MAC layer for IEEE 802.22 standard

A PROJECT REPORT

Submitted in partial fulfillment of the
requirements for the award of the degree

of

BACHELOR OF TECHNOLOGY
in
COMPUTER SCIENCE AND ENGINEERING

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November, 2016

CANDIDATE'S DECLARATION

We hereby declare that the project entitled **"MAC layer for IEEE 802.22 standard"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in **Computer Science and Engineeing** completed under the supervision of **Dr. Vimal Bhatia, Associate Professor, Discipline of Electrical Engineeing, IIT Indore** is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

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It is certified that the above statement made by the students is correct to the best of my/our knowledge.

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Preface

This report on "**MAC layer for IEEE 802.22 standard**" is prepared under the guidance of Dr. Vimal Bhatia, Associate Professor, Discipline of Electrical Engineering, IIT Indore.

Through this report we have tried to explain the various protocols involved in the working of IEEE 802.22 standard for wireless communication.

We have tried to the best of our abilities and knowledge to explain the content in a lucid manner. We have also added figures to make it more illustrative.

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Acknowledgements

We would like to thank our btp supervisor, **Dr. Vimal Bhatia**, for his guidance and constant supervision as well as for providing necessary information regarding the project. He gave us the opportunity and encouraged us to discover and work in this domain throughout the project.

We are especially grateful to **Abhijeet Bishnu** who guided us, explained us the problems and provided us the initial pathway for starting this project in right manner. He simultaneously guided us with useful direction to proceed along whenever necessary.

We are also thankful to our friends and colleagues who have been a constant source of motivation. Finally, we offer sincere thanks to everyone else who knowingly or unknowingly helped us complete this project.

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Abstract

IEEE 802.22 standard specifies the protocol for wireless regional area network (WRAN) using whitespaces in the television. It involves using unused television spectrum for providing broadband access on a non-interfering basis. The standard combines cognitive radio abilities with medium access control layer (MAC) and physical layer (PHY) for communication between customer premise equipment (CPE) using base station (BS). The standard suggests a promising way to provide internet facilities to remote areas, as contrary to the currently existing IEEE 802.11, by operating on lower frequency bands between 54MHz to 862 MHz.

In this document, we intend to discuss the infrastructure behind the medium access control layer (MAC) and the various headers and components involved in a synchronized communication between devices and have efficient control over spectrum sensing.

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Chapter 1

Introduction

In IEEE 802.22 standard, we primarily aim to provide broadband facilities in distant rural areas. In sparsely populated areas, for wired communication the cost of laying wires per head proves out to be too much. In the already existing wireless protocol IEEE 802.11, we use high frequencies bands 2.4 GHz or 5.8 GHz to send broadband packets, which doesn't allows packets to travel farther, making it unsuitable for use in distant areas. In 802.22 we use low frequency spectrum so that the packets can travel longer distance. The broadcasting services operate in frequency band of 54 to 862MHz up to range of 100 km. Due to relatively low level of industrial noise and ionosphere reflections, reasonable antenna sizes and good non -line-of-sight propagation characteristics, the TV broadcast bands in the high VHF/low UHF range are ideal for covering large areas in sparsely populated rural environments. IEEE 802.22 can cover distance up to 30 km. With proper scheduling of the traffic by MAC layer, the standard can further accommodate costumer devices within range of 100 km.

Figure 1.1: Comparison between IEEE 802 wireless networks

The system is formed by Base Station and Customer Premise Equipment. Base station is a professional fixed, generalized set which controls the medium access for all the CPEs attached to it. Base station, along with all CPEs connected to it forms an IEEE 802.22 WRAN cell. Each CPE is assigned a unique station id.

The main essence of 802.22 lies in its spectrum sensing cognitive abilities. In sparse populated areas, generally all the television channels don't use the spectrum assigned to them at all times. We can use these unused frequencies to transmit broadband packets. For this we require real time channel sensing to sense which channels are not being used.

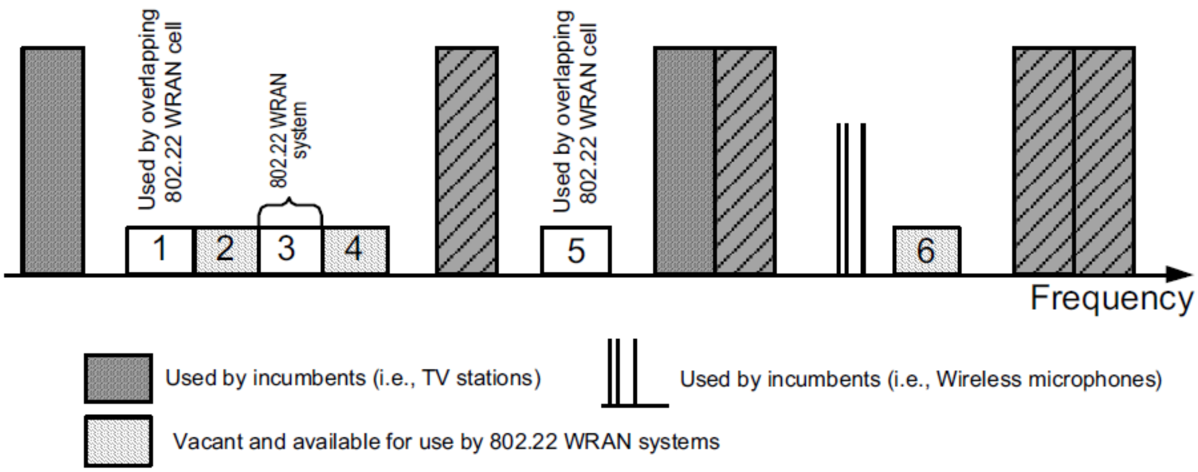


Figure 1.2: Spectrum Allocation in Television Bands

As shown in Figure 2, channel 3 is allocated to the IEEE 802.22 WRAN system, while channels 1 and 5 are in use by overlapping IEEE 802.22 cells. Channels 2, 4, and 6 would be available for more WRAN services in the area.

There are two type of sensing: In band spectrum sensing and Out of band spectrum sensing. In band spectrum sensing is done by CPE to detect the presence of an incumbent signal on the channel that is currently being used by BS to communicate within its cell. The base station stops its transmission for this time period. In Out of band sensing, CPEs sense other channels to locate possible alternate channels for switching, in case the operating channel gets occupied.

All the data gained from spectrum sensing by CPE is sent to BS. The BS, based on the data received, evaluates whether a change is necessary in the channel being used or the cell should continue operating on the same channel.

Chapter 2

Architecture

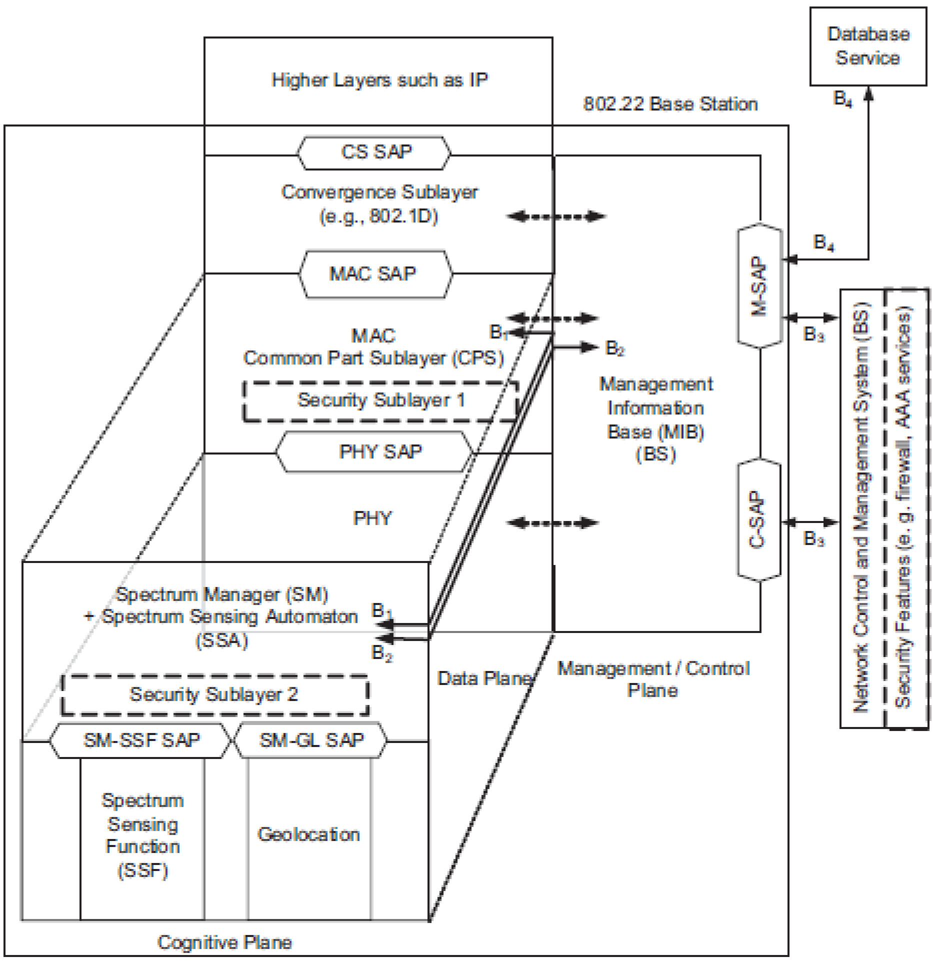


Figure 2.1: Protocol Reference Model of IEEE 802.22 BS

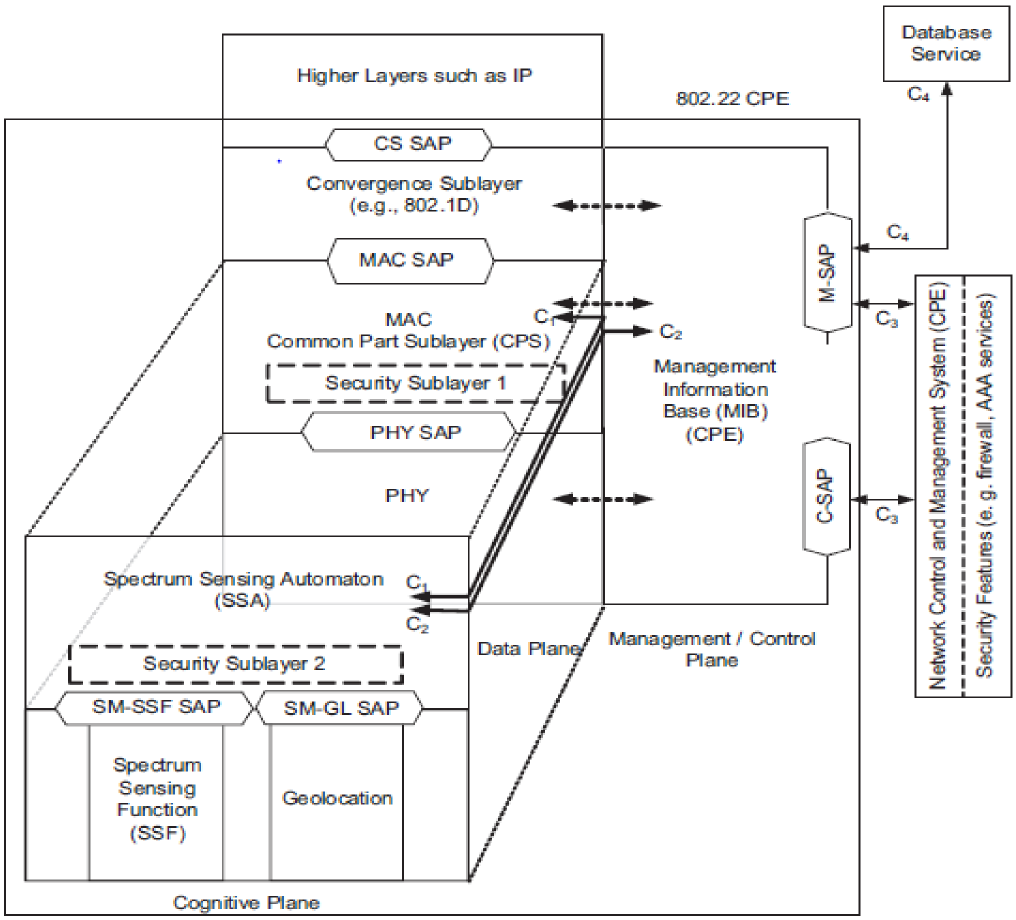


Figure 2.2: Protocol Reference Model of IEEE 802.22 CPE

(i) Data Plane

The data plane consists of the Physical Layer (PHY), the Medium Access Control (MAC) layer and the Convergence sublayer (CS). Service Access Points (SAPs) are added in between these layers to allow modularization.

The Data & Control/Management plane of the MAC shall be comprised of three sublayers: service-specific CS, the MAC Common Part sublayer (CPS), and the security sublayer 1. The service-specific CS shall provide transformation or mapping of external network data that is received through the CS SAP, into MAC Service Data Units (SDUs) and data that is received by the MAC CPS through the MAC SAP. This transformation or mapping shall include classifying external network SDUs and associating them to the proper MAC service flow identifier (SFID) and flow identifier (FID).

The MAC Common Part sublayer shall provide the core MAC functionality of system access, connection establishment, and connection maintenance. The data that the MAC layer receives from the various CSs through the MAC SAP shall be classified to particular MAC connections. QoS is applied to the transmission and scheduling of data over the PHY.

(ii) Management/control plane

The management/control plane shall consist of the Management Information Base (MIB). SNMP is used to communicate with the MIB database and some of its primitives may be used to manage the network entities (BS, CPE, switches, routers, etc.). The MIB primitives shall be used for system configuration, monitoring statistics, notifications, triggers, CPE and session management, Radio Resources Management (RRM), communication with the database service, spectrum sensing and geolocation reporting, etc. The MIB data may be obtained either from the network, pre-defined within the system, or obtained from another device (e.g., BS) after an exchange of information using SNMP over the communication medium.

(iii) **Cognitive plane**

- Spectrum Manager (SM)

The SM shall maintain spectrum availability information, manage channel lists, manage quiet periods scheduling, and implement coexistence mechanisms. The SM shall also take requests from the MAC/PHY. For example, The MAC must inform the SM if an interference situation has been detected (e.g., with incumbents or other IEEE 802.22 cells) during normal operation in the channel. The SM must then take appropriate actions to resolve the issue such as moving to another channel.

The SM has a key role in the overall architecture as it is the central point at the BS where all the information on the spectrum availability resulting from the database service and the spectrum sensing function is gathered.

- Spectrum Sensing Automaton (SSA)

A simpler spectrum management entity, called Spectrum Sensing Automaton, is present at the BS and at the CPEs and independently implements specific procedures for sensing the RF environment at initialization of the BS and before the registration of a CPE with the BS. The SSA at the CPE shall also include essential features to allow proper operation when the CPE is not under the control of a BS such as independent procedures during initialization and channel change and, while the CPE is idle, the SSA shall conduct out-of-band sensing and report to the BS so that it can refresh the status of the channels in the backup/candidate channel list. At any other time, the SSA at the CPE is under the control of the SM. The SSA at the BS is also active when the BS is not transmitting to conduct out-of-band sensing. The SSA located at the BS can also carry-out sensing to clear channels when the base station is not transmitting.

- Security sublayer 2

The role of the security sublayer 2 is to provide enhanced protection to the incumbents as well as necessary protection to the IEEE 802.22 systems. If the IEEE 802.22 beacon has to be detected in the given regulatory domain and the transmission needs to be authenticated, the security sublayer 2 shall be used along with the security mechanism provided (ECC-based signature) to authenticate this beacon.

Chapter 3

MAC Frame Structure

In an IEEE 802.22 cell, multiple CPEs are managed by a single BS that controls the medium access. The downstream is TDM where the BS transmits and the CPE receives. The upstream transmissions, where the CPEs transmit and the BS receives, are shared by CPEs on a demand basis, according to a DAMA/OFDMA scheme. Depending on the class of service (CoS) utilized, a CPE may be issued continuing rights to transmit, or is dynamically allocated by the BS after receipt of a request from the CPE. The MAC supports unicast (addressed to a single CPE), multicast (addressed to a group of CPEs) and broadcast (addressed to all CPEs in a cell) services.

The MAC is connection-oriented. Connections are identified by two items, a 9-bit station ID (SID) and a 3-bit flow ID (FID). The SID uniquely identifies a station that is under the control of the BS. A SID can be for a unicast station, when referencing a single CPE, or for a multicast station, when referencing a multicast group (of CPEs). A FID identifies a particular traffic flow assigned to a CPE. The tuple of SID and FID (SID | FID) forms a connection identifier (CID) that identifies a connection for the CPE. The SID is signaled in the DS/US MAP allocation, and the FID is signaled in the generic MAC header (GMH) of a MAC PDU.

3.1 SuperFrame Structure for normal mode

Frame is the basic time unit over which BS and CPEs communicate with each other. It is comprised of one downstream subframe, one upstream subframe and a self-coexistence window when present.

Superframe is a group of 16 frames. The superframe shall start with a superframe preamble, followed by the first frame preamble, the SCH, and finally the first frame payload. The first frame payload shall be reduced by two symbols with 1/4 cyclic prefix to keep the frame size consistent. In order to associate with a base station, a CPE must receive the SCH to establish communication with the BS. During each MAC frame, the BS shall manage the upstream and downstream operations.

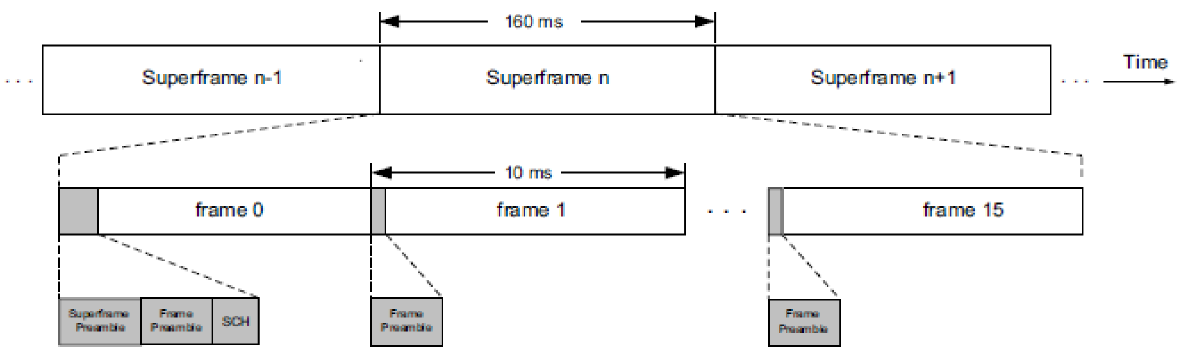


Figure 3.1: General Superframe Structure in normal mode

3.2 SuperFrame Structure for self coexistence mode

In case of multiple BS, problem of self coexistence arrives. Self coexistence is the scenario, where the BSs with overlapping coverage want to operate on the same channel. In such a case BSs have to share the channel of per frame basis i.e. they are allocated some subset of frames in which they are allowed to transmit.

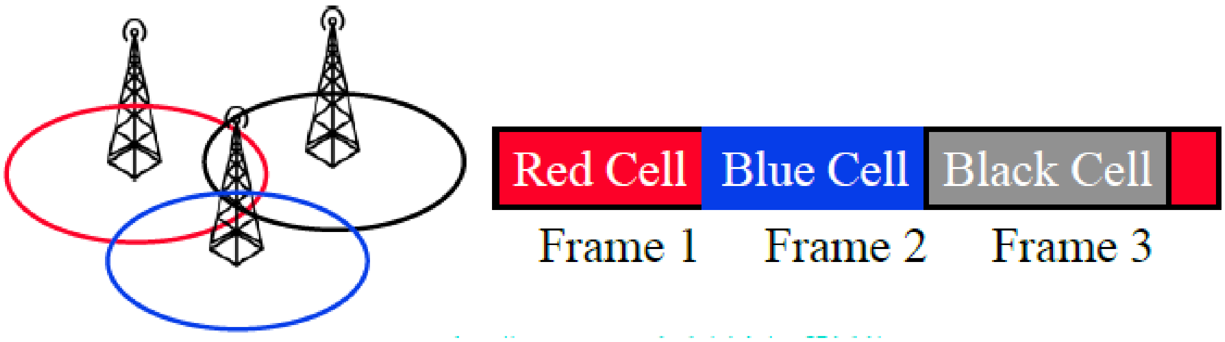


Figure 3.2: Allocation of frames in self coexistence mode

In self coexistence mode, every BS shall transmit the superframe preamble, frame preamble and superframe header in the first frame allocated to it in the current superframe. The BS and CPEs shall only transmit in the active frames allocated to them. Rest of the frames are used by BS and CPE to monitor the channel for transmission from neighbouring cells to improve cell coexistence.

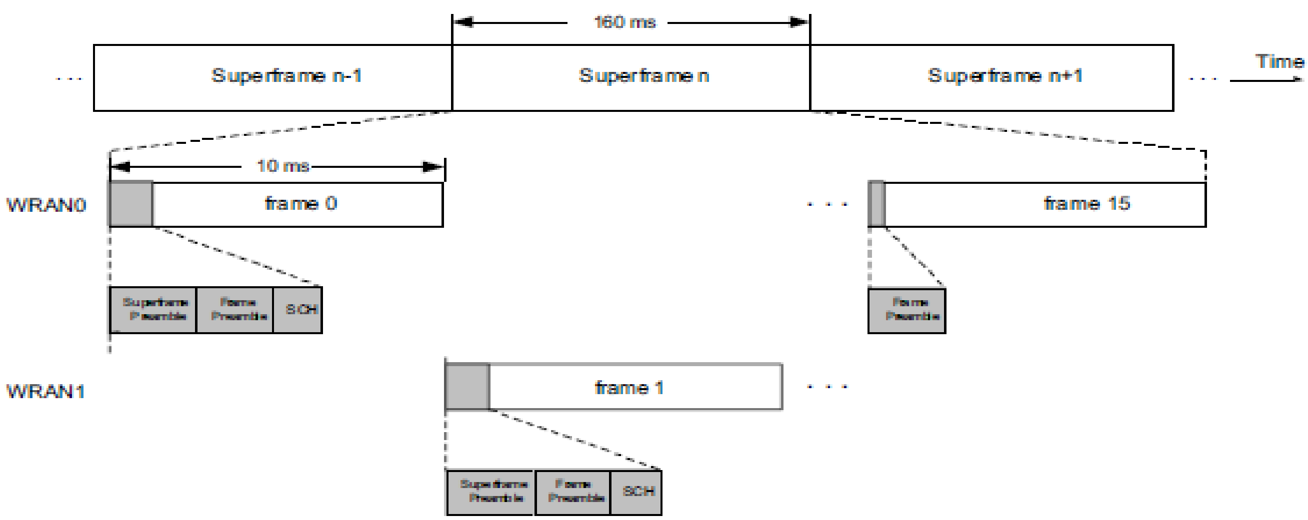


Figure 3.3: General Superframe Structure in self coexistence mode

3.3 General Frame Structure

A frame is comprised of two parts: a downstream (DS) subframe and an upstream (US) subframe. A portion of the US subframe may be allocated as a window to facilitate self-coexistence. This SCW may be scheduled by the base station at the end of the US subframe when necessary to allow transmission of opportunistic coexistence beacon protocol bursts. The SCW includes the necessary time buffers to absorb the difference in propagation delay between close-by and distant base stations and CPEs operating on the same channel. The boundary between the DS and US subframes shall be adaptive to adjust to the downstream and upstream relative capacity. The upstream subframe may contain scheduled upstream PHY PDUs, each transmitted from different CPEs for their upstream traffic.

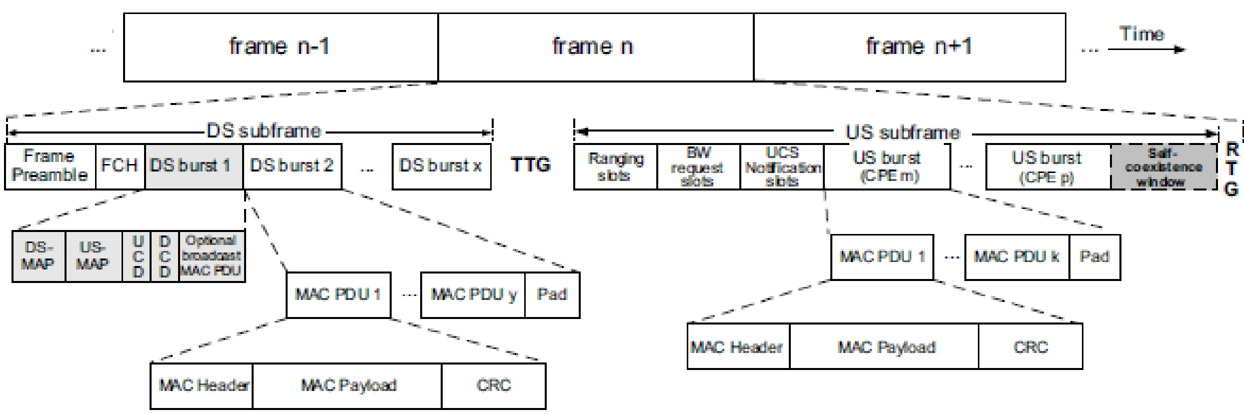


Figure 3.4: General Frame structure

Frame generally starts with a frame preamble (attached by PHY layer), followed by a frame control header. First downstream burst in the frame contains a DS-MAP and a US-MAP followed by DCD (downstream cannel descriptor) and UCD (upstream channel descriptor) in case downstream bursts or upstream bursts are present respectively. Following bursts contain normal payload.

3.4 Control Headers

Superframe Control Header: - The SCH provides information about the IEEE 802.22 cell, in order to protect incumbents, support self-coexistence mechanisms, and support the intra-frame and inter-frame mechanisms for management of quiet periods for sensing. In case of presence of multiple base stations, it also denotes that which frames are allocated to which base station in the current superframe. Since decoding of superframe is critical, it is always encoded with a fixed method.

Frame Control Header: - The encoding information of frame control header is given in SCH. It indicates the length of the frame in number of OFDM symbols from the start of the frame including all preambles. It also specifies the length of the MAP information element following the FCH in OFDM slots.

DS MAP: - The DS-MAP message defines the access to the downstream information. It basically informs the CPE's about the downstream bursts meant for them. It also mentions the encoding and modulation type for each downstream burst.

US MAP: - US MAP mentions about length of all upstream bursts, which upstream bursts are allocated to which CPE and the encoding of the upstream bursts.

DCD: - It contains physical characteristics of downstream burst modulation, coding. It also contains the list of backup and candidate channels to which we have to switch in case of incumbent interference.

UCD: - It contains physical characteristics of upstream bursts modulation, coding. It also contains information elements regarding ranging, bandwidth request, and urgent coexistence situation.

Ranging Slot: - It is used by CPE's to find distance from base station. It is done initially while establishing connection and then periodically to determine frequency, time and power adjustments. It is also used for geo-location.

BW Request Slots: - It is used to request bandwidth in upstream burst. For ex: In the upstream direction, if a CPE does not have any data to transmit in its US allocation, it shall transmit an US PHY burst containing a generic MAC header with its basic FID, together with a Bandwidth Request sub header . This would allow the BS to reclaim this CPE's allocation in the following frames and use the resource for some other purpose.

UCS: - It is used by CPE's to notify the base station about any interference with the incumbents.

Chapter 4

Implementation procedure

We created a simulation environment using java. Sockets were created to connect systems to create a single BS and two CPEs. We created header files providing API function calls to generate superframe control header, frame control header, DS-MAP, US-MAP, DCD and UCD at only base station and generic MAC header at both base station and CPE.

The following text files were present at the BS to gather basic information necessary for creating headers:-

(i) cpe_info: - contains list of all CPEs with their station ids and distance from the base station. The values of distance and station id were randomly chosen.

(ii) sid: - contains the MAC address of the base station. This field is included in the superframe control header sent by the base station and is used by CPE to identify the BS. The MAC address was specified in hexadecimal format.

(iii) server_payload: - contains the payload (in binary) meant to be sent from BS to CPEs.

(iv) channelslist: - contains the currently operating frequency, no of backup channels, total number of backup and candidate channels and the list of channels numbers with their corresponding signal to noise ratio.

(v) serv_recv: - contains the data obtained from CPEs in the upstream bursts along with the generic MAC header and CRC field. The data is stored in binary.

(vi) headers: - contains all the headers associated with a new frame in binary format. It is used by the simulation file to read frame control header, DS- MAP, US-MAP, UCD, and DCD for every new frame and to read superframe control headers for every new superframe.

(vii) gmh_binary: - contains the Generic MAC header to be attached with every MAC payload.

The CPE had following information files

(i) sid: - contains the unique station id assigned to the CPE.

(ii) cpe_payload: - contains the payload, in binary form, that is sent to the BS in every upstream burst.

(iii) cpe_recv: - contains the payload received by the CPE from the BS in downstream bursts along with the generic MAC header and CRC in binary.

(iv) cpe_header_recv: - contains the headers received from BS (in binary). This file is updated in every new frame.

(v) gmh_binary: - contains the generic MAC header that is attached by every CPE to the MAC payload and sent to the BS.

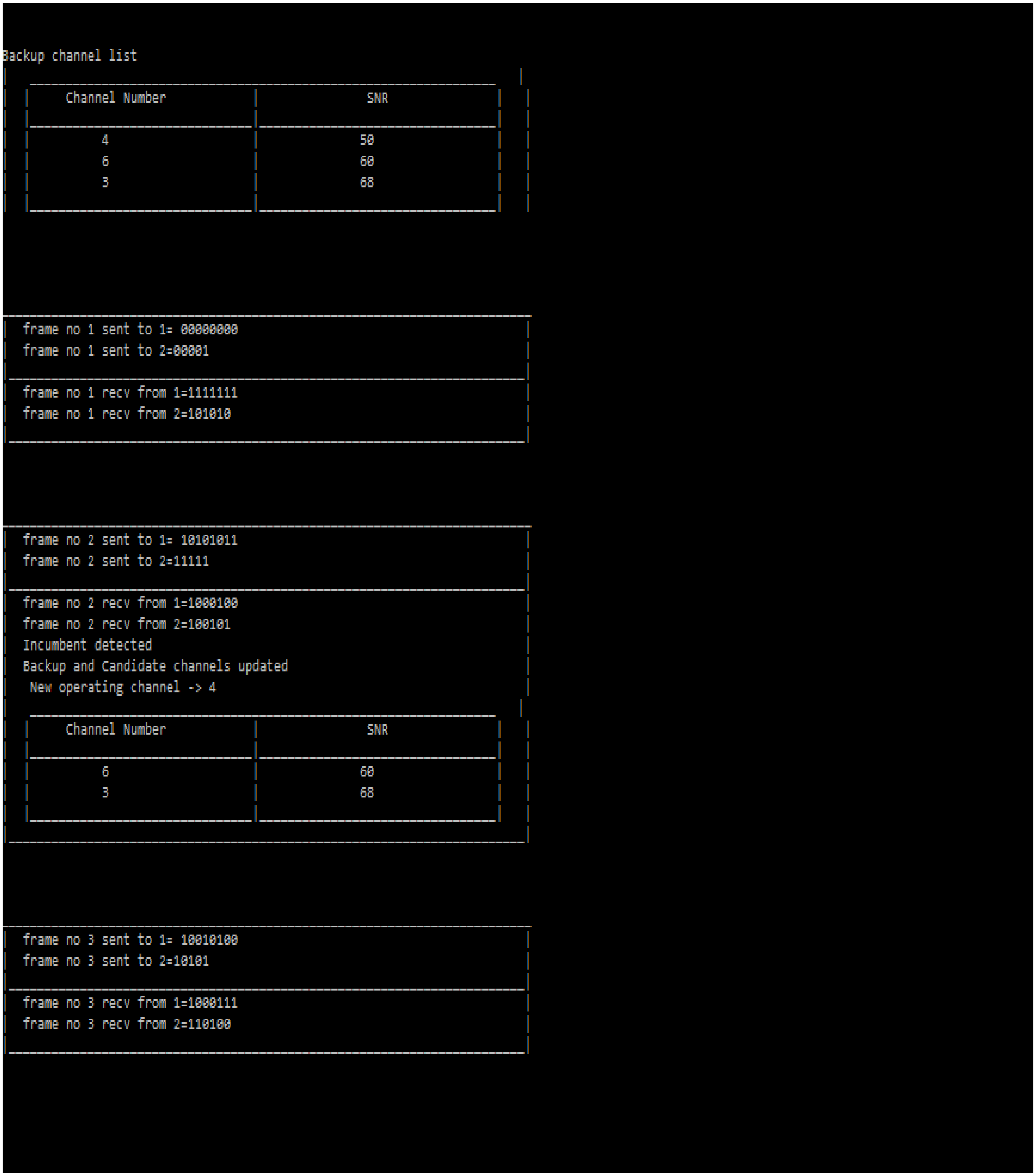
4.1 Downstreaming and Upstreaming

The simulation files create a BS and open two channels on a socket. The CPE files connect to the channels to complete the network. Once the network establishment gets accomplished, the BS reads the list of backup and candidate channels and displays a table denoting the same. Then, the BS starts transmitting the superframe control header, frame control header, DS-MAP, US-MAP, UCD and UCD. Frame Control Header is modulated and coded with pre-decided techniques. CPEs demodulate and decode the frame control header to get the modulation and coding scheme for DS-MAP and US-MAP. After decoding the DS-MAP the CPEs store the bursts numbers in which they will receive the data from the BS. The US-MAP denotes the bursts numbers, which have been allocated to the CPEs for the upstream transmission. The modulation and coding technique are also stored by the CPEs, which is crucial for decoding for proper decoding of data at the receiving end.

The BS starts downstream by transmitting the payload from the file “server_payload” via broadcasting. The CPEs receive the data and decide to store it if current burst number has been allocated to them in the current DS-MAP. Otherwise the packet is discarded.

4.2 Channel switching on incumbent detection

Currently the model sends data for 3 frames with 2 downstream bursts and 2 upstream bursts. In the second frame, one CPE toggles the UCS bit in the generic MAC header (GMH). The BS reads the GMH and chooses the channel from the channel from the backup channel list with the lowest SNR ratio. Lower SNR ratio denotes presence of weaker incumbent signal in the channel, making it most suitable for transmission of IEEE 802.22 packets. The adjacent channels are most subjected to interference. So the adjacent channels of new operating frequency are pushed at the lowest priority position in the backup channel table despite of their SNR value. The updated backup channels table is displayed at the BS. The CPEs also switched to the new operating channel and the transmission continues.



```
Backup channel list
|   ____________________________________________________________   |
|  |     Channel Number           |              SNR            |  |
|  |______________________________|_____________________________|  |
|  |          4                   |             50              |  |
|  |          6                   |             60              |  |
|  |          3                   |             68              |  |
|  |______________________________|_____________________________|  |

 __________________________________________________________________
|  frame no 1 sent to 1= 00000000                                  |
|  frame no 1 sent to 2=00001                                      |
|__________________________________________________________________|
|  frame no 1 recv from 1=1111111                                  |
|  frame no 1 recv from 2=101010                                   |
|__________________________________________________________________|

 __________________________________________________________________
|  frame no 2 sent to 1= 10101011                                  |
|  frame no 2 sent to 2=11111                                      |
|__________________________________________________________________|
|  frame no 2 recv from 1=1000100                                  |
|  frame no 2 recv from 2=100101                                   |
|  Incumbent detected                                              |
|  Backup and Candidate channels updated                           |
|   New operating channel -> 4                                     |
|   ____________________________________________________________   |
|  |     Channel Number           |              SNR            |  |
|  |______________________________|_____________________________|  |
|  |          6                   |             60              |  |
|  |          3                   |             68              |  |
|  |______________________________|_____________________________|  |
|__________________________________________________________________|

 __________________________________________________________________
|  frame no 3 sent to 1= 10010100                                  |
|  frame no 3 sent to 2=10101                                      |
|__________________________________________________________________|
|  frame no 3 recv from 1=1000111                                  |
|  frame no 3 recv from 2=110100                                   |
|__________________________________________________________________|
```

Figure 4.1: Simulation output at Base Station

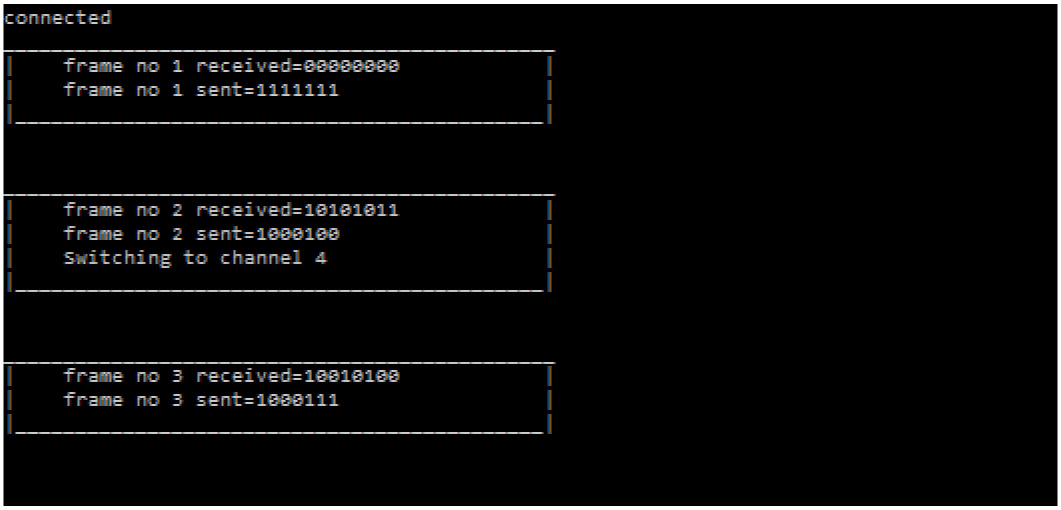


Figure 4.2: Simulation output at Customer Premise Equipment 1

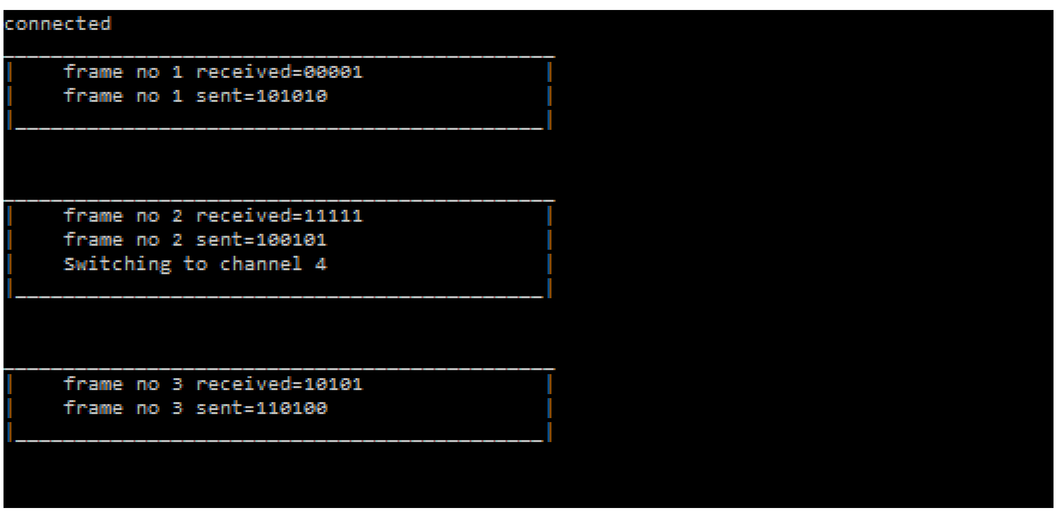


Figure 4.3: Simulation output at Customer Premise Equipment 2

Chapter 5

Conclusion

IEEE 802.22 provides a very promising way of reaching distant areas and providing facilities. With its spectrum sensing abilities and management layers, it provides a neat way of utilizing the existing bands without causing any harm to the licensed users.

Future Work

Though we have implemented the basic headers included in IEEE 802.22 standard, some more headers and management messages can be introduced to the model. Currently, the CPE simply connects to the base station. We can implement the procedure, as per IEEE guidelines, for initiation of connection when a new CPE tries to enter in an IEEE 802.22 cell. This way we can also enhance the security of the broadcasted data, since the encryption key is passed in the initialization. Another important aspect of this standard is to avoid interference between multiple cells. This self coexistence problem is solved by adding coexistence beacons. We intend to add this feature to the existing simulated model. A more robust algorithm for deciding the priority for switching channel can prove to be quite helpful and make the working of MAC layer more effective. Finally we can integrate the MAC layer with the PHY layer and add cognitive radio abilities.

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