Optimization of algorithms for mobility in cellular systems

Bernt Christensen
bernt.e.christensen@gmail.com

Olof Knape
olofknape@gmail.com

June 8, 2016

Master's thesis work in electrical and information technology carried out at Ericsson AB.

Supervisors: Niklas Holmqvist, Niklas.Holmqvist@ericsson.com
Jan Wichert, Jan.wichert@ericsson.com
Fredrik Tufvesson, Fredrik.Tufvesson@eit.lth.se

Examiner: Fredrik Rusek, Fredrik.Rusek@eit.lth.se

Abstract

Inter-frequency measurements are needed to determine when user equipment should make a handover to the best available base station in a cellular mobile network. The measurements are expensive from a resource point of view and therefore there is a need for optimization of this kind of measurements. In this work both this optimization and a way to predict the future of the measurements have been evaluated in a simulated Long-Term Evolution network. Both fast and slowly moving user equipment have been tested and the prediction was made by storing old measurements and calculating the gradient of the signal power. Depending on the resulting signal's gradient, different decisions on what to do were made. The results were then compared to the traditional way of controlling the inter-frequency measurements, in terms of throughput, handover failures and other quality factors.

The results from the simulations show that there is some optimization that can be made without compromising the connection. More specifically, the time spent measuring inter-frequency has been successfully improved (lowered). Handover failures have been harder to control and the throughput has more or less been unchanged throughout the simulations. The speed of the user equipment influenced the results a lot and no setup was found that works best with all UE speeds.

Keywords: Handover, Long-Term Evolution, UE speed, measurement optimization, inter-frequency measurement, prediction, simulation

Acknowledgements

We would like to thank Fredrik Tufvesson at LTH for his important feedback and advice. We would also like to thank Niklas Holmqvist and Jan Wichert for the opportunity to work with this thesis at Ericsson and for their invaluable help and feedback throughout the work. At last we would also like to thank Niclas Palm and Staffan Haglund for their guidance in the technical details of the used simulator.

Abbreviations

3
3G - Third Generation of mobile telecommunications technology
3GPP - 3rd Generation Partnership Project

B
BS - Base Station
BTS - Base Transceiver Station

E
E-UTRA - Evolved UMTS Terrestrial Radio Access
E-UTRAN - Evolved UMTS Terrestrial Radio Access Network
eNB - evolved Node B

G
GSM - Global System for Mobile Communications (originally *Groupe Spécial Mobile*)

H
HO - Handover
HOF - Handover Failure
Hys - Hysteresis

L
LTE - Long-Term Evolution

P
PCell - Primary Cell
PSCell - Primary Secondary Cell

Q
QoS - Quality of Service

R
RLF - Radio Link Failure
RS-SINR - Reference Signal - Signal to Interference and Noise Ratio
RSRP - Reference Signal Received Power
RSRQ - Reference Signal Received Quality
RSSI - Received Signal Strength Indicator

S
SCell - Secondary Cell
SINR - Signal to Interference and Noise Ratio
SON - Self-Organizing Network

T
TTT - Time To Trigger

U
UE - User Equipment
UMTS - Universal Mobile Telecommunications System

Contents

Chapter 1
Introduction

1.1 Background

With a growing number of connected users and an increasing amount of traffic in the mobile network, there is an increasing demand on the availability, performance and quality of the network. The usage of different kinds of streaming services is increasing which requires better throughput but also requires the connection to be more stable and available at all times. At the same time there are limitations on the throughput and how many users there can be within a certain area and still provide good service to all of those users. Therefore it is very important that the load of the network is distributed within the network and that each user is provided with a good connection, based on the user's location. This may sound like an easy task but the fact that the users are moving with various moving patterns and at various speeds makes it harder. Therefore it is important to implement sophisticated algorithms that can estimate a user's movement and be optimized to give the best service possible to the users. At the same time there are limitations on the processing power and what data that can be retrieved from the users, because of the limitations of the user equipment (UE, e.g., a mobile phone or a tablet). Therefore it would be preferable to do as small amount of measurements and calculations as possible without impairing the service and making incorrect mobility decisions.

1.2 Problem Statements

In the thesis we study the following problems:

1. Is it possible for the UE in the simulator to find the current signal quality's rate of change, based on its measurements?

2. Based on the rate of change, is it possible to predict when a handover (HO) should be made (both initiated and finished)?

3. Will this new way be more efficient than current solution, in terms of calculation effort and measurement effort without compromising the Quality of Service (QoS)?

1.3 Purpose

The purpose was to try to find answers to the questions stated in Section 1.2 and by doing so, find a new way to analyze measurements made by the UE. Based on the analysis, which takes the rate of change in signal quality into account, the UE might be able to reduce the number of measurements needed to make a good estimation for when a HO should be made without an unacceptable increase in calculation effort.

1.4 Method

The thesis work was divided into two parts; the first method used was a literature study and the second was experiments using simulations to find whether or not the suggested algorithm gave better performance.

The literature study was used to find research to base this work on. Literature was searched for using Lund University's search engine, LUBsearch and IEEE Explore where keywords such as *handover*, *speed*, *measurement* and *prediction* was used. Once such searches have been made, references in the found papers lead to further papers and references. For documentation regarding the standardization of the technology the homepage of the 3rd Generation Partnership Project (3GPP) has been used. 3GPP is a partnership organization that unites seven telecommunications standard development organizations which together provides and develops the mobile broadband standard.

In the second part experiments were used by simulating both the previous procedure and the new suggested procedure, using an algorithm, both using the same environment. This was used to be able to do a comparison between the performance in the old way and the suggested way of doing this. More on how the simulation was setup is described in Chapter 3.

1.5 Scope

Although there are several different telecommunication technologies in use today this study only took Long-Term Evolution (LTE) under consideration. The study was also limited to making simulations with a simulator provided by Ericsson. All the limits that came with the simulator were also limitations to this work. There was no end to the number of cell deployments available, neither in reality or in the simulator, but it was chosen to limit this study to the usage of 3GPP case 1 and case 3, these are described in Chapter 3.1.

The study considered connected UEs, which means that UEs in an idling state were excluded. The UE is in a connected state when some kind of transfer is ongoing between the UE and the base station (BS), this can be, e.g., a phone call or data transfer due to sending or receiving an E-mail.

The study only took measurements in the UE in consideration and left out the measurements made by the BS. The intra-frequency measurements were also left out of this work, the focus was on inter-frequency measurements. There are different ways to measure the signal power/quality between the UE and the BS, this study was limited to the usage of Reference Signal Received Power (RSRP). The concepts and ideas in this thesis could relatively easily be tried with other measurement units than RSRP. The scope was also limited to the measurements preceding the actual HO, meaning that the study focused on when the HO was made and did not look into the details of how the UE chose target cell or how the HO was made. The result of the HO, if it should succeed or fail, was an important aspect and was taken into account for the end result of the study.

1.6 Report Layout

The first chapter of the report gives an introduction to the area and the problem which was tried to solve. Chapter 2 describes the theory needed to understand the area and goes a bit more into details. After this, Chapter 3 gives a description on how the simulation was setup and why. Chapter 4 describes the different simulations made. In Chapter 5 the result from each of the simulations is presented. Chapter 6 analyzes the results from each of the separate simulations. The total outcome of the results and the analysis are discussed in Chapter 7 and concluded in Chapter 8. Lastly future work related to this work is suggested in Chapter 9.

Chapter 2
Theory

This chapter gives the theoretical background this thesis is built upon. The chapter begins with an overview of cellular networks and explains the different measurements made and why they are important. After this follows a detailed description of HOs and then follows an overview of Self-Organizing Networks which in a way explains the motivation behind this thesis. The chapter ends with an explanation of what factors of QoS that are studied in this thesis.

2.1 Cellular Networks

The radio access network (later referred to as network) that provides UEs with connectivity is divided into several parts. The complete network is composed of many BSs that each has a cell site, a geographical area in which the BS provides connectivity. This site in turn is divided into one or more cells. Each cell uses one frequency interval through which the UE and the BS communicates. Cells with different frequency intervals might cover the same area to provide service to more UEs within that area. Each UE is normally connected to one of these cells in order to be able to use any of the features provided from the phone service provider, e.g., making a voice call or surfing on the Internet.

There are several different sizes of the cells. The largest is covered by a macro BS, within 3GPP categorized as 'wide area BS' and is often used as the base in a network deployment. They use a relatively high transmit power (20-40 W) and the antennas are usually located above roof-top level. Then there is the micro BS that is located below roof-top level and is often limited by neighboring buildings. Micro BS is specified 'medium range BS' in 3GPP and is using 5-10 W. Pico BS is referred to as 'local area BS' in 3GPP and transmits using 0.25 W at most. They cover a small area but still bigger than a femto BS which is intended to use in a small office or at home and is called 'home BS' in 3GPP. It uses 0.1 W at most and differs from the rest by usually being connected to the network through a home broadband connection to a femto gateway [1]. Take notice that the cells does not always align next to each other covering different areas, they often overlap. There could also be a cell within the area of a bigger cell, e.g., a femto cell could be within the area of a macro cell [1][2].

The BS in different network solutions is called different things, in LTE which is the focus in this thesis, the BS is called evolved Node B (eNB) while, e.g., within Global System for Mobile Communications (GSM) the BS is called base transceiver station (BTS). The network itself is also called different things, in LTE the network is called Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) and Evolved UMTS Terrestrial Radio Access (E-UTRA) refers to the interface in use. Where Universal Mobile Telecommunications System (UMTS) is the name of a technology used in the third generation of mobile telecommunications technology (3G). The focus of this thesis is LTE and therefore, from now on, the names and expressions connected to LTE will be used.

The Figure 2.1 below illustrates an example on how an E-UTRAN could look, with eNBs with different number of cells and different cell sizes. There are also some UEs placed in the cells.

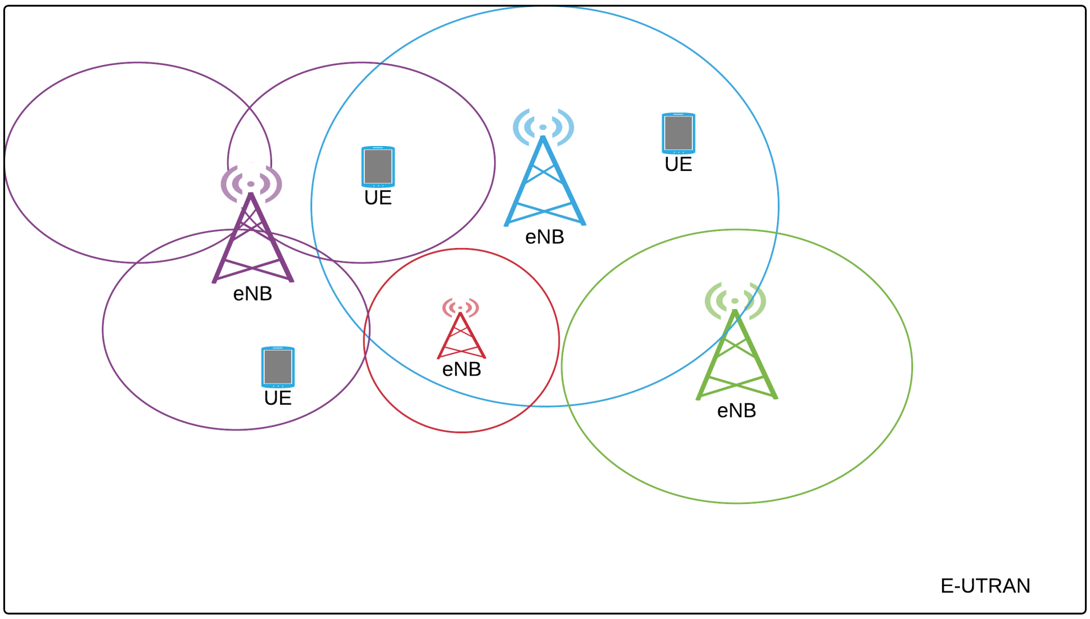


Figure 2.1: An example of an E-UTRAN. Each color represents an eNB and its cells.

2.2 Measurements

A connected UE is continuously making measurements against the cells in the surrounding area in order to find the cell which provides the best service/coverage available to the UE. The measurements are made by monitoring reference signals sent out from the cells. How the measurements should be done is configured by the eNB and this specification can cover how often the measurement are made, what to measure and when to send measurement reports to the eNB. The reports can be configured to be sent within different time intervals or based on defined events, e.g., the UE measures a value lower than a defined threshold value [1][3]. There are several values that can be measured and used to determine which cell to be connected to, what to measure depends on the configuration for that cell [1].

The most basic measurement that could be monitored is the RSRP. RSRP is the average power received from a single cell specific reference signal resource element, measured in watts. In other words, the RSRP provides a measurement of the signal strength between the UE and the cell, measured in the UE [1]. RSRP takes the signal's power in consideration, not the signal's quality. Therefore there is also Reference Signal Received Quality (RSRQ) that states the signals quality by taking the other interfering signals under consideration. RSRQ is defined as

$$N * \frac{RSRP}{RSSI} = RSRQ,$$

where N is the number of Resource Blocks and Received Signal Strength Indicator (RSSI) is the average received total power from the serving cell, other cells and noise from other sources [1][3]. The serving cell refers to all the cells that provides a connection to the UE and consists of the primary cell (PCell) and the secondary cells (SCell). Where PCell refers to the cell that operates on the primary frequency to which the UE performs initial connection and re-establishment. The primary secondary cell (PSCell) has the same responsibility as the primary cell but for the secondary cells, that operates on a second frequency.

Another type of measurement that describes the quality of the signal is signal to noise and interference ratio (SINR) and is defined as

$$SINR = \frac{S}{I + N},$$

where S is the power of the usable measured signals, I is the average interference power and N is the noise power [3][4].

There are two different ways for the UE to find cells in the area, one is using intra-frequency measurements and the other is inter-frequency measurements. The intra-frequency measurements are made by measuring against the neighboring cells using the same frequency currently used between the UE and the serving cell. The other, inter-frequency measurements are made against the cells within transmission gaps. During these gaps the UE retune the receiver to monitor other frequencies, makes the measurements and then goes back to the original frequency again [5][6]. Due to the fact that there cannot be any regular transmissions between the UE and the serving cell during the inter-frequency measurements these are considered costly in terms of resources used and therefore intra-frequency measurements are preferred where the measurements do not cause a transmission gap [5].

2.3 Handovers

When a UE is moving from one cell to another the connection to the cell needs to be transferred from the old cell to the new one. This can be done by either a HO or a cell reselection. A HO refers to a transfer between two cells while the UE is active (connected) in either a voice call or some other kind of data transfer. A reselection is while the UE is in idle mode which means that there is no transfer going on but the UE is still monitoring incoming calls [7].

Usually the UE does a HO or a reselection from the serving cell to the target cell, depending on where the best QoS can be delivered to the UE. QoS in this case refers to which degree of satisfaction a user has for the service, which include different aspects of performance: operability-, accessibility-, retainability- and integrity- performance [8]. From a UE point of view a more specific interpretation of QoS can be found in Section 2.5. The QoS is determined by looking at the different measurements described in Section 2.2.

The user would probably not notice if something goes wrong during a reselection since there is no active transmission going on to the UE. On the other hand, if something goes wrong during a HO, delay-sensitive data transmissions could be interrupted causing, e.g., a broken phone call. Therefore it is more important that the HO procedure is made without complications than the procedure of a reselection. For this reason HO will be in focus of this work.

An unintended loss of the connection between the UE and the cell is called a Radio Link Failure (RLF). This might happen if the connection to the serving cell is lost before a new target cell is ready to establish a connection to the UE.

A HO can be made in three different ways [9][10]:

1. Hard HO, where the current connection between the UE and the serving cell is broken down before a new connection to the target cell is established.

2. Soft HO refers to a scenario where the new connection is established before the current is broken. More specifically soft HO only refers to a HO between two cells with different BSs. The UE consumes double amount of bandwidth in a soft HO compared to a hard HO, because it is connected to two cells during the HO.

3. Softer HO is almost the same as soft HO, but softer refers to a HO between two cells of the same BS. Naturally the UE consumes double amount of resources in a softer HO compared to a hard HO as well.

In LTE there is only hard HO in use, mainly because of the complexity and the waste of resources in soft and softer HO [1]. Therefore hard HO is the focus for the simulations and as of now hard HO is what is meant by HO if nothing else is stated. Because hard HO is the focus this also means that the estimation of when the HO should be made is even more important because the connection is broken before a new connection is established.

Another important aspect of the HO is if the HO is intra- or inter-frequency. As mentioned in Section 2.2 the UE can search for cells on different frequencies than the one currently used communicating with the serving cell. These HOs to other frequencies are called inter-frequency HOs. HOs within the same frequency are called intra-frequency HOs.

2.3.1 Handover events

The UE measures the RSRP periodically and takes action on these measurements when the events below occur. There are six defined events within LTE that can be used to decide when the UE should take action. Each event has at least one entering condition and one leaving condition, these conditions defines when the event starts and ends. The six defined HO events are the following [7]:

Event A1

The A1 event occurs when the signal measurement of the serving cell becomes better than a certain threshold and the hysteresis (*Hys*) combined. The same event is left when the measurement of the serving cell combined with the *Hys* becomes worse than the same threshold. An example of the entry and exit of an A1 event can be seen in Figure 3.2 and the entering condition is defined as

$$M_s - Hys > Thresh$$

and the leaving condition is defined as

$$M_s + Hys < Thresh,$$

where M_s is the value of the serving cell measured in dBm if RSRP is used or in dB in case of RSRQ and Reference Signal - Signal to Interference and Noise Ratio (RS-SINR). *Hys* is the hysteresis expressed in dB and *Thresh* is the threshold measured in the same unit as M_s.

Event A2

When the measurement of the serving cell and *Hys* combined becomes worse than the threshold an A2 event is entered. When the serving cell measurement is better than the *Hys* and threshold combined the leaving condition is fulfilled and the event is left. This can be seen in Figure 3.3 and the entering condition is defined as

$$M_s + Hys < Thresh$$

and the leaving condition is defined as

$$M_s - Hys > Thresh,$$

where M_s is the value of the serving cell measured in dBm if RSRP is used or in dB in case of RSRQ and RS-SINR. *Hys* is the hysteresis expressed in dB and *Thresh* is the desired threshold measured in the same unit as M_s.

Event A3

When a neighboring cell becomes (offset, a value) better than the serving cell and *Hys* combined the A3 event's entering condition is met and the event is entered. If the neighboring cell, offset and *Hys* combined becomes worse than the serving cell with its offset the event is left, as the leaving condition is met. The entering condition is defined as

$$M_n + O_{fn} + O_{cn} - Hys > M_p + O_{fp} + O_{cp} + Off$$

and the leaving condition is defined as

$$M_n + O_{fn} + O_{cn} + Hys < M_p + O_{fp} + O_{cp} + Off,$$

where M_n is the measurements of the neighboring cell, measured in dBm if RSRP is used or in dB in case of RSRQ and RS-SINR. O_{fn} is the frequency specific offset and O_{cn} the cell specific offset, both of the neighbor cell, expressed in dB. M_p is the measurement of the PCell/PSCell, measured in dBm if RSRP is used or in dB in case of RSRQ and RS-SINR. O_{fp} is the frequency specific offset and O_{cp} the cell specific offset, both of the PCell/PSCell, expressed in dB. *Off* is the offset parameter for the event and is expressed in dB. In the Figure 3.4 where an A3 event can be seen, the event offset is the only offset used.

Event A4

An A4 event is entered when a neighboring cell becomes better than threshold and *Hys* combined. The event is left when the neighboring cell and *Hys* combined are worse than the threshold. The entering condition is defined as

$$M_n + O_{fn} + O_{cn} - Hys > Thresh$$

and the leaving condition is defined as

$$M_n + O_{fn} + O_{cn} + Hys < Thresh,$$

where M_n is the measurements of the neighboring cell, measured in dBm if RSRP is used or in dB in case of RSRQ and RS-SINR. O_{fn} is the frequency specific offset and O_{cn} the cell specific offset, both of the neighbor cell, expressed in dB. *Hys* is the hysteresis expressed in dB and *Thresh* is the threshold measured in the same unit as M_n.

Event A5

An A5 event is entered when two entering conditions are fulfilled. First the serving cell and *Hys* combined become lower than the first threshold and secondly the neighboring cell becomes higher than a second threshold and *Hys* combined. An A2 event followed by an A5 event can be seen in Figure 3.5. The A5 event is left if either serving cell becomes higher than the sum of the first threshold and *Hys* or if the sum of the neighboring cell and *Hys* becomes lower than the second threshold. The entering conditions are defined as

$$M_p + Hys < Thresh_1$$

and

$$M_n + O_{fn} + O_{cn} - Hys > Thresh_2$$

and the leaving conditions are defined as

$$M_p - Hys > Thresh_1$$

and

$$M_n + O_{fn} + O_{cn} + Hys < Thresh_2,$$

where M_p is the measurement of the PCell/PSCell and M_n is the measurements of the neighboring cell, both measured in dBm if RSRP is used or in dB in case of RSRQ and RS-SINR. O_{fn} is the frequency specific offset and O_{cn} the cell specific offset, both of the neighbor cell, expressed in dB. *Hys* is the hysteresis expressed in dB. $Thresh_1$ is the first threshold and is expressed in the same unit as M_p and $Thresh_2$ is the second threshold and is expressed in the same unit as M_n.

Event A6

When a neighboring cell's measurement become higher than the sum of the serving cell's measurement, the offset and the *Hys*, an A6 event is entered. If the sum of the same neighboring cell's measurement and the *Hys* becomes lower than the sum of the serving cell's measurement and the offset, the leaving condition is fulfilled and the event is left. The entering condition is defined as

$$M_n + O_{cn} - Hys > M_s + O_{cs} + Off$$

and the leaving condition is defined as

$$M_n + O_{cn} + Hys < M_s + O_{cs} + Off,$$

where M_n is the measurements of the neighboring cell and M_s is the measurement of the serving cell, both measured in dBm if RSRP is used or in dB in case of RSRQ and RS-SINR. O_{cn} us the cell specific offset of the neighbor cell, expressed in dB. *Hys* is the hysteresis expressed in dB. O_{cs} is the cell specific offset of the serving cell and is expressed in dB. *Off* is the offset parameter for the event and is expressed in dB.

General parameters

Time to trigger (TTT) is another important parameter for these events. Time to trigger is the time the enter condition of the event must be fulfilled before the UE takes action. Since the actions should not be based on too temporary conditions this is important. But at the same time a too long time to trigger can lead to decisions being taken too late by the UE. What action to take is configurable but the entering of an event always results in a measurement report sent by the UE to the eNB to inform the eNB of the status of the UE. Besides sending the measurement report the event can also trigger a HO-request or starting/stopping inter-frequency measurements [1].

Offsets are used rather widely within this area and can sometimes be seen as a kind of safety margin, e.g., when a HO should be made without resulting in a radio link failure. The cell can also add an offset to the measurement result in case the cell is heavy loaded as a kind of load balancing. This way the well populated cells can spread their UEs to adjacent cells.

The UE does not make any difference in which eNBs that are available, the only thing that matters is what cells are found and if they are better than current cell. The UE can choose to make a HO to a different cell at the same eNB or to another eNB, the only thing that matters are the results of the measurements and which events (A1-A6) they trigger.

2.3.2 Handover failures

Whenever a HO decision is wrong there is a big risk that the HO process will result in a Handover failure (HOF). When that happens the UE chooses to either reconnect to the previous serving cell or to another neighboring cell. In LTE there are three different HOF [11][12][13][14]:

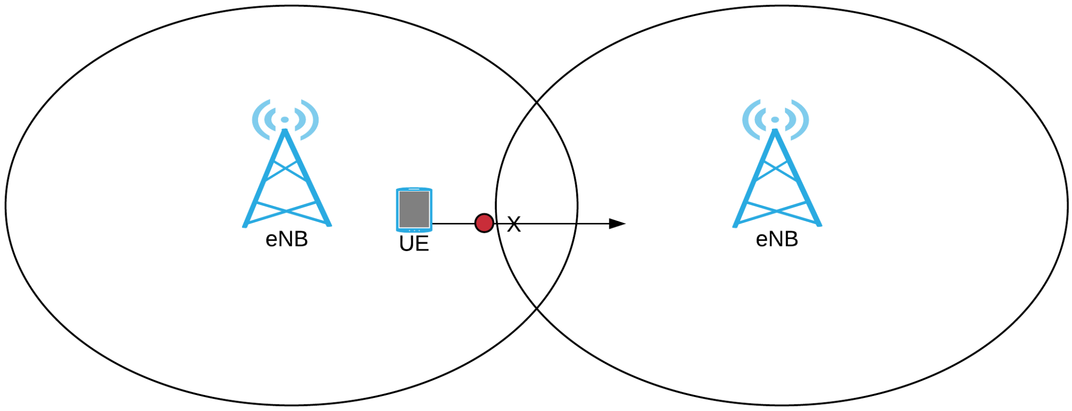


Figure 2.2: A too early HO. The arrow from the UE represents the UE's moving pattern, the x represents radio link failure and the red dot represents a HO.

1. Too early HO usually happens when the value of time to trigger is too low. The HO happens to early and could possibly result in a radio link failure if not the UE performs a HO back to original cell. This procedure can be seen in Figure 2.2.
2. Too late HO usually happens when the value of time to trigger is too high. The HO happens too late and results in a radio link failure. This procedure can be seen in Figure 2.3.

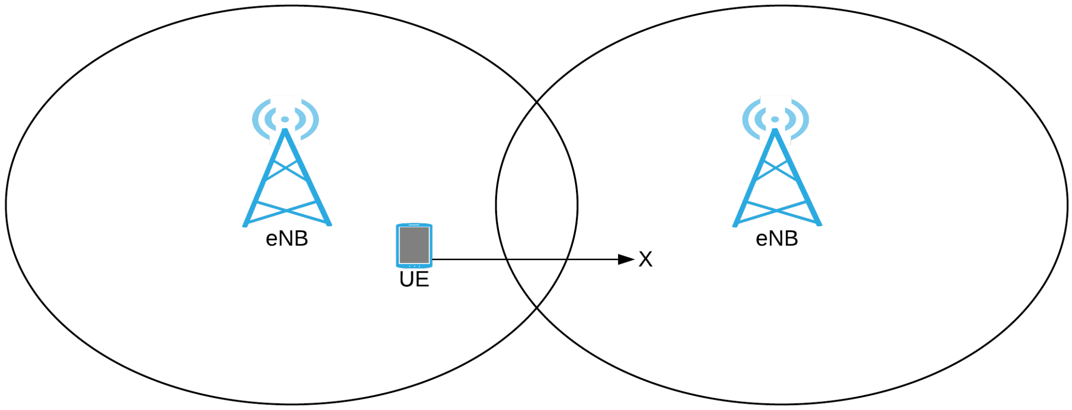


Figure 2.3: A too late HO. The arrow from the UE represents the UE's moving pattern, the x represents a radio link failure.

3. HO to wrong cell involves three cells: the serving cell, the targeted cell and the reconnecting cell. The UE performs a HO to the target cell from the serving cell but it results in radio link failure and the UE reconnects to the third cell. This procedure can be seen in Figure 2.4.

These three are the HOF that can result in a radio link failure but because a HO is

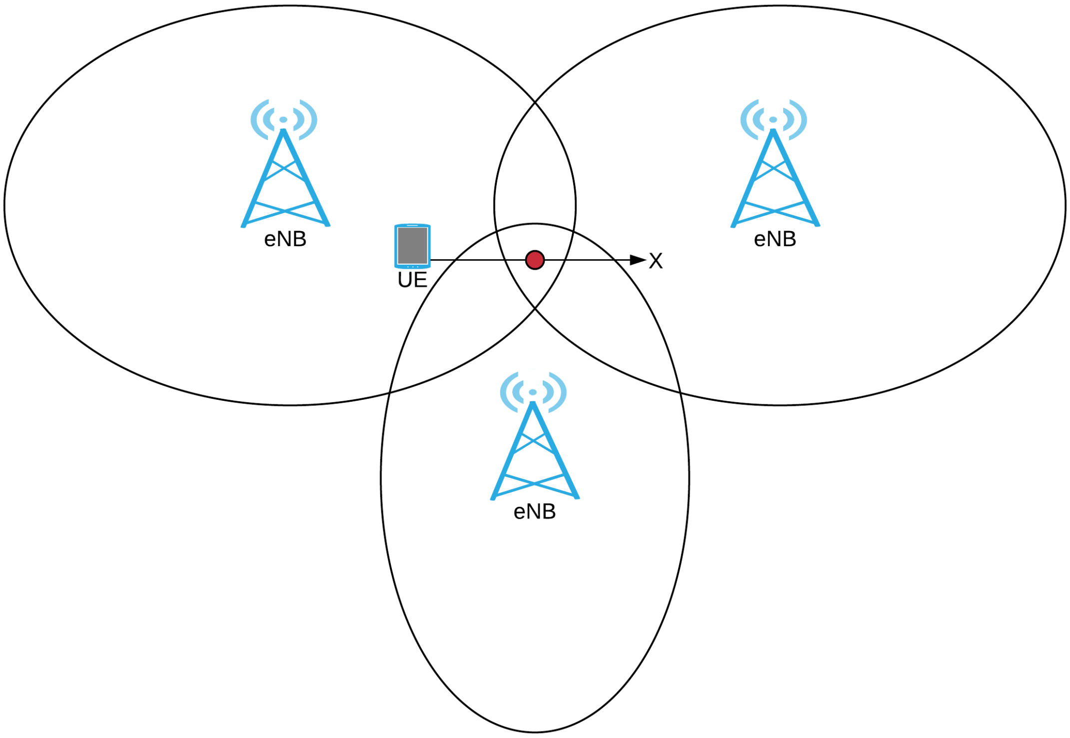


Figure 2.4: A HO to the wrong cell. The arrow from the UE represents the UE's moving pattern, the x represents a radio link failure and the red dot represents a HO.

resource consuming it is desired to avoid another problem called Ping-Pong HO. The Ping-Pong HO happens when a UE moves near the edge of a eNB which can cause a lot of back and forth HO between the serving cell and neighboring cells [11][12][13][14]. See Figure 2.5.

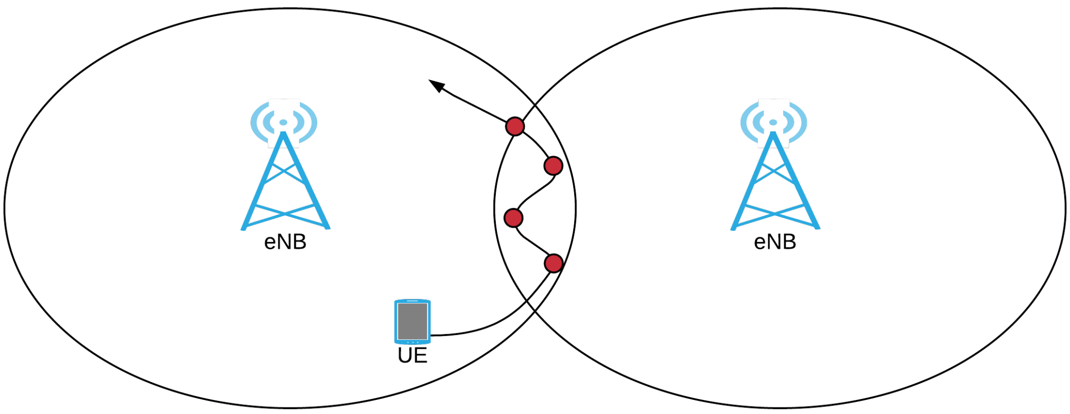


Figure 2.5: Ping-Pong HO. The arrow from the UE represents the UE's moving pattern, the red dot represents a HO.

2.4 Self-Organizing Networks

As the size and complexity of cellular networks such as LTE increases, it is more challenging to handle deployment and maintenance. Therefore there is a need for a network that can configure and maintain itself, a network like that is called Self-Organizing Network (SON). SON consists of three different processes [1][14]:

1. Self-configuration, which is the networks ability to automatically configure a newly deployed cell to fit into the existing network.
2. Self-optimization, which is when the eNB's and the UE's measurements are used for optimizing the configurations automatically to improve the network performance.
3. Self-healing, which refers to the networks ability to detect fault, diagnose fault and to recover from fault.

The self-optimization component uses, among other things, optimization of the HOs by configuring the parameters in the different events (A1-A6) described in Section 2.3 [14]. This is also the component the authors are trying to improve; a better estimation of when the HO should be made that are based on the measurements of the UE, will lead to better self-optimization.

2.5 Quality of Service

As stated in problem statement 3 in Chapter 1.2 QoS factors from a UE point of view are used to evaluate the results. The QoS factors that are considered in this work are:

- The downlink throughput, a measurement made by the UE of how much data it can receive, which should be at its highest at all times.
- HOF, when a HO goes wrong and the connection is lost. It is not desirable as the UE cannot send or retrieve data during a HOF and must also reestablish the connection. This influences the throughput and signaling load in a negative way.
- Inter-frequency measurements, time spent measuring inter-frequency. This is connected to problem statement 3 in Chapter 1.2. The goal is to lower the time spent because during this time there cannot be any regular transmissions between the UE and the eNB.
- Late A2 measurement reports, reports that arrive later than the time needed to prepare for an inter-frequency HO. The authors believe this is important because the number of late A2 measurements reports is strongly correlated to HOFs. More details about late A2 measurements reports can be found in Chapter 4.2.

These four factors were measured and reviewed after each of the simulations and represented the quality factors that we aim to improve. Except for these four factors there were two other things that were measured during the simulations: number of HOs and triggered events. These were not the most important factors but a big increase of HOs was not desirable as the procedure is time consuming and no regular transmissions between the UE and eNB can be made during this time.

Chapter 3
System Description

In this chapter the simulation environment is described both in terms of cell deployment and how the different events are used. The parameters that change between the different experiments are described later on in Chapter 4 where the experiments are described.

3.1 Environment

The chosen simulation environment is defined and used within 3GPP with the purpose to resemble different common scenarios from reality. The cell deployments as a whole is far from the reality, but functions as a good environment for a study such as this thesis. More specifically two different macro-cell deployments have been chosen which are called case 1 and case 3. Case 1 represents a deployment where the distance between the sites are 500 m. Case 3 have a distance of 1732 m between the sites (inter-cell distance) [15]. The cell deployments have 7 sites each and each site has 3 sectors. Each sector has 2 macro-cells which uses one carrier frequency each, 2.14 GHz and 0.88 GHz. This results in a total of 42 cells and an overview of case 1 and case 3 is seen in Table 3.1.

Table 3.1: Features of the cell deployment in case 1 and case 3.

Cell deployment - Case 1 / Case 3	
Inter-Cell Distance	500 m / 1732 m
Number of sites	7
Sectors per site	3
Cells per sector	2
Total number of cells	42
Carrier frequency	2.14 GHz & 0.88 GHz

In case 1 and case 3 the speed of the UE was specified to 3 km/h but since different speeds were essential for the evaluation in this thesis, the speeds 3, 30, 120 and 350 km/h have been chosen. These speeds have been established as standard speeds when testing mobility by 3GPP [16]. The speed of the UE changed between the different iterations of the simulation but within the iteration the speed remained the same for all of the UEs. The UEs move in a straight line with a random start location and direction. The first connection the UEs does is always to a cell with a carrier frequency of 2.14 GHz, the reason for this is to create scenarios where inter-frequency HOs are favorable. This is based on the fact that a high frequency signal does not propagate as good as a low frequency signal and therefore an inter-frequency HO can offer the UE a better cell as they move away from the sector. An example of a newly connected UE and its HOs can be seen in Figure 3.1.

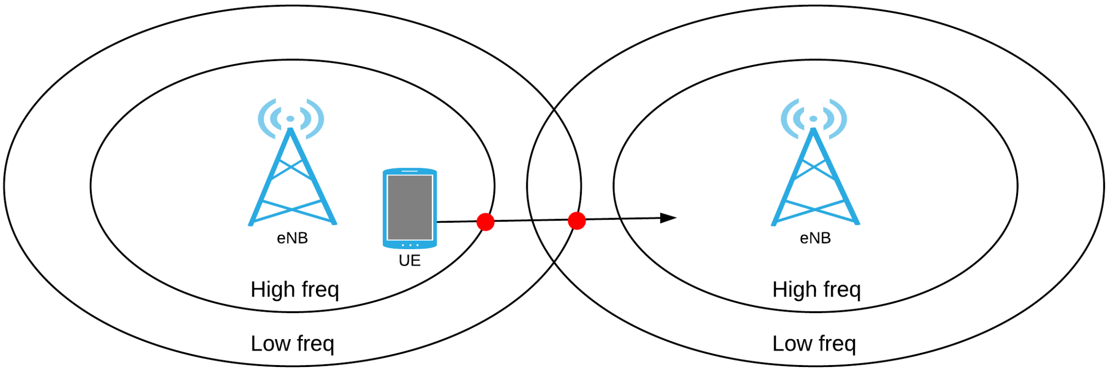


Figure 3.1: The environment contains two frequencies, the low frequency reaches longer than the high. When the UE is moving it makes two HOs, the first red dot shows an inter-frequency HO (from high to low) and the second dot an intra-frequency HO (within low).

The simulations run for 40.5 seconds and in each simulation there are 30 UEs moving around. The reason for using a relatively small amount of UEs is to avoid possible interference between the UEs. The interference could influence the results in undesired ways which is not related to the algorithm itself. Therefore to ensure that enough data is provided to create statistical significance, each simulation runs with 100 different seeds. In conclusion, there are four iterations for each simulation where the speed of the UE is varied, each of the iterations have 30 UEs and run with 100 different random seeds. This results in data from 3000 UEs for each of the iterations and 12000 UEs for each simulation. An overview of the general settings used by all simulations (if nothing else is stated) can be seen in Table 3.2.

Table 3.2: Settings used by all simulations.

General settings	
Simulation time	40.5 s
Seeds per iteration	100
UEs per iteration	30
UE speeds	3, 30, 120, 350 km/h

3.2 Event procedures

As mentioned in Section 2.3.1 there are some events defined to determine what action the UE should take, which are configurable. The configuration that is used in the simulations can be seen in Table 3.3.

Table 3.3: Event settings.

Event Settings	
A1	Deactivate inter-frequency measurements
A2	Activate inter-frequency measurements
A3	Intra-frequency HO
A4	Not used
A5	Inter-frequency HO
A6	Not used

In this configuration some of the events are dependent on other events and some are independent. An A1 event can only trigger after an A2 event, because otherwise there is no inter-frequency measurements to deactivate. After an A1 event has triggered the A2 event can trigger again. An A5 event can also only trigger after an A2 event because the inter-frequency measurements are needed to fulfill the entering conditions of A5. Examples of each event procedure can be seen in the Figures 3.2, 3.3, 3.4 and 3.5. Take notice of that Figure 3.5 contains both an A5 event and an A2 event because of their important relation.

The thresholds, Hys and time to trigger for the events are configurable. The values for each of the parameters used in the simulations are shown in Table 3.4. The A5 threshold has been chosen based on the number of HOFs, which should be as low as possible. A lower threshold give a lower amount of inter-frequency measurements, which is a goal, but this also come with a higher number of HOFs, which is not desirable. The other thresholds have been chosen to fit together with the A5 threshold.

Table 3.4: Parameters related to the events and their values.

Event	Threshold (dB)	Hysteresis (dB)	Time To Trigger (s)
A1	-95	1	0.04
A2	-105	1	0.04
A3	3[1]	1	0.04
A5	-110, -100[2]	2	0.04

[1] The offset between serving cell and best cell.

[2] Serving cell threshold and best inter-frequency cell threshold.

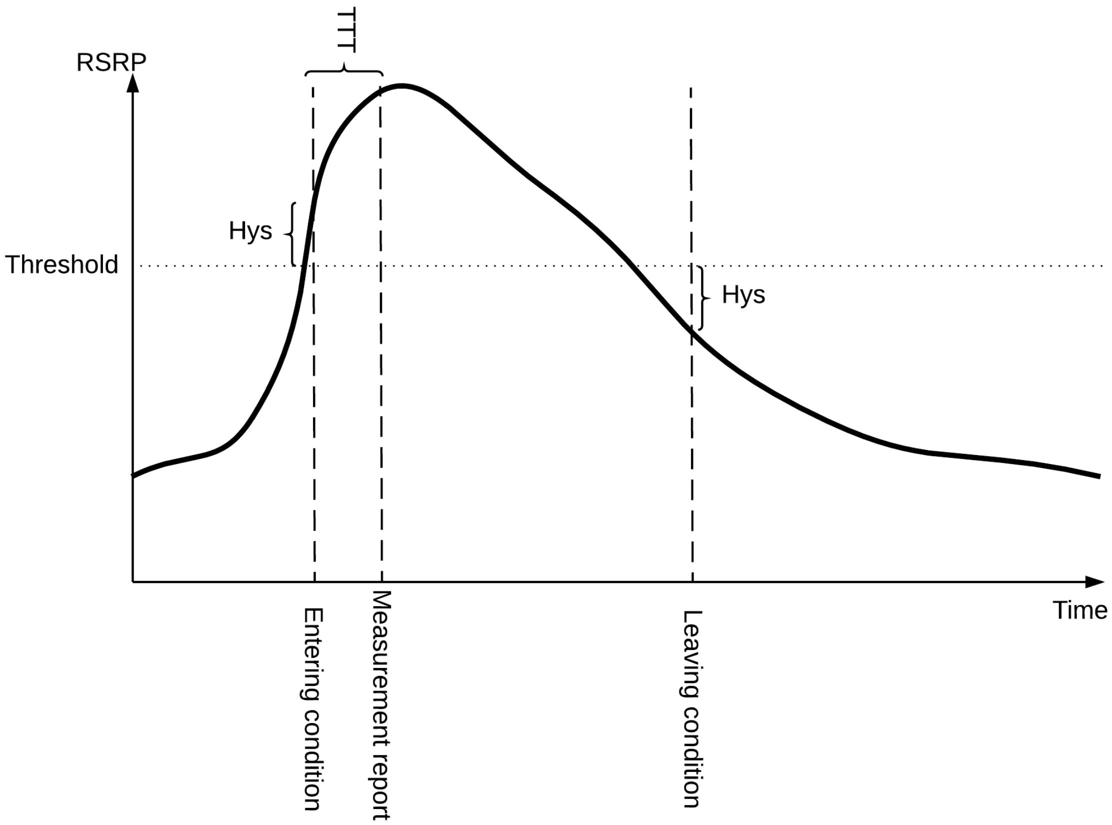


Figure 3.2: An example of an A1 event. The line represents the serving cells RSRP over time. Entering an A1 event occurs when the RSRP-value is greater than the specified threshold and Hys combined for a time period of time to trigger (TTT). Leaving the same event occurs instantly when a RSRP-value is Hys lower than the threshold.

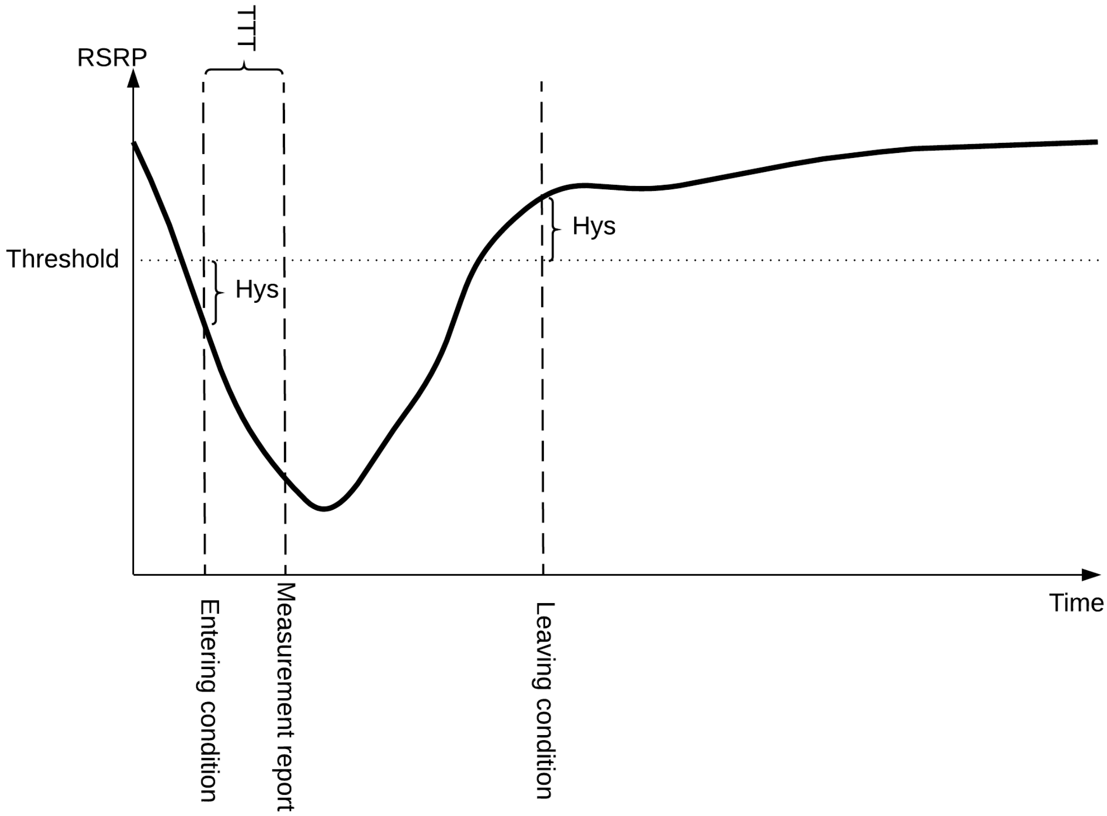


Figure 3.3: An example of an A2 event. The line represents the serving cells RSRP over time. Entering an A2 event occurs when the RSRP-value is lower than the specified threshold and Hys combined for a time period of time to trigger (TTT). Leaving the same event occurs instantly when a RSRP-value is Hys greater than the threshold.

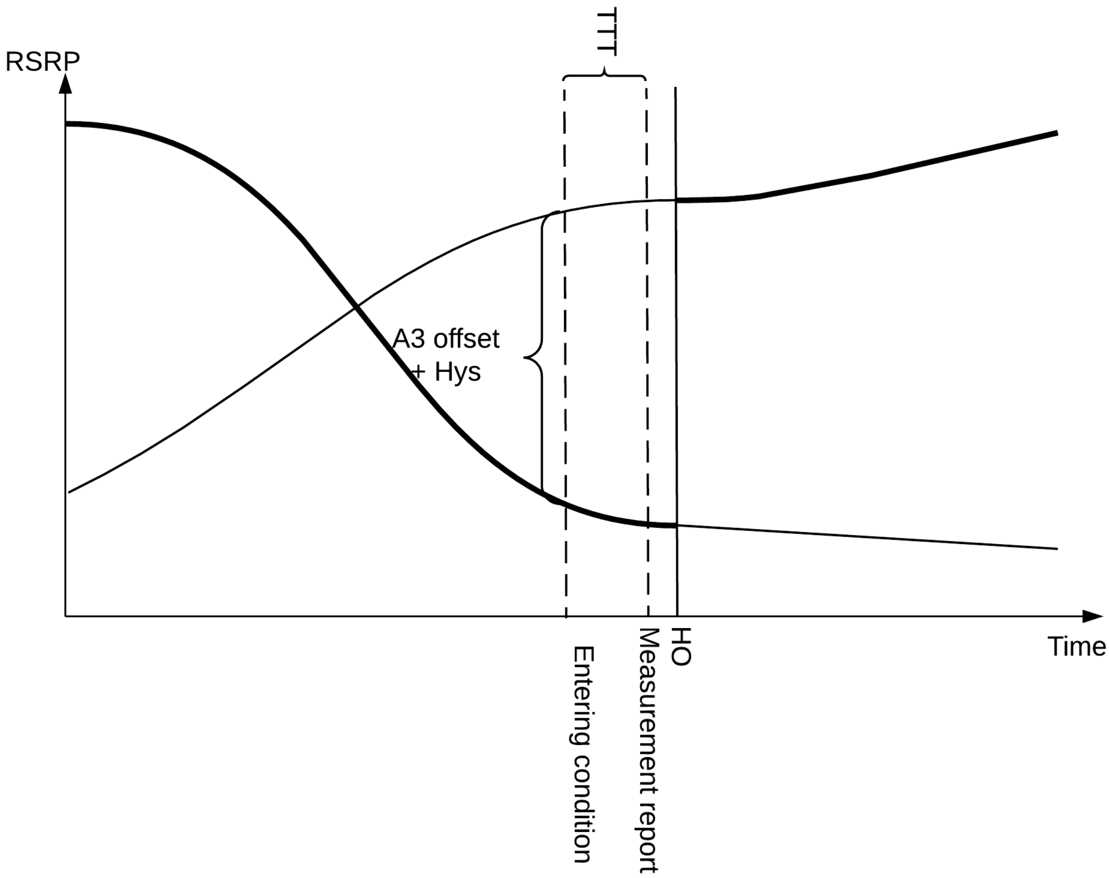


Figure 3.4: An example of an A3 event that results in a HO. The two lines represent two different cells RSRP over time. The bold line indicates if the cell is serving or not. The event occurs when the serving cell is offset and Hys combined lower than the best available cell with the same carrier frequency during the time period of time to trigger (TTT). When the event is triggered an intra-frequency HO is made.

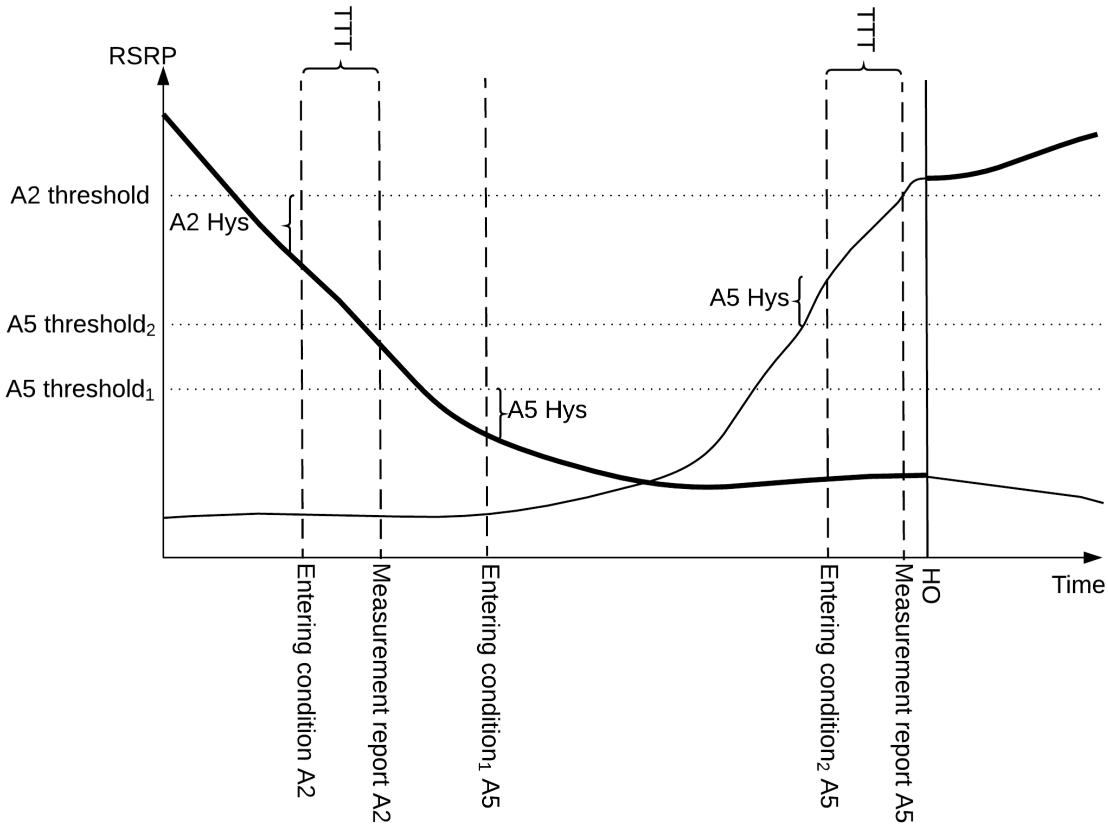


Figure 3.5: An example of an A2 event followed by an A5 event and a HO. The two lines represent two different cells RSRP over time. The bold line indicates if the cell is serving or not. The A2 event occurs and starts the inter-frequency measurements. An A5 event occurs when both entering conditions are satisfied for the duration of the time to trigger (TTT) time interval which results in an inter-frequency HO.

Chapter 4
Experiments

In this chapter the different simulations of the experiment are described more in detail with the different settings used.

4.1 Simulation 1 - Environment evaluation

In the first simulation the environment was evaluated to see if the inter-frequency measurements and HOs were used. The measurements looking for A1, A2 and A5 were turned off and compared to a simulation where they remained turned on. The environments evaluated were case 1 and case 3, as described in Section 3.1. Usually the simulations used 100 seeds to gain enough data but simulation 1 only used 10 seeds. The reason for this was that simulation 1 only was a small study of case 1 and case 3 to gain knowledge about the chosen cell deployments relation to inter-frequency measurements and HOs, therefore 10 seeds was sufficient in this case.

4.2 Simulation 2 - Negative gradient

During the simulations the main goal is to discover if it is possible at all in the simulator to find the gradient of the change in signal measured by the UE. This would be achieved by saving previous measurements and take one of those made measurements, not too far back in the history and calculate the difference between that measurement and the latest measurement. This result is divided by the difference in time between these measurements, in compliance with the expression

$$gradient = \frac{y_2 - y_1}{t_2 - t_1}, \tag{4.1}$$

where y is the RSRP-value in dB for the serving cell and t is the corresponding time measured in seconds. The calculation of the gradient is done every time a new measurement is made by the UE. Based on the gradient the current threshold is evaluated to see if it needs to be altered. All the calculations related to the algorithm are made in the UEs.

When the gradient is negative it can be used to estimate when the signal will hit a certain RSRP threshold value and thereby predict when the inter-frequency measurements should be started in order to have a candidate ready (if any available) when the HO should be made.

Instead of using the time for when the inter-frequency measurements should be turned on the threshold corresponding to that time is used. This is done by finding the time for when the inter-frequency measurements should start. Based on that time a new threshold can be calculated, which is in line with the latest measurement and the gradient from that measurement, as seen in Figure 4.1. There are two reasons for using the threshold instead of the time; the first reason is if the measured RSRP would suddenly change for the better, right before reaching the threshold, it would not result in a false-positive, sending a measurement report when not needed. The second reason is if the RSRP would suddenly change in the other direction, getting worse in an even faster pace. Then the new threshold would work as a kind of safety net, preventing the RSRP to become as low as it would have if waiting the corresponding intended time.

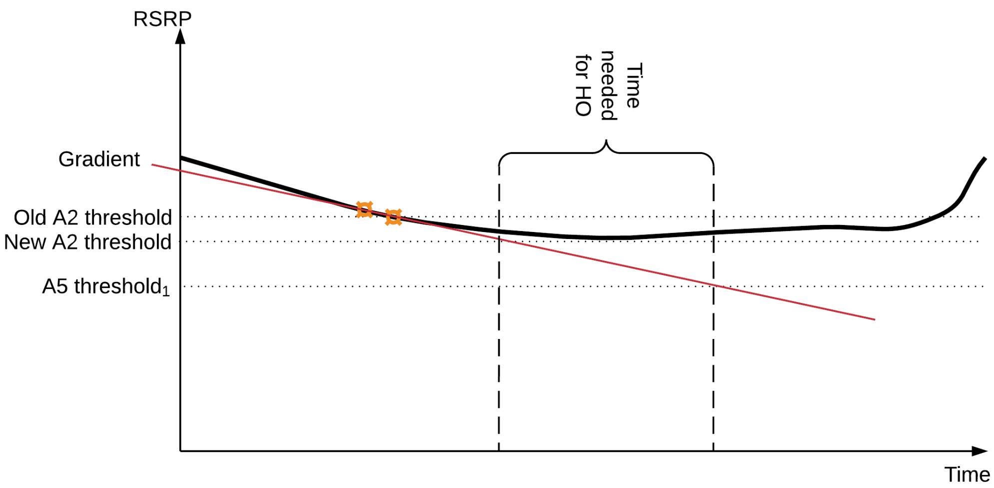


Figure 4.1: An example of how the gradient algorithm can avoid unnecessary inter-frequency measurements. The black line represents the serving cells RSRP over time. The two orange markers indicate the points in the graph that are used for calculating the gradient, which is plotted in red. The time interval shows the estimation based on the gradient plot where to put the new A2 threshold.

The goal of introducing the gradient algorithm has mainly two reasons. The first reason is to avoid turning on inter-frequency measurements when it is not needed, an example of this can be seen in Figure 4.1. As seen in the figure the algorithm calculates a new A2 threshold that is not reached. This results in avoiding turning on inter-frequency measurements, which in this case is not needed. The second reason is to be better prepared when

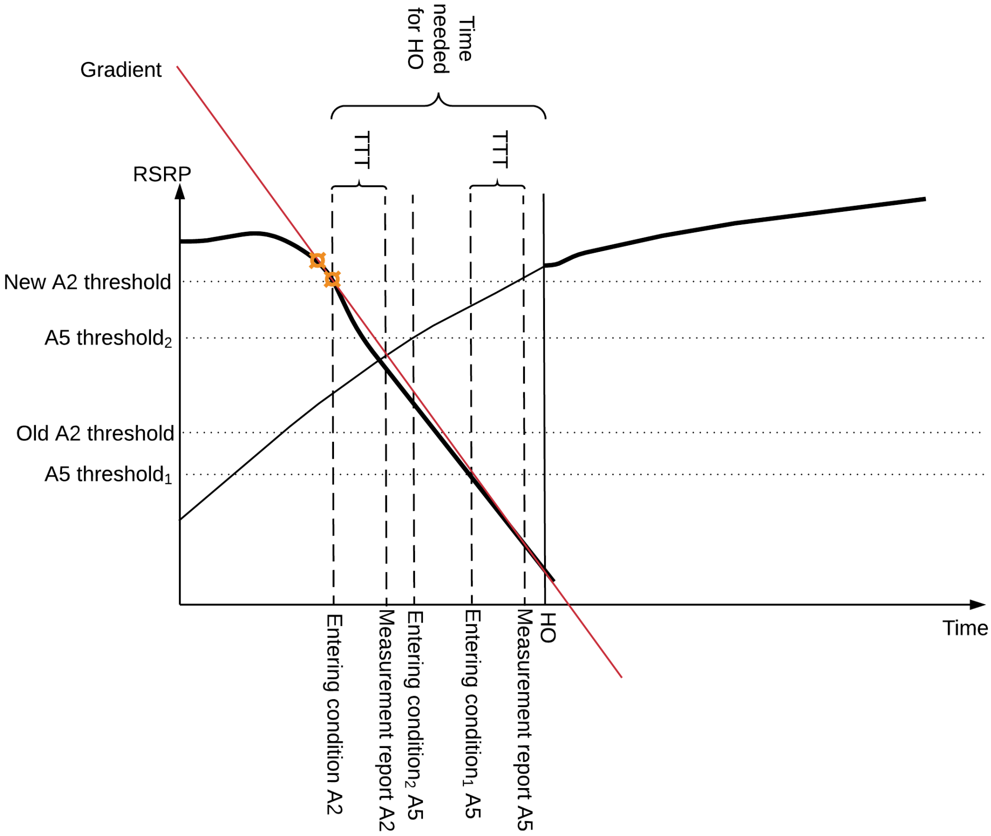


Figure 4.2: An example of how the gradient algorithm can trigger inter-frequency measurements earlier than without the algorithm. The two black lines represent two different cell's RSRP over time. The boldness of the line indicates if the cell is serving or not. The two orange markers indicate the points in the graph that are used for calculating the gradient, which is plotted in red. The time interval shows the estimation based on the gradient plot where to put the new A2 threshold. Take notice of that Hys in this figure is included in the thresholds and not displayed, to make the graph more legible.

the RSRP drops fast by turning on the inter-frequency measurements earlier. It was reasoned that this would lower the HOFs since some time consuming preparations are needed before an HO can be made, an example of this can be seen in Figure 4.2. As seen in the figure, the *RSRP* for the serving cell drops so fast that the old A2 threshold would probably not give enough time to perform the HO and would instead result in a HOF. With the algorithm this is avoided by turning on the inter-frequency measurements earlier. A2 measurement reports sent within the interval *Time needed for HO* (the interval is visible in both Figure 4.1 and Figure 4.2) are categorized as late A2 measurement reports. The reports inside this interval does not offer enough time to perform the HO at *A5 threshold*$_1$ as intended.

If the measurement is below the threshold the gradient should not be calculated, instead the inter-frequency measurements should be started directly. The same would occur if the calculated time to meet the threshold, based on the gradient, is shorter than the time needed to start the inter-frequency measurements and make a HO.

When deciding on the time interval between the measurements used in the algorithm it is reasoned that a too long time span would react slowly on sudden changes, but on the other hand a too short time span could possibly give exaggerated reactions to small changes. Therefore different time intervals are tested to determine the best time interval to use. The time intervals that are tested is 0.04 s, 0.25 s, 0.5 s, 0.75 s, 1 s, 1.25 s, 1.5 s, 1.75 s and 2 s. The shortest time interval, 0.04 s reflects the time between measurements made by the UE in the simulator, giving the gradient between the latest and the second latest measurement. The reason for not testing more, longer intervals is due to the fact that the difference between the longer intervals became too small.

Apart from doing simulations where the algorithm is tested, a simulation is made where no algorithm is introduced, called a baseline. This baseline is used to make comparisons between the simulations to see if the algorithm introduces an improvement.

4.3 Simulation 3 - Positive gradient

In this simulation it is reasoned that if the gradient is positive for a certain amount of time the signal is getting better even though the threshold for deactivating the inter-frequency measurements has not been met. Thus a measuring report should be sent, signaling that the UE could stop its inter-frequency measurements. If the measurement already reached the threshold the gradient should not be calculated. When the gradient is calculated, it is calculated the same way as in Equation 4.1.

As described in Section 4.2 different time intervals are also tested in this experiment to determine the interval which give the best results. The results were compared to the baseline. A significant difference between this experiment and the former is that the UEs do not have a time consuming HO to prepare for, which is an important part of the algorithm (see *Time needed for HO* in Figure 4.1 and Figure 4.2). This open up for a possibility to try how much earlier the A1 event should trigger (instead of using the *Time needed for HO*) to minimize the time spent measuring inter-frequency, without compromising other important factors. It can be reasoned that an earlier A1 event should lead to less time spent measuring inter-frequency, but an too early A1 event would probably lead to turning off inter-frequency measurements when they are needed, which is not wanted. It can also be reasoned that the time interval would not be needed at all and an alternative algorithm should be implemented for the positive gradient. The reason for not implementing an alternative algorithm is the relation between the A1 and A2 event, the leave event of A2 should match the enter event of A1 as they did originally (see Section 2.3.1).

To sum up, two different time intervals are modified for this experiment: the time interval between the measurements used in the algorithm and how early the A1 event should trigger. The changes in this simulation are not combined with the changes made in the second simulation. This way the effects of changing the behavior is not reduced, increased or modified in any other way by the other changes.

4.4 Simulation 4 - Gradients combined

The previous two simulations are combined in this simulation, using both the positive and the negative gradient. The positive gradient is used to determine when to quit the inter-frequency measuring and the negative is used to determine when to start the inter-frequency measurements.

There is one set of settings that are appointed as the best for the positive gradient (see Section 6.3). These settings are combined with all of the different intervals used for the negative gradient in order to try to find the best combination of positive and negative gradient usage. The reason for this is that the results from the negative gradient simulations are not as reassuring as the results from the simulations with positive gradient. The simulations with negative gradients do not have one simulation that is clearly better than the others when looking at both number of HOFs and amount of inter-frequency measurements in all of the UE's speeds.

To verify that the positive gradient simulation is the correct one to use two more simulations are made with a fixed interval at 0.5 s for the negative gradient. Since the used positive gradient interval is 0.04 s, the lowest possible, the two slightly larger intervals is used, 0.25 s and 0.5 s. All of the simulations are also compared to the baseline.

4.5 Simulation 5 - Worst case gradient

This Simulation is designed to try to minimize the number of HOFs rather than lowering the amount of inter-frequency measurements made by the UE. This is done by calculating two negative gradients, one based on the latest measurement combined with one measurement close in time. The second one use the latest measurement and a measurement a bit further back in time. Then it is assumed that the steepest negative gradient would always be correct and thus be used. Other than that the settings is the same as in Section 4.4, Simulation 4 - Gradient combined. The result is then compared to the baseline.

Chapter 5

Results

This chapter presents the results of each of the simulations made. As stated in Section 2.5 the main factor that have been focused on is what the difference in inter-frequency measurements have made to the result compared to the baseline. The other factors that have been considered are the number of HOFs, the average throughput and the number of late A2 measurement reports.

5.1 Simulation 1 - Environment evaluation

The results from using case 1 cell deployment were identical on every single value (throughput, HOF, HO and events triggered). The UEs in the simulation when A1, A2 and A5 measurements were turned off, managed to get along by only using A3 HOs.

The results from using case 3 cell deployment were very different. The simulation with A1, A2 and A5 measurements turned on had fewer HOFs and a great improvement in throughput, this can be seen in Figure 5.1 and Figure 5.2. Subsequent simulations used case 3 cell deployment and 100 seeds.

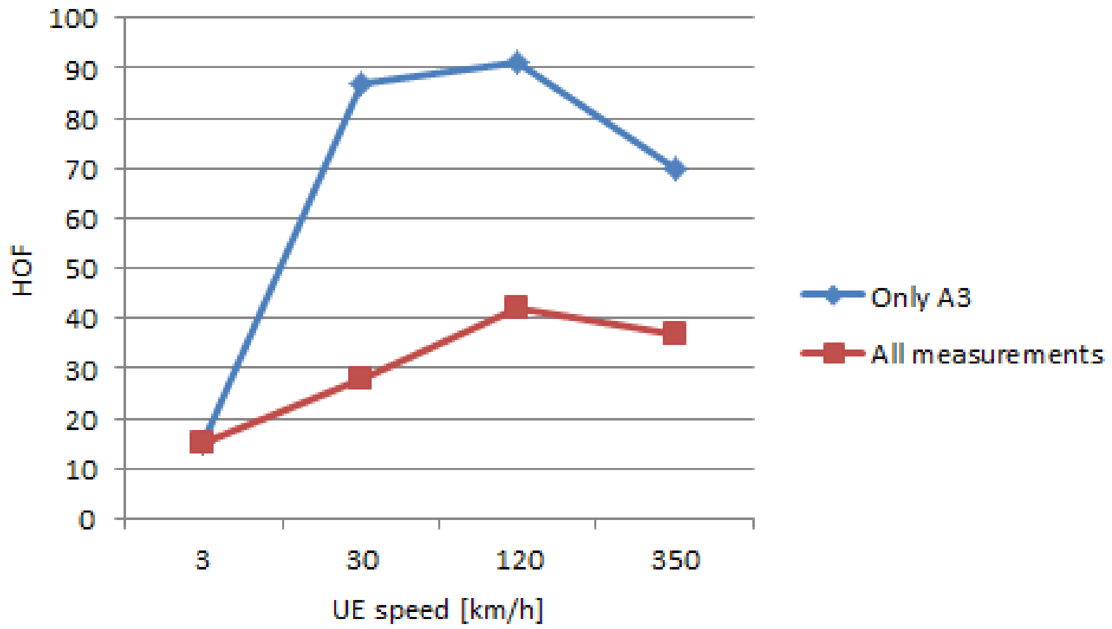


Figure 5.1: A comparison of the number of HOFs is shown when using cell deployment case 3 and 10 seeds from simulation 1.

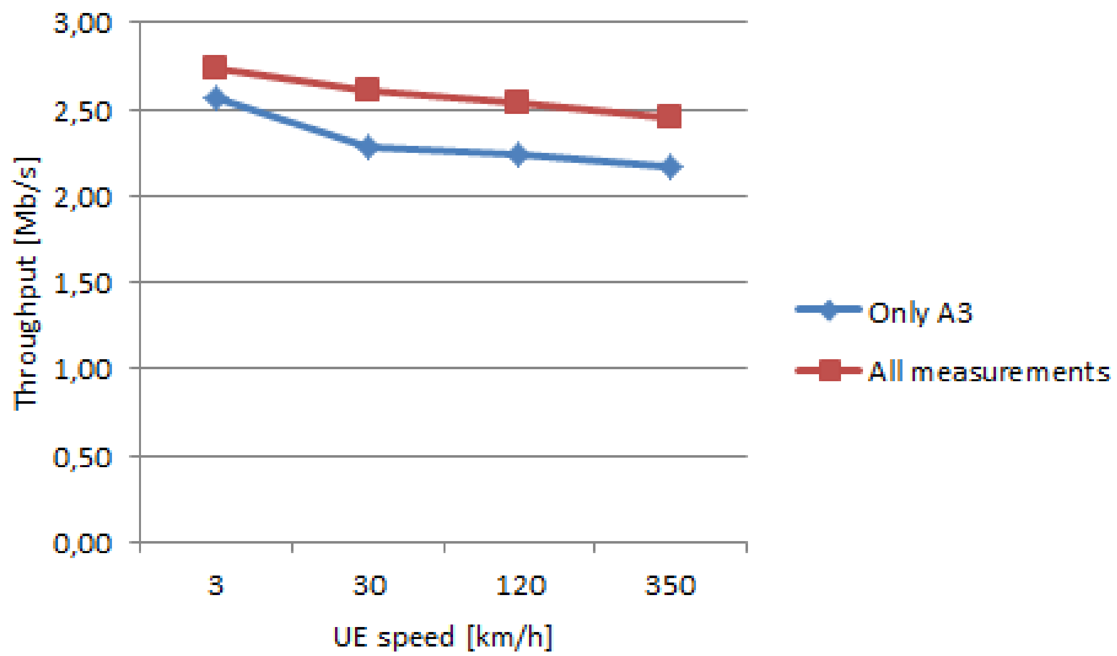


Figure 5.2: A comparison of average downlink throughput for the UEs are shown when using cell deployment case 3 and 10 seeds from simulation 1.

5.2 Simulation 2 - Negative gradient

The implementation of the gradient algorithm in the simulator's UE was successful. It was achieved by doing as described in Section 4.2. This allowed for performing the actual simulation using the negative gradient, finding the HO time and new threshold as described in Section 4.2.

The difference of the throughput between the different time intervals were very small, this can be seen in Figure 5.3. Inter-frequency measurements decreased with bigger time intervals, as seen in Figure 5.4. HOF varied a lot between the different time intervals and speeds of the UEs. Therefore the resulting HOFs are presented divided into the different UE speeds in the Figures 5.5, 5.6, 5.7 and 5.8. The number of late A2 measurement reports was also plotted in these figures.

The Figures 5.9, 5.10, 5.11 and 5.12 shows cumulative distribution functions. In the function the difference in time spent measuring inter-frequency between the baseline simulation and the algorithm using the 0.04 s gradient interval is shown. The cumulative distribution function describes the probability of assuming a value lower than or equal to the value on the *difference in time*-axis. This axis describes the difference in time spent measuring inter-frequency between the simulations. The result has been divided into the four different UE speeds and for each of the UEs the difference in total time measuring inter-frequency has been plotted. A value greater than zero indicates that the simulation with the 0.04 s gradient interval improved the amount of inter-frequency measurements by lowering it. The total time spent in the simulation was 40.5 s. These figures only illustrate the results when comparing to the 0.04 s interval, the other intervals gave very similar results and is not included in this section for this reason.

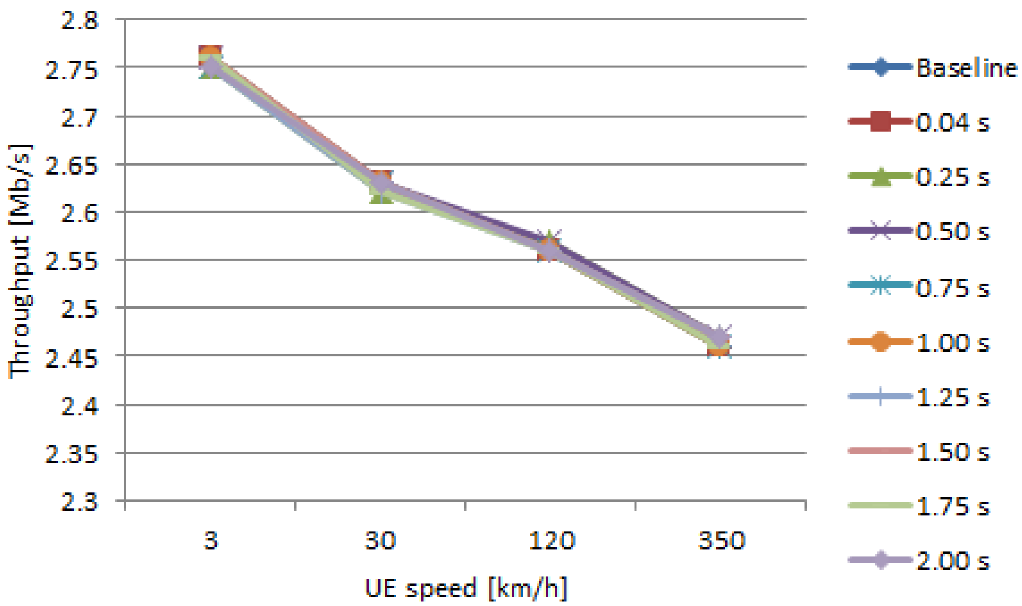


Figure 5.3: A comparison of average downlink throughput for the UEs is shown from each of the different time intervals.

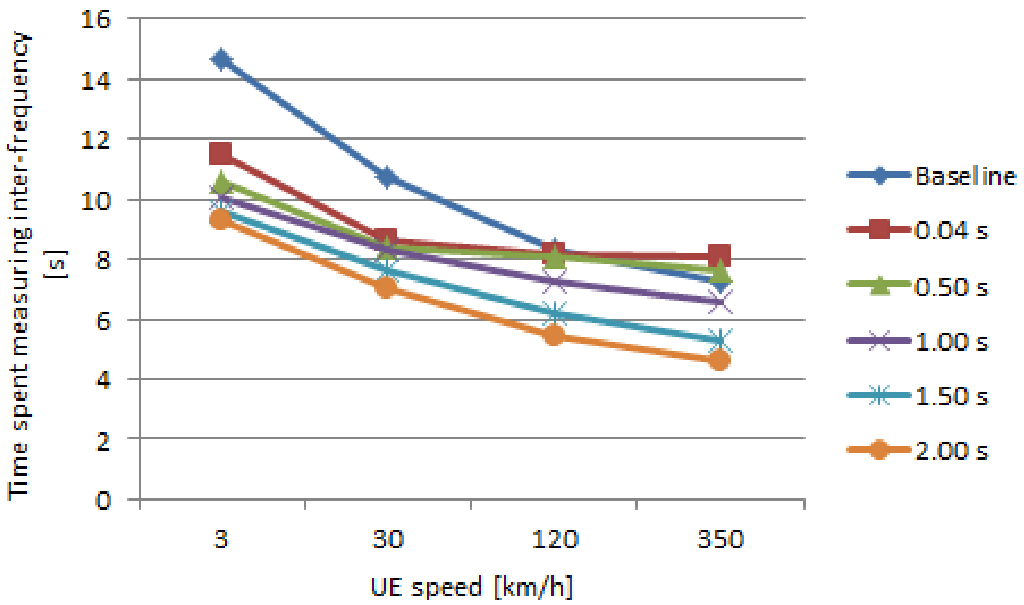


Figure 5.4: A comparison of average time spent measuring inter-frequency for the UEs are shown with different time intervals. For an easier read, not all intervals are shown. The missing intervals follow the pattern; bigger time interval has lower time spent measuring inter-frequency.

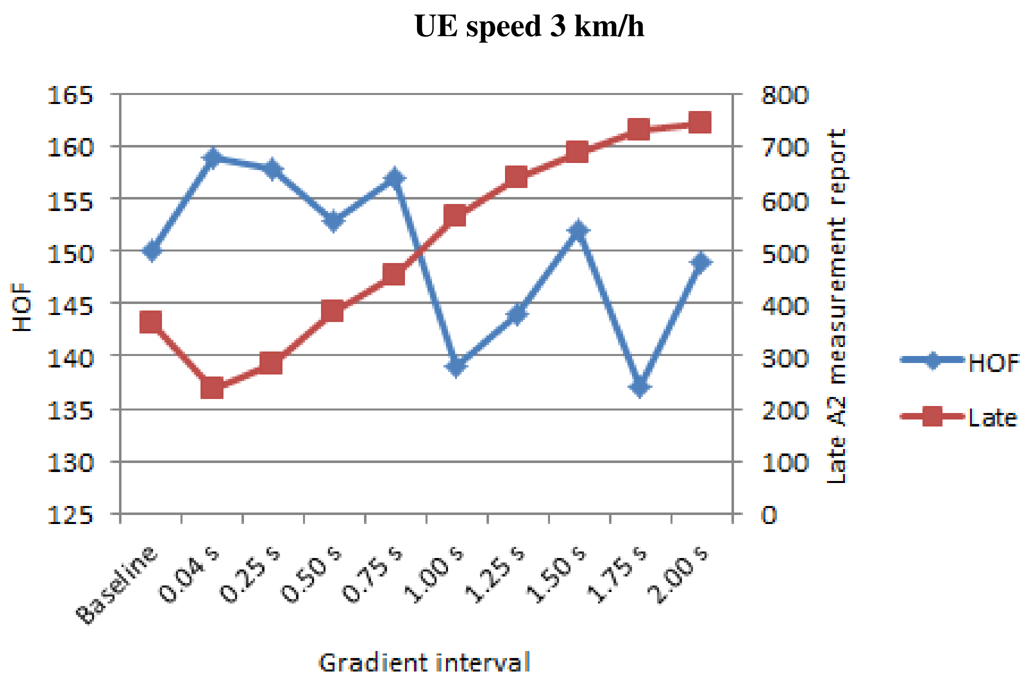


Figure 5.5: The result is from the UEs with the speed 3 km/h. HOFs and late A2 measurement reports are shown for the different time intervals.

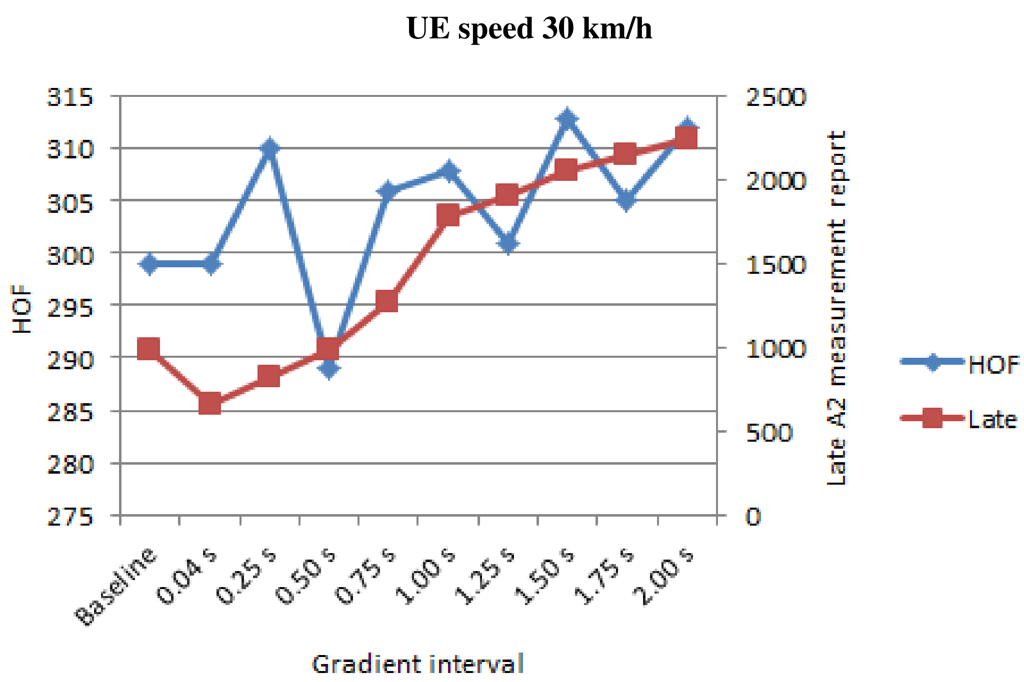


Figure 5.6: The result is from the UEs with the speed 30 km/h. HOFs and late A2 measurement reports are shown for the different time intervals.

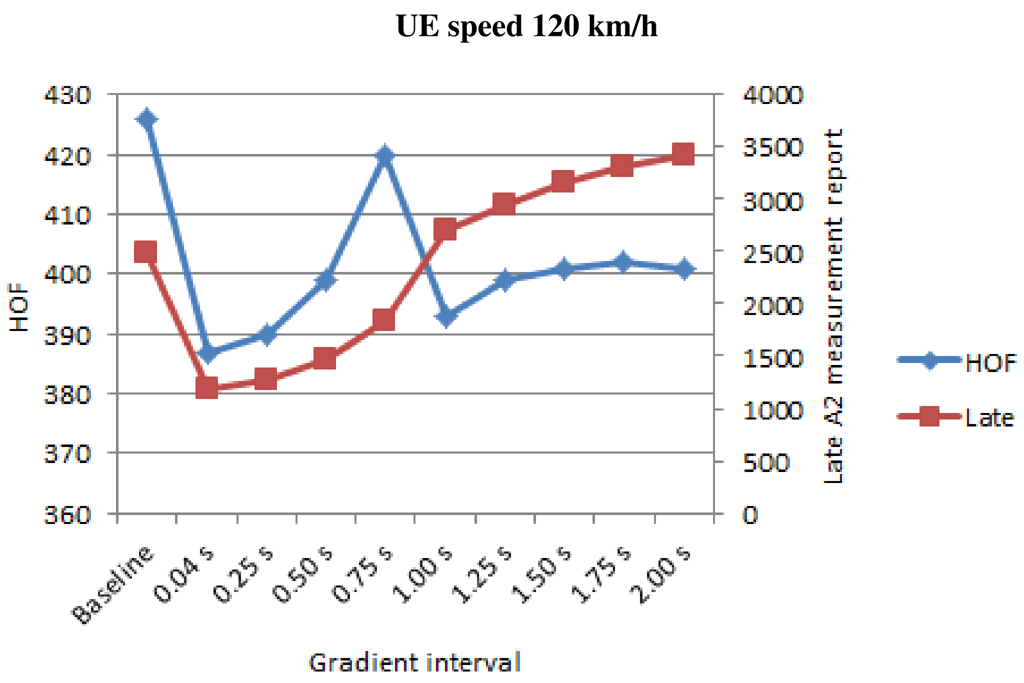


Figure 5.7: The result is from the UEs with the speed 120 km/h. HOFs and late A2 measurement reports are shown for the different time intervals.

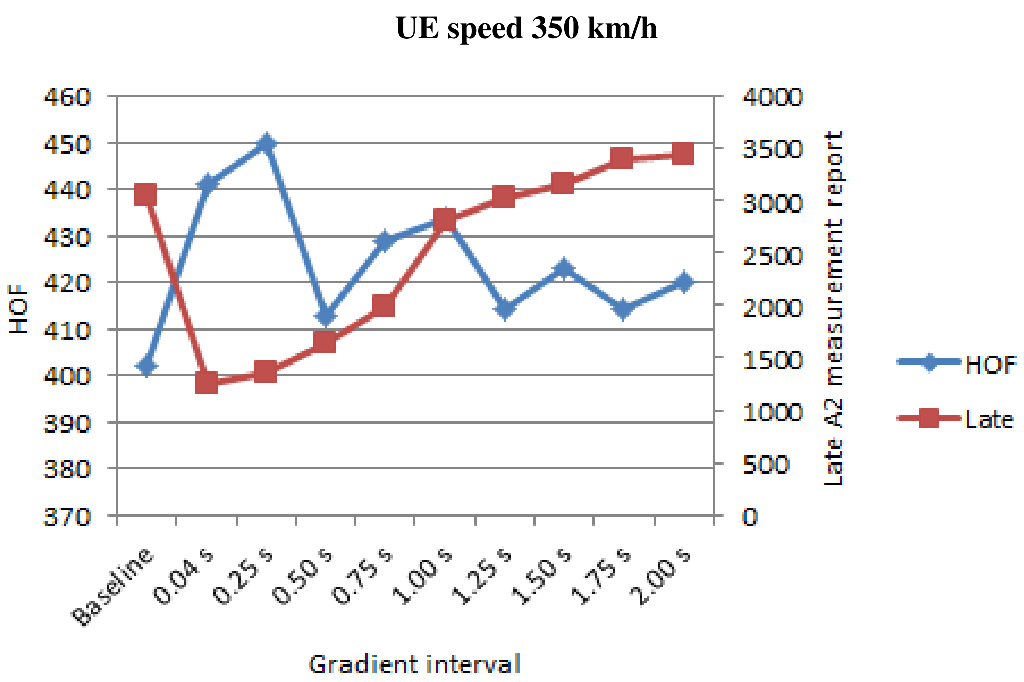


Figure 5.8: The result is from the UEs with the speed 350 km/h. HOFs and late A2 measurement reports are shown for different time intervals.

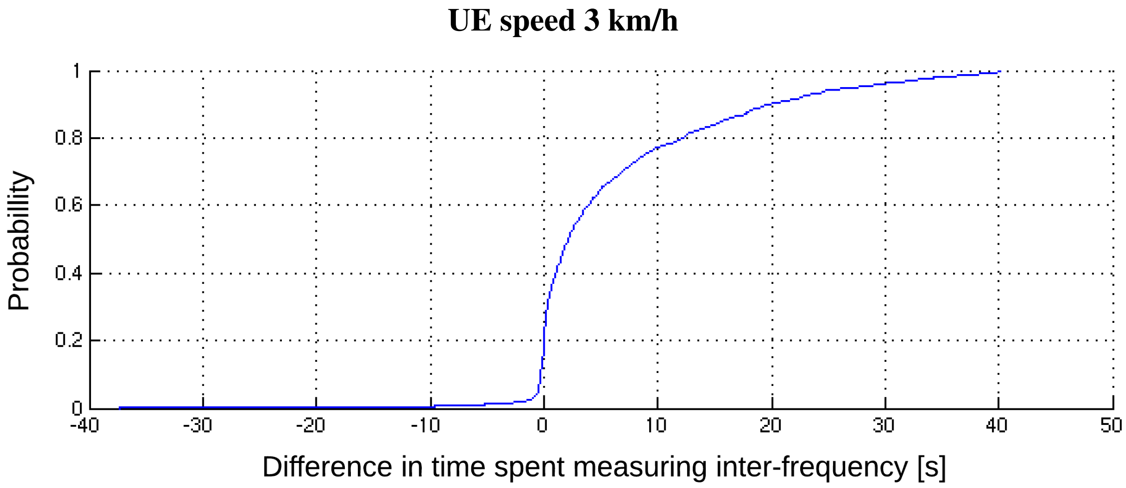


Figure 5.9: The cumulative distribution function of a comparison between the UEs with speed 3 km/h in the baseline simulation and with the algorithm, using the 0.04 s interval. The difference for each of the UEs in how much time it spent doing inter-frequency measurements. Positive value indicates better (lower amount of) inter-frequency measurements in the simulation using the algorithm.

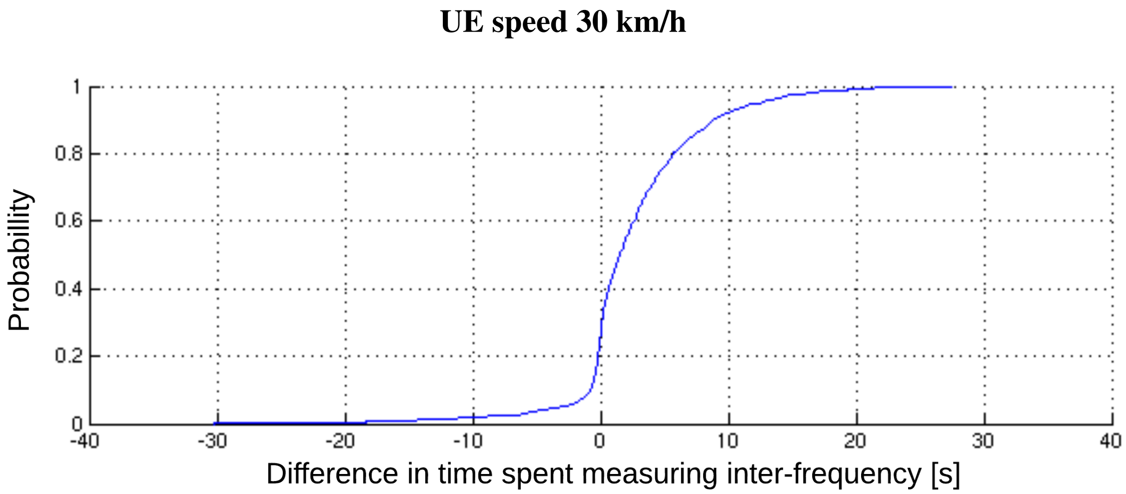


Figure 5.10: The cumulative distribution function of a comparison between the UEs with speed 30 km/h in the baseline simulation and with the algorithm, using the 0.04 s interval. The difference for each of the UEs in how much time it spent doing inter-frequency measurements. Positive value indicates better (lower amount of) inter-frequency measurements in the simulation using the algorithm.

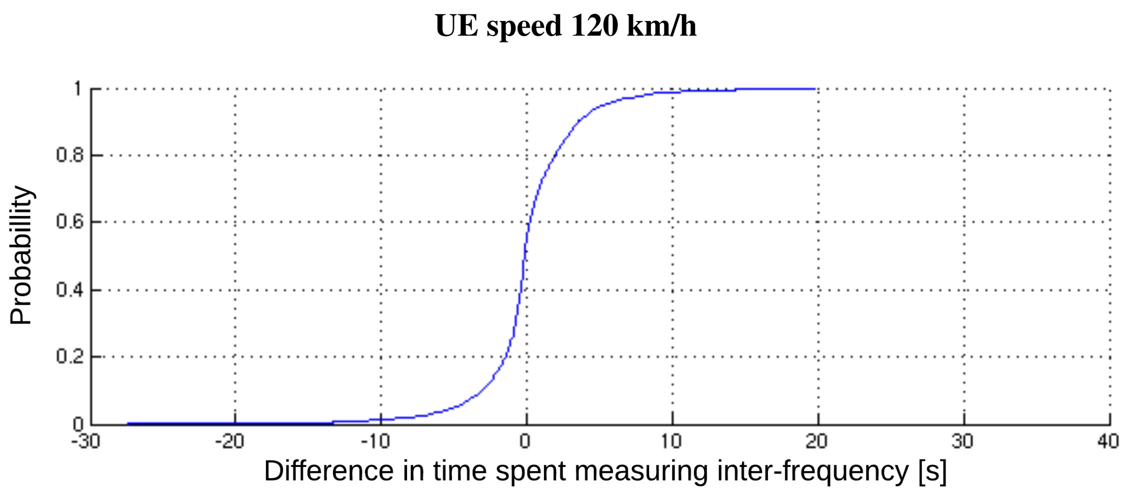


Figure 5.11: The cumulative distribution function of a comparison between the UEs with speed 120 km/h in the baseline simulation and with the algorithm, using the 0.04 s interval. The difference for each of the UEs in how much time it spent doing inter-frequency measurements. Positive value indicates better (lower amount of) inter-frequency measurements in the simulation using the algorithm.

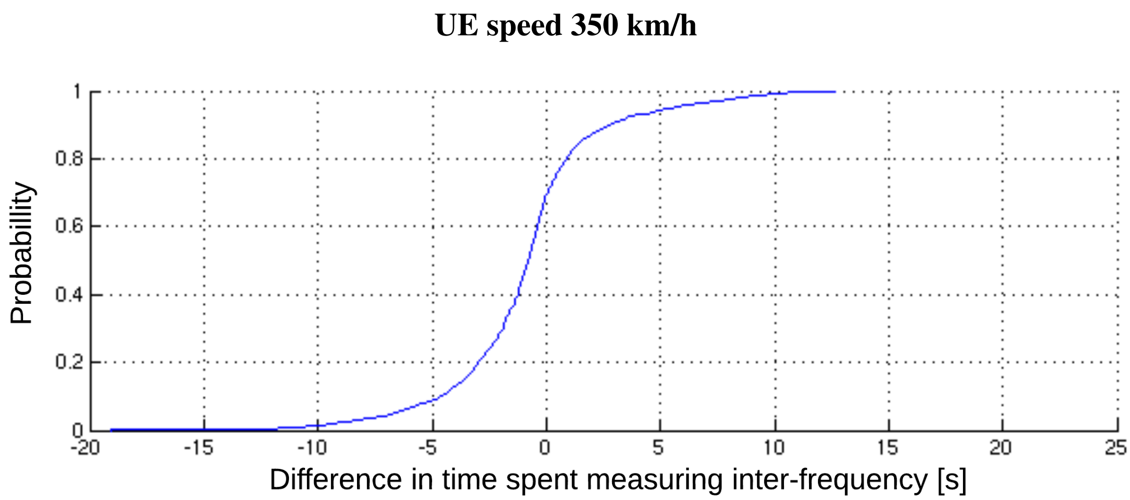


Figure 5.12: The cumulative distribution function of a comparison between the UEs with speed 350 km/h in the baseline simulation and with the algorithm, using the 0.04 s interval. The difference for each of the UEs in how much time it spent doing inter-frequency measurements. Positive value indicates better (lower amount of) inter-frequency measurements in the simulation using the algorithm.

5.3 Simulation 3 - Positive gradient

The outcome of trying to implement the algorithm for a positive gradient was successful and it was achieved by doing as described in Section 4.3. The difference in throughput between the different time intervals was very small. HOF and inter-frequency on the other hand differed between the time intervals and the results from these can be seen in Figure 5.13 and Figure 5.14.

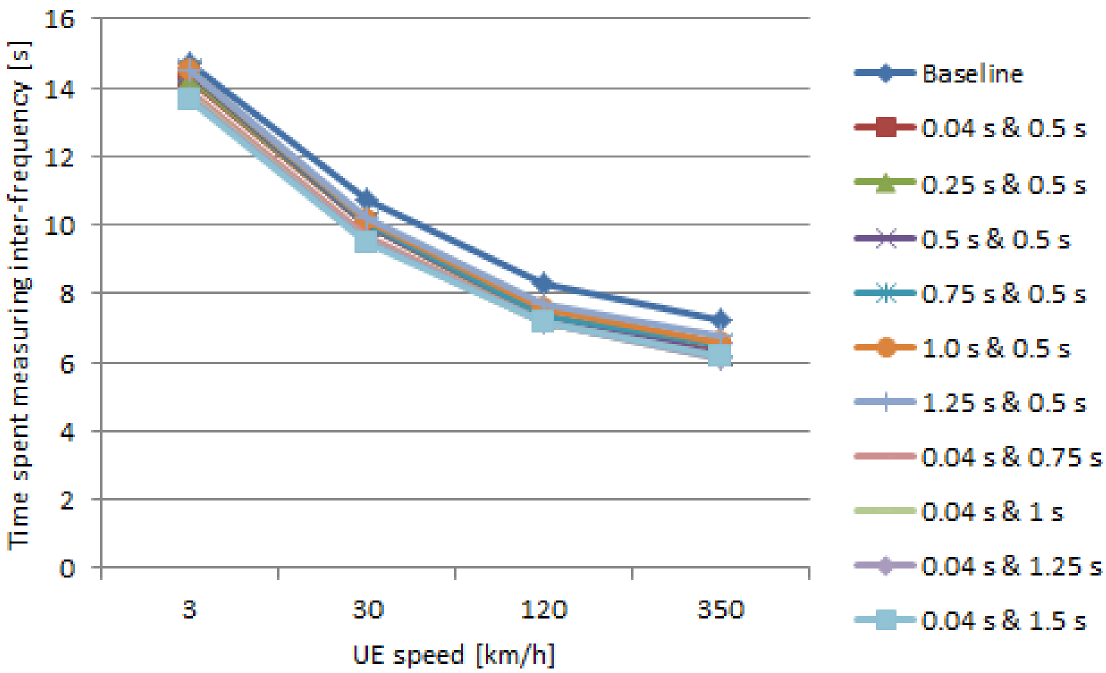


Figure 5.13: A comparison of average time spent measuring inter-frequency for the UEs are shown with different time intervals. The first value in the legend refers to the gradient interval and the second value refers to how early the A1 event should trigger.

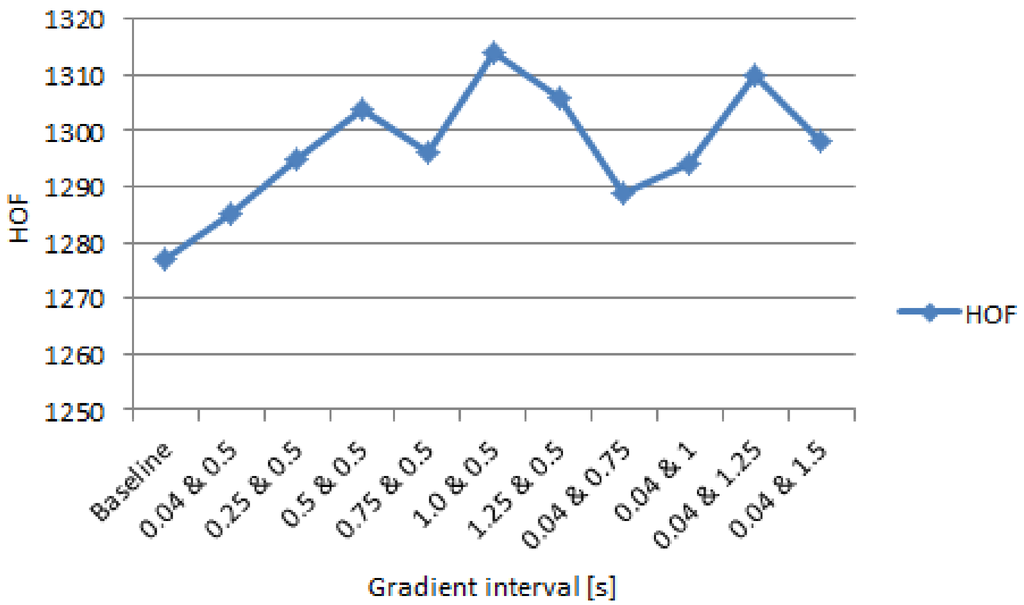


Figure 5.14: The HOF from all the UEs speeds combined is shown for different time intervals. The first value of the gradient interval-axis refers to the gradient interval and the second value refers to how early the A1 event should trigger.

5.4 Simulation 4 - Gradients combined

The positive and negative gradient simulations were successfully combined as described in Section 4.4. The difference in throughput between the different time intervals was very small. The time spent measuring inter-frequency on the other hand has improved and can be seen in Figure 5.15. The HOFs seems to have no correlation with late A2 measurement reports and were instead compared to the HOFs from Section 5.2, Simulation 4 - Negative gradient. This can be seen in Figures 5.16, 5.17, 5.18 and 5.19 for each the different UE speeds.

The Figures 5.20, 5.21, 5.22 and 5.23 shows cumulative distribution functions. In the functions the difference in time spent measuring inter-frequency between the baseline simulation and the combined gradients using 0.04 s gradient interval for both positive and negative gradient is shown. The previous figures from the baseline simulation and the algorithm using the 0.04 s negative gradient interval are presented in the same figure to be able to do a comparison of the results of these two simulations. It is the difference in inter-frequency measurements that is presented in each of the figures, as has been described before in Section 5.2.

When the two extra simulations with a fixed negative interval (0.5 s) combined with positive intervals (0.25 s and 0.5 s) were run, the results from these simulations confirmed the result from simulation 3 - Positive gradient (Section 5.3). The positive gradient interval 0.04 s was the best also when combined with negative gradients, both when considering HOFs and amount of inter-frequency measurements.

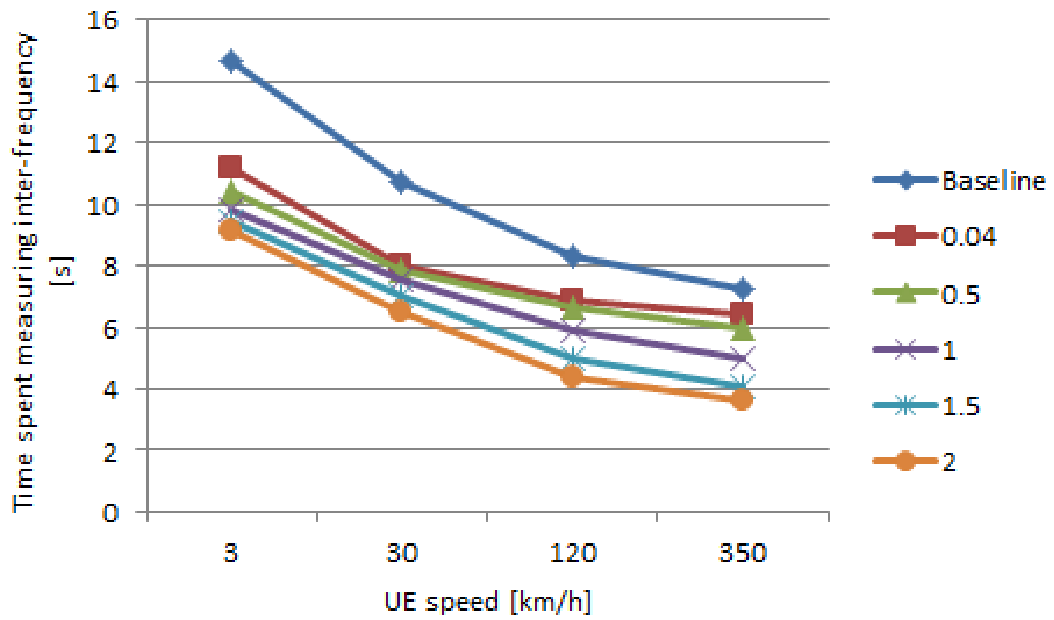


Figure 5.15: A comparison of average time spent measuring inter-frequency for the UEs are shown with different time intervals. For an easier read, not all intervals are shown. The missing intervals follow the pattern; bigger time interval has lower time spent measuring inter-frequency.

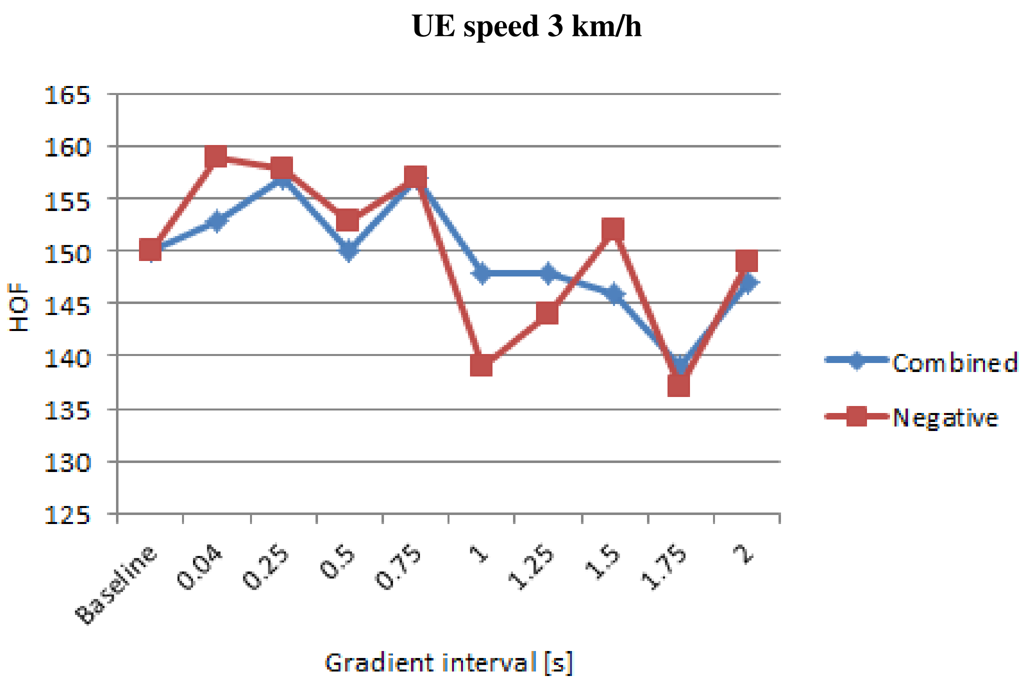


Figure 5.16: The result is from the UEs with the speed 3 km/h. HOFs from simulation 4 - gradients combined and simulation 2 negative gradient is shown for the different time intervals.

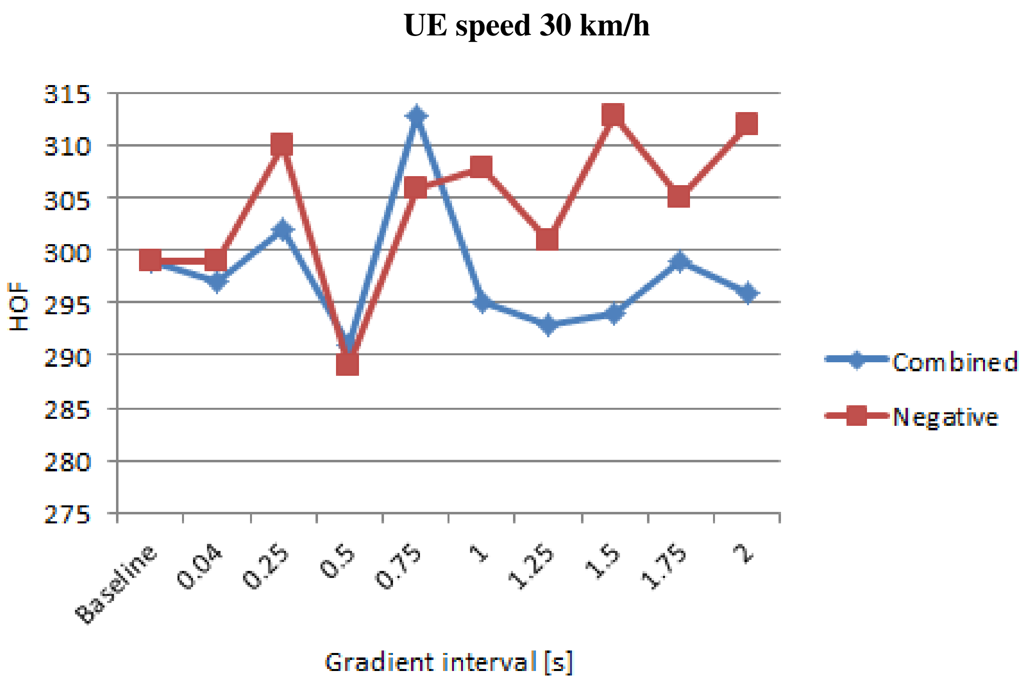


Figure 5.17: The result is from the UEs with the speed 30 km/h. HOFs from simulation 4 - gradients combined and simulation 2 negative gradient is shown for the different time intervals.

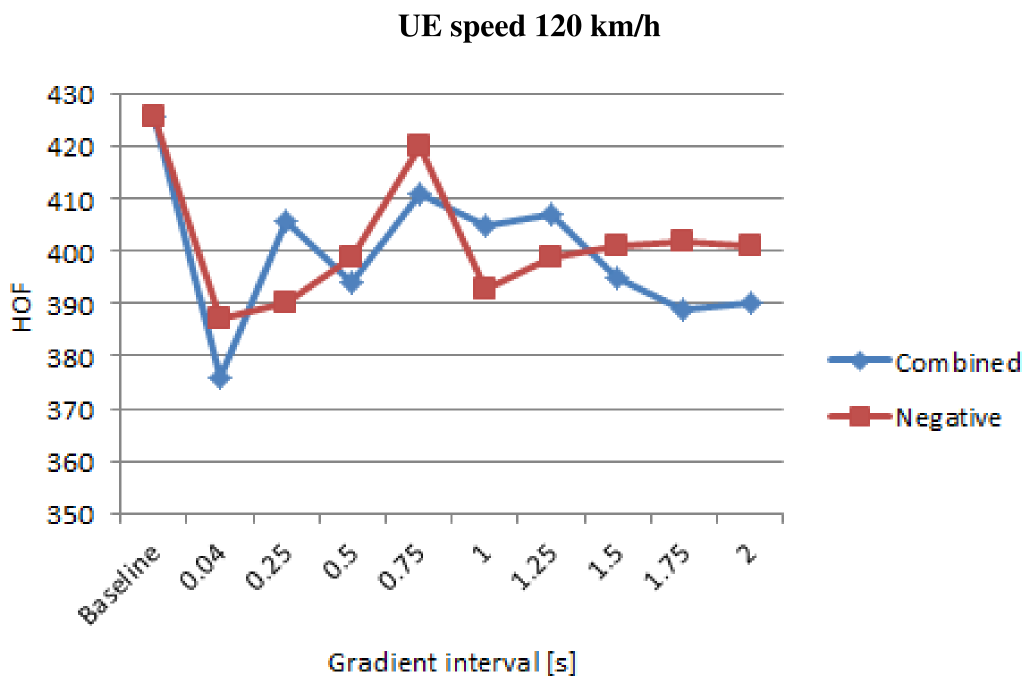


Figure 5.18: The result is from the UEs with the speed 120 km/h. HOFs from simulation 4 - Gradients combined and simulation 2 - Negative gradient is shown for the different time intervals.

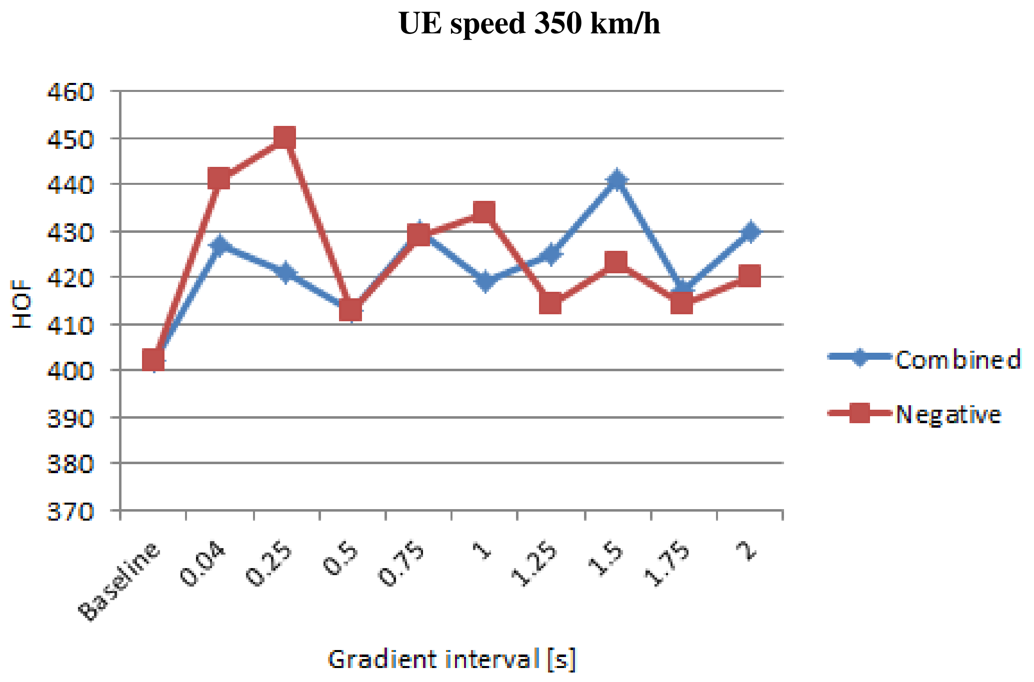


Figure 5.19: The result is from the UEs with the speed 350 km/h. HOFs from simulation 4 - gradients combined and simulation 2 negative gradient is shown for the different time intervals.

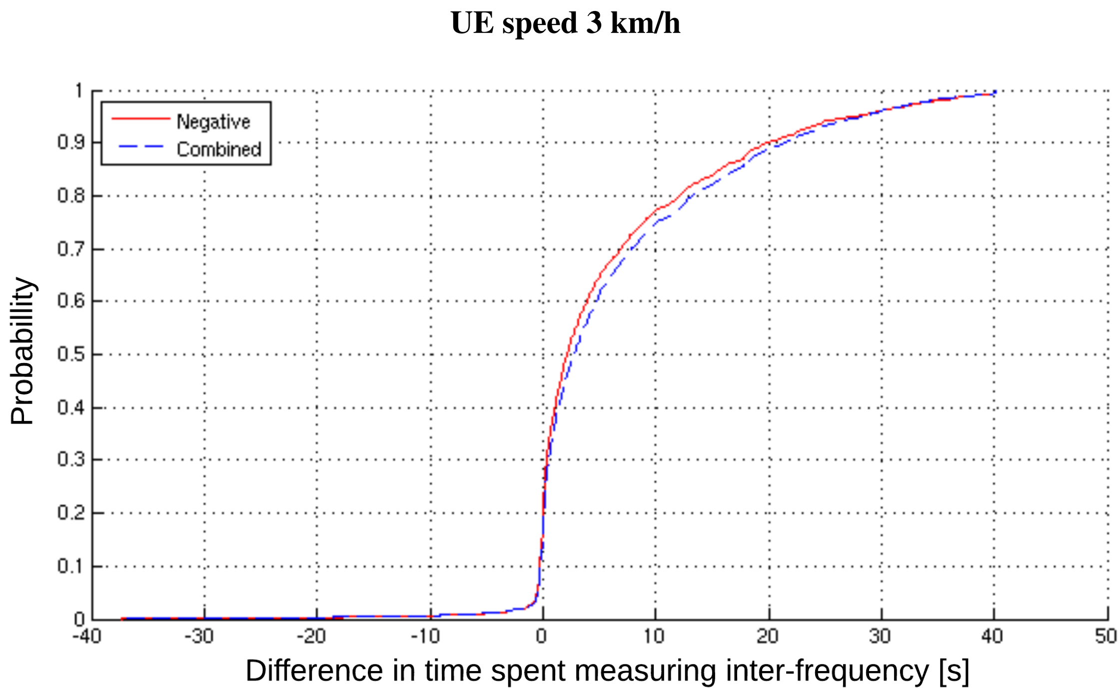


Figure 5.20: Cumulative distribution function for the UEs with speed 3 km/h. A comparison between the baseline simulation and with the negative gradient (0.04 s interval) as well as without the algorithm compared to the combined gradient (0.04 s for both positive and negative gradient). The difference for each of the UEs in how much time it spent doing inter-frequency measurements. Positive value indicates better (lower amount of) inter-frequency measurements than when not using the algorithm.

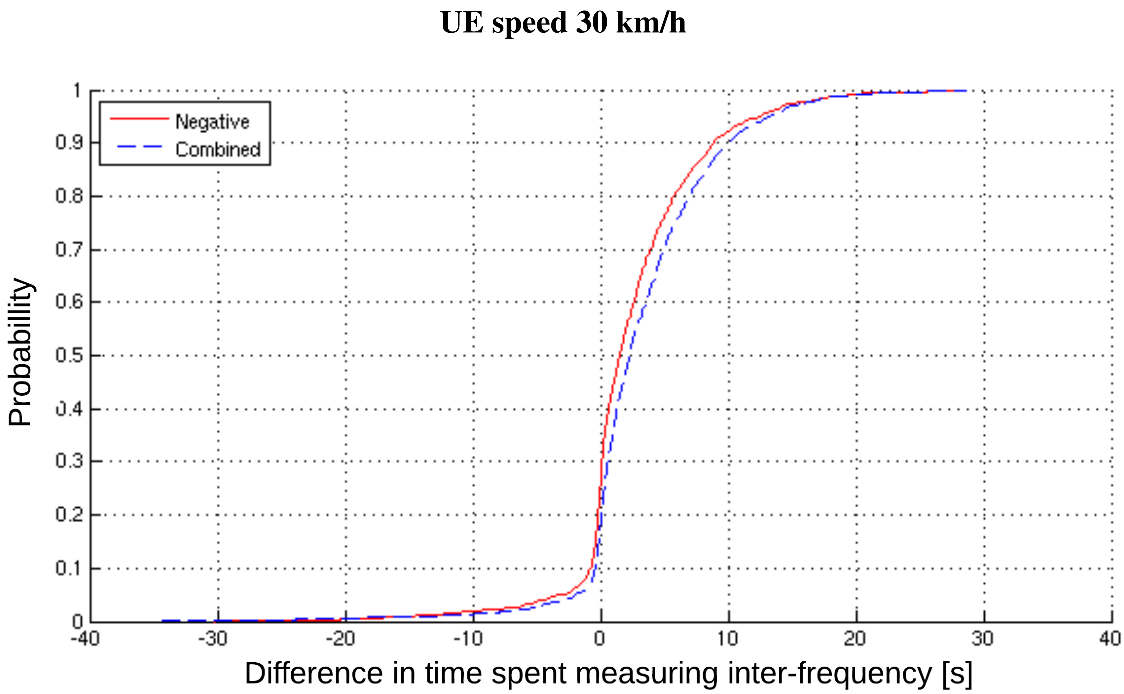


Figure 5.21: Cumulative distribution function for the UEs with speed 30 km/h. A comparison between the baseline simulation and with the negative gradient (0.04 s interval) as well as without the algorithm compared to the combined gradient (0.04 s for both positive and negative gradient). The difference for each of the UEs in how much time it spent doing inter-frequency measurements. Positive value indicates better (lower amount of) inter-frequency measurements than when not using the algorithm

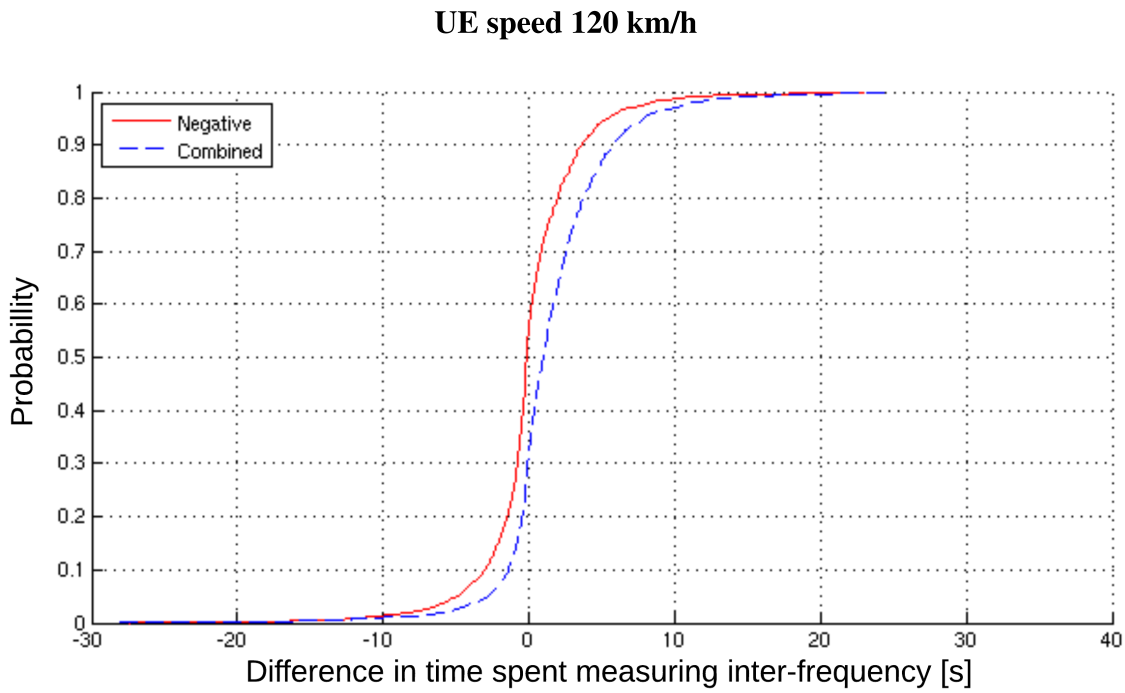


Figure 5.22: Cumulative distribution function for the UEs with speed 120 km/h. A comparison between the baseline simulation and with the negative gradient (0.04 s interval) as well as without the algorithm compared to the combined gradient (0.04 s for both positive and negative gradient). The difference for each of the UEs in how much time it spent doing inter-frequency measurements. Positive value indicates better (lower amount of) inter-frequency measurements than when not using the algorithm

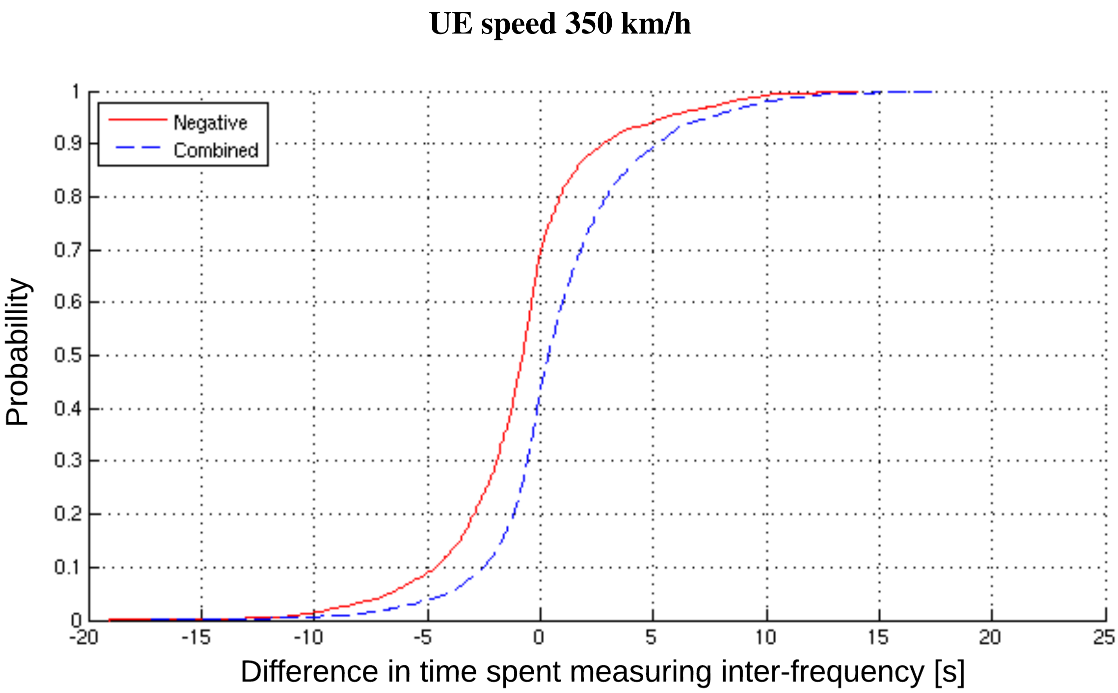


Figure 5.23: Cumulative distribution function for the UEs with speed 350 km/h. A comparison between the baseline simulation and with the negative gradient (0.04 s interval) as well as without the algorithm compared to the combined gradient (0.04 s for both positive and negative gradient). The difference for each of the UEs in how much time it spent doing inter-frequency measurements. Positive value indicates better (lower amount of) inter-frequency measurements than when not using the algorithm

5.5 Simulation 5 - Worst case gradient

The outcome from implementing worst case gradient was successful and was done as described in Section 4.5. The difference in throughput between the different time intervals were very small and the late A2 measurement reports did not seem to correlate to HOF even though they have decreased a lot compared to previous simulations. Inter-frequency on the other hand has been increased for this simulation, as seen in Figure 5.24. The HOFs from the simulation were compared with the HOFs from simulation 4 - Gradients combined, for the different UE speeds and can be seen in the Figures 5.25, 5.26, 5.27 and 5.28.

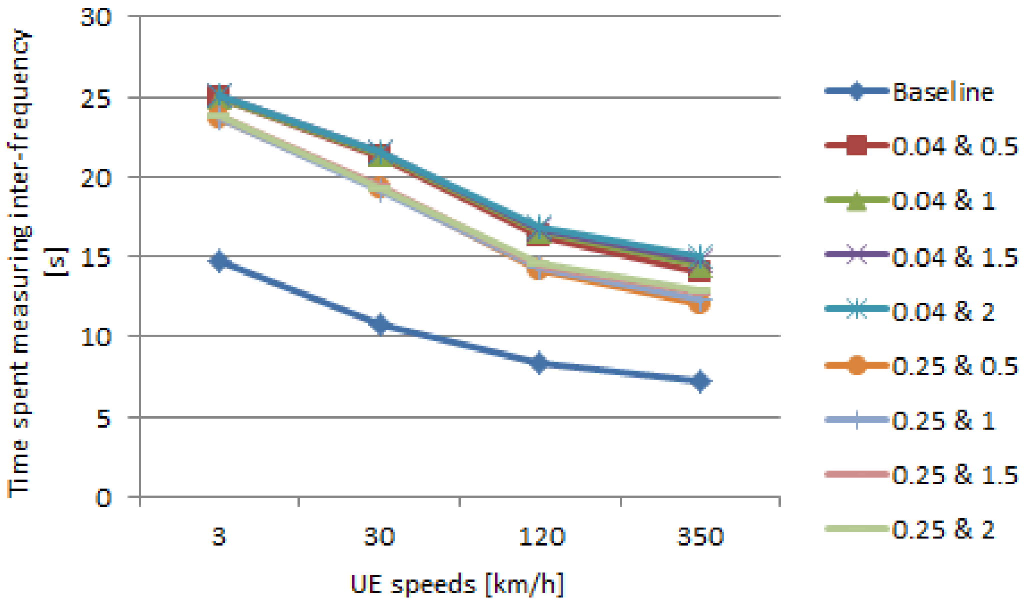


Figure 5.24: A comparison of average time spent measuring inter-frequency for the UEs are shown with different time intervals. The first value in the legend refers to the short gradient interval and the second value refers to the long gradient interval. All intervals are not shown in the figure, but all interval settings follow the same pattern: short interval at 0.04 s are all gathered in the highest line bundle and at 0.25 s are all gathered in the lower line bundle.

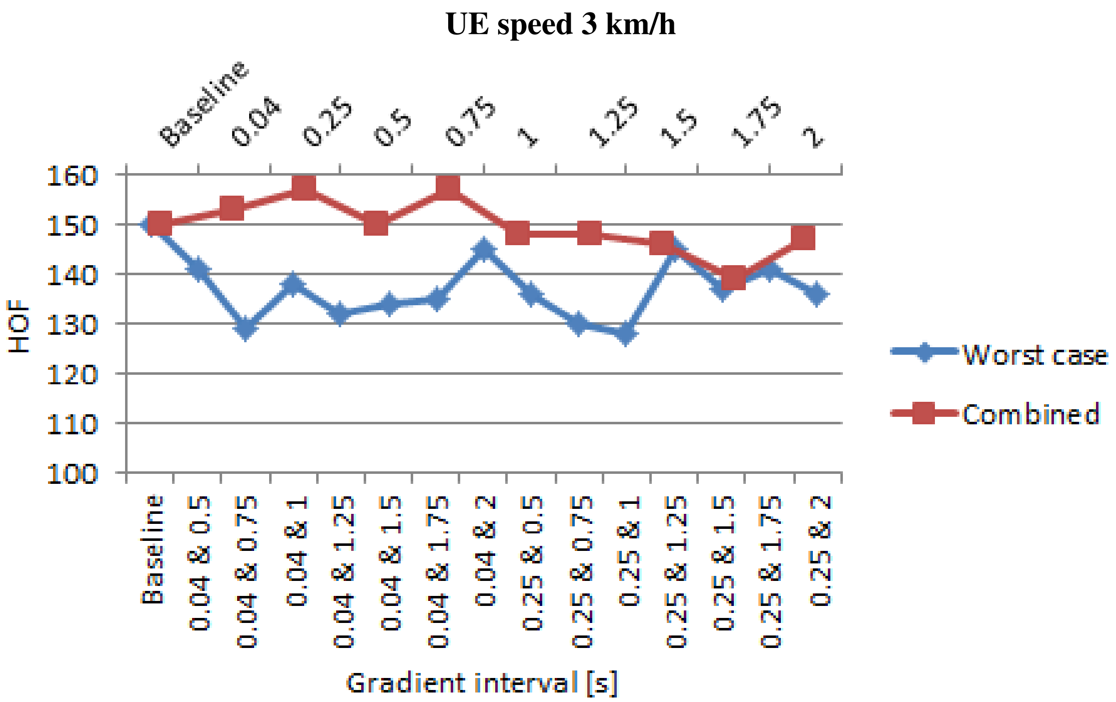


Figure 5.25: HOFs from simulation 4 (combined) and 5 (worst case) are shown for the different time intervals with their own corresponding axis, 4 above and 5 below.

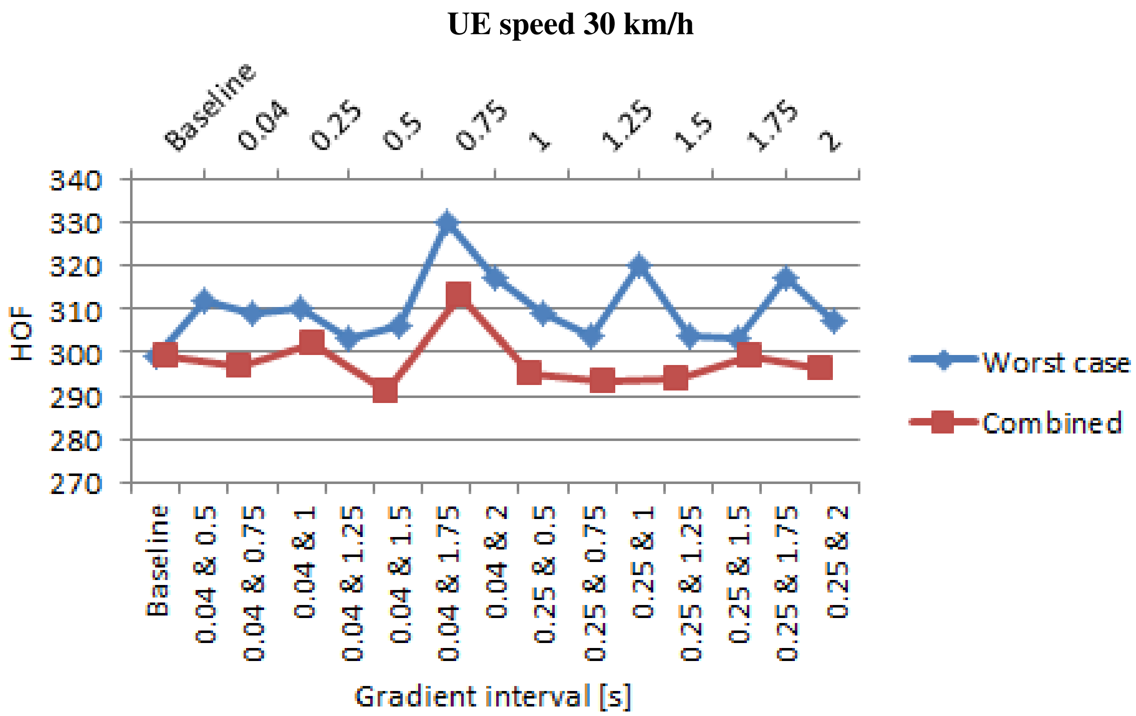


Figure 5.26: HOFs from simulation 4 (combined) and 5 (worst case) are shown for the different time intervals with their own corresponding axis, 4 above and 5 below.

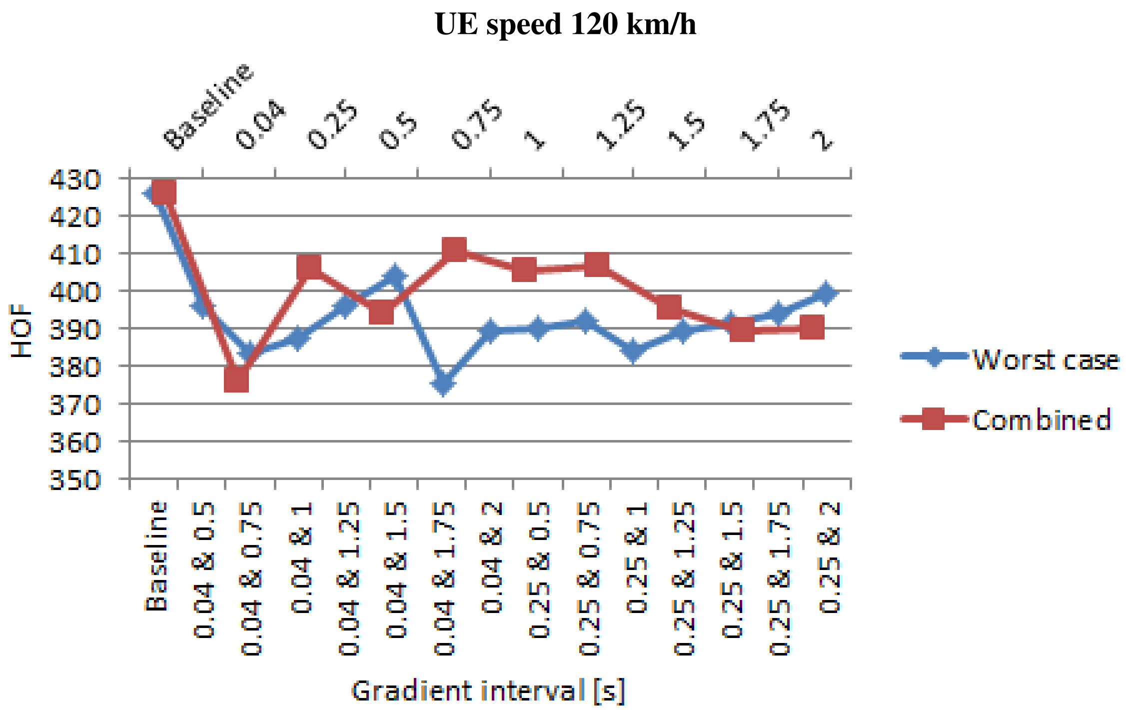


Figure 5.27: HOFs from simulation 4 (combined) and 5 (worst case) are shown for the different time intervals with their own corresponding axis, 4 above and 5 below.

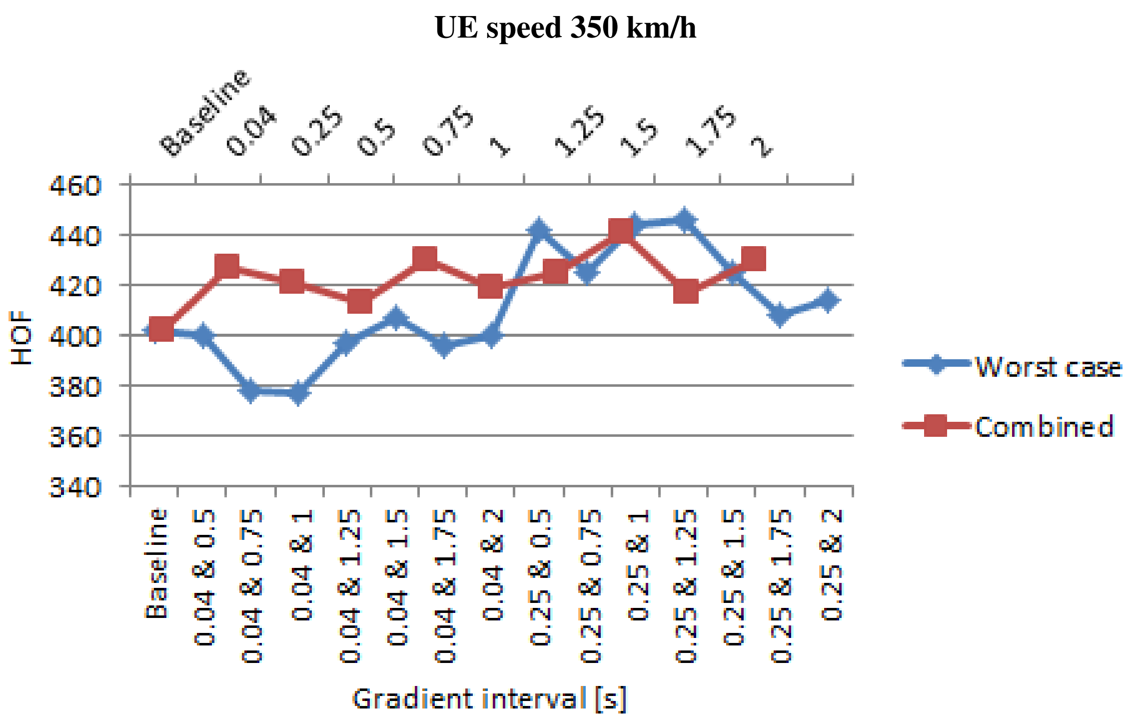


Figure 5.28: HOFs from simulation 4 (combined) and 5 (worst case) are shown for the different time intervals with their own corresponding axis, 4 above and 5 below.

Chapter 6
Analysis

In this chapter the analysis of each individual simulation is made based on the results from the corresponding simulation presented in Chapter 5. When it has been possible the analysis have been made on the simulation as a whole, without considering the UE speed, else the analysis has been divided into the different speeds.

6.1 Simulation 1 - Environment evaluation

The results from the simulations with case 1 indicate that the reception was too good in the cell deployment for inter-frequency measurements to make any difference to the result. Based on this conclusion there is no further interest in investigating case 1.

Case 3 on the other hand showed great improvement in number of HOFs and throughput with A1, A2 and A5 turned on, as can be seen in Figure 5.1 and Figure 5.2. This means that the inter-frequency measurements and HOs have an impact on the result and the environment can be used for investigating inter-frequency HO's relation to the UEs performance.

6.2 Simulation 2 - Negative gradient

As seen in Figure 5.3 the throughput did not change much between the different intervals even if there were some improvements on both time spent measuring inter-frequency and number of HOFs. It seems that inter-frequency measurements and HOFs did not influence the throughput enough to make a noticeable difference in the results.

The time spent measuring inter-frequency was greatly reduced in some cases when using the algorithm which can be seen in Figure 5.4. More specifically the time spent were reduced more when a larger time interval were used in the algorithm. Another pattern that appeared with greater time intervals used in the algorithm was the increase of late A2 measurement reports as seen in Figure 5.5, 5.6, 5.7 and 5.8. One possible reason for this is that large time intervals react slower to sudden changes in RSRP and therefore the A2 event triggers later and thus there is a bigger risk for late A2 measurement reports.

When looking into how the inter-frequency measurements changed within one interval (the case of 0.04 s shown in the figures) there seem to be a larger risk that the amount of measurements is increased when looking at the higher UE speeds. In Figure 5.12 (UE speed 350 km/h) there is a 70 % risk that the amount of inter-frequency measurements increase. In the case with UE speed 3 km/h (Figure 5.9) there is a 75 % chance of improving the results. In between these results the UEs with speed 30 km/h (Figure 5.10) have a 70 % chance of improving the measurements and the results from 120 km/h (Figure 5.11) provide a 50 % probability.

6.2.1 UE speed 3 km/h

When looking at the slow moving UEs (3 km/h) in Figure 5.5, there seems to be no relation between the number of late A2 measurement reports and the number of HOFs. The simulations with a gradient interval of 1.0 s and 1.75 s had the lowest number of HOFs and the later had the lowest amount of inter-frequency measurements.

As previously mentioned the chance of improving the amount of inter-frequency measurements in the 0.04 s interval are 75 %. The probability to improve the result by at least 2.5 s is 47.5 %, making the probability of a very small improvement (between 0 s and 2.5 s) 27.5 % of the total outcome. When looking at the negative results there are a 2.5 % risk the outcome would be 2.5 s worse or more than before. As a total it would seem a rather small risk and pretty much to gain from using this gradient interval at this speed of a UE.

6.2.2 UE speed 30 km/h

The best results was achieved with 0.5 s gradient interval. It had the lowest number of HOFs and a lower amount of inter-frequency than the baseline simulation. There were other intervals that had a lower amount of inter-frequency measurements but there were significantly more HOFs in them. The A2 measurement reports were consistently a bit late but this seemed to have no noticeable impact on the overall result, see Figure 5.6.

As stated earlier, the chance of improving the inter-frequency measurements in the 0.04 s interval are 70 % based on the run simulations. The probability of making it at least 2.5 s better are 40 % and the probability of making it at least 2.5 s worse for the UEs are 6 %. Once again the risk is pretty low, even though it has increased a little bit, there is still much to gain from using this gradient interval at this speed of a UE.

6.2.3 UE speed 120 km/h

A gradient interval of 0.04 s was the best at this UE speed with 387 HOFs compared to 426 HOFs when looking at the baseline, see Figure 5.7. When using a gradient interval of 1.0 s a result with almost as few HOFs as when using 0.04 s was achieved but also with a decrease of 1 s for average time spent measuring inter-frequency.

At this speed it could be reasoned that a connection between late A2 measurement reports and HOFs could be seen. As seen in Figure 5.7 the number of late A2 measurement reports seems to follow the number of HOF over the different time intervals.

The probability of an improvement of the inter-frequency measurements in the 0.04 s interval are, as previously stated, 50 %. There is a 35 % probability of getting an improvement of 2.5 s or more and a 12.5 % risk of getting a 2.5 s deterioration or worse. As seen there is a bigger chance of getting a large improvement than a large deterioration in this speed but there is still a fifty-fifty chance if there will be an improvement at all.

6.2.4 UE speed 350 km/h

As seen in Figure 5.8, the result from the baseline simulation was the best when considering the number of HOFs. At the same time, the number of late A2 measurement reports was pretty high. Later when using the gradient algorithm, there seem to be a high number of HOFs when there was a low number of late A2 measurement reports. This could be concluded to there being no connection between late A2 reports and HOFs when considering this UE speed.

One thing that stood out in Figure 5.4 were that the baseline simulation had lower time in inter-frequency than the simulations using the algorithm with the intervals 0.04 s, 0.25 s and 0.5 s on UEs with the speed of 350 km/h. One possible reason for this is that for UEs with higher speeds there were more situations when the RSRP dropped very fast and small time intervals react faster to this. Resulting in inter-frequency measurements getting turned on earlier than when the algorithm is not used.

As mentioned there is a 70 % risk of increasing the amount of inter-frequency measurements when looking at the 0.04 s interval and a 42.5 % risk of getting a result that is 2.5 s worse or more. The chance of improving the result with 2.5 s or more is 15 % so the stakes for improving the amount of measurements at this speed are pretty high.

6.3 Simulation 3 - Positive gradient

As seen in Figure 5.13 there was small variations in the result overall when trying the different time intervals. However the simulation without the gradient had the highest time spent measuring inter-frequency on all UE speeds. When one or both of the time intervals were increased the time spent measuring inter-frequency was slightly lowered but at the cost of a slight increase of HOF, as seen in Figure 5.14.

Depending on what to prioritize there are two different approaches to take, either go with the lowest time spent measuring inter-frequency or the lowest amount of HOF. It was reasoned that the low gain in inter-frequency was not worth the increase in HOF, therefore the interval setting 0.04 s with 0.5 s to trigger A1 were considered the best and used for the coming simulations.

6.4 Simulation 4 - Gradients combined

The time spent measuring inter-frequency was lower than without the algorithm as seen in Figure 5.15, especially for the UE speeds 120 and 350 km/h and the higher intervals.

When looking at Figure 5.20, UEs with speed 3 km/h, there seem to be no noticeable change in the probability for a deterioration compared to only using the negative gradient. The results for the improved UEs on the other hand show a slight improvement, providing a bit greater values given a certain probability.

In Figure 5.21 the UEs had the speed 30 km/h. The results in the figure shows a slight improved (lower) probability for the impaired UEs compared to the negative gradient simulation. The improved UEs show larger values than the negative gradient simulation.

As seen in Figure 5.22 with UE speed 120 km/h, the probability for a deterioration is lower than the negative gradient simulation and the deteriorations are also smaller. There is also a higher chance of changing to the better rather than to the worse compared to without the algorithm, in contrast with the negative gradient simulation where there is a greater probability the UE's inter-frequency measurements change to the worse.

The overall result is better in this simulation with UE speed 350 km/h (Figure 5.23) compared to both the baseline simulation and with the algorithm using the negative gradient. There is still a risk that there is deterioration for an individual UE compared to not using the algorithm. However, the probability of improving the result for the individual UEs is greater than the risk of making it worse. The probability of deterioration is lower than with the negative gradient and if there is deterioration, the deterioration is lower.

The HOFs compared to simulation 2 - Negative gradient varied in terms of improvement and deterioration. For UE speeds 30 km/h and 120 km/h the HOFs overall had decreased (Figure 5.17 and Figure 5.18) but for UE speeds 3 km/h and 350 km/h the results varied between the different time interval settings (Figure 5.16 and Figure 5.19). The reason for the increase in HOF (for some settings) could probably be explained by the risk of turning off inter-frequency measurements when they were needed (by the positive gradient). Overall the HOF was lowered or approximately the same but accompanied by a decreased time spent measuring inter-frequency, which is very positive.

6.5 Simulation 5 - Worst case gradient

The purpose of this simulation was to decrease the HOF as much as possible and it was successful for the UE speeds 3 km/h and 350 km/h, as seen in Figure 5.25 and Figure 5.28. Most noticeable was the results from 350 km/h because of the fact that this was the first time the number of HOFs were lower than the baseline simulation, with a decrease of 25 HOFs. But at a high cost in time spent measuring inter-frequency, from 7.25 s to 15.42 s, an increase of 113 %. The results from UEs with speed 3 km/h also showed the lowest number of HOFs compared to all simulations, 128 HOFs compared to the 137 HOFs that the simulation 2 - Negative gradient achieved. In conclusion there is a high cost in time spent measuring inter-frequency, which is consistent through all interval settings and UE speeds (see Figure 5.24). It all comes down to how much increase in time spent measuring inter-frequency a HOF is worth.

6.6 Summary

To sum up, no setup was found that gave the lowest time spent measuring inter-frequency and the lowest amount of HOF for all UE speeds. This means depending on what to prioritize different gradient algorithm settings could be used. Some of the simulation results stood out from the others and these can be seen in Table 6.1. First in the table is the baseline simulation for comparison, second comes the simulation with the lowest time spent measuring inter-frequency, third to seventh had the lowest HOFs for the corresponding UE speeds and total, lastly is the simulation that gave a balanced result with low inter-frequency and a fairly low amount of HOFs.

Table 6.1: A summary of the simulation results of interest. The values represent the difference between the corresponding simulation and the baseline simulation.

Simulation	**Quality factor**	**3 km/h**	**30 km/h**	**120 km/h**	**350 km/h**	**Total**
Baseline	HOF	150	299	426	402	1277
	Inter-frequency [s]	14.70	10.72	8.29	7.25	10.24
Combined	HOF	-3	-3	-36	+28	-14
2.00 s	Inter-frequency [s]	-5.57	-4.22	-3.92	-3.66	-4.34
Worst case	HOF	-22	+21	-42	+42	-1
0.25 s & 1.00 s	Inter-frequency [s]	+8.95	+8.47	+5.94	+5.12	+7.12
Negative	HOF	+3	-10	-27	+11	-23
0.50 s	Inter-frequency [s]	-4.10	-2.33	-0.22	+0.38	-1.57
Worst case	HOF	-15	+31	-51	-6	-41
0.04 s & 1.75 s	Inter-frequency [s]	+10.29	+10.78	+8.48	+7.58	+9.30
Worst case	HOF	-12	+11	-39	-25	-65
0.04 s & 1.00 s	Inter-frequency [s]	+10.29	+10.62	+8.27	+7.18	+9.10
Worst case	HOF	-21	+10	-43	-24	-78
0.04 s & 0.75 s	Inter-frequency [s]	+10.24	+10.52	+8.13	+6,95	+8,96
Combined	HOF	-11	0	-37	+15	-33
1.75 s	Inter-frequency [s]	-5.39	-3.99	-3.72	-3.49	-4.14

Chapter 7
Discussion

In the discussion the validity of the report's different parts as well as the report as a whole is discussed. The discussion explains how the experiments have been carried out and if they could have been carried out differently. The given results are discussed and if any part of the result is missing or could be presented in another way. Finally the analysis of the different experiments and an analysis of the overall result are discussed.

7.1 The environment

All the simulations were executed with either 3GPP case 1 or case 3 as cell deployments. This has influenced the results in many ways. The simulated cell deployments are not realistic in the sense of the even distribution of the eNBs, that there are no radio interference except for the UEs themselves and that there is no radio shadow. But because this work was a study and exploration of a new concept, some simplified arrangements were necessary to isolate the algorithm's influence on the UEs and the overall result. It was also important that the cell deployment created an environment where inter-frequency measurements had an important role and were common so it could be properly studied and gave an impact to the result. Case 3 was concluded to do this with the chosen simulation settings.

The UEs themselves and their behavior in the simulations are also questionable. All UEs moved in straight lines with constant specific speeds which could be reasoned is fairly unrealistic. But as already mentioned, some simplified arrangements were necessary to isolate the intended situation so it could be studied. The same goes with the number of UEs which was set to 30 for all the simulations, where possible UE interference was avoided by keeping the quantity low. Throughout all simulations the UEs' speeds influenced the result a lot and it could be reasoned that different speeds should be tested. The reason for choosing these speeds from the beginning was mainly based on 3GPP's recommendations when testing mobility, but for a more reassuring result more speeds could be tested. When the simulation started the UEs were automatically connected to the cells with the short range frequency because it created a scenario where UEs would benefit from making an inter-frequency HO. That setting was important so inter-frequency HOs made a larger impact on the result, but it also meant the algorithm has been primarily tested on scenarios where the inter-frequency HOs gives the best result which makes the result a little biased.

The simulator itself has also made a large impact on the results. The software environment that was used is very complex and might contain some minor unknown faults or errors, as most software does. How close to the reality the simulator was is out of this thesis scope, but should be kept in mind when looking at the results.

7.2 The results

In the results and analysis it has been concluded that the throughput have not been affected or have been affected so little that it is not visible in the result. When the results from the second simulation (Simulation 2 - Negative gradient) showed that the throughput was not affected in any noticeable way, the procedure of how the average throughput was calculated was reviewed to verify the correctness of the calculation. The calculation seemed right and no correction was made to the way of calculating the average throughput. Through the rest of the simulations (3-5) no significant difference in throughput was found.

One explanation to the unaffected throughput could be due to the fact that there are very few UEs compared to the number of available cells. The UEs and eNBs might have had the possibility to make a rescheduling of the data transmissions and in that way eliminate the difference that would occur due to a connection loss or any other event that might affect the throughput. There might also be some other factors that have not been found or not been taken under consideration in this work that could influence the behavior of the throughput.

In contrast to the throughput, the time spent measuring inter-frequency was successfully controlled and decreased throughout the simulations. The negative gradient worked best at the lower speeds 3 km/h and 30 km/h while the positive gradient functioned best at the higher speeds 120 km/h and 350 km/h. Overall in the gradient combined simulation the inter-frequency measurements in the lower speeds were reduced with more seconds compared to the baseline simulation.

The longer the intervals, the less time spent measuring inter-frequency, but this comes with a cost of increased HOF (in most cases). As time spent measuring inter-frequency gets improved (lower) the risk of increasing the time spent measuring is lowered as well, especially for the low UE speeds where the risk is very small. The gradient combined algorithm did not introduce a high risk and high reward, the chance to lower the time spent measuring inter-frequency is always greater than the risk of introducing more inter-frequency measurements, which is very positive.

It is safe to say that the number of HOFs have differed between the simulations and within them. It has been harder to say if the changes made in the settings have affected the HOFs and to what degree. When looking at the different figures showing HOF most of them tend to mimic a zigzag like pattern.

On a conceptual level there is three types of HOFs; those HOFs that are hard to avoid, those HOFs that seems to have no correlation to the algorithm at all and those HOF that could be avoided by introducing the algorithm. It is hard to know the distribution of these three types of HOFs which makes the evaluation of the HOFs difficult. To get more insights about this the worst case scenario simulation was created, where inter-frequency measurements were introduced with the hope of reducing the HOFs. The HOFs in the simulation were in some cases reduced and in some cases unaltered, which leaves the authors wondering about the HOFs correlation to the introduced algorithm.

One important aspect of this work has been the value of a HOF. It could be reasoned that there is an active transmission and a HOF occurs due to too few inter-frequency measurements (in some cases). If the throughput in total would still be higher than the total throughput when making enough inter-frequency measurements to avoid the HOF, resulting in the same amount of data transmitted in both cases. Then there might be some justification for not doing all those measurements. The comparison would need to be looked upon with all the consequences that come with a HOF, such as retransmitting data and finding a new HO candidate.

When starting this work, we had a hypothesis that there would be a correlation between the number of HOFs and the number of late A2 measurement reports. But as seen in the results from the different simulations there seem to be no such correlation. Those few occasions when there seem to be some kind of connection between the late A2 measurement reports and the number of HOFs might as well be a coincidence. There might be some possible explanations to this. One example could be the fact that UEs is not as sensitive to the RSRP being too low as initially thought. This means there are other unidentified factors that influence the numbers of HOF more than the introduction of the gradient algorithm. Another possible reason is if the threshold would be too high, resulting in a late A2 measurement report that is in fact not too late, even thought it was recorded as one. Another factor that could be discussed is the time used to decide whether or not the A2 measurement report would be too late. The time chosen might as well be to short or too long, resulting in faulty recordings.

When deciding on which settings that is the best it comes down to two important factors to have in mind: What UE speeds to prioritize and what is more important between inter-frequency measurements and HOFs. If the goal is to have a setting that gives the overall best results for the different UE speeds, there is a worst case gradient simulation (0.04 s & 0.75 s) that gives the lowest number of HOF combined for all speeds. But on the other hand it gives an increase in time spent measuring inter-frequency compared to many other settings. If the goal is to lower the time spent measuring inter-frequency instead, the best is the gradient combined 2 s settings, which have more HOF compared to previously mentioned worst case gradient setting. To decide on what gradient algorithm settings to use is not easy, and becomes even more complex if weighted UE speeds gets involved.

7.3 Other aspects

The time spent measuring inter-frequency has been decreased with the help of the gradient algorithm but at the same time some extra calculations has been introduced which are more complex than using static thresholds. The simulator did not offer any possibility to measure the power consumption for the kind of calculations the algorithm introduced. But in perspective to other calculations made by the UE, e.g., screen rendering or signal modulation, the introduced extra calculations are very few in comparison. The inter-frequency measurements themselves also consume extra power which is avoided when using the gradient algorithm. So in practice, the inter-frequency measurements have been reduced at the cost of almost nothing in power consumption. On the other hand, the algorithm might introduce a need for some extra processing cycles, which might influence the processor's capability in a negative way.

When looking at the possibility to implement this in the current setting with eNB and UE there is a great challenge in convincing the 3GPP organization to accept this change in the standard. There would need to be further investigation within the area to make sure the improvements are worth more than the effort needed to implement this algorithm. There might also be a conflict in what exact algorithm to use, there are many possible ways to modify the algorithm.

The configuration settings sent from the eNB to the UE might also need to be expanded to be able to send settings such as more thresholds and intervals. The UE in turn needs to be able to receive these settings and adapt to them. This means that each of the different manufacturers needs to implement the algorithm in their UEs. The UEs needs to adapt both in terms of being able to receive the settings and in terms of storing extra variables in the memory and handling them. There might also be a need to keep the old way of doing it, meaning there might be a setting where the eNBs need to be able to send different kind of settings depending on if the UE uses the algorithm or not.

In theory, the concept of the algorithm could also be implemented in other devices, such as eNBs or some other access technologies. This could mean that 3GPP would not need to get involved when introducing a change. The same goes for the measurement unit (RSRP) as this work has focused on, the concept could be used to other units, i.e. RSRQ.

Chapter 8
Conclusions

In this work experiments have been made where the change in signal quality has been used to try to determine when a HO should be made. This has been done by implementing an algorithm that saves old measurements and calculates the gradient of the change in the signal quality. The algorithm has been used both to determine when inter-frequency measurements should be turned on and off. The results show that the algorithm is inconsistent, but there are results that show improvements compared to the baseline simulation. The inconsistency is hard to explain but might occur due to some environment settings who have not been looked upon or some unknown factor of the algorithm. The improvements were in terms of reducing the amount of inter-frequency measurements while keeping the number of HOFs low. The UE downlink throughput was unaltered throughout the experiments and the late A2 measurement reports showed no correlation to the variations in the results.

Is it possible for the UE in the simulator to find the current signal quality's rate of change, based on its measurements?

It was concluded early on in simulation 2 - Negative gradient, that it is possible to find the signal quality's rate of change. This was done by saving old measurements and their time and calculating the gradient from these values. The signal power was quantified by using RSRP but any signal power/quality indicator in theory would be applicable to this work, as long as it changes over time.

Based on the rate of change, is it possible to predict when a handover (HO) should be made (both initiated and finished)?

Yes, it was concluded that it is possible to predict when a HO should be both initiated and finished based on the calculations of the signal quality's rate of change. However, the prediction was not 100 % accurate. There was very fast changes in RSRP which could not be predicted and there was some other situations where HOs was needed, that was unrelated to RSRP measurements, which also could not be predicted.

Will this new way be more efficient than current solution, in terms of calculation effort and measurement effort without compromising the Quality of Service (QoS)?

The new algorithm is more efficient in terms of calculation effort. Some few extra calculations have been introduced in conjunction with the new algorithm. But the improvement (lowering) of the amount of measurements in terms of inter-frequency has been reasoned to be far more important than the few extra calculations the algorithm have introduced.

By optimizing, the time spent measuring inter-frequency was successfully lowered. With the help of the predictions of when the HO should be made, the start of inter-frequency measurements could be delayed to when they were needed or turned off if they were not needed at all. In this way the measurement effort could be made more efficient than the current solution.

In terms of QoS, more specifically throughput and HOFs, the results are more uneven. Throughout the simulations the throughput was more or less unchanged even if the time spent measuring inter-frequency and HOFs was reduced. The probable reason behind this is the fact that there are very few UEs compared to the available cells in the simulations. The UEs and the eNBs then had the possibility to reschedule the data transmissions and in that way eliminate any throughput differences. The HOFs were in some simulations reduced and in some simulations increased. The HOFs varied a lot based on what speed the UE had and how the gradient algorithm was used. No settings was found for reducing the HOFs through all the UE speeds and in some simulations the HOFs seemed to have no (or low) correlation to the time spent measuring inter-frequency, which not was expected. The probable reason for this unexpected pattern is that the HOF is more dependent on other factors than the time spent measuring inter-frequency, which has not been identified by this work. For some algorithm settings the HOFs were greatly reduced but most often with the cost of more time spent measuring inter-frequency. It all comes down to what to prioritize, time spent measuring inter-frequency or HOFs and for which UE speeds.

Chapter 9
Future Work

There are several different ways to continue from this work apart from looking into different variants of how to find the ultimate way to minimize the inter-frequency measurements while keeping HOFs low. There could be other ways to adapt the measurements to the UE's speed which works better than the suggested way in this report. It could also be an idea to look into deploying this kind of algorithm on other platforms where calculations are cheap and measurements expensive. Lastly it would be interesting to see if the introduced changes with using the algorithm could be seen in the overall result from a more reality-based simulation environment and in the end in the actual reality.

Since the average UE throughput was not unaffected, it would be interesting to have more simulations made where this is researched. One aspect could be to maximize the load of the cells so the scheduler would not have enough capacity to reschedule the throughput for the UE.

Depending on how much calculation that could be introduced in the UE or the eNB there are some alternative ways to implement the algorithm that might improve the result even further. There could for example be weight added to the more recent measurements or to the measurements with worse reception, giving them a greater impact if evaluating more than one gradient.

If increased storage and calculation effort is not a problem the calculation could result in a curve from three or more points based on the measurement values. Whether the decision is to make a HO or turn off the inter-frequency measurements, this way more information would be provided to base the decisions on.

If the introduced calculation effort is a problem it could investigated how seldom the calculation of the gradient needs to be done without compromising the effects of the algorithm. It could be reasoned that the calculations are not needed if the gradient is positive for a period of time or if the RSRP is good enough.

If an optimized algorithm was found, it would be interesting to see if it is possible to implement the algorithm on another platform, e.g., an eNB, successfully. The measurements would need to be made in the eNB or be sent to it. From there the calculations could be made and a decision taken based on the result. If making the calculations in the eNB, there seem to be no need to make any changes in the standards from 3GPP.

Bibliography

[1] C. Johnson. *Long Term Evolution in bullets*. Chris Johnson, Northampton, 2nd ed., version 1. edition, 2012.

[2] 3GPP. Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception. TS 36.104, 3rd Generation Partnership Project (3GPP), 2015.

[3] 3GPP. Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer; Measurements. TS 36.214, 3rd Generation Partnership Project (3GPP), 2015.

[4] M.B. Hcine and R. Bouallegue. Analytical downlink effective sinr evaluation in lte networks. In *Advanced Information Networking and Applications Workshops (WAINA), 2015 IEEE 29th International Conference on*, pages 376–381, March 2015.

[5] 3GPP. Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2. TS 36.300, 3rd Generation Partnership Project (3GPP), 2015.

[6] M. Rumney. *LTE and the evolution to 4G wireless: design and measurement challenges*. Agilent Technlogies Publication, [Santa Clara, CA], 2009.

[7] 3GPP. Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification. TS 36.331, 3rd Generation Partnership Project (3GPP), 2016.

[8] 3GPP. Vocabulary for 3GPP Specifications. TR 21.905, 3rd Generation Partnership Project (3GPP), 2015.

[9] N. Hassan, K. Elkhazeen, K. Raahemiafar, and X. Fernando. Optimization of control parameters using averaging of handover indicator and received power for minimizing ping-pong handover in lte. In *Electrical and Computer Engineering (CCECE), 2015 IEEE 28th Canadian Conference on*, pages 92–97, May 2015.

[10] M.S.I. Khan, M.M. Rahman, K. Raahemifar, J. Misic, and V.B. Misic. Self-optimizing control parameters for minimizing ping-pong handover in long term evolution (lte). In *Communications (QBSC), 2014 27th Biennial Symposium on*, pages 118–122, June 2014.

[11] 3GPP. Telecommunication management; Self-Organizing Networks (SON) Policy Network Resource Model (NRM) Integration Reference Point (IRP); Requirements. TS 32.521, 3rd Generation Partnership Project (3GPP), 2012.

[12] B.K.S. Fatty and Po-Chiang L. Mobility robustness optimization in wireless mobile networks. In *Ubiquitous and Future Networks (ICUFN), 2015 Seventh International Conference on*, pages 624–629, July 2015.

[13] I.N.M. Isa, M.D. Baba, R. Ab Rahman, and A.L. Yusof. Self-organizing network based handover mechanism for lte networks. In *Computer, Communications, and Control Technology (I4CT), 2015 International Conference on*, pages 11–15, April 2015.

[14] I.N.M. Isa, M.D. Baba, A.L. Yusof, and R. Ab Rahman. Handover parameter optimization for self-organizing lte networks. In *Computer Applications Industrial Electronics (ISCAIE), 2015 IEEE Symposium on*, pages 1–6, April 2015.

[15] 3GPP. Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects. TR 36.814, 3rd Generation Partnership Project (3GPP), 2010.

[16] 3GPP. Physical layer aspect for evolved Universal Terrestrial Radio Access (UTRA). TR 25.814, 3rd Generation Partnership Project (3GPP), 2006.

Institutionen för Elektro- och informationsteknik | Lunds Tekniska Högskola
Redovisas 3 Juni 2016

Examensarbete: Optimering av algoritmer för mobilitiet i cellulära system
Studenter: Bernt Christensen, Olof Knape
Handledare: Fredrik Tufvesson (LTH), Niklas Holmqvist (Ericsson), Jan Wichert (Ericsson)
Examinator: Fredrik Rusek

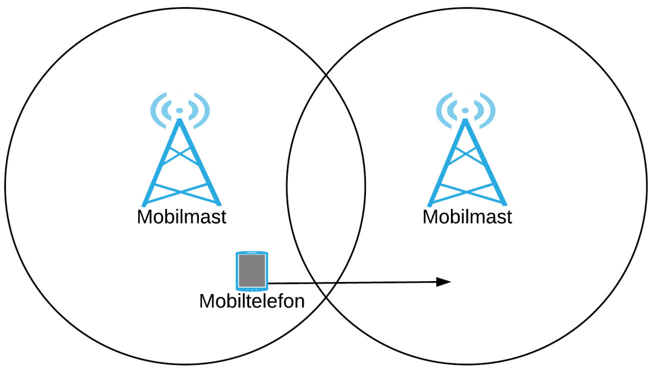
Optimering av mätningar i mobilnätet

Populärvetenskaplig Sammanfattning av *Bernt Christensen, Olof Knape*

Det görs hela tiden mätningar mot master i mobilnätet från din mobil, för att se till att du har bästa möjliga mottagning. Vårt arbete visar att det går att minska mängden av dessa mätningar med 40 % så att mer resurser kan användas till att skicka data.

Antalet enheter som kopplas upp till det mobila nätet ökar ständigt samtidigt som användarna har höga förväntningar på tillgänglighet och ställer allt högre krav på hög överföringshastighet. Bland annat ska det ökande användandet av olika streaming-tjänster tillfredsställas. Det är därför väldigt viktigt att nätverket kan tillhandahålla detta. Samtidigt finns det begränsningar för hur många mobila enheter som kan vara uppkopplade samtidigt mot en mobilmast. Mobilmasten har också en begränsning i hur mycket data den kan hantera. Därför är det viktigt att de mobila enheterna är jämnt fördelade bland de tillgängliga mobilmasterna. Det vill säga det är viktigt att belastningen mellan mobilmasterna utjämnas i så stor utsträckning som möjligt. Detta kanske låter som en lätt uppgift, men med tanke på att de mobila enheterna rör sig i olika mönster och hastigheter hela tiden blir det mycket svårare, förutsättningarna förändras ständigt. För att de mobila enheterna ska kunna vara uppkopplade mot rätt mast, med bästa möjliga mottagning, görs mätningar av signalstyrkan mot de olika mobilmasterna i omgivningen. Dessa mätningar är nödvändiga men de som görs mot andra frekvenser än den som används är också väldigt resurskrävande. Precis som en vanlig gammaldags radioapparat hemma kan man inte lyssna på en radiokanal samtidigt som man letar efter nya radiokanaler (frekvenser). På samma sätt kan inte den mobila enheten lyssna på andra frekvenser med bättre mottagning samtidigt som den tar emot data på den ursprungliga frekvensen. Därför är det viktigt att dessa mätningar mot andra frekvenser hålls på ett minimum och det är där vårt arbete kommer in.

Vi har alltså försökt att minska tiden som behövs för att leta efter nya mobilmaster och på så sätt öka tiden enheten kan skicka och ta emot data. Idén bakom vår algoritm går ut på att studera hur snabbt signalstyrkan mot den nuvarande masten förändras. På så sätt får vi mer information om ett eventuellt mastbyte behöver göras och när, vilket inte den traditionella metoden kan. Förhoppningen var att detta skulle fungera oberoende av hur snabbt den mobila enheten rör sig. Detta jämfördes mot den traditionella metoden i en simulator från Ericsson. Resultatet var positivt och vi lyckades minska de resurskrävande mätningarna i genomsnitt med ca 40 % samtidigt som antalet tappade uppkopplingar minskade med ca 3 %. Tyvärr var algoritmen inte helt oberoende av hur snabbt den mobila enheten rörde sig, de högsta hastigheterna var svåra att parera. Det i övrigt positiva resultatet skapar ändå incitament att undersöka om det går att minska antalet mätningar ännu mer. Det hade också varit intressant att prova algoritmen i en riktig labbmiljö. I vårt arbete undersöktes enbart en 4G-miljö (LTE), men algoritmen skulle relativt lätt kunna modifieras till att passa andra mobila plattformar och teknologier.



En mobiltelefon rör sig mellan två mobilmaster, mobiltelefonen gör därför ett mobilmastbyte för att vara uppkopplad mot den mobilmast med bäst mottagning.