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Implementation of IEEE 802.16a in GloMoSim/QualNet

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Acknowledgements

I would like to thank my supervisor Dr. Seán Murphy for his guidance, enthusiasm and commitment to this project.

Declaration

I hereby declare that, except where otherwise indicated, this document is entirely my own work and has not been submitted in whole or in part to any other university.

Signed: Benoît Louazel. Date: Friday, 17 September 2004

Abstract

The IEEE 802.16a standard, amendment of the IEEE 802.16 standard, addresses needs of the Broadband Wireless Access area.

This project aims at modelling this standard, in order to improve our understanding of it, and allow further implementation in the GloMoSim/QualNet simulator. Understanding the concepts involved in a simulator is the second objective of the project.

Implementation within the simulator implies to firstly build basic blocks, which are the basis for more advanced features, and then implement the model step by step up to a working solution.

A battery of tests and validations is performed to qualify the implementation, and determines the quality of the system.

Finally, directions for simulator improvement and simulation optimisation concludes the project, which has managed to provide a working, realistic implementation of the IEEE 802.16a standard into the GloMoSim simulator.

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Chapter I - Introduction

In the promising area of wireless communications, the IEEE 802.16a amendment [3] to the IEEE 802.16 standard [2] addresses issues of much interest.

Working in the 2-11 GHz band of frequency, it is in continuity with existing technologies. Its synchronised, scheduled way of working makes it a very efficient technology in unlicensed bands of frequency. And it supports Quality of Service, which is now an important, if not essential, aspect in a successful, new technology.

I.A. Project Objectives

The IEEE 802.16a standard has been released a year and a half ago, in January 2003. Still, few devices have been released, and we lack good understanding of the working processes and efficiency.

Many simulators have not yet implemented this standard, preventing us to simulate networks based on its specifications.

The main objective of this project is to provide an implementation of the IEEE 802.16a standard in the GloMoSim/QualNet simulator. The project shall help to improve our understanding of the IEEE 802.16a standard, the issues it addresses and those it raises.

I.B. Report structure

This report is structured in several chapters described below.

The Chapter 2 gives an overview of Broadband Wireless Access (BWA) systems, which is the context of the project. The evolution of needs in the wireless area is described, and Broadband Wireless Access systems are introduced as a solution to current issues. Finally, possible practical deployments are presented.

The IEEE 802.16 and IEEE 802.16a standards are presented in Chapter 3. The main principles of the standards are contained in the IEEE 802.16 standard, described first. Then, modifications introduced by the IEEE 802.16a standard are highlighted.

The two simulators involved in the project, GloMoSim and QualNet, are introduced in Chapter 4. The PARSEC programming language is briefly introduced, and the layered structure of the simulators detailed. An extensive description of GloMoSim and a brief description of QualNet are performed.

The Chapter 5 consists in the project model building. A step-by-step approach is used to build a model from the standard specifications.

In Chapter 6, the implementation features developed for the project are described. The steps defined in Chapter 5 are reused from the coding point of view. Testing procedures are described for each step.

The simulation process, including deployment of three different architectures, from a simple to a complex one, is performed in Chapter 7. Results are examined and discussed with respect to the standard specifications and the level reach by the implementation process.

Conclusions on the project results and achievements are presented on Chapter 8. A description of further possible researches and developments from the project is also performed.

Finally, Appendix A describes resources used and needed for running the simulator. Appendixes B, C and D present the detailed results of Chapter 7 simulations.

Chapter II - Broadband Wireless Access

II.A. Introduction

Now that the project objectives are stated, we introduce in this chapter the Broadband Wireless Access (BWA), which is the context of the project.

Firstly, in section II.B, a brief presentation of wireless communications is performed. The focus is set on how technology has evolved up to now, and which issues still remain to be addressed.

Then, section II.C introduces Broadband Wireless Access systems as a solution to new issues in the wireless area. Possible deployments of Broadband Wireless Access systems are then presented.

II.B. Wireless Communications

Evolution of wireless technologies

Ignited by mobile phone huge success at the end of last century, the demand for wireless services is constantly growing. To face this demand, wireless systems have been and are deployed at a large scale. These include mobility-oriented technologies such as GPRS, CDMA or UMTS, and Local Area Network-oriented technologies such as IEEE 802.11 (WiFi).

Issues

Mobility-oriented technologies are very complex to deploy, and rely on highly synchronised processes, in order to allow hand-over and long range, mobile communications at high bit rate…

Local Area Network-oriented technologies such as WiFi are much more simple technologies, easily deployed. They focus on small coverage areas, usually inside buildings, where a very high bit rate can be achieved. Yet, this technology is not using the air medium efficiently, having an Ethernet-like way of working.

II.C. Broadband Wireless Access Systems

The next step in wireless communications is broadband wireless access systems, which provides long range and large bandwidth.

As mobility is not, yet, a strong requirement for these systems, complexity is drastically lowered compared to the mobility-oriented technologies. However, in order to use the air interface more efficiently, the principle of highly synchronised network is used.

Possible deployments

A very interesting deployment of the IEEE 802.16 standard lies in "Last Mile" (or "First Mile", depending on the literature) systems. These systems focus on the link between end users and the network backbone. Figures II-1, II-2 and II-3 show some possible implementations. The issues raised by this kind of configuration are the handling of many end users, the fast, dynamic adaptation to individual needs and the service tailoring to various specific applications.

Two very similar deployments of the IEEE 802.16 standard are as a backbone for several remote locations (figure II-4) or for Wifi hotspots (figure II-5). The issues are a large bandwidth, as traffic is aggregate from multiple end users, and a long range, to cover many locations.

Figure II-1 – "Last Mile" wireless access for a small town

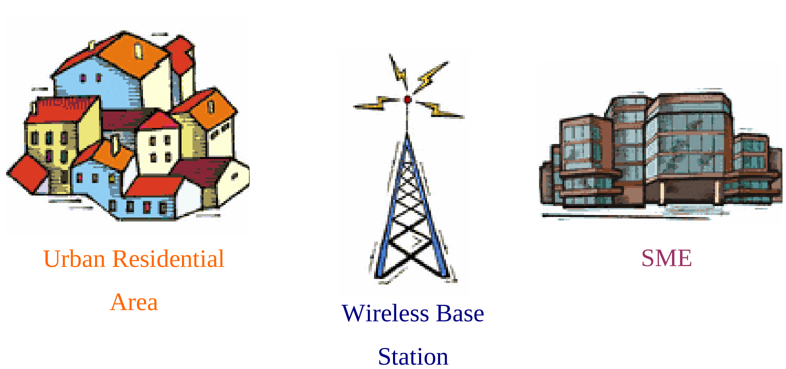

Figure II-2 – "Last Mile" wireless access for an urban area

Figure II-3 – "Last Mile" wireless access for a suburb residential area

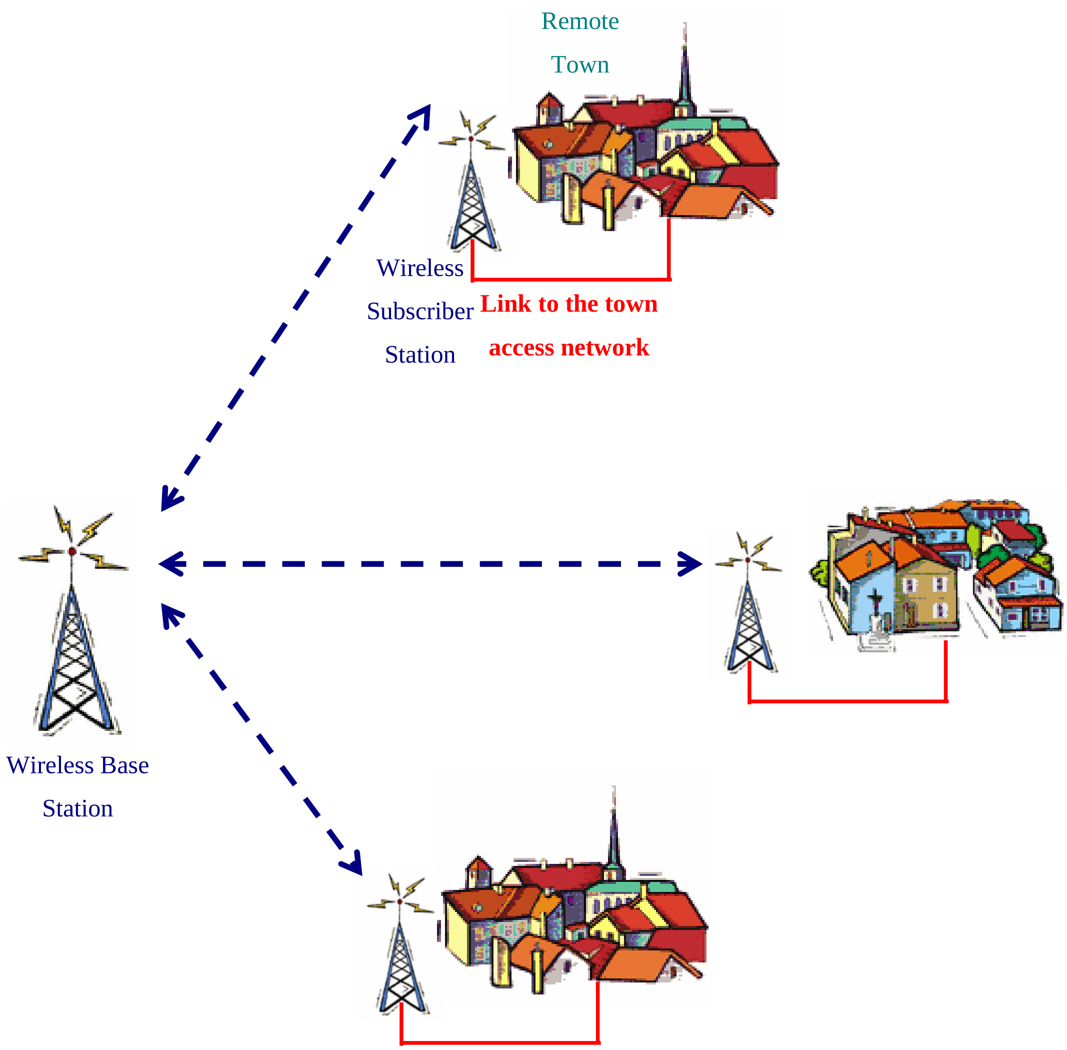

Figure II-4 – Backbone network for remote locations

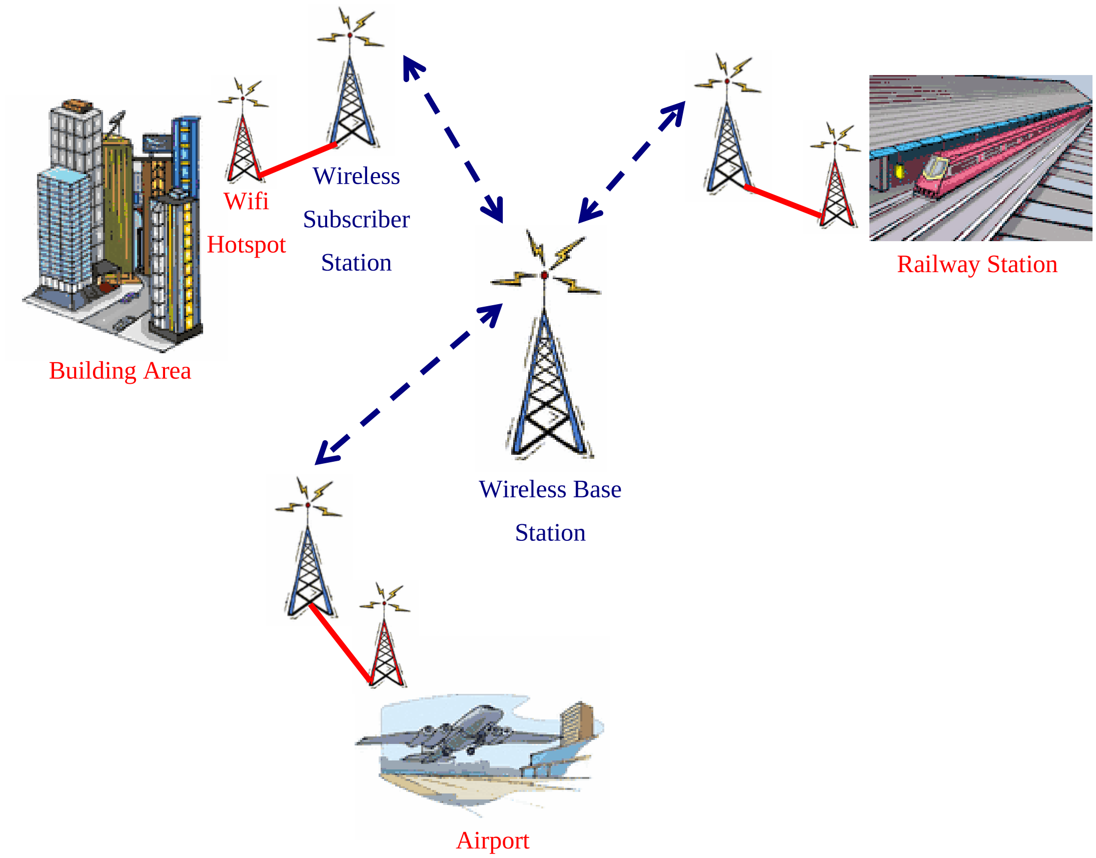

Figure II-5 – Backbone network for Wifi hotspots

II.D. Summary

In this chapter, we firstly have a look at the evolution of wireless communications from the success of mobile phones. Then, current technologies are presented, either mobility-oriented or Local Area Network-oriented, and related issues are discussed.

Finally, Broadband Wireless Access systems are introduced as a solution to these issues, and multiple possible deployments have been presented, from “Last Mile” solutions to WiFi hotspots backhaul solutions.

Chapter III - The IEEE 802.16 and IEEE 802.16a Standards

III.A. Introduction

In the previous chapter, the importance of Broadband Wireless Access systems in addressing the needs in wireless communications is highlighted.

In order to create conditions for an efficient technology, addressing interoperability and competition in this promising market, a standardization effort has been led by the Institute of Electrical and Electronic Engineers (IEEE) [7].

The first released standard, described in section III.B, was the IEEE 802.16, which addresses a wide range of frequencies, and defines the main principles for the series of the IEEE 802.16 standards published afterwards.

The IEEE 802.16a standard, described in section III.C, is an amendment of the IEEE 802.16 standard. It addresses the 2-11 GHz band of frequency, which is of the greatest interest today for cheap and easy deployments.

III.B. The IEEE 802.16 Standard

III.B.1. Scope

The IEEE 802.16 standard specifies the physical layer of the 7-layer OSI model, and the MAC part of the Data Link Layer (see figure III-1). The standard specifies only data and control features, and let management of layers open for vendor implementation.

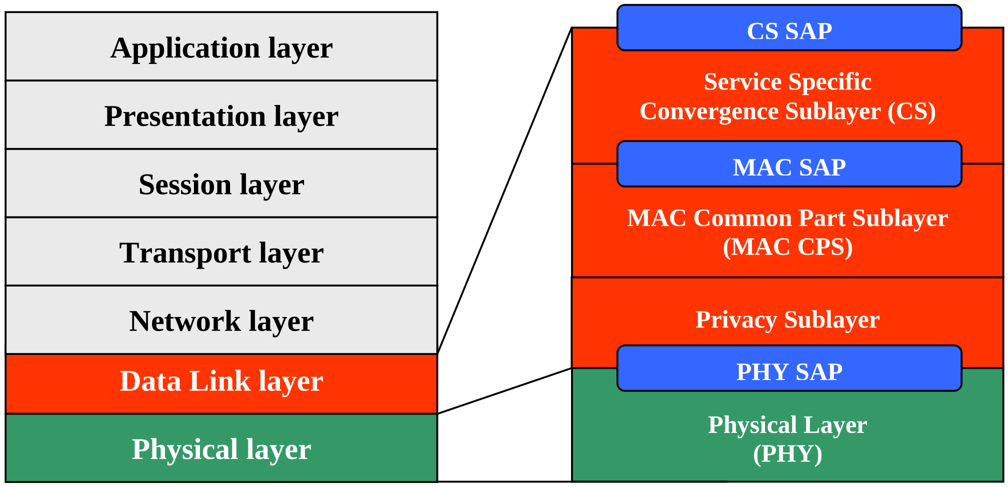

Figure III-1 – OSI 7-layer model - IEEE 802.16 Standard scope

III.B.1.a, Convergence Sublayer (CS)

Systems complying with the IEEE 802.16 standard are to support Asynchronous Transfer Mode (ATM) or packet mode of operation. The convergence sublayer is specified to deal with these two modes of operation, through the Service Access Point (CS SAP). The convergence sublayer accesses Medium Access Control (MAC) functions through the MAC Service Access Point (MAC SAP). So the convergence sublayer role is to interface MAC functions with the next upper layer of the protocol stack.

III.B.1.b, MAC Common Part Sublayer (MAC CPS)

This is the core of the MAC layer, which contains all functions needed to perform data exchange and control at the MAC level.

III.B.1.c, Privacy Sublayer

This sublayer implements all the privacy features required due to the air interface used for communications, like key exchange and encryption/decryption processes. It is interfaced with the physical (PHY) layer through the PHY Service Access Point (PHY SAP).

III.B.1.d, Physical Layer (PHY)

The specification of the physical layer is done in the standard with a

“*…high degree of flexibility, in order to allow service providers the ability to optimise system deployments with respect to cell planning, cost, radio capabilities, services and capacity*.” (from [2], Paragraph 8.2.1).

III.B.2. Frequency Band Covered

The IEEE 802.16 standard covers frequency range from 10 to 66 GHz (mainly licensed band), which implies line of sight propagation. The wide range of frequencies covered by the standard allows adaptation to the various legal environments throughout the world.

III.B.3. Main Principle

The standard has been designed for point-to-multipoint operation, between one Base Station (BS) and several Subscriber Stations (SS), as shown in figure III-2.

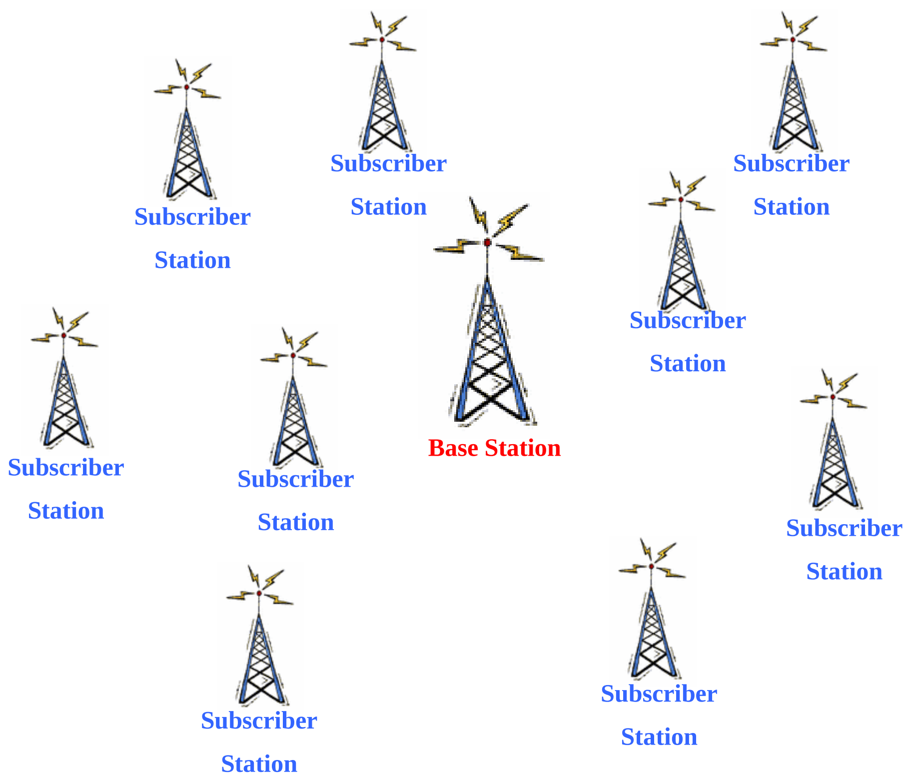

Figure III-2 – One Base Station and multiple Subscriber Stations

Connections

The notion of connection is specified in the standard, which led to the standard being called a connection-oriented technology, even if constantly set connections do not exist. Actually, connections are unidirectional flow of data, established from a base station to a subscriber station or vice versa (see figure III-3). They are of different types: signalling connections, which follow specific rules and can be for different purposes; data connections, which are defined with a service flow, that is Quality of Service (QoS) parameters.

Connections are helpful to allow the definition of multiple QoS for one subscriber station, as described below.

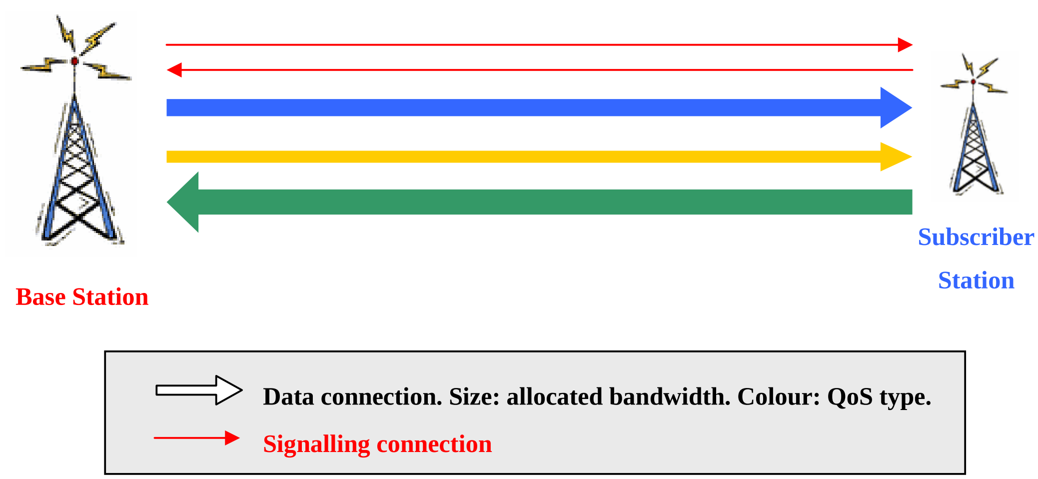

Figure III-3 – Connections between the base station and one subscriber station

Scheduling

In order to have an efficient mode of operation, scheduling has been introduced in the standard. Two different types exist, Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD).

In the FDD mode of operation, data from the base station to the subscriber stations are transmitted at one frequency, and data from the subscriber stations to the base stations are transmitted at another frequency (see Figure III-4).

In the TDD mode of operation, only one frequency is used for data transmission in both directions (see Figure III-5).

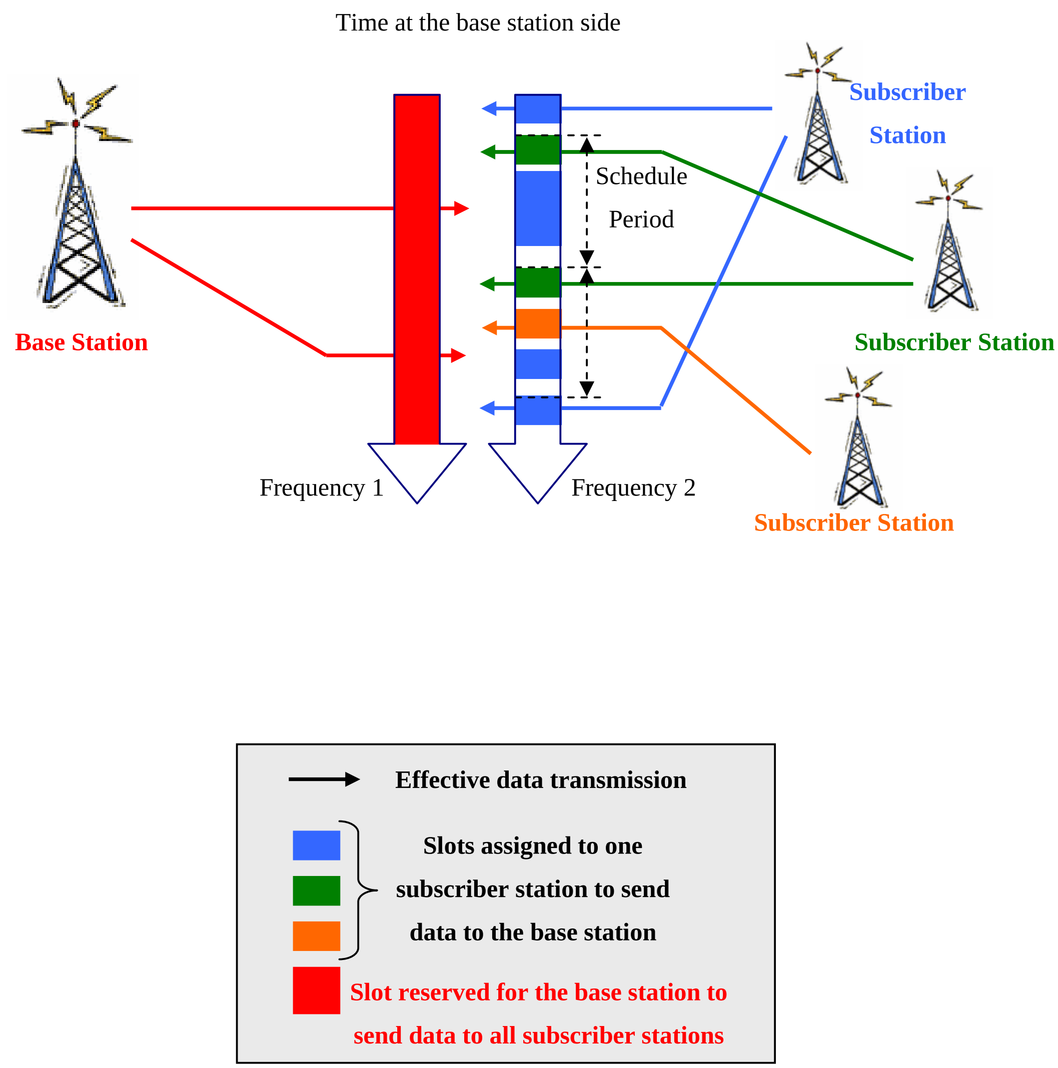

Figure III-4 – FDD scheduling

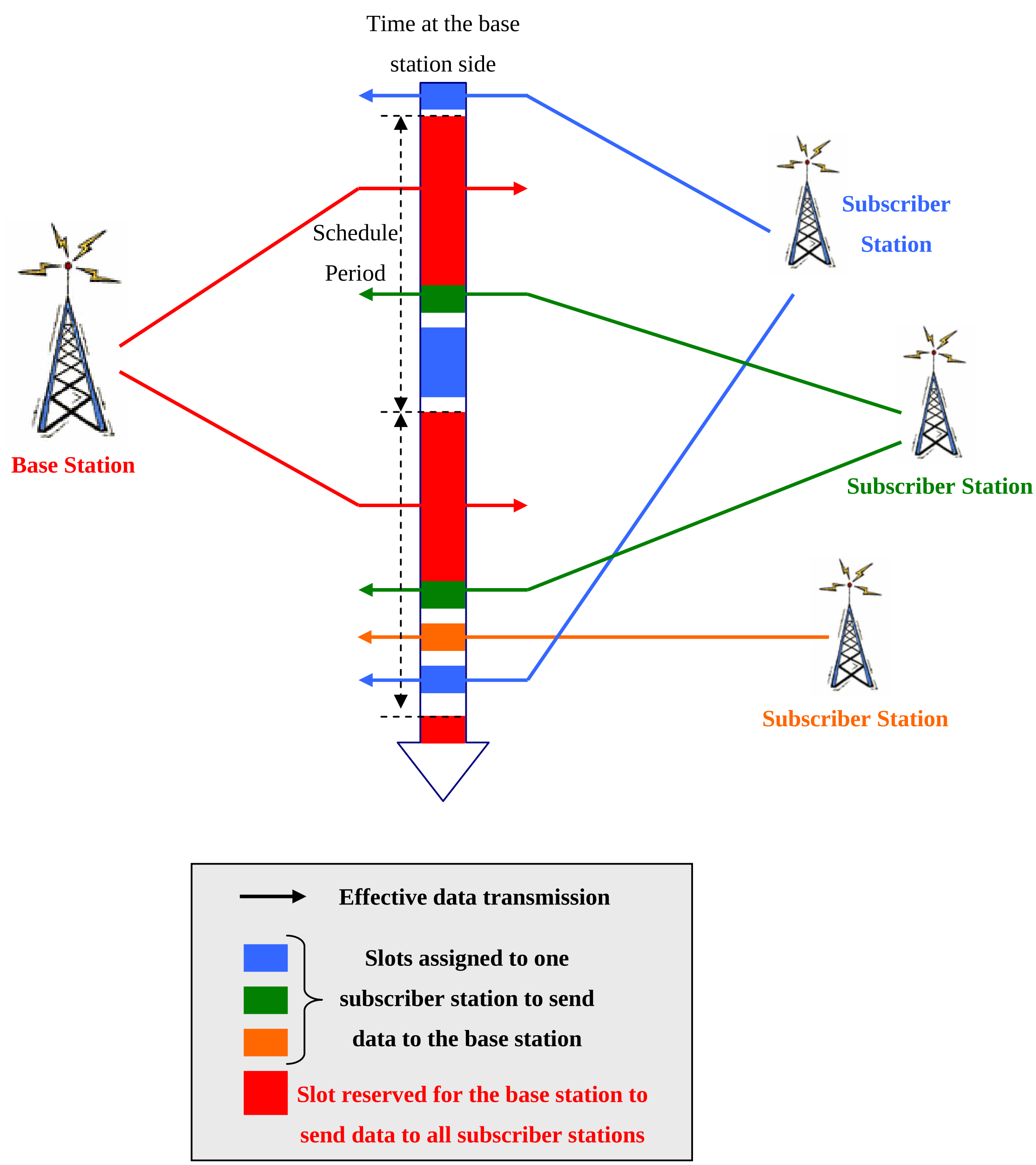

Figure III-5 – TDD scheduling

III.B.4. TDD Scheduling

One uses here the Time Division Duplexing mode of operation to illustrate the scheduling principle, as it is the one used in the project. It can be noted that the Frequency Division Duplexing mode of operation is simpler, and can be derived easily from the TDD case.

At the base station side, as shown in the figures III-5 above, the time is divided into frames, each of which being again divided into a downlink subframe (when the base station can send data) and an uplink subframe (when the subscriber stations can send data). If the frame length is fixed during operation, the sharing of the frame by both subframes can vary from one frame to the other. An illustration of this is done on figure III-6.

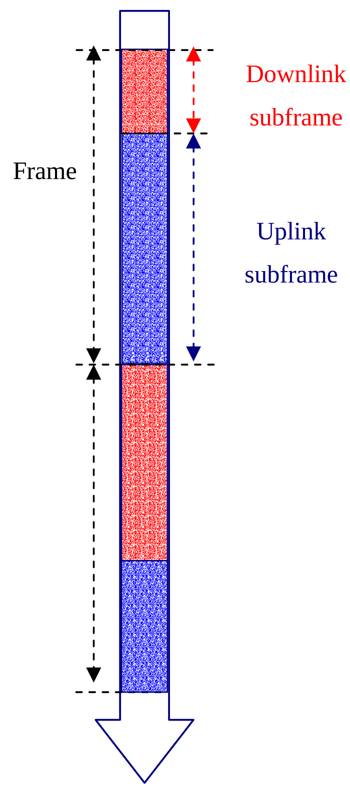

Figure III-6 – TDD – Frame and subframes

Slot Allocation and Maps

In each frame, time slots are assigned to a subscriber station or to a group of subscriber stations. More precisely, these slots of time are reserved for connections belonging to a subscriber station or to a group of subscriber stations.

Thus, during the downlink subframe, the base station sends data on a particular connection at a particular time. In order that a subscriber station knew when to expect data addressed to it during the downlink subframe, a downlink map is sent by the base station at the beginning of each frame. This downlink map details when data for a particular connection is to be expected, as well as the channel encoding parameters used.

During the uplink subframe, a subscriber station can send data on a particular connection if it has been allocated time slots. Time slot allocation, managed by the base station, is transmitted to all subscriber stations thanks to an uplink map. As for the downlink map, it details when data for a particular connection is expected at the base station side, and which channel encoding parameters to use.

Obviously enough, the relevance in allocating time slots for connections is crucial in the achievements of Quality of Service features.

Physical Slots and Minislots

A unit of time is defined in the standard, which allows using integers while referring to an amount of time. The basic unit of time is the Physical Slot (PS), which corresponds to 4 symbols used on the transmission channel. So, its duration depends on the symbol rate used within the system.

Sequencing is based on this unit of time, whether it is the frame sequencing, the frame synchronisation or the downlink subframe allocations.

A unit of time of higher level is used, the minislot, of duration a multiple of a PS. Minislots are used for uplink subframe allocations.

III.B.5. Quality of Service (QoS)

The IEEE 802.16 standard has been designed to fully support multiple network layer protocols, either ATM or packets (IP, Ethernet…). Thus, Quality of Service is a key feature of the standard, as multiple types of traffic may be carried through the network.

Achieving a QoS on the whole system scale is made possible by the standard through the combination of multiple features:

1. Connection allocation, modification and deletion on either Subscriber or Base Station request,
2. Fragmentation of MAC Service Data Units (SDUs) in order to fit in allocated time slots. This parameter is set on a per-connection basis,
3. Packing of MAC SDUs in one allocated time slot. This parameter is set on a per-connection basis,
4. Dynamic setting of the uplink map,
5. Dynamic setting of the downlink map,

The standard does not describe how to implement a particular QoS, but specifies the tools available to achieve such a goal, which allows competition and vendor specific implementations.

III.B.6. Network Layer Adaptation

As said above, the IEEE 802.16 standard has been designed to support multiple network layer protocols. Adaptation of these protocols to the MAC layer is specified in the standard, describing how network layer PDU shall be transformed into MAC layer PDU, and then reconstructed from these latter.

III.C. The IEEE 802.16a Standard

III.C.1. Amendments to the IEEE 802.16 standard

The IEEE 802.16a standard is an amendment to the IEEE 802.16 standard. It introduces additional physical layer specifications for the 2-11 GHz band of frequency. It contains modifications for the MAC layer, including the Mesh mode of operation, Adaptive Antennas Support (AAS), Automatic Repeat Query (ARQ)…

Thus, the main features of the IEEE 802.16a standard for the MAC layer are described in the IEEE 802.16 standard, whereas the physical layer, as specific to the 2-11 GHz band, are described in the IEEE 802.16a.

III.C.2. Frequency Band Covered

The IEEE 802.16a amendment adds physical layer specifications for the 2-11 range of frequency. Thus, it covers licensed and licensed-exempt bands. These have similar propagation properties, but license-exempt bands of frequency present more interferences and limited radiated power. The 2-11 GHz band of frequency used implies that Non Line Of Sight (NLOS) propagation occurs.

III.C.3. Physical layer specifications

Three physical layer specifications are detailed in the standard:

1. the WirelessMAN-SCa, for Single Carrier technology,
2. the WirelessMAN-OFDM, for Orthogonal Frequency Division Multiplexing,
3. the WirelessMAN-OFDMA, for Orthogonal Frequency Division Multiple Access.

All of these techniques are used for Non Line Of Sight operation in the 2-11 GHz band.
For unlicensed bands, additional WirelessHUMAN specifications, for High-speed Unlicensed Metropolitan Area Network, are added.

III.C.4. The Mesh mode

The Mesh mode of operation introduced in the IEEE 802.16a is based on the forwarding of data, received by one node, to another. It allows creating a multipoint-to-multipoint network architecture, as described in figure III-7. Furthermore, nodes beyond the coverage area of the base station can be reached with this mode of operation, if the remote subscriber station is in the coverage area of another subscriber station.

III.C.5. The WiMAX forum

The IEEE 802.11 standard release has not led to major involvements at its date of publication. Only the creation of the WiFi Alliance, whose role is to certify products with respect to the IEEE 802.11 standard, has ignited the WiFi development.
Regarding this, the Worldwide Microwave Interoperability Forum, or WiMAX, has been created. Its role is to certify IEEE 802.16a compliant products with a “WiMAX certified” label, in order to provide transparency for IEEE 802.16a system deployments throughout the world ([1], [6]).

III.D. Summary

The IEEE 802.16 and IEEE 802.16a standards have been designed to address Broadband Wireless Access issues.
The IEEE 802.16 standard specifies the working on the 10-66 GHz band of frequency. Connections are defined between the base station and the subscriber stations to carry data.

The Time Division Duplexing mode of operation focused in the project uses one frequency for uplink and downlink data. Time is divided into downlink and uplink subframes, and time slots are allocated to connections on these subframes. Uplink and downlink maps are used to broadcast time slot allocations to all subscriber stations. Quality of service is performed through a set of tools specified in the standard: map definition, packing/fragmentation of PDU from the network layer. Finally, given the type of network protocol used, adaptation to the MAC layer is performed.

The IEEE 802.16a standard, as an amendment to the IEEE 802.16 standard, only specifies changes from this latter. The Mesh mode is added, creating the possibility for a multipoint-to-multipoint network architecture. Three physical layers are specified, in order to adapt to multiple propagation conditions. The WiMAX forum has been designed to give certificate, in order to back the standard development process.

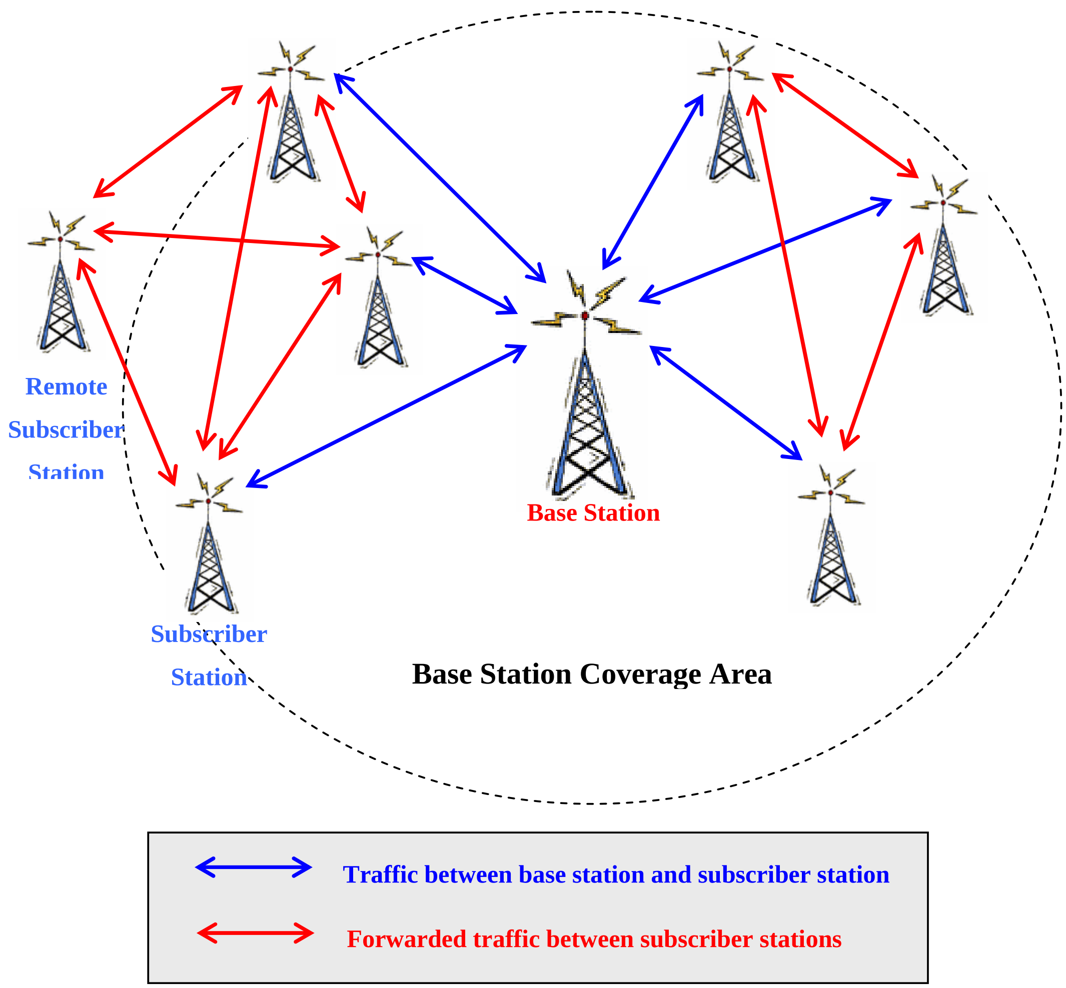

Figure III-7 – Mesh mode– Network Architecture

Chapter IV - Solution Design

IV.A. Introduction

Within previous chapters, we have defined the project objectives, as well as the technical background of the project.

Now, these data and information are used, in section V.B, to build step by step a model of the solution we want to implement.

IV.B. Model Building

IV.B.1. Stations

First of all, the standard specifies two types of stations, the base stations and the subscriber stations. In a system, which corresponds to stations that are sharing common parameters (like operating frequency…) and exchanging data, there are one base station and multiple subscriber stations (see figure IV-1). As all the relations base station/subscriber station are similar in a system, one use from now the model one base station and one subscriber station (see figure IV-2).

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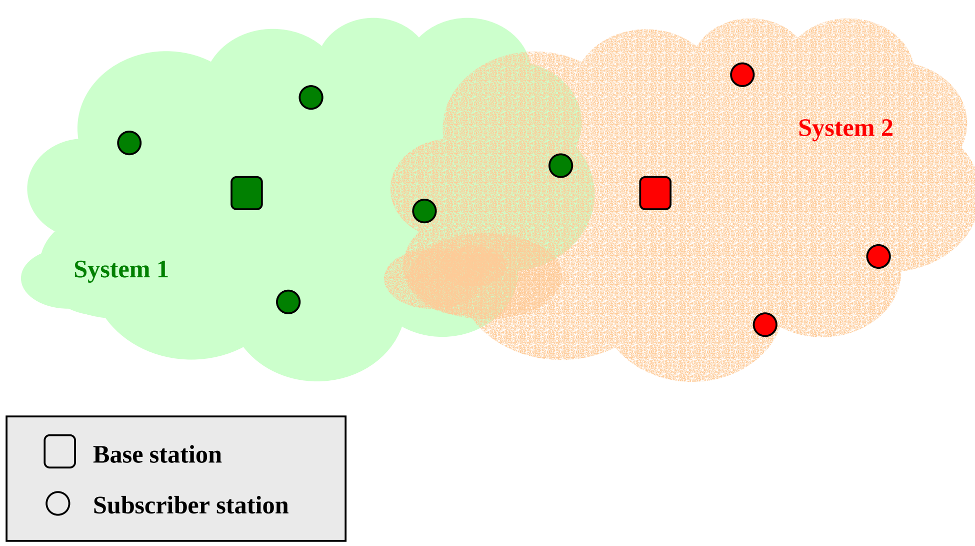

Figure IV-1 – System definition

Figure IV-2 – Base Station/Subscriber Station

IV.B.2. Physical Layer

Now that we have defined our two different entities, we want them to be able to communicate. So firstly, we must define a support for the communication. The physical layer has this role, by defining transmission parameters and setting: frequency, symbol rate, channel encoding…(see figure IV-3).

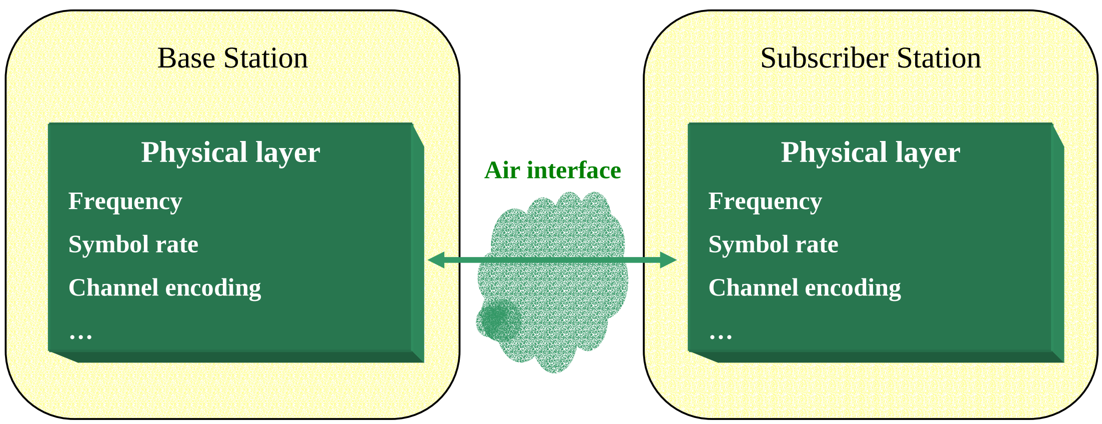

Figure IV-3 – Physical layer

IV.B.3. Frame Sequencing

Since the two entities have now a common channel of communication, one needs to define when they can send data, and when they are expected to receive data. This is achieved through the frame sequencing, which defines a downlink subframe and an uplink subframe on both station (see figure IV-4).

During the downlink subframe, the base station can send data, and the subscriber station shall expect incoming data. During the uplink subframe, the subscriber station can send data on particular time slots, and the base station shall expect incoming data.

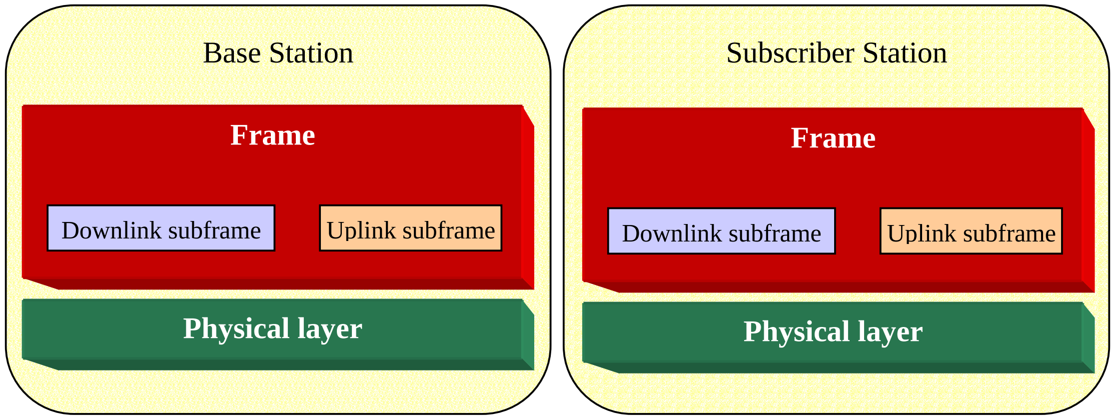

Figure IV-4 – Frame sequencing

IV.B.4. Frame Synchronisation

Frame sequencing is now possible, but subscriber station frame needs to synchronise on the base station frame, due to the time offset introduced by the propagation of the signal through the air interface.

For that purpose, the frame sequencing is started at the base station side, and a signalling message is sent at the beginning of each frame. When a subscriber station receives this message, it can align its own frame sequencing on the base station one, and the situation is as depicted by figure IV-5.

Once this situation is reached, the two stations are able to send data when required or assigned (see figure IV-6).

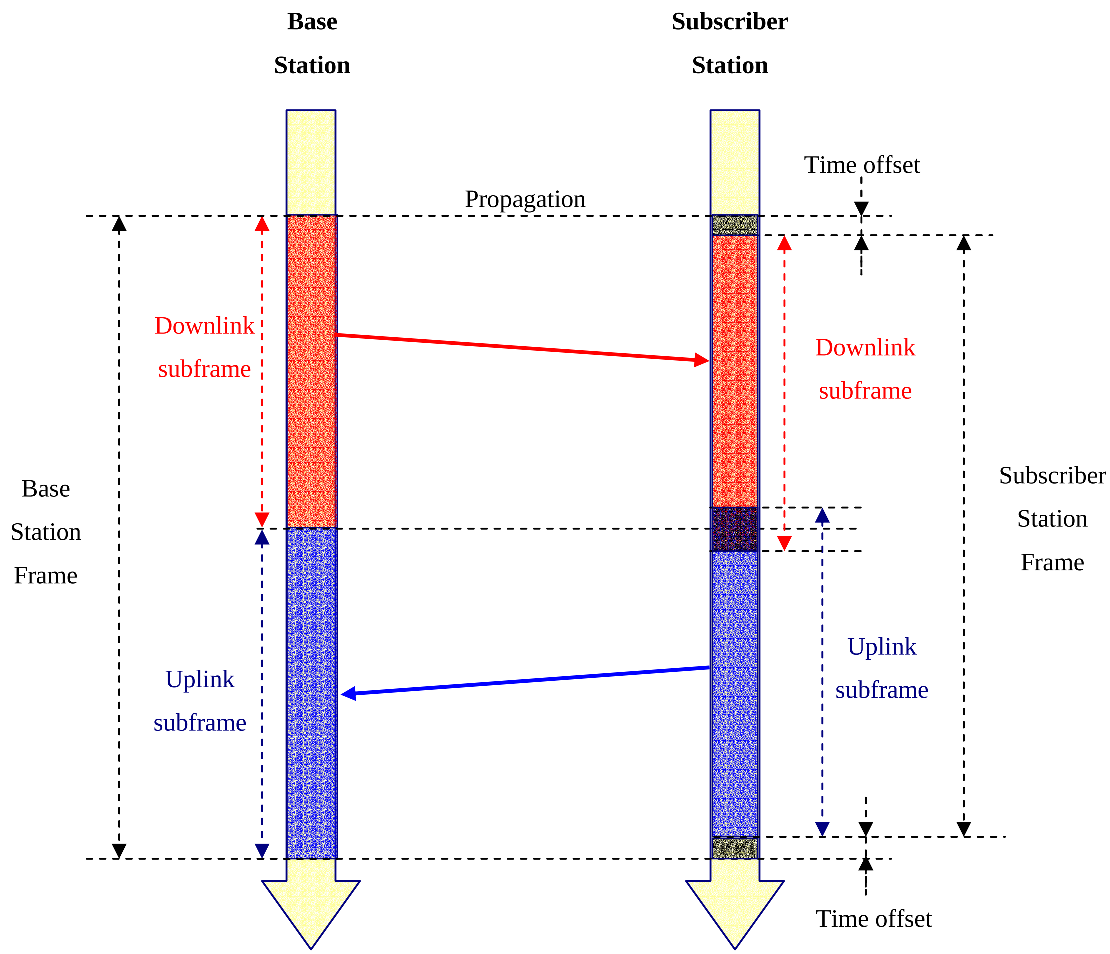

Figure IV-5 – Frames synchronised

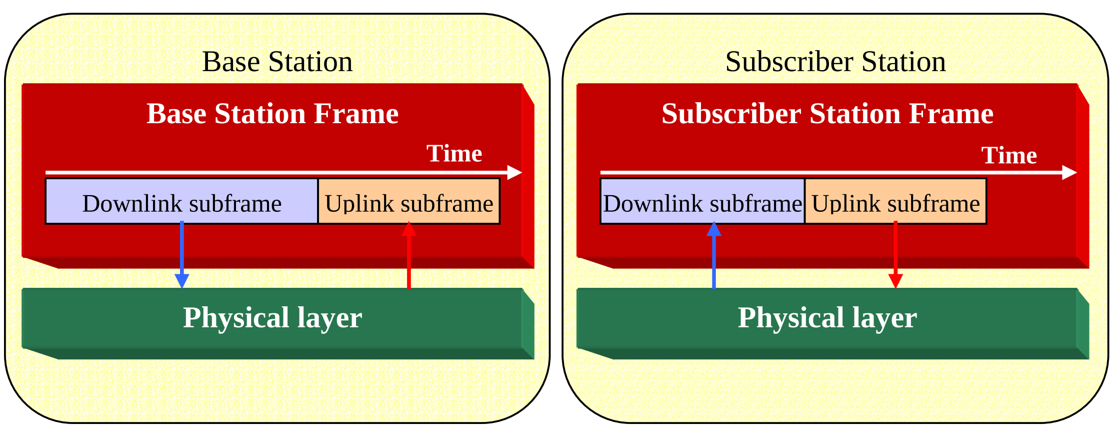

Figure IV-6 – Frame synchronisation

IV.B.5. Connections Definition

Connections definition is the step built above the station frame. As explained earlier, unidirectional connections are defined from the base station to a subscriber station, and vice versa, to carry data or for signalling.

Each connection has an identifier (CID), which is referred to during the communication process.

For each connection, a buffer is defined. It allows to store incoming PDUs from the network layer, before sending them, and to provisionally store fragments of messages received from the remote station, before reassemble them (see figure IV-7).

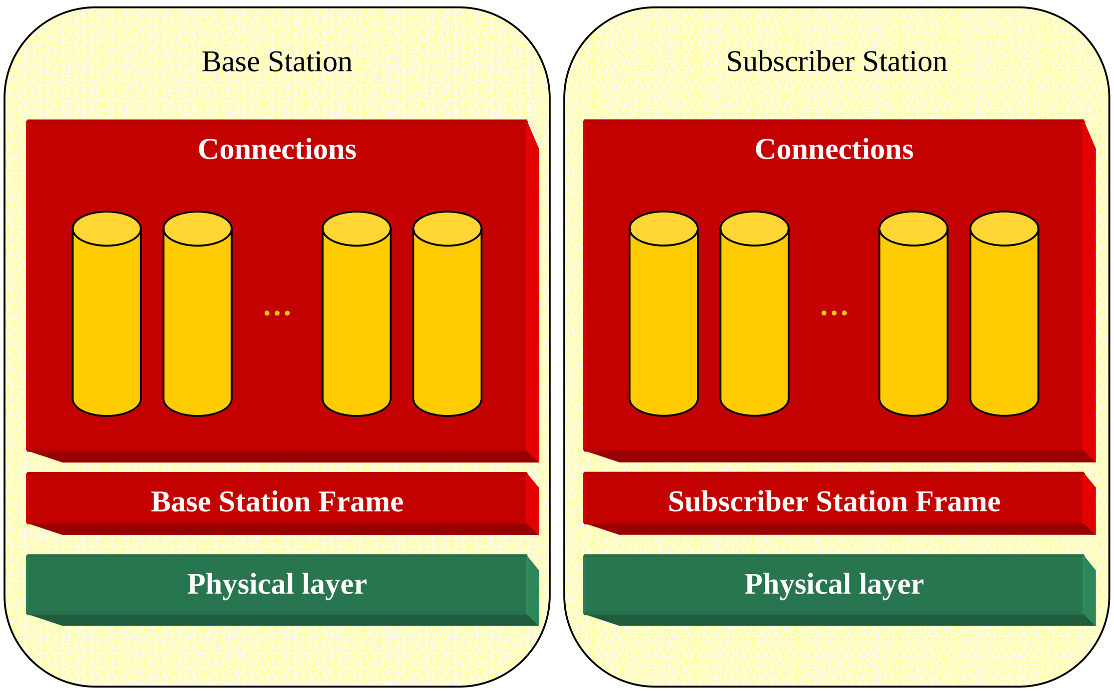

Figure IV-7 – Connection Definition

IV.B.6. QoS Handling

Connections are associated a Quality of Service, through a set of connection-dependent parameters. The QoS Handling aims at enforcing the QoS for all the connections, and is driven by the base station (see Figure IV-8).

On the downlink subframe, given the QoS of a connection, and the presence of a packet in its buffer, a portion of the downlink frame is attributed to send data (see figure IV-9).

On the uplink subframe, the base station defines in a map when connections can send data within the uplink frame, and sends this map to the subscriber stations (see figure IV-10).
A map building takes into account the QoS of a connection, and requests from subscriber stations to reduce or increase their available bandwidth.

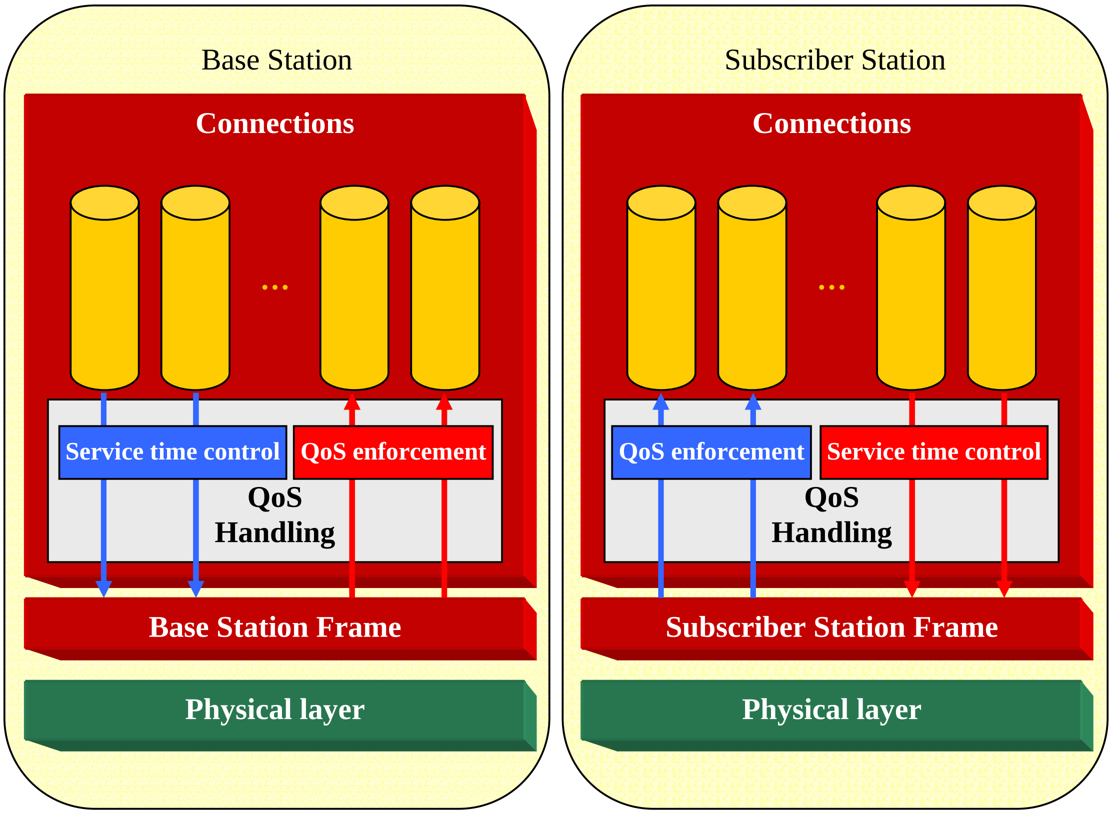

Figure IV-8 – QoS Handling

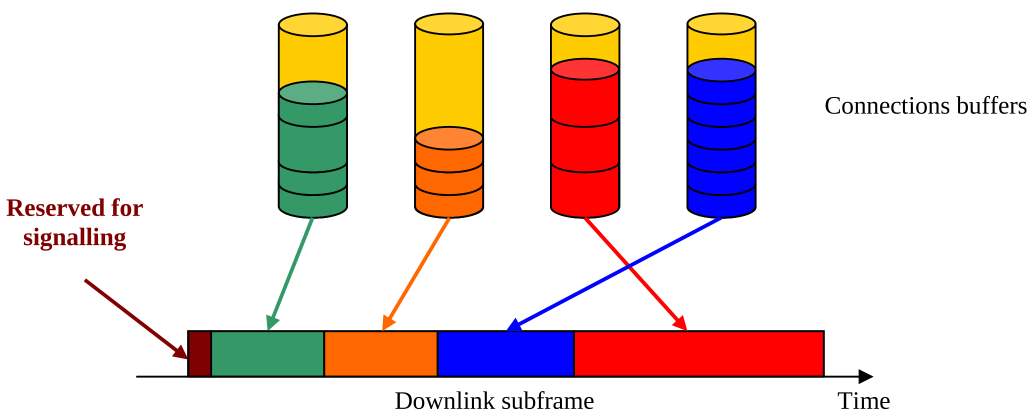

Figure IV-9 – Downlink subframe sharing

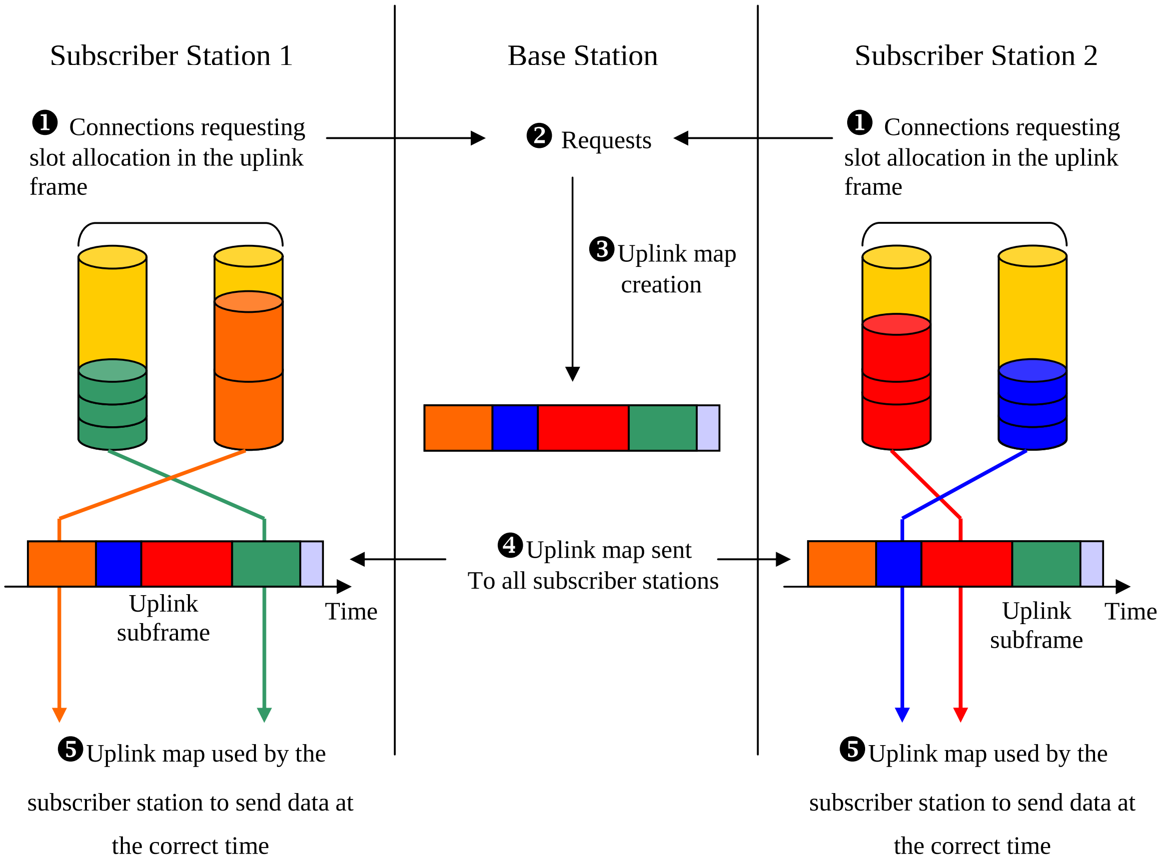

Figure IV-10 – Uplink subframe sharing

IV.B.7. Network Layer Adaptation

Finally, as both stations now have defined slots when to send data, the last part consist in the adaptation to the network layer. It provides adaptation between ATM cells, IP or Ethernet packets, and the format handled by the MAC layer (see figure IV-11).

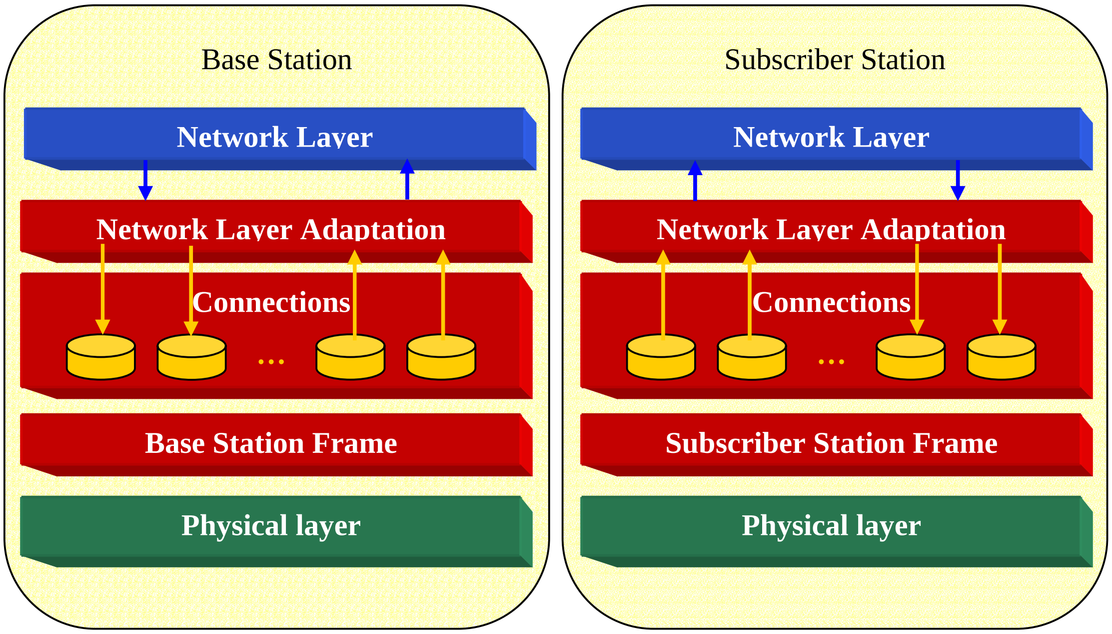

Figure IV-11 – Network layer adaptation

IV.B.8. Final Model

Finally, we have described our whole model, which corresponds to the IEEE 802.16a standard (see figure IV-12).

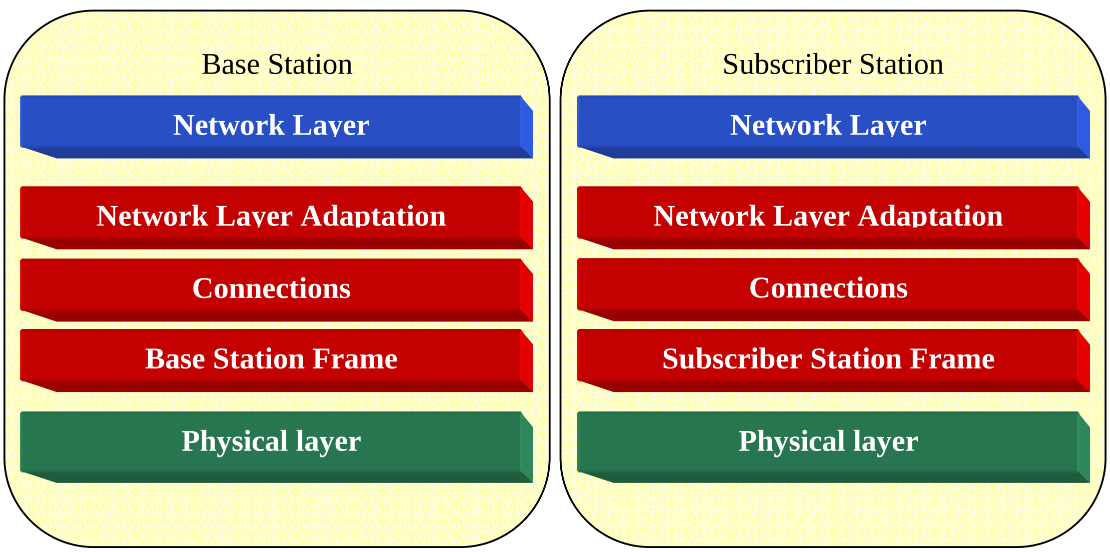

Figure IV-12 – Final Model

IV.C. Summary

The model extracted from the standard firstly highlights two basic structures, a base station structure and a subscriber station structure. Physical layer specifications define transmission parameters and conditions. Frame sequencing is introduced, and frames are synchronised between the base station and the subscriber stations. Then, connections are defined to carry data with associated Quality of Service. Finally, network layer specific methods allow adapting on several different network protocols.

Chapter V - The GloMoSim and QualNet Simulators

V.A. Introduction

We have described above the model, which we want to implement in the GloMoSim/QualNet simulators.

First of all, section IV.B details the common basis of the GloMoSim and QualNet simulators. PARSEC is introduced in section IV.B.1, and the layered structure of the simulators is described in section IV.B.2.

Then, the GloMoSim simulator is described in further details in section IV.C, especially its organisation and its working.

Finally, the QualNet simulator is introduced and differentiated from GloMoSim in section IV.D.

V.B. Common Features of the Simulators

V.B.1. PARSEC

PARSEC (Parallel Simulation Environment for Complex Systems) is a C-based programming language. Its capacity to simulate discrete events is the reason why it is used by the GloMoSim/QualNet simulators.

The main principle of PARSEC is to pass messages between several entities.

Multiple entities allows having a parallel mode of operation, with one entity defined per processor, which increases greatly the running time. In the project, the sequential mode of operation has been used, simulating all the nodes of the simulation into only one processor.

Messages exchanged by entities, or sent internally within an entity, are key features, which allows to create timers and to sequence events in the simulation.

V.B.2. Layered Architecture

The two simulators are based on a layered architecture [5], which emulates the OSI 7-layer model. Each layer is made of two different parts: The first part is made of interfaces used by upper and lower layers to send/request data to that particular layer. Components within this part are not specific to one protocol, but rather allow multiple protocols to be implemented and deployed easily. The second part contains the implementation of different protocols defined for that layer. For instance, the MAC layer contains wired, CSMA, TSMA, IEEE 802.11…, and now IEEE 802.16a, implementations.

V.C. GloMoSim

The first simulator involved in this project is the GloMoSim 2.03 simulator, developed at the Department of Computer Science, University of California, Los Angeles (UCLA).
This simulator is focused on modelling wireless networks, providing advanced handling of the air interface.

The Application Layer

Multiple protocols are available (FTP, HTTP, TELNET, CBR…), and a combination of them can be defined in order to simulate network operation.

The Transport Layer

Both Transport Control Protocol (TCP) and User Datagram Protocol (UDP) are implemented. The choice of one protocol instead of the other one is hard coded into the GloMoSim simulator.

The Network Layer

In the version of GloMoSim available, only the Internet Protocol (IP) is implemented. Moreover, several routing protocols are implemented in the network layer (Bellman-Ford, AODV, DSR, WRP).

The MAC Layer

The MAC layer offers several protocols for the simulation (wired, CSMA, TSMA, MACA, 802.11). The MAC layer part of the IEEE 802.16a standard implemented on the project stick to the generic structure used by these protocols.

The Radio and Channel Layers

These layers implement several propagation conditions: with or without noise,…

V.D. QualNet

The QualNet simulator is a commercial product distributed by Scalable Network Technologies, and based on the features introduced in GloMoSim. As a commercial version, it has much more advanced features as a Graphical User Interface (see figure V-1), many implemented protocols…

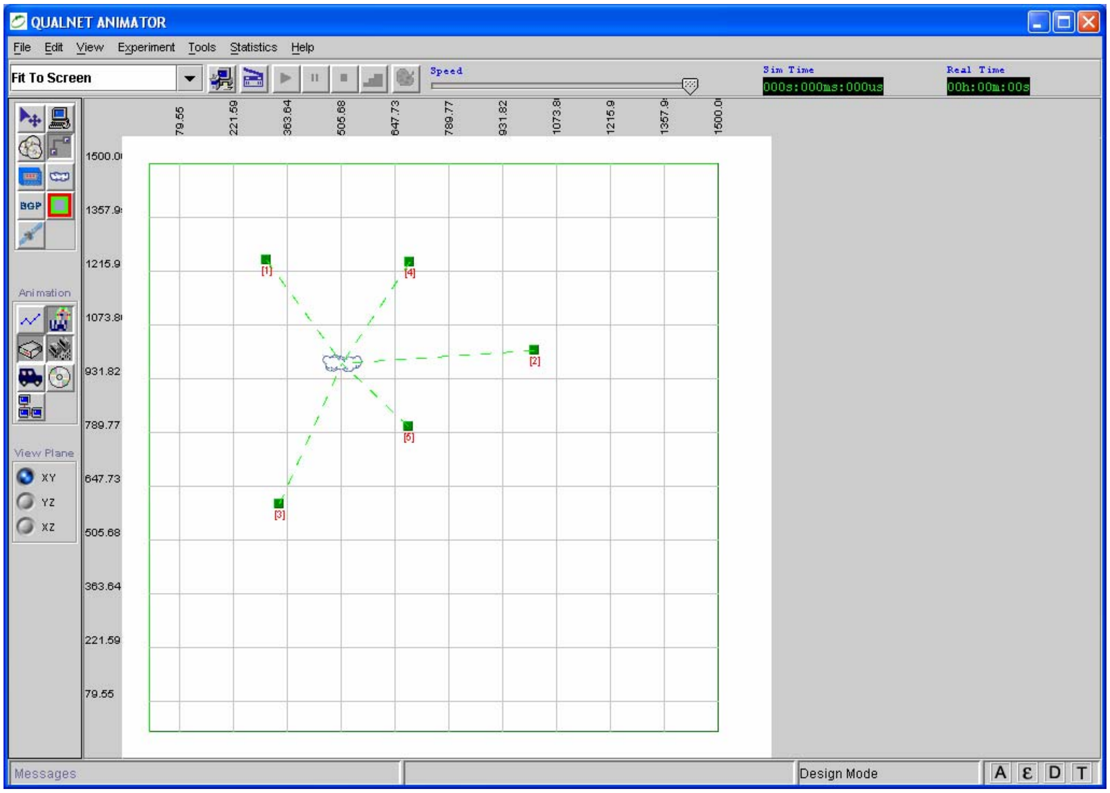

Figure V-1 – QualNet– Graphical User Interface

Protocol developments are to follow C++ specifications, but already implemented protocols in the PARSEC language need only few modifications.

V.E. Summary

The GloMoSim and QualNet simulators share the same basis. The PARSEC language is used for its capacity to simulate discrete events, and its parallel mode of operation, which reduces the running time. The simulators are based on a layered structure, which matches the OSI 7-layer model, allowing to deploy and simulates easily new protocols. The GloMoSim simulator, used in the project, has already implemented protocols and applications. The QualNet simulator has not been directly used, but some of its features have been studied in order to understand its architecture and working.

Chapter VI - Implementation in GloMoSim

VI.A. Introduction

The previous chapter has introduced several successive steps up to the final model described in the standard. This chapter describes how these steps have been implemented in the GloMoSim simulator. Extensive description of methods and variables is performed in the code itself, through the comments.

The section VI.B presents the implementation performed for each step, with features, issues and choices made. It describes how close to the standard the implementation is, and which parts have been implemented whereas not specified in the standard.

VI.B. Implementation steps

VI.B.1. Stations

Implementation features

One generic 802.16a MAC structure is defined, containing variables that are not specific to the station type, but rather specific to the 802.16a MAC layer.

A base station structure and a subscriber station structure are defined, with parameters and methods specific to the station type.

The generic MAC 802.16a structure along with a station structure defines the whole MAC 802.16a layer for this station type, as shown on figure VI-1.

It is possible to define multiple 802.16a MAC instances on the same node, allowing building advanced network configurations. An example of this feature is presented in Annex D.

Code layout

In regard with this generic structure and these two types of station, the code layout separates the generic MAC 802.16a methods and structures, the base station specific methods and structures and the subscriber station specific methods and structures.

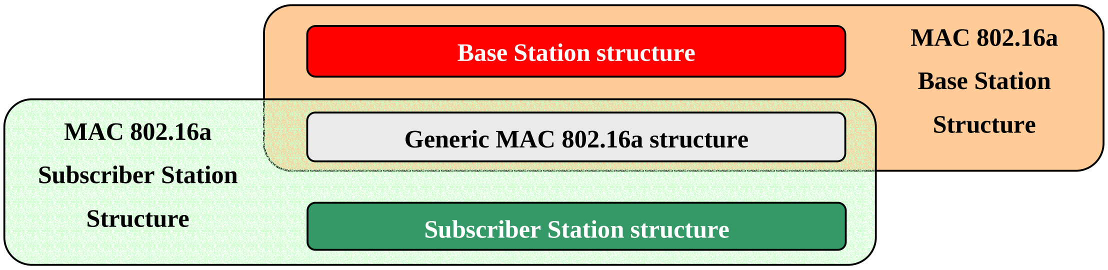

Figure VI-1 – Station Structures

VI.B.2. Physical Layer

Implementation features

As described at the section V.C, the physical layer has not been implemented as specified in the standard. Physical layer parameters have been compiled to produce values used within the model and for the simulation initialisation.

VI.B.3. Frame Sequencing

Base Station

On the base station side, as shown in figure V-5, one frame is directly following the previous one. Once the sequencing has started, it is straightforward to enforce it, as shown in figure VI-2, thanks to the sending of messages allowed in GloMoSim.

Subscriber Station

On the subscriber station side, as shown in figure V-5, frame sequencing is dependent of the base station frame start, the frame length, the downlink subframe length, and the propagation time between the base station and the subscriber station. Once the first signalling message is received on the subscriber side (see below section VI.B.4), the subscriber station can retrieve these four parameters: base station frame start, frame length, downlink subframe length and propagation time. Then, it can starts its sequencing as shown in figure VI-3.

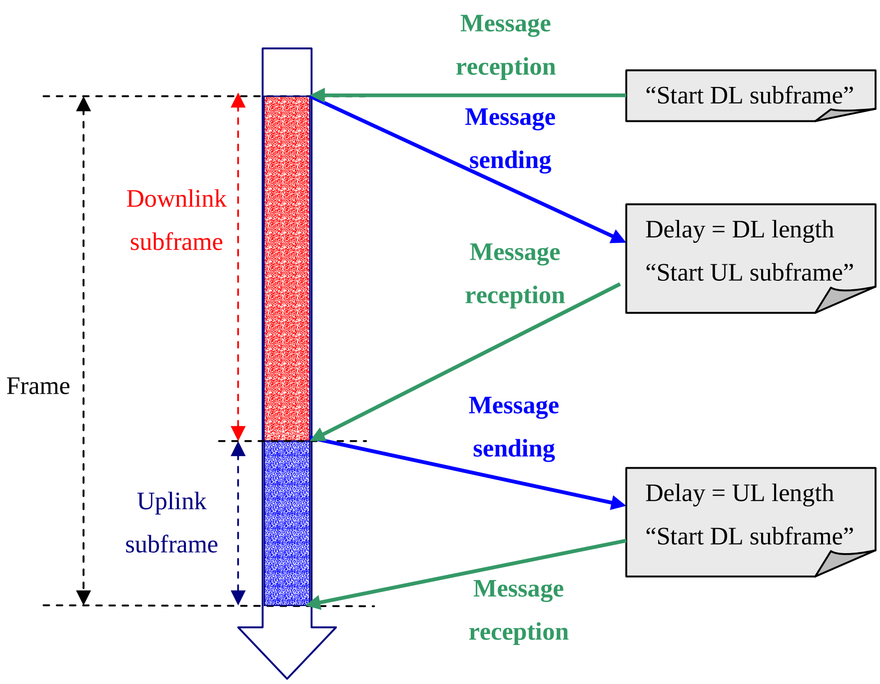

Figure VI-2 – Base Station – Frame Sequencing

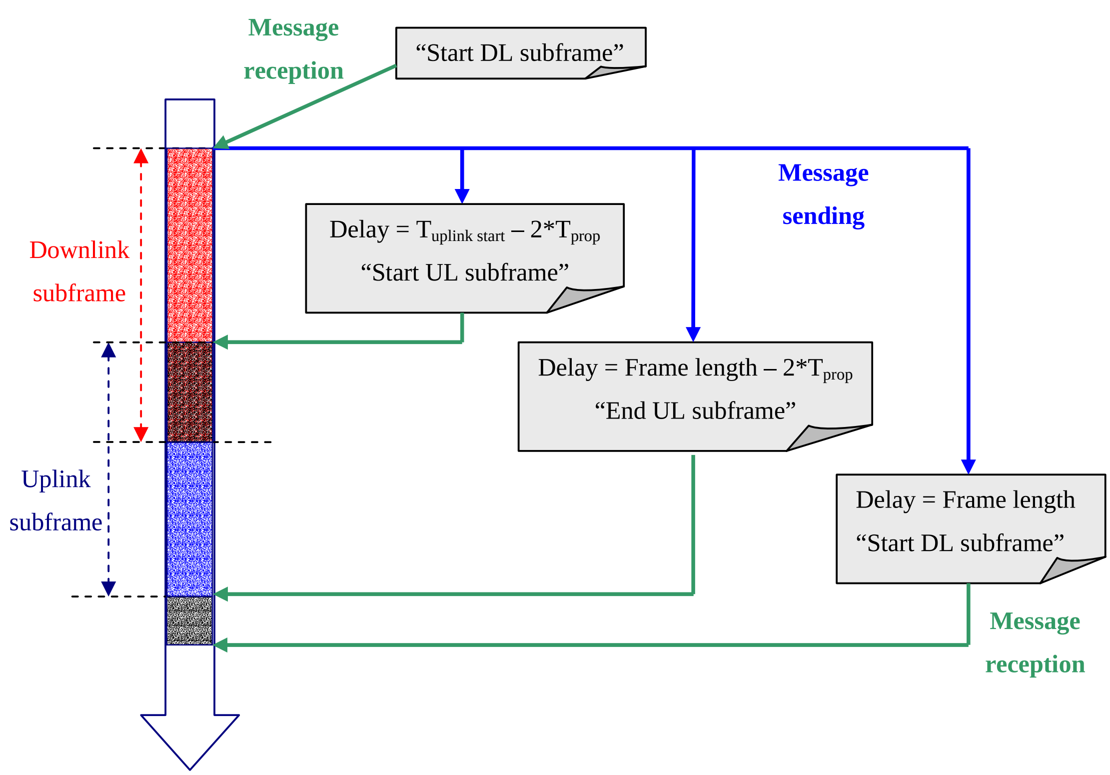

Figure VI-3 – Subscriber Station – Frame Sequencing

VI.B.4. Frame Synchronisation

Base Station

On the base station side, signalling messages are created and sent at the beginning of a frame. First, there are Uplink and Downlink Channel Descriptors, which contains channel parameters used for the transmission, and which are sent only every 10 seconds (chosen and hard coded), controlled by a timer. There are also Uplink and Downlink Maps, which contains time slot allocations for connections and other related parameters, which are sent at every beginning of a frame.

Subscriber Station

On the subscriber station, the reception of the first signalling message from the base station allows it to retrieve needed parameters for its synchronisation on the base station frame. These parameters, already described above on section VI.B.3, are firstly the propagation time, computed with the creation time of the message on the base station side. Then, the start of the frame on the subscriber station is computed from the length of the signalling message. Then, the frame length is extracted from the Downlink Channel Descriptor signalling message. Finally, the Allocation Start Time, corresponding to the length of the downlink subframe, is extracted from the Uplink Map signalling message.

VI.B.5. Connections Definition

The connection structure contains mainly an identifier and a buffer. It is designed to allow definition of linked lists of connections.

For each subscriber station, and for both downlink and uplink, 3 signalling connections are defined, carrying specified type of messages. These connections are established along the initialisation process. It starts with the basic and primary connections, established during the initial ranging process, and ends with the secondary connection, established during the registration process.

Then, transport connections can be defined in order to carry data. A process of request-response-acknowledgment is used to create and establish these connections from the base station to a subscriber station, or from a subscriber station to the base station. In the current implementation, only one transport connection can be defined to carry data, in the sake of simplicity.

The different types of connections are:

- Downlink basic connection,
- Uplink basic connection,
- Downlink primary connection,
- Uplink primary connection,
- Downlink secondary connection,
- Uplink secondary connection,
- Downlink transport connection,
- Uplink transport connection.

Base Station

On the base station side, multiple lists of connections are defined for each type of connection (see types above).

Subscriber Station

On the subscriber station side, due to the fact that only one transport connection is defined by subscriber station, there is only one connection per type (see types above).

VI.B.6. QoS Handling

The Quality of Service is achieved through a set of tools specified in the standard. Only some of these tools have been implemented. Yet, structures have been designed to allow further implementation of the other QoS features into the simulator.

Indeed, the base station defines the map allocations, and these new maps are then sent to all subscriber stations, which take into account these changes. The dynamic map allocation is not implemented, but the map extraction of allocated time slots is implemented on the subscriber station side, for the uplink subframe.

What is more, the Dynamic Service Addition (DSA) has been implemented. It is used to create a new connection when data need to be sent from one station to the other. All the structures, and the whole process, are implemented without any Quality of Service-related parameters: these latter are fixed, unrelated to any definition algorithm. Still, it is quite straightforward to enhance the structures and methods to add those parameters. Moreover, the DSA implementation provides a model on which to build the Dynamic Service Modification and the Dynamic Service Cancellation.

The fragmentation feature is not implemented in the current project. Packets from the network layer are simply sent as one entity through the network.

Finally, time allocation to each connection on the downlink subframe is very simply implemented: connections are scanned one after the other, always in the same order, and if there is a packet buffered, it is sent.

VI.B.7. Network Layer Adaptation

As only the IP network layer was available in the GloMoSim version used for the implementation, only IP packets can be handled in the project.

VI.C. Summary

The implementation process follows solution design steps. Firstly, station structures are defined, then the physical layer specifications are used to initialise radio and channel parameters. Frame sequencing is implemented, and frame synchronisation is performed. Then, signalling and data connections are defined, some Quality of Service features implemented and finally adaptation to the IP network layer is achieved in a simple manner.

Chapter VII - Simulation

VII.A. Introduction

The implementation process has produced a working system from the model.

Section VII.B describes a simple network configuration and its simulation results. Section VII.C presents two simple network linked by a wired connection, and shows results of this simulation. Section VII.D corresponds to a more complex architecture. Results are discussed in section VII.E.

VII.B. Configuration 1 – Simple Network

Architecture

The first simulation used to validate the system is a very simple architecture, with one base station and 4 subscriber stations, as described in the figure VII-1. This very simple architecture was used throughout the implementation process to validate each step.

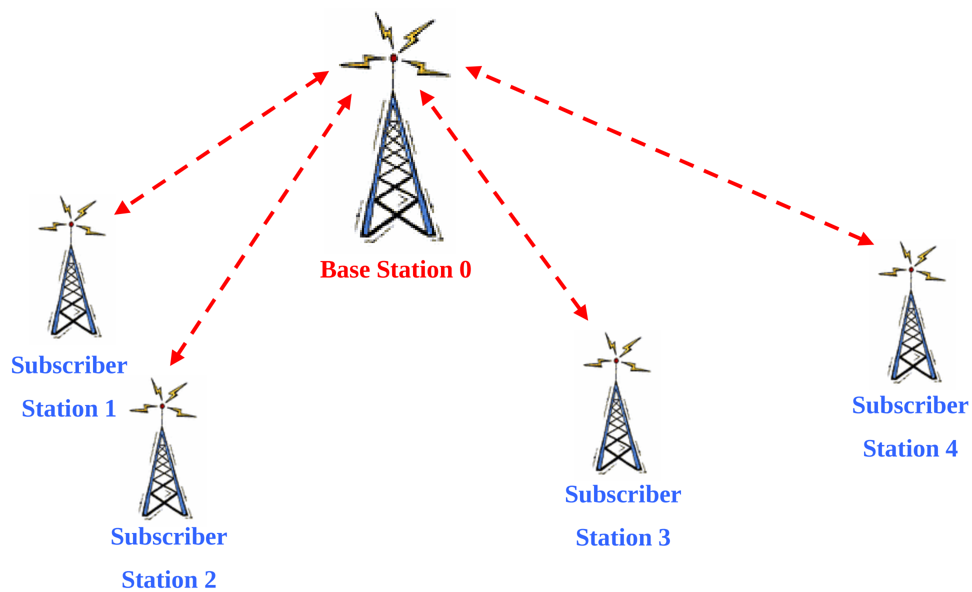

Figure VII-1 - Configuration 1 – Architecture

Applications

Based on this architecture, several applications are defined between the nodes: FTP, CBR and HTTP. A detailed list of implemented applications is provided in Appendix B.

Results

FTP		
Server Address	Client Address	Throughput (in kbit/s)
2	3	348
0	1	282
4	0	264

HTTP		
Server Address(es)	Client Address	Number of pages per connection on average
1	2	43
0	3	37
0 - 1	4	7

CBR		
Client Address	Server Address	Throughput (in kbit/s)
1	3	888
3	4	444
0	2	296

VII.C. Configuration 2 – Two Simple Networks Wired

Architecture

The second simulation is a combination of two simple networks as used before, with the two base stations linked by a wired connection, as described in the figure VII-2.

Parameters

The wired link has a bandwidth of 100 Mbit/s full duplex.

Applications

Based on this architecture, several applications are defined between the nodes: FTP, CBR and HTTP. A detailed list of implemented applications is provided in Appendix C.

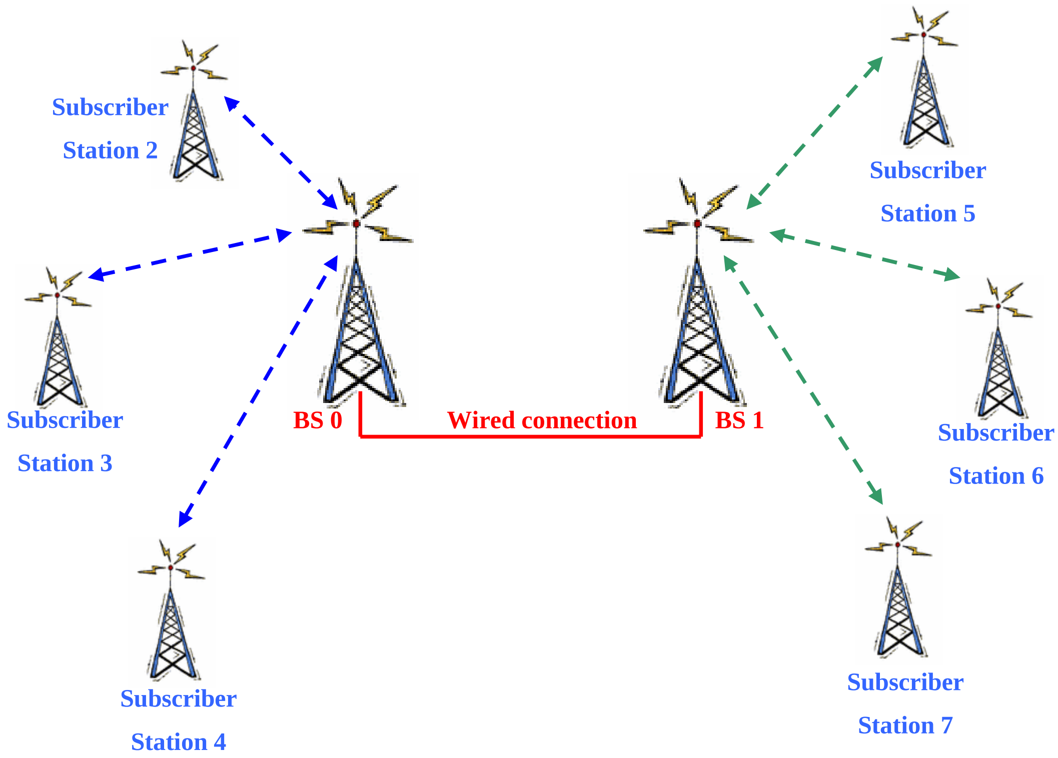

Figure VII-2 – Configuration 2 - Architecture

Results

FTP		
Server Address	Client Address	Throughput (in kbit/s)
7	3	29
4	6	349
1	3	361

HTTP		
Server Address(es)	Client Address	Number of pages per connection on average
0 - 2	2	8
0 - 2	4	8
0 - 2	6	6

CBR		
Client Address	Server Address	Throughput (in kbit/s)
1	3	888
4	5	296
7	2	444

VII.D. Configuration 3 – Two Level of Simple Networks

Architecture

The third simulation defines a first simple network, with one base station and 3 subscriber stations. Then, each subscriber station of this first network is defined as a base station for 3 other subscriber stations. Figure VII-3 shows the architecture.

Applications

Based on this architecture, several applications are defined between the nodes: FTP, CBR and HTTP. A detailed list of implemented applications is provided in Appendix D.

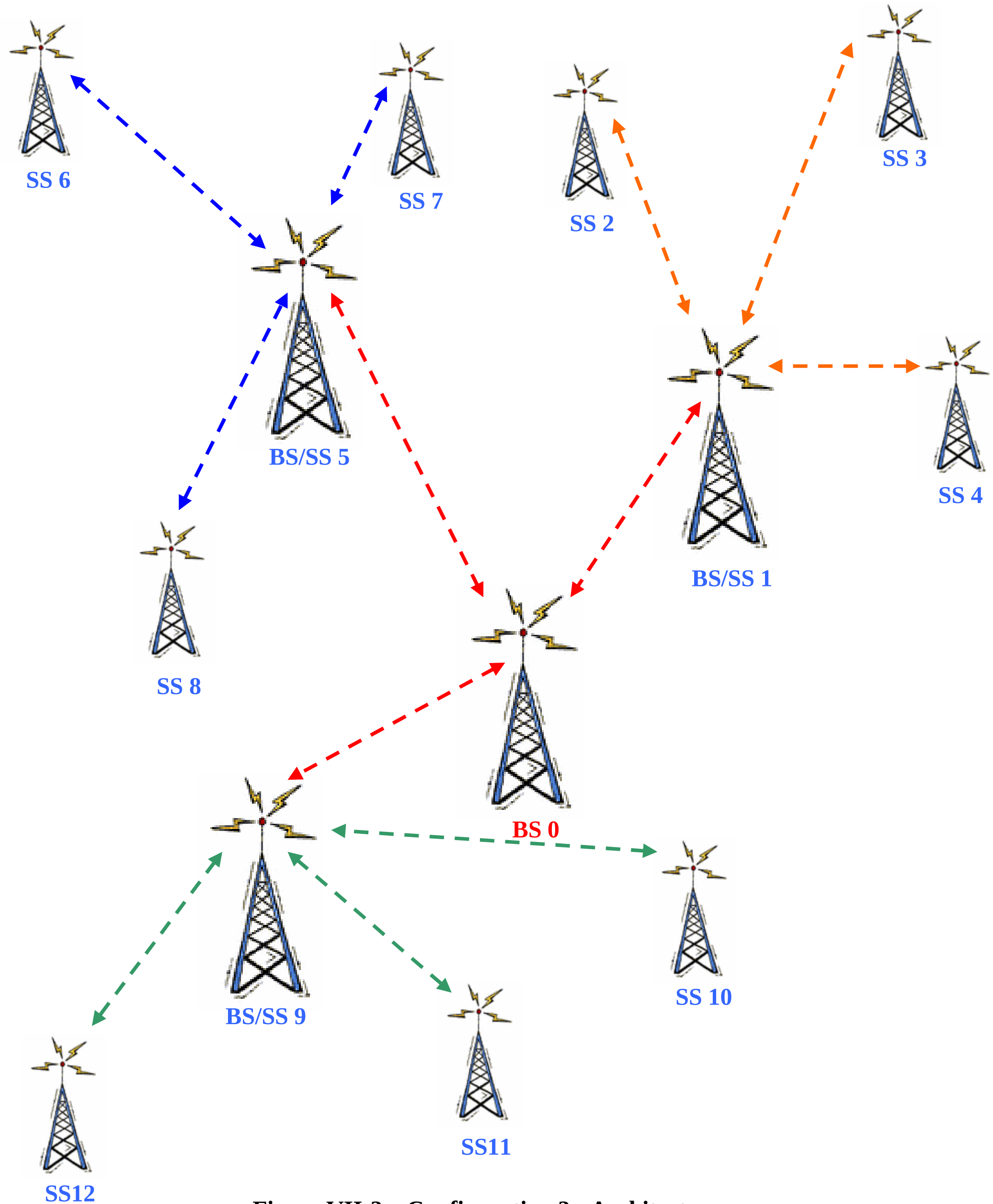

Figure VII-3 – Configuration 3 - Architecture

Results

FTP		
Server Address	Client Address	Throughput (in kbit/s)
2	6	68
3	10	168

5	0	133
6	4	170
8	12	145
1	9	201

HTTP		
Server Address(es)	Client Address	Number of pages per connection on average
9	2	15
2 - 9	3	21
2 - 9	7	6
2 - 9	8	5
2	9	22
2 – 9	12	10

CBR		
Client Address	Server Address	Throughput (in kbit/s)
1	3	890
3	4	891
0	2	888

VII.E. Results Discussion

We can see from these results that our simulation is working. Transport connections are created to carry data when needed, routing packets are exchanged between nodes. The low bitrates obtained are due to the fixed, largely not optimised map allocation algorithm. No Quality of Service is defined nor enforced, which leads to poor results for the simulation.

VII.F. Summary

Three different network configurations are simulated here, from a very simple one, used during the implementation process, to a more advanced configuration. Results show some consistency: achievable bandwidth is very low. This is due to Quality of Service features not being fully implemented.

Chapter VIII - Conclusion and Further Developments

VIII.A. Introduction

The validation and the study of the system quality, performed in the previous chapter, have stated what has been achieved during the project, with respect to the initial objectives.

In section VIII.B, remaining issues, which should be addressed to have an accurate simulator, and issues, which should be studied to improve the efficiency of the simulator, are presented.

Then, section VIII.C details the conclusions on the project.

VIII.B. Directions for further developments

This project has built the basis of a simulator for the IEEE 802.16a standard. As discussed briefly above, many issues are still not addressed, either related the standard implementation accuracy or to the simulation efficiency.

VIII.B.1. Standard Implementation Accuracy

Basic blocks are implemented in the standard, some with simplistic features, which are not reflecting the exact standard specifications.

Physical Layer

As the project focus is on the MAC layer implementation, physical layer specifications are not fully implemented.

First of all, the basic physical variables, such as transmission power and transmission frequency, can vary during the operation of the standard, under specific conditions. This has not been implemented, and is a possible direction for further developments.

Then, various uplink and downlink bursts, which correspond to different configurations of the transmission channel, are present in the implementation but not used. Various burst types allows adapting to various propagation conditions, and may be of interest if testing efficiency of the standard in realistic conditions.

Signalling

In order to simplify the coding, signalling was reduced to the simplest, needed features. Thus, message size is not always correct, and may be improved.

Network Layer Adaptation

Network layer adaptation needs also to be improved, in order to add fragmentation and packing features, which help to reach very high bit rates.

Quality of Service

In order to achieve a better accuracy in the simulation, dynamic addition, modification and deletion of connections need to be implemented. Only the addition part has been partly implemented, and is based on a fixed allocation of resources.

VIII.B.2. Simulation Efficiency

Other further developments of interest lies in the optimisation in the operation of the standard, once we have implemented a satisfying model.

Physical Layer

Influence of burst choice, channel encoding schemes and parameters should be studied to analyse the standard efficiency.

Quality of Service

In the project implementation, allocation of uplink and downlink time slots is fixed, whereas it should be dynamic. This is one of the features in the standard that has the most influence on the final global throughput of the system, so should involve further developments.

VIII.C. Conclusions

The work performed during the project has firstly produced an analysis of the IEEE 802.16 and IEEE 802.16a standards, in the Broadband Wireless Access context. It appears that these standards can address new issues raised in this area, from the long range and the large bandwidth to the various legal environments and propagation conditions.

The GloMoSim and QualNet simulators are of much interest to implement new standards, thanks to their layered architecture, which allows quick deployment and tests.

The initial objective of modelling the IEEE 802.16a standard is reached, and leads to a better understanding of the standard technical working.

The second initial objective of implementing the IEEE 802.16a standard into a simulator is reached to a great extent. What is of importance is that the basic structures and methods exist, as well as most of the more advanced features, leading to a working, realistic model.

Moreover, parts partially or not implemented are well identified and open to further developments.

Finally, some directions for optimising the simulation efficiency are given, giving an end to the project.

References

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[4] “GloMoSim: A Scalable Network Simulation Environment”, Lokesh Bajaj, Mineo Takai, Rajat Ahuja, Ken Tang, Rajive Bagrodia, Mario Gerla, UCLA.

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Appendix A

Resource Requirements

Developments and simulations are performed for this project on a FUJITSU-SIEMENS Amilo-M 7300 laptop, with Intel Pentium Mobile processor and with Linux Red Hat 9 (kernel version 2.6.6).

Software requirements:

- Gcc 2.3 or above
- GloMoSim version 2.03

Appendix B

Configuration parameters

```
SIMULATION-TIME                     10M
TERRAIN-DIMENSIONS                  (2000, 2000)
NUMBER-OF-NODES                     5
NODE-PLACEMENT                      RANDOM

PROPAGATION-LIMIT                   -111.0
PROPAGATION-PATHLOSS                TWO-RAY
NOISE-FIGURE                        10.0
TEMPARATURE                         290.0
RADIO-TYPE                          RADIO-ACCNOISE
RADIO-FREQUENCY                     2.5e9
RADIO-BANDWIDTH                     12000000
RADIO-RX-TYPE                       SNR-BOUNDED
RADIO-RX-SNR-THRESHOLD              10.0
RADIO-TX-POWER                      50.0
RADIO-ANTENNA-GAIN                  0.0
RADIO-RX-SENSITIVITY                -91.0
RADIO-RX-THRESHOLD                  -81.0

MAC-PROTOCOL                        802.16a
NODE-ADDRESS[0:0]                   802_16a-STATION-TYPE   BASE-STATION
MAC-PROPAGATION-DELAY               1000NS

NETWORK-PROTOCOL                    IP
NETWORK-OUTPUT-QUEUE-SIZE-PER-PRIORITY 100
ROUTING-PROTOCOL                    BELLMANFORD

APP-CONFIG-FILE                     ./app_SimpleNetwork802_16a.conf
```

Applications

FTP			
Server Address	Client Address	Number of items sent	Starting time (in seconds)
2	3	20	20
0	1	20	30
4	0	20	20

HTTP			
Server Address(es)	Client Address	Waiting time between two requests (in seconds)	Starting time (in seconds)
1	2	50	10
0	3	30	10
0 - 1	4	20	10

CBR						
Source Address	Destination Address	Number of items to send	Item size (in octets)	Waiting time between two packets (in seconds)	Starting time (in seconds)	Ending time (in seconds)
1	3	10	100	1	10	600
3	4	10	100	2	10	600
0	2	10	100	3	10	600

Appendix C

Simulation parameters

```
SIMULATION-TIME                        10M
TERRAIN-DIMENSIONS                     (2000, 2000)
NUMBER-OF-NODES                        8
NODE-PLACEMENT                         RANDOM

PROPAGATION-LIMIT                      -111.0
PROPAGATION-PATHLOSS                   TWO-RAY
NOISE-FIGURE                           10.0
TEMPARATURE                            290.0
RADIO-TYPE                             RADIO-ACCNOISE
NODE-ADDRESS[0:0]                      RADIO-FREQUENCY         3.5e9
NODE-ADDRESS[1:1]                      RADIO-FREQUENCY         3.51e9
NODE-ADDRESS[2:4]                      RADIO-FREQUENCY         3.5e9
NODE-ADDRESS[5:7]                      RADIO-FREQUENCY         3.51e9
RADIO-BANDWIDTH                        12000000
RADIO-RX-TYPE                          SNR-BOUNDED
RADIO-RX-SNR-THRESHOLD                 10.0
RADIO-TX-POWER                         50.0
RADIO-ANTENNA-GAIN                     0.0
RADIO-RX-SENSITIVITY                   -91.0
RADIO-RX-THRESHOLD                     -81.0

NODE-ADDRESS[0:0]                      MAC-PROTOCOL[1]         WIRED
NODE-ADDRESS[1:1]                      MAC-PROTOCOL[1]         WIRED
WIRED-LINK-FILE                        links_wired_BS_802_16a.in
NODE-ADDRESS[0:0]                      MAC-PROTOCOL[0]         802.16a
NODE-ADDRESS[1:1]                      MAC-PROTOCOL[0]         802.16a
MAC-PROTOCOL    802.16a
NODE-ADDRESS[0:0]                      802_16a-STATION-TYPE    BASE-STATION
NODE-ADDRESS[1:1]                      802_16a-STATION-TYPE    BASE-STATION
MAC-PROPAGATION-DELAY                  1000NS

NETWORK-PROTOCOL                       IP
NETWORK-OUTPUT-QUEUE-SIZE-PER-PRIORITY 100

ROUTING-PROTOCOL                       STATIC
STATIC-ROUTE-FILE                      rtable_wired_BS_802_16a.in

APP-CONFIG-FILE                        ./app_wired_BS_802_16a.conf
```

Applications

FTP			
Server Address	Client Address	Number of items sent	Starting time (in seconds)
7	3	20	20
4	6	20	20
1	3	20	20

HTTP			
Server Address(es)	Client Address	Waiting time between two requests (in seconds)	Starting time (in seconds)
0 - 2	2	50	10
0 - 2	4	20	10
0 - 2	6	30	10

CBR						
Source Address	Destination Address	Number of items to send	Item size (in octets)	Waiting time between two packets (in seconds)	Starting time (in seconds)	Ending time (in seconds)
1	3	10	100	1	10	600
4	5	10	100	2	10	600
7	2	10	100	3	10	600

Appendix D

Simulation parameters

```
SIMULATION-TIME             5M
TERRAIN-DIMENSIONS          (2000, 2000)
NUMBER-OF-NODES             13
NODE-PLACEMENT              RANDOM

PROPAGATION-LIMIT           -111.0
PROPAGATION-PATHLOSS        TWO-RAY
NOISE-FIGURE                10.0
TEMPARATURE                 290.0
RADIO-TYPE                  RADIO-ACCNOISE
NODE-ADDRESS[0:0]           RADIO-FREQUENCY            3.5e9
NODE-ADDRESS[1:1]           RADIO-FREQUENCY[0]         3.5e9
NODE-ADDRESS[1:1]           RADIO-TYPE[0]              RADIO-ACCNOISE
NODE-ADDRESS[1:1]           RADIO-FREQUENCY[1]         3.51e9
NODE-ADDRESS[1:1]           RADIO-TYPE[1]              RADIO-ACCNOISE
NODE-ADDRESS[2:4]           RADIO-FREQUENCY            3.51e9
NODE-ADDRESS[5:5]           RADIO-FREQUENCY[0]         3.5e9
NODE-ADDRESS[5:5]           RADIO-TYPE[0]              RADIO-ACCNOISE
NODE-ADDRESS[5:5]           RADIO-FREQUENCY[1]         3.52e9
NODE-ADDRESS[5:5]           RADIO-TYPE[1]              RADIO-ACCNOISE
NODE-ADDRESS[6:8]           RADIO-FREQUENCY            3.52e9
NODE-ADDRESS[9:9]           RADIO-FREQUENCY[0]         3.5e9
NODE-ADDRESS[9:9]           RADIO-TYPE[0]              RADIO-ACCNOISE
NODE-ADDRESS[9:9]           RADIO-FREQUENCY[1]         3.53e9
NODE-ADDRESS[9:9]           RADIO-TYPE[1]              RADIO-ACCNOISE
NODE-ADDRESS[10:12]         RADIO-FREQUENCY            3.53e9
RADIO-BANDWIDTH             12000000
RADIO-RX-TYPE               SNR-BOUNDED
RADIO-RX-SNR-THRESHOLD      10.0
RADIO-TX-POWER              50.0
RADIO-ANTENNA-GAIN          0.0
RADIO-RX-SENSITIVITY        -91.0
RADIO-RX-THRESHOLD          -81.0

MAC-PROTOCOL                802.16a
NODE-ADDRESS[0:0]           802_16a-STATION-TYPE[0]    BASE-STATION
NODE-ADDRESS[1:1]           802_16a-STATION-TYPE[0]    SUBSCRIBER-STATION
NODE-ADDRESS[1:1]           802_16a-STATION-TYPE[1]    BASE-STATION
NODE-ADDRESS[1:1]           MAC-PROTOCOL[0]            802.16a
NODE-ADDRESS[1:1]           MAC-PROTOCOL[1]            802.16a
NODE-ADDRESS[5:5]           802_16a-STATION-TYPE[0]    SUBSCRIBER-STATION
NODE-ADDRESS[5:5]           802_16a-STATION-TYPE[1]    BASE-STATION
NODE-ADDRESS[5:5]           MAC-PROTOCOL[0]            802.16a
NODE-ADDRESS[5:5]           MAC-PROTOCOL[1]            802.16a
NODE-ADDRESS[9:9]           802_16a-STATION-TYPE[0]    SUBSCRIBER-STATION
NODE-ADDRESS[9:9]           802_16a-STATION-TYPE[1]    BASE-STATION
NODE-ADDRESS[9:9]           MAC-PROTOCOL[0]            802.16a
NODE-ADDRESS[9:9]           MAC-PROTOCOL[1]            802.16a
MAC-PROPAGATION-DELAY       1000NS

NETWORK-PROTOCOL            IP
NETWORK-OUTPUT-QUEUE-SIZE-PER-PRIORITY 100

ROUTING-PROTOCOL            STATIC
```

```
STATIC-ROUTE-FILE          rtable_main-sub_BS_802_16a.in

APP-CONFIG-FILE            ./app-main-sub_BS_802_16a.conf
```

Applications

FTP			
Server Address	Client Address	Number of items sent	Starting time (in seconds)
2	6	20	20
3	10	20	30
5	0	20	20
6	4	20	20
8	12	20	30
1	9	20	20

HTTP			
Server Address(es)	Client Address	Waiting time between two requests (in seconds)	Starting time (in seconds)
9	2	50	10
2 - 9	3	20	10
2 - 9	7	30	10
2 - 9	8	50	10
2	9	30	10
2 – 9	12	20	10

CBR						
Source Address	Destination Address	Number of items to send	Item size (in octets)	Waiting time between two packets (in seconds)	Starting time (in seconds)	Ending time (in seconds)
1	3	10	100	1	10	600
3	4	10	100	2	10	600
0	2	10	100	3	10	600