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# Self-Organizing Networks (SON)

TD-ICIC Implementation In a Network
Simulator

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# *Abstract*

Co-channel interference is becoming a real headache for operators when deploying HetNets but a solution presents itself in the form of inter-cell interference coordination (ICIC). One form of ICIC is called almost blank subframes (ABS) and in this report one implements an ABS system in a network simulator. The implementation is documented and discussed.

# CONTENTS

# ABBREVIATIONS

| | |
|---|---|
| **eNB** | **e**volved **N**ode **B** |
| **UE** | **U**ser **E**quipment |
| **ABS** | **A**lmost **B**lank **S**ubframes |
| **VUE** | **V**ictim **U**ser **E**quipment |
| **VMUE** | **V**ictim **M**acro **U**ser **E**quipment |
| **VPUE** | **V**ictim **P**ico **U**ser **E**quipment |
| **MUE** | **M**acro **U**ser **E**quipment |
| **PUE** | **P**ico **U**ser **E**quipment |
| **FUE** | **F**emto **U**ser **E**quipment |
| **QoS** | **Q**uality **o**f **S**ervice |
| **HetNet** | **Het**erogeneous **Net**works |
| **ICIC** | **I**nter-**C**ell **I**nterference **C**oordination |
| **eICIC** | **e**nhanced **I**nter-**C**ell **I**nterference **C**oordination |

# CHAPTER 1

# INTRODUCTION

Growing demand for smart phones and an ever increasing data consumption from the consumers forces operators to increase the capacity of their mobile network. One of the methods chosen is cell splitting, in which one employs a tighter base station grid with often smaller cells to cover specific hot spots or important business partners. These networks are referred to as heterogeneous networks where the cells are of different character, have different parameters and often different carriers. But the aim of 3gpp is that of a single carrier heterogeneous network able to combat strong interference through coordination between cells.

One special type of coordination has been considered in this report where the cell grid consists of normal base stations with LTE radios called macro-cells and smaller base stations with less transmit power called pico-cells. The pico cells deploy cell range expansion which, in turn, increases interference for the cell-edge users at the pico-cell in the 'expanded zone'.

A fix for this interference problem is deployment of so called time-domain Inter-Cell Interference Coordination(TD-ICIC). This technique aims at increasing overall network throughput through scheduling different cells in the time domain through coordination between cells. This approach is called Almost Blank Subframes and is standardized in 3gpp release 10.

In order to use TD-ICIC in the most efficient way and gain a substantial throughput increase one must design algorithms and test them in a realistic simulator. One such simulator is the network simulator 3 (NS-3) which has a lte module designed to facilitate radio resource management techniques.

The current NS-3 LENA-lte module does not support any of the features required for subframe blanking, cell range expansion or TD-ICIC specific communication. This report is based on implementing such a module on top of the already existing LENA module and documenting the progress done. Unfortunately not all features required for full scale ABS system has been implemented but future directions are laid out.

This report will focus on documenting an extension for the NS-3 LENA-lte module to support TD-ICIC and discuss some of the challenges facing ABS and HetNets. Hopefully the reader will get a look at how an ABS implementation can be done in NS-3 and be able to make his own features to support ones research into optimisation algorithms using ABS.

CHAPTER 2

# HETEROGENEOUS NETWORKS(HETNETS)

## 2.1 Introduction

In order to exploit the new technology implemented in the LTE standard, LTE-Advanced aims to increase the system capacity through cell-splitting and universal frequency reuse. This is accomplished by introducing new nodes in the network like femto-, picocells and relay-nodes. These changes will naturally increase the performance of the system but will also present new challenges.

The focus of this report is mainly the macro-/pico-cell relationship but in this chapter one will also discuss femto-cells since TD-ICIC is able to solve a problem scenario with closed subscriber group femto-cells. The goal of this chapter is to inform the reader of the challenges of HetNets so that one can understand the motivation behind Self-Organising Networks and ICIC techniques.

## 2.2 Pico-cells

Unlike the new Femto-cells introduced in release 8, the pico-cell is planned by the operator, meaning that it can be configured by the operator like the traditional eNB. The Pico-cell is essentially a miniature version of the macro cell with less transmit power/cell range. The Cell is meant to be used as a hot-spot in the new network topology, covering areas of high user density like train-stations, malls and large businesses[1].

The pico-cells have less txpower than the macro cells meaning that their server range is severely limited if it's positioned close to a macro-cell. This is not optimal as the pico-cells main task is to increase throughput and capacity and hence needs to cover a bigger area.

## 2.3 Femto-cells

Femto-cells are user-deployed mini base stations with limited functionality compared to pico and eNBs. They have a plug and play functionality in terms of deployment so the operator has no say in where the cells should be from a planning perspective. This results in a lot of problems for operators as the cell planning becomes impossible and the network will be continuously changing.

Another issue with the management of femto-cells is the limited backhaul connection to other cells like macro eNBs and pico eNBs. This ensures that coordination between nodes becomes difficult and that the QoS provided by the operator also relies on a broadband connection that they have no control over. Signalling between the nodes becomes complicated as the signalling should be kept to a minimum[1].

Unreliable backhaul is also a problem. The operator has no control over the QoS delivered to the customer since the femto-cell is deployed on the home network. This in turn makes the femto-cell somewhat unreliable for coordination schemes but solutions have been implemented where one coordinates through the HeNB-Gateway allowing for SON-functionality.

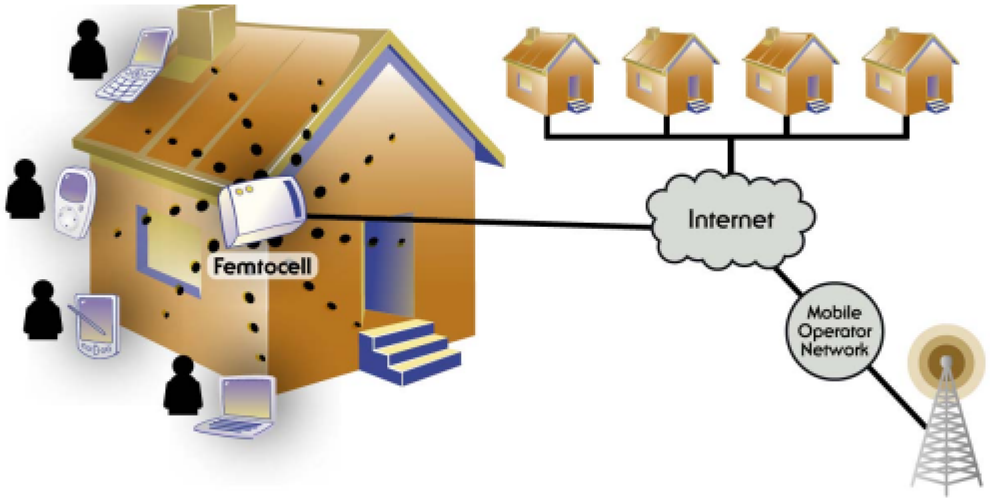

FIGURE 2.1: Picture of a femto-cell deployment and network architecture, taken from [2]

## 2.4 Closed Subscriber Group

Co-channel deployment, meaning 2 nodes close to each other using the same bandwidth, is described in LTE-A as either a macro-pico deployment or macro-femto deployment. The main difference between these two deployments is the Subscriber Group function that can either be open or closed, meaning that the node can be "private" to a selected group of users or open. This is an important feature when looking at HetNets as the possibility of interference from CSGs is large when none-subscriber users are in close vicinity of the node. The last subscriber group is the Hybrid Subscriber Group, where Certain users can get preferential treatment. The pico-cell is meant to be in open mode[1].

## 2.5 Interference scenarios with femto-cell deployment

The challenges of introducing femto-cells into the network topology are many, but mostly there is a problem with interference which is the topic of this report. Deploying smaller cells inside a macro cell using the same frequency band and with closed subscriber mode, are bound to cause interference problems for users. If the user wishes to deploy a femto-cell in a place where the existing signal level is acceptable, the interference can be substantial and can cause overall network degradation if left unchecked. This section describes the scenarios that cause interference for the user in a femto-cell environment.

A new feature in LTE-Advanced is the Closed Subscriber Group(CSG). CSGs allow users to deploy femto-cells with access only for a specific set of users, meaning that non subscribers are unable to use the given node. This entails that non-subscribers suffer a great deal of interference near these CSG femto-cells if the femto-cells transmit on the same downlink resource blocks as the macro eNB downlink resource blocks because the user receives a high power signal being close to the femto CSG, but cannot connect to it as it does not have the same CSG-ID corresponding to the femto-cell[3]. This creates a coverage hole for the macro cell that can only be solved through the coordination of resources.

The interference issues that emerge with the introduction of femto-cells in LTE-A is severe and needs attention. The limitations operators have in planning of such networks demands that such networks must be intelligent and adaptive.

It is clear that the introduction of the femto-cells also known as HeNB(Home eNB) requires new ways to mitigate and avoid interference. Not only do the techniques have to be very good to make up for the loss in throughput but they also have to be dynamic. In the new age of interference management it is required that the nodes are able to communicate through the back-haul and fix problems as they occur. This new approach requires that the femto-cells have ways to communicate with the macro cells and pico-cells so that victim UE's can be identified and resources coordinated through the backhaul.

## 2.6 Interference scenarios with pico-cell deployment

One of the biggest problems with the introduction of pico-cells comes from cell association protocols. Traditionally the user connects to the cell with the highest signal power to achieve maximum user performance but in the case of HetNets this can degrade the overall throughput because the pico-cells have much lower transmit power than the macro cells. This means that the macro cell serves more UEs than it should and the pico-cell becomes under utilised because of small coverage area.

What has been suggested is to give the pico-cells the option to add a bias to the signal strength indicator measured by the UE. The bias value will be communicated by the pico-cell making the UE connect to the pico even if the signal strength from the macro cell is stronger. This bias value can be static, meaning that it's set by the operator or adaptive, hence the cell range is set based on the total load of the pico and/or nearby cells.

This solution along with the CSG femto-cell solution are the two major interference problems in HetNet, outlined by the LTE release 10 standard for E-UTRAN in annex K [3].

CHAPTER 3

# INTER-CELL INTERFERENCE COORDINATION

## 3.1 Introduction

Solving the problems highlighted in the previous chapter requires coordination between cells and adaptive solutions. The introduction of inter-cell interference coordination(ICIC) was first made in release 8 of LTE and has been carried on in LTE-advanced with enhanced-ICIC.

In this chapter the reader will be introduced to the history of ICIC and hopefully gain understanding of how TD-eICIC works. One will also be given an overview of the work that has been done with ABS systems and given an introduction to CRE.

## 3.2 Inter-Cell Interference Coordination in rel. 8/9

The LTE release 8 introduced new ways to deal with interference through ICIC. The reason for doing so was to cope with the high frequency reuse factor adopted by the LTE standard. With a frequency reuse factor of 1 the interference for cell edge users from neighbouring macro-cells is substantial and has to be handled appropriately.

ICIC is the coordination of Physical Resource Blocks(PRB) in a manner that reduces or avoids interference on all the PRBs to maximise system performance. This is coordinated through communication between UEs and macro-cells but also between macro-cells using the X2 interface.

interference mitigation in release 8 and 9 of the LTE standard focuses primarily on the frequency domain through soft frequency reuse. Soft frequency reuse divides the cells in two, the cell edge users and the cell centred users. For cell centred users the power allocated to the different frequency bands is unchanged, whilst at the cell edge the power allocated should follow a different frequency reuse pattern for each cell. This requires that UE's are classified as either a cell edge user or cell centred user [1]. The classification is based on the CQI value of the measuring UE and filtered to avoid oscillating in and out of cell edge.

In LTE, the X2 interface is used for interference coordination. LTE introduces new indicators so that macro-cells can coordinate on scheduling for cell edge users. The Relative Narrowband Transmit Power(RNTP) indicator is used to communicate to another macro-cell that a certain set of Physical Resource Blocks(PRB) will be used on the downlink in the future. This means that one can use these indicators to create ICIC algorithms for power control, resource assignment and frequency reuse patterns. Other indicators like Overload Indicator(OI) and High Interference Indicator(HII) are used for the uplink to measure interference and inform of transmission respectively.

For LTE release 8 and 9 one divides ICIC into static and semi-static ICIC. Static ICIC requires almost no signalling and is related to cell planning and cell configuration. Static ICIC is therefore not optimal when it comes to changing user distributions and cell loading.

An example of ICIC in release 9 is Fractional Frequency Reuse(FFR). The main purpose of FFR schemes are to divide the users between cell edge users and cell centred users and allocate different frequency domains to each group. This is done to improve the SINR levels of cell edge users without limiting the spectral efficiency. Figure 3.1 displays two types of FFR schemes, namely *soft* and *strict* FFR. Each cell is divided into cell centred users and cell edge users and given different bandwidths based on their location in the network topology[1].

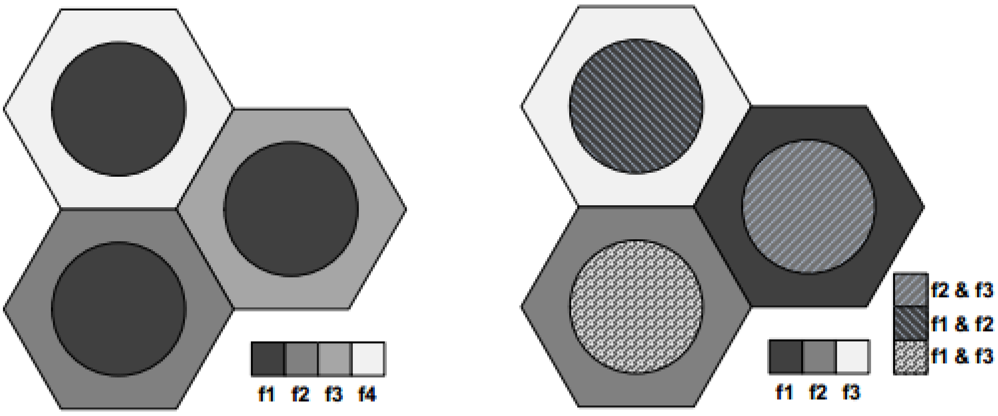

FIGURE 3.1: Strict and soft FFR, taken from [4]

For HetNet the problems become more complicated and conventional ICIC becomes obsolete in a co-channel environment that has to deal with CSG femto-cells and CRE pico-cells[3]. Femto to Femto interference mitigation however is showing promise with an adaptive FFR scheme introduced in [5].

## 3.3 RSRP and RSRQ

RSRP stands for reference signal received power and is a RSSI type measurement, measures the average received power over the reference signals measured on the resource elements that carry cell specific reference signals. This measurement is available in both RRC_connected mode and RRC_idle mode while its companion the RSRQ is only available in RRC_connected mode.

Reference Signal Received Quality(RSRQ) is the received quality of the reference signal defined by:

$$RSRQ = \frac{N * RSRP}{RSSI} \tag{3.1}$$

where RSSI is the received signal power of the radio signal and N makes sure RSRP is calculated over the same bandwidth. The LTE standard allows for a lot of flexibility when implementing and using these measurements. How the eNB chooses to do handover for example, whether it be through RSRQ, RSRP or both is entirely up to the vendor implementation.

## 3.4 Cell Range Expansion

Release 10 introduces cell range expansion (CRE) to deal with the problem from section 2.6. The approach of CRE is to apply a offset value to the RSRQ or RSRP cell association procedure in order to increase the coverage area of the cell in question. The Cell, both macro and pico-cell broadcast this offset value to the user who then makes the choice based on the highest power value. For a cell $i$, received power $P$(RSRP as discussed in 3.3) and offset value $\alpha_i$ the chosen cell k is calculated:

$$k = \arg\max_i \left(P_i + \alpha_i\right) \tag{3.2}$$

The parameters above needs to be adjusted by the network operator to achieve the best overall throughput and minimize over- and under-utilization of pico-cells. This also means that the network can achieve a downlink/uplink imbalance as the macro-cell that provides the best uplink doesn't necessarily provide the best downlink. In addition the CRE will introduce new interference scenarios especially in the downlink since the macro-cell has a higher signal power than the connected pico-cell.

eICIC techniques introduced in release 10 can be divided into 3 main categories.

- Time-domain ICIC techniques
- Frequency-domain ICIC techniques
- Power-control ICIC techniques

This report will only focus on the time-domain techniques of eICIC.

## 3.5 Almost Blank Subframes(ABS)

Ideally the operator will have 2 separate carriers to deploy HetNet environments, but that is not always the case. In a multi-carrier environment one can deploy the Pico and femto-cells on one carrier and the macro-cells on the other. When all the nodes in the network operate on one carrier, problems of co-channel interference arise. This problem can be solved through coordinating the network elements through algorithms using the X2 interface. Essentially one wishes to divide the available frequency resources between users drowning in interference and users with good radio link quality to achieve maximum overall network throughput.

Release 10 of LTE makes it possible for an eNB to "almost" mute certain subframes so that another node may transmit in the same subframes without interference. Almost blank means that the eNB transmits at low Tx power in the given subframe, no data channels are used and limited control channels are used. This technique is referred to as Almost Blank Subframes(ABS, sometimes called ABSF). The technique relies on signalling over the X2-interface to ensure that each node knows when and where to schedule the interference-subjected UE which will be referred to as the Victim UE(VUE) from now on. Time-synchronisation becomes vitally important with this type of scheme compared to other interference avoidance techniques[1].

There are two major challenges when trying to implement ABS. The first one is trying to find the appropriate association-rules in terms of CRE(see 3.4). The optimal algorithm has to take CRE into account given the level of inter-cell interference it produces and also its significance in achieving optimal load. The second challenge is determining the amount of radio resources to allocate to the pico in a macro-pico deployment through the use of ABS[6].

The ABS scheme is standardised in release 10, but the exact algorithm for using ABS is still up to the operator. This is very important for a SON approach as the algorithms will vary over different parts of the network.

## 3.6 Marking a UE as a Victim

In order to use ABS effectively the network must be able to identify and track a VUE. According to [7] the standardized SINR threshold for classifying a UE as victim are -4 dB and -6 dB but the authors recommend the threshold to be -3 dB, corresponding to a CQI value of 3. It is however not appropriate to classify a UE as a VUE at the first sight of a CQI below 3 because interference is often bursty. This is done by passing the CQI values through a simple filter to properly determine whether the UE is a victim. The proposed algorithm is as follows:

$$\mathrm{CQI}_f[n] = \alpha \mathrm{CQI}[n] + (1-\alpha)\mathrm{CQI}_f[n-1] \tag{3.3}$$

Where $\mathrm{CQI}_f[n]$ are the filtered CQI values, the $\alpha$ is the filter coefficient, determined through experiments. When choosing the tracking period one has to take into account the QoS demands from certain applications and the authors therefore suggest 50 ms. The tagging of a VMUE from an aggressor femto-cell is started when a wideband CQI value of 3 is observed and if the CQI value is 3 or lower after the tracking period of 50 ms, the MUE is tagged as victim and an ABS request is sent.

This scheme expects that the CQI reporting in LTE will be periodic with decent period so that the victim state is reached at the appropriate time.

The authors in [8] give a way to detect coverage holes in macro-femto deployment according to the RSRQ values measured. When the MUE is receiving heavy interference from a CSG femto-cell, the UE is instructed to mark for a coverage hole if the RSRQ value of the femto-cell goes above a certain value. Likewise the RSRQ measured at the macro-cell can also trigger a coverage hole detection with detecting RSRQ below a certain specified value, either statically or dynamically.

## 3.7 New Toolbox for ABS Coordination

The coordination of subframes in the time-domain requires new information elements to be sent between the nodes to facilitate the coordination. Messages include sending ABS request, sending information about deployed ABS subframes and request information on ABS subframes. An example of communication done over X2-interface can be seen in figure 3.2.

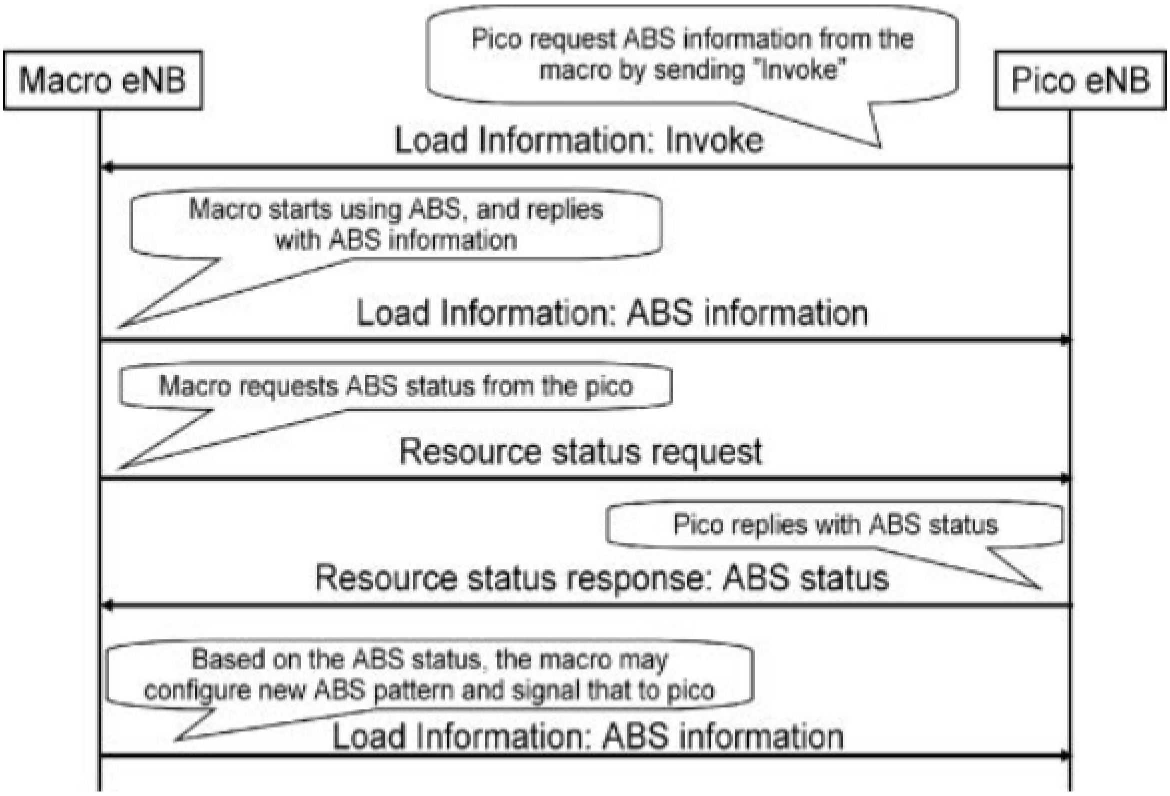

FIGURE 3.2: ABS information exchange, taken from [9]

The PeNB then receives information from the PUE indicating that it is a VUE(more on this in section 3.6) and starts the ABS-procedure over X2. The ABS-request is sent to the macro-cell over X2 and the macro-cell starts the ABS-configuration. The ABS-bitmap is then sent back to the pico-cell so that the coordination on the downlink can occur. Finally, a message is sent back to the macro-cell giving the node information about the pico-cell status.

## 3.8 Macro-Pico ABS Scenario

The main problem with macro-pico deployment is the cell range expanded users who have to connect to a node with lower signal strength. So in this scenario the victim is usually the PUE. In this section the work of different authors to combat this problem is laid out. The authors in [10] propose to calculate the number of ABS subframes at the macro. This is done with an algorithm based on load information at the Pico and macro, differentiating regular pico-users from the cell range expanded pico-users.

The article [6] discusses the macro-pico eICIC scenario with respect to the downlink. The downlink is considered to be the most vulnerable to interference because of the QoS demands. To combat the interference CRE-users experience, the authors suggest an algorithm for calculating the CRE bias value along with an eICIC algorithm. This approach has shown significant results, "performing within the 90 % of the optimal for realistic deployment scenarios, and 5th percentile of UE throughput in the pico coverage area can improve up to more than 50% compared to no eICIC; the improvements can be 2$*$ for lower throughput percentiles" ([6]).

An optimisation problem is presented which is solved with two algorithms. First a non-linear program is solved, treating two integer constraints as non-integers and then performing integer rounding to account for this in the second algorithm. This is done by maximising an objective function with respect to variables for number of ABS subframes deployed, the airtime and average throughput. They use a dual based approach which consists of a dual problem that acts as a lower bound for the primal problem. It is also shown that the problem can be divided into separate problems for the individual UEs, macro-cell and pico-cell.

Another important aspect that the authors address is the CRE of macros and picos calculated by cell selection bias. The CSB is standardised according to the description in section 3.4, so to continuously optimise this value one has to take the evolving standardisation into account. The authors have determined to calculate the cell selection bias parameter in accordance to the weights received from the second algorithm. This is to coordinate their own cell association algorithm in algorithm 2 with the bias level of the given pico-cell.

To account for the lack of standardisation for the scheduler in HetNet environment, the authors in [11] discuss this for the macro-pico scenario. They introduce two new schedulers, namely strict scheduling and dynamic scheduling. The main difference is that the strict scheduler only assigns resources blanked by the macro to cell edge users in the cell expanded zone. The dynamic scheduler works as the scheduler already defined for LTE which can be studied in [1].

Deployment scenario with SON is also discussed in [6], giving reasons for each SON case, meaning decentralized-, centralized- and Hybrid-SON. The Hybrid case seems favourable to the authors given that the algorithm is very complex. In Hybrid-SON, most of the computations are done at the Operations Support Systems(OSS) layer of the system while some smaller measurements and reports are done at the RAN level.

## 3.9 Macro-Femto ABS Scenario

The Macro-Femto ABS scenario is dependent on the fact that the X2-interface will be present at the femto-cell. X2-interface for femto-cells is not fully standardised yet. Thus, any attempts at proposing an eICIC scheme for macro-femto deployment will be dependent on that this will be standardised in the future work by 3GPP. Femtocell interference mitigation will therefore rely heavily on autonomous solutions such as different SON algorithms.

Based on detection of CSG macro-femto coverage holes for MUEs as mentioned in 3.6, the authors in [8] deploy muted subframes at the CSG femto-cell and uses a restrictive scheduling algorithm at the macro-cell in order to make sure that the non-victim users don't use the muted resources too often.

Authors in [10] present a similar approach to the macro-pico case explained in section 3.8 where they assume a backhaul connection between femtocell and macro-cell. The number of ABS subframes are calculated according to a formula based on macro-victim load, femto load and macro UE load as in the macro-pico case.

A problem arises when there are both pico-cells and femto-cells inside the a macro-network with co-channel deployment. The fact that both the macro-cell and the femto-cell are performing subframe blanking to mitigate interference on the down-link means that there is a chance that the macro and femto-cell blank the same subframe. A CRE-UE at a pico-cell requests ABS from the macro-cell in the same subframe that the macro wants to schedule a VMUE. Additionally two or more femto-cells might blank the same subframe, giving the MVUEs less subframes to be scheduled. This results in decreased throughput at the macro and pico-cell as shown in [10].

Their solution to this problem is to deploy ABS orthogonally over femto and macro-cells. This is a solution that makes sure the nodes deploy and schedule ABS in an organised way and the authors present their results, showing a significant rate increase for macro and pico-cells.

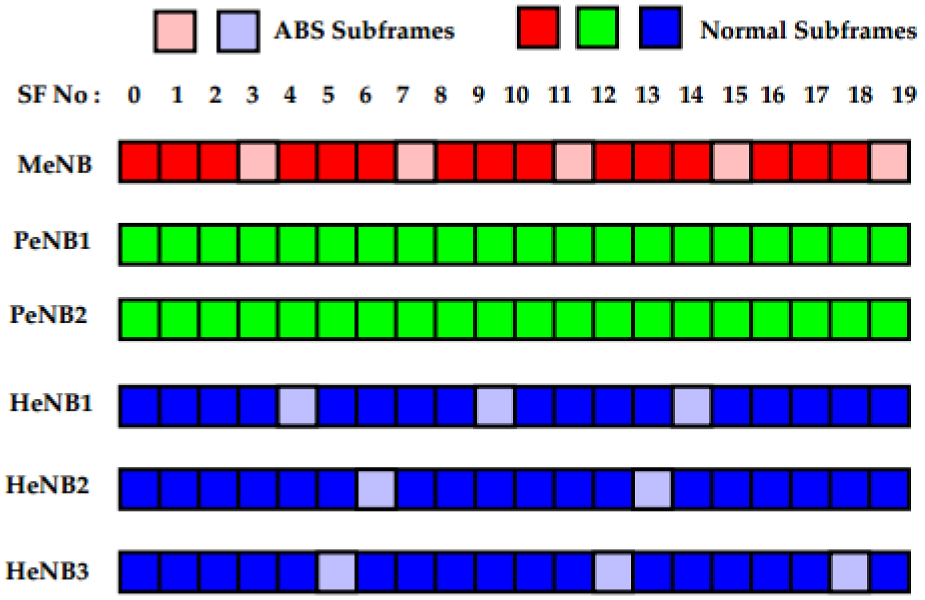

FIGURE 3.3: An example of orthogonal ABS scheme with 2 pico and 3 femto-cells, taken from [10]

## 3.10 CQI signaling in ABS systems

In order to get the correct modulation and coding scheme for the given UE, whether it is connected to the macro-cell or the pico-cell, requires a new framework for measuring Channel Quality Indicators (CQI). This is because the macro-cell will transmit with a lower tx-power in the given subframe and so the CQI generator will think that the channel conditions are worse than they really are and provide a Modulation and Coding Scheme that is much lower than the next non-protected subframe can support.

This means that one needs two CQIs, one for protected subframes and one for unprotected. This is implemented in release 10 of 3GPP so ABS systems need to wait for the UEs to be updated before one can utilize it at all.

This requires additional signalling over the radio interface between the UE and eNB to signal whether the subframe is protected or not.

## 3.11 Scheduler modification for ABS deployment

The schedulers also need modification to support ABS since one doesn't want to send data in a blanked subframe on the macro side and preferably want to send data during blanked subframes on the pico side. This will naturally depend on the pattern and periodicity chosen.

When employing a 1/8 ratio of protected subframes per subframe one might want to schedule a high number of UEs connected to the pico cell in unprotected frames to ensure high overall throughput.

The macro cell should not schedule any UEs in a protected frame. This means that the macro-cell ABS-trigger mechanism must be implemented in a way that recognises the average throughput of the macro-cell in comparison with the number of victim UEs.

A very simple model of the scheduler at the macro cell is shown in figure 3.4. This is important since a good scheduler will minimize the throughput loss at the macro cell with the limited resources available and ensure correct HARQ behaviour.

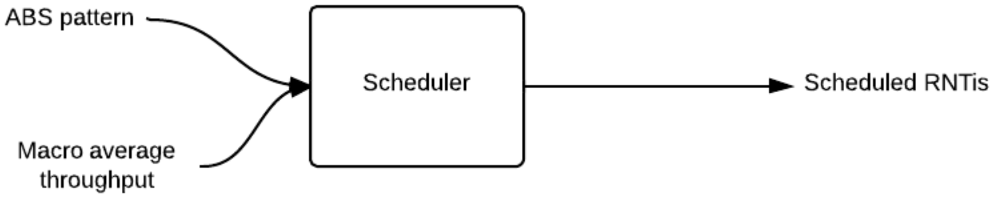

FIGURE 3.4: Simple macro scheduler in ABS environment

## 3.12 Disadvantages of time-domain eICIC

The main disadvantage is the level of time-synchronization needed at the eNBs. This needs to be synchronized through either the X2-interface or through GPS synchronization, utilized in CDMA systems to coordinate the PN-offset assignment. Because of the cyclic prefix used in LTE the time synchronization needs to be accurate down to a couple of microseconds.

CHAPTER 4

# NS-3

NS-3 is a powerful simulator based on c++ but also available through pyton bindings. It is mostly used for wireless, wimax, lte and ip based internet traffic. NS-3 is built in such a way that it is well documented while containing highly realistic models. The learning curve for using NS-3 is very steep so one has to sink a lot of time into getting to know the classes and namespace in order to excel. [12]

In order to make the c++ programming easier for the user NS-3 contains many templates and functions for allowing the user to avoid messy pointers while simultaneously allowing a great deal of flexibility in editing the simulator. Helper functions allow for easier creation of network nodes and use of mobility models such that there is a hopefully steadily increasing learning curve towards being able to master the simulator and creating your own modules.

Modifying NS-3 modules can be difficult at first when trying to make sense of the giant library. The doxygen documentation is great for navigating classes and functions and look at the inheritance between objects.

Each technology that is implemented in NS-3 has its own module which contain many c++ files with names of the classes represented in the files. Time is kept using *class Time* and the simulator schedules events (functions) using the *Simulator::Schedule ()* function at specific time instances. A script-like .cc file is used to set up and execute a simulation, setting up parameters and actions.

The *class Node* is used to create nodes in the network and then abilities, technology and network connections are aggregated to the node through the *class Object*. An example of this procedure is shown in figure 4.1 where one can see the UE node object with aggregated functionality. This is to ensure that the library is easy to modify with new functionality if the user wants to implement something different.

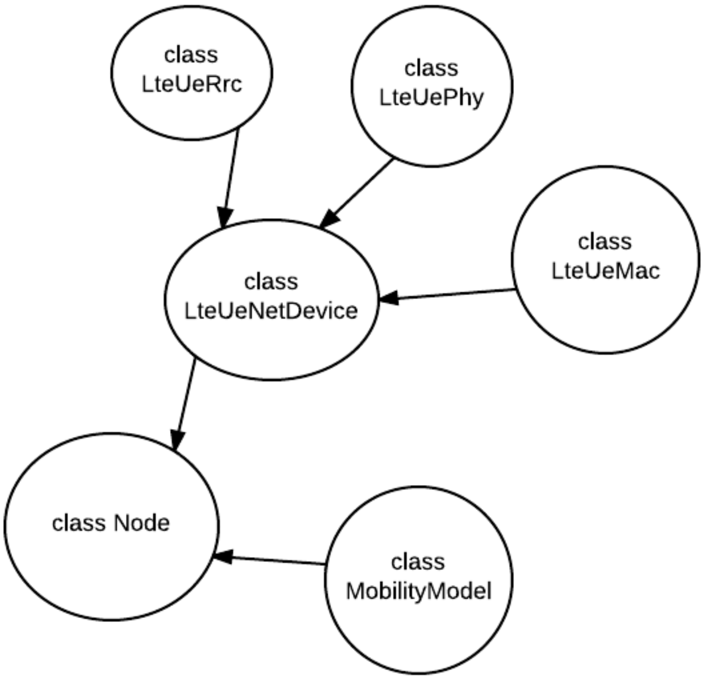

FIGURE 4.1: Object aggregation to UE node

To create a new object, use the command:

```
Ptr <Node> node = CreateObject <Node> ();
```

Subsequently one can aggregate an object to the node using:

```
Ptr <NetDevice> dev = CreateObject <NetDevice> ();
node->AggregateObject (dev);
```

To minimize the the lines of code necessary to write a functioning script, helper classes are implemented to make sure the entire node-aggregation tree is well put together. The *class LteHelper* is used to initialise LTE nodes, both UEs and eNBs. This is done by setting up the connections between the different layers and store object pointers so they can access each others functions and variables.

Different parameters and variables can be set through the *TypeId::SetAttribute ()*, so for instance if one wants to use maximum bandwidth in LTE one types:

```
Config::SetDefault ("ns3::LteEnbNetDevice::DlBandwidth", UintegerValue (100));
```

This sets the number of resource blocks on the downlink available to 100 which equals 20MHz. The flexibility of the framework allows for all kinds of implementations based on the existing modules or the ability to add new modules to the library.

## 4.1 LENA project

LENA stands for LTE/EPC Network Simulator and is an open source project which rely heavily on contributions from the community. The core motivation for the LENA project is to provide an educational simulator of LTE which can be modified to test different algorithms with a large degree of flexibility.

Some models are unfortunately missing, one of the key ones being IDLE-mode. One has to manually attach UEs to a eNB either through physical distance from the node or through forcing it to connect to a node. This can be highly disruptive if one wishes to connect many UEs to a eNB and many of them don't connect at all or doesn't try to reconnect to a more suitable node. [13]

## 4.2 The granularity of the LENA lte model

The most computationally taxing to a simulator of this kind is the physical level and so approximations has to be made to make sure that the simulator runs smoothly. Radio link level granularity on a per symbol basis is therefore ruled out. Although one wishes to compute fast certain requirements are made. At the radio level the minimum granularity has to be that of a resource block in order to enable accurate modelling of inter-cell interference on a per resource block basis. This is very important for SON implementations regarding ICIC.

### 4.2.1 The Mac-layer

In order to provide an accurate and hopefully real-life model of the mac-layer the LENA project has decided to implement the femtoforum API. This ensures that the model behaves like a real implementation as much as possible even though most vendors use their own APIs. [14]

The interface allows the scheduler to communicate with the mac layer while staying independent of the PHY layer. It uses Service Access Points (SAP) to provide access between layers and uses a push strategy towards parameters, which means all the parameters are sent to the scheduler at certain times. A pull strategy on the other hand would mean that the scheduler access parameters when they're needed. A figure describing the interface can be seen in 4.2. The framework described is the exact same as is expected to be used in femto-cells which makes it possible to test radio resource management solutions in a test environment.

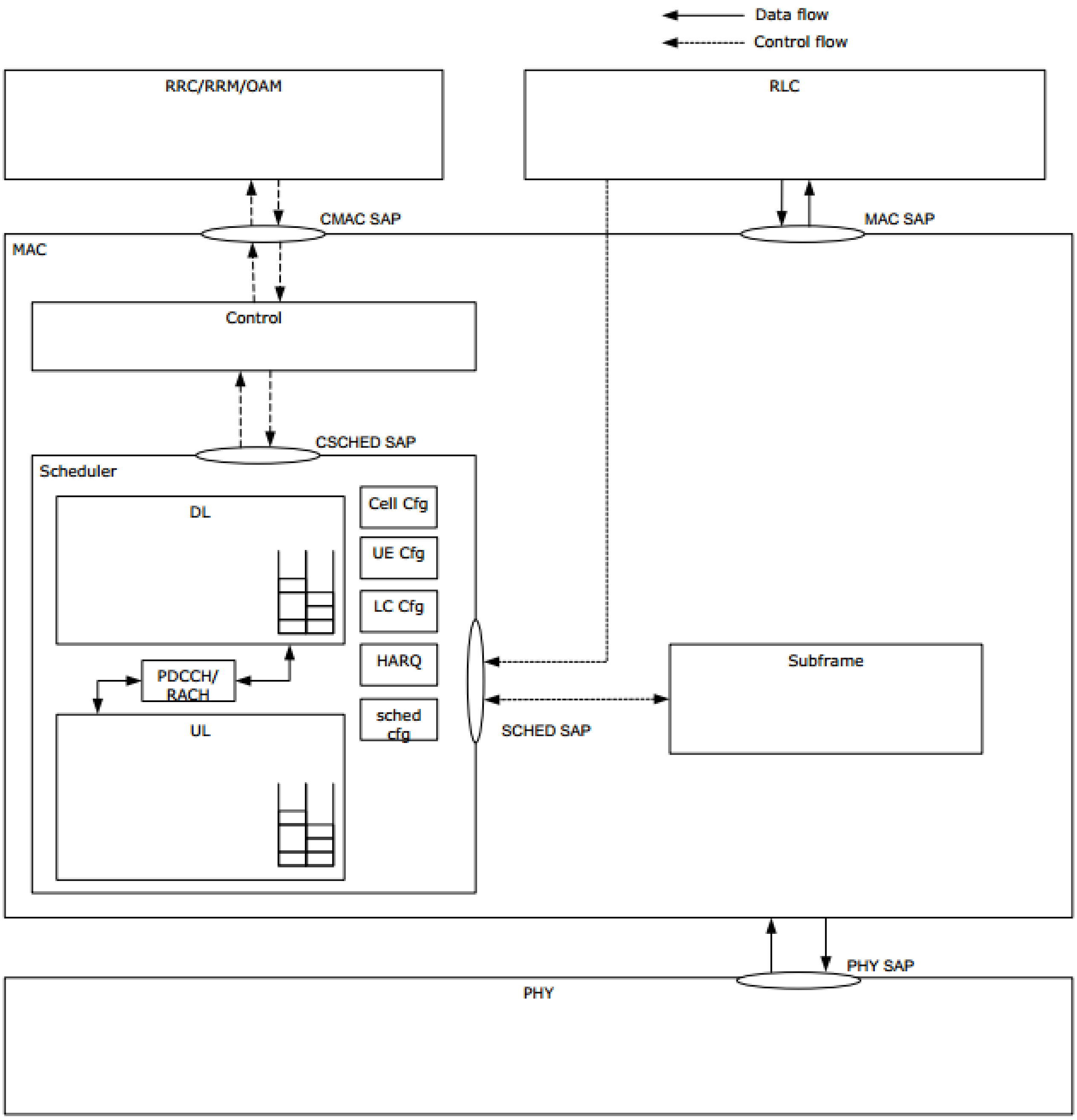

FIGURE 4.2: Femto-forum SAP interface between layers, taken from [14]

### 4.2.2 Approximations that influence simulation results

When interpreting results coming from simulations in the lte module one has to take into account the different approximations made in the module. The documentation[15] provided specifies the granularity of the different models used. Starting with the fading model one observes that the model specifies different parameters:

- user speed
- number of multiple paths considered
- sampling time of the trace
- frequency granularity of the model
- number of users

The frequency granularity of the LTE module is one RB, and the time granularity is one TTI (1ms). For user speed, different discrete values are set based on common scenarios including walking, driving and urban scenarios. These models are represented in TS36.104[16] annex B-2 and give the relative power to the signal for different excess tap delays. A simplification of the per user fading trace is also provided to decrease complexity.

### 4.2.3 The PHY-level in the LENA-lte model

The time and frequency granularity specified above needs to be adapted to the transmission of Physical Downlink Control Channel (PDCCH), Physical Control Format Indicator Channel (PCFICH) and the Physical Downlink Shared Channel (PDSCH) on the downlink and Sounding Reference Signals (SRS), Physical Uplink Shared Channel (PUSCH) and Physical Uplink Control Channel (PUCCH) on the uplink. These channels make up a subframe in LTE which last a TTI or 1 millisecond. This is modelled by having separate models for the control and data channels.

The data error model uses Link-to-System Mapping (LSM) which goal is to limit the computational complexity of the simulator. This is done by combining both the system level simulator and link level simulator into a mapping of for example SINR, MCS and BLER, where SINR is the Signal-to-Interference plus Noise Ratio and BLER is the Block Error Rate.

The MIESM model implemented in NS-3 LENA uses this method to calculate the BLER from a mapping of SINR and MCS for the entire system and link performance. The operation can be seen in figure 4.3.

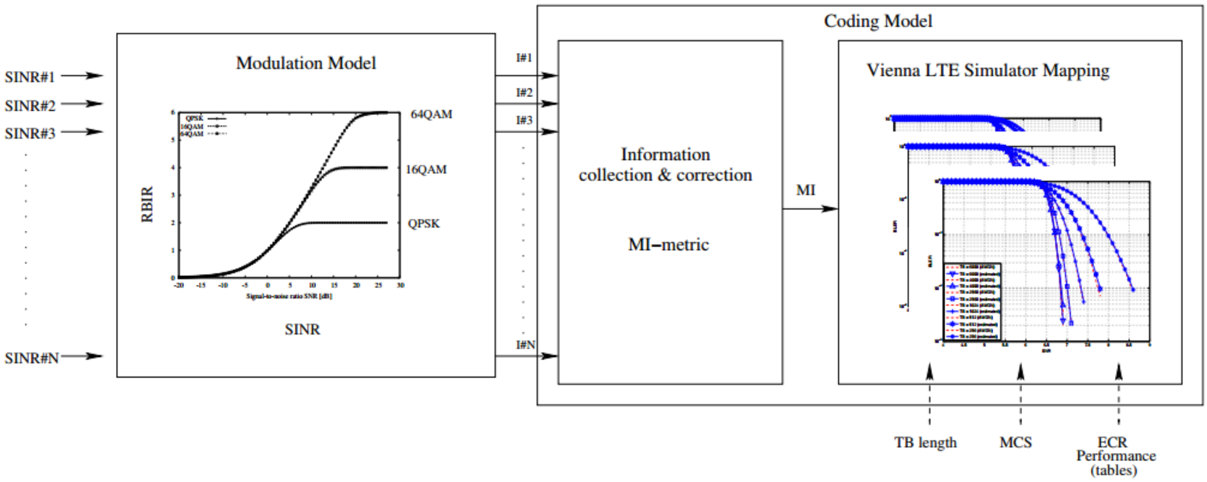

FIGURE 4.3: MIESM implemtation in LENA, taken from [15]

MIESM stands for Mutual Information Based SINR Metric and is used in the LENA model with mapping provided by the Vienna LTE simulator [17]. Since this is only a network simulator, not a radio link simulator, the LENA project has decided to implement a flat frequency response in each RB and the Transport Block Error Rate (TBLER) is calculated by averaging the BLERs over RBs. The implementation also has to account for different code block(CB) sizes used in coding. This is done by estimating the CB size according to [18]. The Code Block Error Rate (CBLER) of CB i is calculated with:

$$CBLER_i = \frac{1}{2}[1 - erf(\frac{MI_{TB} - b_{ECR}}{\sqrt{2}c_{ECR}})] \tag{4.1}$$

where $MI_{TB}$ is the mutual information of a transport block where the approximation of mutual information is converted into look-up tables given as vectors of type double in *class LteMiErrorModel*. *erf* is the error function, and $b_{ECR}$ and $c_{ECR}$ is the mean and standard deviation of the Effective Code Rate (ECR), a guassian process.

The control channels also use the MIESM model to calculate errors in PCFICH and PDCCH. Since the PCFICH is used to decode the PDCCH these two have their own separate processes. In order to decode PDCCH and get the resource allocations from the DCI stored within one needs to first decode PCFICH. This is because the PCFICH tells us how many symbols are used for the PDCCH to potentially limit the number of symbols used for control channels.

## CHAPTER 5

# ABS IMPLEMENTATION IN NS-3

In this chapter one will look at the ABS framework that have been implemented on top of the already existing NS-3 v-3.18. Hopefully the reader will understand how it is implemented so that one can expand on the model and use it effectively. The chapter focuses on explaining each part implemented on top of the LENA-lte module and give examples of future improvements to the module.

Unfortunately the model is not entirely completed because of many debugging setbacks associated with ns-3 and ones own implementation. But hopefully this chapter can give an idea of what one can implement in the future if one wants to test out algorithms.

## 5.1 Cell range expansion

In order to accurately model the problem, solvable through ABS, one has to model the Cell Range Expansion(CRE) offered by the pico-cell. The LENA model uses RSRQ values to determine handover thresholds calculated from the RSRP and RSSI as seen in eq. 3.1. The CRE scheme requires the use of additional signalling to provide the UE with the information on what type of cell (macro, pico?) and the assigned offset. In this implementation, with the flexibility of a c++ based simulator, one takes the liberty to implement a pointer based, delay free solution. The *class BiasHelper* assigns offset values directly to the UEs in the simulation with a neighbour list of CellIds used to identify pico cells. The BiasHelper is then called from within the starter script to assign the pico-cell CIDs to the bias list. The class is then called from within *LteUePhy::ReportUeMeasurements ()* which is responsible to signal to the eNB every 0.5s, the RSRP and RSRQ in order to initiate cell reconfiguration.

## 5.2 ABS-Trigger mechanism

In order to get the most out of a blanked subframe one has to classify victim RNTIs at each pico node. One has to then send an inquiry to each neighbour macronode which then makes the decision to initiate. This is highly necessary in order to take the macro-nodes throughput and buffer size into account when making the decision to initiate a blank subframe pattern. The general structure of the implementation can be seen in figure 5.1.

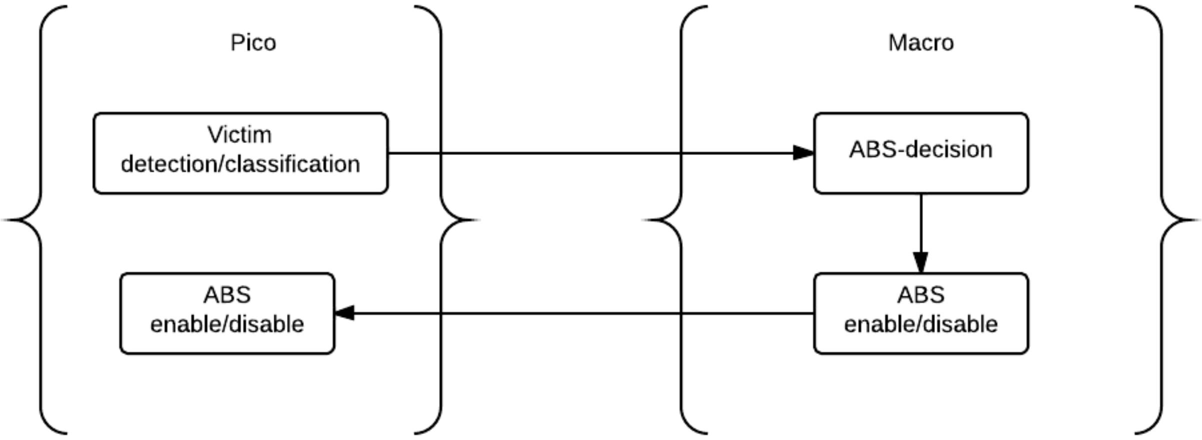

FIGURE 5.1: Victim classification and ABS initiation

The basis for the implementation is the Round Robin femto-forum scheduler. All abs triggering mechanisms are implemented here, in the files: rr-ff-mac-scheduler.cc/h.

The classification of victim PUEs has been implemented as part of the CQI updating function *RrFfMacScheduler::DoSchedDlCqiInfoReq ()* as defined in [14]. *std::list <uint_16t> victimList* has been added to store victims and the function *VictimListEdit ()* has been added to facilitate updates to victim status by removing and adding new RNTIs. The victim threshold has been set to a static value $CQI <= 3$.

In order to coordinate the subframe scheduling each scheduler has a pointer address to the other schedulers which makes it possible to use public functions and initiate abs. This is a simplification to avoid having to implement new X2 messages and create new messages between the RRC->MAC->Scheduler interfaces.

## 5.3 NS-3 CQI implementation

In order to get the correct CQI value when transmitting data in a blanked subframe framework, one has to have two separate CQI values as discussed in section 3.10. A new control message is required for the downlink in order for the UE to realize whether it is performing calculations on a blanket subframe or a regular subframe. The new message is called *class AbsCtrlMessage* and holds a boolean value for protected/unprotected subframe. The control messages are defined in *class LteControlMessage*. The UE then has to signal to the eNB if the cqi value calculated is on a protected subframe or not. This is done by adding a parameter in the downlink CQI message carried on the uplink.

The different CQIs are then stored in the scheduler for further use when creating DCIs for Tx. Ideally one would use the CQI for the data plane but as this is not implemented a solution where one uses the control plane CQI has been chosen.

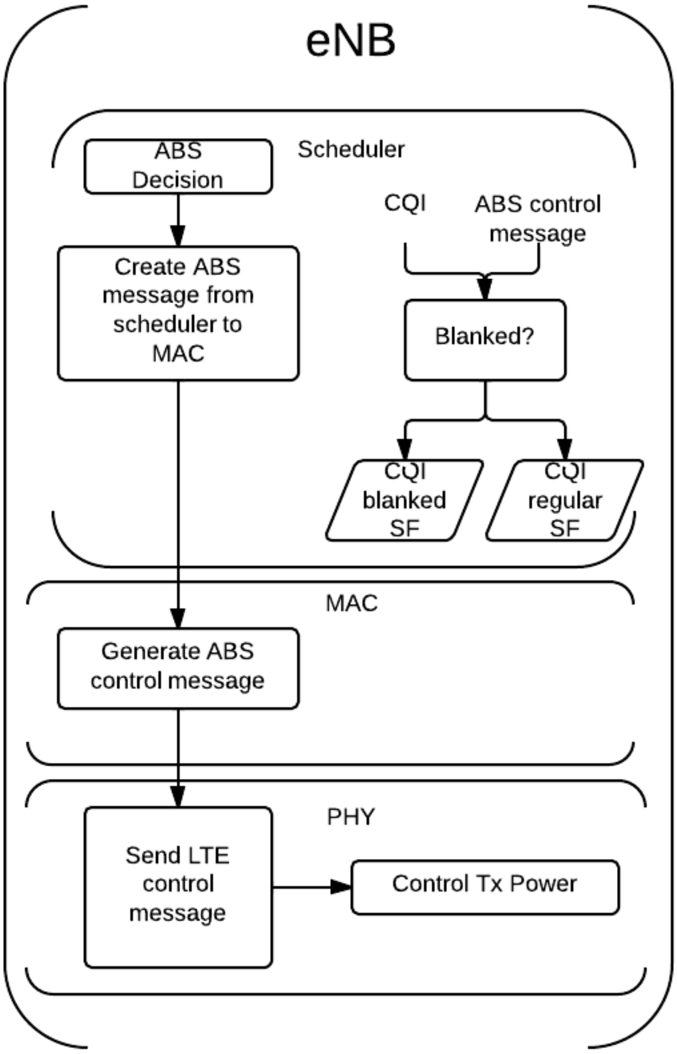

FIGURE 5.2: Handling of CQI at the eNB

The layers need to communicate with each other through new messages to account for the possible longer than 1 TTI MAC-delay. A new message has also been added to the SchedDlCnfInd message standardised in the femto-forum technical paper [14]. This is because it is the MAC that creates the control messages and sends it to the physical layer through a PHY-SAP. The message then controls the Tx-power to blank the subframe at the PHY-layer.

## 5.4 Additional features

In order to get the most out of a blanked subframe, changes has to be made to the scheduler both at the pico-cell and the macro-cell. Which RNTIs should be given special treatment in blanked subframes and which can be deployed partly in protected/unprotected subframes? These are questions that are essential when deploying ABS since the whole point is to increase overall throughput.

Right now, the X2-message only sends a boolean between the macro- and pico-cell. In order to make a better decision at the macro-cell whether to use ABS, more information is needed about the current state of the pico-cell load, rlc buffer size and amount/severity of the victim-PUEs. New messages can therefore be defined over the X2 interface to clear the way for this information exchange.

An adaptive approach of cell range expansion can also be evaluated based on the load at the pico cell. If one experiences a high load at the pico-cell one can adjust the bias value towards the pico-cell. This has to be communicated over-the-air interface but also over the backhaul to other nearby nodes so that the UEs can make correct handover decisions.

# CHAPTER 6

# CONCLUSION

In order for vendors and researchers to test ICIC algorithms they need access to a simulator which supply an accurate representation of the network environment. NS-3 LENA-lte module provides a good model of the different layers and flexibility in terms of adding new features.

When dealing with ABS the synchronisation between the cells is important. This is the main challenge facing TD-eICIC since the eNBs have to be synchronised down to microseconds in order to achieve the desired results, lowered interference. This synchronisation error is not accounted for in the current NS-3 version where the nodes are running at the same exact time and the error models are based on approximations.

Although the granularity of the model doesn't exceed resource block level, the model is good enough to test ICIC algorithms on since the results will be more dependant on the higher layers, the MAC/RLC/scheduler layers than the lower layers, PHY-layer and Spectrum channel.

The ABS coordination procedure implemented will however be a hindrance towards algorithms sensitive to delays since the X2-interface is not used to communicate the initiate abs message and pico load. Depending on the QoS demands that the broadband/fiber provider offers, the messages will have varying delay in the entire network. This framework, unless X2 messages are created in the future, is therefore not reliable to test algorithms of this kind.

Algorithms that are not sensitive to delay will likely perform much more realistically in the network simulator and therefore is more suited. This is though a fair approximation of the real life case where the first distributed SON-algorithms will most likely not be delay sensitive to begin with.

ABS requires two CQI values to be stored in order to facilitate correct MCS in the protected/unprotected subframe. The choice of measuring the CQI over control channels rather than the data channels will have an impact on the results where the scheduler could give a pessimistic MCS value for protected subframe based on activity present in the control channel of macro cell in said subframe.

In addition to new CQI procedures, new control messages and X2-messages have to be standardised. When making the decision whether to use ABS and to what extent one needs information from the pico-cell indicating the current load and number of victims.

# APPENDIX A

# NS-3 IMPLEMENTATION

## A.1 Files

This appendix contains a guide to set up the implemented model in NS-3. The .zip file that comes with the report contains the necessary c++ files to have a look at the ABS model implemented. First one has to download the **NS-3 3.18** version which is the one used for this report. In order to get installation instructions for NS-3 go to [13].

Extract the files included in the zip file to the folder with the same DIR in the final LENA pull NS-3 3.18.

## A.2 Code

The NS-3 simulator is written entirely in C++ and the different modules of the lte system have their own .h and .cc files located in the /lena/src/lte/model/ directory. Most of the implementation has been written in rr-ff-mac-scheduler.h and rr-ff-mac-scheduler.cc since the round robin scheduler was the basis of the implementation all of the relevant code has been put on top of the existing scheduler code. lte-control-message.h has also been edited to support a new control message, lte-enb-phy.cc has been edited to blank certain subframes and various other files have been edited to support for CRE and allow interaction between layers.

The code is not finished at this point for various reasons but the code has been included in case someone wants to finish it or get ideas for their own NS-3 project. A run file is included with the code that one can use to test the implementation with 2 nodes.

There exists a bug in this version of NS-3 which sometimes causes a memory leak during multiple HO, hopefully this will be fixed in future versions.

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