain and off-the-shelf 802.11b Access-Points(APs) at each hop location. The APs are operated in bridge-mode. Several challenges relating to Physical layer, MAC layer, routing and reconfigurable issues are discussed in [12]. DGP follows Spatial-reuse TDMA (STDMA) scheduling for communication. STDMA means, scheduling the various links of the network for transmission, taking into account what simultaneous transmissions, or spatial-reuse is possible.

Low-cost WiFi-based Long Distance (WiLD) networks

WiFi-based Long Distance (WiLD) project is started with aim providing new appropriate wireless technologies that can provide low-cost, rapidly deployable connectivity solutions for low user-density regions[6]. WiLD project deployed testbeds in India (a 9-link topology), Ghana (5link) and San Francisco Bay area in US (7 link). WiLD testbed consists of multi-hop nodes with high gain antennas. They used low-cost electronically steerable antennas to avoid misalignment due to environmental effects like wind etc. Distance covered by WiLD network vary from 10-80km. It is LoS deployment, but relays are installed where there is no LoS. Some of the challenges described in [6] are (a) MAC layer issues; like ACK time out, collisions due to bidirectional traffic and Multi-link interference, (b) Loss recovery; done using retransmission with Bulk ACKs, (c) QoS Provisioning issues, (d)trouble shooting; reconfigurable and management issues, (e) Network planing and deployment issues. WiLD uses sliding-window based flow-control approach with the TDMA slots. For supporting simultaneous transmit and receive it uses TDMA slot scheduling.

2.2 Overview of WiMAX

WiMAX is World wide Interoperability for Microwave Access. It is 802.16 Air Interface Standard[17]. For a Point-to-Multipoint (PMP) topology, a controlling base station (BS) connects multiple subscriber stations (SS) to various public networks. The standard defines a connection oriented MAC protocol, and a mechanism for QoS guarantee. It can support multiple communication services (data, voice, and video) with different QoS requirements by properly defining scheduler at MAC layer that control BS and SS data transmissions. This system supports at different data rates based on PHY encoding scheme.

Network Initialization

Sequence of steps during network initialization in WiMAX are listed below.

1. Scanning the downlink channel and establishing **synchronization** with the BS.

2. Obtaining the transmit parameters (from UCD message)
3. Perform **ranging** process
4. Negotiating basic capabilities
5. Authorization of SS and performing key exchange
6. Performing **registration** process
7. Establishing the **IP connectivity**
8. Establishing the time of day
9. Transferring the operational parameters
10. Setting up connections

MAC

In this layer, QoS is done by service flow mechanism. It is a connection oriented mechanism. After completion of registration process by SS, all connections are being associated with the service flow type. When a customer needs new service then new connections are being established. These connections need active maintenance. When everything is done the connections are being terminated. The BS controls assignments on the uplink channel through the ULMAP message and determines which mini slots are subject to collisions (contention slots). Collisions may occur during the initial ranging. SS uses a random back-off algorithm to resolve contention.

Scheduling Services

Different types of service flows have been defined based on type of traffic. The services which are defined are UGS, rtPS, nrtPS and BE. Based on service type, scheduling of frame is done. There is no specific scheduling technique defined by standard. There are several scheduling strategies proposed by researchers. The comparison between these techniques can be found in[15].

PHY

WiMAX PHY is designed using OFDMA (Orthogonal Frequency Division Multiple Access) technique, it support high data rates (ex: 46Mbps for DL and 14Mbps for UL) over long distances. But it works on licensed spectrum only, turns more costlier. It can be operated in 1.25, 3.5, 5, 8.75, 10MHz channels. WiMAX supports a variety of modulation and coding schemes and allows for the scheme to change on a burst-by-burst basis per link, depending on channel conditions. Using the channel quality feedback indicator, mobile can provide the base station with feedback on the downlink channel quality. For the uplink, the BS can estimate the channel quality, based on the received signal quality. The base station scheduler can take into account the channel quality of each users uplink and downlink and assign a modulation and coding scheme that maximizes the throughput for the available signal-to-noise ratio. Adaptive modulation and coding significantly increases the overall system capacity, as it allows real-time trade-off between throughput and robustness on each link.

2.3 Overview of WiFi

WiFi (802.11b) stands for Wireless Fidelity [16], which is a standard protocol for Wireless communication. Except for 802.11a, which operates at 5GHz, WiFi uses the spectrum near 2.4GHz, which is standardized and unlicensed by international agreement. Although the exact frequency allocations vary slightly in different parts of the world, as does maximum permitted power. WiFi is typically used for indoor ranges of 30m which can be operated at 11Mbps and 90m which can be operated at 1Mbps. With high-gain external antennas, the protocol can also be used in long distance fixed Point-to-Point (P2P) arrangements, typically this range is up to 8km.

MAC

The basic medium access mechanism in WiFi is Distributed Coordination Function (DCF), which uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) technique. There is another method called Point Coordination Function (PCF), which uses polling technique to select which station to transmit at a given time. Due to high propagation delay in DCF mode (carrier sense) this standard will not suitable for long range application. Distributed Inter

Frame Sequence (DIFS) delay should be high to support long range. PCF mode will not work efficiently when number of clients are more due to centralization. WiFi MAC designed mainly to work for home and office applications.

PHY

Depending on the current infrastructure and the distance between the sender and receiver of 802.11b system offers 11, 5.5, 2 or 1 Mbps data rate. Maximum user data rate is approximately 6Mbps. Lowest data rates 1 and 2 Mbps use the 11 bit Barker sequence and DBPSK or DQPSK respectively. The new data rates 5 and 11 Mbps use 8-chip complementary code keying (CCK). There are three PHY types supported: Frequency Hop Spread Spectrum (FHSS) in 2.4GHz band, Direct Sequence Spread Spectrum (DSSS) in 2.4GHz band and InfraRed (IR).

DGP and WiLD projects are main basis for our project to show that we can change the MAC layer of 802.11 by keeping the same PHY chipset. In these projects they have changed the MAC layer of 802.11 as TDMA based MAC, so that it works like a router. They have configured the network as a mesh network. Main disadvantages of this project include the fact that it is not ad-hoc, more computation power needed at each access point as each act as a router, and it does not provide any QoS guarantee. We also studied the MAC functionalities of WiMAX and WiFi to get clarity on different things that ee need to taken care during the implementation.

Chapter 3

WiFiRe Protocol

In this chapter we are going to discuss the architectural details of WiFiRe. For complete details on architecture refer [1].

3.1 Network Initialization

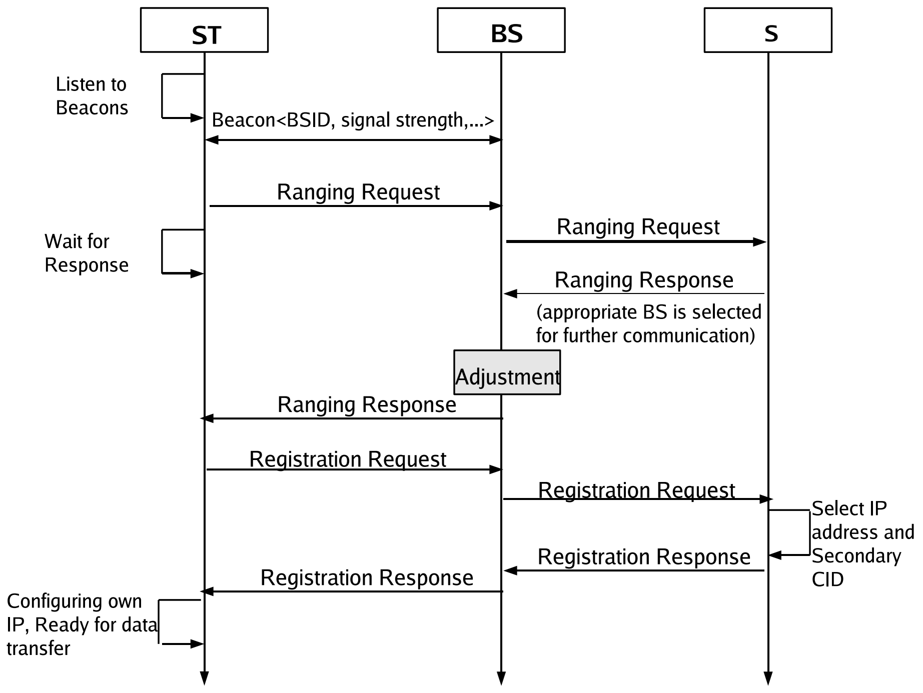


Figure 3.1: Basic communication sequence diagram[1]

Flow of packet exchanges between ST and System (S) during network initialization phase is shown in Figure 3.1. The association between a ST and System is static. But deciding on which BS to use for communication is done through ranging and registration process. New and non-synchronized STs are allowed to range and register. When power-up sequence and self-initialization are done the ST enters the process of Ranging in order to synchronize the clock and other physical parameters with the System (S). It is also performed periodically to keep in synchronization with S. In this process S assigns ST two connection-IDs (CIDs) called Primary CID (PCID) and Basic CID (BCID). PCID is used further for exchange of management services and BCID is used further for periodic ranging requests. Registration process required prior to any data connection. During this process, ST and S exchanges operational parameters and capabilities. Registration process enables the ST to acquire IP address to setup provisioned connections.

3.2 MAC Overview

As earlier said WiFiRe uses TDD-MSTDM mechanism. To coordinate medium access among the sectors by scheduling slots to each BS. Time is divided into frames, which is further divided into Down Link (DL) and Up Link (UL) segments, which may not be of equal time intervals (see Figure 3.2). Thumb rule is 2:1 of DL:UL ratio. In each DL slot zero or one transmissions can place in each sector (groups all the packets, explained in Section 4.1.2). Multiple BS antennas can transmit in DL simultaneously, provided they do so in a non-interfering manner. Same as the case in UL except that Multiple STs can transmit to a single BS, provided they do so in a non-interfering manner. Beacons are being transmitted at the start of each DL segment, which contains information for time synchronization of the STs in that sector, information regarding the DL and UL slot allocations (which are called DL and UL MAPs respectively) for that frame and other control information. These DL and UL MAPs are computed online because there may be site dependent or installation dependent losses and different time varying requirements at each point of time.

The DL segment begins with each BS in the System transmitting a beacon packet, in a non-interfering manner. Even though beacons can be transmitted simultaneously their content need not be the same. Each beacon will be of the structure contains [Operator ID, System ID, BSID], BSID differ for each BS beacon. DL-MAP and UL-MAP have the information belongs to all registered STs scheduled for that frame and their corresponding slot assignments. There is a guard band of few slots between the end of DL segment and the start of UL segment so that it

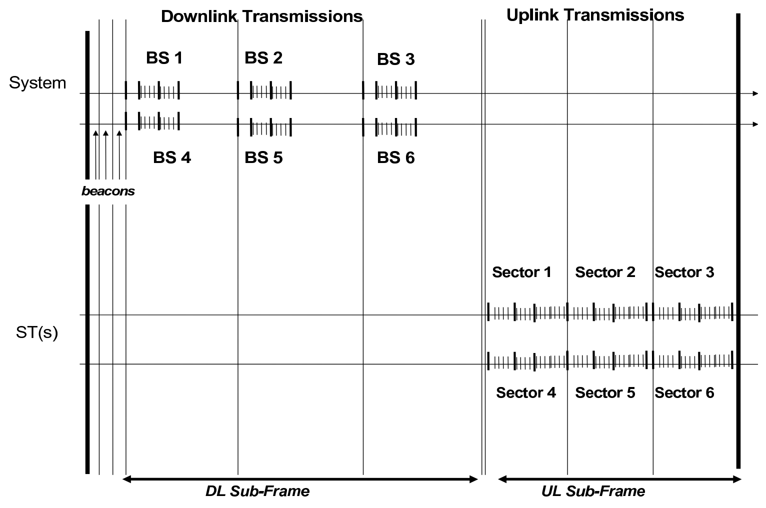


Figure 3.2: Medium Access Control (MAC) mechanism and Timing sequence of WiFiRe[1]

ensures appropriate propagation delay is handled. MAC is a connection-oriented, a connection defines both the mapping between peer data link process that utilize the MAC and a service flow.

3.3 Framing Structures

3.3.1 Basic MAC PDU

MAC PDU starts with a fixed length generic MAC header followed by payload followed by optional CRC (Cyclic Redundancy Check). The payload information is variable length and can hold zero or more sub-headers and zero or more MAC SDUs (Service Data Units). MAC PDU is bounded by maximum size payload accepted by WiFiRe in which fragmentation is not supported. MAC PDU format is shown in Figure 3.3.

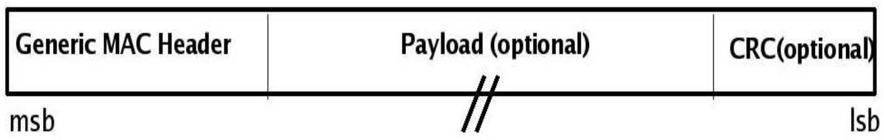
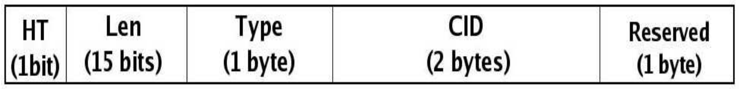


Figure 3.3: MAC PDU format

3.3.2 MAC Headers

MAC headers are defined in following formats:

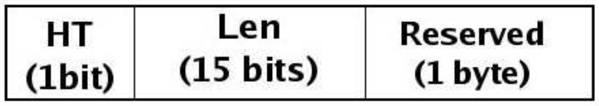
- **Generic MAC Header** consist of *HT* field for header type and is set to 0 for generic header, *Len* field of 15 bits to represent the length of whole MAC PDU including the header length, *Type* field 1 byte long defines the type of message being contained by PDU (such as Ranging, Registration, Dynamic Service and data payload). Generic MAC header format is shown in Figure 3.4.



HT	Len	Type	CID	Reserved
(1bit)	(15 bits)	(1 byte)	(2 bytes)	(1 byte)

Figure 3.4: Generic MAC header

- **Beacon Header** is comparatively small in size and transmitted whenever a beacon is generated at BS. It has HT field for header type set to 1 for beacon header followed by Len field of 15 bits to represent the length of MAC PDU. Figure 3.5 gives the notion of beacon header. Further details of specifications are given in [1]. One byte is kept reserved



HT	Len	Reserved
(1bit)	(15 bits)	(1 byte)

Figure 3.5: Beacon header

  for future use in both headers.

3.4 Bandwidth Request grants and Service classes

WiFiRe designed to support different types of bandwidth grant mechanisms along with different service classes, those are listed below

3.4.1 Service classes

- **Unsolicited Grant Service (UGS):** This is designed to support fixed-size data packets at a Constant Bit Rate (CBR). Examples of applications that may use this service are T1/E1 emulation and VoIP without silence suppression. The mandatory service flow parameters that define this service are *maximum sustained traffic rate, maximum latency, tolerated jitter and request/transmission policy*.

- **Real-time Polling Service (rtPS):** This service is designed to support real-time service flows, such as MPEG video, that generate variable-size data packets on a periodic basis. The mandatory service flow parameters that define this service are *minimum reserved traffic rate, maximum sustained traffic rate, maximum latency and request/transmission policy*. The BS shall provide periodic unicast request opportunities, by assigning appropriate polling slots in the UL.

- **Non-real-time Polling Service (nrtPS):** This service is designed to support delay-tolerant data streams, such as an FTP, that require variable-size data grants at a minimum guaranteed rate. The mandatory service flow parameters to define this service are *minimum reserved traffic rate, maximum sustained traffic rate, traffic priority, and request/transmission policy*. The BS typically polls nrtPS CIDs on an interval (periodic or non-periodic).

- **Best Effort Service (BE)**: This service is designed to support data streams, such as Web browsing, that do not require a minimum service-level guarantee. The mandatory service flow parameters to define this service are *maximum sustained traffic rate, traffic priority, and request/transmission policy*.

3.4.2 Type of Grants

Types of band width grant mechanism which are intend to support in WiFiRe as per draft are listed below.

- *Grant per Connection (GPC)*: System (S) explicitly grants for each connection.

- *Grant per Subscriber Station/Terminal (GPSS)*: All connections from a single SS are treated as a single unit and bandwidth is being allocated accordingly. An additional scheduler in SS determines in which order the service is being granted slot.

- *Grant per Flow Type (GPFT)*: Grants are allocated based on service flow type.

Chapter 4

WiFiRe Design and Implementation Overview

This chapter explains previous work done in WiFiRe design and implementation [4][5]. It includes design of WiFiRe, how WiFiRe System (S) connected with different BS antennas and different assumptions made during the implementation. And also explains present implementation plan.

4.1 Design Overview

4.1.1 Real System Components

In current WiFiRe implementation plan, *WiFiRe-MAC* and *BS-PHY* are separate from each other (see Figure 4.1). PHY boards are being developed independently and require MAC frame to be delivered on Ethernet cable. Eventually, MAC and PHY will be integrated as single entity. Current hardware keep six different NICs for six BSs. These six NICs are connected by single switch.

This leads to Ethernet cable as single communication medium. All the non-WiFiRe control messages such as 2 byte control data (explained later in this chapter) have to be transferred using same link. Extra control modules have to be written to handle, because such messages adds more complexity to implementation. WiFiRe frames are to be sent to this switch with destination address as a given BS-PHY MAC address. Frame structure and slot size is fixed. There is a centralized module which instructs all six BS-PHYs to synchronize with each other

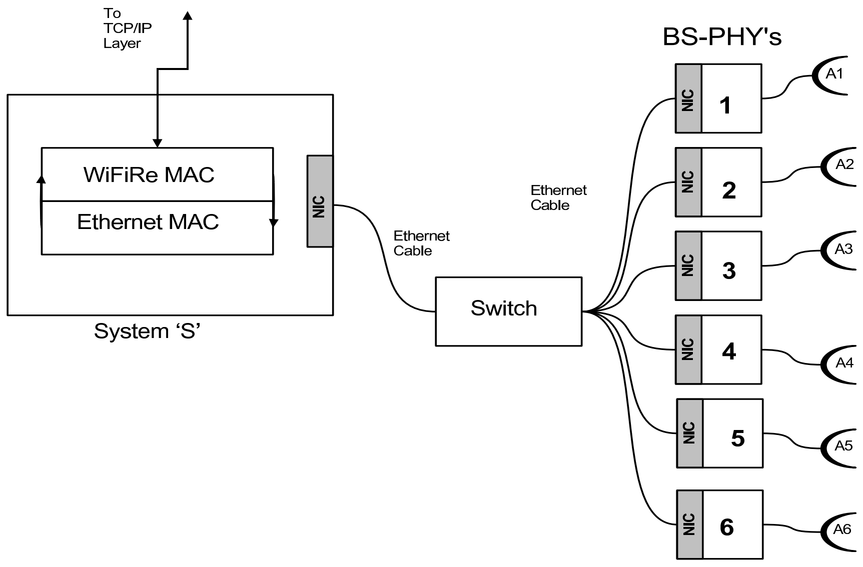


Figure 4.1: BS hardware: proposed WiFiRe real system component [5]

and send data as and when required.

4.1.2 Proposed solution for reducing PHY overhead

In our approach both BS-PHY and BS-MAC are separate from each other (Figure 4.1). There are various ways (broadcast, indexing, bitmap and consecutive allocation) to transmit a frame which is built by WiFiRe MAC from BS-MAC to respective BS-PHY such that each BS-PHY should know when to transmit the data frame.

We also need to optimize the PHY overhead, which is of 4 slots, for every new transmission at BS-PHY [1]. Among the available methods, concatenation has low PHY overhead. Using concatenation we allocate all slots which belong to same BS consecutively, thereby reducing PHY overhead. We use a 2 byte control packet per DLTB (Down Link Transport Block), having information<**starting slot, number of consecutive slots**> and then transmitted to BS-PHY. At BS-PHY, it reads the information present in control packet and acts accordingly.

Figure 4.2 shows how this approach works. Total DL frame is divided into groups (B1, B3, B5 are in a group) and each group belongs to the respective BS-PHY. Beacons are transmitted to every BS-PHY at same time. Down link Transport Blocks (DLTB is a group of slots which belongs to the same BS. Each BS have zero or more DLTBs and this number depends on Ethernet packet size) are created before inserting the WiFiRe frame into Ethernet packets.

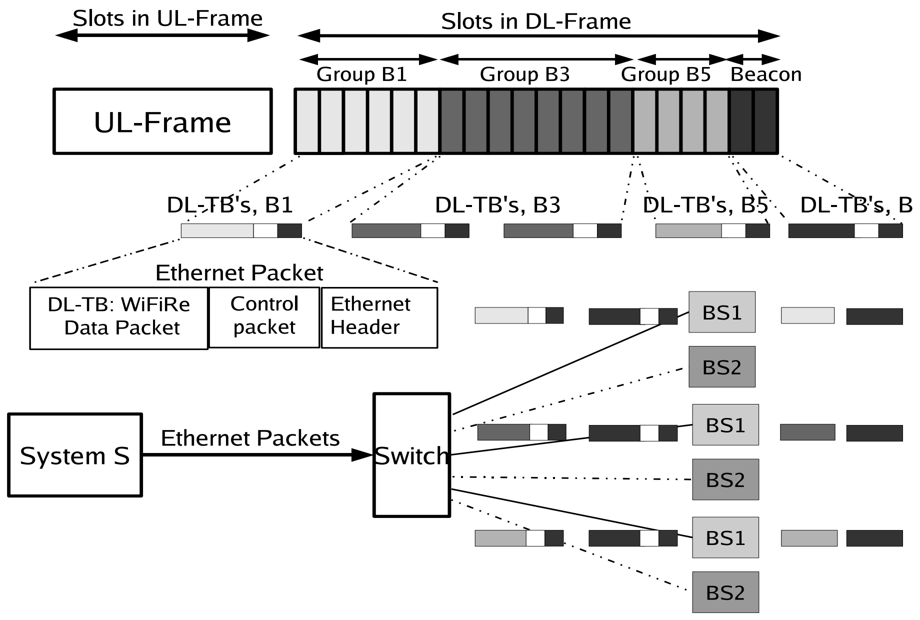


Figure 4.2: Consecutive allocation of DL slots for each BS [4]

For example, when BS-PHY receives an Ethernet packet having a control packet <05,15>, it transmits from slot 05 to 19. This method has advantage of fixed size memory requirement (PHY buffer need to store single frame at any given time) at BS-PHY, minimal control and PHY overhead. However it increases the complexity of scheduler. Scheduler has to take care of constructing DLTBs.

Information present in the MAPs and CID table is helpful for ST-PHY (antenna) to transmit and receive data. Appropriately above procedure is applied for UL as well for reducing PHY overhead at ST. In that case, grouping of slots are done at ST level instead of BS.

4.1.3 Assumptions made on PHY board

By considering above design details we started working on emulation of protocol using testbed due to absence of actual hardware. We have discussion with the group who are handling WiFiRe PHY part, then prepared some assumptions during the implementation. One of the important agreement between our two groups (IITM and IITB groups) is, we need to send DLTBs along with small control packet (refer section 4.1.2) to appropriate BS-PHY in case of BS. We believe that, lot of modules we are implemented be used directly in actual hardware, there will be some miner changes expected.

The list of assumptions made during the emulation (at PHY) are as follows

(a) Clock has capable of generating 1 tic per every time slot.

(b) Board had capable of reading control packet and transmitting DLTBs at appropriate time slots.

(c) Handling multiple Ethernet Packets at Board. Because some times single DLTB may not be sufficient for transmitting all the slots which belongs to single BS.

(d) Buffer with min size of a complete frame (210 * 44B) is required. This is equivalent to 7 Ethernet Packet (1500B). Assuming that only one frame will present at a given frame interval.

(e) FCFS queue at BS.

4.2 Implementation Overview

4.2.1 LAN emulation

We have emulated the WiFiRe protocol using LAN as the basic medium of propagation between ST and BS. In emulation, WiFiRe MAC layer is over application layer implemented using C sockets on Ethernet LAN where it will construct, process and execute the packets on the WiFiRe MAC and will pass the packet to socket layer assuming it to be the PHY layer of WiFi 802.11. The assumption here is that the application layer of the Ethernet act as the MAC layer of our protocol and assuming the layers down to it as the PHY. Here the characteristics of PHY layer can be ignored while implementing the MAC layer through C sockets as the device driver will take care of the PHY at lower levels.

Why Emulation on LAN?[4]

1. To understand and ensure that steps involved in WiFiRe protocol works.
2. It is comparatively easy to debug and make changes at the application layer rather than at kernel level.
3. WiFiRe hardware is not ready and in order to test the protocol, there is need of already setup network infrastructure which is already setup(i.e. LAN in this case).

4. Design and implement data structures and small working modules in order to test and reuse them with minimum changes when porting them on actual hardware

4.2.2 Testbed setup

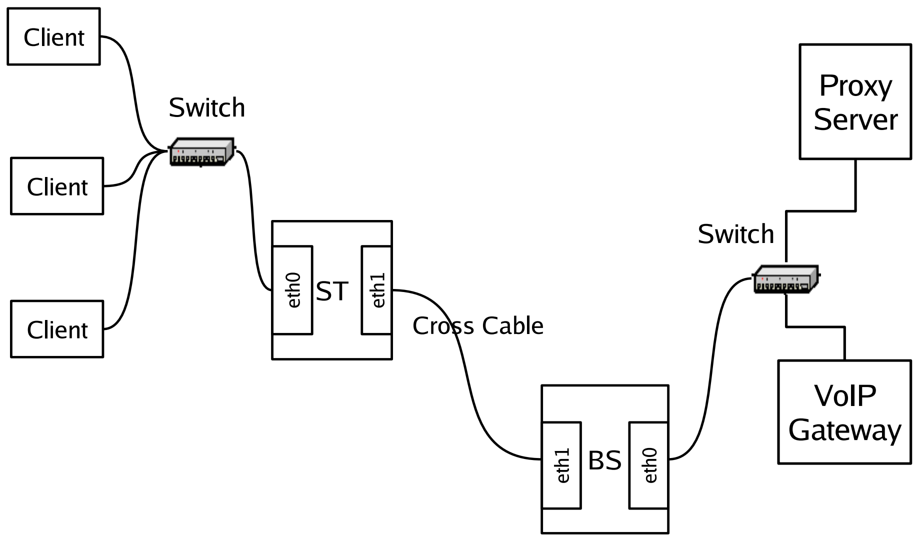


Figure 4.3: WiFiRe Test Bed

WiFiRe testbed shown in Figure 4.3 includes a BS with two NICs, an ST with two NICs, a server(or gateway) which acts as FTP, Proxy and web server. Proxy server takes care of forwarding all HTTP/FTP requests to Internet. Several end-users (Clients) are connected to ST through Ethernet switch. BS is connected to ST using DIX based Ethernet cross cable. This link is treated as wireless link of WiFiRe. Subsequently, it will be replaced with the hardware for WiFiRe PHY. STs *eth0* is connected with end users via switch. BS is connected to server using *eth0* and sends data to ST by other interface *eth1*. *eth0* of ST and BS have plain 802.3 MAC based connectivity and it makes the network transparent for end users and S respectively. End-user clients send packets to ST, ST follows WiFiRe MAC slot structure (refer section 3.2) and sends packets to BS in designated slots. BS receives these packets, processes using WiFiRe modules and forwards them to S as normal Ethernet packets. Server sends reply to BS, which forwards to appropriate ST and finally, Client receive the packets. More than one server can be connect to the system S via switch. In our case, a proxy server which is running a squid proxy[10] helps to connect Internet and a VoIP gateway[13] helps to connect PSTN network. Configuration details about Proxy settings and VoIP gateway are included in Appendix A.

Assumptions and limitations of WiFiRe Emulation

- Both BS and ST are connected using a cross cable, which eliminates problems of propagation delays, ranging, synchronization and other such wireless specific issues. We assume that such issues will be taken care by underlying hardware in actual implementation.
- Implementation does not perform real ranging procedure as test-bed uses Ethernet cable where propagation delay is not variable. In this scenario, Beacon transmission is enough for synchronization. Purpose of ranging here is to assign and transfer basic and primary CIDs only.
- As our emulation runs on Ethernet, and PCs are connected directly using RJ-45 cables, it can not get total flexibility on frame structure, size, CRC etc. This Ethernet link restricts size of individual packets and WiFiRe MPDUs as well.
- Due to absence of real hardware clock, software timers are used in implementation which guarantees precision up to milliseconds.

4.2.3 GPSS mode

Among the available grant services (ref section 3.4.2) we selected GPSS mode for implementation due to simplicity. In GPSS mode, all connections from a single ST are treated as a single unit and BW is being allocated accordingly. Mode of BW allocation is completely depends on scheduler and Call Admission Control (CAC) at BS. An additional scheduler at ST determines whom to allocate available slots. Same scheduler can also be used at ST.

In GPSS mode, total functionalities distributed between BS and ST. In this mode, decision about DL slots will be taken at BS, but decision about UL slots will be taken at ST. Available UL slots are distributed among active STs at the time of frame sent. Each ST has its own local scheduler, it allocate allotted slots between clients.

There are some other reasons for selection are listed below,

- We want to make design as simple as possible (we want to avoid the problems created by the data connections or dynamic change of connection requirements at this level).
- Helps to effective utilization of available BW (probability of availability of data packets which belongs to particular connection at a given time is much lower than whole ST aggregated connections).

- We can easily extend to GPC mode by making related changes at BS.
- It also avoids the work load done by the System S.

4.3 Modules at BS and ST

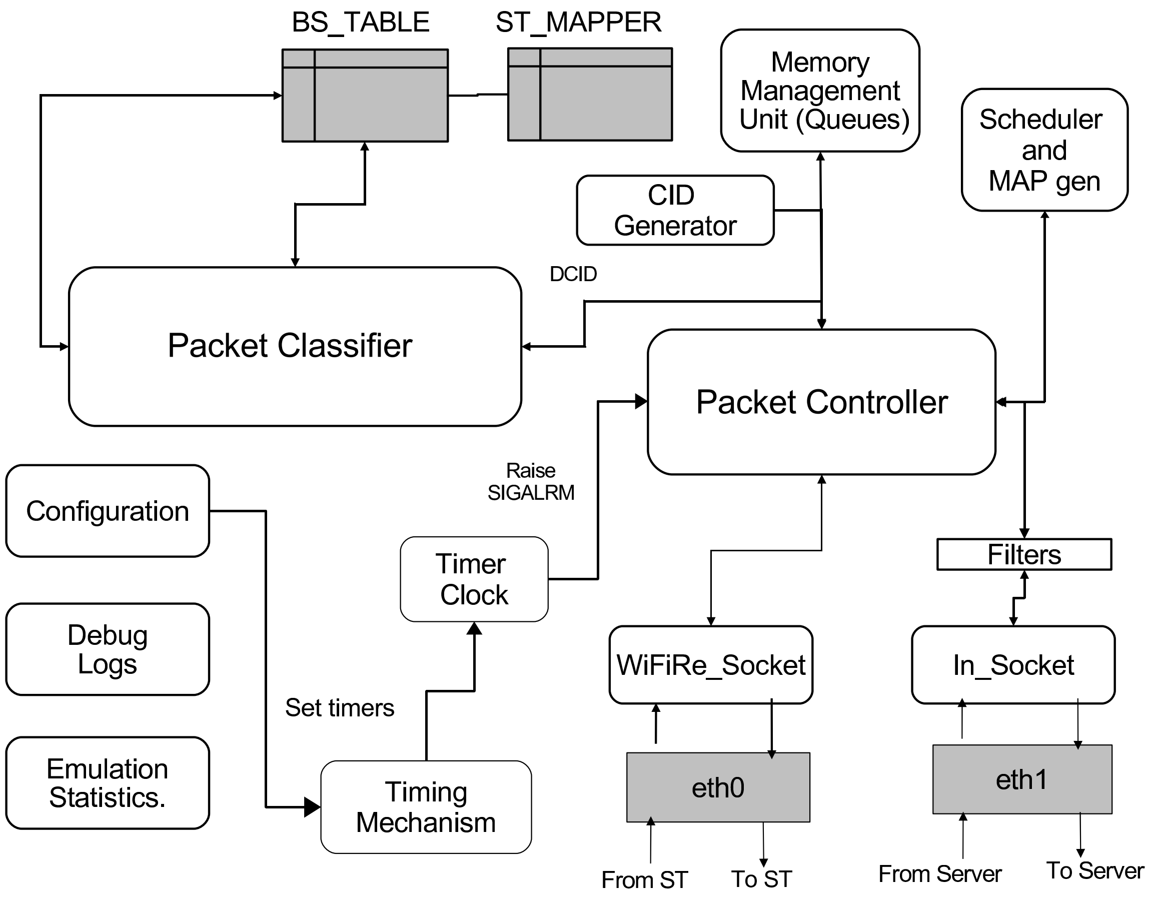


Figure 4.4: Block diagram for BS

As shown in Figure 4.4, BS MAC functionalities distributed between different modules. Modules namely packet classifier, CID generator, packet controller, scheduler and MAP generator,Memory Management Unit (MMU) and timer clock. Also includes some of the supporting modules like filters, emulation stats, debug logs and configuration to help further debugging purpose and also useful for end user. Each module has specific task in the protocol implementation. Overview of the modules are given below. Complete details like how each module work and significance of particular module is described in next chapter.

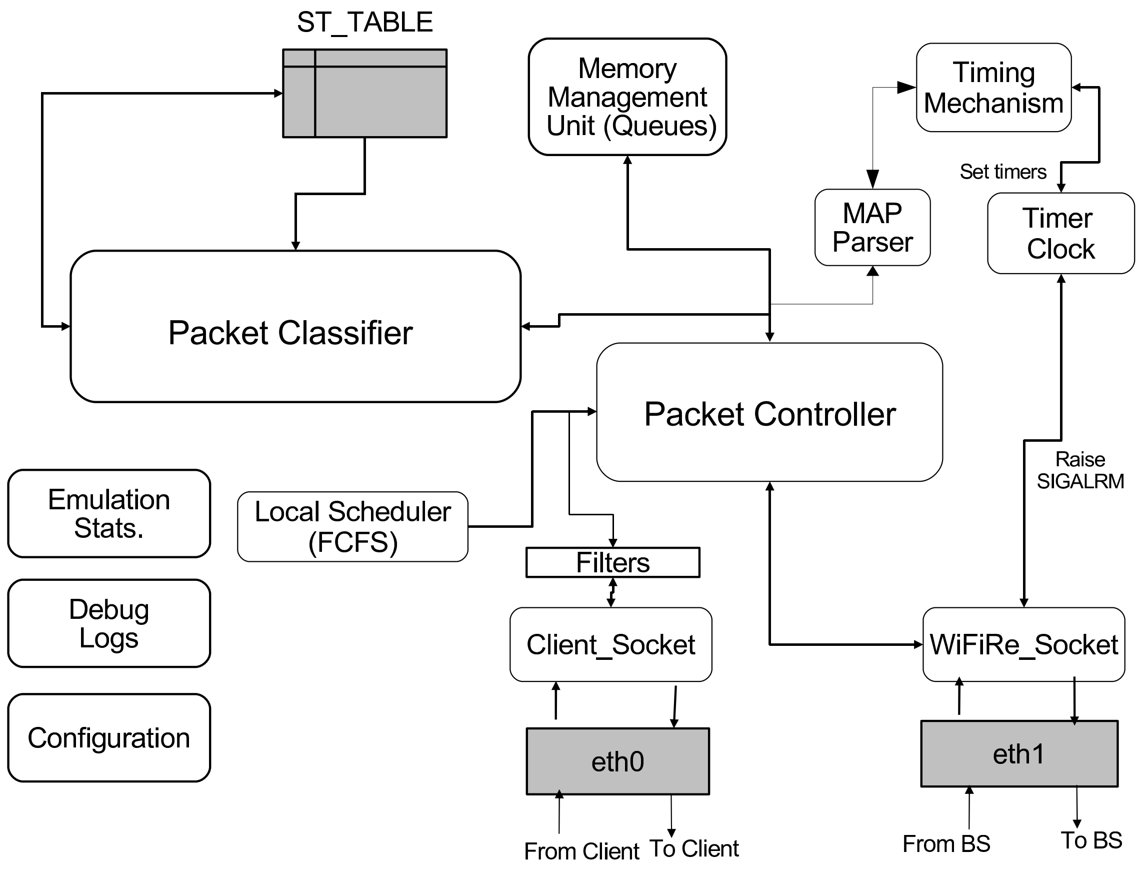


Figure 4.5: Block diagram for ST

Packet classifier, broadly divide total incoming traffic into two types with the help of *type* field in the WiFiRe frame (*type* field is explained in next chapter). Management packet used to establish connection between BS and ST. All remaining packets treated as data packets. Data packets further classified based on destination MAC address. It also makes appropriate entries in the mapping table when packet received from new Client. CID generator module generates 16-bit CID for each connection. These 16 bits are divided in subgroups, such that each group of bits represents ST, ClientID and ToS.

Packet controller, sends/receives packets to/from MMU and socket buffers. Other important task done by this module is DLTB construction, encapsulation and fragmentation. Scheduler keep track of all connections requirements and generates DLMAP and ULMAP. Both MAPs will be sent in first slot of DL segment to all STs. MMU maintain a set of queues and allocate/de-allocate memory dynamically. Timer clock generate periodic signal to packet controller to prepare and send WiFiRe frame.

Filter module drops packets based on predefined rules (rules are explained in section 5.7). Stats modules helps in calculating different statistics like number of frames sent, emulation duration, number of data packets Tx/Rx etc. Debug and Logs module keep track of flow of protocol and log all the details into a file. Configuration module read all config parameters from config file, if any value missing from config file then it assign default values. All details about configuration parameters and default values are explained in Section 5.7.

As shown in Figure 4.5, ST also have similar but simpler MAC compare to BS. ST has MAP parser instead of MAP generator helps to send signals to packet controller for Tx/Rx packets at particular time based on present MAP. When packet classifier received a packet from a new client, it make entries in ST-TABLE. Local scheduler schedules UL traffic. Timer clock generate SIGALRM signal to packet controller to Tx when UL frame started.

Chapter 5

WiFiRe Implementation Modules

This chapter explains detailed functionalities of WiFiRe module. Here, every section is explained with respect to actual implementation.

5.1 Threads, Buffers, Sockets and their interaction

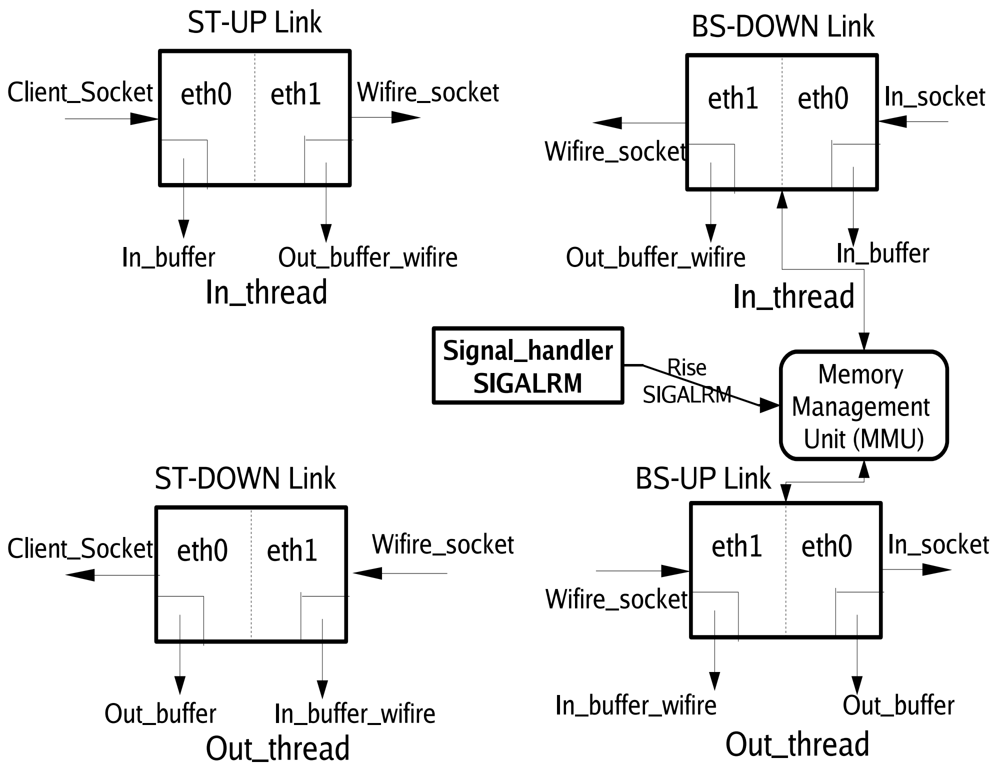


Figure 5.1: Sockets, Buffers, Threads and Ethernet interfaces

The Figure 5.1 shows how sockets, buffers and threads are connected with Ethernet adapter at ST and BS in actual implementation.In this figure all *eth1* are in same subnet (ex:192.168.1.* /255.255.255.0). All *eth0*, Proxy and all Clients should be under same subnet (ex:172.168.1.* /255.255.0.0) for communication.

Various modules in BS and ST, dedicated to different functions of WiFiRe MAC are shown in Figure 4.4 and Figure 4.5. There are completely four threads running at both BS and ST. Responsibilities of each thread at higher level are as follows:

- **main_thread:** Initializing tables, buffers, queues, setting config values, activate timer clock, creating sockets, reading local MAC details and keeping track of console to display stats

- **signal_handler:** when ever it catches a SIGALRM signal it will do following two actions in sequence,

  1. Dequeue raw Ethernet packets from *MMU*, create WiFiRe frame (encapsulation of Ethernet frames) and put it into *Out_buffer_wifire* for DL Tx

  2. Read WiFiRe frame from *In_buffer_wifire* which is Rx in UL, convert them into normal packets and put them into *Out_buffer* for Tx

- **In_thread:** At BS, Rx Ethernet frames from *In_socket* i.e Ethernet interface *eth0* (from Proxy) and stores into *In_buffer*. At ST, Rx Ethernet frames from *Socket_fd* i.e Ethernet interface *eth0* (from Client) and enqueue into *In_buffer*. MMU read from *In_buffer* and enqueues into respective queue. In BS, each active ST has one dedicated queue to store frames belonging to that ST for Tx in DL.

- **Out_thread:** At BS, Rx WiFiRe frames from *Wifire_socket* i.e Ethernet interface *eth1* (from WiFiRe network during UL), and put them into *In_buffer_wifire*. At ST, Rx WiFiRe frames from *Wifire_socket* i.e Ethernet interface *eth1* (from WiFiRe network during DL) and put them into *In_buffer_wifire*. MMU reads *In_buffer_wifire* and either deques from respective queue or put it into *Out_buffer* for Tx through socket.

In addition to above, MMU has one additional queue for holding broadcast packet (DCID = 0xfff). Our simple scheduler (FCFS) reads frames from queues one by one till the queue empty.

5.2 Timer Management

Timer management module reads the *FRAME_DURATION* value from *configuration module* and set the SIGALRM period by calling *wifire_setalarm()*. *settimer()* is an API declared in #include <systime.h>. The code snippet of *wifire_setalarm()* is given below,

```
     unsigned int wifire_setalarm(unsigned int sec, unsigned long
int intv) {
//sec = start after, intv = FRAME_DURATION, usec means in micro seconds
struct itimerval new, old;
//interval is for frame periodicity
//dont make interval=0; it will be set only once
new.it_interval.tv_sec = 0;
new.it_interval.tv_usec = (long int)intv;
//dont make it_value=0; it will disable alarm
//it_value defines when to start first interrrupt after process starts
new.it_value.tv_sec=0;
new.it_value.tv_usec = 1;
if(setitimer(ITIMER_REAL ,&new, &old)<0)
return 0;
else return old.it_interval.tv_sec;
}
```

By setting this value, system clock generates sequence of SIGALRM signals with specified interval. *signal_handler()* catches this signal and prepares for frame Tx in DL. This module is implemented only at BS. ST starts Tx in UP link after immediate completion of DL Rx. We havn't implemented timer at slot level due to soft timer limitations. We did not consider any propagation delay between ST and BS, because our testbed machines are connected through Ethernet cables.

5.3 CID generator

The format of the CID is shown in Figure 5.2. The first two bits implicitly identify the type of the CID: (00) implies it is a basic CID; (01) implies primary CID; both (10) and (11) imply data

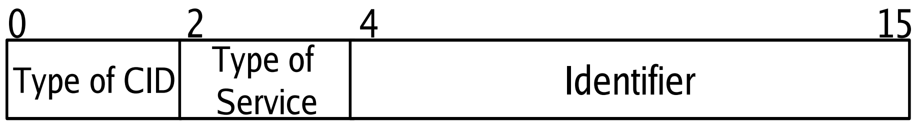


Figure 5.2: CID format

CID. In case of data CID,the next two bits implicitly identify the type of the associated service flow: (00) for UGS, (01) for rtPS, (10) for nrtPS and (11) for BE.

CID generator return new CID based on request type and service flow at BS. In current implementation BCID and PCID are issued at in response to received *ranging request* and also make proper entries in BS-TABLE. DCID is issued when ever BS receives first data packet from new Client and also makes entry in the ST-MAPPER table. In case, particular CID count reaches maximum number then this module return an error indicating no CID left of this type and wait till some one removes their CID from the active list. There are some special CIDs 0x0000, 0xffff etc.implemented based on draft[1], those are used for some special purpose. For example, *0xffff* used for broadcast packets and all STs read this frame in DL, *0x0000* used to transmit dummy frames if required. Present implementation support only BE traffic, all the incoming traffic is treated as BE.

5.4 Packet Controller

Packet controller is responsible for storing all incoming packets from proxy to respective ST queue with the help of memory management unit. It is also responsible for constructing WiFiRe data frame by embedding Ethernet packets, and also do reverse operation at other end. When ever it receive SIGALRM signal it starts constructing WiFiRe DL frame with help of DLTB construction module and fragmentation module by using current DL-MAP generated by Scheduler and MAP generator. MAP generator also prepares UL-MAP. All available slots in UL-MAP is equally distributed among all active STs. After creation of current frame it Tx beacon frame followed by data frame. Packet controller at BS in UL, forwards all incoming data packets to packet classifier.

Packet Controller at ST forwards the received beacon frame always to the Timing Mechanism at ST which generates sequence of time intervals from DL/UL MAP constructed by scheduler. These sequence is sent to Clock timer to raise SIGALRM at the beginning of designated slot interval. This helps ST to wake-up or become ready to Tx UL frame at designated time. Here, due to absence of real hardware clock, software timers are used in implementation which guarantees precision till milliseconds. It also stores all incoming Ethernet packets into queues with the help of memory management unit.

5.4.1 DLTB construction

Detailed description of DLTB has been explained in section 4.1.2. We have implemented this module as specified in section 4.1.2, but not at slot level. One of the main aim of implementing encapsulation and fragmentation modules are to build DLTBs. At present maximum WiFiRe frame length is equal to one Ethernet frame (1500B), because our testbed assumes LAN as medium of communication.

In DL at BS, Each ST has one specific queue in MMU. Based on scheduler (FCFS in our implementation) packet controller dequeues packets from each ST queue, till either queue is empty or max allowed bytes of frame is reached to form DLTB. MAP generator use this information to build DL-MAP. It also does fragmentation when complete packet will not fit into the current frame. Fragmented frame is stored in temporary *fragment_buffer* along with STID. Remaining part of fragmented packet is Tx in next immediate frame. Similar task has been done at ST in UL, except here MMU has single queue to en-queue all client data packets.

5.5 Packet classifier

All packets received from packet controller are classified into two types (see Figure 5.3)based on connection identifier type (refer section 5.2).

5.5.1 Management packet handler

As mentioned in section 3.1 there are three basic steps *Beaconing, Ranging and Registration* which constitute network initialization. For each step there is a module in the actual implementation.

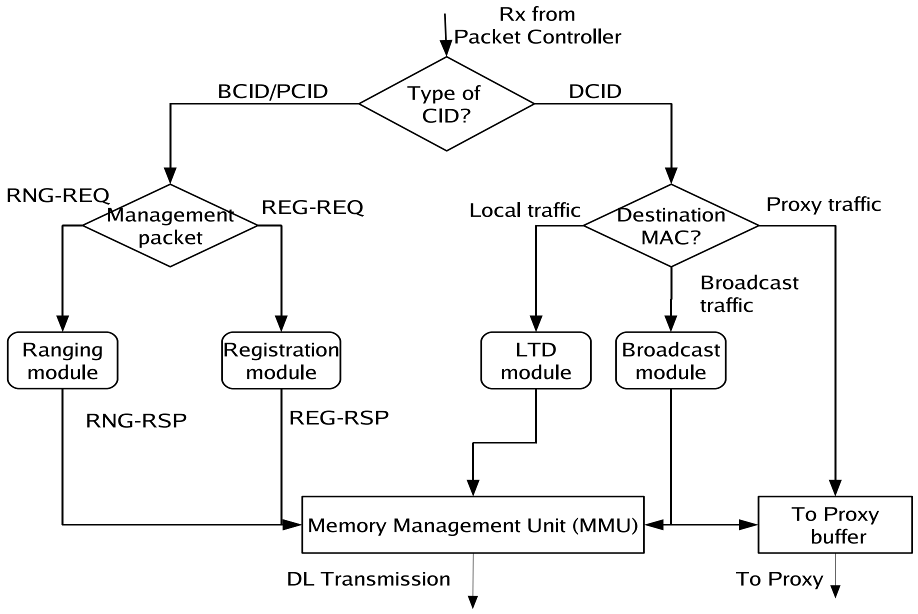
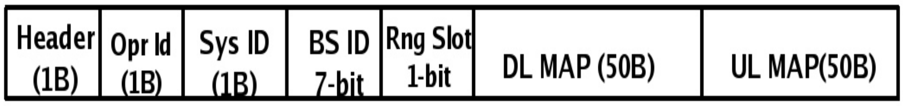


Figure 5.3: Packet flow in Packet classifier module



Header (1B)	Opr Id (1B)	Sys ID (1B)	BS ID 7-bit	Rng Slot 1-bit	DL MAP (50B)	UL MAP(50B)

Figure 5.4: Beacon Message

Beacon transmission

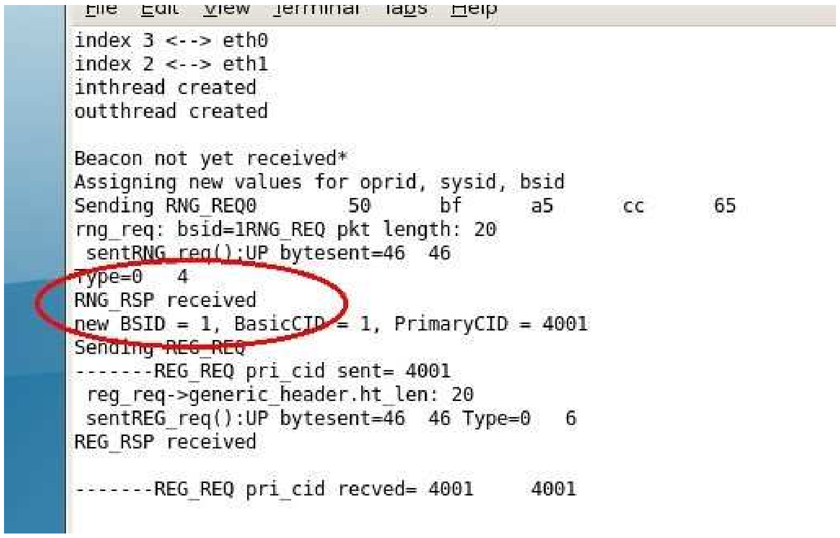
BS transmits beacons periodically after System (S) get booted. The period length depends on the frame size. Packet controller creates beacon frames when it receives SIGALRM signal. These beacon have the information like SystemID, OperatorID, BSID, DLMAP and ULMAP as shown in the Figure 5.4. SystemID and OperatorID help to recognize particular network. These values are given by the service provider and used for authentication purpose.

When ST boots up, it listens the medium for beacon. This process also called PHY synchronization. When first time ST reads beacon packet, it stores all system parameters into local variables. Now ST is ready to for ranging. ST checks these values on reception of every beacon to ensure every thing is working correctly.

Ranging and Registration

As explained in the previous chapter, during this ranging and registration phase different messages are exchanged between ST and BS. These messages are Ranging-Request (RNG-REQ), Ranging-Response (RNG-RSP), Registration-Request (REG-REQ) and Registration-Response (REG-RSP).

The implementation does not perform real ranging procedure as the testbed uses Ethernet cable, where propagation delay is not variable. Here, ranging is done to assign and transfer Basic and Primary CIDs. After ranging procedure ST finally get registered. In Figure 5.5

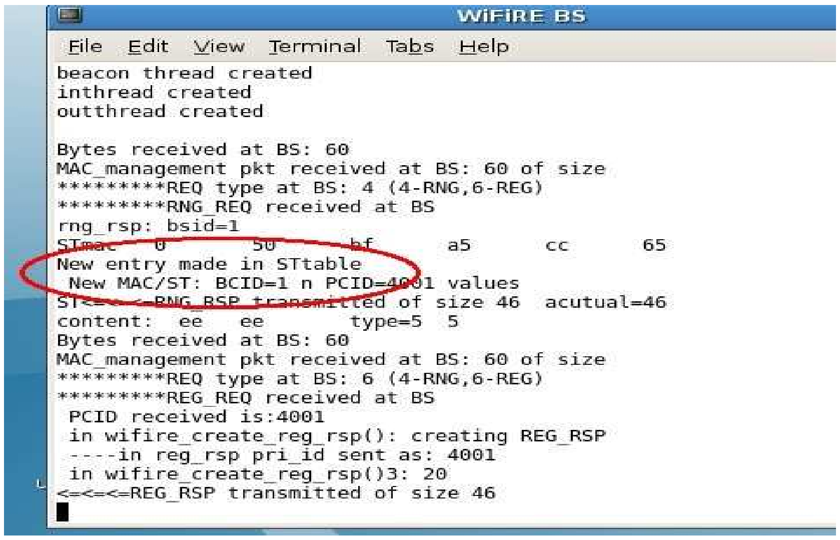


```
index 3 <--> eth0
index 2 <--> eth1
inthread created
outthread created

Beacon not yet received*
Assigning new values for oprid, sysid, bsid
Sending RNG_REQ0        50      bf      a5      cc      65
rng_req: bsid=1RNG_REQ pkt length: 20
 sentRNG_req():UP bytesent=46  46
Type=0   4
RNG_RSP received
new BSID = 1, BasicCID = 1, PrimaryCID = 4001
Sending REG_REQ
-------REG_REQ pri_cid sent= 4001
 reg_req->generic_header.ht_len: 20
 sentREG_req():UP bytesent=46  46 Type=0   6
REG_RSP received

-------REG_REQ pri_cid recved= 4001     4001
```

Figure 5.5: Sequence of steps at ST when it receives responses from BS

explains sequence of steps done by the ST after synchronization. When ST receives RNG-RSP, it gets allocated Base StationID (BSID), PrimaryCID (PCID) and BasicCID (BCID). In this example BSID=1, BCID=0001 and PCID=4001. When ST receives REG-RSP, it get DataCID (DCID). Now ST can transfer data to BS using allocated CIDs.

In Figure 5.6 explains sequence of steps done by BS when it receives a request form new ST. When ever it receives RNG-REQ, BS make entries in BS-TABLE then allocate PCID, BCID and BSID. Some times BS receives RNG-REQ from previously allocated ST, this time BS check for duplicate update. If it found duplicate it send same allocated PCID, BCID, BSID. These PCID and BCID are used for exchanging management packets. When BS receives REG-REQ it sends DCID from the available pool. This DCID is used for further data communication. ST is now ready to serve its Clients request.



```
beacon thread created
inthread created
outthread created

Bytes received at BS: 60
MAC_management pkt received at BS: 60 of size
*********REQ type at BS: 4 (4-RNG,6-REG)
*********RNG_REQ received at BS
rng_rsp: bsid=1
STmac    0       50      bf      a5      cc      65
New entry made in STtable
 New MAC/ST: BCID=1 n PCID=4001 values
ST<=<=<=RNG_RSP transmitted of size 46  acutual=46
content:  ee   ee      type=5  5
Bytes received at BS: 60
MAC_management pkt received at BS: 60 of size
*********REQ type at BS: 6 (4-RNG,6-REG)
*********REG_REQ received at BS
 PCID received is:4001
 in wifire_create_reg_rsp(): creating REG_RSP
 ----in reg_rsp pri_id sent as: 4001
 in wifire_create_reg_rsp()3: 20
<=<=<=REG_RSP transmitted of size 46
```

Figure 5.6: Sequence of steps at BS when it receives new request from ST

Some of the boundary conditions that we are handling are listed below

1. *ST rebooted after registration*: Start from synchronization.

2. *BS rebooted after ST registration*: If ST did not receive a beacon in a specified time interval then it resets all its local values (OperationID, SystemID etc) then get rebooted. This feature is not handled yet.

3. *ST received different operationID*: Drop the received packet then start from Ranging.

4. *ST received different systemID*: Drop the received packet, and restart ranging process again.

5. *ST received packet with different BSID*: Drop the packet or ignore it.

6. *ST received packets with different STID (ST-MAC)*: Drop the packet or ignore it.

7. *ST never forwards packet till registration done*

5.5.2 Data packet handler

After registration is done, clients are allowed to access services like web, ftp, telnet, VoIP etc. provided by the server. In our implementation DCID is same as clientID. Packets with DCID type (see Figure 5.2) are treated as data packets and these packets are en-queued into specific

ST queue through MMU. These packets are handled differently at BS and ST. At ST in DL, all received data packets from WiFiRe frame are directly forwarded to clients. At BS in UL, all received data packets further categorized based on destination MAC.

1. **Proxy packets**: Packet with destination MAC as proxy will be forwarded to proxy directly.
2. **Local Traffic**: Packet with destination MAC as any one of its local client, then packet is enqueued to respective ST queue.
3. **Broadcast packets**: Packets with destination address with all 0xff are sent to proxy and also enqueued to broadcast queue. These packets are transmitted in DL with special CID (0xffff). ST Rx all packets in DL (because DL is broadcast) but reads packets matching with its own DCID and also DCID with *0xffff*, all other packets are dropped.

Local Traffic Diversion (LTD)

This module is implemented only at BS, and helps to provide communication with in the WiFiRe network (between different STs). When ever packet classifier receives data packet and finds (with help of ST-TABLE) that the received packet is intended for local WiFiRe Client, then it enqueues the packet to destination Client ST queue for DL transmission. Otherwise packet is transmit to Proxy directly.

5.6 Tables

Table 5.1, explain ST-TABLE entries, size of each entry and short description about it. This table is stored at ST and updated when ever new client packet arrives. Table 5.2, describe fields in ST-MAPPER, and this table make entries when it receive ranging and registration request from new ST. Table 5.3, describe different fields in BS-TABLE, and this table make entries when it receive a new connection request from some active ST Client. All supplementary functions to access Tables are implemented.

Field Type	**Size in Bytes**	**Remarks**
DCID	2	Data Connection Identifier; connectionID, primary key
Type	1	Flow type (UGS = 0, rtPS = 1, nrtPS = 2 and BE = 3). Not used
ClientID	6	Client Identifier; Client MAC
Validity	1	indicates connection status

Table 5.1: ST-TABLE at ST; used for storing Client details at ST

Field Type	**Size in Bytes**	**Remarks**
STID	6	Subscriber Terminal Identifier; ST MAC address, primary key
BSID	1	Base Station Identifier [1..6]
BCID	2	Basic Connection Identifier; used for periodic Ranging
PCID	2	Primary Connection Identifier; used for management packets

Table 5.2: ST-MAPPER at BS; used for mapping between ST and BS

Field Type	**Size in Bytes**	**Remarks**
ClientIP	4 (6)	IP address of Client. Not used
DCID	2	Data Connection Identifier; connectionID, primary key
Type	1	Flow type (UGS = 0, rtPS = 1, nrtPS = 2 and BE = 3). Not used
STID	6	Subscriber terminal Identifier; ST MAC address
ClientID	6	Client Identifier; Client MAC
upfragment	-	To hold fragmented pkt in Up-Link if fragment exists of this ST
Downfragment	-	To hold fragmented pkt in Down-Link if fragment exists of this ST
Brokenflag	-	Indicates fragment status; 1 = fragment exist, 0 = no fragment
LTDQHead	-	Local Traffic Diversion queue head; holds pkts for with in system
total_packets	2	Current buffer size of this ST (in terms of packets)
stats_packetstx	2	Total number of packets transmitted from this ST; used for stats and debug

Table 5.3: BS-TABLE at BS; used for storing Client details at BS

5.7 Filters and Stats display

Filters

During the implementation and experimenting process, we observed lot of illegal packets affecting the performance of WiFiRe. This module is implemented at both ST and BS. Examples of illegal packets are,

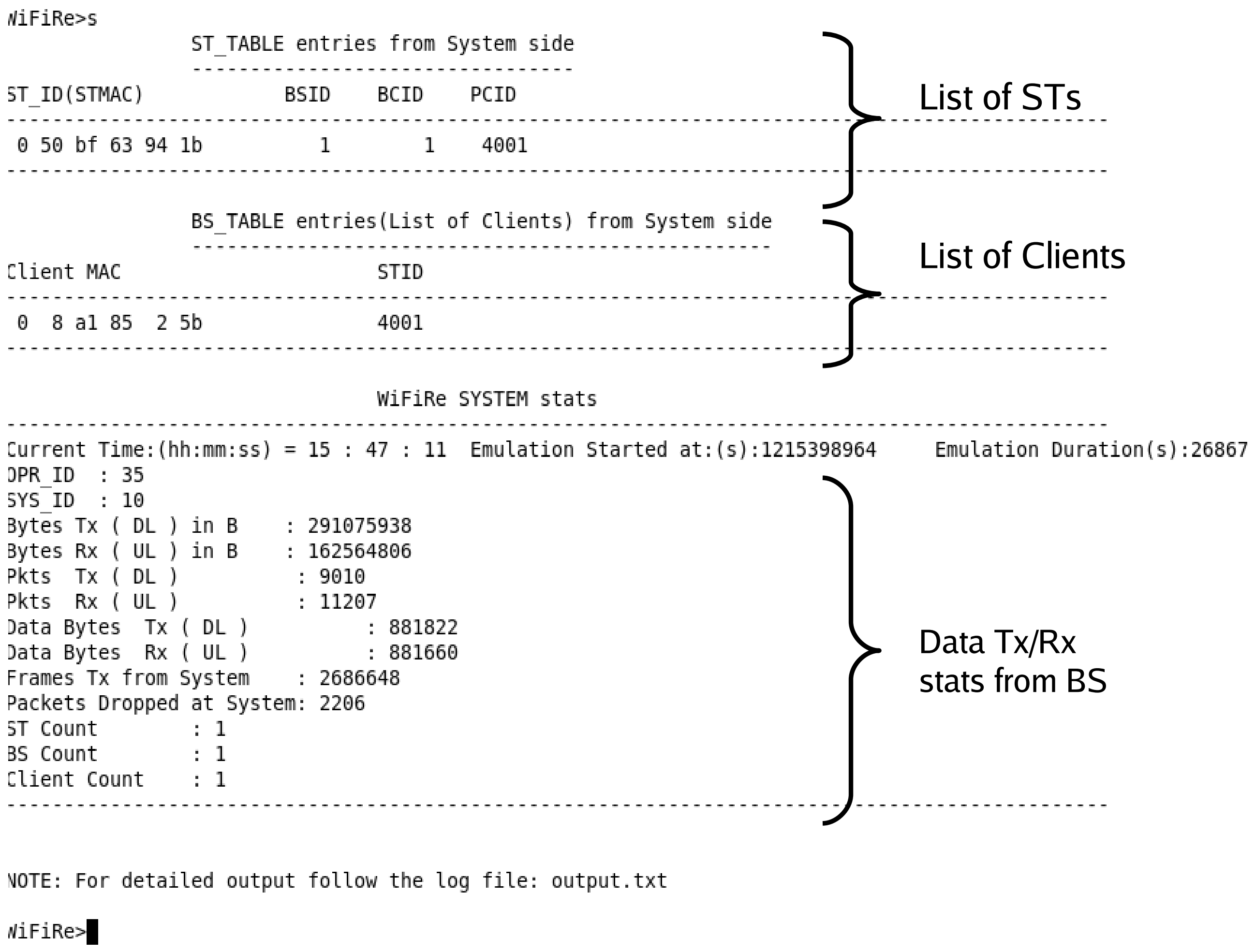
- Packet with destination MAC as {0x00, 0x00, 0x00, 0x00, 0x00, 0x00}
- Packet with destination MAC as its own BS MAC, i.e destined for *eth1* (proxy interface) received from Proxy in BS
- Packet with destination MAC as its own ST MAC, i.e destined for Client interface (*eth1*) received from Client in ST
- Packet with destination MAC with other than local WiFiRe clients

Stats display

We implemented few features in GUI for supporting end user. This is also helpful in measuring performance of WiFiRe. All the functions relating to emulation statistics are implemented under this module. Statistics include emulation duration, number of frames sent, number of data packets Tx/Rx, packet drop count, display of present UL-MAP and DL-MAP, list of active STs (BS-TABLE), list of active Clients (ST-MAPPER), etc.

Figure 5.7 shows one of the output screenshot, where program ran more than 7hr (26867 sec, in this case) with only ping active between Proxy and Client. The active ST and Client MAC can observe in the same figure. Total number of frames Tx is around 2686648 (with frame length = 10ms) which also prove the working of soft timer. Packet drop count (2246) indicates, these many number of packets were dropped because of any one condition getting satisfied from filters section.

We also support certain commands like h-help, s-show stats, a-advanced stats, x-exit from running, m-display current MAP and r-to restart emulation. It also displays all configuration variable values before beginning of emulation.



```
WiFiRe>s
                ST_TABLE entries from System side
                --------------------------------
ST_ID(STMAC)            BSID    BCID    PCID
-----------------------------------------------------------------------------------------------
 0 50 bf 63 94 1b          1        1    4001
-----------------------------------------------------------------------------------------------

                BS_TABLE entries(List of Clients) from System side
                -------------------------------------------------
Client MAC                      STID
-----------------------------------------------------------------------------------------------
 0  8 a1 85  2 5b               4001
-----------------------------------------------------------------------------------------------

                                WiFiRe SYSTEM stats
-----------------------------------------------------------------------------------------------
Current Time:(hh:mm:ss) = 15 : 47 : 11  Emulation Started at:(s):1215398964     Emulation Duration(s):26867
OPR_ID  : 35
SYS_ID  : 10
Bytes Tx ( DL ) in B    : 291075938
Bytes Rx ( UL ) in B    : 162564806
Pkts  Tx ( DL )          : 9010
Pkts  Rx ( UL )          : 11207
Data Bytes  Tx ( DL )          : 881822
Data Bytes  Rx ( UL )          : 881660
Frames Tx from System    : 2686648
Packets Dropped at System: 2206
ST Count        : 1
BS Count        : 1
Client Count    : 1
-----------------------------------------------------------------------------------------------

NOTE: For detailed output follow the log file: output.txt

WiFiRe>
```

Figure 5.7: WiFiRe Statistics screenshot (GUI)

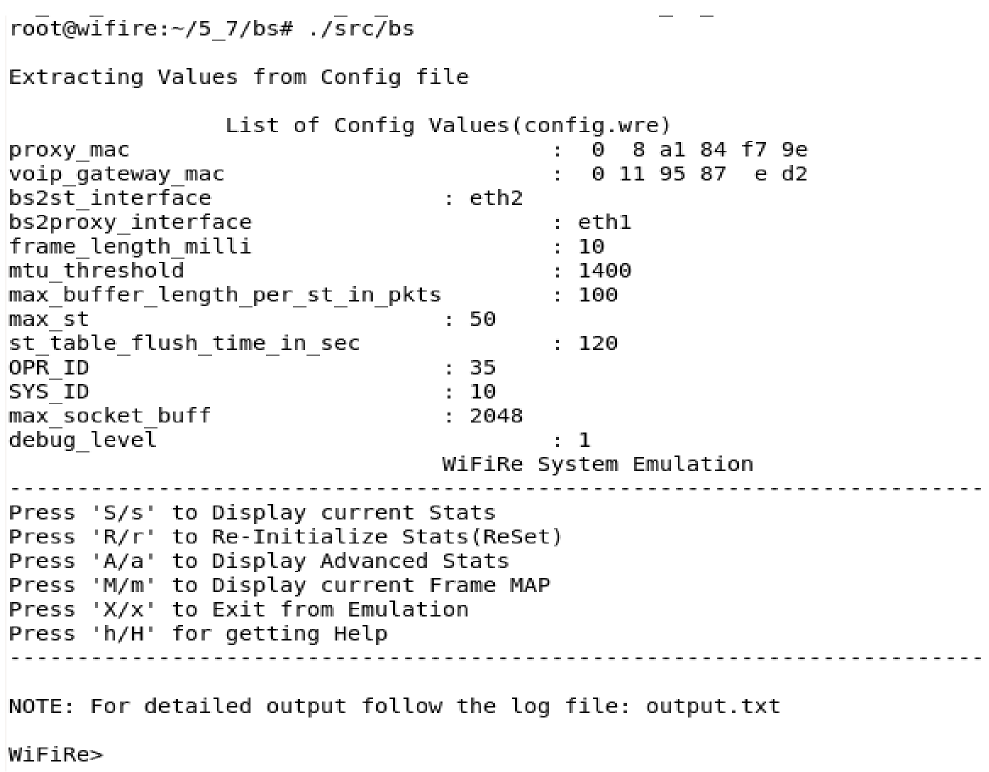
5.8 Config file and IO Debug levels

Configuration

Functions relating to parsing config file (*config.wre*) and setting config values to respective variables are implemented. We also mentioned some default values for each variable, in case cofigured value is miss typed or represented wrongly it takes default value. These default values are listed in Table 5.4. Figure 5.8 shows the welcome screenshot of BS, it shows all present configuration values.

Config variable	**BS,ST**	**Default value**	**Remarks**
opr_id	BS	10	OPR_ID
sys_id	BS	35	SYS_ID
frame_length_milli	BS	10	frame length in milli seconds
mtu_threshold	BS, ST	1400	MTU max threshold
max_buffer_length	BS, ST	100	Max buffer length per ST in packets
max_st_idle_time_in_sec	ST	5	max ST scan or idle time, if BS goes down or ST just wake-up on sec
bs_table_flush_time_in_sec	BS	120	for removing in-active clients from system
st2bs_interface	ST	eth0	ether card name between st and bs
st2client_interface	ST	eth1	ether card name between st and client
bs2st_interface	BS	eth0	ether card name between bs and st
bs2proxy_interface	BS	eth1	ether card name between bs and proxy
proxy_mac	BS	MAC[6]	proxy mac, should be in config file, BS can't read itself
voip_gateway_mac	BS	MAC[6]	VOIP GW mac, if present
max_st_scan_time_in_sec	ST	5	max ST scan time, if BS goes down or ST just wake-up on sec
debug_level	ST, BS	5	sets the debug level depth, for complete list refer Table 5.8

Table 5.4: *Config.wre:* Different configuration variables and their default values



```
root@wifire:~/5_7/bs# ./src/bs

Extracting Values from Config file

                List of Config Values(config.wre)
proxy_mac                               :  0  8 a1 84 f7 9e
voip_gateway_mac                        :  0 11 95 87  e d2
bs2st_interface                 : eth2
bs2proxy_interface                      : eth1
frame_length_milli                      : 10
mtu_threshold                           : 1400
max_buffer_length_per_st_in_pkts        : 100
max_st                          : 50
st_table_flush_time_in_sec              : 120
OPR_ID                          : 35
SYS_ID                          : 10
max_socket_buff                 : 2048
debug_level                             : 1
                                WiFiRe System Emulation
-------------------------------------------------------------------------
Press 'S/s' to Display current Stats
Press 'R/r' to Re-Initialize Stats(ReSet)
Press 'A/a' to Display Advanced Stats
Press 'M/m' to Display current Frame MAP
Press 'X/x' to Exit from Emulation
Press 'h/H' for getting Help
-------------------------------------------------------------------------

NOTE: For detailed output follow the log file: output.txt

WiFiRe>
```

Figure 5.8: List of red Config values and Menu commands

IO Debug levels

In order to keep track on the execution of the protocols, DEBUG LEVELS has been introduced to get output information at user defined level of depth. Table 5.5 defines the levels and their purpose of execution.

Memory management unit (MMU), encapsulation, fragmentation modules are explained in [2]. All the modules we implemented are functioning properly as we expected without any interruption for longer time.

Debug Level	**Purpose**
0	No Output
1	Event And High-Level Information Messages
2	Track The Flow Of Command Processing
3	For Inner Loops, Table Traversals, Etc
4	I/O Debug - Mover Messages Traces
5	Trace-Level Debug
6	Redundant Information

Table 5.5: Debug Levels

Chapter 6

Experiments and Learnings

This chapter describes the experiment conducted during the implementation. And slo listed technical problems we encountered during the implementation of protocol. The observations, guesses, causes and the solution to problems are also described.

6.1 Experiments conducted

As mentioned earlier, our primary goal is to provide web and VoIP connectivity between WiFiRe client and outside client. We spent lot of time for setting up testbed and tested with different kinds of traffic loads. For experimental purpose we conducted these tests in our lab.

6.1.1 Within same ST

List of experiments we have conducted are given below,

- **Ping interaction between Client and Proxy :** Able to ping between *Client11* and *Proxy* as shown in Figure 6.1, and also achieved round trip delay of less than 20 ms. Theoretical value should be more than *FRAME_DURATION*, i.e 10ms in our case.

- **VoIP call between local WiFiRe Client to PSTN phone via Gateway :** Able to make call from *Client11* to *land-line phone* located outside in PSTN. Also achieved un-interrupted quality of voice.

- **Accessing Internet pages :** Able to make TCP connection with outside server without any connection break in between. Example, from *Client11* we are able to access *www.google.com* pages.

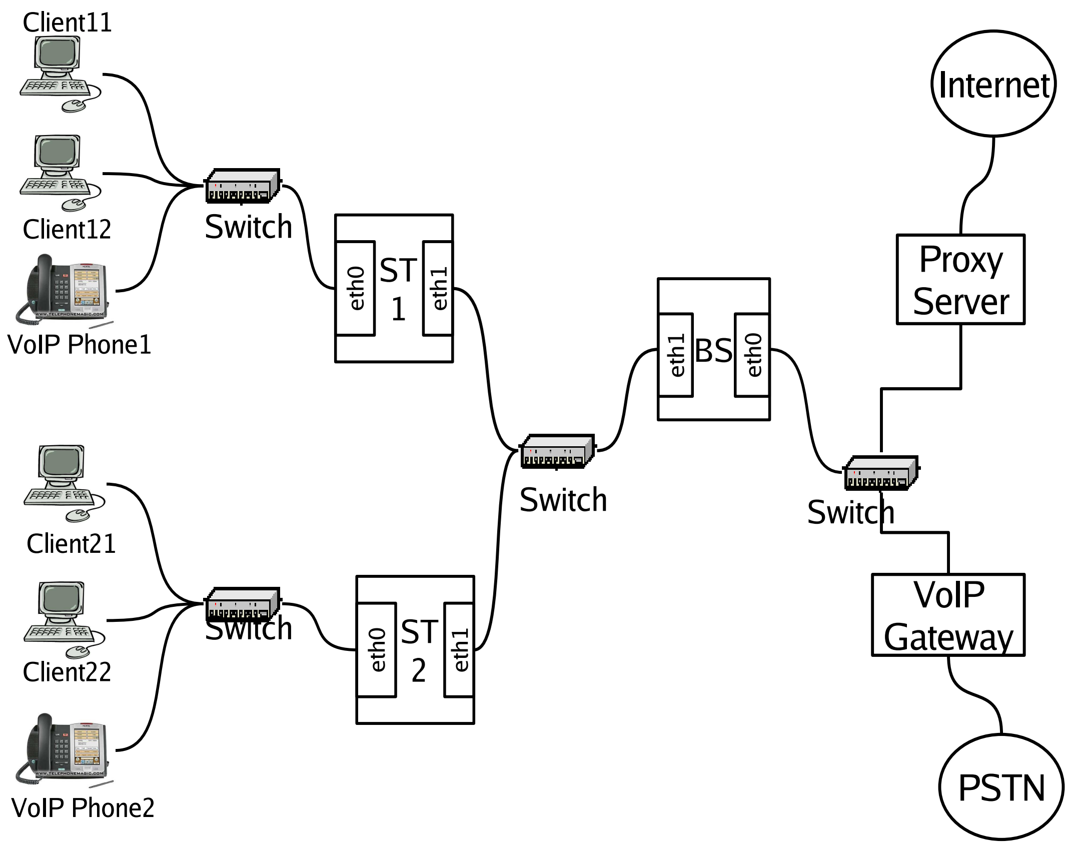


Figure 6.1: Final Single sector Testbed used for experiments

- **Downloading FTP files :** Able to make FTP connection and downloaded files from *Client11*.

6.1.2 Between different STs

List of experiments we have conducted in lab are given below

- **Ping interaction between clients in two different STs :** Able to ping between *Client11* and *Client21* as shown in Figure 6.1, and also achieved round trip delay of less than 20 ms. Theoretical value should be more than *FRAME_DURATION*, i.e 10ms in our case.
- **VoIP call between clients in two different STs:** Able to make call from *Client11/VoIP-phone1* to *Client21/VoIP-phone2*. Also achieved un-interrupted quality of voice.
- **Accessing SSH services :** Able to access ssh service between *Client11* and *Client12*.

Other Applications required to conduct experiments

For all above experiments, we consider frame duration as 10ms, and proxy as a gateway. For supporting different types of traffic like web, ftp, VoIP etc., we need to run certain applications at ProxyClient.

List of applications required are given below.

- *HTTP Proxy* : at Proxy, to access Internet, ex: squid proxy [10]
- *HTTP Server*: at Proxy, to access http pages from proxy, ex: Apache [7]
- *VoIP PBX Server*: at Proxy, to support VoIP calls, ex: Asterisk [8]
- *DHCP Server*: at Proxy, to configure IP address dynamically [3]
- *DNS Server* : at Proxy, to resolve DNS queries coming from client. ex: MaraDNS [9]
- *VoIP Client*: at Client, to make connection with server, ex: SJPhone [11]
- *DHCP Client*: at Client, to make DHCP request [3]
- *VoIP-PSTN gateway*: a device connected in place of proxy, to act as VoIP adapter between VoIP clients and PSTN network, ex: SPA300 [13]

6.2 Learnings

6.2.1 ARP Cache Flush

- **Naive Assumption:** Since, the protocol is working correctly for single ST, it should work for multiple STs under same BS.
- **Observation:** Although, Proxy is able to reply all ARP requests, it seem that packets are not reaching ST.
- **The Guess:** The problem might possibly either ST is not able to receive packets in WiFiRe network, or it dropped all the packets because they found to be garbled or illegal packet.

- **The Cause:** In our implementation forward all broadcast packets to all STs within the WiFiRe network. ARP request is an broadcast packet, so this packet is transmitted back to all STs which results same source packet is received at client. It results ARP cache flushing at client. After some waiting time, now client again sends new ARP request, this process continued. This results ARP flooding in the network.

- **The solution:**There are two solutions, we can drop these packets at ST or we can transmit packets to all active STs other than the originated ST. Second approach, results wastage of bandwidth because we have to Tx same packet to all other STs individually (with different DCID's). We implemented first approach because it avoids duplicate Tx in WiFiRe network. Broadcast packets are Tx with special DCID (0xeeee). When ever ST receives this special DCID packets, it search for source MAC in list of local Client MAC from ST_TABLE. If entry found then it drops the packet, otherwise Tx to all clients.

6.2.2 Moving from 32 bit to 64 bit machine

- **Naive Assumption:** Since, the protocol successfully running on IITB testbed, it should also work at any other testbed.

- **Observation:** After successful completion of protocol implementation supports single sector communication, we went to IITM to handover the code for integrating into PHY hardware. We has done all the testbed setup and configured Clients, STs, BS and Proxy as we have done at IITB lab. We observed only beacon Tx in DL, we are not able to exchange single data frame in WiFiRe network.

- **The Guess:**The problem might possibly that all packets are dropped at both BS and ST, or our source code has some dependency with machine(PCs) hardware.

- **The Cause:**After spending some valuable time on debugging, we found at some point we are capturing address of a memory location into some *unsigned int* variable which is of size 32-bit by default in gcc. We realize that, our lab machines has 32-bit physical address so our program runns successfully, but new machines need 64-bit field to capture whole address.

- **The solution:** We ran a small C program in the testbed machine, and found size of address of memory location as 64-bit. We immediately updated all required *unsigned int* declarations into *unsigned long int*.

6.2.3 Problem with RTP packets

- **Naive Assumption:** Since, we are able to establish VoIP call between clients with in the same ST, it should support for communication among different STs too.
- **Observation:** All the clients from different STs are able to register with VoIP PBX (ex: Asterix) by exchanging SIP packets. When ever we made call between two clients, call gets registered with server successfully. RTP communication works perfectly when two clients are connected under same ST, but not working for clients under different ST.
- **The Guess:** The problem might be at BS, either RTP packets are dropping or forwarding through wrong interface.
- **The Cause:** BS not forwarding RTP packets back to intended ST.
- **The solution:** We implemented a module *Local Traffic Diversion (LTD)*. It detects data packets intended for local clients from UL traffic and put them into respective queue for DL Tx. LTD is explained clearly in section5.5.2

6.2.4 Problem with Non-WiFiRe packets in WiFiRe network

- **Naive Assumption:**Since, only our protocol is running in WiFiRe network, only WiFiRe packets are exchanged between BS and ST.
- **Observation:** We implemented protocol using PF_PACKET socket. PF_PACKET socket family allows an application to send and receive packets dealing directly with the network card driver. That is, any packet sent through the socket will be directly passed to the Ethernet interface [14]. But some how we are receiving general Ethernet frames (ex: ARP, multicast etc. any packet generated by ST or BS machine) with source address of either BS or ST interface. It results in program termination with error message *Segmentation fault*.
- **The Guess:** These non-WiFiRe packets are treated as WiFiRe packets, results wrong off-set calculation in packet extraction. This might be force process to access illegal memory location.

- **The Cause:** Either BS or ST machines itself trying to communicate with others. Lets consider a situation, where BS want to communicate (ping, web traffic etc) with ST, then BS generates one ARP query into WiFiRe network. Now ST receives this packet (because both are connected to same switch) and assumes it as WiFiRe packet, and trying to read data bytes with help of available MAP, results *segmentation fault*.
- **The solution:** We implemented a *Filter* module to filter out non-WiFiRe packets. All such packets are dropped.

6.2.5 Problem with multiple DHCP servers

- **Observation:**Since, our protocol works perfectly with L2 switch, we started testing the protocol by replacing L2 switch Access Point (AP). We generated DHCP request from client and got reply. We observed no packet transmissions between client and ST, instead we received packets with different IP.
- **The Guess:** Something going wrong at AP, because observed packets at ST belongs to AP subnet.
- **The Cause:** By default AP activated its own DHCP server
- **The solution:** Either replacing the AP with Switch or disabling DHCP service we can solve this problem.

6.2.6 Memory Management Unit

- **Naive Assumption:** Since, we implemented semaphore to access different memory locations and buffer queues, it should not give any memory related errors during protocol execution.
- **Observation:** Although, protocol runns perfectly in our testbed, at some random point of time execution is halted with error message indicating either *Segmentation fault* or *double free or corruption*.
- **The Guess:**Machine generates high priority interrupt (*segmentation fault*) when you have done some illegal operations on memory.

- **The Cause:** There are two threads *in_thread* and *out_thread* in our implementation at both ST and BS. We are dynamically allocating and freeing memory for data packets. Some how one of the thread was trying to access/free the memory location which is already freed. Because of high priority interrupt, we are not able to find exact location in source code where things went wrong by reading debug messages

- **The solution:**We solved this problem by implementing an efficient memory management unit (MMU) at both ST and BS. It has two modules *my_malloc()* and *my_free()*. *my_malloc()* method allocate requested memory and also store the address of the memory location into some dynamic list. *my_free()* method frees memory only when address of memory location matches with any one of the entry from available list of addresses, otherwise it just prints a debug error message.

6.2.7 Soft timer limitation

- **Naive Assumption:**Since, soft timer which we are implemented is able to generate SIGALRM signal at every 10ms (frame duration), it should also generate signal for 32μs.

- **Observation:**When we started generating signals at slot level using soft-timer based on MAP at scheduler, our program experienced unexpected delays in packet Tx/Rx. Ex: Normal round trip ping delay should not exceed 20ms in WiFiRe network, but on average we observed 2 sec delay.

- **The Guess:**The probable reason might be either processor (desktop machine) is not able to handle interrupts at this speed (One interrupt per every 32μ) or our soft timer is not able generate interrupts at demanding interval due to its own limitations.

- **The Cause:**We dont know the exact reason.

- **The solution:**Require some special hardware and software (ex: hardware clock, minimal OS).

These are the technical problems encountered and their respective solutions we followed during the implementation.

Chapter 7

Conclusions and Future Work

7.1 Conclusions

WiFiRe implementation over the test bed comes up with satisfactory results. We have made different experiments to access different applications (HTTP, FTP, SSH, etc.) including VoIP during the implementation and got satisfactory results. WiFiRe protocol performs up to the mark as designed for communication between BS and ST. WiFiRe packets can be captured over the link between BS and ST verifies the factual working of the protocol.

We have done emulation for one sector, for single BS and multiple STs with multiple clients under each ST, but it can be modified easily to accommodate multiple sectors. Set of problems we encountered and solutions we followed during the implementation are explained in the thesis. We believe modules we implemented are useful while integrating with WiFiRe hardware with miner modifications.

To perform better in terms of protocol implementation, packet delivery and time synchronization we propose some extensions in the future work section

7.2 Future work

This project can be enhanced by performing following tasks:

- Present implementation supports communication in single sector, can be extended to multiple sectors

- Present implementation runs in user space, need some efforts to implement as a device driver

- Software clock we use support up to mill seconds precession, need to improve precession level up to micro seconds to get slot (32 micro sec) level control as per draft requirements
- Integration with actual WiFiRe PHY
- An efficient call admission control (CAC) and scheduler can be implemented to meet QoS requirements

Appendix A

Other required software configurations

WiFiRe proxy has two interface: one connects to WiFiRe network other connects to external world. First interface connects to BS using cross-cable. It can be connected using L2 Ethernet switch as well. Other interface connects to external Router/Gateway using 802.3 based Ethernet LAN. Throughout this document, we will assume First interface as *eth0* with IP address of 172.168.1.1. Second interface is *eth1* with IP address of 10.129.41.2.

Squid: HTTP proxy

Squid is proxy server and web cache daemon. It has a variety of applications including speeding up a web server by caching repeated requests, to computer network lookups for a group of people sharing network resources, to filtering traffic [10]. It supports HTTP, HTTPS, FTP, and more. It reduces bandwidth and improves response times by caching and reusing frequently-requested web pages.

Configuration details of /etc/squid/squid.conf:

```
http_port: 8080
cache_peer proxy.it.iitb.ac.in parent 80 0 no-query no-digest
```

Configuration details on proxy.it.iitb.ac.in:

```
acl wifire_MTPexp src 10.129.41.2
```

Command on shell for Squid:

```
#/etc/init.d/squid start
#/etc/init.d/squid stop
#/etc/init.d/squid restart
```

WiFiRe proxy listens on TCP port number 8080 and its parent is proxy.it.iitb.ac.in.

Here proxy.it.iitb.ac.in is main proxy which handles web access of KReSIT building. WiFiRe proxy forwards all its request to this proxy. At proxy.it, we should mention that WiFiRe proxy is authorised proxy and it should entertain the requests coming from it. We setup acl for the same.

Asterisk: VoIP proxy

Asterisk[8] is an open source implementation of a PBX mainly used for VoIP. It supports SIP, H232 and many other protocols. It supports PSTN integration with IP telephony. It has AGI scripts which allows asterisk to integrate with other programs and daemon like LDAP, perl scripts, SMTP servers etc.

Configuration of /etc/asterisk/sip.conf:

```
    [janak]
type=friend
callerid=janak <100>
host=dynamic
username=janak
context=sip
```

Configuration of /etc/asterisk/extensions.conf: `[sip]`

```
exten => 100,1,dial(SIP/janak)
exten => janak,1,dial(SIP/janak)
```

Here, janak is the username for SIP client which has extension number of 100.

Command on linux shell to start asterisk:

```
#asterisk -vvvvc
```

Once started, command on Asterisk shell:

```
sip show users
stop gracefully
```

DHCP server

We used DHCP server from version 3 of the Internet Software Consortium DHCP package[3]. Dynamic Host Configuration Protocol (DHCP) is a protocol like BOOTP. It assigns IP addresses to clients based on lease times. It is probably essential in any multi-platform environment. Most of the WiFiRe clients does not know their network configuration like Default gateway or DNS server. DHCP server automatically assigns all this details to client and overhead of configuring clients is reduced by this.

Configuration of /etc/dhcp3/dhcpd.conf:

```
    option domain-name-servers 172.168.1.1;
default-lease-time 86400;
max-lease-time 604800;
authoritative;

     subnet 172.168.0.0 netmask 255.255.0.0 { range 172.168.0.200
172.168.0.229;
option subnet-mask 255.255.0.0;
option broadcast-address 172.168.0.255;
option routers 172.168.1.1;
}
```

Here, 172.168.1.1 is Server's IP and range is client IP's range.

Command on shell for DHCP server:

```
# /etc/init.d/dhcp3-server start
# /etc/init.d/dhcp3-server stop
# /etc/init.d/dhcp3-server restart
```

maraDNS: DNS server

MaraDNS[9] is a package that implements the Domain Name Service (DNS). MaraDNS can function either as an authoritative DNS server or ”recursive” DNS cache that uses the DNS root. We use it as recursive DNS for our purpose.

Configuration of /etc/maradns/mararc:

```
bind_address = "172.168.1.1"
chroot_dir = "/etc/maradns"
upstream_servers["."] = "10.129.1.1"
```

Command on shell for DNS server: `#/etc/init.d/maradns start`

```
#/etc/init.d/maradns stop
#/etc/init.d/maradns restart
```

SPA3000: VoIP-PSTN gateway

SPA-3000 is PSTN-VoIP gateway which converts PSTN signals to VoIP signals and vice-versa. It has two interface: one connects to PSTN line using RJ-11 cable, other connects to Ethernet LAN using RJ-45 cable. It has web-based interface to configure its Settings. We keep it parallel to proxy and BS can directly communicate to it. Configuration is mentioned at [13].

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I. I. T. Bombay

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