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Neighbor Cell List Management for Handover in Mobile Networks

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Study methods for creation and management of a neighbor cell list in mobile networks. Compare selected methods of neighbor's cell list management and ways for its distribution among user equipments. This comparison should consider, among others, complexity of implementation of the algorithms into LTE-A networks. Furthermore, evaluate performance of individual approaches and their impact on various network parameters, such as, scanning time, amount of signaling overhead, etc.

Bibliography / sources:

[1] Vondra, M.; Bečvář, Z.: Distance-based Neighborhood Scanning for Handover Purposes in Network with Small Cells. IEEE Transactions on Vehicular Technology, Vol. 65, No. 2, February 2016.
[2] Bečvář, Z.; Mach, P.; Vondra, M.: Self-optimizing Neighbor Cell List with Dynamic Threshold for Handover Purposes in Networks with Small Cells. Wireless Communications and Mobile Computing, Vol. 15 No. 13, September 2015.
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[4] Nguyen, V. M.; Claussen, H.: Efficient Self-optimization of Neighbour Cell Lists in Macrocellular Networks. IEEE Personal, Indoor and Mobile Radio Communications (PIMRC 2011), September 2011.
[5] Moon, J.M..; Cho, D.H.: Efficient Scanning Algorithm for Integrated Mobile and Nomadic Systems: A Hierarchical Approach. IEEE Communications Letters 2009; Vol. 13, No. 4, 2009.

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III. Assignment receipt

The student acknowledges that the master’s thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the master’s thesis, the author must state the names of consultants and include a list of references.

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V Praze dne 11. 2. 2018

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Bc. Matěj Korych

Abstrakt:

Efektivní správa Seznamu okolních buněk (NCL) v mobilních sítích může přinést výrazně nižší počet skenovaných a reportovaných buněk, jež uživatelské zařízení (UE) poskytuje v intervalech nazvaných Skenovací perioda. Zvláště, pokud je v síti nasazeno velké množství Femto buněk, může být NCL poměrně velký a UE musí skenovat a reportovat kvalitu signálu mnoha buněk i v případě, že jsou tyto buňky nevhodné pro handover. Tento případ může vést až k nadměrnému zatížení signalizačního kanálu a ke zkrácení doby určené pro přenos dat, jelikož tento čas je místo přenosu dat použit pro skenování okolních buněk. Tato diplomová práce navrhuje zlepšení stávajícího algoritmu pro redukci velikosti NCL založeném na SINR, který byl publikován v [1]. Zlepšení spočívá v aplikaci predikce SINRu pro výpočet dynamického prahu, který je dále použit pro redukci NCL. Navrhnuté řešení bylo vyhodnoceno pomocí rozsáhlé simulace, porovnáno s konkurenčními algoritmy a následně byl demonstrován přínos tohoto řešení z hlediska definovaných metrik.

Klíčová slova: **optimalizace seznamu okolních buněk, NCL management, handover, SINR, pravděpodobnost výpadku, skenované buňky, handover failure rate, predikce, extrapolace, kubický splajn, Home eNB, historie handoverů**

Abstract:

Effective management of Neighbour Cell List (NCL) in Mobile Networks can bring a significantly lower number of scanned and reported cells, provided by the User Equipment at intervals called Scanning period. Especially when a large number of Femtocells is deployed in the network, the NCL can be quite large and thus the UE must scan and report signal quality of many cells even if those are inappropriate for the handover. This can lead to the signalization overhead and reduce the time for the data transmission since this time is used for the neighbouring scanning instead. This thesis proposes an improvement of the existing SINR-based NCL reducing algorithm proposed in [1]. The improvement consists in the application of the SINR prediction for calculation of dynamic threshold used for the NCL reduction. The proposed solution was evaluated using extensive simulation and compared with competitive algorithms to show its improvement in terms of defined metrics.

Keywords: **Neighbour Cell List optimization, NCL management, handover, Signal to Interference plus Noise Ratio, outage probability, scanned cells, handover failure rate, prediction, extrapolation, cubic spline, Home eNB, handover history**

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Chapter 1. Introduction

In this chapter, the main motivation of this thesis is presented as well as the background and existing solutions followed by the thesis organization.

1.1 Motivation

Nowadays scanning algorithms use standard Neighbour cell list (NCL), which can contain up to 32 cells [2]. Each cell from the NCL should be periodically scanned by User Equipment (UE). The interval between two consecutive scans of neighbour cells is called scanning period. When the UE does this scanning, it cannot transmit or receive any data to or from the serving cell. In consequence, we have a limitation in data throughput caused by the scanning [3]. Another negative aspect of redundant cell scanning is increased power consumption which has negative effect on UE´s usable time and battery life cycle as well. Therefore, the number of scanned cells and NCL respectively should be kept as low as possible. In most cases, there is no need to scan all cells in the list. For example, many of cells can be too far away and thus their signal strength can be too low for handover to be done. In this case, we can omit these cells from the list a do not perform its scanning.

The topic of this thesis is to get familiar with methods of creation of Neighbour Cell List in Mobile Networks and to improve the existing method proposed in [1], in terms of getting better performance in its key parameters.

With cooperation with the supervisor of this thesis, the main goals of the thesis were set up:

- Improvement of an existing algorithm for reducing the size of NCL
- Find an optimal method of improvement
- Evaluation of the algorithm using the simulation in MATLAB
- Comparison of obtained outputs with competitive algorithms

Improvement should keep the number of cells in NCL as low as possible preferably with zero handover failure rate and lowest outage probability, while it should not use any other information needed for the reducing than those already available to the UE.

As a solution, SINR prediction using the extrapolation techniques was proposed and its contribution to the improvement of the existing method was proved by the simulation.

1.2 Background

The purpose of this chapter is to define the concepts used in the NCL reduction problem. Firstly, few basic technical definitions will be introduced.

1.2.1 Home eNB

Home eNB, acronym HeNB, is a name for the indoor femtocell in LTE networks. Unlike the Evolved Node-B (eNB), which is installed by providers, to usually serve a large number of users and thus cover the large area, HeNBs are typically located indoor with only low transmit power and coverage as well. These cells are installed by subscribers, with the main purpose of enhancing the coverage or capacity in a certain location, where the subscriber is located, mostly in homes and offices. The HeNB can either operate in open or closed mode. In open mode, any UE of the same provider can access the HeNB. If the closed mode is selected, only the specified UEs, usually selected by the subscriber, can access the HeNB. [4]

1.2.2 Neighbour Cell List

In Mobile Networks, every cell must keep its own table containing information about all cells to which handover can be made from this cell. This table is called Neighbour Cell List (NCL). The exact content of this list depends on the network technology, but generally, it consists of Cell identification and other parameters that can simplify the scanning for the UE, such as cell frequency, cell priority in term of cell capacity, size of the cell, technology etc. [5]. NCL is broadcasted to all UEs connected to the cell using a Broadcast Control Channel (BCCH). UEs periodically scan all cells from NCL while connected to this serving cell, which provided this list. Period of the scanning is called Scanning period (**TS**) and it is set by the serving cell based on the number of handovers during a time window, thus it is indirectly proportional to the user’s speed. During scanning, UE measures the signal quality of these cells and report it to the serving cell, where these data are handled and the decision about handover target can be made based on these data.

Neighbour#	PCI	ECGI (52 bits)	Other info
1	2	…	No X2,…
2	3	…	X2,…
3	4	…	…
4	5	…	…
5	6	…	…

Figure 1 – Example of NCL content

There are two ways how to make an NCL for each cell:

1) Manual way
2) Automatic way

Manual way consists of making NCL using network planning tools such as a mathematical model of cell coverage and include all cells within the computed coverage of a cell into its NCL. This approach can be very inaccurate and very dependent on the parameters used for the model. Another approach is to use a manpower to perform many tests within the coverage region to determine the more precise coverage map. Both methods are very costly and take a long time, thus they are useless if we have small cells in the networks, which can be deployed by the consumers in random locations and even change its location as well [1] [6].

On the other hand, the automatic approach can provide very quick detection of newly deployed cells and update NCL in all cells within its coverage. These methods are based on automatic sensing of cells by measurements made by NCL's creating cell. Since the sensing can be insufficient because the neighbour cell can have too weak signal to be sensed by the serving cell (e.g. cell hidden behind the wall), more advanced techniques such as Hidden Neighbour Discovery [7] or Automatic Neighbor Relation were proposed, to optimize automatic NCL creation.

1.2.3 Handover

Handover is a process in Mobile Networks, in which the serving cell or frequency channel of the UE is being changed.

There are several types of handovers:

a) intra-cell handover
b) inter-cell handover
c) inter-technology handover (vertical handover)

Intra-cell handover happens only within one physical cell when only the channel between UE and Serving cell is changed. Inter-cell handover is a case when UE changes the Serving cell completely. It means the Serving cell can be changed for another with different ID within the same base station or even for the cell in a different location. Inter-technology handover is a special case of the previous types when there is also o change of network technology (e.g. UMTS to GSM) besides the change of channel or serving cell.

Besides those handover types, we also distinguish between so-called Soft and Hard handover. Soft handover or make-before-break represents the case, when UE is simultaneously connected to more than one cell until the handover procedure is complete, then the connection with the former serving cell is terminated and the target cell becomes a new serving cell. This type is used in the CDMA networks. [8]

Hard handovers or break-before-make, terminates the connection between the former serving cell and establish the new connection with the target cell, which becomes a new serving cell. This will cause a short time without any connection. It is used in FDMA and TDMA networks. [8]

Handover can be triggered by several reasons:

- UE is moving and it will get at the end of the coverage area of its serving cell and handover must be performed to another cell with better coverage
- Capacity of serving cell is already exhausted and thus the serving cell must be changed
- Channel used between UE and serving cell becomes interfered

Since for purposes of this thesis we only consider the inter-cell handover triggered by the UE going towards the edge of its serving cell, the further text will be devoted to this case only.

Generally, there are 2 most impact parameters on the handover decision: **Handover hysteresis and Time to Trigger.** Besides those two parameters, parameter A3 offset is used in addition to the two previous parameters.

Handover hysteresis is a margin in dB which is added to the reported Received Signal Strength Indicator (RSSI) of the serving cell and then this value is compared to the reported RSSI of the neighbouring cells. A3 Offset is another margin in dB which is added to RSSI of the serving cell, besides the handover hysteresis in order to fulfill the handover hysteresis condition (A3 event):

$$RSSI_{neighbour} > RSSI_{serving} + hysteresis + A3_{offset} \tag{1}$$

Purpose of the handover hysteresis is to prevent from handovers between cells with a very similar value of RSSI, which can cause the ping-pong effect when UE continuously switches cells in very short intervals.

Time to Trigger (TTT) is a time interval during which the handover hysteresis condition (1) must be continuously fulfilled. Purpose of this parameter is to omit unnecessary handovers, caused by the short time drop of RSSI for example due to multipath propagation. TTT can range from a few tens of milliseconds to a few seconds and should be set dynamically according to the speed of UE [9]. Handover decision using those three parameters is visualized in the figure below.

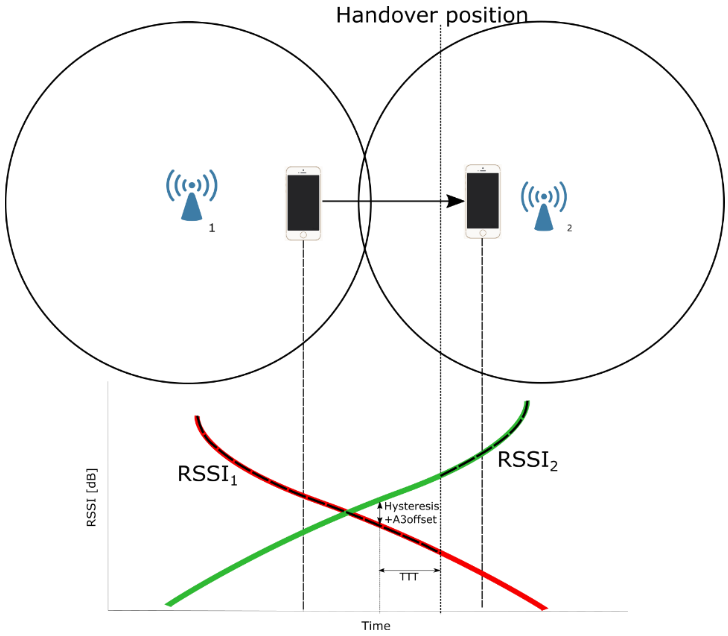

Figure 2 – Handover parameters

1.2.4 Signal to Noise plus Interference Ratio

Signal to Noise plus Interference Ratio (SINR) is a one of the signal quality describing metrics. It is defined as:

$$SINR = \frac{P}{I + N} \tag{2}$$

where P represents the total power received by UE from serving cell, I represents the sum of received power of all other cells and N represents the background noise. It is usually expressed in decibels as $SINR_{dB} = 10 \log SINR$

1.2.5 Missing target cell

Since UE scans and reports only the cells from the NCL, the situation when the best handover target cell is near the UE, although not included in the NCL, can happen. Because eNB does not have a measurement report of this cell from the UE, it is not considered for the handover. Therefore, handover can be performed to the cell with lower SINR rather than to the real target cell which is missing and an unnecessary decrease in connection quality can occur or even handover might not be performed at all due to the strong interference of missing target cell and thus handover hysteresis for other cells might not be fulfilled. In such case, UE will stay connected to the serving cell until the connection is lost and an outage occurs.

1.3 Existing Solutions

This chapter aims to briefly introduce the algorithm which is improved in the thesis as well as other different approaches for NCL reducing.

1.3.1 Algorithm to be improved

The main task of this thesis is to improve an algorithm proposed by Bečvář et. al in [1] and [10]. The proposed algorithm is based on reducing the size of the NCL by omitting all cells with handover probability lower than the dynamic threshold, which is defined as:

$$P_{t,dyn} = \begin{cases} 0 & ,SINR_{a,UE} \leq SINR_{min} \\ 1 - \left(1 - \dfrac{SINR_{a,UE} - SINR_{min}}{SINR_{max} - SINR_{min}}\right)^{E} & ,SINR_{min} < SINR_{a,UE} < SINR_{max} \\ 1 & ,SINR_{a,UE} \geq SINR_{max} \end{cases} \tag{3}$$

where $SINR_{a,UE}$ is a SINR between serving cell (cell a) and UE, $SINR_{min}$ is the minimal level of SINR, $SINR_{max}$ is the maximal level of SINR and E is the parameter for changing the shape of the function.

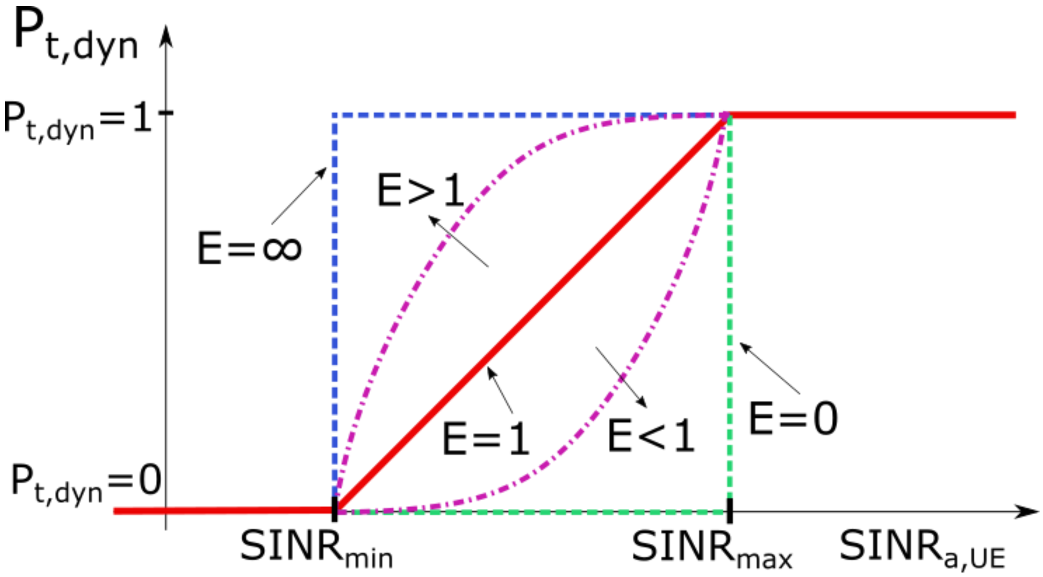

Figure 3 – Relation of dynamic threshold and SINR

Function of $P_{t,dyn}$ is generally a function of SINR between serving cell and the UE. When UE observes SINR lower or equal to $SINR_{min}$, probability threshold is set to 0 and thus all cells from the original NCL are inserted in to the reduced NCL. Exactly the opposite situation, when UE is very close to the serving cell location and observed SINR is larger than maximal SINR (maximal in terms of the SINR needed for the highest transmission rate), cause the threshold to be set to 1 and thus the reduced NCL will be either empty or includes only one cell with handover probability equal to 1. If observed SINR is between $SINR_{min}$ and $SINR_{max}$ and parameter E is set to 1, threshold has linear relation and corresponds to the margin between observed SINR and minimal SINR divided by the range of SINR. That means the threshold will be set accordingly to the position of UE within the serving cell coverage area. If the UE is close to the serving cell location, observed SINR is near the maximal SINR and threshold is almost 1, otherwise if UE is close to the cell edge, SINR is close to the minimal SINR and value of threshold is close to 0 since handover is expected.

In case the parameter E is smaller or larger than 1, the function of the threshold between minimal and maximal value of the SINR, becomes non-linear, while in its extreme points, equal to 0 and ∞, the whole $P_{t,dyn}$ function will become a step function with the step located either in minimal or maximal SINR as it can be seen in Figure 3.

Setting E to 0 is useless in terms of NCL reducing since it will make no reduction of the original NCL unless the observed SINR is above the maximal value. On the other hand, setting E to the large value for example 1000 will cause the threshold to be set to 1 almost all the time when the observed SINR is larger than minimal unless the UE is very close to the cell edge when threshold can drop under 1. It will cause the situation when UE will not scan any cell except the cell with handover probability equal to 1 if any until it reaches the cell edge represented by $SINR_{min}$.

This setting will ensure very low average NCL size, however, in real networks, SINR is not measured continuously by the UE. The problem can occur when UE is moving towards the cell edge with speed of let's say 1 m/s and observed SINR is sampled periodically at discrete time points. In the first point, the measured SINR was larger than $SINR_{min}$ and thus threshold was set very closely to 1. None of cells from N_o has handover probability larger than the threshold and thus N_{new} is completely empty and no scanning nor handover was performed. UE moves continuously and it crosses the cell edge before next SINR sample was measured. In this point, the UE lost the connection to the serving cell and is in an outage state due to the NCL reduction and call drop might happen.

Note that this situation can also happen in case of E set to 1 or any other value different than 0 because the real target cell can have a very low probability of handover and thus it can still be missing from the optimized NCL even the threshold is almost 0.

To solve this problem, authors of this approach proposed a modification in [1]. This modification proposes adding the parameter Δ to the original equations as follows:

$$P_{t,dyn} = \begin{cases} 0 & , SINR_{a,UE} \leq SINR_{min} + \Delta \\ 1 - \left(1 - \dfrac{SINR_{a,UE} - (SINR_{min} + \Delta)}{SINR_{max} - (SINR_{min} + \Delta)}\right)^{E} & , SINR_{min} + \Delta < SINR_{a,UE} < SINR_{max} \\ 1 & , SINR_{a,UE} \geq SINR_{max} \end{cases} \quad (4)$$

Influence of Δ parameter to the dynamic threshold function can be seen in the figure below.

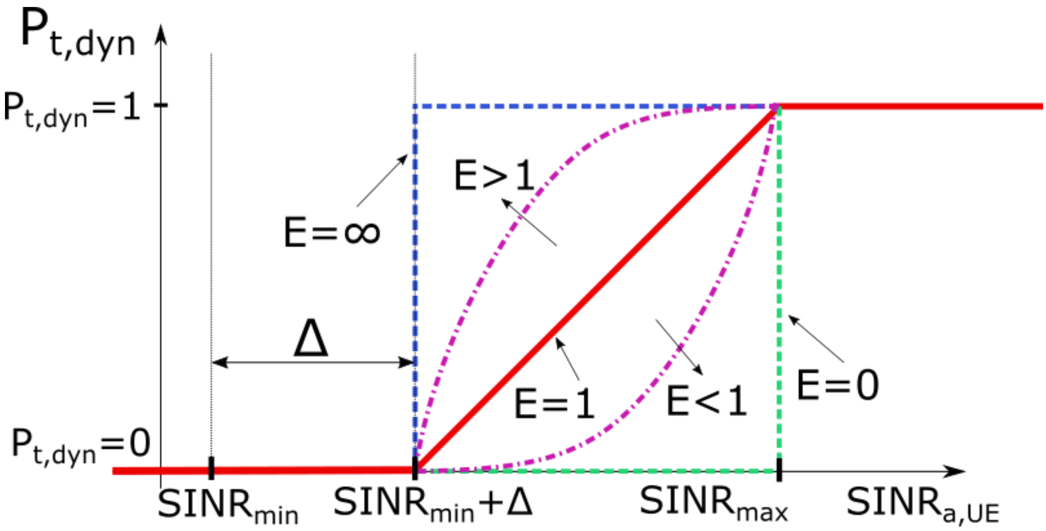

Figure 4 – Influence of Δ to the dynamic threshold function

Purpose of Δ is to reflect the difference of SINR, which can occur between two consecutive measurements of SINR, given by the scanning period TS and it can be expressed as:

$$\Delta = SINR_{a,UE}(t) - SINR_{a,UE}(t + TS) \quad (5)$$

where $SINR_{a,UE}(t + TS)$ is a level of SINR observed in the next measurement and $SINR_{a,UE}(t)$ is a level of SINR observed in a current measurement.

Authors of this algorithm proposed to set fixed Δ, denoted as Δ_{opt}, which stays constant for all UEs in the certain area. Purpose of Δ_{opt} is to achieve the goal, that all neighbouring cells will be included in the reduced NCL at the time when UE crosses the cell edge and thus no handover failure due to the missing cell should occur. Δ_{opt} is derived as the largest observed difference of SINR between two consecutive measurements among all UE's, during the period of collecting statistics. Δ_{opt} reduces the occurrence of missing cell to zero, but on the other side it increases the size of the reduced NCL more than necessary.

Since Δ_{opt} is computed as the worst case of the observed SINR difference, it does not reflect the real situation of each UE. For example, Δ_{opt} can be set as 4 dB and $SINR_{min}$ as -9 dB. UE observes SINR level of -6 dB. According to equation (4), $P_{t,dyn}$ will be set to 0 and reduced NCL will contain all cells from the original NCL, because outage is assumed before next SINR measurement. None of the cells fulfil the handover condition and UE continues to be connected to the serving cell. The level of the SINR in the next measurement is -7 dB and thus no outage occurs, although algorithm assumed it. Hence the setting of $P_{t,dyn}$ as 0 and subsequent stopping of NCL reduction was unnecessary. The text above implies the main drawback of this algorithm, which is how to set the Δ parameter effectively. Δ used in the algorithm should be set as close as possible to the formula (5), since inclination from this formula can evoke either unnecessary scanning or even call drop in the worst case. Setting the constant Δ for all UE's disregarding any other information has been already proved as ineffective in terms of the number of scanned cells in chapter 5.2.1. Better approach is to derive individual dynamic Δ which is unique for each UE in each neighbour scanning. Thus, it can better correspond to the real position and movement of the UE within the cell. To find out the implementation of this approach is the main goal of this thesis and it is described in the Chapter 3.

1.3.2 Other existing solutions

There are other existing solutions based on different approaches. In [11] authors proposed to collect individual statistics of handover for each user and then omit all cells whose probability is lower than 1%. A similar approach was proposed in [12], with considering cumulative long-term statistics of all users instead. This concept still provides a relatively high number of scanned cells, while call drop due to missing cell increases.

[13] introduces the concept, in which a group of users close to each other is considered. Assuming these users can measure very similar signal strength, authors propose to use these users as a cluster and split the NCL measurements equally between them. This will reduce the number of scanned cells for each user since each user only scans one part of the NCL. Although it requires the network to know the very precise location for each user to make a cluster, which can be impossible to ensure.

In [14] authors proposed mechanism, where reported measurements of the pilot signal quality of all neighbours from the original NCL are reported to the serving cell. Serving cell collects those measurements from all UE and creates a table, where each row represents the reported value in one location within the serving cell coverage. All measurements are first filtered by the minimal signal quality threshold and cells with reported measurements lower than this threshold, are omitted from the table. Next, from the remaining cells, the cell which covers the maximum number of location, represented by the measurement reports is picked up to be added to new NCL. Those locations are then removed from the table, and another cell covering the maximum number of locations is picked up again. This process continues until all reported locations are covered by at least one cell. This algorithm aims to create the minimal NCL covering the maximal number of locations. The drawback of this algorithm is, that it needs quite an excessive size of the reduced NCL, to ensure low call drop.

Hogue et al. [15], proposed exponential polynomial function as the threshold for reducing the NCL of the femtocells. They first reduce the initial NCL by omitting cells with RSSI lower than the certain fixed threshold and then apply the cognitive programmed threshold, which depends exponentially on the number of femtocells deployed within the range of the serving cell to further reduce the NCL firstly reduced by the fixed RSSI threshold. It can reduce the size of NCL well, but it requires the knowledge of the number of cells within the serving cell coverage including the hidden and closed cells.

1.4 Thesis Organization

The content of this thesis is organized as follows. In Chapter 2, the System Model of the NCL reduction, consisting of the general description, definitions of the performance metrics and list of assumptions together with the list of algorithm’s input and output parameters, is introduced. Chapter 3 provides detailed information about the proposed modification, while Chapter 4 presents adopted simulation model, including its parameters, scenarios, and algorithms which are being used for the comparison of obtained results.

In Chapter 5, obtained results are summarized and accuracy of the prediction demonstrated. Conclusion, together with concepts of the future algorithm development are discussed in Chapter 6.

Chapter 2. **System Model**

This chapter summarizes the problem and assumptions of the NCL optimization solved in this thesis.

2.1 General Principle of NCL reduction

Let's assume the original NCL, N_o, provided by the serving cell, which contains all neighbouring cells, that are within the coverage area of the serving cell. N_o is composed of two separate lists of cells. First list, denoted as N_s, is composed of those cells, that can be sensed by the serving cell directly. That means that coverage of these cells overlaps the location of serving cell and signals from those cells can be received by the serving cell. The criterium for including the sensed cell in to the list is the value of the cell's SINR observed by the serving cell. This SINR must be above defined threshold in order to include this cell in to the list N_s.

The second list denoted as N_{hidden}, is the set of cells, that are within the coverage area of the serving cell, but their signal is not strong enough to be sensed by the serving cell. Thus, this list must be build up using more complex methods. One of the approach of setting N_{hidden} is proposed in [16].

According to the text above, N_o can be expressed as follows:

$$N_o = N_s \cup N_{hidden} \tag{6}$$

Figure located below shows the difference between the hidden and sensed cells. Hidden cells are displayed in green colour, while sensed cells are displayed in blue colour as well as their coverage area. Serving cell and its coverage area are displayed in red colour.

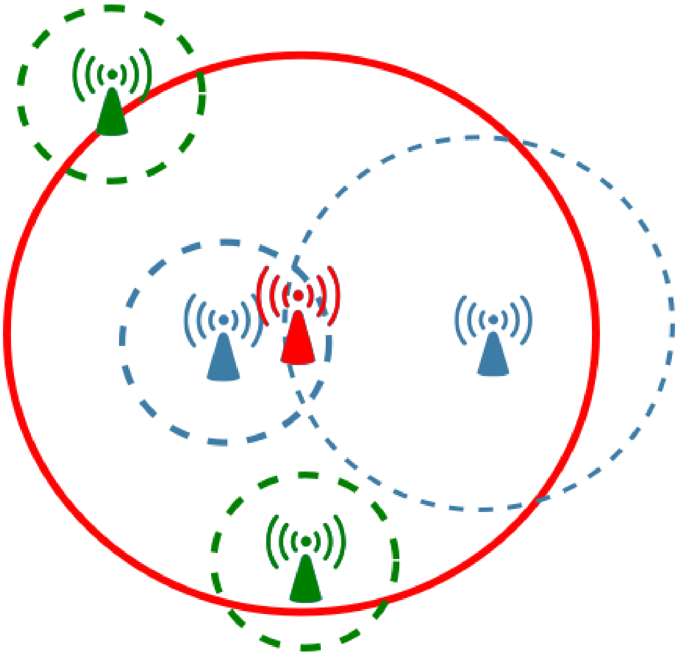

Figure 5 – Demonstration of sensed cells, hidden cells, and serving cell

Size of N_o after the initiative stage can be large and it can contain cells, to which handover is very unlikely to be performed and reduction of the N_o should be done. For example, if UE use the red cell as its serving cell, both blue and green cells are included in its original NCL and thus all of them are scanned. However, this UE can move mostly in a small part of the overall area covered by this serving cell and visit the other part of this area only rarely or even never. In the figure bellow, we can see the situation when UE moves only within the black dot area all the time. In this case, while using cell 1 as a serving cell, only cells 2 and 5 are among the possible handover target. Therefore, all other cells except those two can be omitted from the NCL.

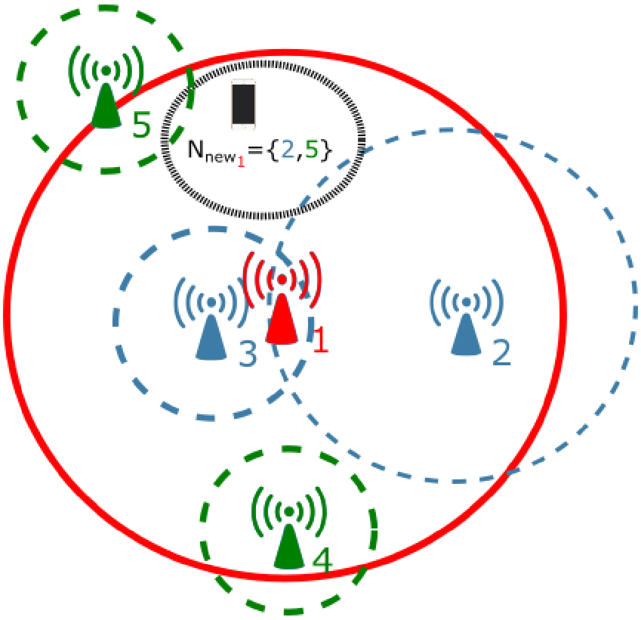

Figure 6 – Demonstration of NCL reduction

Our model assumes, that every UE has collected long time statistics for each serving cell the UE was connected to. These statistics consist of number of handovers between this serving cell and each neighbouring cell included in N_o.

Having these statistics, each UE can set its own individual handover probability list for each serving cell. Handover probability of UE from serving cell a to a neighbouring cell b can be then expressed by the following formula:

$$P_{a,b} = \frac{H_{a,b}}{\sum_{g \in N_o} H_{a,g}} \tag{7}$$

where $H_{a,b}$ is the total number of handovers performed by UE from serving cell a to the neighbouring cell b and $H_{a,g}$ is the total number of handovers performed by UE from serving cell a to all set of cells from the N_o, denoted as g.

Note that if there is no statistic collected for a certain serving cell, handover probabilities cannot be calculated and thus are not available for the further needs of the algorithm. If the UE happens to do a handover into this cell and algorithm finds no handover probabilities available, no NCL reduction will be done and complete N_o will be used for the scanning.

With known individual handover probabilities, we assume to create a reduced NCL, N_{new}, using the UE’s own individual dynamic probability threshold $P_{t,dyn}$:

$$N_{new} = \{cell_b \subseteq N_o : P_{a,b} \geq P_{t,dyn}\} \tag{8}$$

Reduced NCL, N_{new}, contains all cells from N_o with handover probabilities larger or equal to the dynamic threshold $P_{t,dyn}$.

Now the problem is how to efficiently set the dynamic threshold for each UE. Our algorithm aims to improve the algorithm proposed in [1] and described in detail in chapter 1.3.1. This algorithm has its weak spot in assuming either no change of SINR between two consecutive scanning or assuming fixed difference given by the largest difference observed between two scans, for the setting of a dynamic threshold. As explained in that chapter, those settings can either cause missing cell in the first case or not an efficient reduction in the second case. As a solution, we propose to use a prediction to predict a difference SINR between current and next measurement of SINR in order to set the dynamic threshold more efficiently.

2.2 Assumptions

As assumptions for our algorithm, we consider the following requirements:

- **All users move with the constant speed and only outdoors**

  Explanation:

  Indoor movement is not considered since when the user is located indoor, he typically stays in one fixed point (e.g. sitting in the office) or moves in the very small area (e.g. flat) and thus stays connected to one outdoor eNB or indoor HeNB without the need of handover.

- **Scanning Period is dependent on the user's speed only**

  Explanation:

  The Scanning Period in real networks is assigned depending on the user's speed together with requirements of the handover procedure. Since we do not intend to improve handover procedure, we assume the dependence of Scanning Period on the user's speed only and denoted as:

  $$TS[s] \propto \frac{1}{v} \tag{9}$$

  where v represents the speed of the user in m/s.

- **Handover statistics have been collected and are available for the purposes of the algorithm**

  Explanation:

  Handover statistics must be collected for at least one cell in the area prior to the reduction deployment since it is essential for the NCL reduction. Otherwise, the reduction is not possible. Original NCL will be used instead and no improvement in the number of scanned cells will be observed.

- **Original NCL includes all cells within the coverage area of the serving cell**

  Explanation:

  Original NCL should include all cells, to which the handover is possible to eliminate the situation when a missing cell will occur even when the reduction of NCL is stopped and original NCL is used instead. [16]

- **Each SINR sample is assumed to be a short time average**

  Explanation:

  The SINR observed and reported to the serving cell by the UE and used for the algorithm as well, is an average in a short time window compared to the scanning period, while long enough to almost mitigate the multipath fading from the samples of SINR used in the algorithm. Therefore the influence of multipath fading is not considered. [17]

2.3 Performance Metrics

Four key performance parameters for demonstrating the algorithm's contribution and its competitiveness were defined:

2.3.1 Average number of scanned cells

An average number of scanned cells is defined by the following equation:

$$N_{new}^{avg} = \frac{\sum_{i=1}^{S_{sim}} N_{new}^{size}\,(i)}{S_{sim}}\ [-] \tag{10}$$

where $N_{new}^{size}(i)$ is the number of cells in the reduced NCL in *i*-th scan and S_{sim} is the total number of scans during the simulation.

It represents the number of cells used for neighbour scanning (size of the reduced NCL used for scanning) in each performed scanning, divided by the total number of scans during the observation. In our simulation case, it is equal to 120 000 scans. If the UE is in the outage state in the *i*-th scan, then all cells, which can be sensed by the UE, are considered as the number of scanned cells in this step, since all neighbour cells must be scanned to find the strongest one and leave outage state.

2.3.2 Handover failure rate

Handover failure rate caused by a missing target cell, HFR, is defined in % by the following equation:

$$HFR = \frac{N_{HO}^{fail}}{N_{HO}} * 100\ [\%] \tag{11}$$

where N_{HO}^{fail} is the total number of handovers, which were not performed in time due to missing handover target in reduced NCL and thus $SINR_{serving}$ dropped under $SINR_{min}$ and N_{HO} is the total number of handovers performed during the observation.

Handover failure represents the case when there is a suitable handover target in the original NCL, but this target has been removed by the optimizing algorithm and no other suitable target is available. As a consequence, $SINR$ drops under the $SINR_{min}$ and outage occurs. It is the main metric in terms of a user experience.

2.3.3 Outage probability

Outage probability in % is defined as follows:

$$O = \frac{t_{out}}{t_{sim}} * 100\ [\%] \tag{12}$$

where t_{out} [s] is the total time when the condition $SINR_{serving} \leq SINR_{min}$ is fulfilled and t_{sim} [s] is the total observation time.

Outage probability represents the ratio of the time when UE observes $SINR$ equal or lower than $SINR_{min}$. Outage can be either caused by the missing target cell in reduced NCL, insufficient coverage or missing target cell in the original NCL.

2.3.4 Average SINR

Average SINR is defined by the following formula:

$$SINR_{avg} \frac{\sum_{i=1}^{S_{sim}} SINR\,(i)}{S_{sim}}\ [dB] \tag{13}$$

where $SINR(i)$ is the value of $SINR$ in *i*-th scan.

It represents the average value of SINR between UE and serving cell through the entire number of scans performed including the outage state when SINR is under the minimal SINR.

Chapter 3. **Proposed Algorithm**

Since the approach proposed in the algorithm described in chapter 1.3.1 does not provide optimal results due to the fixed Δ. Author of this thesis proposes an improved algorithm, which uses dynamic Δ calculation for each UE, according to the real conditions.

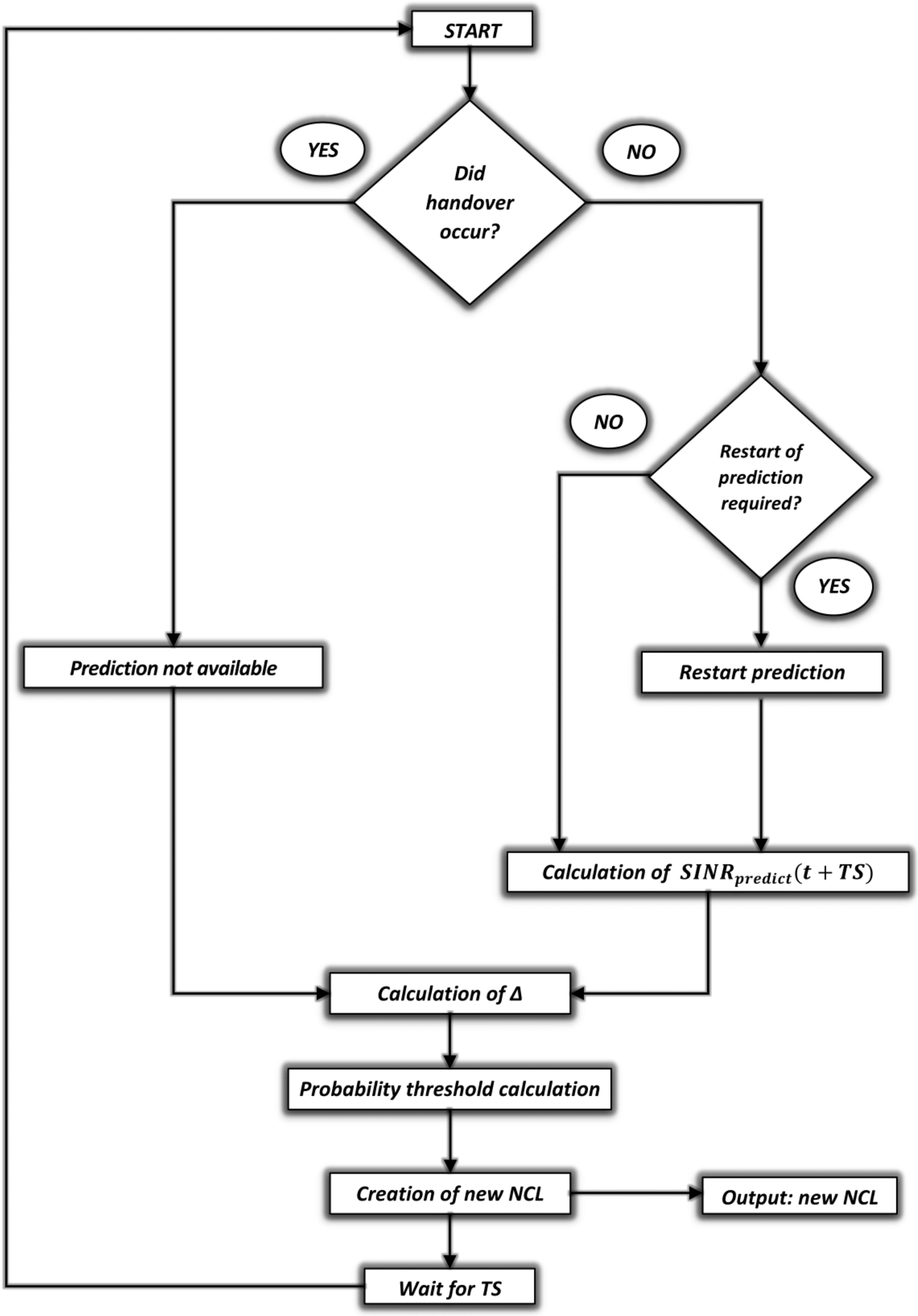

Figure 7 – Basic flowchart of the proposed algorithm

3.1 Basic concept

Flowchart placed above represents the basic concept of the proposed algorithm. It proposes the new way how to dynamically calculate Δ based on a SINR prediction. Immediately after its start, the algorithm tests, if handover occurred since the last run. If yes, prediction cannot be used as we do not have enough previous samples of SINR for the prediction algorithm. We only have current sample ($\boldsymbol{SINR_{a,UE}(t)}$), which is the first sample after the handover. Thus, we inform the "Calculation of Δ" block about the prediction not being available.

If handover did not occur since the last run, the algorithm proceeds to the block where it decides, whether the restart of the prediction is needed or not. The detailed mechanism of this block is explained later in chapter 3.3.

Finally, the determination of predicted value of SINR, $\boldsymbol{SINR_{predict}(t+TS)}$, using $\boldsymbol{n}$ samples of previous values of SINR and a current sample of SINR, is done in a block of prediction, which is further descripted in chapter 3.2,

Value of $\boldsymbol{SINR_{predict}(t+TS)}$ further enters the block of "Calculation of Δ", where Δ is calculated according to the following formula:

$$\Delta = \begin{cases} \boldsymbol{SINR_{a,UE}(t)} - \boldsymbol{SINR_{predict}(t+TS)}, & if\ \boldsymbol{SINR_{predict}(t+TS)}\ is\ available \\ 0, & if\ \boldsymbol{SINR_{predict}(t+TS)}\ is\ not\ available \end{cases} \quad (14)$$

In case of SINR prediction being available, Δ is set as a difference between the current observed sample of SINR and predicted SINR in time t+TS. If there is no prediction available, Δ is set to zero. Since the latter case happens only immediately after the handover when the SINR is assumed to be far away from the minimal SINR, absence of correct Δ until the next scanning is not a real problem.

Next block calculates the probability threshold needed for the NCL reduction. Since the dynamic Δ proposed above, can be both negative and positive, depending on whether the algorithm predicts improvement of SINR (negative Δ) or deterioration of SINR (positive Δ), the author proposes following innovation of the equation (4) to enable setting the threshold according to the predicted change of SINR value:

$$P_{t,dyn} = \begin{cases} 0, & (SINR_{a,UE} - \Delta) \leq SINR_{min} \\ 1 - \left(1 - \dfrac{(SINR_{a,UE} - \Delta) - SINR_{min}}{SINR_{max} - SINR_{min}}\right)^{E}, & SINR_{min} < (SINR_{a,UE} - \Delta) < SINR_{max} \\ 1, & (SINR_{a,UE} - \Delta) \geq SINR_{max} \end{cases} \tag{15}$$

When the deterioration of SINR is predicted, Δ is positive and thus this value is subtracted from the observed value of SINR and the threshold is set according to this new value. When improvement of SINR is predicted, Δ is negative and thus the value used for setting the threshold is composed of the value of observed SINR plus Δ (since subtracting the negative delta creates adding). Unlike the threshold defined in (4), this modification preserves slope of the threshold function in the section between minimal and maximal SINR, independently on the Δ parameter. It also gives us a chance to set the threshold to 1 when predicted SINR is higher than the maximal SINR.

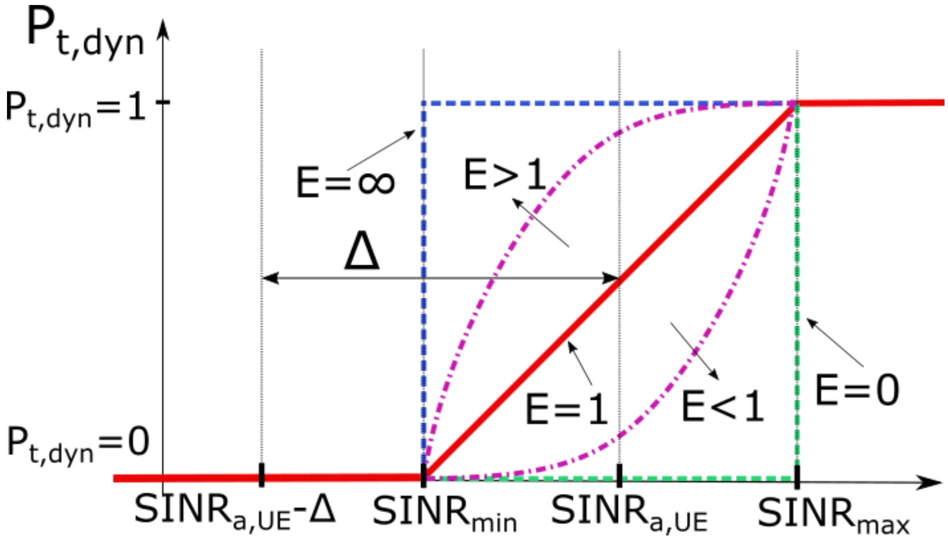

Figure 8 – Modification of the dynamic threshold function

When the probability threshold (15) is calculated, algorithm proceeds to the block where new reduced NCL is generated, using the equation (8). After creating new NCL, the algorithm waits for the time given by the scanning period (TS) and then starts over again.

3.2 Prediction of SINR

This chapter provides the details about SINR prediction which is represented by the block "***Calculation of*** $\boldsymbol{SINR_{predict}(t+TS)}$**"** in the flowchart shown in Figure 7. Following flowchart demonstrates the key concept of the prediction mechanism:

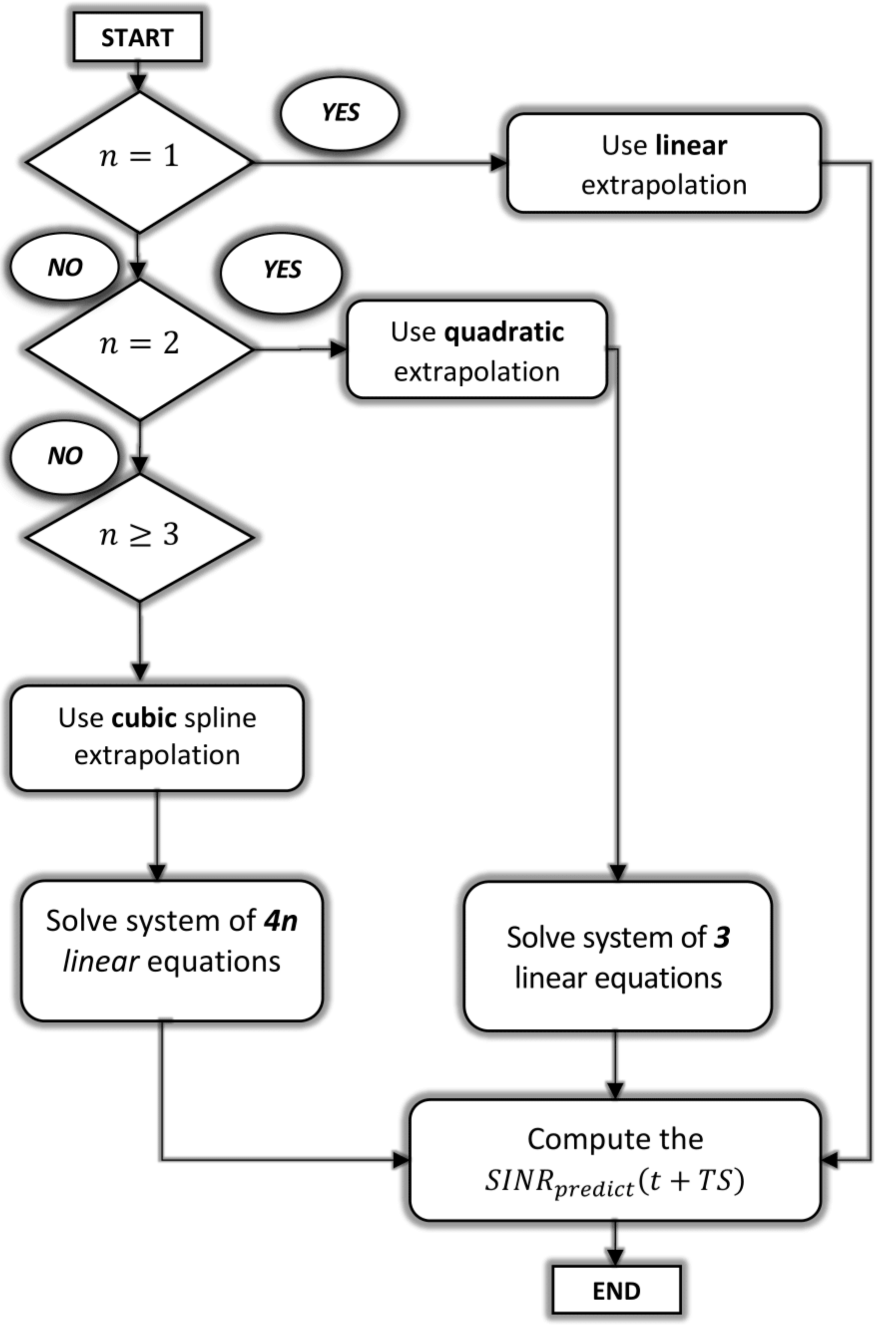

Figure 9 – Flowchart of the prediction

Prediction is based on the numerical extrapolation. Extrapolation is a method which gives an estimation of future values based on the relations of the previous values in the time series. [18]

The proposed algorithm uses three different extrapolation methods, depending on the number of previous samples available. The primary extrapolation function of the proposed algorithm is the cubic spline extrapolation, however since there is a minimum number of 3 previous samples to construct cubic spline function [18] [19], the author also proposes to use a quadratic and linear extrapolation to allow prediction with only 2 or 1 previous samples available. The further text discusses those three methods of extrapolation in details.

3.2.1 Linear Extrapolation

Linear extrapolation uses linear function (straight line) as an estimation of the future value. Since it only requires knowledge of the two points, we can use it in case we have only 1 previous sample of SINR available. It can be generally expressed as [18]:

$$y = y_0 + \frac{y_1 - y_0}{x_1 - x_0}(x - x_0) \tag{16}$$

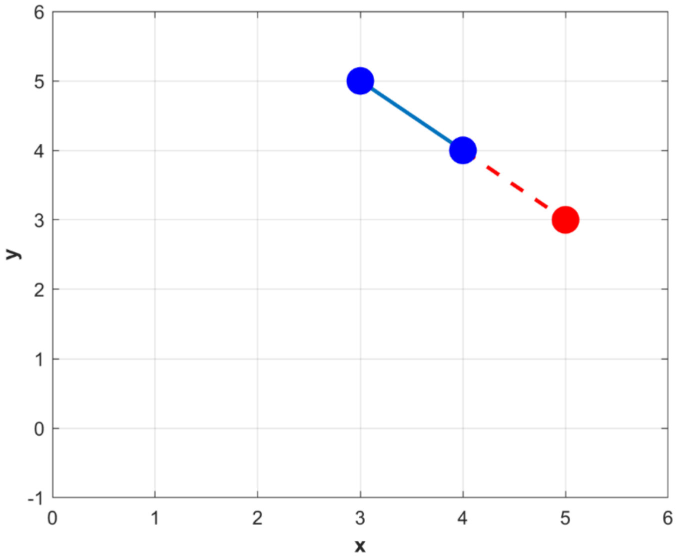

Figure 10 – Example of linear extrapolation

In the figure above, we can see the example of linear extrapolation using 2 points (blue color). The extrapolated point is in red color. It is made by fitting a straight line between two blue points and extending its end to get a value of red extrapolated point.

In our case of SINR prediction, assuming that the time difference of each sample is equal to TS, (16) can be modified as:

$$\begin{aligned} SINR_{predict}(t+TS) &= SINR(t-TS) + \frac{SINR(t)-SINR(t-TS)}{t-(t-TS)}\big((t+TS)-(t-TS)\big) \\ &= SINR(t-TS) + \frac{SINR(t)-SINR(t-TS)}{TS}2TS \\ &= SINR(t-TS) + 2\big(SINR(t)-SINR(t-TS)\big) \\ &= \mathbf{2}\big(\boldsymbol{SINR(t)-SINR(t-TS)}\big) \qquad (17) \end{aligned}$$

The figure below shows this method applicated to our problem with the SINR prediction, the real observed SINR and its extrapolated value using the linear extrapolation.

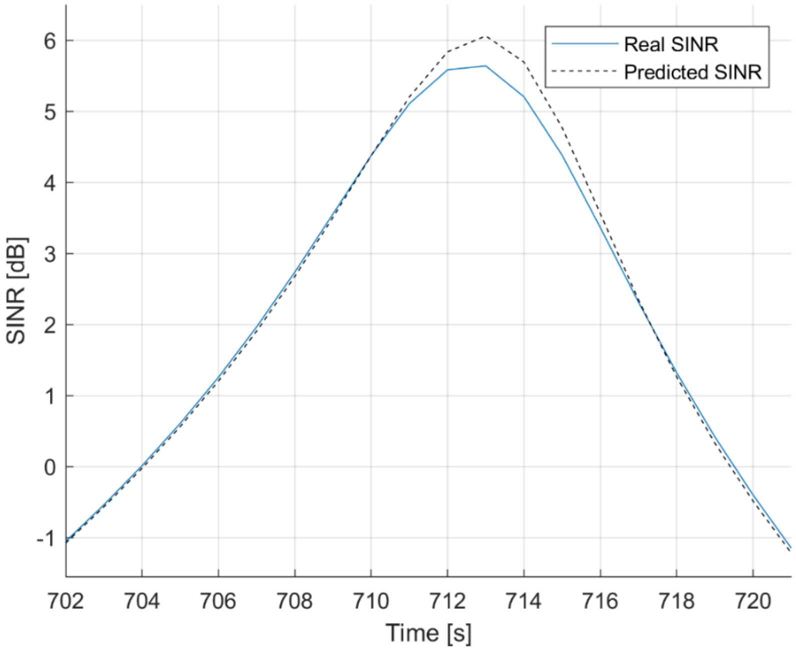

Figure 11 – Example of SINR prediction using linear extrapolation only

As we can see, this method is not very precise, since it only uses information from 1 current a 1 previous samples, however using this method in case we don’t have more than 1 previous sample can be acceptable.

3.2.2 Quadratic Extrapolation

In case there are 2 previous samples available, more precise quadratic extrapolation will be used instead of linear extrapolation. Quadratic extrapolation can be generally expressed as [18]:

$$y = a + b(x - x_k) + c(x - x_k)^2 \tag{18}$$

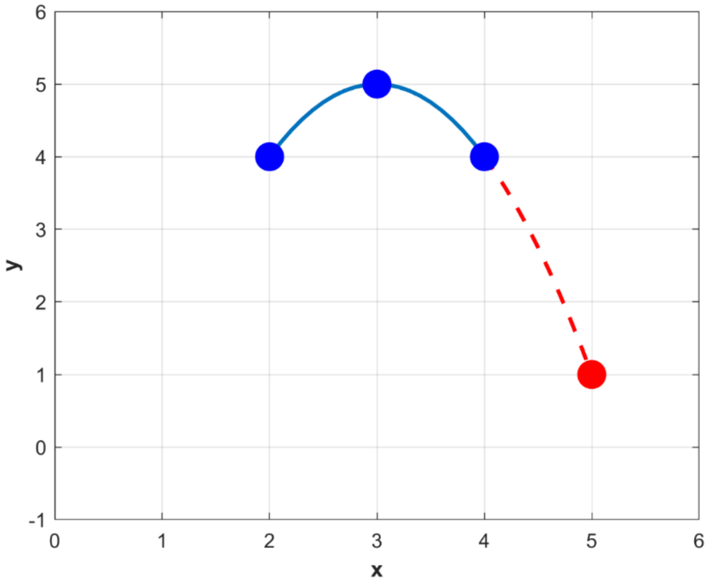

Figure 12 - Example of quadratic extrapolation

Figure located above shows the example of quadratic extrapolation using 3 blue points. It is made by fitting the parabola function within those 3 points a then extending its end to get a value of red extrapolated point.

For our case of SINR extrapolation in time *t*+*TS*, we can rewrite it as:

$$SINR_{predict}(t + TS) = a + b\big(t + TS - (t - 2TS)\big) + c\big(t + TS - (t - 2TS)\big)^2$$

$$= a + b(3TS) + c(3TS)^2$$

$$= \boldsymbol{a + 3bTS + 9c(TS)^2} \tag{19}$$

Now we have 3 unknown constants $\boldsymbol{a}$, $\boldsymbol{b}$ and $\boldsymbol{c}$. For a unique solution, we need a system of 3 linear equations. Since the quadratic function must pass through all points, we can set the equation system by using the 2 previous samples and the recent sample of SINR as those points and fit them into the equation (18):

$$\begin{aligned} SINR(t-2TS) &= a + b\big(t-2TS-(t-2TS)\big) - c\big(t-2TS-(t-2TS)\big)^2 \\ &= \boldsymbol{a} \end{aligned} \tag{20}$$

$$\begin{aligned} SINR(t-TS) &= a + b\big(t-TS-(t-2TS)\big) - c\big(t-TS-(t-2TS)\big)^2 \\ &= \boldsymbol{a} + \boldsymbol{bTS} + \boldsymbol{c}(\boldsymbol{TS})^{\boldsymbol{2}} \end{aligned} \tag{21}$$

$$\begin{aligned} SINR(t) &= a + b\big(t-(t-2TS)\big) - c\big(t-(t-2TS)\big)^2 \\ &= \boldsymbol{a} + \boldsymbol{2bTS} + \boldsymbol{4c}(\boldsymbol{TS})^{\boldsymbol{2}} \end{aligned} \tag{22}$$

Then the algorithm solves this system of 3 linear equations to get values of all 3 constants and then calculates the predicted value of SINR using equation (19).

The example of using this extrapolation method for the SINR prediction with 2 previous samples of SINR and recent sample of SINR respectively, can be seen in the figure below.

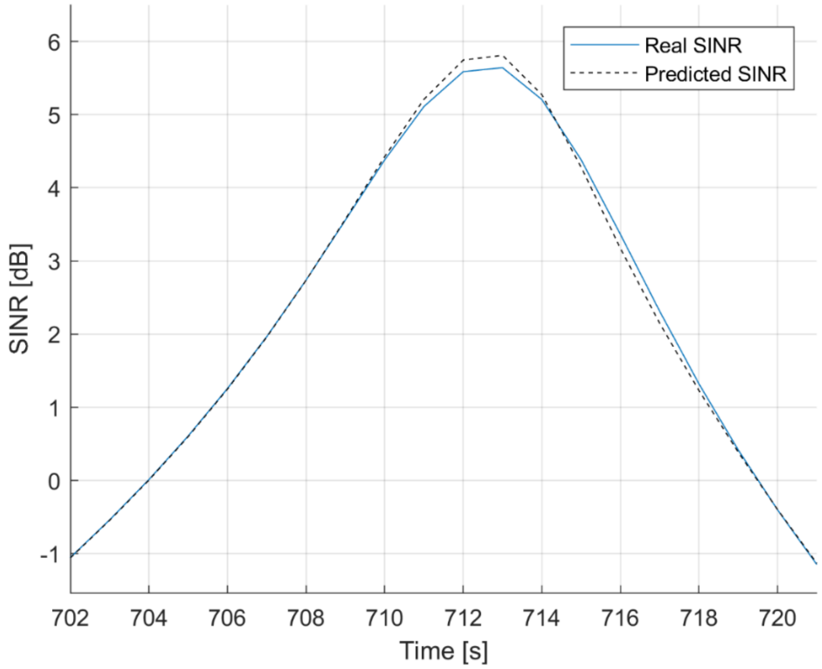

Figure 13 – Example of SINR prediction using quadratic extrapolation only

The extrapolated value of SINR fits better to the real value of SINR in comparison with the linear extrapolation shown in Figure 11. However, a more precise method of extrapolation is still needed. Thus, we propose the third method of extrapolation in the following chapter.

3.2.3 Cubic Spline Extrapolation

In case of at least 3 previous sample of SINR available, the most precise method available in this algorithm will be used. This method uses cubic spline extrapolation. A cubic spline is a piecewise polynomial of the third degree, defined uniquely between each set of two consecutive points also called knots [19]. The cubic spline can be mathematically defined as [18]:

$$S(x) =$$

$$\begin{cases} p_1(x) = a_1 + b_1(x - x_1) + c_1(x - x_1)^2 + d_1(x - x_1)^3, & x_0 \leq x < x_1 \\ p_2(x) = a_2 + b_2(x - x_2) + c_2(x - x_2)^2 + d_2(x - x_2)^3, & x_1 \leq x < x_2 \\ \vdots & \\ p_n(x) = a_n + b_n(x - x_n) + c_n(x - x_n)^2 + d_n(x - x_n)^3, & x_{n-1} \leq x < x_n \end{cases} \tag{23}$$

The characteristic of the cubic splines is that every two consecutive splines are continuous in their common knot and also their first and second derivatives are continuous at this knot [18]:

$$p_i(x_i) = p_{i+1}(x_i), \quad p_i'(x_i) = p_{i+1}'(x_i), \quad p_i''(x_i) = p_{i+1}''(x_i), \quad i = 1,2,\dots,n-1 \qquad (24)$$

Splines must also fulfill the condition of matching in value with all their knots [18]:

$$p_i(x_{i-1}) = f(x_{i-1}), \quad p_i(x_i) = f(x_i) \quad i = 1,2,\dots,n \qquad (25)$$

There are four unknown coefficients in each spline. Assuming, there is one spline between each consecutive pair of points, and we have a total of n+1 points, the total **4n** unknowns need to be solved since the total number of splines is **n**. Therefore the system of **4n linear equations** must be set to solve the system.

Conditions of continuity (24), give us 3(n-1) equations and condition of matching in value (25), gives us another n+1 equations. This is a total 4n-2 equations and thus we still need 2 more equations to set a 4n system.

The most common imposed additional condition is so-called “**natural cubic spline**” [18] [19]:

$$p_1''(x_0) = 0, \quad p_n''(x_n) = 0 \qquad (26)$$

gives us 2 remaining equations and thus we can solve the system of equations to get the coefficients of all splines.

Once the system is solved, coefficients calculated and the splines are constructed, we use the last spline as the equation for the extrapolation:

$$\begin{aligned} SINR_{predict}(t+TS) &= a_t + b_t(2TS) + c_t(2TS)^2 + d_t(2TS)^3 \\ &= \boldsymbol{a_t + 2b_t(TS) + 4c_t(TS)^2 + 8d_t(TS)^3} \end{aligned} \qquad (27)$$

and calculate the predicted value of SINR.

The following figure shows the general concept of cubic spline extrapolation with 4 samples overall. The unique spline is created for each pair of two consecutive blue points and then the last spline is extended to extrapolate the value of red point.

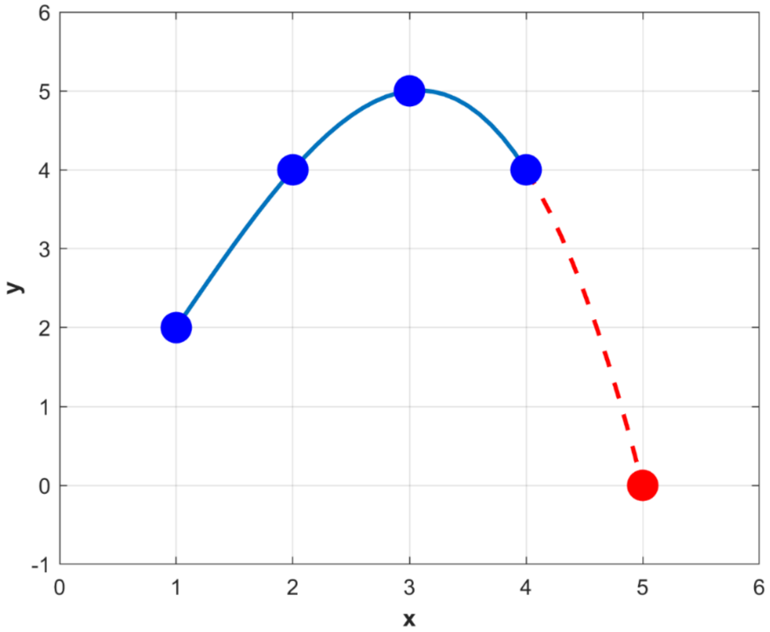

Figure 14 - Example of cubic spline extrapolation

The following figure shows the cubic spline extrapolation applicated to the SINR prediction, using 3 previous samples of SINR and the recent sample of SINR. We can see the prediction fitting the real value best of all methods.

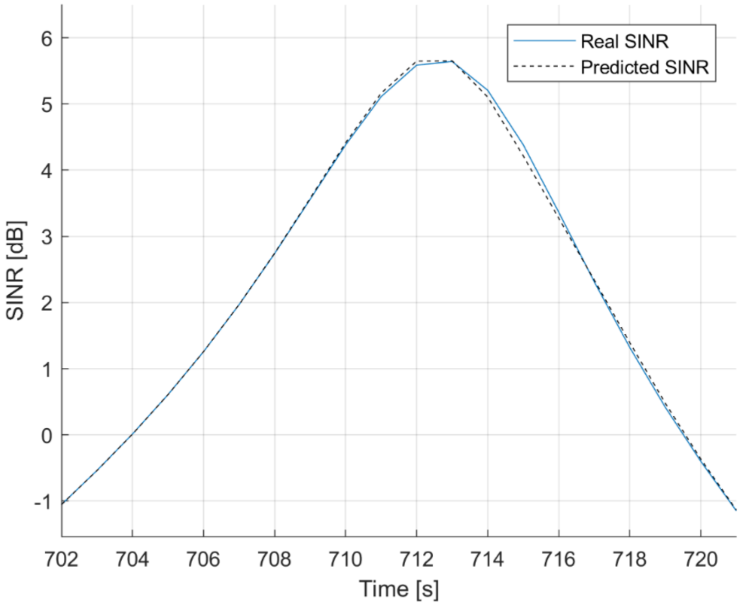

Figure 15– Example of SINR prediction using cubic spline extrapolation with 3 previous samples

3.3 Restart of prediction

Since the prediction needs to be restarted when the observed error of the prediction overgrows certain threshold, the author proposes the following mechanism to handle the prediction restart:

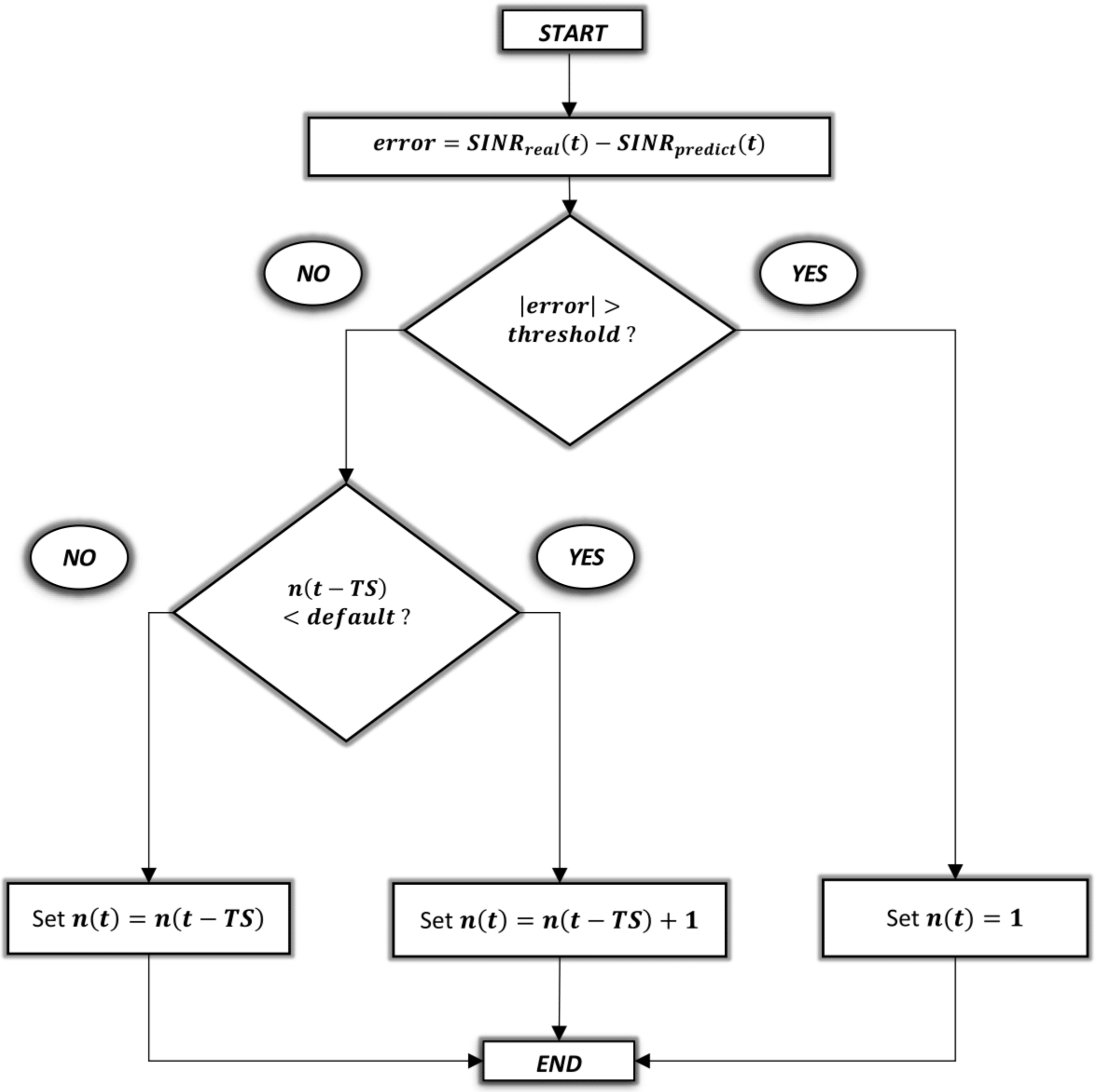

Figure 16 – Flowchart of the prediction restart

Restart means, that we change the number n of previous samples of $SINR_{real}$ used for prediction, to $n = 1$. The purpose of the prediction restart is to detect the error of prediction caused by the sudden change of SINR characteristic (e.g. UE change its direction of movement or handover occurs). In this case all collected samples before this change become outdated for the needs of extrapolation and cause an error. Restart is done by discarding all previous values of SINR until the point, where the prediction error was observed. Thus, after the restart, only the current one and 1 previous sample of SINR will be used for the prediction in this run.

After the start of the restart algorithm, it first calculates the error caused by the prediction, which consists simply of subtraction of the current value of SINR ($\boldsymbol{SINR_{real}(t)}$), and value of predicted SINR in current step ($\boldsymbol{SINR_{predict}(t)}$). Note that the $\boldsymbol{SINR_{predict}(t)}$ is a product of previous run of prediction in time $\boldsymbol{t - TS}$ of the algorithm, in which $\boldsymbol{SINR_{predict}(t + TS)}$ was determined. If the absolute value of calculated error is larger than threshold, then the prediction will be restarted by setting $\boldsymbol{n(t) = 1}$. In case the error is not larger than threshold, then there will be a check of number of samples from previous run ($\boldsymbol{n(t - TS)}$). If the last number of used samples was lower than the default number, than the current number will be increased by 1. If the last number was equal to default number, the algorithm just uses the same value for the prediction. This must be done because after the restart, the number of used samples is set to 1 and linear extrapolation is used. In order to improve the accuracy of prediction, we need the increase the number of used samples in each run, until we reach the default number.

Chapter 4. Simulation scenarios and models

In following chapters, the simulation used for the evaluation and verification of proposed algorithm will be introduced. The simulation was performed in MATLAB R2017b.

4.1 Simulation Parameters

The table below summarizes the parameters used in the simulation.

Table 1 – Simulation Parameters

Parameter	**Value**
Carrier frequency [GHz]	2 [20]
Bandwidth [MHz]	20 [20]
Transmitting power of eNB [dBm]	27 [20]
Transmitting power of HeNB [dBm]	15 [20]
Height of eNB [m]	32
Height of HeNB [m]	3/4.5/6/7.5/9/10.5/12/13.5
Height of UE [m]	1.5
Number of eNB/HeNB/UEs	4/30-120/60
Attenuation of walls [dB]	10 [20]
Mobility Model	Manhattan with POI [20]
Pathloss model for eNB	COST 231 Hata Model [21]
Pathloss model for HeNB	ITU-R P.1238 [22]
Hysteresis for handover [dB]	4 [20]
SINRmin [dB]	-9.478 [23]
SINRmax [dB]	19.809 [23]
RSSImin [dBm]	-109.2 [24]
Scanning period *TS* [s]	1
Monitoring period [s]	80 000
Simulation real-time [s]	200 000
Number of Drops	20
Speed of UE [m/s]	1
Default number of samples for SINR prediction [-] / threshold for restart [dB]	4/0.1

4.2 Simulation area

Simulation area represents the real streets and blocks of the neighbourhood of Holešovice, part of the capital city of Prague in the Czech Republic. The simulation area has 643x363 metres and contains 4 horizontal and 5 vertical streets together with 12 blocks. Each street is 16 metres wide including two sidewalks on each side of the street with 2 metres in width. There are total 10 blocks of residential buildings, 2 offices, 2 shops and 2 restaurants in the area, which corresponds to the real situation in the area. Location of all four eNBs placed in the simulation area also corresponds to the real location of Vodafone Czech Republic eNBs with the height of 32 meters above the streets. Locations of HeNBs are randomly chosen inside the houses for each simulation drop. The height of HeNB is also randomly chosen within the range defined in Table 1. Transmitting power of each eNB was set as 27 dBm and 15 dBm for HeNB respectively. Number of HeNBs placed in the area varies from 0 to 120 with the step of 30 HeNB.

Example of the eNB (red dot) and HeNBs (red star) locations within the simulation area is shown in the following two figures. While the first figure represents the classic map of the simulation area with streets highlighted by grey colour, the second figure represents the satellite view of the simulation area with the streets highlighted by blue colour.

Figure 17 - Map of the simulation area with positions of eNBs, HeNBs, and streets

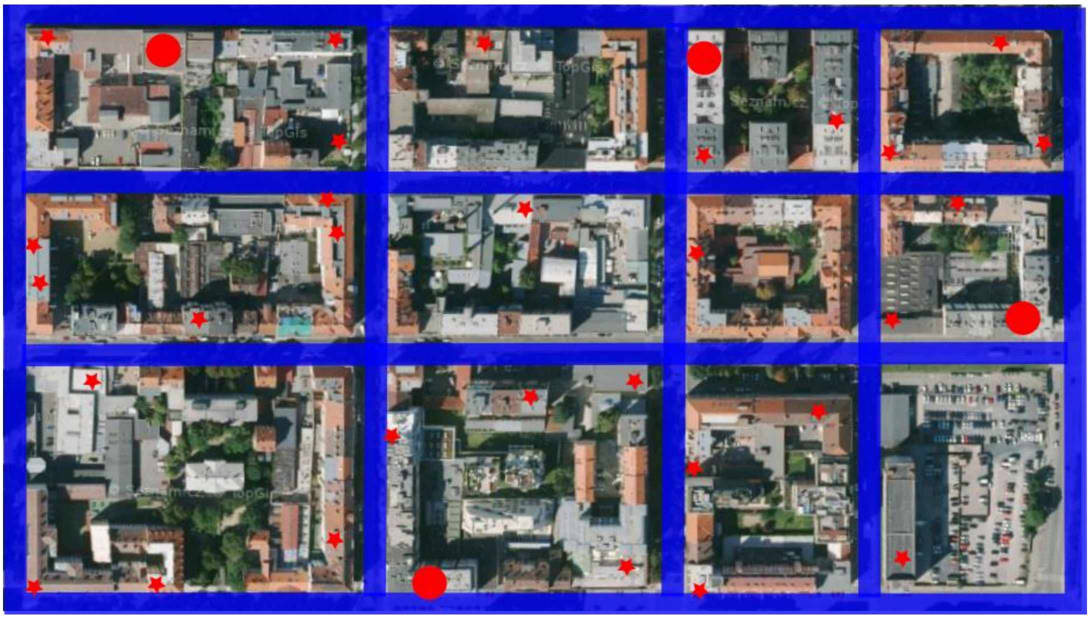

Figure 18 - Satellite view of the simulation area with positions of eNBs, HeNBs, and streets

4.3 Mobility model

This neighbourhood consists of grid-like street topology with large blocks of houses in rectangular shape, thus we can apply the Manhattan mobility model well [20]. In our mobility model, users move with a constant speed of 1 m/s along the streets in the middle of the sidewalk with changing the direction permitted at the intersections between blocks only. At each intersection, the user has only 3 options how to change the direction: keep going forward the same direction, turn left or right. Crossing the streets is only possible at the intersections. The height of the UE hold by the user is considered as 1.5 meters above the ground.

This simulation uses the Manhattan mobility model enhanced with points of interests (POIs) [20], where POIs are represented by residential buildings, offices, shops, and restaurants. Each user chooses one POI depending on the group he belongs to and then follows the shortest path to reach this destination. The shortest path to the chosen destination is calculated using the graph theory. After reaching the destination, the user immediately picks another place and continues walking without stop. Thus, we can better utilize the simulation, since when the user Is not moving, the SINR is not changing and handover does not occur. Note that only outdoor movement is considered.

A total number of 60 users is divided into four groups based on the real behaviour of urban users [20].

The first group of so-called "workers" includes 18 users. Those users live outside the simulation area and come to the simulation area for work. They can work either in the office with a probability of 80%, in a shop with a probability of 10% or in a restaurant with a probability of 10%. For each user of this group, the place of employment remains the same for the whole time of simulation in each drop. Each user also has only one intersection at the edge of the area where he both enters and exits the area.

After entering the area, the user can go straight into his work with a probability of 90 % or visit a shop with a probability of 10%. Before exiting the area on the way home from work, he can visit a restaurant (20 %), shop (20 %) or go straight home (60 %). Example of one movement of the worker is demonstrated in the following figure:

Figure 19 - Example of movement of "worker"

The second group represents "resident" users. There are total 24 users in this group. These users are the exact opposite of the "workers". Resident user lives in one of the 10 blocks of residential buildings in the area and works outside this area. Therefore each user also has one point for both entering and exiting area on the way to work and back home. With 50 % of probability, the resident goes straight from home to work and back without visiting any other place in the area. With the rest 50 % of probability, the user can visit a shop (20 %) or a restaurant (20 %) on his way back to home from work or can first go home and then visit a shop (30 %) or a restaurant (30 %) from his home and go back afterwards. Example of the resident's movement is shown in the following figure:

Figure 20 - Example of movement of “resident”

The third type of users is “visitors”. Visitor neither lives or works in the area and he uses random intersection to enter and leave the area each time he visits the area. Note that the point of entry and exit can be different for this type of user. Visitors can either visit some place inside the area, e.g. office with a probability of 5 %, shop (25 %), restaurant (25 %), residential building (20 %) or just walk through the area without any stop (25 %). This group is represented by a total number of 12 users. Example of 3 movements of the visitor can be seen below:

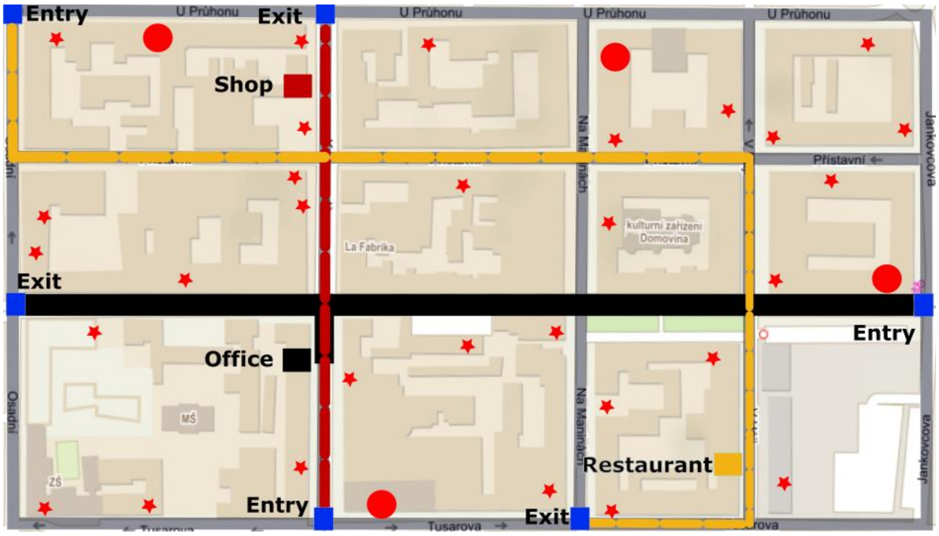

Figure 21 - Example of movement of “visitor”

Fourth and the last type of users is a “roaming resident”. These users live in the area but never leave the area. They don’t have any POI as their destination, only walk randomly within the area. After a certain time, which is random for each user, the user ends his walk and returns home. Hence the first and last point of their journey is at one of the residential buildings. A total number of this type of users is 6. Figure bellows represents one walk of the roaming resident:

Figure 22 - Example of movement of “roaming resident”

4.4 Simulation Scenario

The simulation was performed 20 times for all algorithms and HeNBs density. In each run, the location of HeNBs and initial location of each user was randomly determined. Conclusive results for each algorithm and HeNB density is an average of all 60 users in all 20 runs.

Original NCL for each cell in the area is created by using the computed coverage map of each cell. This map is first created by dividing the entire simulation area into squares of area 1x1 meter. Then, for each square, the RSSI of each cell is calculated in the middle of this square and then considered the same within the area of this square. Afterwards, for each square, the SINR of each cell is calculated. If the calculated SINR is higher than minimal SINR, then this square is included into the coverage area of this cell. Finally, the original NCL is made of all cells, whose coverage overlaps any square of the cell coverage, for which the original NCL is created.

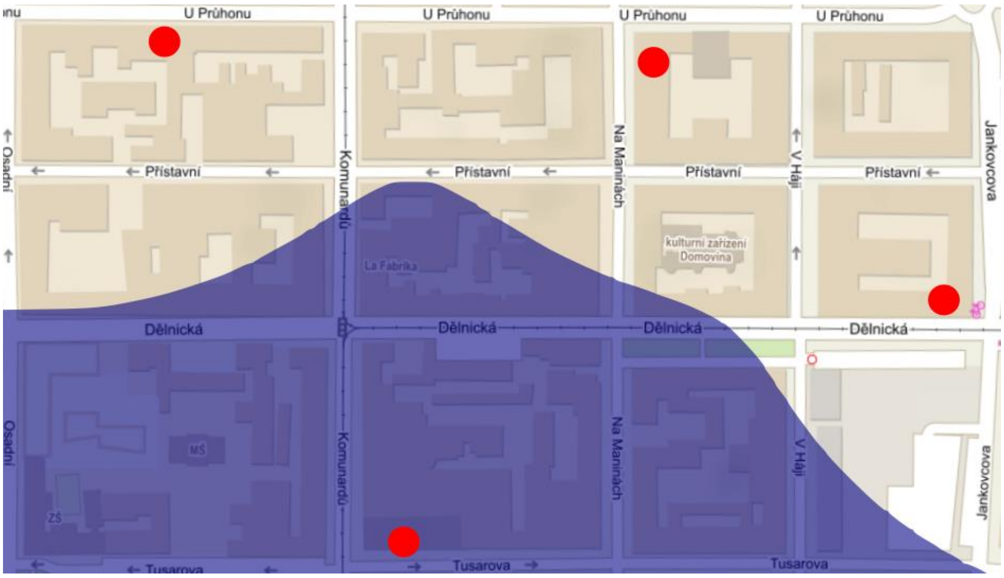

Figure 23 – Example of cell coverage

After creating the original NCL, the simulation itself starts. First, we need to calculate the distance between UE and all cells in the area. This is done by calculating the Euclidean distance using 3-D coordinates of both UE and cells. Afterwards, we need to calculate the RSSI of all cells at the UE's location. For this calculation, we exploit two pathloss models: COST 231 Hata Model [21] and ITU-R P.1238 Model [22].

COST 231 Hata Model is an enhanced Okumura-Hata model for usage with frequencies up to 2 GHz. It is suitable only for cells located above the rooftops of surrounding buildings, thus we use it for our 4 eNBs only. It is defined by the following formula [21]:

$$L[dB] = 46.3 + 33.9 \log f - 13.82 \log h_b + (44.9 - 6.55 \log h_b) \log d + C - a \quad (28)$$

where C is defined as:

$$C[dB] = \begin{cases} 0\ dB\ for\ medium\ sized\ city\ and\ suburban\ area \\ 3\ dB\ for\ metropolitan\ centres \end{cases} \quad (29)$$

And a is defined as:

$$a[dB] = (1.1 \log f - 0.7)h_m - (1.56 \log f - 0.8) \quad (30)$$

where f is the frequency in MHz, h_b is the height of the base station in metres, h_m is the height of the UE above the ground in metres and d is the distance between UE and base station in km.

In our simulation, h_m is considered as a constant value of 1.5 metres for all users, while h_b is set to 32 metres for all 4 eNBs. Since the simulation area is considered as a suburban area, parameter C is set to 0 dB for our simulation.

On the other hand, the ITU-R P.1238 Model, used for the HeNBs, represents the situation when the cell is located indoor and thus the attenuation caused by the indoor environment is assumed. It is defined by the following equation [22]:

$$L[dB] = 20 \log f + N \log d + L_f - 28 \tag{31}$$

where f is the frequency in MHz, d is the distance between UE end HeNB in metres, N is the distance power loss coefficient and L_f is a floor loss factor.

For the purposes of simulation according to [22], N andL_f is set to 28 and 4 respectively, which corresponds to the residential buildings.

Total propagation loss given by the pathloss models is then simply subtracted from the transmitting power of each type of cell, since we consider isotropic radiators on both cell and UE's site, with Gain equal to 0 dBi.

With known RSSI between UE and each cell, we can simply calculate the SINR, using the equation (2). As the background noise, we consider the thermal noise in decibels, given by the formula:

$$N[dBm] = 30 + \log(k_B T B) \tag{32}$$

where k_B represents Boltzmann's constant in joules per kelvin, T is the temperature in kelvins and B is the bandwidth in Hertz.

In our simulation, we use the bandwidth of 20 MHz and consider temperature equal to 290 kelvins. Hence the used background noise was set to -100.961 dBm.

With known SINR, simulation continues to apply either the proposed algorithm or competitive algorithms to reduce the NCL, which is consequently used for neighbours scanning. Maximal and minimal SINR for purposes of SINR based algorithms were set to 20 and -9.748 dBm respectively, according to the highest and lowest SINR threshold for setting the Modulation and coding scheme in LTE system as denoted in [23].

In case of the proposed algorithm, the default number of previous samples of SINR used for the prediction was set to 4. According to the following plots, which show the Mean squared error of the prediction depending on the number of previous samples and the variance of the prediction error, when we use more than 4 samples, it does not bring better accuracy. Therefore we use 4 samples for the purposes of the simulation.

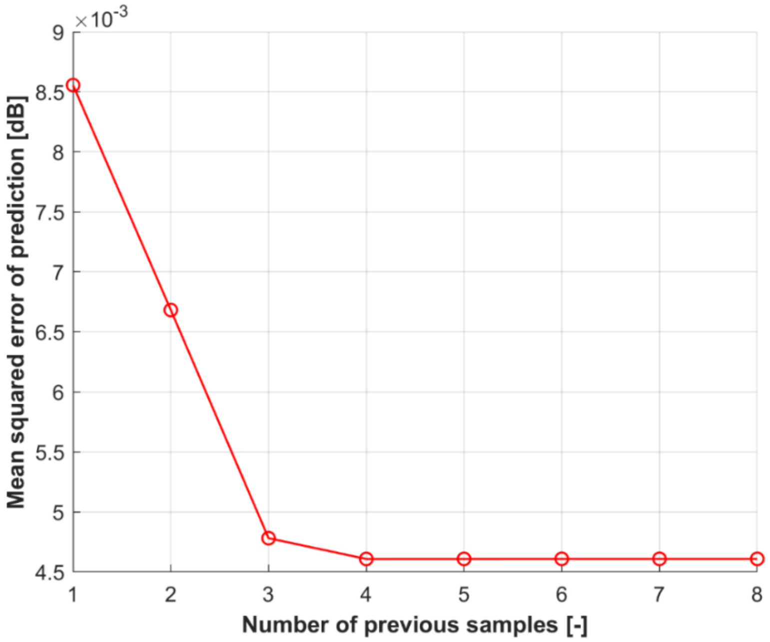

Figure 24 – MSE of the prediction depending on the number of samples

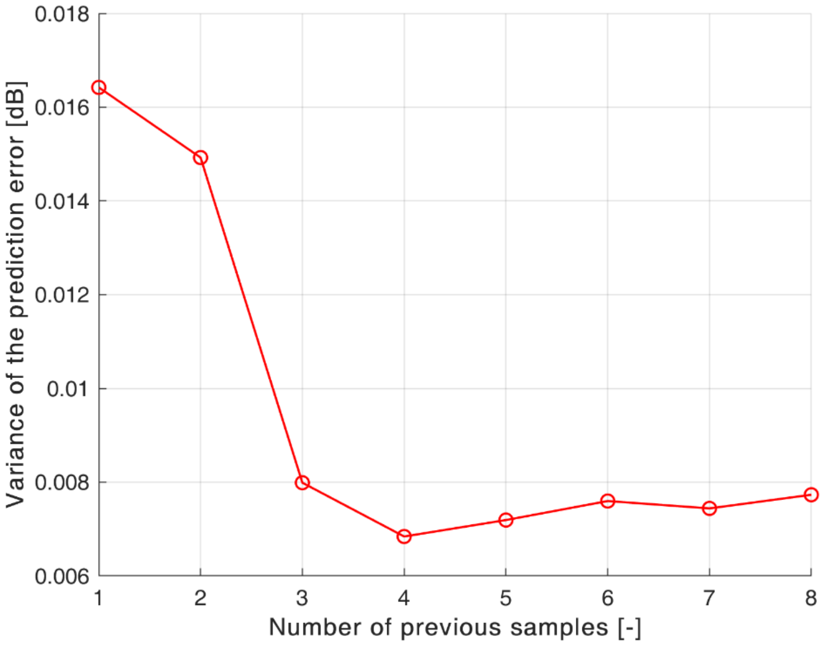

Figure 25 – Variance of the prediction error depending on the number of samples

The whole simulation is divided into two parts. The first part is so-called “monitoring period” with a total duration of 80 000 s and the second part is so-called “simulation period” with a total length of 120 000 s. Thus, the total length of the simulation is 200000 s. Since the scanning period was set to 1 second, one step of simulation also corresponds to 1 second.

Purpose of the Monitoring period is to collect handover statistics needed for the handover probability determination as mentioned in 2.1. During this period, only original NCL is used for scanning. The only condition for making a handover decision in the simulation is the handover hysteresis which is set to 4 dB. Each handover between a certain pair of cells is logged by the handover counter and stored in a handover statistics table. If handover occurs, the total number of handover between the pair will be increased by 1. Note that the direction of handover between a pair of cells is distinguished and counted as two different handovers. At the end of this period, the table with handover probabilities between each pair of cells is calculated using the collected statistics.

Simulation period represents the deployment of the NCL reducing algorithm. Unlike the monitoring period, it does not use the original NCL but the NCL is reduced by one of the optimizing algorithms defined in 4.5. At the end of this period, statistical processing to get the results according to the performance metrics defined 2.3, is run.

4.5 Algorithms for comparison

The total number of 6 competitive algorithms together with 3 versions of the proposed algorithm is used for the performance comparison using defined performance metrics. Competitive algorithms consist of 3 unique algorithms: Full NCL algorithm, Handover History algorithm, and SINR-Based algorithm. The latter one is used in 4 modifications, therefore a total number of algorithms for comparison is 6.

4.5.1 Full NCL algorithm

Full NCL algorithm represents the current method used in nowadays network. There is no optimization of the original NCL provided by the network and thus all cells are scanned. NCL used for the scanning is identical to the original NCL provided by the serving cell:

$$N_{new} = N_o \tag{33}$$

In terms of our metrics, this algorithm should provide the best performance in all metrics except the Average number of scanned cells, where this algorithm should provide the worst result (highest number of scanned cells). On the other site, the Handover failure rate caused by the missing cell should be always 0% for this algorithm, since there cannot be a missing cell in the original NCL. The same rule applies for the outage probability, where no outage caused by the missing cell can occur and thus this algorithm should have the lowest value of this metric among all others.

4.5.2 Handover history algorithm

Handover history algorithm [11] uses collected handover statistics from monitoring period and then omit all cells from Original NCL whose handover probability is under 1%. It represents the method with the fixed probability threshold for all UEs in all situation.

Optimized NCL of this algorithm can be quoted as:

$$N_{new} = \left\{cell_b \subseteq N_o : P_{a,b} \geq 0.01\right\} \tag{34}$$

4.5.3 Competitive SINR based algorithm

All 4 modifications of the SINR-based algorithm [1] are based on the dynamic threshold reduction:

$$N_{new} = \{cell_b \subseteq N_o : P_{a,b} \geq P_{t,dyn}\} \tag{35}$$

The only difference between those modifications is the way how to calculate $P_{t,dyn}$, respectively which settings of parameter Δ and E are used for its calculation based on the equation (4).

First two SINR-based algorithms both do not use Δ parameter, respectively use $\Delta = 0$, together with E=1 for the first one and E=1000 for the second one. It represents the modification introduced in the formula (3) in chapter 1.3.1.

Last two SINR-based algorithms use optimal Δ parameter, Δ_{opt} [1], together with E=1 or E=1000. Purpose of $\Delta_{opt}$is to ensure 0% handover failure rate due to the missing cell. It is set statistically for each cell density and simulation run, as the largest observed mitigation of SINR between two consecutive neighbour scans. Therefore, the algorithm expects the outage since the time when SINR falls under the Δ_{opt}+$SINR_{min}$ and will set dynamic threshold to 0. Since Δ_{opt} represents the worst case of the SINR mitigation between two consecutive scans, algorithm mostly set the threshold to 0 too early, even if the real situation does not require scanning of all cells, because the UE is still relatively far from the cell edge.

4.5.4 Proposed algorithm

The proposed algorithm is simulated in three modifications of the E parameter. First two modification use the constant E with value 1 and 1000. The third modification uses dynamically set E parameter according to the following formula:

$$E = \begin{cases} 1000, & if\ SINR_{real}(t) > -6.658\ dB \\ 1, & otherwise \end{cases} \tag{36}$$

E is dynamically set to 1000 or 1 depending on the current value of SINR. As a threshold value for changing E from 1000 to 1 or backward, -6.658 dB was selected. This value corresponds to the SINR threshold for setting the lowest Channel Quality Indicator as denoted in [23].

The throughput of the LTE network given by the modulation and coding scheme is the lowest after crossing this threshold, therefore eventual handover does not bring lower throughput. The purpose of using dynamical E is to compensate the low average SINR which will occur when E is set to 1000 all the time, since with this value, it mostly scans other cells only when the SINR is near its minimum value and thus also the handover is performed when the user is very close to the cell edge or even beyond. It can consequently cause the lower throughput of the connection in comparison with using E set to 1. Proposal of dynamical E should ensure better average SINR together with keeping the average number of scanned cell almost as low as with the E set to 1000 only.

Chapter 5. Evaluation of proposed algorithm

In the following section, evaluation of the proposed algorithm will be discussed. The first chapter is about the prediction accuracy while the second chapter uses plots provided by the simulation to compare proposed algorithm with the competitive algorithms based on the performance metrics introduced in chapter 2.3.

5.1 Prediction accuracy

The accuracy of used prediction can be demonstrated in two separate ways. We can simply calculate the error of prediction by subtracting the predicted value of SINR from the real value of SINR in each step of the simulation. With these results, the Cumulative distribution function and probability histogram of the prediction error can be shown:

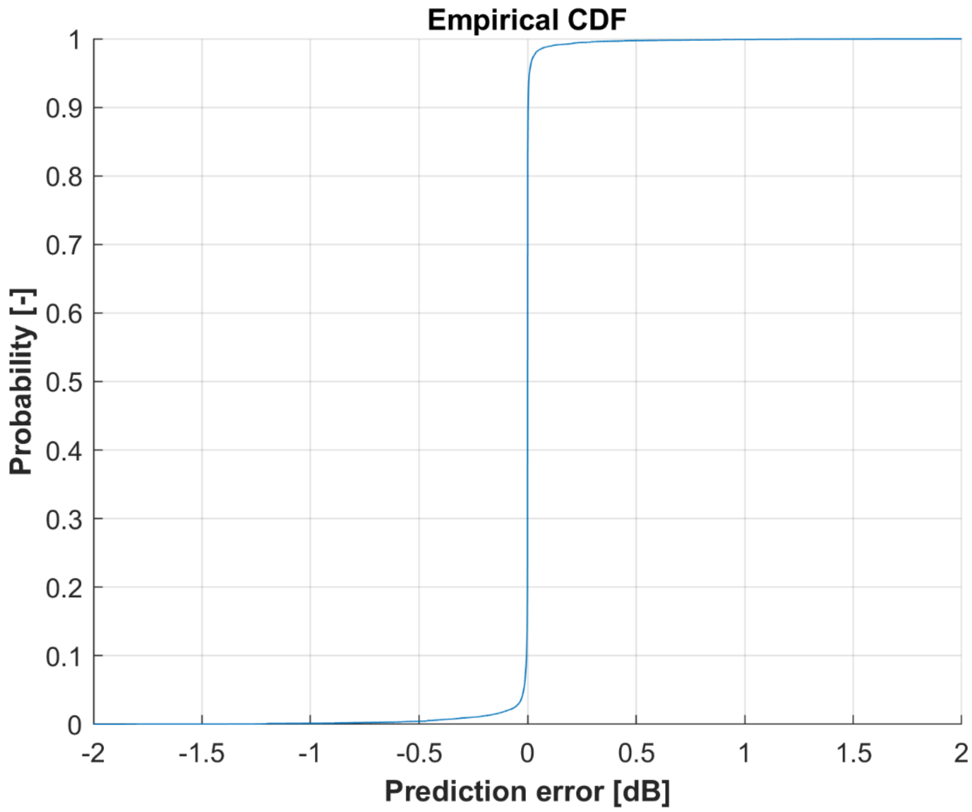

Figure 26 – CDF of the prediction error, whole time

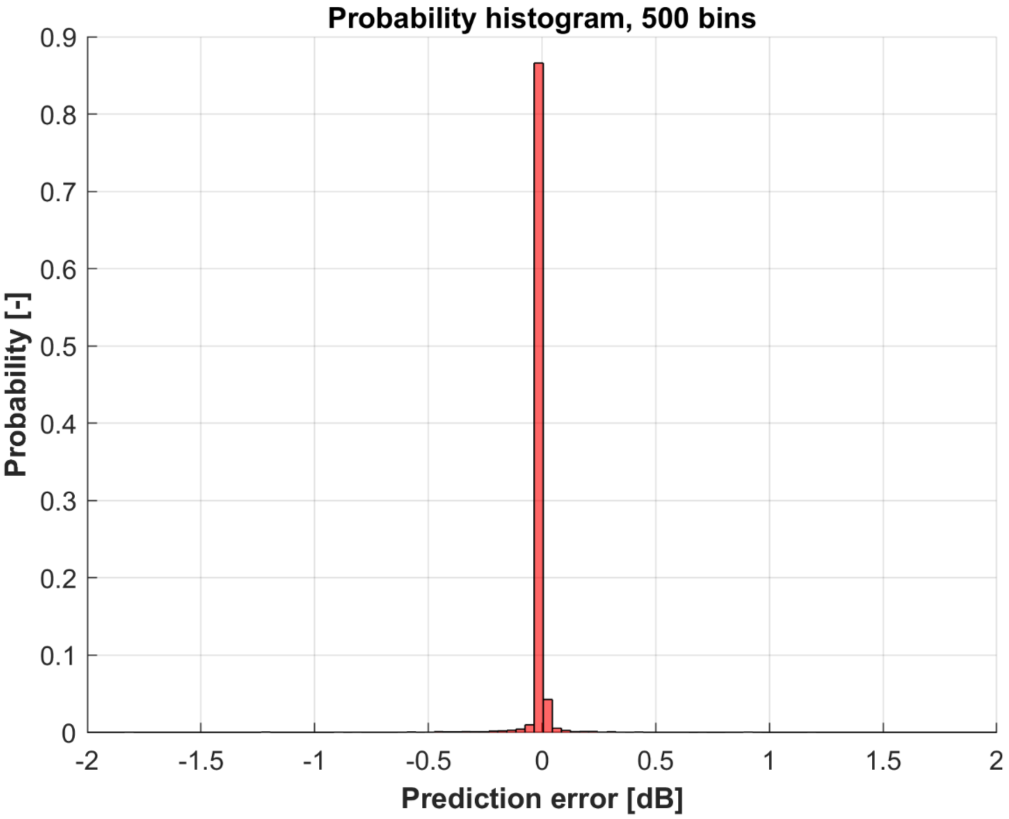

Figure 27 – Probability histogram of the prediction error, whole time

As can be seen from both CDF plot and Probability histogram, the predicted value of SINR fits very precisely to the real value most of the time. However large error of several dB can rarely happen. Such error is caused by the change of direction at the intersection, especially when connected to the HeNB when the SINR can drop very quickly with the distance because the coverage area of this cell is low as well. CDF and Probability histogram only for cases when UE changes direction can be seen in the plots below.

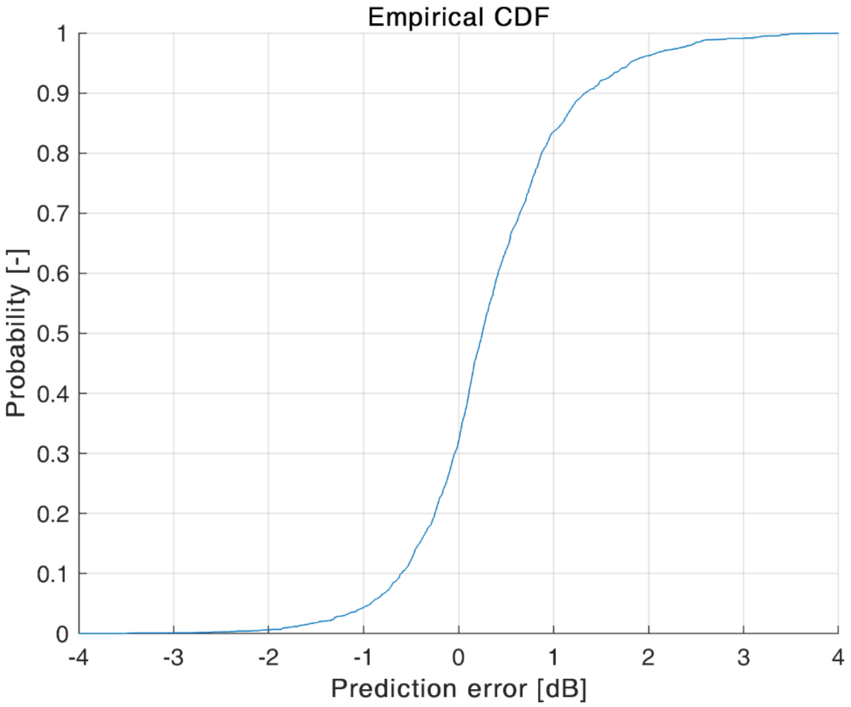

Figure 28 - CDF of the prediction error, direction change only

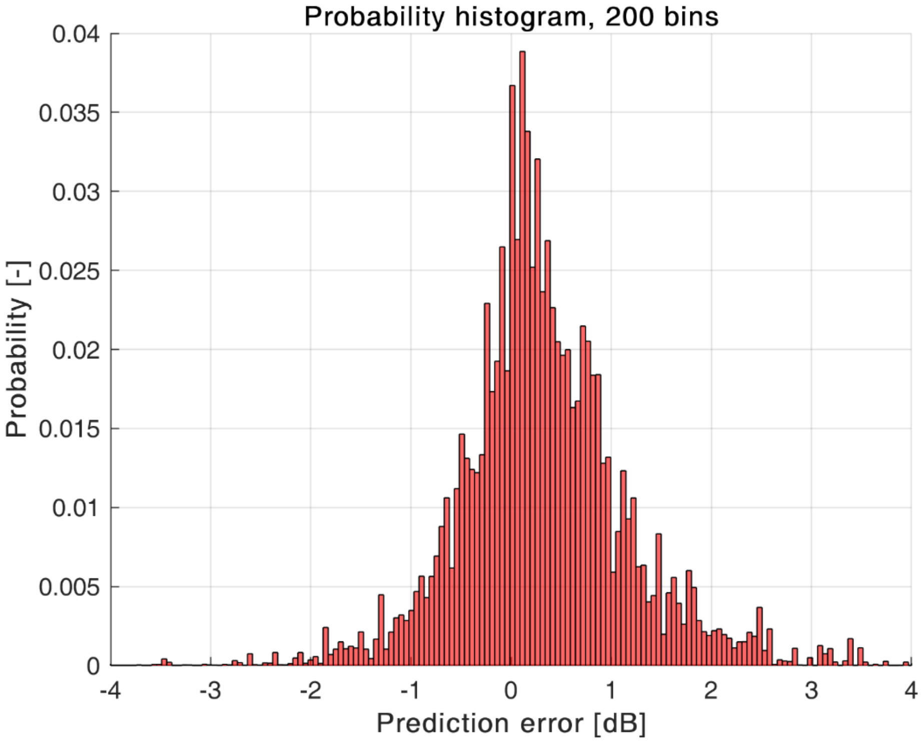

Figure 29 – Probability histogram of the prediction error, direction change only

However, the exact predicted value of the SINR is not essential for the proposed algorithm. The main goal of the proposed algorithm is to predict whether the outage before the next scanning of neighbours will happen or not. Therefore the algorithm decides, whether the predicted value of SINR will be under or above the threshold given by the minimal SINR. For example, if the predicted value of SINR was -10 dB and the real value was-15 dB, the prediction error is 5 dB, however since the both real and predicted value is under the minimal SINR, the decision based on the prediction was correct. The outage was predicted and it also happened.

There can be total 4 for cases which can happen:

Table 2 – Conditions for correct decision

$SINR_{predict}(t+TS) \leq SINR_{min}$	$SINR_{real}(t+TS) \leq SINR_{min}$	Correct Decision
YES	YES	YES
YES	NO	NO
NO	YES	NO
NO	NO	YES

The first row represents the case, when we predict the outage and this will occur, thus the decision was made correctly. The second row is the case when the prediction predicts outage, although this will not happen. In this case, NCL will not be optimized and more neighbours than necessary will be scanned. The third case is when we do not predict the outage, although the outage will be observed. The wrong decision was made, NCL was reduced and this can cause the missing cell in the NCL and handover failure caused by the algorithm. The last case represents the situation when no outage is going to happen and also the prediction predicts no outage. In this situation, the NCL is reduced correctly since handover is not expected.

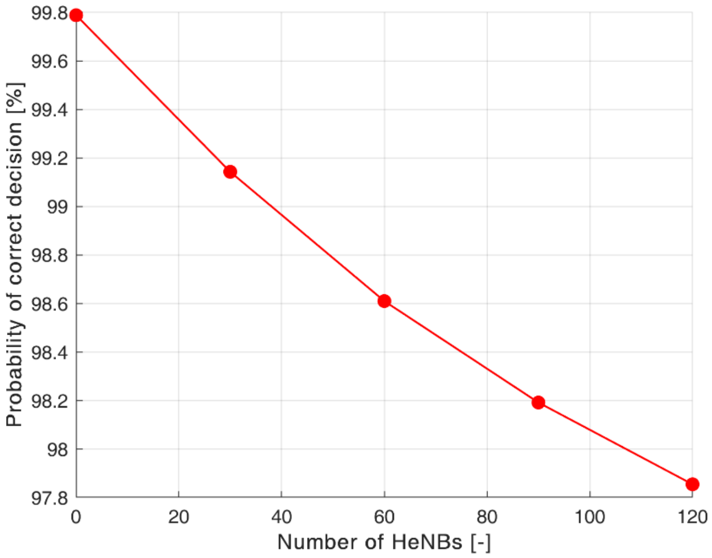

Figure 30 – Probability of correct decision

5.2 Comparison of proposed algorithm with competitive algorithms

In this chapter, the comparison of the algorithms is shown. In each section, representing one of the four performance metrics is first shown the overall plot showing all 9 algorithms, in other plots, the number of algorithms is reduced to provide better readability. Depending on the metric, besides the proposed algorithms, either SINR based algorithm or Full NCL algorithm is shown in the plots with a reduced number of algorithms.

5.2.1 Average number of scanned cells

Plot located bellow shows performance in terms of the metric Average number of scanned cells introduced in 2.3.1.

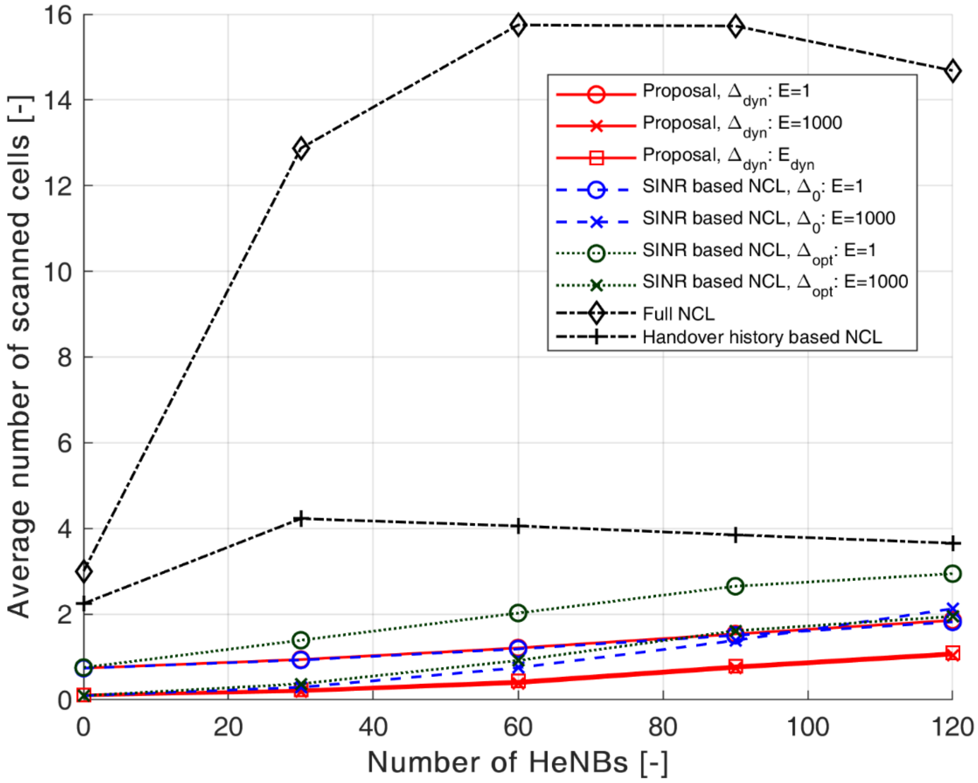

Figure 31 – Average number of scanned cells, all algorithms

As we can see in this plot, according to the assumptions, the worst result in this metric has the Full NCL algorithm. As described in 4.5.1, this algorithm does not use any NCL reduction and it always scans all cells provided by the serving cell in the original NCL. The number of scanned cells gets saturated with a rising number of HeNBs and even decrease a little because the more HeNBs are deployed in the area, the more part of the overall time the UE spends connected to the HeNBs instead of one of four eNBs. When connected to the HeNB, the number of cells in its NCL is naturally lower than in the eNB, since the HeNB has lower coverage area than eNB. Handover history algorithm provides a significant improvement compared to the Full NCL. Same saturation as for Full NCL applies in this case, even more influenced by the principle of the handover history algorithm described in 4.5.2, because it also considers the real handover statistics based on user's behaviour in the area. Thus, the cells located in the streets where the user never or rarely walked in the monitoring period were omitted from the NCL and better performance can be observed.

For further discussion, the modified plot, containing proposed and SINR based algorithms only, is used.

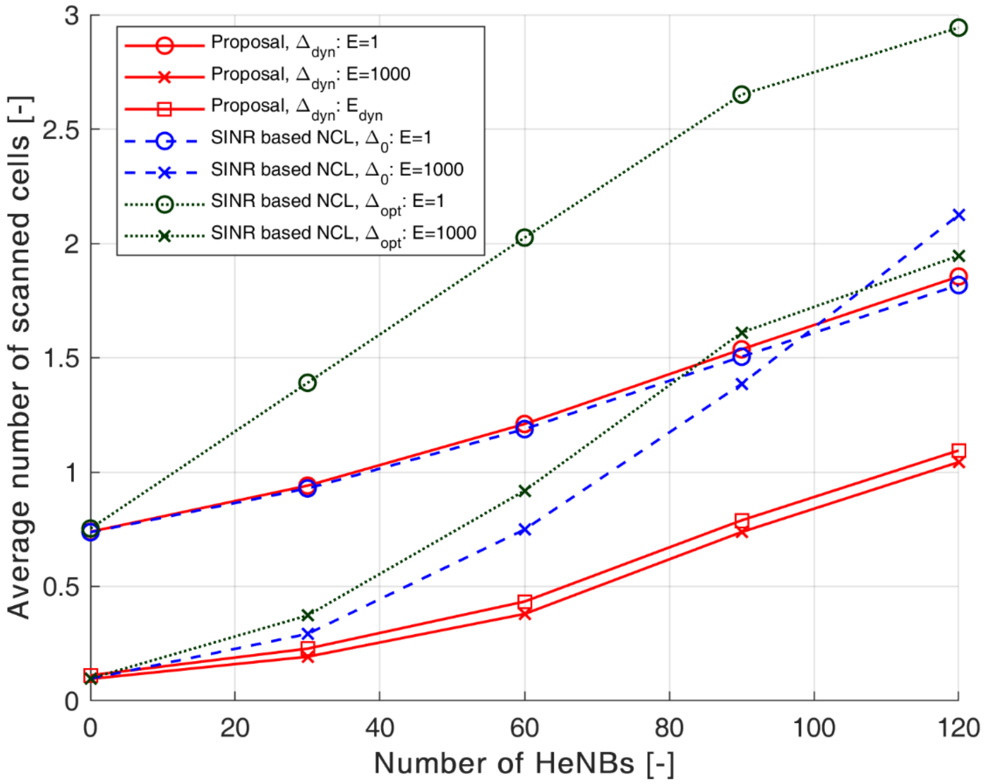

Figure 32 – Average number of scanned cells, reduced plot

A proposed algorithm with E=1 provides almost the same performance as a competitive SINR based algorithm with Δ_0 and E=1. It gets only slightly worse with a rising number of HeNBs, but the difference is less than 2% for the worst case of 120 HeNBs. This is caused by the prediction error when the outage is predicted, although it does not occur and NCL reduction was stopped needlessly early.

Significant improvement of performance using a proposed algorithm with E=1000 compared to others can be seen. Unlike the SINR based algorithm with Δ_0 and E=1000, proposed algorithm does not raise the number of scanned cells as fast. This is caused by the successful prediction of the outage state when the algorithm stops reducing NCL just before the outage occurs. On the other site, an algorithm with Δ_0 stops reducing the NCL only when the outage is observed and in this case, all surrounding cells, not only those in the original NCL, must be scanned in order to get out of outage. This includes all cells which can be sensed by the UE and this can be a far larger number of cells, than in the original NCL, since UE also senses those cells, which are strongly interfered and might not be a part of the original NCL, because NCL is based on SINR and thus respects the signal quality not only its strength. Due to this attribute, it is even worse than using E=1 in case of 120 HeNBs.

Proposed algorithm provides similar results with difference less than 5%, for both dynamically set E and E=1000, since, in case of dynamically set E, it works as an algorithm with E=1000 most of the time and only switches to E=1 near the edge of the cell. Its main goal is to provide better performance in the metric of average SINR as it will be shown in chapter 5.2.4. Especially from the number of HeNBs larger than 30, these two sets of E in proposed modification bring significantly better performance than other algorithms. In comparison with SINR based algorithm without prediction, our proposal brings more than 50% lower number of the scanned cell. If compared to using the Full NCL for scanning, the reduction can go up to 97% in the worst case of 60 HeNBs.

5.2.2 Handover Failure Rate

As expected the highest HFR has the SINR based algorithm with Δ_0 and E=1000, while the rest of the algorithm has HFR lower than 0.6%. Besides, both modification of SINR-based algorithm with Δ_{opt} have 0% HFR, while proposed algorithm with both E=1 and dynamical E has 0.002% HFR. Full NCL algorithm provides 0% HFR as well since there cannot be any missing cell. A proposed algorithm with E=1000 has HFR not exceeding 0.2% for the worst case of 120 HeNBs, which gives a reduction of more than 99% in comparison with the SINR based algorithm with Δ_0 which does not use a prediction.

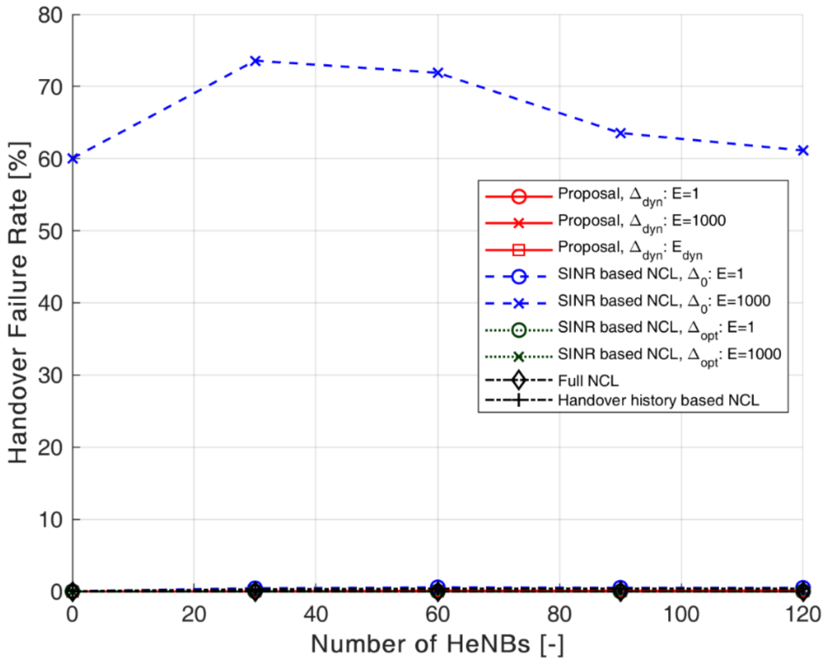

Figure 33 – Handover Failure Rate, all algorithms

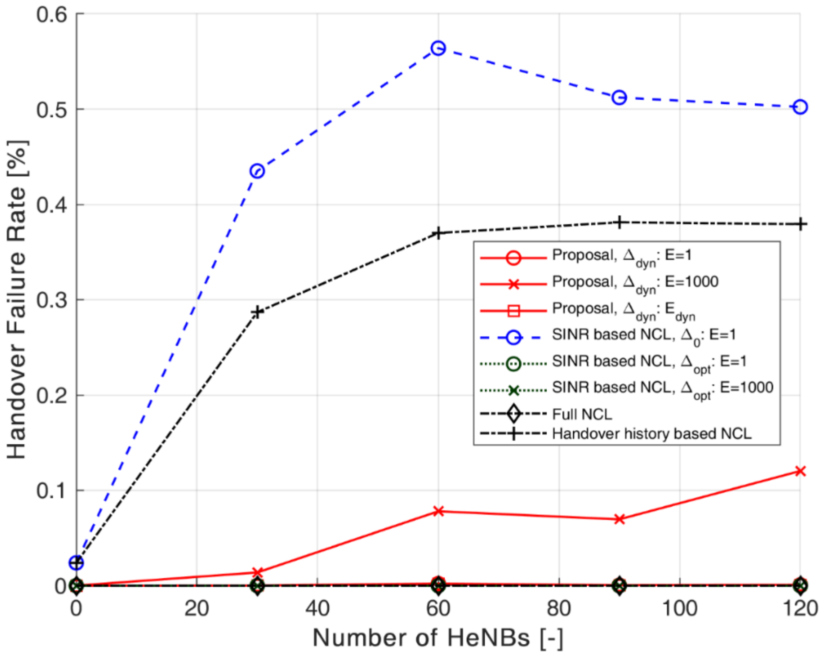

Figure 34 – Handover Failure Rate, zoomed

5.2.3 Outage Probability

According to the plot below, the highest outage probability has the SINR based algorithm with Δ_0 and E=1000. All Proposed algorithms have outage probability same as the Full NCL until 60 HeNBs. For 90 and 120 HeNBs, the outage probability of proposed algorithm with E=1000 is slightly worse about 2%, which is caused by the missing cell due to the prediction error according to the plot of Handover Failure Rate in Figure 34.

Note that the outage in our case can happen for two reasons:

1) Outage caused by the unfulfilled handover hysteresis condition even when the NCL is not reduced
2) Outage caused by the missing cell in the reduced NCL

Full NCL algorithm and both SINR based algorithms with optimal Δ as well, cannot have an outage caused by the missing cell, therefore they represent the case with outage caused only by the unfulfilled hysteresis condition. Since that, those algorithms represent the best performance which can be obtained using this metric and we can use it as a benchmark. Any other result with higher outage probability is caused only by the algorithm itself.

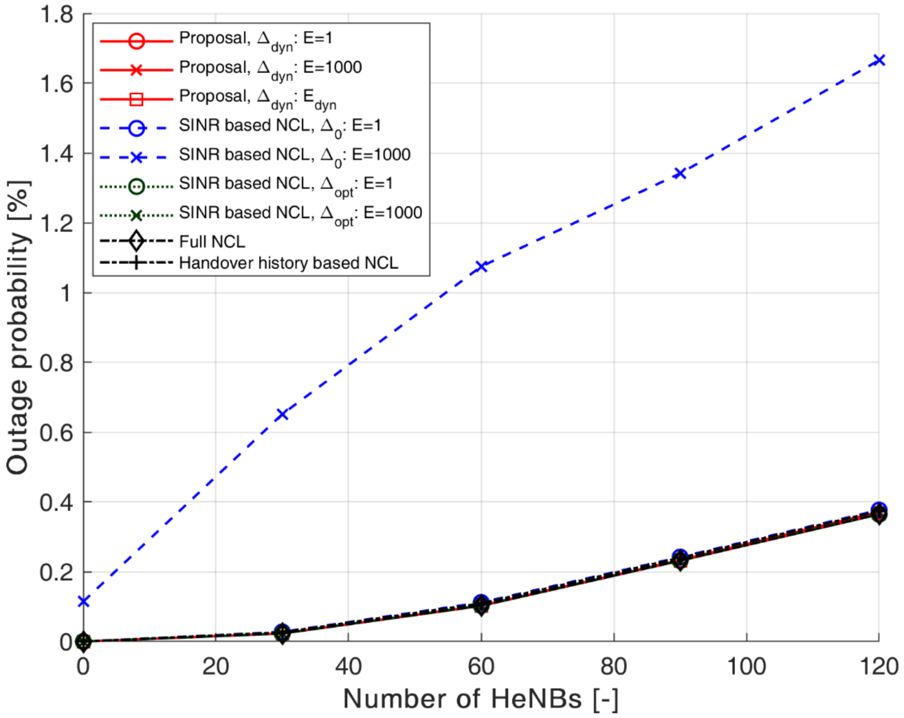

Figure 35 – Outage probability, all algorithms

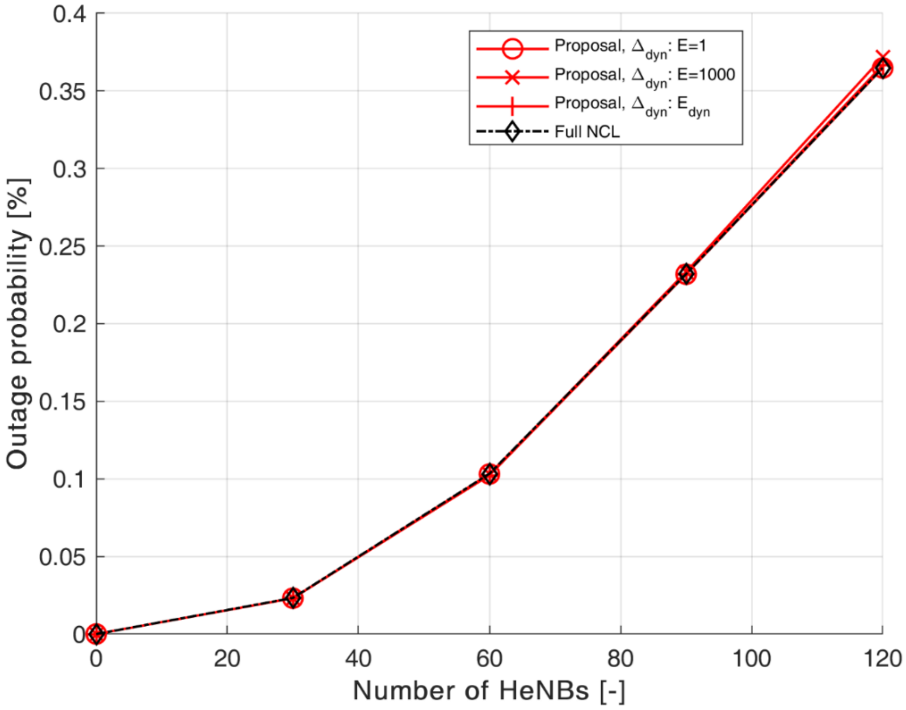

Figure 36 – Outage probability, proposed + Full NCL algorithm

5.2.4 Average SINR

Purpose of this metric is to compare the influence of the algorithm to the Average value of the observed SINR. As can be seen in the plot below, parameter E set to the value of 1000, cause a lower average SINR than other algorithms. This behaviour is expected since this value causes scanning and eventual handover mostly near the edge of the cell.

The average SINR of the proposed algorithm with E=1000 is around 1 dB lower than with the E=1. Since the Modulation and coding scheme depends on the observed SINR, setting E to 1000 can lower the transmission speed of the connection with a comparison to other algorithms. On the other site, dynamically set E parameter provides only 0.2 dB lower average SINR than the proposal with E=1 and Full NCL algorithm, while the average number of scanned cell is almost same as with E=1000 as it was discussed in chapter 5.2.1.

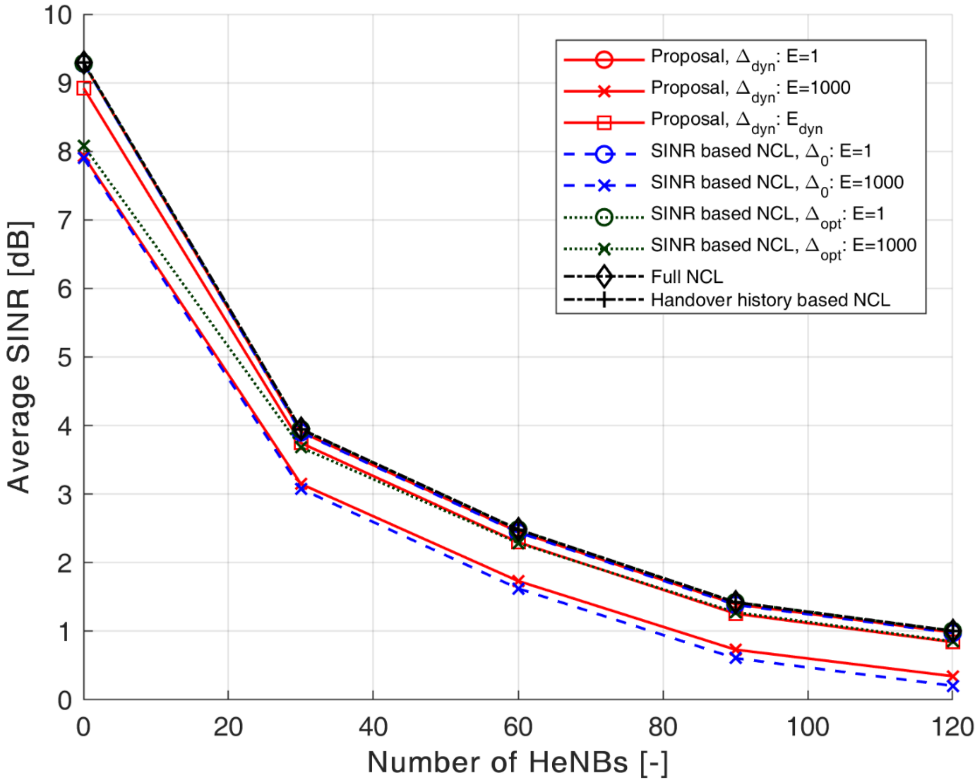

Figure 37 – Average SINR, all algorithms

Chapter 6. **Conclusion and Future Works**

This work proposed an improved algorithm of NCL reduction using the extrapolated value of SINR in the next scanning to mitigate handover failures due to the missing cell in the reduced NCL. Our proposal can effectively eliminate the occurrence of the missing cell during the time when handover is needed. According to the results obtained from the algorithm's evaluation using simulation, version of the proposed algorithm with dynamically set E parameter, provides near 0% handover failure rate due to the missing cell, respectively it provides 0.002% handover failure rate in the worst case. That means that chance of the missing cell during the handover is extremely rare, only roughly one of 50 000 performed handovers failed due to the missing cell. Therefore, also the outage probability remains the same as for the nowadays algorithm which does not use the NCL reduction. The main goal of the proposed algorithm was to lower the average number of the scanned cell. It was achieved up to 97% reduction comparing to the use of Original NCL instead of the reduced one provided by the proposed algorithm. For the worst case of Original NCL with the 60 HeNBs, the proposal can reduce the number of scanned cells from roughly 15 to 0.4. Even for the worst case of the proposal result with 120 HeNBs, the reduction is still around 92% of the Original NCL size. The only drawback of our proposal is the lower average observed SINR by roughly 0.2 dB comparing to the use of Original NCL. This is caused by forcing the handover to be done later, when the observed SINR of the serving cell will be weaker, instead of performing the handover immediately when the target cell fulfills handover conditions since this target is not reported to the serving cell, because of the NCL reduction.

Since the weak point of the SINR prediction is at the intersection, where the proposed prediction can cause a large error, further improvement can be applied. Within the typical users in the urban area, there are some users which usually follow a certain pattern in their movement. These users are represented by the groups workers and residents in the simulation used. We could use the statistics of the previous pass through each intersection, depending on the entry direction and then calculate probabilities. Those probabilities could be then used for the prediction improvement. The issue of this solution is how to get the information about the user's location to decide whether the intersection will follow and which one it will be. One of the options is to use the GPS system to get the location of the user and then check if the user is approaching the intersection. Together with user's location, it is also necessary to have a database with intersection coordinates. On the one site, GPS provides very good precision for our purposes, on the other site, the power consumption of this system is quite large and the improvement of the prediction used for the NCL reducing, would cause the battery drain much higher than the NCL reduction can save.

Another improvement can be made on the computing resources, needed for the prediction calculation. Especially if we use E=1000 or dynamic E we don't have to use the prediction as long as the observed SINR is high enough, because the probability threshold will be set to 1 anyway. Setting a trigger for prediction start based on the current observed SINR, can save a computation resources most of the time and start the prediction only when SINR drops below a certain value. This value could be equal to the Δ_{opt}+$SINR_{min}$ introduced in 4.5.3.

Chapter 7. **References**

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