On Uncoded High Rate Transmission over Synchronous Gaussian Multiple–Access Channels

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Abstract — **On Gaussian multiple–access channels a penalty in power efficiency is to be paid if total transmission rate is higher than 1 bit/s/Hz per dimension. This usually results from the need for higher order modulation schemes required to maintain orthogonality of all users' signal waveforms. In this paper, we show that keeping binary modulation and accepting some multiple–access interference, is a more power efficient strategy by presenting simulation results of transmission systems outperforming orthogonal schemes for rates between 1.25 and 1.75 bit/s/Hz per dimension.**

I. Introduction

While total capacity and capacity region are well–known, the theoretical limits of uncoded transmission are still not completely analyzed. As data delay is considered to be a problem for many applications, investigation of efficient low–delay transmission is not only of theoretical interest. A first step of insight into this problem will be given by understanding zero–delay (uncoded) multiple–access communication.

In the following we consider all K users to apply linear bandlimited modulation. Thus, the users' signal waveforms can be described by their Nyquist sample vectors (signature sequences) $\boldsymbol{b}_k, 1 \leq k \leq K$ of length N. For synchronous transmission disturbed by additive white Gaussian noise $\boldsymbol{n}$ we have $y_k = \sum_{i=1}^{K} \langle x_i \boldsymbol{b}_i + \boldsymbol{n}; \boldsymbol{b}_k \rangle \, \forall k$, in general [1]. Hereby, x_k and y_k are denoting i.i.d. symbols at transmitter and receiver site, respectively. The users are assumed to be not aware of the data of other users. Thus, applying standard methods of channel coding in user direction is not possible.

II. Non–Orthogonal Transmission

Non–orthogonal transmission, i.e. $\langle \boldsymbol{b}_i; \boldsymbol{b}_k \rangle \neq 0, k \neq i$, cannot break thru the performance limit of orthogonal transmission if total transmission rate $\Gamma = \frac{K}{N} \log_2(M)$ is less or equal to 1 bit/s/Hz per dimension, as it is optimal to choose $M =$ 2–ary modulation. In contrast to orthogonal transmission, non–orthogonal transmission allows to keep the use of binary modulation, even if total transmission rate exceeds the limit of 1 bit/s/Hz per dimension, as every user can apply more than one signature waveform. (For fractional rates time–sharing with other users is possible.)

By loss of orthogonality optimum multiuser detection becomes a np–complete problem [1] which is unfeasible in practice if the number of users is not very small. But optimum multiuser detection can be approximated very closely by (not np–complete) iterated soft–decision interference cancellation with adaptively optimized soft–cancellation (ISDIC–OSC), if the number of users is sufficiently large [2].

The bit error rate versus normalized signal–to–noise ratio E_b/N_0 for transmission with randomly chosen signature waveforms detected by the ISDIC–OSC algorithm is investigated

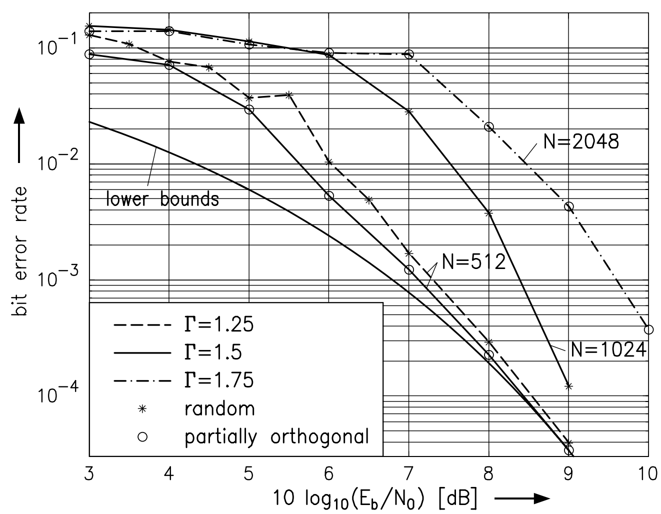

Fig. 1: Bit error rate of ISDIC–OSC [2] vs. signal–to–noise ratio.

by means of simulation and compared to the lower bound[1]

$$\mathrm{BER} \geq \max \left\{ \mathrm{Q}\left(\sqrt{2\frac{E_\mathrm{b}}{N_0}}\right); \mathrm{h}^{-1}\left(1 - \frac{1}{2\Gamma}\log_2\left(1 + 2\Gamma\frac{E_\mathrm{b}}{N_0}\right)\right)\right\}$$

with $\mathrm{Q}(\cdot)$ and $\mathrm{h}^{-1}(\cdot)$ denoting the complementary unit cumulative Gaussian distribution and the inverse of the binary entropy function within $[0; \frac{1}{2}]$, respectively. As one can observe from Fig. 1, the loss to the performance bound is almost very small in the high E_b/N_0 range.

The asymptotic power loss from 4PAM to 2PAM is $10\log_{10}(5/2) \approx 4$ dB for the gain of one additional bit/s/Hz being able to be transmitted. Thus, for $1 < \Gamma < 2$ the trade–off between power and bandwidth efficiency is roughly described by the need of 4 dB/bit. Applying this rule for comparison, random choice of signature waveforms is definitely preferable.

III. Partial Orthogonality

The essential conclusion of Sec. II is to avoid non–binary modulation. This implies pairwise non–orthogonality of *some*, but *not all* signature waveforms. Thus, to transmit with rate $\Gamma > 1$ we shall choose N signature waveforms orthogonal to each other and the remaining $N(\Gamma - 1)$ ones in a different manner, e.g. randomly. Fig. 1 shows, that this concept is indeed superior to that one discussed in Sec. II.

References

[1] S. Verdú, "Minimum probability of error for asynchronous Gaussian multiple-access channels," *IEEE Trans. Inf. Th.*, vol. 32, pp. 85–96, 1986.

[2] R. Müller, J. Huber, "Iterated soft-decision interference cancellation for CDMA" *Digital Wireless Communications*, Luise and Pupolin eds., Springer, London, U.K., 1998.

[1] The bound holds, as the sum of capacities of N virtual binary symmetric sub–channels cannot exceed the overall total capacity.