Hybrid Power Control in Time Division Scheduling Wideband Code Division Multiplex Access

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Abstract

With high date rates using Enhanced Uplink (EUL), a conventional signal to interference ratio (SIR) based power control algorithm may lead to a power rush due to self interference or incompatible SIR target [2]. Time division (TD) scheduling in Wideband Code Division Multiplex Access (WCDMA) is considered to be a key feature in achieving high user data rates. Unfortunately, power oscillation/peak is observed in time division multiplexing (TDM) at the transition between active and inactive transmission time intervals [1]. Therefore there is a need to revisit power control algorithms for different time division scheduling scenarios.

The objective of power control in the context of this study is to minimize the required rise over thermal noise (RoT) for a given data rate, subject to the constraint that the physical layer control channel quality is sufficient (assuming that the dedicated physical control channel (DPCCH) SIR should not go below 3dB with a probability of at most 5%). Another goal is to minimize the local oscillation in power (power peaks) that may occur, for example due to transitions between active and inactive transmission time intervals.

The considered hybrid power control schemes are: (1) non-parametric Generalized rake receiver SIR (*GSIR*) Inner Loop Power Control (ILPC) during active transmission time intervals + Received Signal Code Power (RSCP) ILPC during inactive transmission time intervals and (2) *RSCP* ILPC during active transmission time intervals + *GSIR* ILPC during inactive transmission time intervals. Both schemes are compared with pure *GSIR* and pure *RSCP* ILPC.

Link level simulations with multiple users connected to a single cell show that:

- The power peak problem is obviously observed in GSIR + GSIR transmit power control (TPC), but in general it performs well in all time division scenarios studied. GSIR outperforms other TPC methods in terms of RoT, especially in the TU channel model. This is because it is good in combating instantaneously changed fading and accurately estimates SIR. Among all TPC methods presented, GSIR + GSIR TPC is best in maintaining the quality of the DPCCH channel. No power rush is observed when using GSIR + GSIR TPC.

- RSCP + RSCP eliminates the power peak problem and outperforms other TPC methods presented under the 3GPP Pedestrial A (pedA) 3km/h channel in terms of RoT. However, in general it is worse in maintaining the control channel's quality than GSIR + GSIR TPC.

- GSIR + RSCP ILPC eliminates the power peak problem and out-performs GSIR power control in the scenario of 2 and 4 TDM high data rate (HDR) UE and 2 TDM HDR UE coexistence with 4 Code DivisionMultiplex (CDM) LDR UE, in the pedA 3km/h channel, in terms of RoT. However, the control channel quality is not maintained as well during inactive transmission time intervals.

- It is not recommended to use RSCP + GSIR TPC since it performs worst among these TPC methods for most of the cases in terms of RoT, even though it is the second best in maintaining the control channel quality. The power peak is visible when using RSCP + GSIR TPC.

To maintain the control channel's quality, a minimum SIR condition is always used on top of all proposed TPC methods. However, when there are several connected TDM HDR UEs in the cell, results indicates that it is challenging to meet the quality requirement on the control channels. So it may become necessary to limit the number of connected terminals in a cell in a time division scenario.

Key Words: WCDMA, High-Speed Uplink Packet Access, Power Control, GRAKE+

Sammanfattning

Med den höga datahastighet som Enhanced Uplink (EUL) medger kan en konventionell algoritm för effektkontroll baserad på signal to interference ratio (SIR) leda till effekthöjning beroende på självinterferens eller felaktigt SIR mål. Time division (TD) schedulering vid Wideband Code Division Multiple Access (WCDMA) anses vara en nyckelfunktion för att uppnå höga datahastigheter. I övergången mellan aktiv och inaktiv transmissionstidsintervall vid time division multiplexing (TDM) har effektoscillering/effektpeak observerats. Detta gör det nödvändigt att se över algoritmerna för effektkontroll vid olika scenarion av TD schedulering.

Målet med effektkontrollen i denna studie är att minimera rise over thermal noise (RoT) för en given datahastighet givet begränsningen att kvaliteten på physical layer control channel är tillräcklig (beaktande att dedicated physical control channel (DPCCH) SIR inte understiger 3dB med en sannolikhet på som mest 5%). Ett annat mål är att minimera den lokala effektoscillationen (effektpeakar) som kan inträffa till exempel vid övergång mellan aktiv och inaktiv transmissionstidsintervall.

De undersökta hybrida metoderna för effektkontroll är: (1) icke-parametrisk Generalized rake receiver SIR (GSIR) Inner Loop Power Control (ILPC) vid aktiv transmissionstidsintervall + Received Signal Code Power (RSCP) ILPC vid inaktiv transmissionstidsintervall och (2) RSCP ILPC under aktiv transmissionstidsintervall + GSIR ILPC under inaktiv transmissiontidsintervall. Båda metoderna jämförs med ren GSIR och ren RSCP ILPC.

Länk nivå simulering med flera användare anslutna till en enda cell visar att:

- Problemet med effektpeakar observeras tydligt vid GSIR + GSIR transmit power control (TPC) men generellt sett presterar den bra i alla studerade TD scenarion. GSIR presterar bättre än andra TPC metoder beträffande RoT, speciellt i TU kanal modellen. Detta beror på att metoden är bra på att motverka momentant förändrad fading och med god precision estimerar SIR. Bland alla presenterade TPC metoder är GSIR + GSIR TPC den bästa på att behålla en god kvalitet på DPCCH kanalen. Ingen effekthöjning har observerats vid GSIR + GSIR TPC.

- RSCP + RSCP eliminerar problemet med effektpeakar och presterar bättre än andra TPC metoder presenterade under 3GPPs Pedestrial A (pedA) 3km/h kanal beträffande RoT. Dock är metoden generellt sett sämre på att behålla kontrollkanalens kvalitet än GSIR + GSIR TPC.

- GSIR + GSIR ILPC eliminerar problemet med effektpeakar och presterar bättre än GSIR power control i ett scenario med 2 och 4 TDM high data rate (HDR) UE och 2 TDM HDR UE tillsammans med 4 Code Division Multiplex (CDM) LDR UE i pedA 3km/h kanalen beträffande RoT. Dock kan inte kvaliteten på kontrollkanalen behållas i detta fall heller under inaktiv transmissionstidsintervall.

- Det är inte rekommenderat att använda RSCP + GSIR TPC eftersom den presterar sämst av alla TPC metoder beträffande RoT i de allra flesta fall. Till dess fördel är att den är den näst bästa på att behålla kvaliteten på kontrollkanalen. Effektpeakar har observerats när RSCP + GSIR TPC använts.

För att behålla kontrollkanalens kvalitet används alltid en minimum SIR nivå ovanpå alla föreslagna TPC metoder. När det finns flera anslutna TDM HDR UEs i cellen indikerar resultaten att det är en utmaning att behålla kvalitetskraven på kontrollkanalen. På grund av detta kan det bli nödvändigt att begränsa antalet anslutna terminaler i en cell i ett TD scenario.

Nyckelord: WCDMA, High-Speed Uplink Packet Access, Power Control, GRAKE+

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Acronyms and abbreviations

3GPP	Third-Generation Partnership Project
ACK	Acknowledgment
BLER	Block error rate
CDF	Cumulative Distribution Function
CDM	Code DivisionMultiplex
CDMA	Code Division Multiple Access
CRC	Cyclic redundancy Code
DCH	Dedicated Channel
DPCCH	Dedicated Physical Control Channel
E-TFC	Enhanced Transmission Format Combination
EUL	Enhanced Uplink
E-DPCCH	E-DCH Dedicated Physical Control Channel
E-DPDCH	E-DCH Dedicated Physical Data Channel
E-TFCI	Enhanced transport-format combination indicator
GRAKE	Generalized rake
GSIR	Generalized rake receiver SIR
HARQ	Hybrid automatic repeat request
HDR	High data rate
HS-DPCCH	Dedicated Physical Control Channel (uplink) for HS-DSCH
HS-DSCH	High Speed Downlink Shared Channel
ILPC	Inner Loop Power Control
km/h	Kilometer per hour
LDR	Low data rate
NACK	Negative Acknowledgment
OLPC	Outer loop power control
olpc_TTE_ target	Outer Loop Transmission Attempt Error Rate target
pedA	Pedestrian A
RoT	Rise over Thermal
RSCP	Received Signal Code Power
SIR	Signal to Interference Ratio
SINR	Signal to Interference and Noise Ratio
TD	Time Division
TDM	Time Division Multiplex
TPC	Transmit Power Control
TTI	Transmission Time Interval
TTE	Transmission Target Error
TU	Typical urban
UE	User Equipment
ULW	Uplink Wideband
WCDMA	Wideband Code Division Multiplex Access

1 Introduction

1.1 Background

Networks based upon the Third-Generation Partnership Project (3GPP) specification have been widely deployed around the world for third generation (3G) mobile systems since the end of 1998. 3GPP lead the standardization of Wideband Code Division Multiplex Access (WCDMA) based radio access using the ITU's UMTS Terrestrial Radio Access Frequency Division Duplexing mode **Error! Reference source not found.**. WCDMA utilizes a Direct-Sequence Code Division Multiple Access (CDMA) technique transmitting on a pair of 5MHz-wide radio channels.

The first release of the series of 3GPP specification, Rel-99 focused on voice services and moderate transmission data rates. A data rate of 384 kbps was often the maximum data rate supported in practice, while in principle a maximum 1.96Mbps peak rate could be achieved by using a Dedicated Channel (DCH) **Error! Reference source not found.**. In Release 5, the High Speed Downlink Packet Access feature was added to support high transmission data rates over the downlink. In release 6, the Enhanced Uplink (EUL) was introduced to support higher transmission data rates over the uplink. Combining High Speed Downlink Packet Access and EUL supports high data rate broadband traffic.

Due to the selection of CDMA the users transmit data on a non-orthogonal shared uplink channel, the total received uplink power in a cell should not exceed a given limit in order to maintain uplink coverage. This is necessary because users at the cell border also need to be heard and to be demodulated and be decoded with a certain quality. Therefore, the inner loop power control which determines the transmission power of user equipment (UE) plays a critical role in maintaining the uplink interference level and cell coverage. Moreover, when introducing high bit rate packet data service by EUL, the uplink transmission power of an individual link is increased and number of active transmitters can be dramatically reduced in comparison with voice services as the uplink interference headroom in a cell can easily be filled by high data rate users.

Time Division (TD) scheduling has been identified as a key feature for high spectral efficiency in the WCDMA uplink. In EUL TD scheduling, only one user is allowed to transmit payload data on E-DCH Dedicated Physical Data Channel (E-DPDCH) in a given Transmission Time Interval (TTI), while other users only transmit uplink control data via Dedicated Physical Control Channel (DPCCH) and the high speed Dedicated Physical Control Channel (HS-DPCCH). UEs alternate their data transmissions in subsequent TTIs. For the remainder of this report, a UE which is transmitting payload data on the E-DPDCH in a particular TTI will be referred to as active and a UE which is not transmitting payload data on the E-DPDCH in a TTI but only utilizes the control channels will be referred to as inactive. The main benefit of TD scheduling is to reduce the *intra* cell interference for the active UE, hence enabling high uplink data rates in an uplink interference limited system. Moreover, due to the non-orthogonality of uplink channels among different UEs, the active UE suffers less interference from inactive Ues, while the inactive UE suffers more interference mainly from the active UE. As a consequence, the interference a UE perceives changes abruptly at transitions between active and inactive state, with the interference typically being higher in the inactive state.

Nowadays, the most commonly used conventional Inner Loop Power Control (ILPC) method is signal over interference ratio (SIR) based. This means that the SIR is estimated (typically on the DPCCH) and the SIR estimate is compared with the SIR target. If the estimated SIR is higher than (or equal) to the SIR target, the transmit power of the UE is ordered down, and vice versa. This ILPC operates at 1500 Hz. The SIR target is adjusted through an outer loop power control (OLPC) according the quality of the data channel E-DPDCH in terms of block error rate (BLER) and other predefined quantities. When the UE stops transmitting data on E-DPDCH, the SIR target will remain unchanged, since there is no information available to base an update upon. OLPC and ILPC cooperate throughout the whole transmission connection. SIR based power control has the advantage of maintaing the quality of control channels and maintaining synchronization, but it is also risks causing a power rush problem at high interference levels or high transmission rates. For this reason some additional ILPC methods have been proposed, for example RSCP based [3] and RoT based [2] Transmit Power Control (TPC).

1.2 Problem with Existing Power Control

Some power control studies have been done for EUL TD scheduling. In [3], the power peak problem is addressed when pure SIR based ILPC is used, i.e. an inactive UE suffers more interference so it has to raise its transmission power substantially at the transition to inactive state in order to maintain a SIR close to the SIR target. When an inactive UE becomes active, the SIR is well above the SIR target and the power is reduced since there is less interference. Therefore the conventional SIR based power control algorithm may lead to power peaks in TD scheduling scenarios [3]. The behavior of increasing and decreasing the transmit power repeats as the state changes from active to inactive throughout the connection. This is schematically depicted in Figure 2 on page 12.

The high transmission power of inactive UEs will increase the RoT in the cell which makes it difficult to achieve high peak data rates when using TD scheduling. Moreover, the active UE is likely to transmit with too high power (exceeding the SIR target) when entering the active state during a TTI.

1.3 Contributions

Because the interference level and SIR level vary widely during active and inactive TTIs, this study aims to flexibility set different power or SIR target levels by adopting different TPC methods during in active and inactive TTIs. In active TTIs one of the TPC methods described in Chapter 2 (e.g. SIR, RSCP, and RoT based power control) can be used for power control, while a different TPC method can be adopted in inactive TTIs.

1.4 Thesis Outline

The thesis is organized as follows:

- Chapter 2 presents a short description of main features of the High-Speed Uplink Packet Access technique. Then TD scheduling for EUL is explained. The uplink High-Speed Uplink Packet Access physical channels (including the power settings) are described in detail.

- In Chapter 3, the pure inner loop power control is discussed; where either the conventional SIR based ILPC and or the RSCP based ILPC is used throughout the whole transmission of a user.
- Chapter 4 introduces a proposed hybrid transmission power control method. The corresponding algorithms and the desired behavior are examined in detail.
- Chapter 5 presents the simulator’s configuration, lists the basic assumptions that have been made, and lists the scenarios that were simulated.
- Chapter 6 contains the simulation results for each of the different scenarios of the previous chapter. An analysis is presented for each scenario.
- Finally, some conclusions are drawn in Chapter 7. Additionally, some suggestions for future work are given.

2 Key System Concepts

2.1 High-Speed Uplink Packet Access General Principles

2.1.1 Hybrid Automatic Repeat Request (with Soft combining)

Automatic Repeat Request is as an error-control method for data transmission that uses acknowledgements and timeouts to achieve reliable data transmission over an unreliable service. If the receiver detects an error in the received data, then a negative acknowledgment (NACK) will be sent to the sender. If the sender does not receive an acknowledgment before a specified timeout, then a retransmission of the frame/packet is requested until the sender receives an acknowledgment or a predefined number of retransmissions is exceeded [4]. In order to maintain continuous transmission of frame/packet data, hybrid automatic repeat request (HARQ) uses multiple stop-and-wait-Automatic Repeat Request processes to ensure continuous data transmission during the retransmission waiting time. For a 10ms TTI, 4 HARQ processes are used, while for a 2ms TTI, 8 HARQ processes are used in parallel.

Moreover instead of simply discarding erroneously received packets, HARQ with soft combing stores the erroneously received data in a buffer and combines it with the received retransmission to obtain a single, combined packet which is more reliably correctly decoded than its constituent parts [1].

2.1.2 EUL Scheduling

In a WCDMA uplink, the common resource shared among the terminals is the amount of tolerable interference, i.e., the total received power at the base station. The amount of common uplink resources a terminal is using depends on the data rate (and transport format) used. Generally, the higher the data rate, the larger the required transmission power and thus the higher the resource consumption [1]. The details of uplink transmission power for a UE are further explained in section 2.2.

Scheduling is the key to ensuring the uplink interference does not exceed the limit level by determining *when* a certain terminal is allowed to transmit and at *what* maximum data rate. The information of when and at what rate a UE is allowed to transmit during the coming TTI is specified by the radio base station through a dedicated channel called the Enhanced Absolute Grant Channel. When UE receives the absolute grant from the radio base station, the maximum allowed Enhanced Transmission Format Combination (E-TFC) will be known. The available data in UE's transmitter's buffer and the remaining transmission power of the UE also need to be taken into consideration in determining the final transmission block size.

2.1.3 Short TTI

High-Speed Uplink Packet Access users can transmit a data payload either in a 10ms or 2ms Transmission Time Interval (TTI). The short TTI of 2ms is a basic feature of the Enhanced Uplink to shorten the roundtrip time delay and to achieve a higher peak data rate when compared with a 10ms TTI. In a 10ms TTI the peak rate is 1.38Mbps, while in a 2ms TTI the peak data rate is 5.76Mbps. During the 10ms TTI, 4 HARQ processes are transmitted in parallel; this means the time between retransmission and the previous transmission of the same transmission block is a 40ms interval. While in the case of 2ms TTI, 8HARQ processes are transmitted in parallel yielding a 16ms' interval for retransmissions. In case of retransmission, the 2ms TTI gives much shorter time to receive the retransmitted data, hence reducing the delay to correctly receive the frame.

2.2 TD Scheduling for High-Speed Uplink Packet Access

TDMA and CDMA are two different well-known channel access methods. Relatively little work has been reported on using time division techniques together with CDMA. The reason to introduce TD scheduling in high speed uplink packet access is to improve the EUL capacity and peak bit rate as compared to the current "CDMA" scheduling [6].

In WCDMA, users are non-orthogonal to each other, i.e. they generate interference to each other even within the same cell. Therefore the system has an upper interference limitation, so that the cell noise rise will not continuously increase, thus enabling the system to remain stable. This limits the maximum cell capacity. One way to increase WCDMA's efficiency is to use time-division of user transmissions rather than code-division. During the 2ms TTI only one user at a time is allowed to transmit, thus achieving full orthogonality during transmission. This increases the probability of successfully transmitting at very high data rates. Initial ideal simulation results indicate that TD scheduling gives around 30-40% higher capacity than pure "CDMA"[6].

Considering the end user's performance, specifically latency, only 2ms TTI is used for EUL TD scheduling. This means that there are 8HARQ processes in total, these could be allocated to at most 8 different TDM users rather than allocating all 8HARQ processes to the same UE.

2.3 Uplink Physical Channels and relative power settings

There are five types of uplink dedicated physical channels: the uplink Dedicated Physical Data Channel (uplink DPDCH), the uplink Dedicated Physical Control Channel (uplink DPCCH), the uplink E-DCH Dedicated Physical Data Channel (uplink E-DPDCH), the uplink E-DCH Dedicated Physical Control Channel (uplink E-DPCCH), and the uplink Dedicated Control Channel associated with high speed downlink shared channel transmission (uplink HS-DPCCH). The DPDCH, DPCCH, E-DPDCH, E-DPCCH and HS-DPCCH from the same UE are distinguished by orthogonal channelization codes and are I/Q code multiplexed [5]. The transmission power on various uplink physical channels for a specific UE constitutes the total uplink transmission power of this UE.

2.3.1 DPCCH and DPDCH

The uplink DPDCH is used to carry the DCH transport channel. There may be zero, one, or several uplink DPDCHs on each radio link which may have spreading factor from 256 to 4.

The uplink DPCCH is used to carry *control* information generated at Layer 1. It consists of known pilot bits to support channel estimation for coherent detection, transmit power-control (TPC) commands, feedback information, and an optional transport-format combination indicator (TFCI). The TFCI informs the receiver about the instantaneous transport format combination of the transport channels mapped to the simultaneously transmitted uplink DPDCH radio frame. There is one and only one uplink DPCCH on each radio link and the spreading factor of DPCCH is 256.

The transmission power of DPDCH has a power offset to DPCCH, i.e. the square of DPDCH gain factor $\beta_d^2 = (A_d/A_c)^2$. Where A_d and A_c correspond to the transmission signal amplitude of DPDCH and DPCCH respectively and A_d depends on the Transmission Format Combination of DPDCH.

2.3.2 HS-DPCCH

The HS-DPCCH carries uplink feedback signaling associated with high speed transmission, which consists of HARQ Acknowledgement (HARQ-ACK) and Channel-Quality Indication and if the UE is configured in multiple input-multiple output mode a Precoding Control Indication as well. There is at most one HS-DPCCH on each radio link. The HS-DPCCH can only exist together with an uplink DPCCH.

The transmission power of HS-DPCCH is relative to DPCCH with power offset $\beta_{hs}^2 = (A_{hs}/A_c)^2$, where A_{hs} and A_c correspond to the transmission signal amplitude of HS-DPCCH and DPCCH respectively.

2.3.3 E-DPCCH and E-DPDCH

E-DPDCH is used to carry the E-DCH transport channel. There may be zero, one, or several E-DPDCH on each radio link. The spreading factor of E-DPDCH varies from a spreading factor of 256 to multiple codes (2 spreading factor=4 + 2 spreading factor=2).

The E-DPCCH is a physical channel used to transmit control information associated with the E-DCH, including the enhanced transport-format combination indicator (E-TFCI) needed to decode the data in the E-DPDCH. There is at most one E-DPCCH on each radio link.

E-DPDCH and E-DPCCH are always transmitted simultaneously and E-DPCCH can only exist together with an uplink DPCCH. The power offset of E-DPDCH and E-DPCCH to DPCCH are the square of the E-DPDCH gain factor $\beta_{ed}^2 = (A_{ed}/A_c)^2$ and square of E-DPDCH gain factor $\beta_{ec}^2 = (A_{ec}/A_c)^2$, here A_{ed}, A_{ec}, and A_c represent the signal amplitudes of E-DPDCH, E-DPCCH, and DPCCH respectively. The value of A_{ed} is mostly determined by the E-DPDCH Transmission Format Combination (E-TFC).

2.3.4 Uplink Transmission Power

The total uplink transmission power of a UE consists of the power from all the uplink physical channels that are present.

$$\begin{aligned}Power_{tx\_ul} &= Power_{DPCCH} + Power_{DPDCH} + Power_{HS\text{-}DPCCH} + Power_{E\text{-}DPCCH} + Power_{E\text{-}DPDCH} \\ &= Power_{DPCCH}\,(1 + \beta_d^2 + \beta_{hs}^2 + \beta_{ec}^2 + \beta_{ed}^2)\end{aligned}$$

The power of DPCCH is controlled by the uplink inner loop power control, see the next chapter for details.

3 Pure Power Control Scheme

3.1 GSIR Inner Loop Power Control

SIR based power control is the currently used power control method in products. SIR is measured on DPCCH and compared with its target.

```
if SIR > SIRtarget
   TPC command = down
else
   TPC command = up
end
```

Here SIR is an estimate of the instantaneous signal to interference ratio, and SIRtarget is adjusted and updated by the SIR based OLPC to maintain the data channel quality according to BLER.

The advantage of SIR based power control is that it can quickly combat perceived interference and fading condition changes thanks to the slot based fast TPC. However, when there is increased interference level the reaction of SIR ILPC would be to increase the transmission power in order to maintain the SIR target. This will increase the interference level and other UEs will be forced to increase their power inorder to maintain their own SIR target, which may cause power rushes and RoT violation risks. Moreover, a single UE can also be limited by its self-interference when it is transmitting at a high data rate or can be affected by high interference from other UEs in the same cell. This means that the measured SIR may be unable to reach the target SIR even though the transmission power reaches the maximum power limitation, which eventually may lead to a power rush.

There are different SIR estimation methods with different accuracies. A previous study of power control on TD scheduling [3] has shown that non-parametric GRAKE (this applies to GRAKE+ as well) gives very good SIR estimation accuracy. All TD scheduled UEs in the report are simulated with a GRAKE+ equalizer unless explicitedly stated otherwise, and GRAKE SIR was calculated based on the Ru matrix retrieved from non-parametric GRAKE.

GRAKE+ is a blind method to estimate all possible interference (inter symbol interference, multi-user interference, inter-cell interference and thermal noise) to a connected UE by despreading the received data with one or more unused channelization codes. Since the unused code is orthogonal to the used channelization code for data under the same scrambling code (i.e. the same UE), only the interference remains after the dispreading [7].

GRAKE+ SIR has following expression:

Equation 1: $$SIR = \frac{\left|w^H h\right|^2}{w^H \cdot Ru \cdot w}$$

where h is the net channel estimate, w is the combining weight,

$w = Ru^{-1} * h$,

and *Ru* is the impairment matrix estimated by the GRAKE+ receiver.

The impairment matrix *Ru* is updated very fast, e.g. once per slot, so GRAKE+ SIR captures the interference level well, hence it provides nearly instantaneous accurate SIR measurements.

3.2 RSCP Inner Loop Power Control

Received Signal Code Power (RSCP) based power control is considered a key concept to replace SIR based power control for the EUL TDM. It avoids the power rush risks of SIR based power control in situations with increased interference, since the interference level is **not** considered by RSCP based ILPC. Instead, it is up to the RSCP based OLPC to set a proper RSCP target for the experienced interference in order to maintain the targeted BLER [2].

RSCP based power control scheme is as simple as SIR based power control:

```
if RSCP > RSCPtarget
   TPC command= down
else
   TPC command = up
end
```

Here RSCP is the mean received power on the despread DPCCH pilot symbols, which is calculated as follows:

Equation 2: $$DPCCH\ RSCP = P_{pilots} = \left\| mean(pilots) \right\|^2,$$

and RSCPtarget is adjusted and updated by the RSCP OLPC according to the instantaneous BLER and the targeted BLER.

RSCP based power control gives better control in terms of the RoT budget. However, one drawback is that the quality of the control channel may **not** be maintained when the UE has a bad radio condition or when the interference level increases abruptly. Either of these is likely to lead to a block error increasing the BLER. As a consequence RSCP OLPC will raise the RSCPtarget and update it in the RSCP ILPC hence it will be used in the next scheduled TTI. The update frequency of the RSCPtarget value depends on the amount of UL data transmission, i.e. the RSCPtarget will not be updated when UE is inactive since there is no data input for the cyclic redundancy code (CRC) check.

Additional mechanisms normally are needed along with RSCP based ILPC to assure control channel quality, e.g. the minimum SIR requirement method described in section 3.3.

3.3 Minimum SIR Requirement

The Minimum SIR requirement is a method to be combined on top of other power control methods in order to assure control channel quality. It will force TPC command to be an “up” if the measured SIR is below a given minimum SIR threshold, e.g. 3dB, no matter what the decision is made from SIR/RSCP ILPC. It is feasible to set the value of minimum SIR threshold so as to try to maintain the quality of control channel above a certain desired level.

4 Hybrid Inner Loop Power Control for TD Scheduling

This chapter describes two different hybrid power control combinations. The algorithm for each is described in terms of a flow chart. The the delay compensation for RSCPtarget (SIRtarget) is described for each of the hybrid power control combinations.

4.1 GSIR in active TTI and RSCP in inactive TTI

The idea of this hybrid power control scheme is to maintain a given target DPCCH power during the inactive TTIs, while SIR based TPC is used during the active TTIs. The target power value for the inactive TTIs is obtained by estimating the received DPCCH power in the active TTIs, i.e. to adapt the inactive TTI target power based on the situation during the active TTIs. In the remainder of this report, this scheme will be referred to as the GSIR + RSCP method. The algorithm for this method is shown in Figure 1.

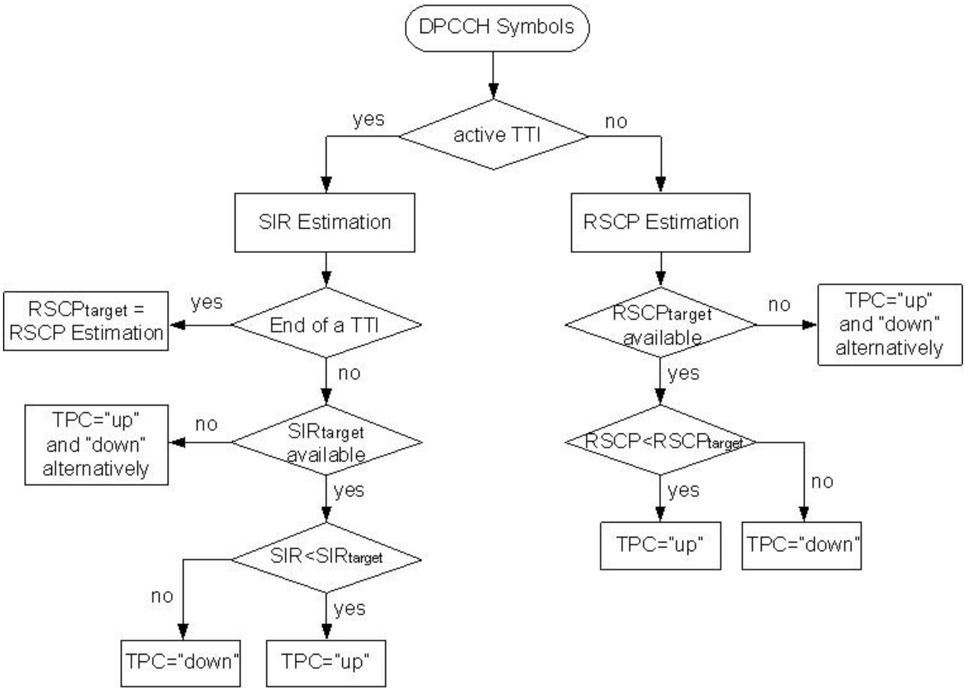

Figure 1: proposed GSIR+RSCP ILPC algorithm in TDM

The algorithm consists of:

1. (a) Employ the conventional SIR ILPC (base design) in an active sub-frame (i.e., in an active TTI). This adjusts the transmission power to get the correct SINR, taking potential rapid changes in background interference into account, e.g., G-Rake+ SINR can be used here.

   (b) Estimate the RSCP during the active sub-frame to set RSCPtarget.

2. Switch to constant RSCP TPC in inactive sub-frames, using the estimated RSCPtarget value in (1b) as target. This maintains the received power at a constant level which is the "best guess" of the necessary power in the next active sub-frame.

3. Outer loop power control works in a similar way to the baseline, i.e., increase or decrease target SIR in active sub-frames based on CRC status.

Note that the above flow chart is for illustration purposes only. The relevant values may be filtered or adjusted in order to improve performance. Moreover, the above algorithm may be constrained with a minimum SIR level that shall be maintained in inactive TTIs in order to ensure that synchronization is maintained and that the quality of the DPCCH and HS-DPCCH are maintained

Figure 2 illustrates how the GSIR + RSCP ILPC method works from active TTI to inactive TTI and vice verse. The dashed line shows the power usage when conventional SIR based ILPC is used (baseline). This power peak would result in high transmission power during an inactive TTI and power waste during an active TTI. In principle, the GSIR + RSCP ILPC method should be able to avoid the power peak problem in TDM, enabling the UE to have a suitable power level when it enters the active TTI from and inactive TTI.

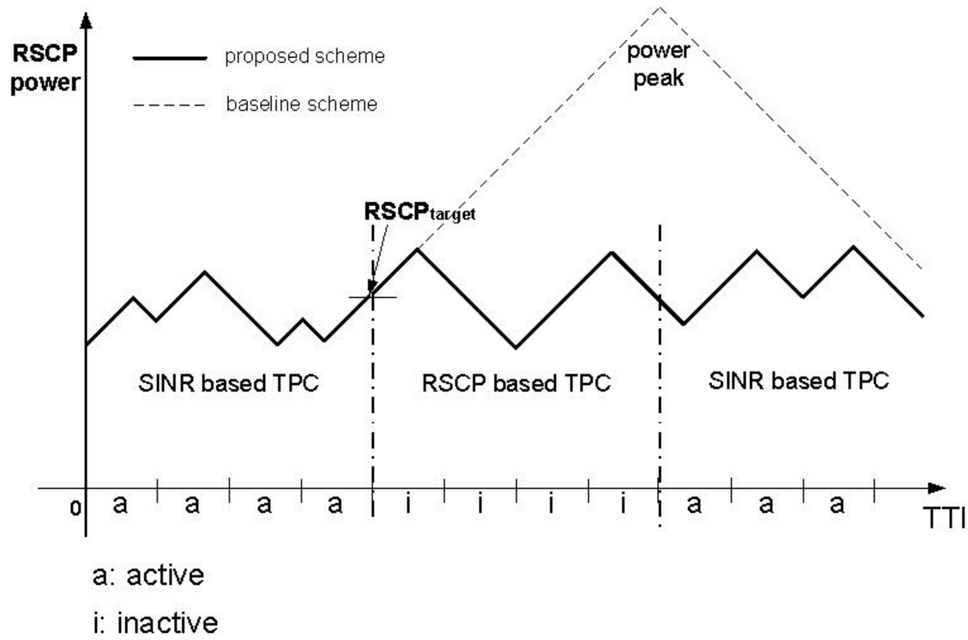

Figure 2: GSIR + RSCP Inner loop power control in TDM

4.1.1 TPC delay compensation on RSCPtarget

Considering the two slot delay in uplink TPC and the possibility of a TD UE being scheduled for transmission shortly, e.g. active for one TTI out of every eight TTIs, TPC delay compensation of the RSCPtarget is a method to adjust the RSCP target value by taking into consideration the TPC commands from the previous two active slots into account [8]. The RSCPtarget is only calculated and will be used when the UE enters an inactive TTI from an active TTI, while the SIRtarget during the active TTI is provided by OLPC. The RSCPtarget is formulated as following:

RSCPtarget(t) = RSCPmeas(t-1) + tpc(t-1) + tpc (t-2);

Where RSCPtarget(t) is the RSCP target used by inner loop power control during inactive TTI, RSCPmeas(t-1) is the RSCP measurement in the previous active slot, and tpc(t-1) and tpc(t-2) are the TPC commands generated in the previous and the pre-previous active slots respectively. All parameters use the dB scale. The value for tpc is calculated using the following pseudo code:

```
if tpc_command = up
   tpc = 1
else
   tpc = -1
end
```

4.2 RSCP in active TTI and GSIR in inactive TTI

The idea of this hybrid power control scheme is to maintain a given target DPCCH power during the inactive TTIs, while SIR based TPC is used during the active TTIs. The target power value for the inactive TTIs is obtained by estimating the received DPCCH power during the active TTIs, i.e. to adapt the inactive TTI target power based on the situation during the active TTIs. In the remainder of this report, this scheme will be referred to as the RSCP + GSIR method. The algorithm for this method is shown in Figure 3.

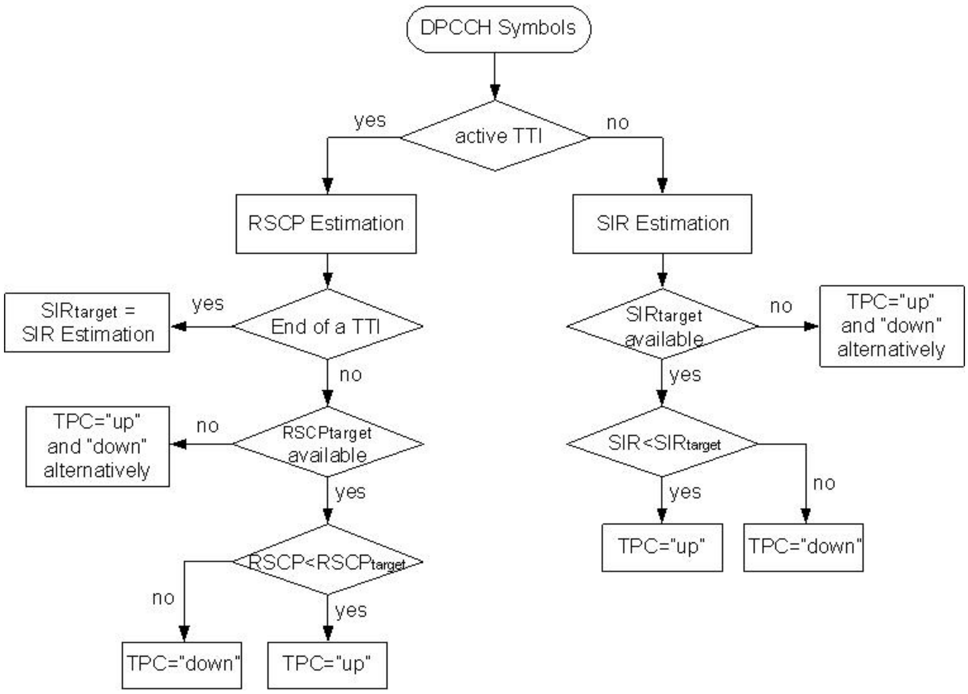

Figure 3: proposed RSCP + GSIR ILPC algorithm in TDM

The algorithm consists of:

1. (a) Employ a constant RSCP TPC during an active sub-frame. This adjusts the TPC to get the correct RSCP level, while the potential rapid changes in background interference are taken into account by RSCP OLPC.

(b) Estimate the SINR during the active sub-frame as SINRtarget.

2. Switch to conventional SINR based ILPC in inactive sub-frames, using the estimated value in 1b) SINRtarget as target.

3. Outer loop power control works in a similar way as the baseline, but RSCP based, i.e., increase / decrease target RSCP in active sub-frames based on CRC status.

Figure 4 illustrates how the RSCP + GSIR ILPC method works from active TTI to inactive TTI and vice verse. The dashed line shows the power usage when conventional SINR base ILPC is used through out the whole connection (baseline).

By using the RSCP TPC method in active TTI, the power rush problem can be avoided by an active UE. The SINR based ILPC method is used during inactive TTIs, which means that the inactive UE needs to adjust its power according to the SIR target value derived from the SIR level during active TTIs. Since the SIR is usually high during the active period, the inactive UEs are likely to raise their power to maintain a high SIR target when it enters the inactive TTI from an active TTI. Thus the RSCP + GSIR method is similar to pure SIR based ILPC in the sense that both methods are likely to cause a power peak at the transition from the inactive period to the active period.

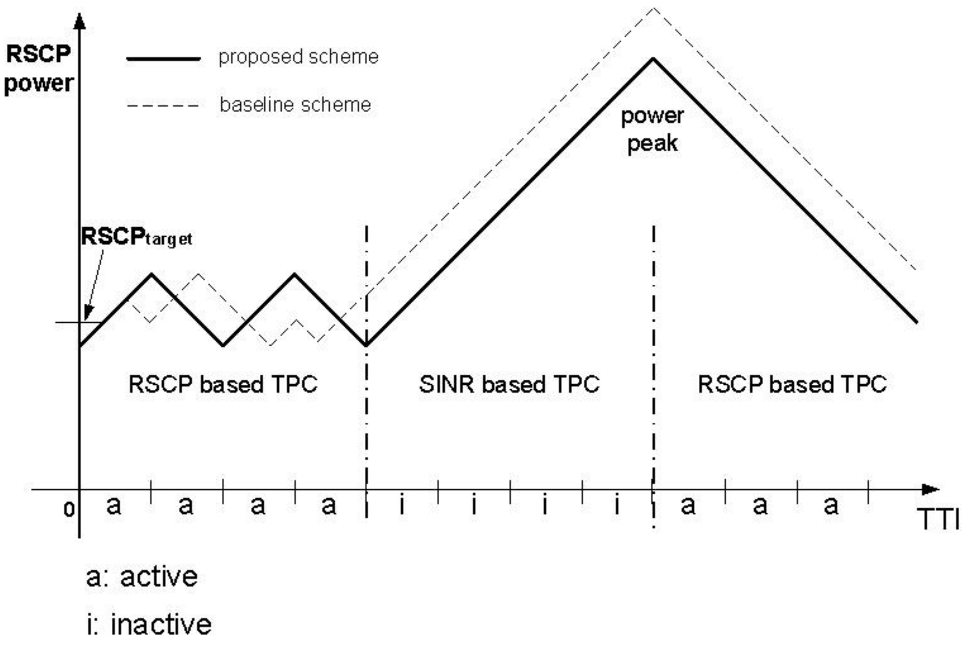

Figure 4: RSCP + GSIR Inner loop power control in TDM

4.2.1 TPC delay compensation on SIRtarget

Similar to TPC delay compensation of the RSCPtarget, TPC delay compensation of the SIR target is a method to adjust the SIR target value by taking into consideration the transmission power control commands during the previous two active slots. The SIRtarget is only calculated and will be used when the UE enters an inactive TTI from an active TTI, while the RSCPtarget during an active TTI is provided by OLPC. The SIRtarget is formulated as following:

SIRtarget(t) = SIRmeas(t-1) + tpc(t-1) + tpc (t-2);

Where SIRtarget(t) is the SIR target used by inner loop power control during inactive TTI, SIRmeas(t-1) is the SIR measurement in the previous active slot, and tpc(t-1) and tpc(t-2) are the TPC commands generated in the previous and the pre-previous slots respectively. All parameters are in dB scale. The value for tpc is calculated using the following pseudo code:

```
If tpc_command = up
   tpc = 1
else
   tpc = -1
end
```

5 Simulations

In order to evaluare the proposed hybrid power control methods we will use simulation. This chapter describes the simulator that was used, the assumptions that have been made to configure the simulator, the calculation of the relevant parameters, and the scenarios that will be simulated.

5.1 Uplink WCDMA Link Simulator

The simulator used for these simulations is the Uplink WCDMA (“ULW”) simulator. This is a floating point simulator developed by the WASP project at Ericsson Research.

5.2 General Simulation Assumption

There are a few assumptions made in the Uplink WCDMA link simulator:

- A single cell is modeled *without* inter-cell interference;
- No uplink DPDCH is configured in EUL transmission; and
- No anti-wind up in OLPC (anti-wind up is an OLPC mechanism preventing large difference between the estimated SIR and the SIR target)

5.2.1 Receiver Algorithms and Modeling

In these simulations channel estimation and SIR estimation are modeled. A GRAKE+ (non-parametric GRAKE) receiver is used for TDM high data rate (HDR) users while a RAKE receiver is used for CDM HDR users. All other algorithms, such as frequency error estimation, are assumed to be ideal and the path searcher is assumed to be ideal, in the sense that they operate with no errors. Also, automatic gain control and quantization are not modeled. The simulations presented below were performed using four fold over-sampling, unless stated otherwise. No frequency drift or perfect sampling were assumed, and thus no sampling error is introduced throughout these simulations. Two receiver antennas are always used unless stated otherwise.

The modeling of TPC, channel estimation, and SIR estimation were based upon:

- TPC is done with a two slot delay (one slot SIR estimation delay).
- Log-max Turbo decoder is used (it++ implementation [9]).

In these simulations, the BLER target could not be explicitly applied by OLPC due to retransmissions resulting in almost zero BLER as seen at the radio network controller. Therefore, the parameter olpc_TTE_target (Outer Loop Transmission Attempt Error Rate target) is used to steer the outer loop power control. The update speed of inner loop power control target value, e.g. SIR target or RSCP target is affected by the olpc_TTE_target value. For instance, with lower olpc_TTC_target = 5% (at least 19 transmissions among 20 transmissions reach the targeted number of transmission attempts) corresponds to a slower update speed of OLPC while a higher olpc_TTC_target = 20% refers to a higher update speed of ILPC target (at least 4 transmission among 5 transmissions reach the targeted number of transmission attempts).

In all the simulations, a maximum of four transmission attempts are allowed and the targeted number of transmission attempts is set to one.

All the simulation results presented in this report exclude the ramping up period which OLPC needs to converge.

5.2.2 Channel estimation

The *multi-slot filtering channel estimator* is used, where the channel estimate is estimated by averaging the channel over n slots. The current and n-1 previous slots are used for averaging of de-spread and de-rotated pilot and non-pilot symbols.

5.2.3 SIR estimator

There are two SIR estimators used:

1. *The GSIR* estimator refers to GRAKE+ SIR and it is used by all TDM HDR UEs. GRAKE+ SIR is estimated based on the *Ru* matrix derived from a non-parametric GRAKE receiver. See section 0for details of this calculation.
2. "p_over_pilot_variance" is a SIR estimator for low data rate (LDR) users, here used for CDM LDR UEs. This estimator estimates the power of demodulated and de-rotated DPCCH and the variance of the same. The variance is filtered over many slots before being used to calculate the interference part of SIR.

5.3 Performance Metric

Good control of the cell RoT and of the quality of the DPCCH control channel are considered two important criteria when comparing the performance of various TPC methods. DPCCH transmission power is plotted to show the transmission power level of the various power control methods and to see whether they have a power peak problem or not at the transition between active and inactive status. In addition, the cell throughput is also considered to be a good criterion to examine.

Each parameter is described in following:

- ***Rise over Thermal*** (***RoT***) estimates the noise rise in a cell. It is calculated per slot by averaging the *RoT* of each antenna branch.

$$RoT = \frac{\sum_{k=1}^{nr\_of\_antennas} (Ec\_all_k + N_0)/N_0}{nr\_of\_antennas}$$

  where Ec_all_k is the total received power on antenna branch *k* from all users in a slot.

- ***Actual DPCCH SIR*** calculates the 'true' received DPCCH SIR in GRAKE+ assuming that there is not any error in channel estimation (using true channel coefficients) and the calculated value is output every slot. There is a contraint on DPCCH SIR, in that DPCCH SIR should not be less than 3 dB with a probability greater than 5%.
- ***Averaged DPCCH transmission power*** is the averaged transmission power of DPCCH over twenty four slots/8TTIs according to the TDM transmission pattern.

$$DPCCH(n) = \frac{\sum Tx\_dpcch(n)}{length(Tx\_dpcch(n))}, n = 1,2,3...24$$

where $Tx\_dpcch(n)$ is a vector containing all the simultaneous DPCCH power within the nth slot of a TDM transmission pattern. It is computed as following:

$$Tx\_dpcch(n) = Tx\_dpcch(remainder(i/24)+1)$$

```
if UE is inacitve
```

$$Tx\_dpcch(i) = tx\_Ec(i)$$

```
else
```

$$Tx\_dpcch(i) = \frac{tx\_Ec(i)}{1+(\beta\_ec/\beta\_c)^2+(\beta\_hs/\beta\_c)^2+(\beta\_ed/\beta\_c)^2+(\beta\_ec/\beta\_c)^2}$$

Where $tx\_Ec(i)$ is the total power of the transmitted signal from an UE in the ith slot, $(\beta\_ec/\beta\_c)^2$, $(\beta\_hs/\beta\_c)^2$ and $(\beta\_ed/\beta\_c)^2$ are the power offset of E-DPCCH, HS-DPCCH, E-DPDCH, and E-DPDCH to DPCCH respectively.

- ***Cell throughput*** is the sum of the individual throughputs within the cell. The throughput of each UE is calculated based on the frames with a successful CRC check and is averaged over the complete simulation.

5.4 Study Scenarios

Since for 2ms EUL, 8HARQ processes is used. Therefore maximum 8 UEs could be allocated to transit in each HAQR process.

There are four scenarios that will be studied:

1. 2TDM UEs, each occupying 4 consecutive TTIs
   HDR UEs (E-TFCI = 117)
   channel types: 3GPP Pedestrian A (pedA) 3km/h, 3GPP typical urban (TU) 3km/h
2. 4TDM UEs, each occupying 2 consecutive TTIs
   HDR UEs (E-TFCI = 117)

   channel types: pedA 3km/h, TU 3km/h
3. 8TDM UEs, each occupying 1 TTI
   HDR UEs (E-TFCI = 117)

   channel types: pedA 3km/h, TU 3km/h
4. 2TDM UEs, each occupying three consecutive TTIs and 4CDM UEs occupying two consecutive TTIs
   HDR TDM UEs (E-TFCI = 117)
   LDR CDM UEs (E-TFCI = 60) = 507.5kbps

   channel types: pedA 3km/h, TU 3km/h

6 Simulation Results

This chapter presents the link-level performance of each of the hybrid with each of the hybrid transmission power control algorithms for TD scheduling using simulations of each of the four scenarios (presented in the previous chapte).

6.1 Scenario 1: 2 TDM UEs, each occupying 4 consecutive TTIs

This scenario consists of two TD scheduled UEs in the same cell who are scheduled alternately (as illustrated in Figure 5). Each UE transmits its data on E-DPDCH in four consecutive TTIs. After that, the UE is inactive while the other UE is active and transmits its E-DPDCH data in the following four TTIs. No interferers are considered in this scenario. The results for HDR (E-TFCI = 117) under various channel conditions are presented below.

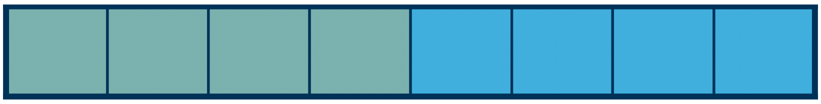

Figure 5: Transmitting scheme for scenario 1.

6.1.1 3GPP Pedestrian A (pedA) 3km/h channel

First, we study the performance for the two high data rate TD scheduled UEs under the pedestrian A 3kmph (pedA 3) channel model. The UEs' E-TFCI = 117, corresponds to a peak data rate of 4 Mbps. Figure 6, Figure 7, and Figure 8 are the outcomes for olpc_TTE_target at 5% , while Figure 9, Figure 10 ,and Figure 11 show the performance for olpc_TTE_target at 20%. A cell throughput of around 3.8 Mbps is reached with olpc_TTE_target = 5% with all the methods presented, while a cell throughput pf around 3.1 Mbps is reached with olpc_TTE_target = 20% with all the methods presented (see table1)**.** Figure 6 and Figure 9 show that the RoT in a cell is lower with a higher error rate requirement, i.e. with olpc_TTE_target at 20% as compared to the low error rate requirement when olpc_TTE_target is at 5%.

In Figure 6 with olpc_TTE_target = 5%, both *GSIR* + *RSCP* and pure *RSCP* TPC methods give approximately 0.3 dB RoT gain, while the *RSCP* + *GSIR* method gives around 0.4dB higher RoT compared to pure *GRAKE SIR* method at the 90th-percentiles. All TPC methods presented except for *GSIR* + *RSCP* satisfy the DPCCH quality requirement, i.e. DPPCH SIR is not lower than 3dB at the 5th percentile, see Figure 7. In Figure 9 with olpc_TTE_target = 20%, the four TPC methods perform similarly. *GSIR* + *RSCP* and pure *RSCP* TPC methods give approximately 0.2dB and 0.1dB RoT gain respectively, while *RSCP* + *GSIR* power control has around 0.2dB RoT loss compared with pure *GRAKE SIR* TPC method at the 90th-percentiles. However, only the pure *GRAKE SIR* and *RSCP* + *GSIR* TPC meet the DPCCH quality requirement, see Figure 10.

The averaged DPCCH transmission power is plotted for the first UE in Figure 8 and Figure 11 over 24 slots / 8 TTIs. According to the transmission scheme, the first 12 slots are the active slots and the remaining 12 slots are inactive slots. In these figures, the power peak problem is seen in both pure *GRAKE SIR* and *RSCP* + *GSIR* methods, while the transmission power is much more stable in both *RSCP* + *GSIR* and pure *RSCP* methods, i.e. there is no power peak symptom. Moreover, it is observed that the DPCCH transmission power is around 1.5dB lower with an olpc_TTE_target = 20% than when olpc_TTE_target = 5%, which leads to lower RoT in the cell.

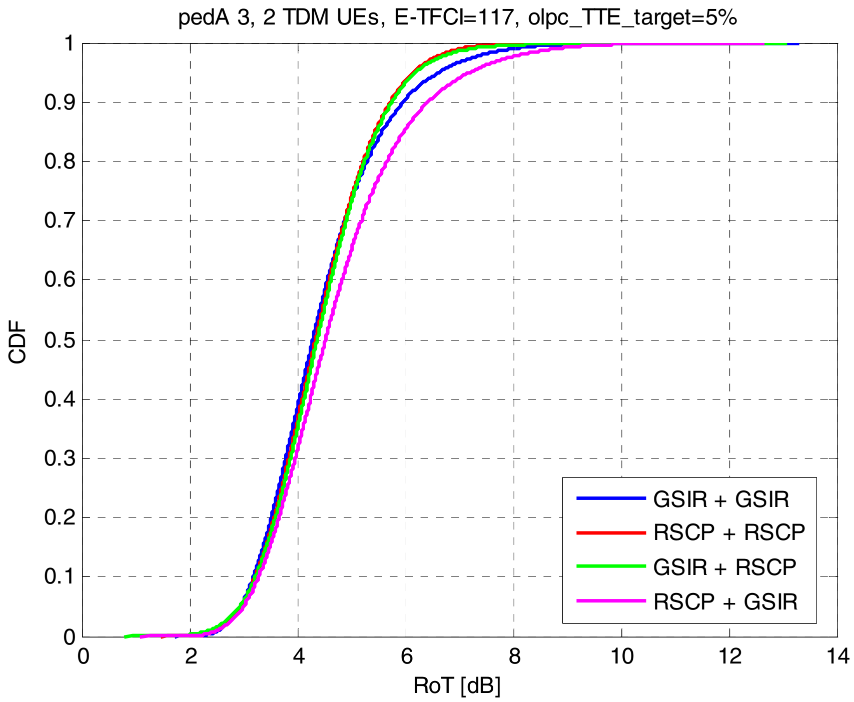

Figure 6: RoT for two high data rate TD UEs in pedA 3, with a low error rate requirement.

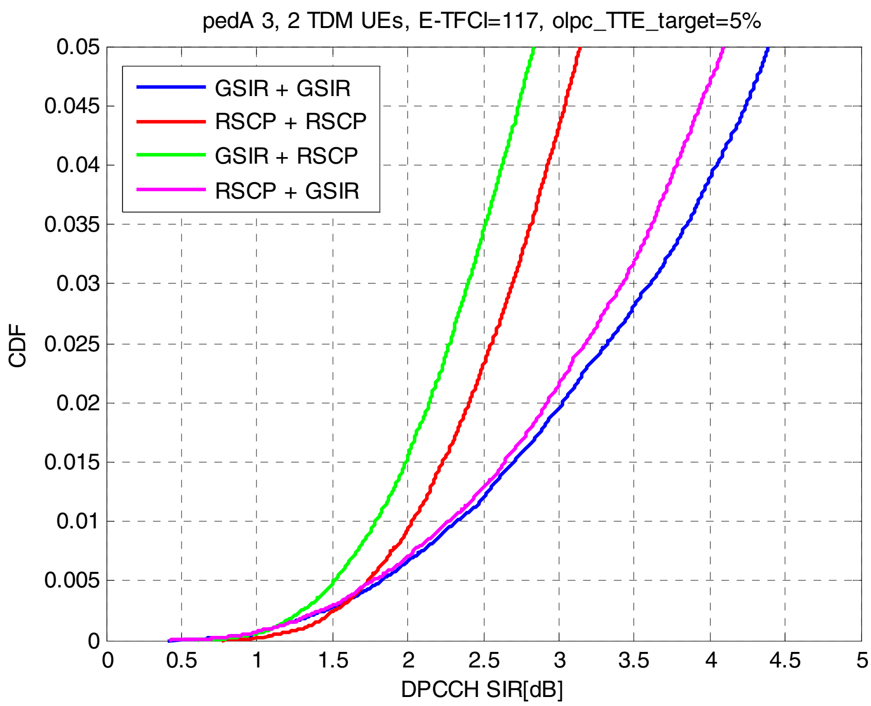

Figure 7: Partial plot of DPCCH SIR for two high data rate TD UEs in pedA 3, with a low error rate requirement. The complete plot is shown in the Appendix [Figure 39].

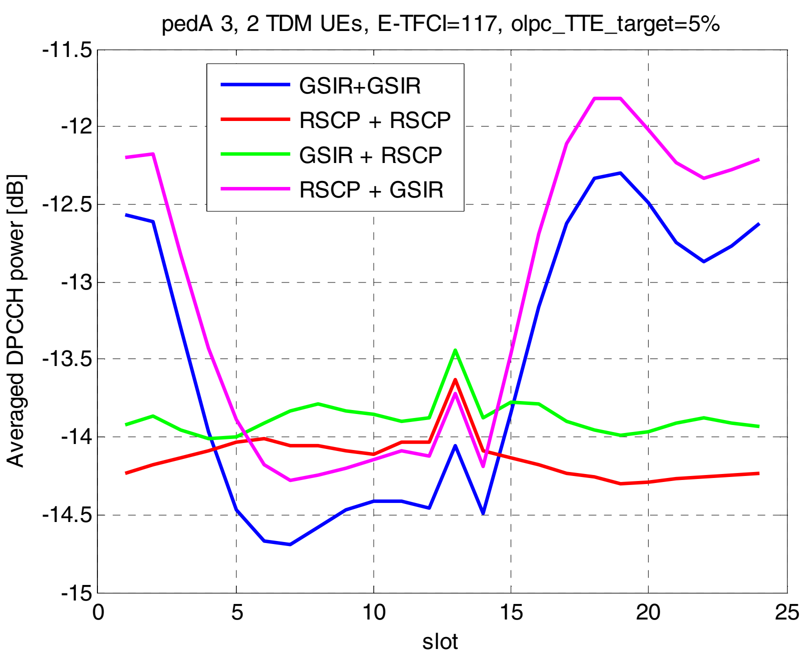

Figure 8: Averaged DPCCH transmission power for two high data rate TD UEs in pedA 3, with a low error rate requirement.

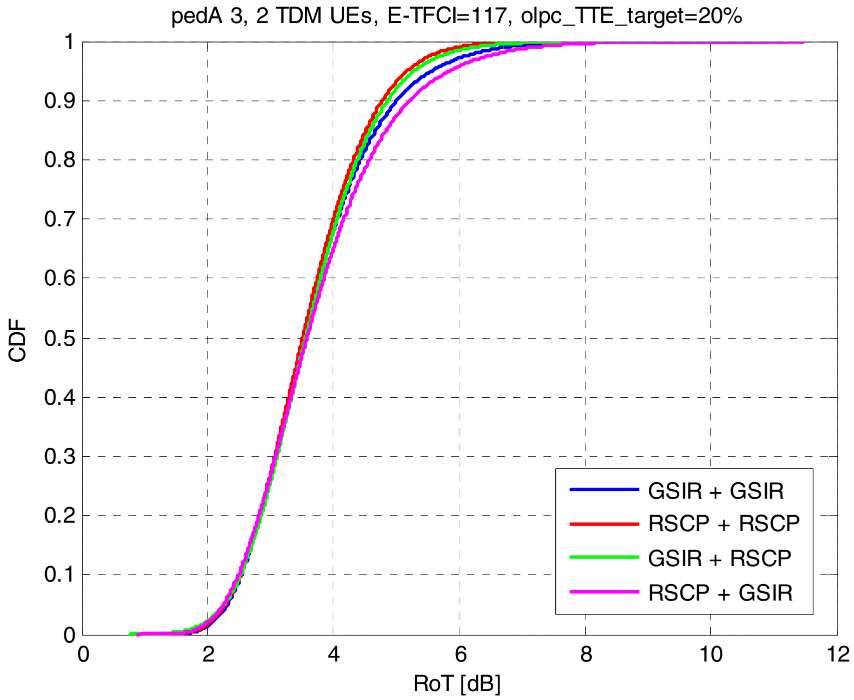

Figure 9: RoT for two high data rate TD UEs in pedA 3, with a higher error rate requirement.

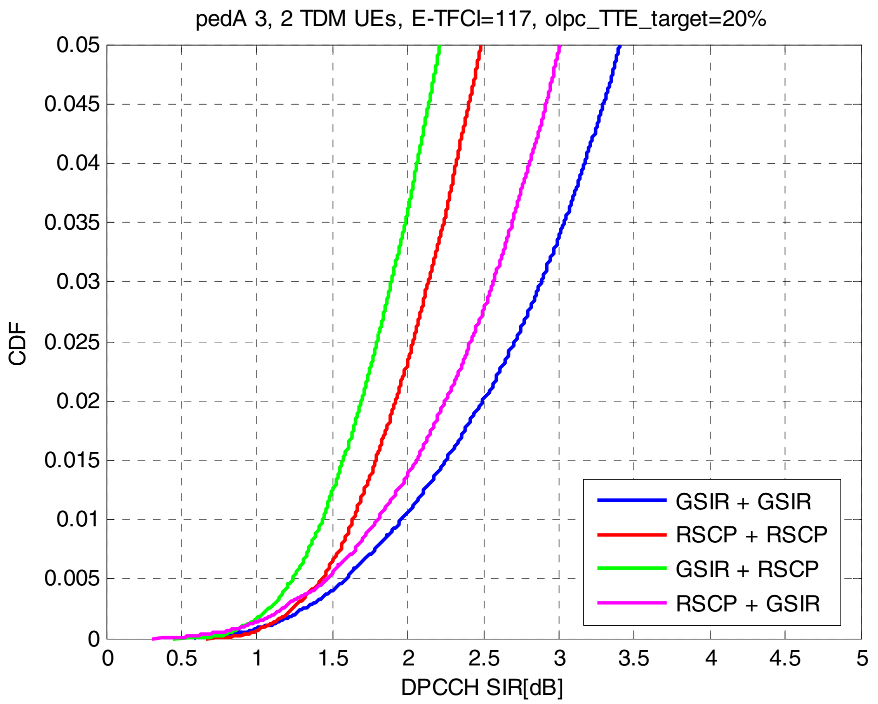

Figure 10: Partial plot of DPCCH SIR for two higher data rate TD UEs in pedA 3, with higher error rate requirement. The complete plot is in Appendix [

Figure 40].

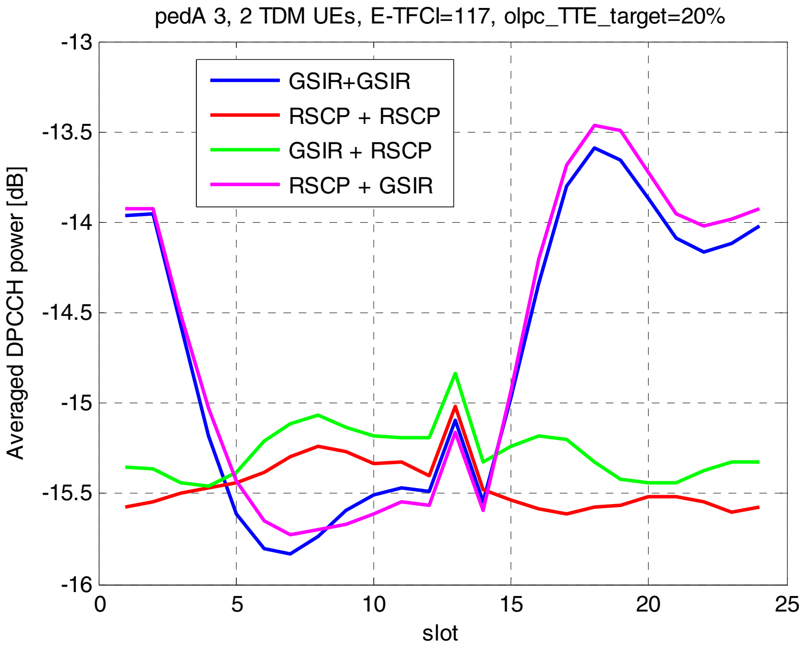

Figure 11: Averaged DPCCH transmission power for two high data rate TD UEs in pedA 3, with higher error rate requirement.

6.1.2 3GPP typical urban (TU) 3km/h channel

Now, we will study the performance for the two high data rate TD scheduled UEs under Typical Urban (TU) channel. Figure 12, Figure 13 and Figure 14 are the outcomes for olpc_TTE_target at 5%, while Figure 15 and Figure 16 and Figure 17 show the performance for olpc_TTE_target at 20%. Cell throughput around 3.8 Mbps is reached with olpc_TTE_target = 5% with all the methods presented, and cell throughput around 3.1 Mbps is reached with olpc_TTE_target = 20% with all the methods presented, see table1. Similar to pedA 3 channel, Figure 12 and Figure 15 illustrate that the higher error rate requirement olpc_TTE_target at 20% gives lower RoT in a cell compared to lower error rate requirement olpc_TTE_target at 5%.

In Figure 12 at olpc_TTE_target = 5%, pure *GRAKE SIR* over performs other hybrid TPC methods. Pure *RSCP*, *GSIR* + *RSCP* and *RSCP* + *GSIR* TPC methods have approximately 0.2dB, 0.7 dB and 1.0dB RoT loss respectively compared to pure *GRAKE SIR* TPC at 90-percentiles. All TPC methods satisfy with the DPCCH quality requirement, see Figure 13. In Figure 15 at olpc_TTE_target = 20%, the four presented TPC methods perform similar. Pure *GSIR* and pure *RSCP* power control methods have approximately 0.3dB RoT gain compared to the other two TPC methods, i.e. *RSCP* + *GSIR* and *GSIR+RSCP* method at 90-percentiles. All TPC methods presented except for *GSIR* + *RSCP* satisfy with the DPCCH quality requirement see Figure 16.

The averaged DPCCH transmission power for the first UE under TU channel is plotted in Figure 14 and Figure 17. Power peak symptom is visible in both *GRAKE SIR* and *RSCP* + *GSIR* TPC, while the transmission power is more or less stable in both *GSIR*

+ *RSCP* and pure *RSCP* methods. Moreover it is observed in Figure 14 that *GSIR* operates at around 1dB lower DPPCH transmission power on average than *GSIR* + *RSCP* TPC, which is due to the 1dB SIR target difference in between, see Figure 50. Therefore *GSIR* power control gives 1dB lower cell RoT than *GSIR* + *RSCP* even though the latter one performs without power peak problem.

As a matter of fact, it is observed that the *GSIR* + *RSCP* method always operates at a higher SIR target level on average compared with pure *GSIR* power control method during active TTIs, see chapter 0. To explain why the SIR target is higher during active TTIs by using the hybrid *GSIR* + *RSCP* method, the probability that SIR is below the SIR target when UE enters the active TTI from the inactive TTI is looked into. The simulation results indicates that it is more likely (from 50 ~90% probability depending on the scenarios) to get lower SIR than SIR target at the transition from inactive status to active status by using *GSIR* + *RSCP* power control method compared to using pure GSIR TPC. The high probability of low DPCCH SIR than target SIR may lead to higher probability of error transmission and higher BLER, and the SIR target is increased as a consequence by OLPC.

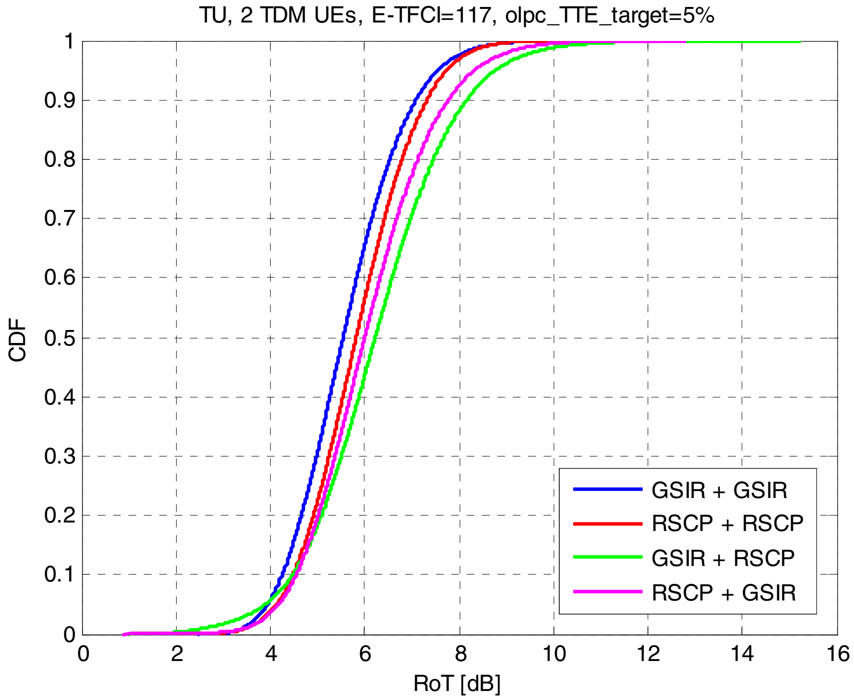

Figure 12: RoT for two high data rate TD UEs in TU, with a low error rate requirement.

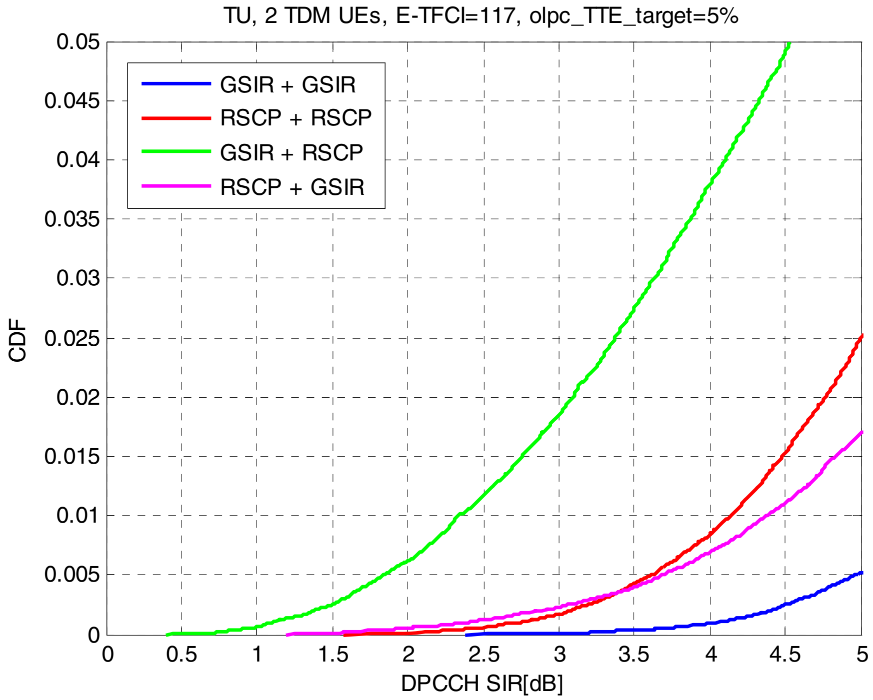

Figure 13: Partial plot of DPCCH SIR for two high data rate TD UEs in TU, with a low error rate requirement. The complete plot is shown in the Appendix [Figure 41].

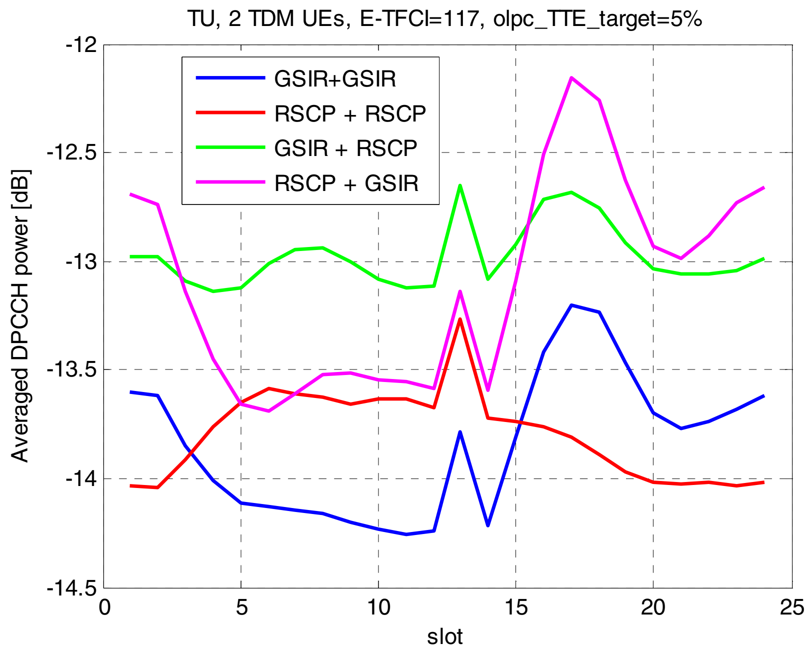

Figure 14: Averaged DPCCH transmission power for two high data rate TD UEs in TU, with a low error rate requirement.

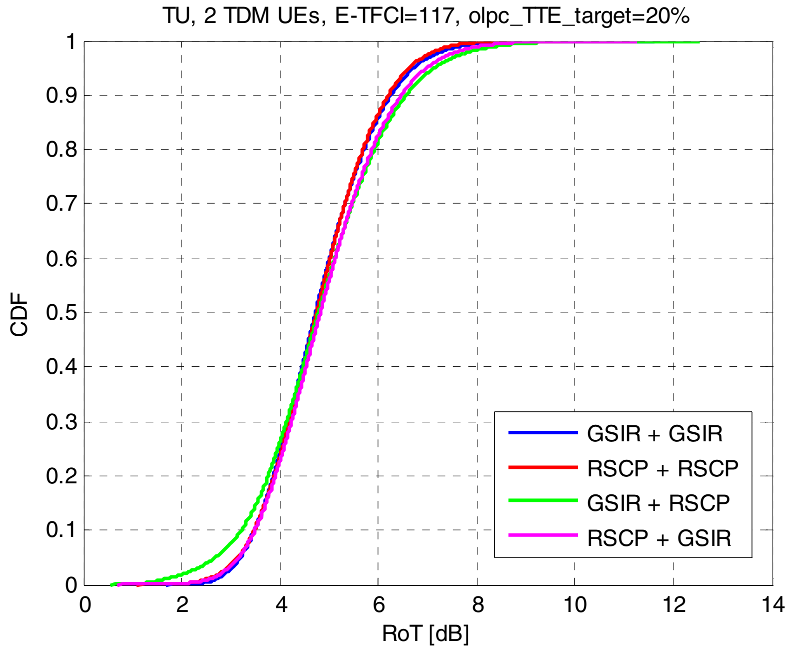

Figure 15: RoT for two high data rate TD UEs in TU, with a higher error rate requirement.

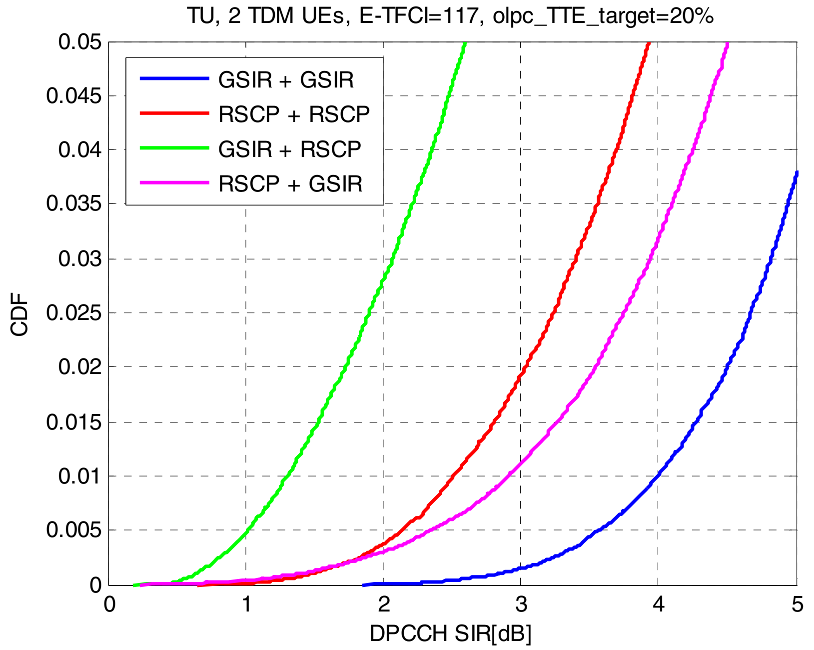

Figure 16: Partial plot of DPCCH SIR for two higher data rate TD UEs in TU, with higher error rate requirement. The complete plot is shown in the Appendix [Figure 42].

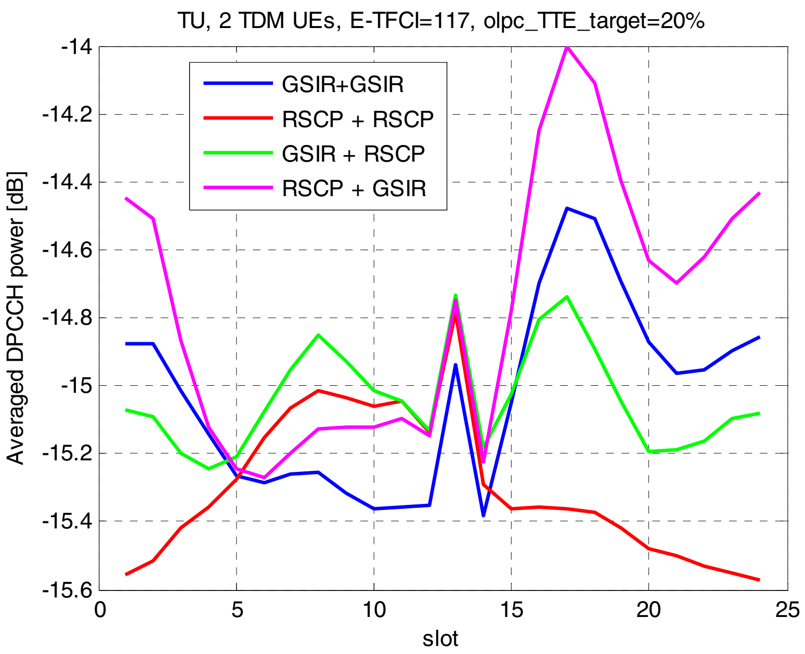

Figure 17: Averaged DPCCH transmission power for two high data rate TD UEs in TU, with a higher error rate requirement.

Table 1: Achieved cell throughput for the four hybrid TPC methods

Hybrid TPC methods / Cell throughput [Mbps]	PedA 3		TU	
	olpc_TTE_ target = 5%	olpc_TTE_ target = 20%	olpc_TTE_ target = 5%	olpc_TTE_ target = 20%
GSIR + GSIR	3.79	3.12	3.79	3.12
RSCP + RSCP	3.77	3.12	3.76	3.10
GSIR + RSCP	3.79	3.16	3.75	3.08
RSCP + GSIR	3.77	3.11	3.76	3.11

6.2 Scenario 2: 4 TDM UEs, each occupying 2 consecutive TTIs

This scenario constitutes of 4 TD scheduled UEs in a same cell and the UEs are scheduled alternately. Each UE transmits its data on E-DPDCH in 2 TTI and keeps inactive in following 6 TTIs. No interferer is considered in this scenario. The transmitting scheme is illustrated in Figure 18. All the UEs are configured with E-TFCI = 117.

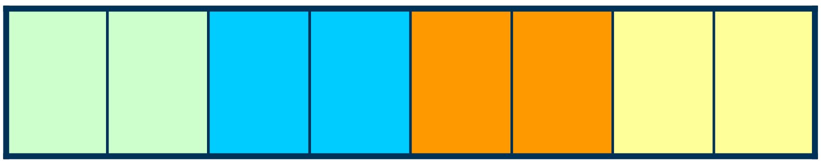

Figure 18: Transmitting scheme for scenario 2.

6.2.1 3GPP Pedestrian A (pedA) 3km/h channel

First, we study the performance for the four high data rate TD scheduled UE under pedestrian A 3kmph (pedA 3) channel. Figure 19, Figure 20 and Figure 21 are the outcome for olpc_TTE_target at 20%. Cell throughput around 3.2~3.3 Mbps is reached with all the methods presented, see table2.

Figure 19 illustrates that pure RSCP method over performs other three hybrid TPC methods. Pure RSCP and GSIR + RSCP TPC methods give approximately 0.5 dB and 0.2dB RoT gain respectively, while RSCP + GSIR gives around 0.3dB higher RoT compared to pure GSIR method at 90-percentiles. However in Figure 20, none of the TPC methods meet the DPCCH quality requirement.

The averaged DPCCH transmission power is plotted for the first UE among 4UEs over 24slots/8TTIs, see Figure 21. According to the transmission scheme, the first 6 lots are the active slots and the remaining 18slots are the inactive slots. The power peak problem is seen both in GRAKE SIR and RSCP + GSIR TPC, while the averaged transmission power is much stable in both GSIR+RSCP and pure RSCP methods.

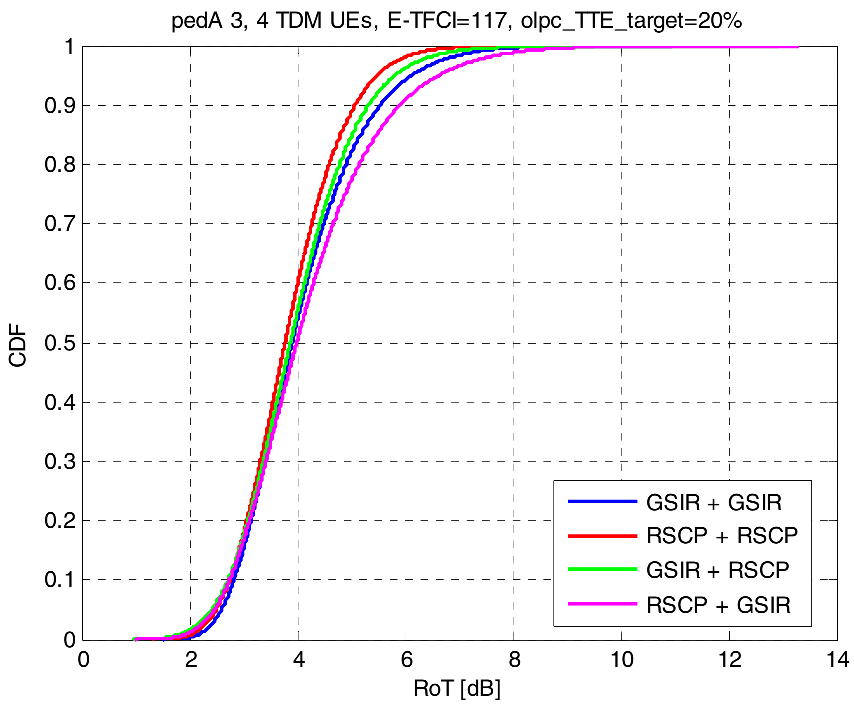

Figure 19: RoT for four high data rate TD UEs in pedA 3, with a higher error rate requirement.

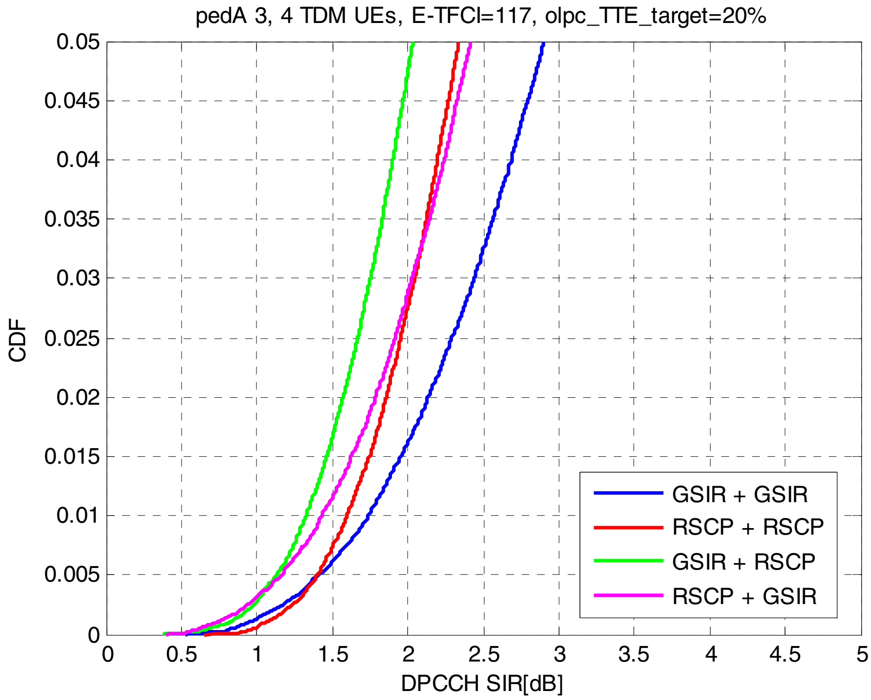

Figure 20: Partial plot of DPCCH SIR for four high data rate TD UEs in pedA 3, with a higher error rate requirement. The complete plot is shown in the Appendix [Figure 43].

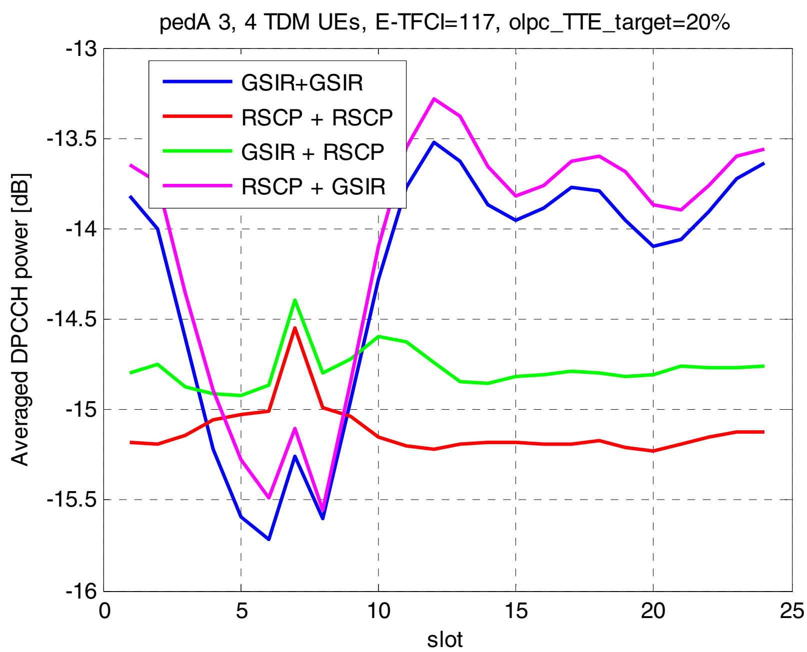

Figure 21: Averaged DPCCH transmission power for four high data rate TD UEs in pedA 3, with a higher error rate requirement.

6.2.2 3GPP typical urban (TU) 3km/h channel

Now, we look at the performance of the four high data rate TD scheduled UE under Typical Urban (TU) channel. Figure 22, Figure 23 and Figure 24 are the outcomes for olpc_TTE_target at 20%. Cell throughput of 3.1 Mbps is reached by GSIR+RSCP TPC and approximately 3.2Mbps cell throughput is achieved with other three TPC methods presented.

Figure 22 shows that pure RSCP and pure GSIR TPC perform similar which give approximately 0.6 dB and 0,9dB RoT gain compared to RSCP + GSIR and GSIR + RSCP methods respectively at 90-percentiles. Meanwhile in Figure 23, the DPCCH quality requirement is met by all methods presented except for the GSIR + RSCP TPC.

The averaged DPCCH transmission power is plotted for the first UE among 4UEs under TU channel, see Figure 24. Power peak problem is seen in both GSIR and RSCP + GSIR TPC. Moreover it is observed that GSIR operates at around 0.5dB lower DPPCH transmission power on average than GSIR + RSCP TPC, which is due to the 0.5dB SIR target difference in between, see Figure 51. Therefore GSIR power control gives lower cell RoT than GSIR + RSCP.

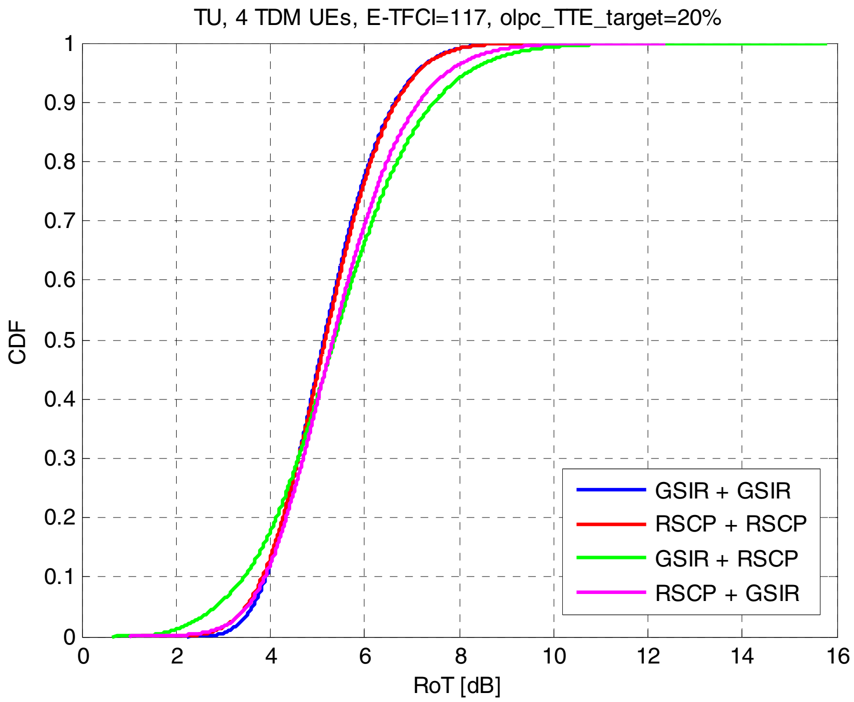

Figure 22: RoT for four high data rate TD UEs in TU, with a higher error rate requirement.

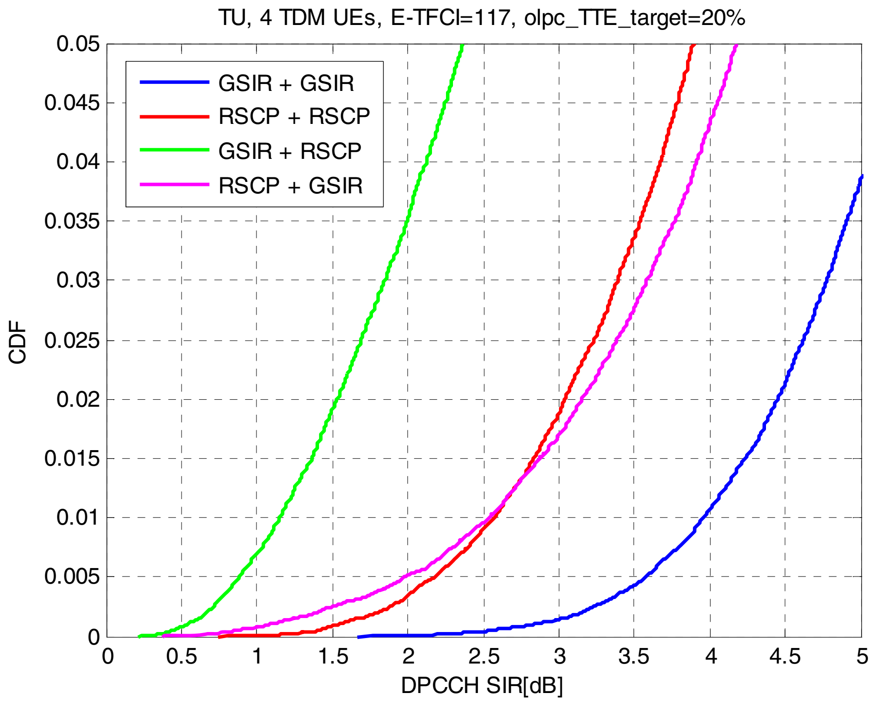

Figure 23: Partial plot of DPCCH SIR for four high data rate TD UEs in TU, with a higher error rate requirement. The complete plot is shown in the Appendix [Figure 44].

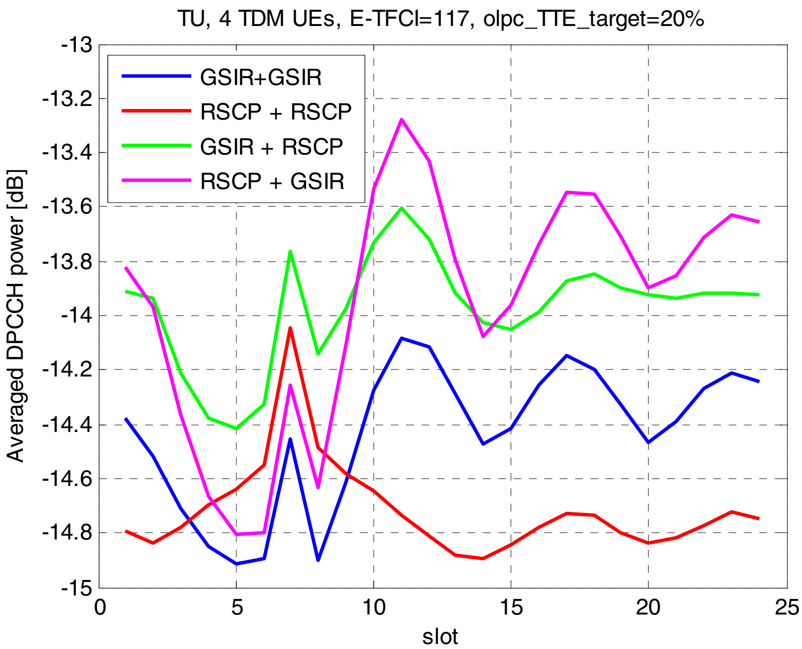

Figure 24: Averaged DPCCH transmission power for four high data rate TD UEs in TU, with a higher error rate requirement.

Table 2: Achieved cell throughput for the four hybrid TPC methods

Hybrid TPC methods / Cell throughput [Mbps]	PedA 3 olpc_TTE_ target = 20%	TU olpc_TTE_ target = 20%
GSIR + GSIR	3,28	3,26
RSCP + RSCP	3,23	3,21
GSIR + RSCP	3,25	3,13
RSCP + GSIR	3,23	3,21

6.3 Scenario 3: 8 TDM UEs, each occupying 1 TTI

This scenario constitutes of 8 TD scheduled UEs in a same cell and the UEs are scheduled alternately. Each UE transmits its data on E-DPDCH in 1 TTI and keeps inactive in following 7 TTIs. No interferer is considered in this scenario. The transmitting scheme is illustrated in Figure 25. All the UEs are configured with E-TFCI = 117.

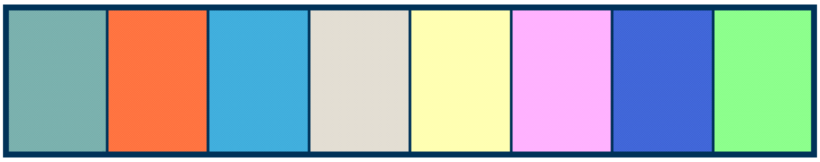

Figure 25: Transmitting scheme for scenario 3.

6.3.1 3GPP Pedestrian A (pedA) 3km/h channel

First, we study the performance for the eight high data rate TD scheduled UE under pedestrian A 3kmph (pedA 3) channel. Figure 26, Figure 27 and Figure 28 are the outcome for olpc_TTE_target at 20%. Cell throughput around 3.3Mbps can be achieved with all four TPC methods, see table3.

Figure 26 shows that pure RSCP method performs best among all TPC methods, which gives approximately 0.3 dB RoT gain compared to pure GSIR TPC at 90-percentiles. While the RoT of *GSIR + RSPC* and *RSCP + GSIR* TPC methods are 0.3dB and 3dB higher than pure GSIR power control at 90-percentiles respectively. However, none of the TPC methods can meet the DPCCH quality requirement see Figure 27.

The averaged DPCCH transmission power is plotted for the first UE among 8UEs over 24slots / 8TTIs, see Figure 38: Partial plot of DPCCH SIR TDM UEs in the coexistence scenario with TDM and CDM UEs in TU. The complete plot is shown in the Appendix [Figure 48].. According to the transmission scheme, the first 3 slots are the active slots and the remaining 21slots are the inactive slots. The power peak problem is not visible in any methods. It is seen that RSCP + GSIR TPC uses around 15dB higher DPPCH transmission power than other three methods. This leads to high interference level and high RoT in cell.

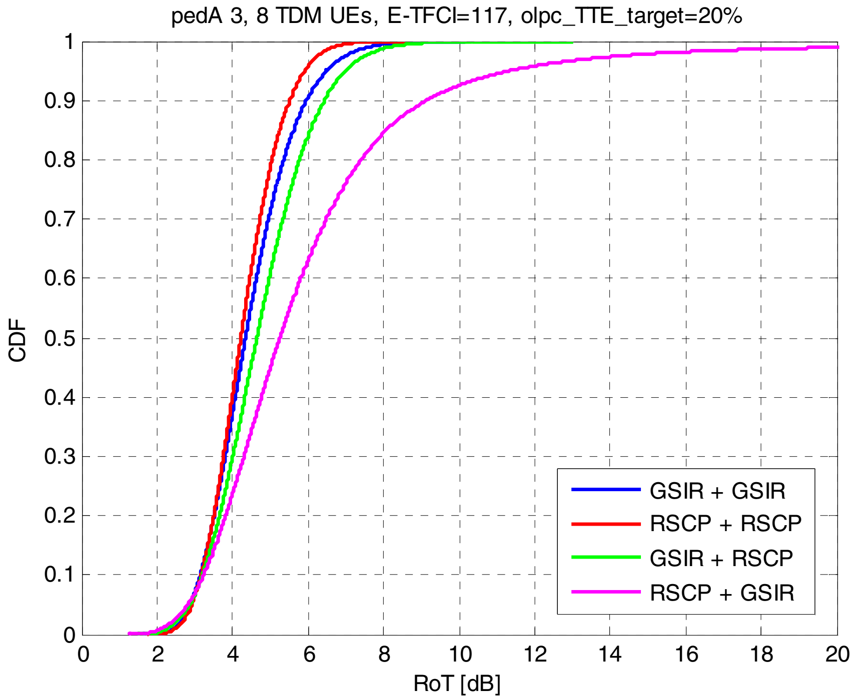

Figure 26: RoT plot for 8 TD scheduled UEs in pedA 3.

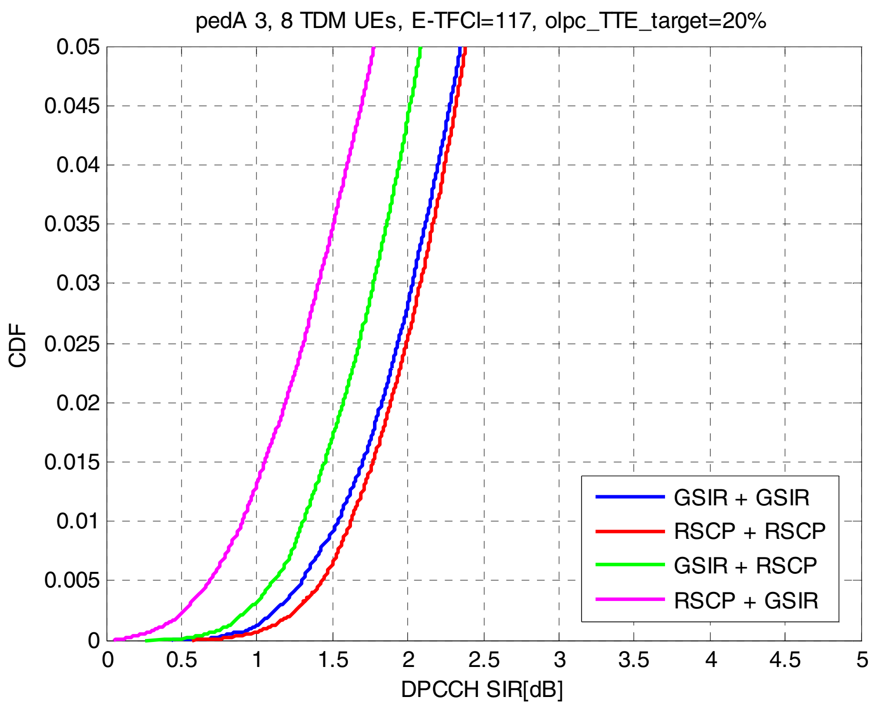

Figure 27: Partial plot of DPCCH SIR for 8 TD scheduled UEs in pedA 3. The complete plot is shown in the Appendix [Figure 45].

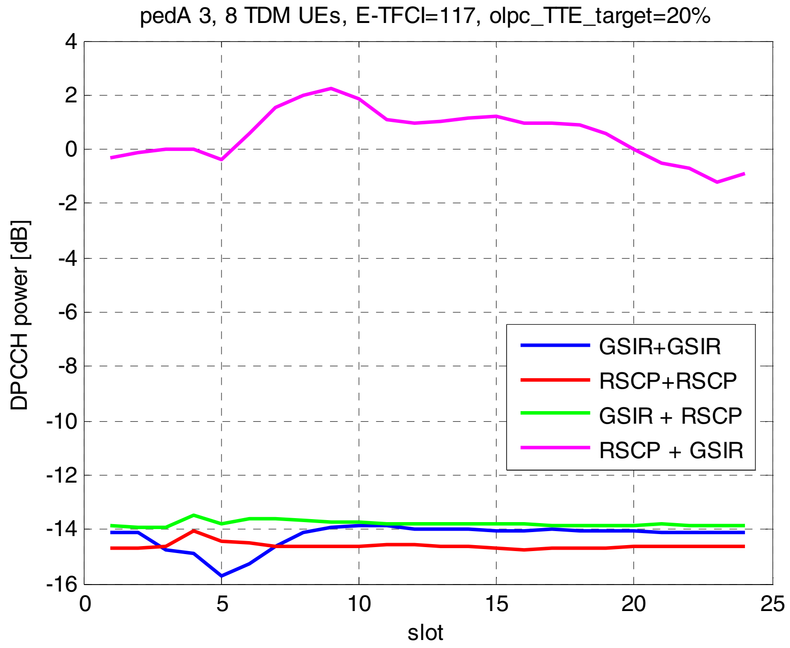

Figure 28: Averaged DPCCH transmission power for eight high data rate TD UEs in pedA 3, with a higher error rate requirement.

6.3.2 3GPP typical urban (TU) 3km/h channel

Now, we look at the performance for the eight high data rate TD scheduled UE under Typical Urban (TU) channel. Figure 29, Figure 30 and Figure 31are the outcomes for olpc_TTE_target at 20%. A cell throughput of 3.2~3.3 Mbps is reached by all four power control methods.

Figure 29 illustrates that pure *GSIR* power control performs best among all TPC methods, which gives approximately 0.2dB, 2dB and 3dB RoT gain compared to pure *RSCP*, *RSCP* + *GSIR* and *GSIR* + *RSPC* TPC methods respectively at 90-percentiles. Meanwhile in Figure 30, all TPC methods met the DPCCH quality requirement except for the *GSIR* + *RSCP* method.

The averaged DPCCH transmission power for the first UE among 8UEs under TU channel is plotted, see Figure 31. Trivial power peak problem is still visible in both *GSIR* and *RSCP* + *GSIR* TPC. Moreover it is observed in Figure 31 that *GSIR* operates at around 2.5dB lower DPPCH transmission power on average than *GSIR* + *RSCP* TPC, which is due to the 2.0dB SIR target difference in between during active TTI, see Figure 51. Therefore *GSIR* power control gives lower cell RoT than *GSIR* + *RSCP*.

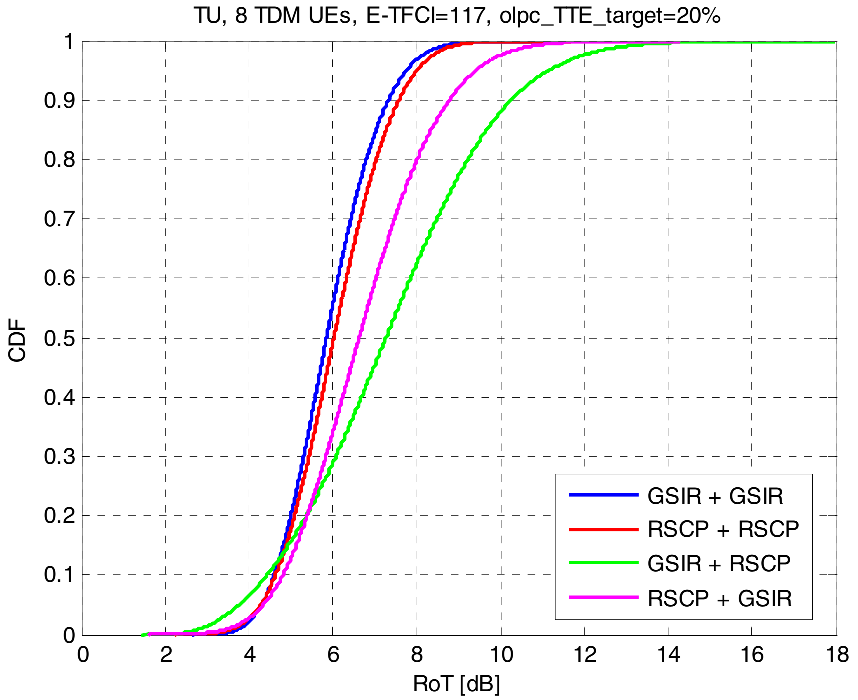

Figure 29: RoT plot for 8 TD scheduled UEs in TU.

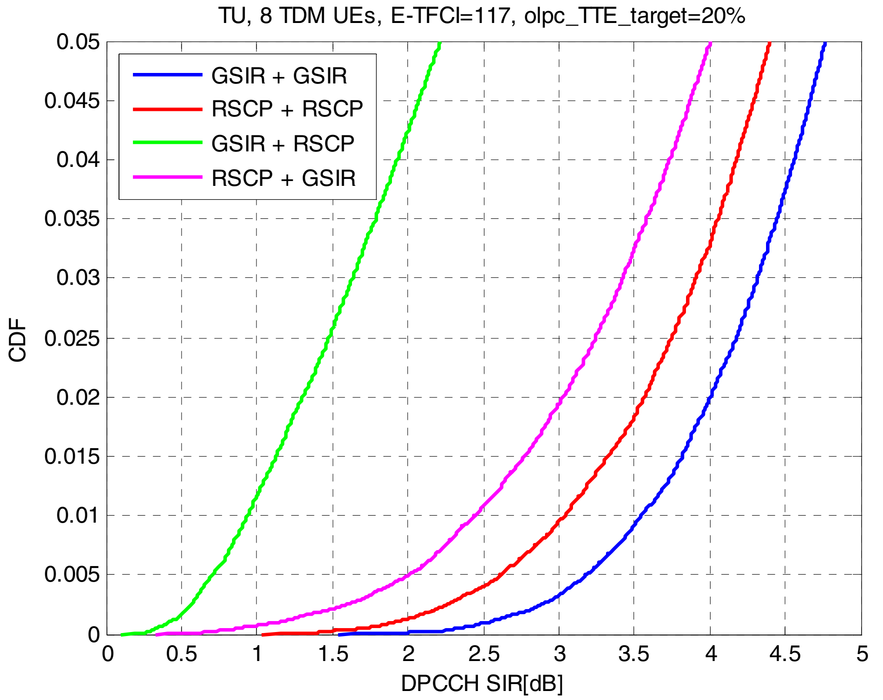

Figure 30: Partial plot of DPCCH SIR for 8 TD scheduled UEs in TU. The complete plot is shown in the Appendix [Figure 46].

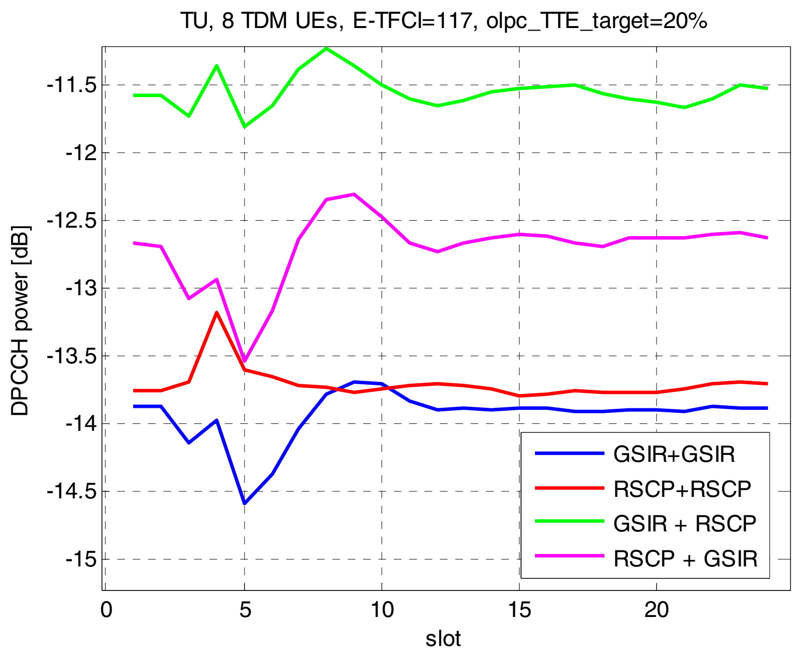

Figure 31: Averaged DPCCH transmission power for eight high data rate TD UEs in TU, with a higher error rate requirement.

Table 3: Achieved cell throughput for the eight hybrid TPC methods

Hybrid TPC methods / Cell throughput [Mbps]	PedA 3 olpc_TTE_ target = 20%	TU olpc_TTE_ target = 20%
GSIR + GSIR	3,33	3,33
RSCP + RSCP	3,33	3,31
GSIR + RSCP	3,33	3,23
RSCP + GSIR	3,31	3,31

6.4 Scenario 4: Coexistence with CDM UEs

This scenario constitutes of a mixture of TD scheduled UEs and CDM UEs in one cell. Two TD scheduled UEs are scheduled alternately: the first TD UE occupies the first three TTIs, and the second TD UE occupies the following three TTIs. After that, four CDM UEs are parallel scheduled in the subsequent two TTIs. The transmitting scheme is illustrated in Figure 32. The 2 TDM UEs are configured with E-TFCI = 117 while the 4 CDM UEs have E-FTCI = 60[1].

[1] E-TFCI = 60 corresponds to a peak data rate at 507.5Kbps.

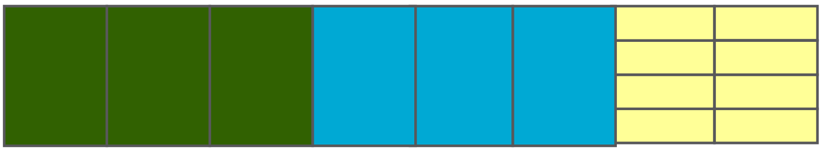

Figure 32: Transmitting scheme for scenario 4.

Different power control methods are applied on the TD scheduled UEs only. The CDM UEs are simulated with legacy SIR based power control and the SIR estimate is calculated with *p-over-variance* SIR method.

6.4.1 3GPP Pedestrian A (pedA) 3km/h channel

First, we study the performance for the TD scheduled UE in coexistence with CDM UE under pedestrian A 3kmph (pedA 3) channel. The UEs' E-TFCI = 117 or E-TFCI = 60, corresponding a peak data rate at 4Mbps and 0,5Mbps respectively. Figure 33, Figure 34 and Figure 35 are the outcome for olpc_TTE_target at 20%. A cell throughput of around 2.8~2.9Mbps is achieved with all four methods presented (see table4).

Figure 33 shows that pure *RSCP* and *GSIR* + *RSCP* TPC perform similar which give approximately 0.4dB RoT gain compared to both pure *GSIR* and *RSCP* + *GSIR* TPC methods at 90-percentiles. However in Figure 34, none of the TPC methods presented meet the DPCCH quality requirement.

The averaged DPCCH transmission power is plotted for the first TD scheduled UE among 6UEs over 24slots / 8TTIs, see Figure 35. According to the transmission scheme, the first 9 slots are the active slots and the remaining 15 slots are the inactive slots. The power peak symptom is visible in *GSIR* and *RSCP* + *GSIR* TPC, and the DPCCH transmission power is stable in both *GSIR* + *RSCP* and *RSCP* methods.

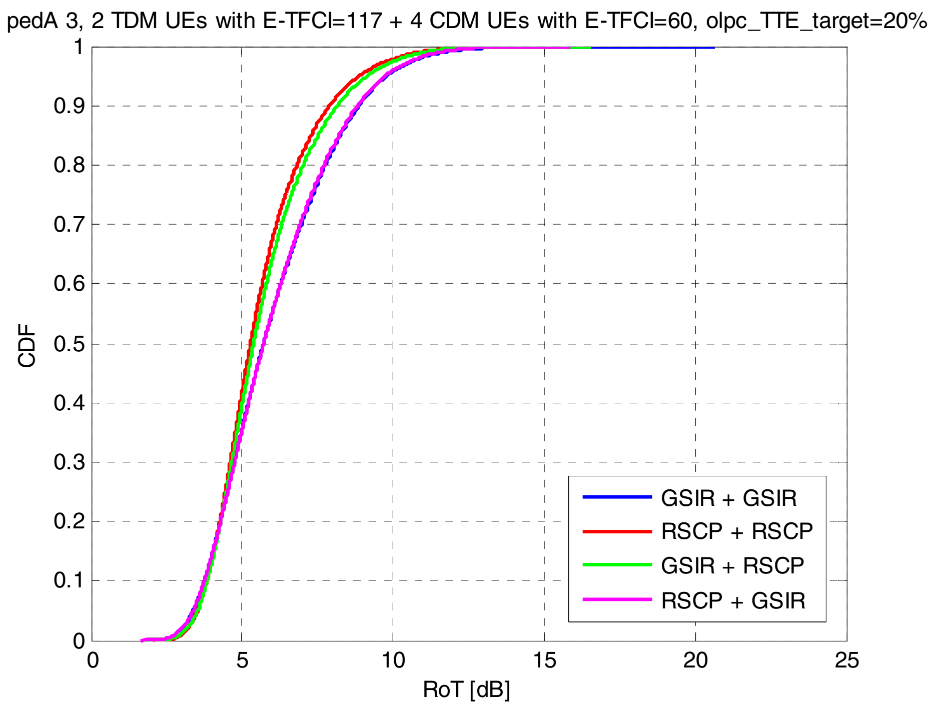

Figure 33: RoT plot for the coexistence scenario of TDM and CDM UEs in pedA 3.

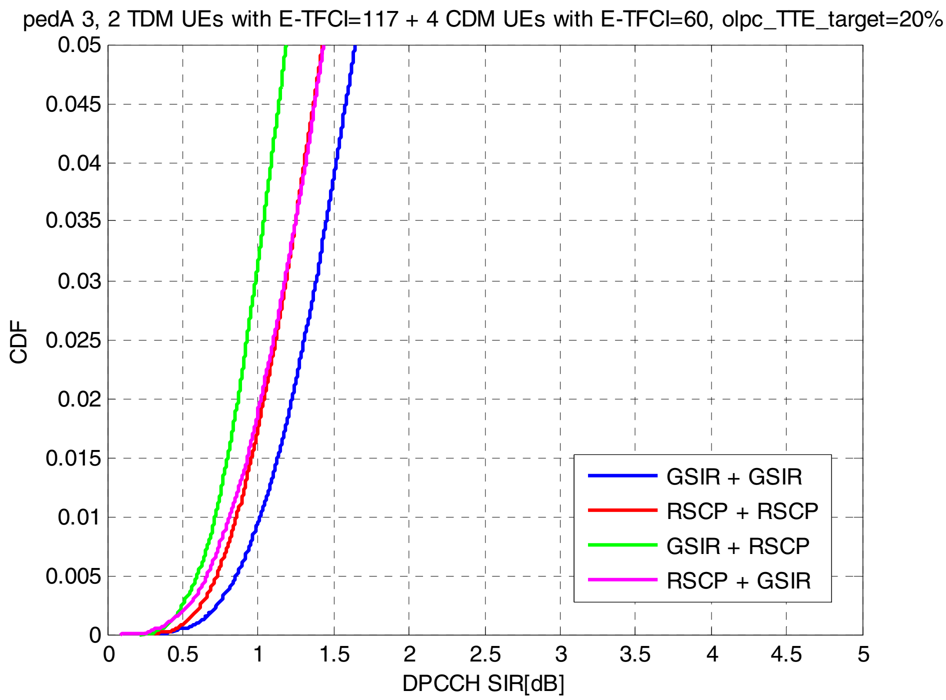

Figure 34: Partial plot of DPCCH SIR TDM UEs in the coexistence scenario with TDM and CDM UEs in pedA 3. The complete plot is shown in the Appendix [Figure 47].

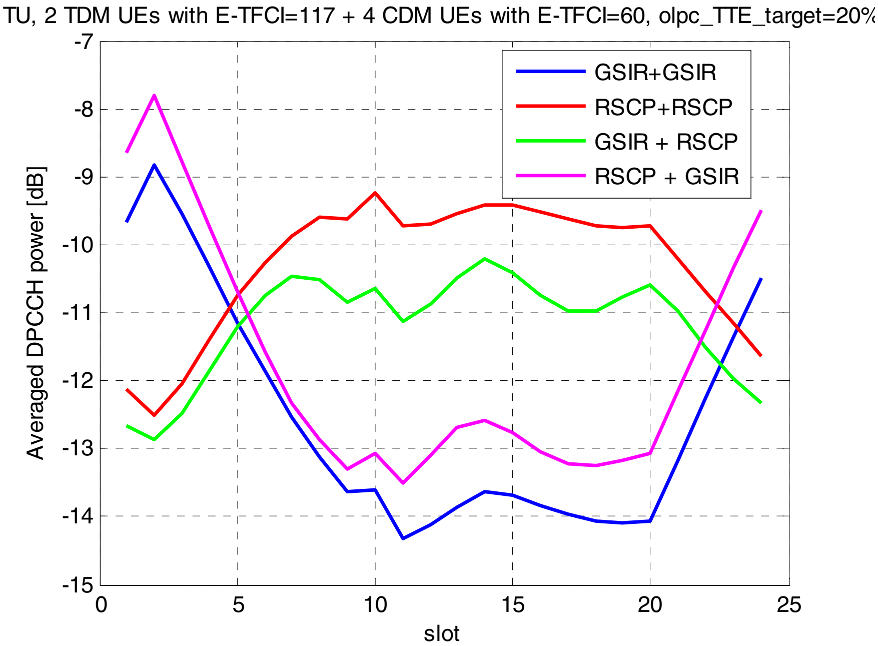

Figure 35: Averaged DPCCH transmission power for TD UEs in the coexistence scenario of TDM and CDM UEs in pedA 3, with a higher error rate requirement.

6.4.2 3GPP typical urban (TU) 3km/h channel

Now, we study the performance for the TD scheduled UE in coexistence with CDM UE under Typical Urban (TU) channel. Figure 36, Figure 37, and Figure 38 are the outcome for olpc_TTE_target at 20%. Cell throughput 2.55Mbps is reached by *GSIR + RSCP* and cell throughput around 2.7~2.8Mbps is achieved by other three TPC methods presented, see table4.

In Figure 36, all four power control methods' performances are similar. Pure *GSIR* TPC over performs a little bit better than other methods which gives around 0.1dB, 0.2dB and 0.4 dB RoT gain respectively compared to *GSIR + RSCP*, *RSCP + GSIR* and pure *RSCP* TPC at 90-percentiles. However, none of the TPC methods presented met the DPCCH quality requirement see Figure 37

The averaged DPCCH transmission power is plotted for the first TD scheduled UE among six UEs under TU channel, see Figure 38. The power peak symptom is visible in *GSIR* and *RSCP + GSIR* TPC. However, since the DPCCH power in *GSIR + RSCP* are sometimes higher than pure *GSIR* TPC during inactive TTIs, the *GSIR* power control gives lower RoT in the cell than *GSIR + RSCP* even though the latter performs without power peak problem.

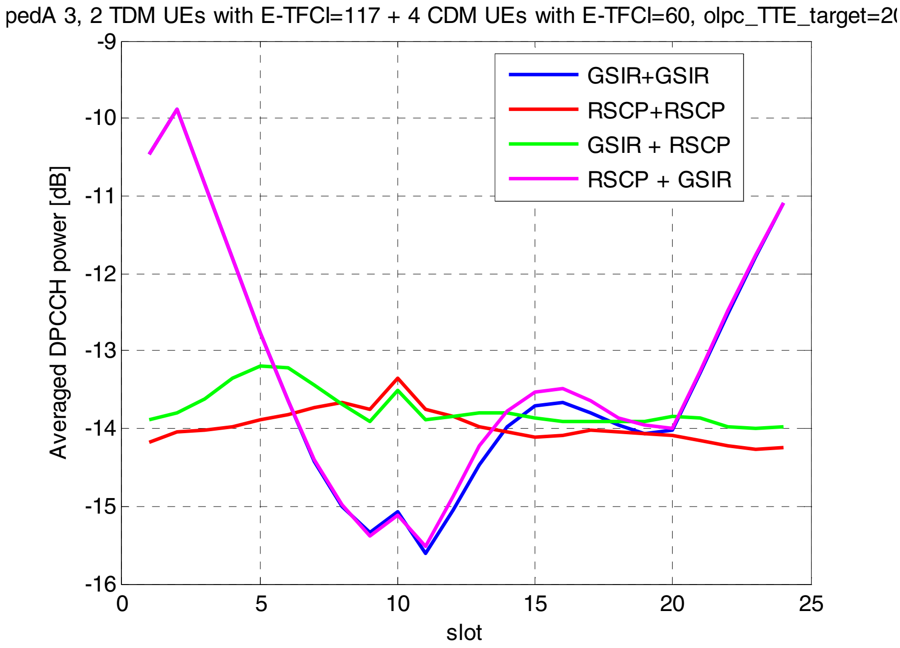

Figure 36: Averaged DPCCH transmission power for TD UEs in the coexistence scenario of TDM and CDM UEs in TU, with a higher error rate requirement.

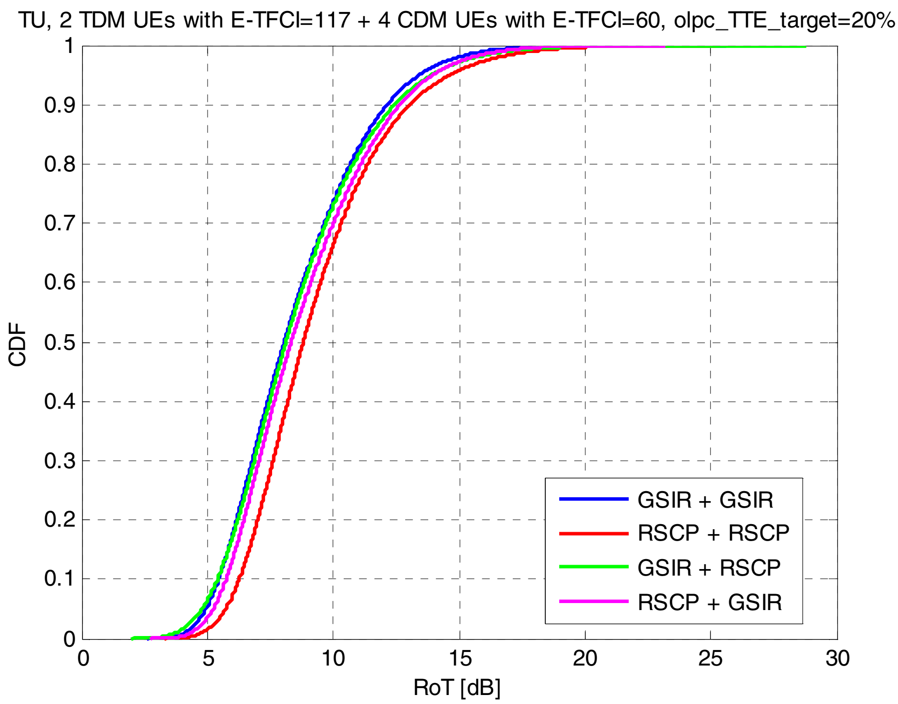

Figure 37: RoT plot for the coexistence scenario of TDM and CDM UEs in TU.

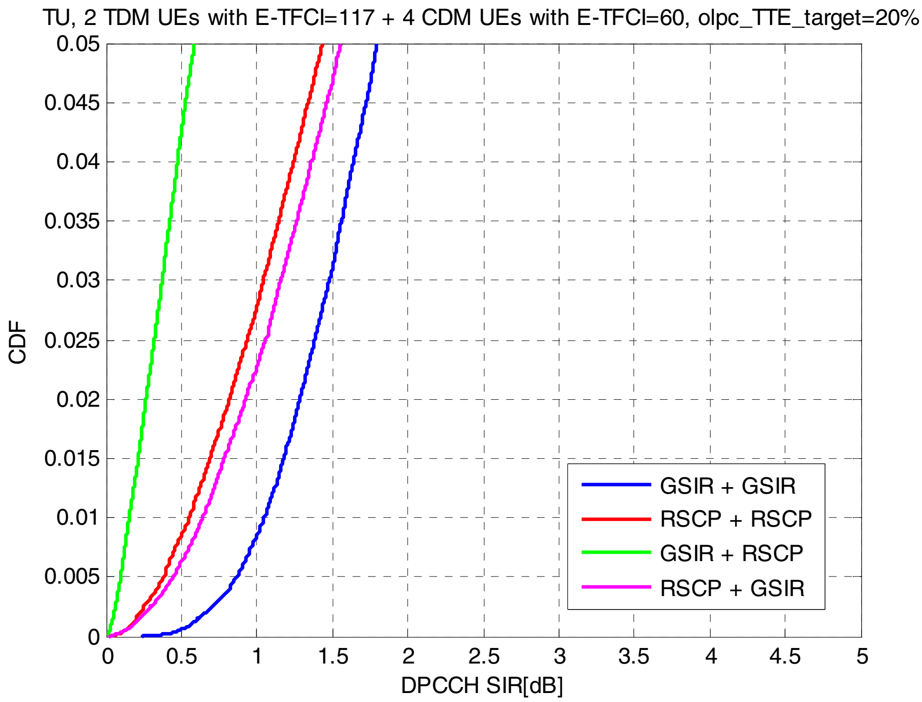

Figure 38: Partial plot of DPCCH SIR TDM UEs in the coexistence scenario with TDM and CDM UEs in TU. The complete plot is shown in the Appendix [Figure 48].

Table 4: Achieved cell throughput for the four hybrid TPC methods

Hybrid TPC methods / Cell throughput [Mbps]	PedA 3	TU
	olpc_TTE_ target = 20%	olpc_TTE_ target = 20%
GSIR + GSIR	2,90	2,85
RSCP + RSCP	2,82	2,72
GSIR + RSCP	2,87	2,55
RSCP + GSIR	2,86	2,79

7 Conclusions and Future Work

This chapter summarizes the conclusions drawn based upon the simulations results of the previous chapter and suggests future work that should be done.

7.1 Conclusions

The performance of the different hybrid TPC methods vary from scenario to scenario and it is hard to draw a general conclusion about which one outperforms the others. The performance of four ILPC methods that were studied can be summarized as follows:

Pure GRAKE SIR and RSCP based power control both perform well in all TD scenarios studied. A power peak problem is visible in GSIR TPC, while RSCP maintains the DPCCH more stable transmission power. The RSCP TPC method gives a little gain of RoT (around 0.3dB ~ 0.5dB) compared to GSIR TPC method under pedA3 channel, and the GSIR TPC performs similar or a little bit better than RSCP method under the TU channel condition. Moreover, the pure GSIR power control shows advantages in maintaining the quality of DPCCH channel over pure RSCP TPC. No power rush arises in either of the two TPC methods.

RSCP + GSIR TPC performs worst among all TPC methods most of the time in terms of RoT, but it maintains the quality of control channel second best. The power peak symptom is observed when using RSCP + GSIR TPC.

GSIR + RSCP ILPC out performs pure GSIR TPC method in scenario of 2, 4 TDM HDR UE and 2TDM HDR UE coexistence with 4CDM LDR UE under pedA 3 channel in terms of RoT. It gives around 0.3~0.4dB RoT gain at the 90th-percentiles compared to GSIR ILPC. The power peak problem is eliminated by using GSIR + RSCP TPC, i.e. the DPCCH transmission power when a UE is not scheduled is kept at the same power level as when the UE is scheduled. However, the control channel's quality can barely be maintained in those scenarios. Moreover, GSIR + RSCP TPC losses its RoT advantage to GSIR power control under TU channel condition due to higher SIR target in the active TTIs and a higher averaged DPCCH transmission power.

The TPC delay compensation of RSCP and SIR target is implemented in hybrid TPC methods GSIR + RSCP and RSCP + GSIR respectively, see sections 0 and 0. This solves the possible power rush and extremely high RoT problem in case when UE is scheduled quite soon. Due to the two slot TPC delays, there is an even shorter time for GRAKE SIR to adjust the power in order to maintain the SIR target when a UE is scheduled, e.g. in case of 8TDM UE, the GSIR power control will really take effect only in the last slot of the active TTI. The TPC delay compensation of RSCP/SIR target adjust the RSCP / SIR target to better predict the power level needed for active status and to maintain the power level when a UE is inactive

Moreover, it is difficult to maintain the SIR of DPCCH above 3dB within 5 percent for a TDM HDR UE with any of the TPC methods presented when there are four or more TDM HDR UEs under the pedA channel conditions. None of the TPC methods presented satisfy with the predefined control channel's quality in the scenario of 2TDM HDR UE coexistence with 4CDM LDR UE.

In conclusion, an important observation is that the power rush problem is not seen with active high data rate TDM users when using the conventional SIR based inner loop power control with GRAKE+ receiver. GSIR+RSCP and pure RSCP both work as desired to minimize the local oscillation in power (power peak) at a transition between active and inactive TTIs, while the DPCCH SIR is harder to maintained with the faster fading TU channel conditions as compared with GSIR power control. Considering the more stable performance of GSIR ILPC in maintaining the link quality in various scenarios and also the RoT, it is recommended to use the conventional SIR based inner loop power control with GRAKE+ receiver in conjunction with TDM. More investigation is need to find a hybrid method for ILPC in conjunction with TDM.

7.2 Future Work

Since the link simulation only considers a single cell with multiple UEs, no inter-cell interference is considered. In this case the UEs in the cell will have greater RoT headroom when transmitting at a high data rate. To extend the link simulation results to a multi-cell system simulation, the inter-cell interference needs to be considered – as this gives less RoT headroom to the UEs in a cell. This will lead to lower UE peak data rates with the same number of TDM UEs or fewer TDM UEs in a cell. Future work should simulate the TDM UEs with a lower data rate to meet the lower RoT budget should make the results more realistic from a system and radio network's point from view.

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[9] IT++ Documentation, http://itpp.sourceforge.net/current/, Sep 2010

Appendix A: Complete plots of DPCCH

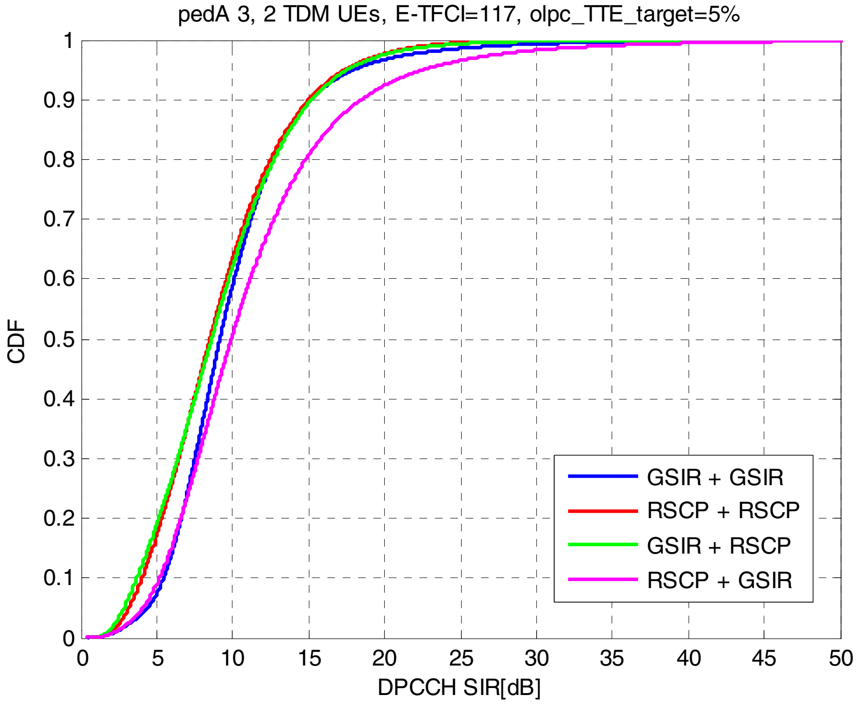

Figure 39: Complete plot of [Figure 7]: DPCCH SIR TD for two high data rate TD UEs in pedA 3, with lower error rate requirement.

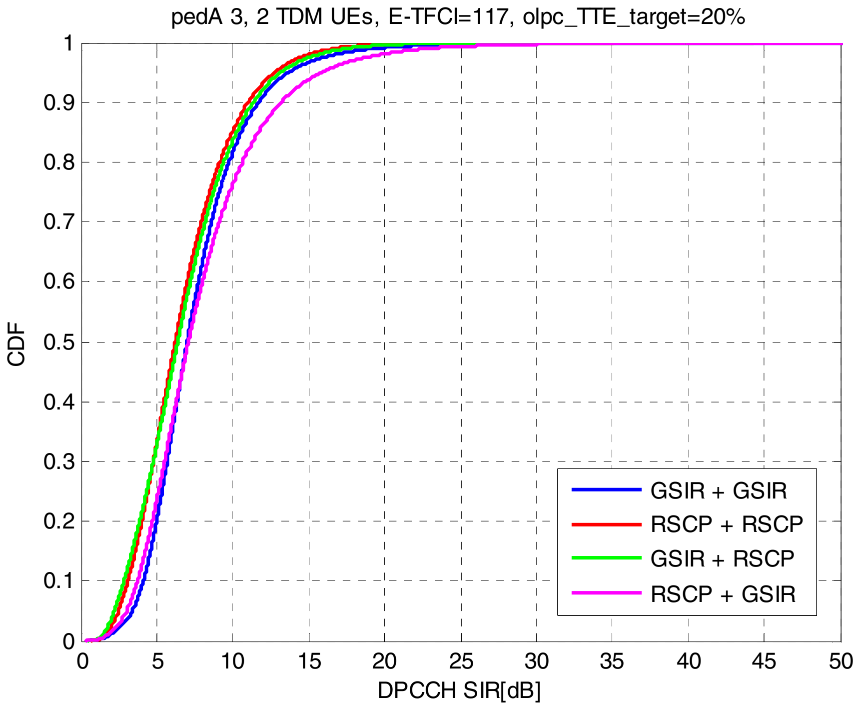

Figure 40: Complete plot of [Figure 10]: DPCCH SIR TD for two high data rate TD UEs in pedA 3, with higher error rate requirement.

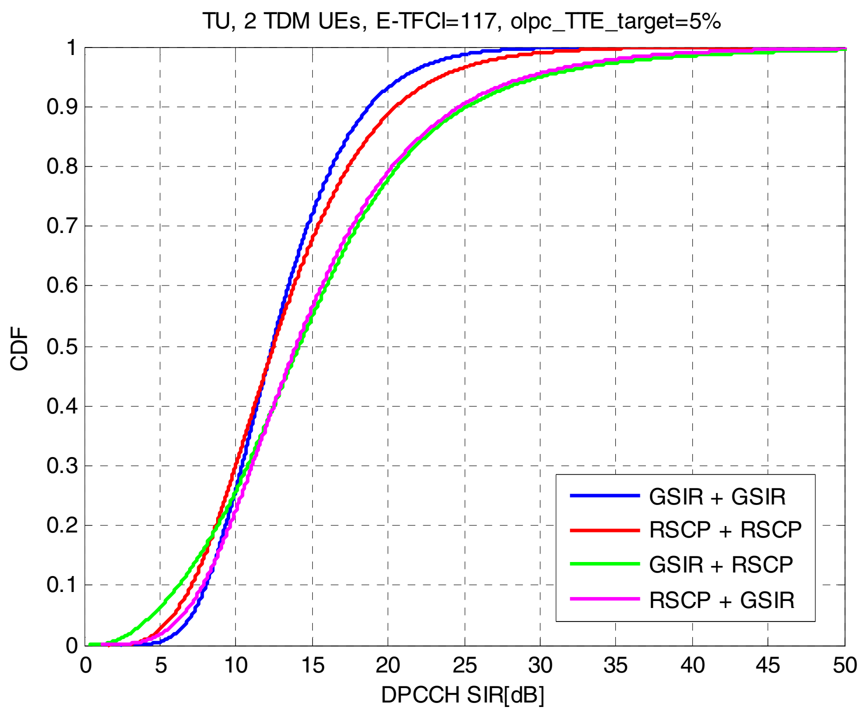

Figure 41: Complete plot of [Figure 13]: DPCCH SIR TD for two high data rate TD UEs in TU, with lower error rate requirement.

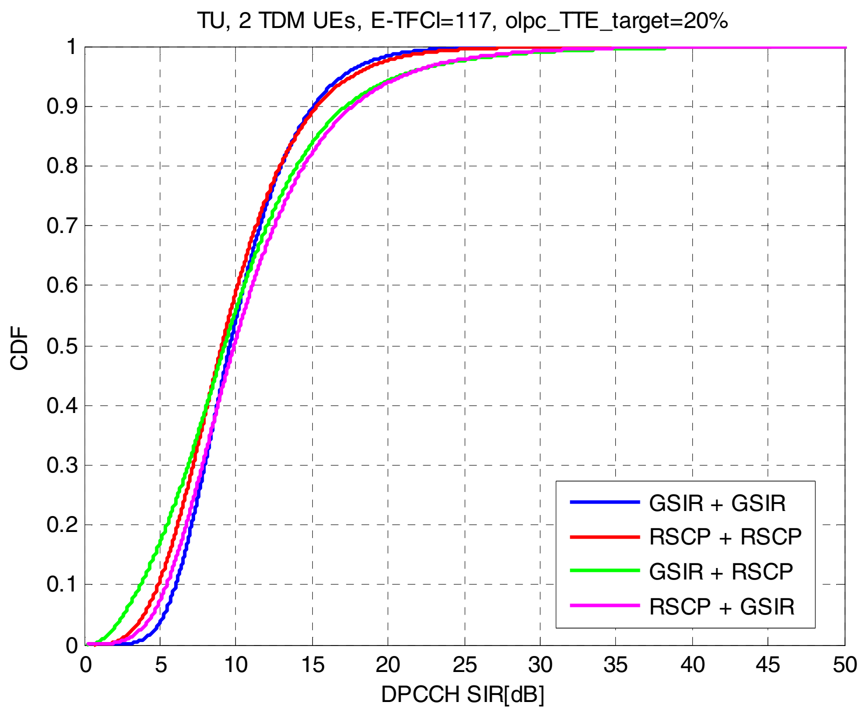

Figure 42: Complete plot of [Figure 16]: DPCCH SIR TD for two high data rate TD UEs in TU, with higher error rate requirement.

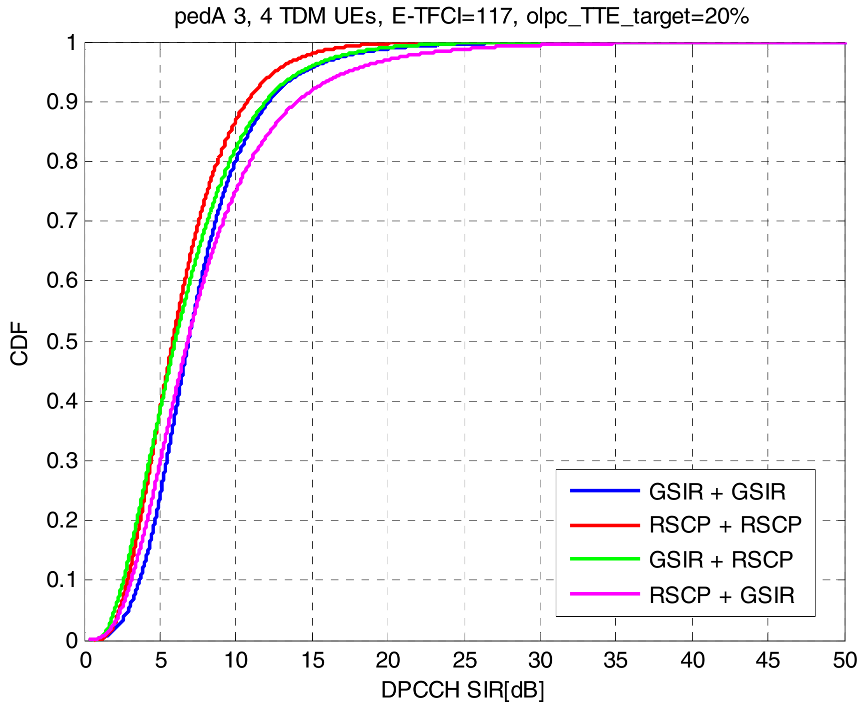

Figure 43: Complete plot of [Figure 20]: DPCCH SIR TD for two high data rate TD UEs in pedA 3, with higher error rate requirement.

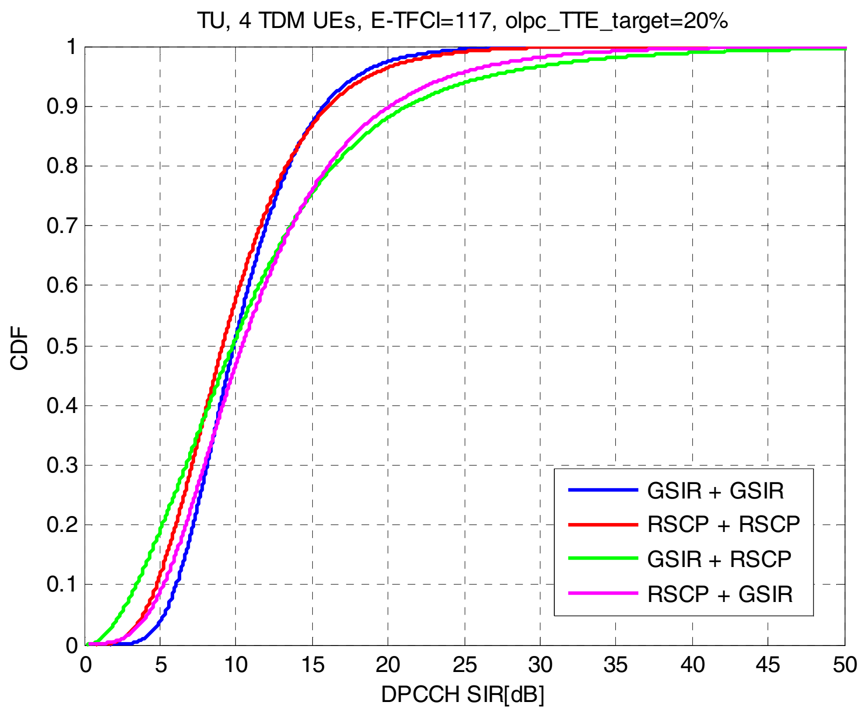

Figure 44: Complete plot of [Figure 23]: DPCCH SIR TD for four high data rate TD UEs in TU, with higher error rate requirement.

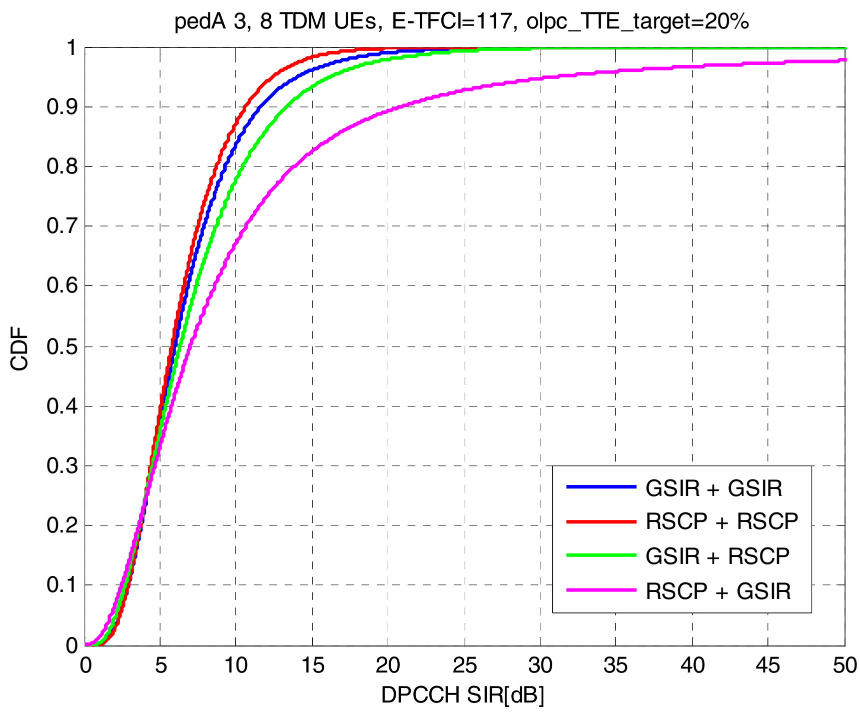

Figure 45: Complete plot of [Figure 27]: DPCCH SIR TD for eight high data rate TD UEs in pedA 3, with higher error rate requirement.

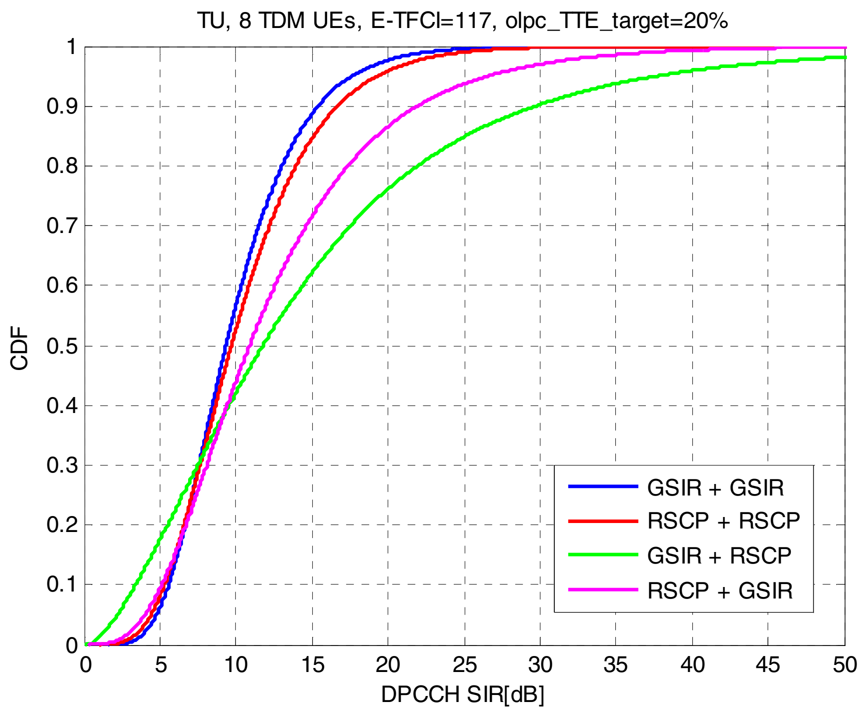

Figure 46: Complete plot of [Figure 30]: DPCCH SIR TD for eight high data rate TD UEs in TU, with higher error rate requirement.

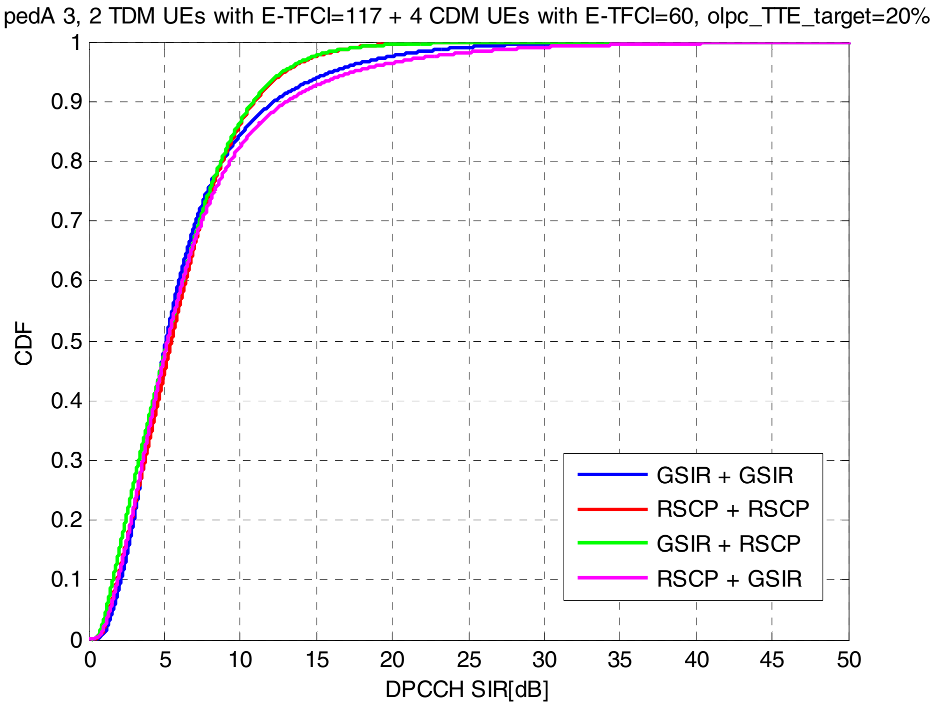

Figure 47: Complete plot of [Figure 34]: DPCCH SIR for TD UEs in the coexistence scenario of TDM and CDM UEs in pedA 3, with higher error rate requirement.

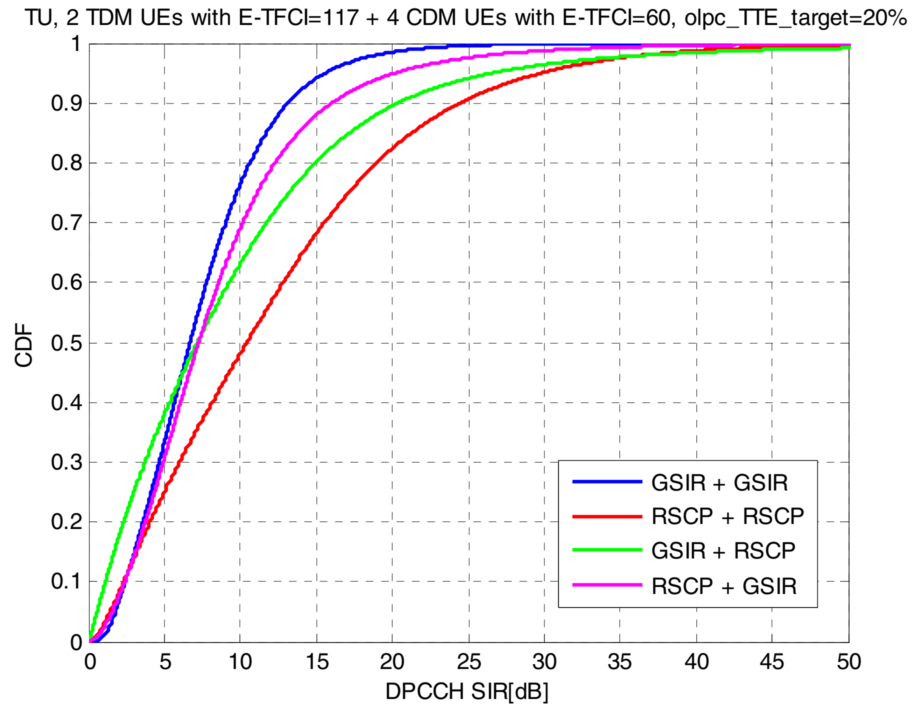

Figure 48: Complete plot of [Figure 38]: DPCCH SIR for TD UEs in the coexistence scenario of TDM and CDM UEs in TU, with higher error rate requirement.

Appendix B: SIR target (active TTI) GSIR vs GSIR + RSCP

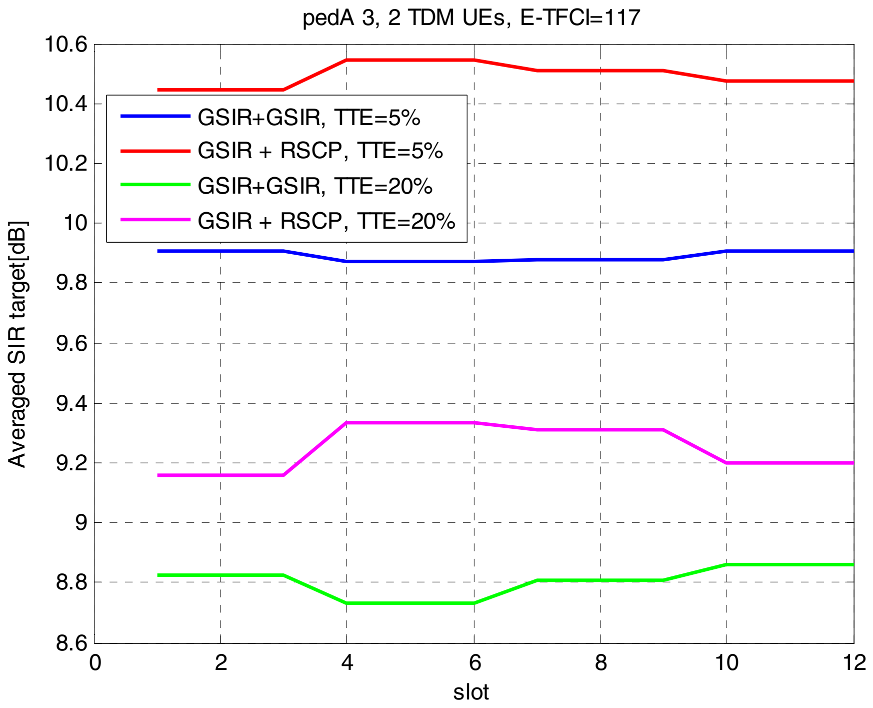

Figure 49: Averaged SIR target during active TTIs for two high data rate TD UEs in pedA 3.

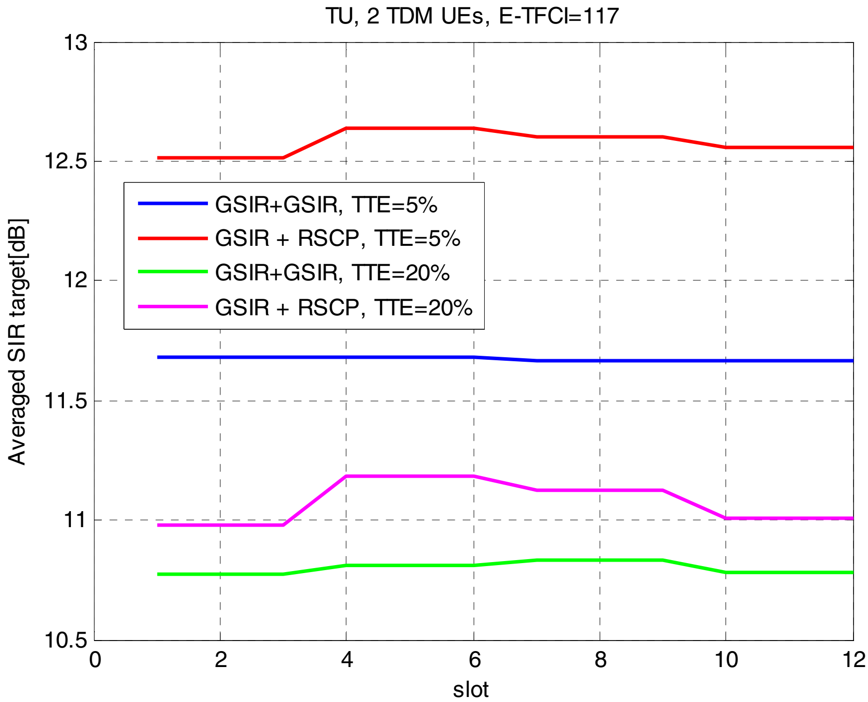

Figure 50: Averaged SIR target during active TTIs for two high data rate TD UEs in TU.

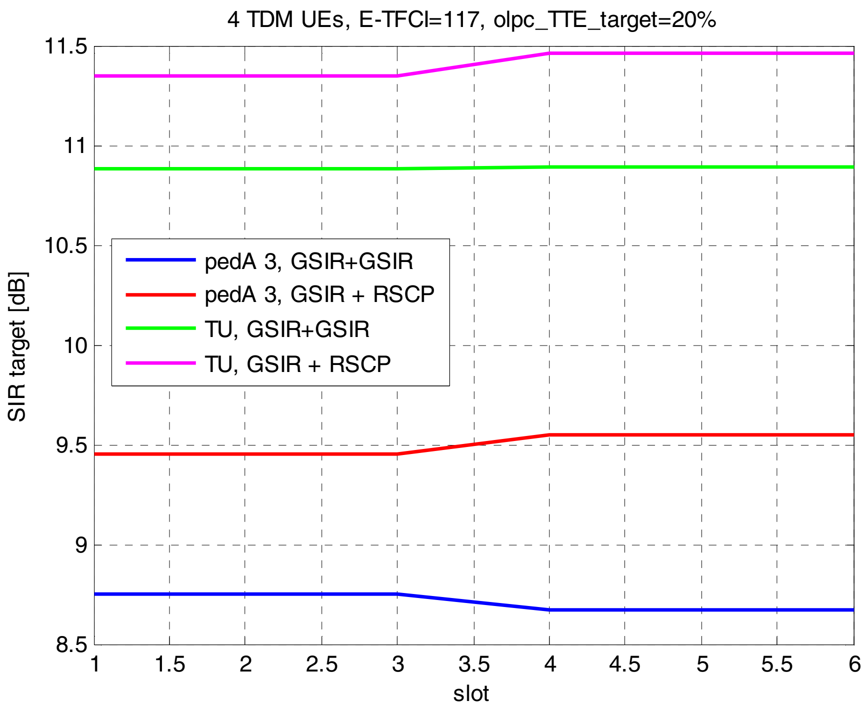

Figure 51: Averaged SIR target during active TTIs for four high data rate TD UEs.

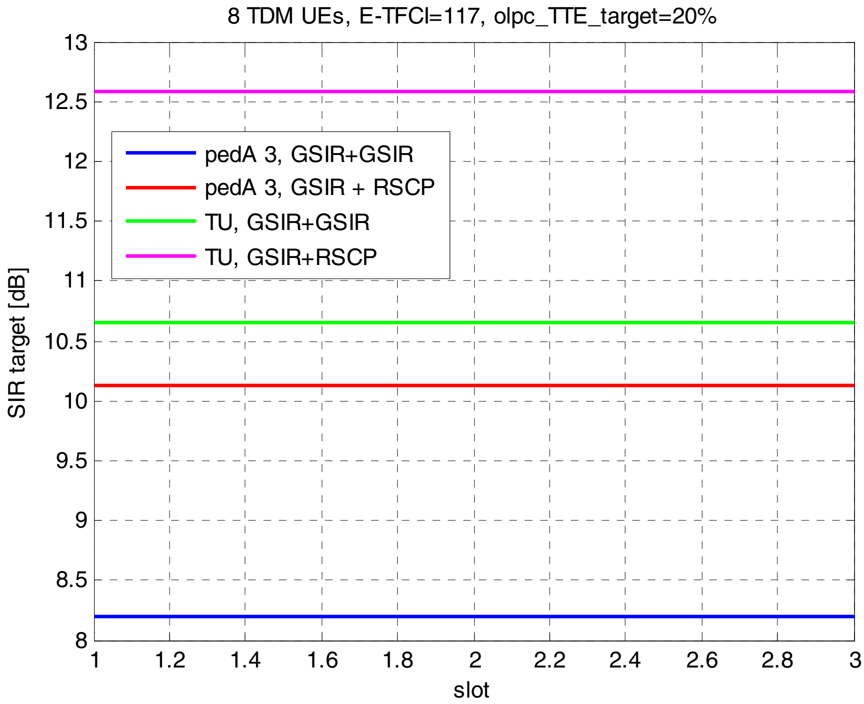

Figure 52: Averaged SIR target during active TTIs for eight high data rate TD UEs.

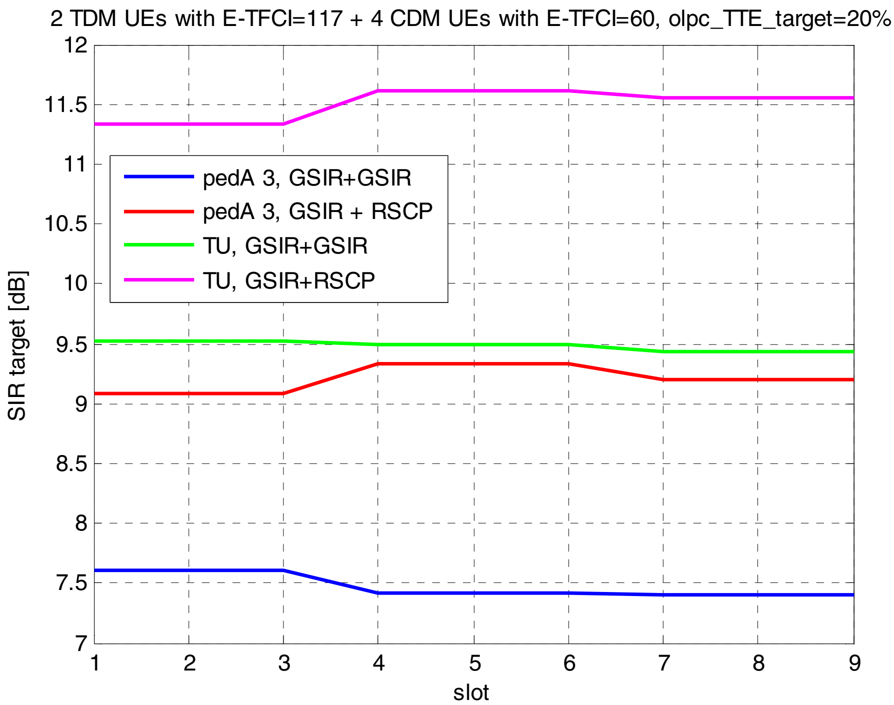

Figure 53: Averaged SIR target during active TTIs for TD UEs in the coexistence scenario of TDM and CDM UEs.

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