Optimum Power Ratio between Pilot and Information Bits if User Specific Beamforming is used in UMTS FDD

Thomas Baumgartner[1], Alberto Gil Ferrás[2†], Werner Weichselberger[1]
[1]Institut für Nachrichtentechnik und Hochfrequenztechnik, Technische Universität Wien
Gusshausstrasse 25/389, A-1040 Wien, Austria
[2]Centro Politécnico Superior de Universidad de Zaragoza
c/ Maria de Luna 1, E-50018 Zaragoza, Spain

Abstract—Mobiles operating in a UMTS network that uses user specific beamforming have to use the so called dedicated pilot bits for channel estimation that are time multiplexed with the user data. The reason therefore is that the Common Pilot Channel that is broadcast into the entire cell and typically used for channel estimation experiences a different radio channel than the user data sent on the user specific beam. In this paper, we determine the optimum power ratio between the dedicated pilot bits and the information bits for the 144kbit/s reference channel specified for terminal conformance tests in the UMTS specification. For the ITU-Vehicular A channel with 3km/h mobile speed, we find the optimum power ratio between dedicated pilot bits and information bits at 4 to 7dB. This optimum power ratio gives a $\frac{E_b}{N_0}$ reduction of more than 1.5dB for a target block error rate of 1% compared to a system with equal power for all bits.

I. Introduction

The first Universal Mobile Telecommunication System (UMTS) networks are currently launched in Europe. These networks will bring high data rate services to the mobile user. As the number of subscribers increases there will be the need to extend the capacity of the initially deployed UMTS networks. From a technical viewpoint, the easiest method to increase the capacity of a UMTS network is to increase the number of base station sites. Due to the high number of already existing base station sites, especially in areas with high user densities, it will be quite hard to find and acquire additional new suitable base station sites. This will generate the need for technically more advanced capacity enhancement methods like smart antennas. These methods exploit the spatial domain of the mobile radio channel with the help of an antenna array and appropriate signal processing at the base station. In literature, there are several approaches for the implementation of such smart antennas. These approaches can be divided into two main strategies, the fixed beam methods, cf. [1], [2], and methods that apply user specific beam forming, cf. [3], [4]. The fixed beam methods lay a specific number of fixed beams over the coverage area. All mobiles in the coverage area of one beam are served by this beam. Thus in the fixed beam approach, typically more than one mobile is served by a specific beam. On the other hand, the user specific beam forming methods typically serve only one user per beam. Generally the beam patterns for these user specific beams are generated in order to fulfill different constraints, e.g. minimum path loss towards the desired user or minimum interference to all other users.

Typically, the mobiles in the downlink of the UMTS Frequency Division Duplex (FDD) mode use a so called Common Control Physical Channel (CPICH) to estimate the radio channel in order to properly decode the received data [5]. The CPICH is a continuous predefined sequence that is broadcast with constant power into the entire cell (Primary CPICH) or just into a part of the cell (Secondary CPICH). Mobiles operating in a network using a fixed beam method can use the Secondary CPICH for channel estimation, if the Secondary CPICH is also transmitted on the serving beam together with the data channels of the served users. For user specific beamforming, where each beam serves just one user, it does not make sense to transmit a Secondary CPICH on each beam as the power of all the Secondary CPICHs would exceed the amount of power used for transmitting actual user data. On the other hand, if the mobiles served by a user specific beam use the Primary CPICH for channel estimation, their performance will degrade with increasing angular spread of the radio channel. The radio channel experienced by the Primary CPICH, transmitted e.g. with a single antenna element, will be different from the radio channel experienced by the user data transmitted on a narrow beam. In [6], it is shown that the performance of a mobile served by a user specific beam (formed by eight antenna elements) degrades significantly for a relatively small angular spread of six degrees if the mobile uses the Primary CPICH for channel estimation. In such situations, the UMTS network can force the mobile to use the so called dedicated pilot bits for channel estimation. The dedicated pilot bits are time multiplexed with the information bits

[†] During this work Alberto was with the Institut für Nachrichtentechnik und Hochfrequenztechnik via the Erasmus student exchange program

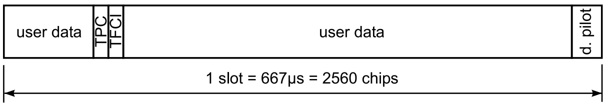

Fig. 1 Slot structure of the DPCH in the UMTS FDD downlink. The length of the data, Transmit Power Control (TPC), Transport Format Combination Indicator (TFCI) and dedicated pilot fields have a scaling equal to the slot format number 14, which is used for the 144kbit/s reference channel.

of the user. The structure of the Dedicated Physical Channel (DPCH) that carries the user data in the UMTS FDD downlink is shown in Figure 1. The disadvantage of using the dedicated pilot bits is that this pilot sequence is shorter than the sequence of the CPICH. For example, the length of the dedicated pilot bits in the slot format used for the 144kbit/s reference channel is 128 chips per slot compared to 2560 chips per slot for the CPICH. Therefore, the quality of the channel estimation will be worse than the estimation quality if the CPICH is used. Due to this degraded channel estimation, the necessary $\frac{E_b}{N_0}$ (energy per bit over noise plus interference) for a certain Block Error Rate (BLER) will be higher. A possibility to improve the channel estimation quality is to increase the transmit power of the pilot bits. The UMTS specification allows power offsets between data bits and pilot bits of up to 6dB [7]. As a UMTS network can schedule the start of the DPCH slots serving different users in steps of 256 chips [8] the influence of this power offset on the crest factor of the base stations output is quite low. For example, the crest factor of a base station that transmits 15 independent equally powered DPCHs increases from 3.4, with equal power for all bits, to 3.6 if the power of the dedicated pilot bits is 6dB higher than the power of the information bits.

The scope of this paper is to find the optimum power ratio between the dedicated pilot bits and the information bits that minimizes the required $\frac{E_b}{N_0}$ for a Block Error Rate (BLER) of 1% if the 144kbit/s reference channel specified in [9] is used. Our link level simulations show that the minimum of the required $\frac{E_b}{N_0}$ is achieved with a power ratio between dedicated pilot bits and information bits of 4 to 7dB. Using these power ratios, the required $\frac{E_b}{N_0}$ for a BLER of 1% is more than 1.5dB lower than for a system using equal powers for all bits.

II. System model

The model of the analyzed system is shown in Figure 2 and can be divided into four parts: the base station, the radio channel, the receiver and the analyzation block.

A. Base station

The base station generates the Primary CPICH; Primary Common Control Physical Channel (P-CCPCH) filled with random information; the Synchronization Channel (SCH) that is time multiplexed with the P-CCPCH; the DPCH that transports the data of the desired user; and the so called Orthogonal Channel Noise Simulator (OCNS) that simulates data channels of other users. According to the conditions of the terminal conformance tests described in [9], the power of the Primary CPICH (P_{CPICH}) and the power of the P-CCPCH together with the SCH ($P_{PCCPCH+SCH}$) are 10% (-10dB) and 6.3% (-12dB) of the total transmit power of the base station, respectively. The power of the DPCH (P_{DPCH}) carrying the data of the desired user, is adjusted according to the power control commands from the receiver in ± 1dB/slot steps. The power of the OCNS (P_{OCNS}) is adjusted in such a way that the total transmit power of the base station P_{BS} is unity

$$P_{BS} = 1 = \\ P_{CPICH} + P_{PCCPCH+SCH} + P_{DPCH} + P_{OCNS}. \quad (1)$$

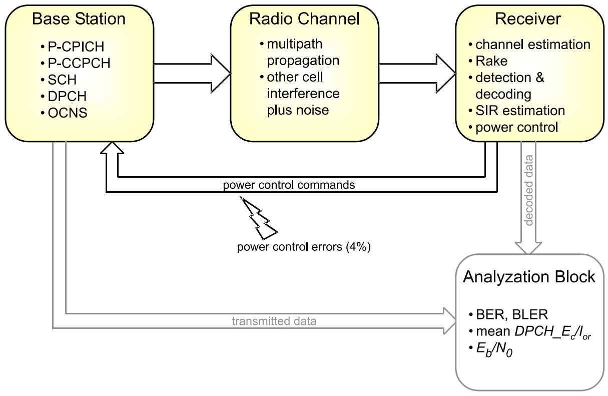

Fig. 2 System Model

According to the 144kbit/s downlink reference channel defined in [9], the DPCH carrying the data of the desired user has the slot format number 14 (cf. [8]). This means that the data is spread with a spreading factor of 16, and there are 16 dedicated pilot bits that have a length of 128 chips after QPSK modulation and spreading. The data transported by the DPCH consists of the Dedicated Transport Channel (DTCH), this is the data the user actually is interested in, and the Dedicated Control Channel (DCCH) used for higher layer signaling. The DTCH consists of data blocks of 2880 bits that are transmitted every 20ms. First there is a 16 bit Cyclic Redundancy Check (CRC) added to the data block. Then the data is turbo coded with a rate of $\frac{1}{3}$. After rate matching, where 2.7% of the bits are discarded, the data is interleaved, multiplexed with the coded data of the DCCH and mapped on the DPCH. The DCCH produces 100 bit data blocks every 40ms, uses a 12 bit CRC and is convolutional encoded with a rate of $\frac{1}{3}$. For further details see [8] and [9].

The OCNS consists of 16 random DPCHs, 11 with

TABLE I

Spreading Factor (SF), number of the used Orthogonal Variable Spreading Factor Code (OVSF num.), time shift of slot structure relative to the Primary CPICH, and relative power of the 16 DPCHs forming the OCNS

Number	SF	OVSF num.	Time shift [chips]	Rel. power [dB]
1	16	11	1280	-1
2	16	12	1024	-3
3	16	13	512	-3
4	128	23	1280	-5
5	128	31	768	-2
6	128	38	512	-4
7	128	47	2304	-8
8	128	55	768	-7
9	16	14	256	-4
10	128	69	2048	-6
11	128	78	0	-5
12	128	62	2048	-9
13	128	94	0	-10
14	128	102	256	-8
15	128	113	2048	-6
16	16	15	768	0

spreading factor 128 and equal power for all bits and 5 with spreading factor 16 and the same power ratio between dedicated pilot bits and information bits as the DPCH of the desired user. Detailed information about the used spreading codes, time shifts of the DPCHs' slot structure compared to the Primary CPICH, and the relative powers of the OCNS is given in Table I. The relative powers and the time shifts of the channels are equal to the OCNS definition in [9].

After summing up all physical channels (Primary CPICH, SCH, P-CCPCH, DPCH, OCNS) the output of the base station is filtered with a root-raised cosine filter with a roll-off factor of 0.22 [10].

B. Radio channel

The radio channel consists of a Finite Impulse Response (FIR) filter with six taps for simulating multipath propagation and a band limited noise source that simulates the interference coming from other cells and thermal noise. Note: In Code Divison Multiple Access (CDMA) systems like UMTS, the interference coming from other cells is typically much larger than the thermal noise. The band limited noise is produced by filtering white noise with an equal root-raised cosine filter as used as transmit filter in the base station. Before summing up the noise with the output of the FIR filter, the noise is weighted in such a way that its power spectral density I_{oc} fulfills

$$G = \frac{\mathrm{E}\left\{\hat{I}_{or}\right\}}{I_{oc}}, \qquad (2)$$

TABLE II

Average powers and relative delays of the delay taps in the ITU-Vehicular A channel [11]

Tap number	Ave. power [dB]	Rel. delay [ns]
1	0	0
2	-1	310
3	-9	710
4	-10	1090
5	-15	1730
6	-20	2510

where $\mathrm{E}\left\{\hat{I}_{or}\right\}$ is the expectation over the whole simulation length of the received spectral energy from the serving base station. The so called geometry factor G is an input parameter of the simulator.

The weights for the FIR filter change on a slot by slot basis in order to implement the ITU Vehicular A channel [11] for mobile speeds of 3km/h. The ITU Vehicular A channel consists of six taps with classic Doppler spectrum each. The relative powers and delays of the taps are given in Table II. In our simulation environment, we have rounded the delays to the closest quarter of a chip length ($\frac{260.4\text{ns}}{4} = 65.1$ns).

C. Receiver

The receiver filters the received signal with a root-raised cosine filter equal to the transmit filter in the base station. Then the receiver estimates the channel impulse response for slot n, $\hat{\mathbf{c}}(n)$, by correlating the received signal with the known pilot sequence. The weights and relative delays of the four Rake fingers are determined by searching for the four largest peaks in the estimated channel impulse response. The peak search is done in a two stage process. First the peaks are searched in the channel impulse response $\hat{\mathbf{c}}(n)$ where the amplitude of valid peaks has to be 13dB above the median value of $\hat{\mathbf{c}}(n)$ and no more than 10dB below the largest peak. If the first step finds less peaks than the number of Rake fingers then the second stage searches for peaks in the averaged channel impulse response $\bar{\mathbf{c}}(n)$ that is given by

$$\bar{\mathbf{c}}(n) = \mu\bar{\mathbf{c}}(n-1) + \hat{\mathbf{c}}(n). \qquad (3)$$

Where μ=0.9 is the forgetting factor. In this stage, the peak amplitude has to be 6dB above the median value of $\bar{\mathbf{c}}(n)$. Additionally it is required that the value of $\hat{\mathbf{c}}(n)$ at the same position is no more than 10dB below the largest peak in $\hat{\mathbf{c}}(n)$. Doing so reduces the probability of choosing a peak that exists no more in a birth-death scenario. If both stages find no peak the position of the maximum in $\hat{\mathbf{c}}(n)$ is taken as peak. The Rake finger weight for a peak at position k is given by $\hat{c}_k(n)^*$ that is the complex conjugate of the channel impulse response $\hat{\mathbf{c}}(n)$ at position k.

After applying the Rake, the receiver descrambles and despreads the received sequence. After decoding the despread sequence, the receiver decides if the received block is erroneous by checking the CRC value.

The estimated Signal to Interference Ratio (SIR) is given by the ratio between estimated signal power and estimated interference power. The signal power is estimated by determining the power of the received signal after despreading with the user's OVSF code. In the same way the interference power is estimated by the power of the received signal after despreading with an unused OVSF code. A power up command is sent to the base station if the estimated SIR is lower than the target SIR. Otherwise a power down command is sent. In order to simulate an erroneous feedback channel, 4% of the power control commands are changed to their contrary values.

D. Analyzation block

The analyzation block calculates the BLER after channel decoding and the average ratio of the transmitted energy per chip of the desired channel $DPCH\_E_c$ to the total transmit power spectral density I_{or} of the base station.

For a BLER of 1%, the required ratio between the average transmit energy per chip of the desired channel to the total transmit power spectral density of the base station $\frac{DPCH\_E_c}{I_{or}}$ is determined by repeating the simulation with different target SIRs resulting in different $\frac{DPCH\_E_c}{I_{or}}$ and BLER values. The required $\frac{DPCH\_E_c}{I_{or}}$ for a BLER of 1%, is calculated by interpolating the BLER versus $\frac{DPCH\_E_c}{I_{or}}$ curve. With the help of the non-orthogonality factor α, the $\frac{E_b}{N_0}$ is calculated by

$$\frac{E_b}{N_0} = \frac{\frac{DPCH\_E_c}{I_{or}}}{\alpha + \frac{1}{G}}. \tag{4}$$

Note: In contrast to other publications, we define α as non-orthogonality factor. Further we postulate that α is a property of the channel. Therefore α is independent of the receiver.

III. RESULTS

We used RadioLab3G[1] for performing the link-level simulations over a duration of 5000 radio frames. This equals 50s in real time or 2500 user data blocks. In the first step, we assumed ideal channel estimation and determined the necessary $\frac{DPCH\_E_c}{I_{or}}$ for a BLER of 1% for different G factors. Then we calculated the required $\frac{E_b}{N_0}$ for a BLER of 1% and the non-orthogonality factor α by least-squares fit of $\frac{E_b}{N_0}$ and α in (4) regarding different

[1]We use RadioLab3G under license from Radioscape. The views expressed in this paper are those of the authors and do not necessarily reflect the views within Radioscape.

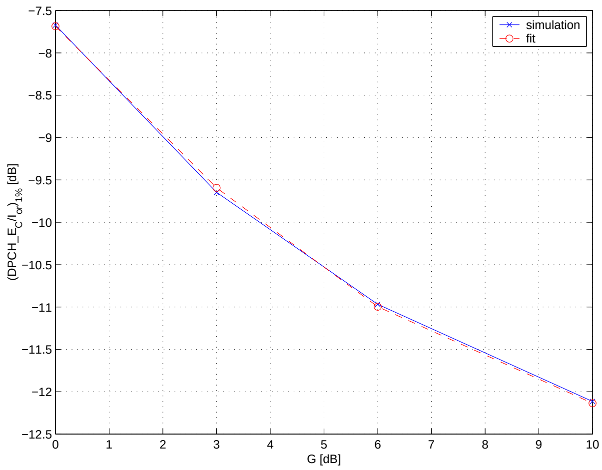

Fig. 3 For a receiver with ideal channel knowledge for BLER=1% required $\frac{DPCH\_E_c}{I_{or}}$ over G. The solid line corresponds to simulated values and the dashed line shows the fitted curve using $\frac{E_b}{N_0} = 5.1$dB and $\alpha = 0.4$.

G factors. This method is described in [12]. The result of the fit was a required $\frac{E_b}{N_0} = 5.1$dB for a receiver with ideal channel knowledge and a non-orthogonality factor $\alpha = 0.4$. Figure 3 illustrates the very small difference between the simulated and the fitted $\frac{DPCH\_E_c}{I_{or}}$ over G curves.

In a second step we simulated the above system with geometry factors G of 3dB, 6dB and 10dB and various power ratios between dedicated pilot bits and information bits. Figure 4 shows the required $\frac{E_b}{N_0}$ for a BLER of 1% if the receiver uses the dedicated pilot bits for channel estimation. It can be clearly seen that the curves for different geometry factors show the same trend with a flat minimum for a power ratio between pilot and information bits between 4 and 7dB. This operation point is feasible within the framework of the current UMTS specification. Using the optimum power ratio results in a required $\frac{E_b}{N_0}$ of about 7dB.

Note: The optimum power ratio between dedicated pilot bits and information bits for other services using different data rates depends on the used slot format, i.e how many chips of a slot are used for the dedicated pilot bits, the channel coding and the target BLER, i.e how much $\frac{E_b}{N_0}$ is needed to reach the target BLER.

Figure 5 illustrates the required $\frac{E_b}{N_0}$ for a BLER of 1% for the 144kbit/s reference channel if the terminal can use the CPICH for channel estimation. Where the CPICH is transmitted using either 10 or 20% of the total base station transmit power. It can be seen that the required $\frac{E_b}{N_0}$ is lower if the CPICH is transmitted with higher power. Further Figure 5 illustrates that the required $\frac{E_b}{N_0}$ decreases slightly with increasing G. I.e. the required $\frac{E_b}{N_0}$ increases with the distance to the base station. This is typically neglected in system simulations. However, if the terminal

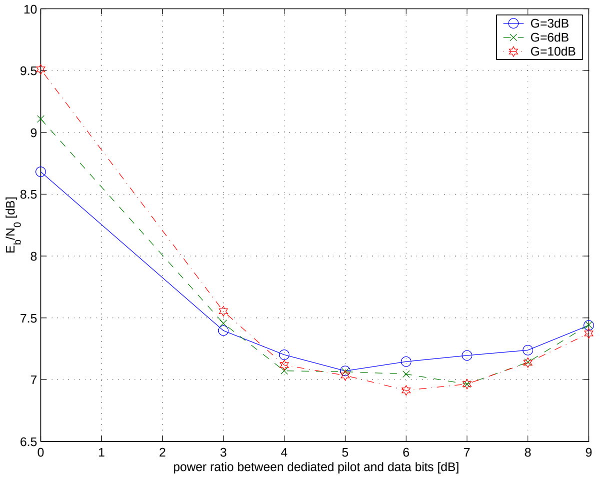

Fig. 4 Required $\frac{E_b}{N_0}$ for BLER=1% for the 144kbit/s reference channel using different power ratios between dedicated pilot bits and information bits if the dedicated pilot bits are used for channel estimation.

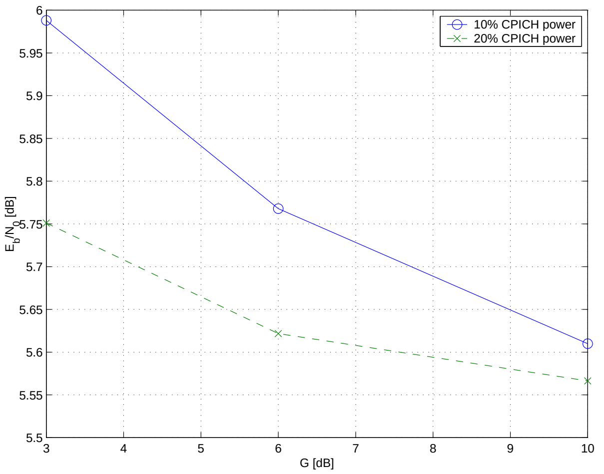

Fig. 5 Required $\frac{E_b}{N_0}$ for BLER=1% for the 144kbit/s reference channel if the terminal can use the CPICH for channel estimation.

can use the CPICH for channel estimation, the required $\frac{E_b}{N_0}$ is at least 1dB lower than in the situation where the dedicated pilot bits have to be used for channel estimation and the optimum power ratio between pilot and information bits is used.

IV. Conclusion

In this paper, we showed that it is beneficial to use different powers for the information and pilot bits of the DPCH if UMTS mobiles have to use the dedicated pilot bits for channel estimation. This is the case if user specific beamforming is used in an environment with angular spread. For a 144kbit/s data service, as specified in [9], in a ITU Vehicular A radio channel [11] with mobile speeds of 3km/h, the optimum power ratio between dedicated pilot bits and information bits is 4 to 7dB. This operation point is feasible within the framework of the current UMTS specification. Using this power ratios reduces the required $\frac{E_b}{N_0}$ for a BLER of 1% by more than 1.5dB compared to a system using equal power for all bits in the DPCH. Even if the optimum power ratio between dedicated pilot bits and information bits is used, a receiver that has to use the dedicated pilot bits for channel estimation needs a more than 1dB higher $\frac{E_b}{N_0}$ than a receiver that is able to use a CPICH for channel estimation.

V. Acknowledgment

Thomas Baumgartner thanks *Mobilkom Austria* for financial support of this work. The views expressed in this paper are those of the authors and do not necessarily reflect the views within *Mobilkom Austria*.

References

[1] E. Tiirola and J. Ylitalo, “Performance evaluation of fixed-beam beamforming in WCDMA downlink,” in *VTC 2000 - Spring*, vol. 2, (Tokio, Japan), pp. 700–704, May 2000.

[2] T. Baumgartner, T. Neubauer, and E. Bonek, “Performance of a simple downlink beam switching scheme for UMTS FDD,” in *The 6th CDMA International Conference*, (Seoul, Korea), October 30 - November 2 2001.

[3] J. Ylitalo and M. Katz, “An adaptive antenna method for improving downlink performance of CDMA base stations,” in *IEEE 5th International Symposium on Spread Spectrum Techniques and Applications*, vol. 2, (Sun City, South Africa), pp. 599–603, July 1998.

[4] M. Kitahara, Y. Ogawa, and T. Ohgane, “A base station adaptive antenna for downlink transmission in a DS-CDMA system,” in *VTC 2000-Spring*, vol. 2, (Tokio, Japan), pp. 710–715, May 2000.

[5] H. Holma and A. Toskala, eds., *WCDMA for UMTS Radio Access for Third Generation Mobile Communications*. Chichester, New York, Weinheim, Brisbane, Singapore, Toronto: John Wiley & Sons, Ltd, 2000.

[6] Nokia, “Proposal for user-specific beamforming for UTRA FDD.” TSG-R WG4 document, TSGR4#17(01)0528, Gothenborg, Sweden, May 2001.

[7] 3GPP, “UTRAN Iub interface NBAP Signalling - TS 25.433 V3.11.0 (Release 1999).” http://www.3gpp.org, September 2002.

[8] 3GPP, “Physical channels and mapping of transport channels onto physical channels (FDD) - TS 25.211 V3.12.0 (Release 1999).” http://www.3gpp.org, September 2002.

[9] 3GPP, “Terminal conformance specification; radio transmission and reception (FDD) - TS 34.121 V3.10.0 (Release 1999).” http://www.3gpp.org, September 2002.

[10] 3GPP, “BS radio transmission and reception (FDD) - TS 25.104 V3.10.0 (Release 1999).” http://www.3gpp.org, March 2002.

[11] “Guidelines for evaluation of radio transmission technologies for IMT-2000.” Recommendation ITU-R M. 1225, 1997.

[12] J. Laiho, A. Wacker, and T. Novosad, eds., *Radio Network Planning and Optimisation for UMTS*. John Wiley & Sons, Ltd, 2002.