

# **Closed loop power control for LTE uplink**

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This chapter includes the thesis introduction, including scope and thesis objective. To facilitate the reader, thesis outlines are also added.

## 1.1 Thesis objective

The objective of this thesis study is to design and implement the closed loop power control scheme in combination with the fractional path loss compensation factor for the physical uplink shared channel (PUSCH). Furthermore, to investigate different values for the path loss compensation factor and choose an optimal value that results in best cell edge and mean user throughput.

## 1.2 Thesis scope

The scope of the thesis is limited to the closed loop power control for the PUSCH only. The specifications for the 3GPP Long Term Evolution (LTE) supports advanced antenna systems including multiple transmit and receive antennas i.e. multiple-input and multiple-output (MIMO), but for practical reasons this study is limited to single transmit and receive antenna systems i.e. single-input and single-output (SISO). MIMO systems can achieve better performance, but the aim of this thesis is to provide a relative comparison between methods not to find absolute values on performance.

3GPP LTE can be used in both paired (FDD) and unpaired (TDD) spectrum. This thesis focuses on FDD. LTE is designed to support flexible carrier bandwidths from below 5MHz up to 20MHz, in many spectrum bands. This study only deals with 10MHz bandwidth. The scheduling algorithm used by eNB is pure time division multiplexing (TDM).

## 1.3 Assessment methodology

The implementation and simulations are carried out using a multi-cell radio network dynamic simulator implemented in MATLAB. The simulator includes enhanced traffic and Hybrid ARQ (HARQ) models. In the simulator, the network performance is simulated for a certain period of time, which then includes events like arrival of new users, departure of users (whose calls are finished) and user movement. The simulator also includes a set of radio resource management (RRM) algorithms such as cell selection, scheduling, link adaptation, and transmit beam forming. A detailed explanation of the simulation environment is presented in Appendix A.

In order to evaluate the performance in terms of system, as well as user performance of different power control schemes and the implemented closed loop algorithm, a set of key performance indicators (KPIs) have been chosen.

**Cell-edge user throughput:** The cell edge user throughput is defined as the 5<sup>th</sup> percentile point of the Cumulative Distribution Function (CDF) of user throughput. It is an indicator of the coverage performance.

**Average per-user throughput:** The average per-user data throughput is defined as the sum of the average data throughput of each user in the system divided by the total number of users in the system. The average per-user throughput is also referred to as average or mean user throughput.

**Uplink received signal-to-interference and noise ratio (SINR):** CDF plot of user SINR distribution in the uplink, representing both 5<sup>th</sup> percentile and mean per-user SINR.

**Power utilization:** CDF plot of power utilization. It provides the percentage of users using maximum allowed power for communication.

## 1.4 Thesis outlines

Chapter 2 provides the theoretical background about wireless communication channel impairments and fundamentals of cellular networks. It also presents an overview of the capabilities of the long term evolution (LTE) and the physical layer of the LTE. The theoretical background about power control schemes and PUSCH power control formula is also included in this chapter. Furthermore, with the help of mathematical expressions and figures, the underlying differences between power control schemes are also explained.

Chapter 3 describes the problem statement and a mathematical representation of the implemented solution. It also describes implementation methodology and issues involved in the implementation. The methodology includes implementation of closed loop with full path loss compensation, closed loop with fractional path loss compensation factor and SINR filtering. Moreover, the text also explains absolute error and delay models and its implementation.

Simulation results and analysis are presented in Chapter 4. The conclusions can be found in Chapter 5, followed by the discussion of possible continuation of this thesis work.





















































(3-7)

The path loss obtained using eq. (2-9) involves  $P_{PUSCH}$ , but in the real world, the eNB can use power headroom report ( $P_h$ ) received by the eNB from the UE in order to find path loss of each user.

(3-8)

$$P_h = P_{PUSCH} = P_{\max} \text{ when } PL = PL_{\max}$$

It is worthwhile to note that calculation of  $PL$  using eq. (3-7) leads to ideal study of the closed loop power control with fractional path loss compensation factor. For realistic study  $PL$  is calculated using eq. (3-8), which involves power headroom reporting.

Using eq. (3-4) - (3-6) SINR target based on the path loss and is given by

(3-9)

In eq. (3-9), users at  $PL \geq PL_{\max}$  will use  $SINR_{\text{target}} \neq SINR_{\text{target}}$ , indicating that there is no increase in the SINR target for users which are already using  $P_{PUSCH} = P_{\max}$ . Furthermore,  $U = 1$  turns the designed closed loop scheme into conventional closed loop power control meaning that the SINR target setting is independent of the path loss.

In case of the closed loop with fractional path loss compensation factor, TPC commands will be generated based on  $SINR_{\text{target}}$  and received SINR.

### 3.5 Investigating values for path loss compensation factor

In order to investigate different values for the path loss compensation factor, both the full buffer and simple upload traffic model are used. Full buffer and simple upload traffic models are discussed in detail in Appendix A. However, simple upload traffic model simulates more realistic behavior than the full buffer.

### 3.6 SINR filtering

Estimated received SINR is smoothened using an exponential filter. The general expression representing exponential filter is given below

(3-10)

where

- ⟨  $Y(t)$  is the output of the filter at time moment  $t$ .
- ⟨  $Y(t-1)$  is the output of the filter at the previous time moment  $(t-1)$ .
- ⟨  $X(t)$  is the input of the filter.
- ⟨  $0 \leq a \leq 1$  is the filter parameter.

In simple words, the output  $Y(t)$  of the exponential filter is the weighted sum of the previous output  $Y(t-1)$  (taken with weight  $1-a$ ) and the current input value  $X(t)$  (taken with weight  $a$ ). The smaller the parameter  $a$ , the longer the "memory" of the exponential filter and the greater the degree of smoothing the estimated received SINR.

The general expression is modified by introducing an additional factor; the modified expression is given by

(3-11)

where  $m(t)$  is calculated as

(3-12)

The factor  $m(t)$  increases every time the user is scheduled, which means that the more frequent the user is scheduled the greater will be the value of  $m(t)$  for this user. It means that the filter memory depends both on  $m(t)$  and  $a$ .

## 3.7 Delay and absolute error models

### 3.7.1 Processing and round trip time delay model

Time delay occurs between issues of a TPC command by the eNodeB but not yet received power adjusted transmission from the UE. This delay is typically propagation round trip time (RTT), processing time at the UE and the eNB. The total time delay used during simulations is of 5 ms. In detail explanation and demonstration of delay is discussed in Appendix B.

### 3.7.2 Absolute error model

The open loop power control error usually results from the factors such as accuracy of measurements of reference symbol received power (RSRP) at the UE and inaccuracies in the radio parts such as temperature sensitivity and tolerances in the standard. The absolute error is identified as a slowly varying component and varies between



This section presents results obtained using both the full buffer and simple upload traffic models. As discussed in section 3.5, simple upload buffer model provides more realistic results and provides a better scale for performance analysis.

The results of performance comparison between open loop and closed loop power control with fractional path loss compensation factor are presented in Appendix C. Investigation for the optimal value of the PL compensation factor

### 4.1 Investigation for the optimal value of the PL compensation factor

Each value of  $U$  is investigated for each closed loop SINR target from a set of SINR targets. The criterion that selects optimal value of  $U$  for a given SINR target is optimized for cell-edge bit rate i.e. that value of  $U$  has been chosen which gives the best cell edge performance for a given SINR target.

**Figure 4-1: Investigating cell-edge and mean bit rate for different values of  $U$  for the closed loop power control using full buffer model.**



































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This section presents the performance comparison of the closed loop and open loop power control for different values of the path loss compensation factor. Furthermore, the

### C.1 Performance comparison for different values of the PL compensation factor

**Figure C- 1: Open loop versus closed loop, the plotted values are optimized for best cell-edge bit rate**

It can be seen in Figure C- 1, the closed loop power control using  $\mathcal{U} = 0.8$  shows performance gain, in terms of cell-edge and mean bit rate, over open loop power control with full compensation.

However, comparing closed loop and open loop power control for same value of  $\mathcal{U} = 0.8$ , it leads to a trade-off between cell-edge and mean user bit rate.

