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Source: **InterDigital Communications Corporation**

Title: **Outer Loop Power Control in TDD mode**

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1. Introduction

During the last WG1 meeting #6, A procedure for outer loop power control for TDD uplink DPDCH [1] has been approved in principle. The implementation of this concept requires Layer 2/3 procedures: i.e. messaging between NodeB and RNC and between RNC and UE. The performance of the outer loop scheme is demonstrated in [3]. In [2], the outer loop algorithm of [3] is modified in order to reduce the rate of higher layer (L2/3) signaling. In this contribution, we evaluate the performance of the modified outer loop power control scheme combined with weighted open loop TPC for TDD uplink DPDCH [3]: i.e. the reference SIR for open loop TPC is adjusted at the UE through the modified outer loop.

2. Outer Loop Power Control

For illustration, we will assume CRC-based outer loop power control. In the case where there is no CRC, the outer loop scheme may be based on BER measurement. Figure 1 summarizes the modified outer loop power control algorithm introduced in [2]. The main characteristic of the proposed outer loop is that observably poor performance shall be corrected quickly, while nominally correct performance is refined at a relatively slow rate. Such a characteristic allows slow messaging rate between RNC and UE, while satisfying the quality requirement (like target FER or BER).

Also, this simulation assumes that the change in target SIR is at prespecified increments; the actual messages defined from RNC to UE define the target SIR levels and therefore will provide additional flexibility for optimization.

In Figure 1, “OPC bit” denotes the quality indicator of a given uplink DPDCH. If “OPC bit” is 1, then the corresponding RNC sends a higher layer message to the UE to increase the reference SIR value, denoted as $SIR_{reference}$, by a predetermined increment amount, denoted as *SIR_step_up_db*. If “OPC bit” is –1, then the RNC requests the UE to decrease $SIR_{reference}$ value by a predetermined decrement amount, *SIR_step_dn_db*. Otherwise, that is if “OPC bit” is 0, the RNC doesn’t take any action.

The system parameters that determine the performance of the proposed outer loop power control are listed below:

- *Uncertainty level* : includes the effects of gain and interference uncertainties between UL and DL (its sign can be +/-)
  remark): As the uncertainty level increases, longer transition state period may be required.

- *Constant value* : This value shall be set via layer 3 message.
- *N*: Maximum number of observation frames for decision of "OPC bit"

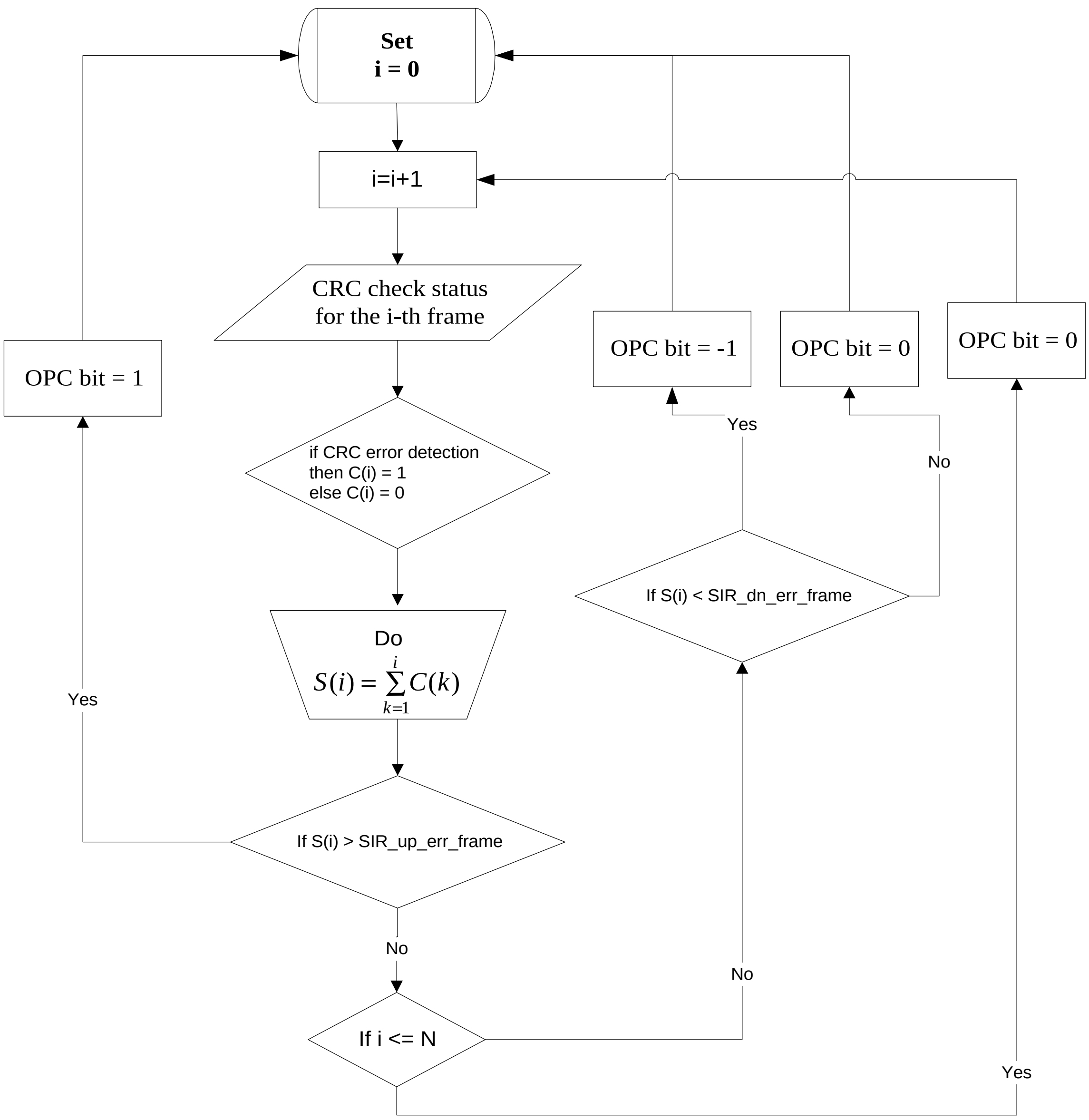

Figure 1: Flow chart of the proposed outer loop power control

- FER_{Target} : Target frame error rate for power controlled UL DPDCH
  remark): This is set according to quality of service type under consideration.
- $SIR_{reference}$: Reference SIR in dB for open loop TPC, whose initial value is broadcast on BCH. Then it is updated through outer loop
  remark): The value is related directly to either FER or BER after channel decoding. Ideally $SIR_{reference}$ should converge to target SIR, denoted as SIR_{Target}, at which a given uplink DPDCH meets the quality requirement.

- *SIR_step_up_db* : Increment amount of reference SIR in dB
  remark) : The larger is the value of *SIR_step_up_db*, the faster is the convergence from transition state to steady state.
- *SIR_step_dn_db* : Decrement amount of reference SIR in dB
  remark) : The same situation as *SIR_step_up_db*
- *SIR_up_err_frame* : Threshold for increasing $SIR_{referencet}$ by *SIR_step_up_db*
  remark) : The larger is the value of *SIR_up_err_frame*, the slower is the correction rate
- *SIR_dn_err_frame* : Threshold for decreasing $SIR_{reference}$ by *SIR_step_dn_db*
  remark) : The smaller is the value of *SIR_dn_err_frame*, the slower is the correction rate.

Among the above parameters the last 4 items are the major parameters which affect the outer loop performance, especially the messaging rate between RNC and UE.

2.1 Steady State Message Rate

This section shows that, in steady state, the modified outer loop requires very infrequent messaging between RNC and UE; on the order of once per 8 minutes.

Assuming a given Frame Error Rate (FER), we can find the probability that each of the following events occurs:

i) $SIR_{reference}$ increment case:

P{"OPC bit" = 1} = P{ number of frame errors in (n<=*N*) frames >= *SIR_up_err_frame* }

$$= \sum_{k=SIR\_up\_err\_frame}^{n} \binom{n}{k} \left(FER_{Target}\right)^{k} \left(1 - FER_{Target}\right)^{n-k} \qquad (1)$$

ii) $SIR_{reference}$ decrement case:

P{"OPC bit" = -1} = P{ number of frame errors in *N* frames <= *SIR_dn_err_frame* }

$$= \sum_{k=0}^{SIR\_dn\_err\_frame} \binom{N}{k} \left(FER_{Target}\right)^{k} \left(1 - FER_{Target}\right)^{N-k} \qquad (2)$$

iii) *No* $SIR_{reference}$ correction after receving *N* frames

P{"OPC bit" = 0} = P{ *SIR_dn_err_frame* < number of frame errors in *N* < *SIR_up_err_frame*}

= 1- P{"OPC bit" = 1} - P{"OPC bit" = -1}

$$= \sum_{k=SIR\_dn\_err\_frame+1}^{SIR\_up\_err\_frame-1} \binom{N}{k} \left(FER_{Target}\right)^{k} \left(1 - FER_{Target}\right)^{N-k} \qquad (3)$$

We can approximate the above probabilities by the discrete normal CDF (cumulative distribution function), using the Demoivre-Laplace theorem in [4], which states the following:

if (*number of observation frames*)*(FER_{Target})* (1- FER_{Target}) $= \sigma^{2}$ >>1, then we have

$$\binom{n}{k} \left(FER_{Target}\right)^{k} \left(1 - FER_{Target}\right)^{n-k} \cong \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\left(k - n*FER_{Target}\right)^{2}/2\sigma^{2}} \qquad (4)$$

It can be verified that the above condition is satisfied for typical system parameters. Figure 2 illustrates how the probabilities in (1) through (3) can be approximately expressed in terms of the normal PDF (probability density function).

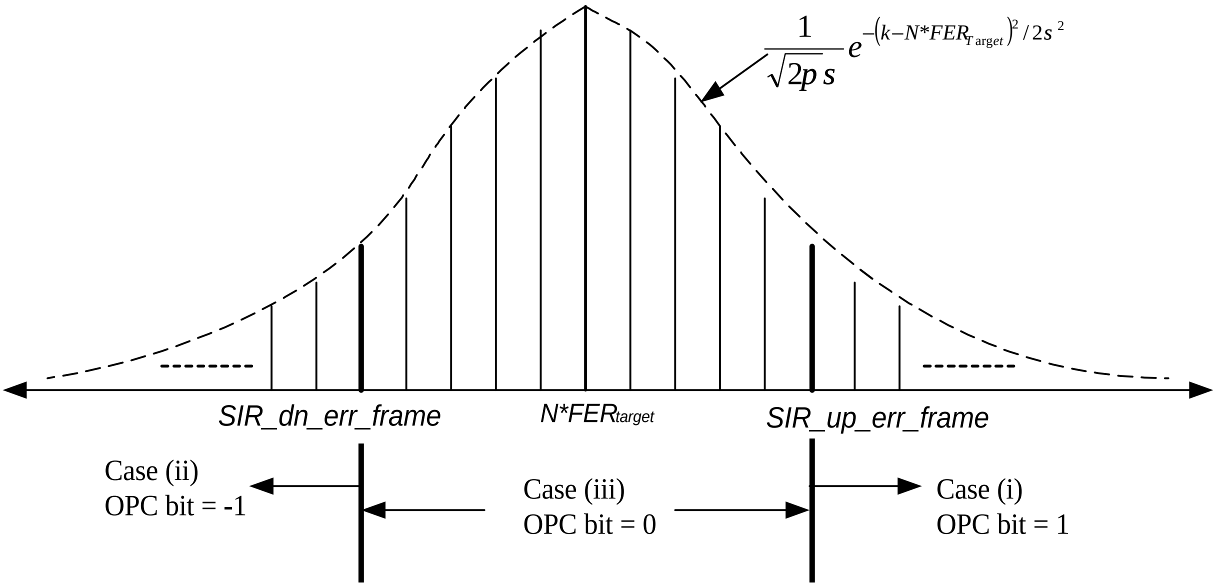

Figure 2: Illustration of the probabilities of Case (i) through Case (iii)

Let's consider the following example serving as an illustration.
We assume that

- Steady state operation with nominal FER=1%
- One(1) CRC check per frame (10 msec)
- FER averaging time = 1000 frames = 10 seconds
- *SIR_up_err_frame* = 18 errors in 10 seconds
- *SIR_dn_err_frame* = 2 errors in 10 seconds

Using the analytic expressions [1] and [2] we predict that a high threshold crossing and a low threshold crossing would each occur, on average, once per 1000 seconds, or 16 minutes; or, combined we would expect one correction per 8 minute.

2.2 Transition Issues

This section discusses the requirement to correct large errors in the target SIR; e.g. when the UE enters a new cell. During transition state, the outer loop functions to compensate for the effects of both gain/interference uncertainties and incorrect estimate of *Constant value* in UL open loop power control. This stage shall require a larger *SIR_step_up_db* and possibly a larger *SIR_step_dn_db* in order for the outer loop to converge fast.

Note that, in the actual message from RNC to UE, target SIR is transmitted; not step size. This fact supports algorithms in the RNC which produce larger step changes in transition and smaller step changes in steady state and different values for increment and decrement.

2.2 Simulation Performance of (weighted) Open Loop TPC with Modified Outer Loop

By Monte-Carlo experiments based on symbol-level simulation, we evaluate the performance of weighted open loop TPC combined with the proposed outer loop, varying the system parameters of interest. We consider the same simulation model and assumptions as in [3], except for the following parameters:

Simulation Conditions

- No FEC applied
- CRC check is performed every frame: it is assumed that a frame error occurs when there are at least two raw bit errors over a given frame. It is also assumed that the considered traffic channel occupies one time slot per frame
- Maximum CRC observations for decision on OPC bit: *N*=1000 frames (10 seconds)
  Note that a correction is made as soon as the error count exceeds its threshold; process does not wait for the full averaging interval in this case.
- Target FER: 1% => average of 10 frame errors per 10 seconds
- Reference SIR_{TARGET} is updated only if OPC bit is either +/- 1
- $L_0 = 0$ dB and gain (interference) uncertainties = +/- 1.5 dB
- Mobile speed: 3 km/h
- Delay in slots between uplink and downlink: 2 time slots

Simulation Results

Figures 3 through 5 show the performance results of the weighted open loop TPC with the proposed outer loop scheme. Recall that $SIR_{reference}$ is updated according to the outer loop criteria described in Section 2. We evaluated the impact of the system parameters of interest on the performance including higher layer messaging rate for adjusting $SIR_{reference}$ from RNC to UE, and convergence time to steady state. As observed in Figure 3-4, as *SIR_step_dn_db* value increases from 0.1 to 0.25 (dB), the combined open loop/outer loop TPC scheme converges faster to steady state, which may reduce the messaging rate during transition state. Regarding the influence of *SIR_up_err_frame/SIR_dn_err_frame*, Figure 4 and Figure 5 indicate that selecting larger *SIR_up_err_frame* and smaller *SIR_dn_err_frame* significantly reduces the messaging rate in steady state. Notice that for all cases, the combined open loop/outer loop scheme very closely meets the given target FER equal to 1%, by overcoming gain/interference uncertainties of +/- 1.5 dB. Table 1 summarizes the performance for the average messaging rate in steady state, for *SIR_step_up_dn/SIR_step_dn_db* equal to 0.25/0.25 dB. For reference, the analytical result based on the normal approximation and the derivation of Section 2 is included.

Table 1: Summary of combined open loop/outer loop performance for average message rate

Cases	Simulation result (average messaging rate)	FER	Analytical result (Averaging messaging rate)
SIR_up_err_frame: 15 *SIR_dn_err_frame*: 6	36 (SIR up/down) messages in 15 minutes => **1 message per 25 seconds.**	1.05 %	21 (SIR up/down) messages in 16.6 minutes => **1 message per 47 seconds.**
SIR_up_err_frame: 17 *SIR_dn_err_frame*: 4	15 (SIR up/down) messages in 15 minutes => **1 message per minute**	1.01%	6 (SIR up/down) messages in 16.6 minutes => **1 message per 2.7 minutes.**
SIR_up_err_frame: 20 *SIR_dn_err_frame*: 2	2 (SIR up/down) messages in 15 minutes => **1 message per 7.5 minutes.**	1.0 %	1 (SIR up/down) messages in 16.6 minutes => **1 message per 16.6 minutes.**

3. Conclusion

- The proposed outer loop power control can be implemented at a relatively slow higher layer messaging rate – on the order of one message per several minutes.
- The combined open loop/outer loop TPC can converge to the ideal value within a fraction of 1 dB.

Reference

[1] InterDigital, "Text proposal for S1.24", TSGR2#6(99)974, August 1999.

[2] InterDigital, "Outer Loop Power Control for TDD Mode", TSGR2#6(99)777, August 1999.

[3] InterDigital, "Performance Evaluation of Combined Outer loop/Weighted Open Loop Scheme for Uplink Power Control in TDD", Tdoc R1-99973, Espoo, Finland, July 1999.

[4] Athanasios Papoullis, "Probability, Random Variables, and Stochastic Processes", Third Edition, McGraw Hill.

[5] InterDigital, "Uplink Outer Loop Power Control for TDD Mode", TSGR3#6(99)907, August 1999

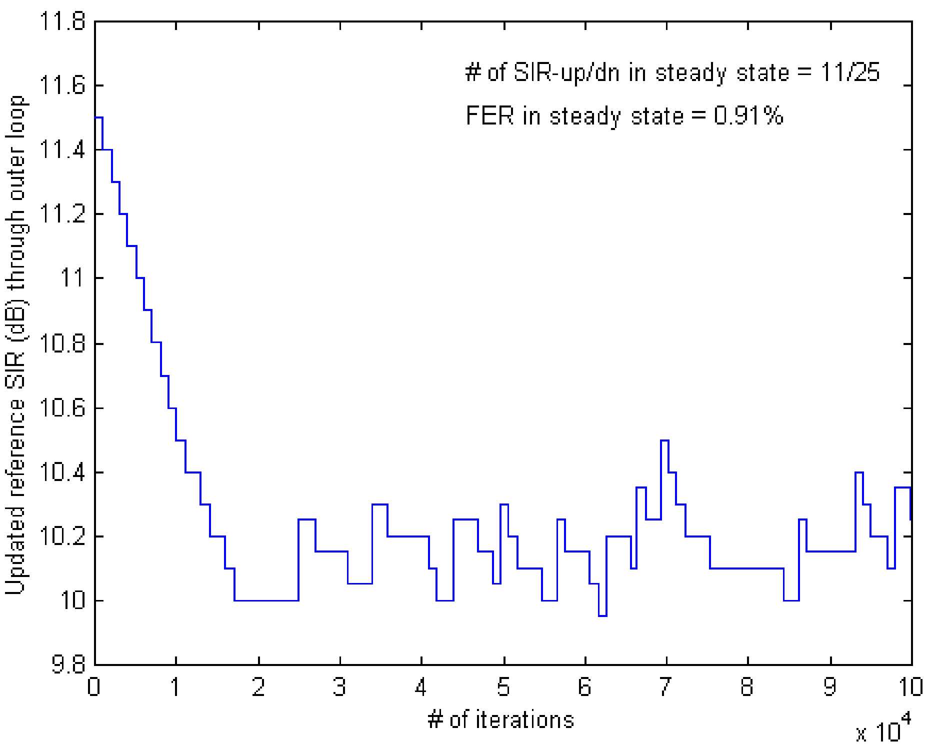

Figure 3: Delay = 2 time slots, **SIR_step_up/dn = 0.25/0.1(dB),** up/dn_err_frame = 15/6

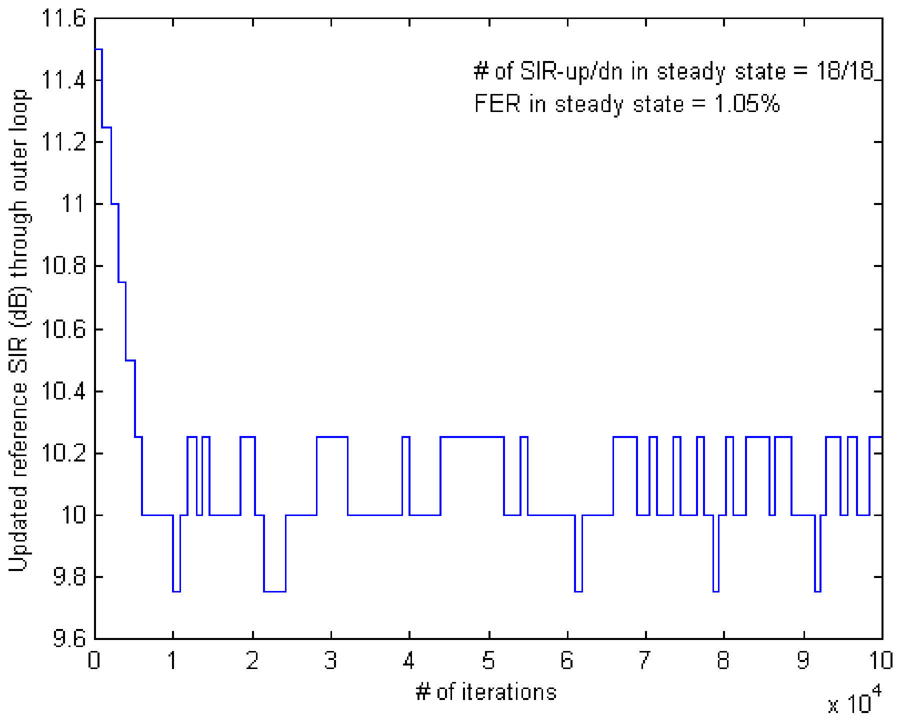

Figure 4: Delay = 2 time slots, SIR_step_up/dn = **0.25/0.25(dB)**, up/dn_err_frame = 15/6

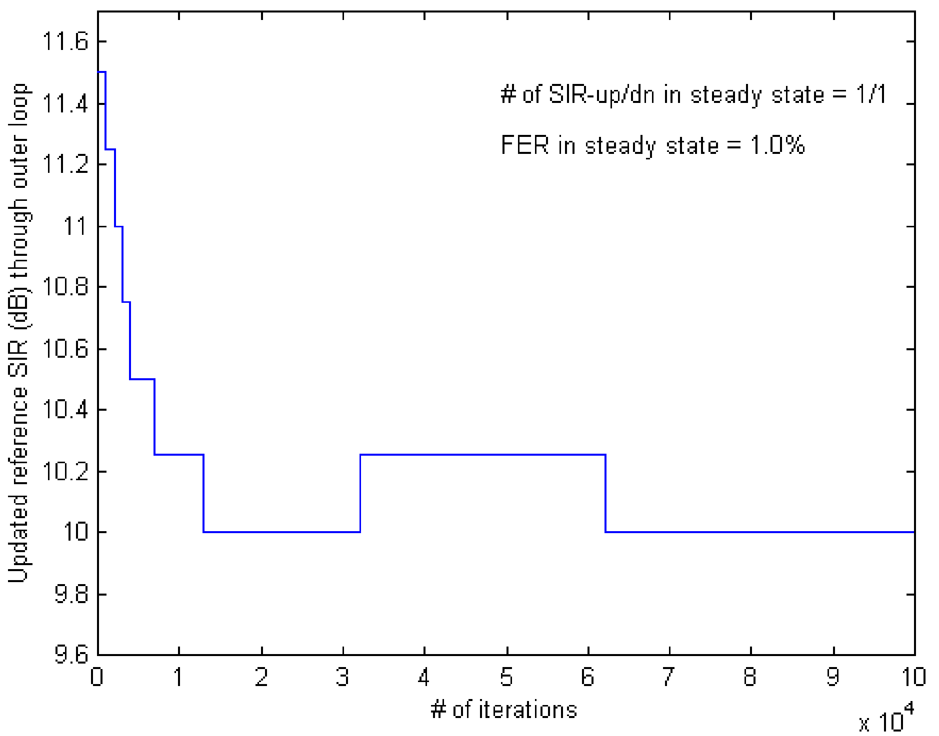

Figure 5: Delay = 2 time slots, SIR_step_up/dn = 0.25/0.25(dB), **up/dn_err_frame = 20/2**