On the Multi-User Interference Study for Ultra Wideband Communication Systems in AWGN and Modified Saleh-Valenzuela Channel

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Abstract- This paper studies the effects of multiple access interference (MAI) for Ultra Wideband (UWB) systems in AWGN and multipath fading channels. Time hopping (TH) and direct sequence (DS) based UWB spreading approaches are performed utilizing binary pulse amplitude modulation (PAM) and pulse shape modulation (PSM). Both the possibilities of having synchronous and asynchronous users have been taken into account. In fading channel case, different coherent and non-coherent detection methods have been considered. Simulated performance results are depicted for the above mentioned UWB systems when a variable number of equally powered users are operating in the channel. Results show that in both AWGN and fading channel the DS system performance shows sensibly different results in synchronous and asynchronous case. This is due to the continuous time transmission of the different users. This problem does not occur in systems using TH spreading since the different users are less overlapped in time, due to the spreading approach used. In the fading channel, TH systems show a general higher performance loss in all cases compared to DS, in contrast to what happens in AWGN case. That is, the allocation of the TH codes creates a higher interfering effect due to MAI in presence of multipath fading. In general, DS-based systems outperform the corresponding TH ones.

1. Introduction

The presence of multiple signals transmitting at the same time is a typical source of interference for wireless signals. Going under the name of multiple access interference, its effect in UWB transmission depends on the particular modulation technique and spreading approach adopted.

The MAI signals implemented for our study are supposed to have the same structure (pulse type, spreading technique and modulation) of the user of interest. Both synchronous and asynchronous access is studied. The performance measure in the study is bit-error-rate (BER) vs. signal-to-noise ratio (SNR). Several modulation schemes are used in order to compare their characteristics in a multi-user transmission environment.

2. System Model

2.1 Modulation and spreading

Several possible UWB communication systems have been considered in this paper. Some common parameters are chosen in order to cope with the restrictions introduced by FCC [1] and CEPT [2] regulations, such as are the particular pulse waveform in the channel and the length of the UWB pulse (T_p = 0.5 ns). For an overview upon the UWB spectra and regulations refer to [3].

Two different spreading approaches are implemented for the study: time hopping (TH) and direct sequence (DS) [3]. The pseudo-noise (PN) codes used in the simulations for the signal spreading are optimized Gold sequences of length 127 obtained using the minimum mean-square cross-correlation cross-optimal (MSQCC/CO) criterion [4]. Two different binary modulation schemes have been adopted. Pulse shape modulation (PSM) is based on the transmission of two different orthogonal waveforms which are, in our case, the 4^{th} and the 5^{th} derivatives of the Gaussian pulse. Binary pulse amplitude modulation (PAM) is an antipodal scheme which uses only the 4^{th} derivative [3].

2.2 MAI approach

In this study, MAI is modelled as coming from other UWB users having the same basic signal characteristics as the user of interest, but using different spreading codes. The received signal $r(t)$ can be written as

$$r(t) = s^{(1)}(t) \otimes h^{(1)}(t) + i(t) + n(t)\,, \qquad (1)$$

where $s^{(1)}(t)$ is the signal of interest at the output of the receiving antenna, $h^{(1)}(t)$ represents the impulse responses of the channel, $n(t)$ is the Gaussian noise and $i(t)$ is the interference coming from the other $N_U - 1$ users, defined as

$$i(t)=\sum_{n=2}^{N_U} s^{(n)}(t-\tau_n)\otimes h^{(n)}(t)\,, \tag{2}$$

where $h^{(n)}(t)$, $n = 2,..., N_U$ are the impulse responses of the channel the N_U-1 users are passing through, and τ_n is the delay of the arrival time of the n^{th} user from the user of interest, for which we have assumed $\tau_1 = 0$. The transmitted signals $s^{(n)}(t)$, $n = 1,..., N_U$ can be written, in the assumption of DS-PSM modulation, as

$$s^{(n)}(t)=\sum_{k=-\infty}^{+\infty}\sum_{j=1}^{N_p} w_{d_k^{(n)}}\left(t-kT_d-jT_c\right)\left(c_p\right)_j^{(n)}\,, \tag{3}$$

where

- $w(t)$ is the used pulse waveform
- $(c_p)_j$ is the j-th chip of the PN code, generated using bipolar PN sequences with values {−1, +1}
- d_k is the k-th data bit chosen which, in PSM case, defines also the pulse waveform to be transmitted
- N_p represents the number of pulses per databit
- T_c is the chip length
- T_d is the data bit length defined as $T_d = N_p T_c$.

The system is characterized by single-user detection. The interfering users are considered either synchronous or asynchronous with the user of interest. In the synchronous case, the receiver is synchronized with all the other users in order to receive all of them at the same time instant (frame synchronization). In the asynchronous case, the interfering signals arrive at the receiver with resolution of a time sample. The asynchronism is performed between every interfering user and the user of interest, and among the interfering users as well. In order to have a good average for the evaluation of the results, the transmission delays of the other signals are randomly changed during the simulation.

Regardless of the chosen scheme, each user goes through a different channel realisation, that is

$$h^{(n)}(t)\neq h^{(m)}(t),\ \forall\ \ n,m=1,...,N_u,\ \ \ n\neq m\,. \tag{4}$$

Each MAI user has the same power of the user of interest, leading to the assumption of perfect power control. This system concept corresponds to the situation where, e.g., one access point is serving several users that are operating at the same time in the same network. Furthermore, perfect synchronization is assumed between the signal of interest and the correlator at the receiver.

2.3 Channel model

The UWB system performances are studied using the modified Saleh-Valenzuela (SV) channel model [5] adopted by the IEEE802.15.3 working group. Out of the four different SV-models, two have been selected to present the propagation environments; SV1 which is a line-of-sight (LOS) model for distances between 0-4 m, and SV3 that is a non-line-of-sight (NLOS) model for distances between 4-10 m. The RMS delay spreads for SV1 and SV3 are 5.28 ns and 14.28 ns, respectively.

2.4 Detection techniques

In case of multipath fading channel, different detection techniques have been tested. For PAM and PSM maximal ratio combining (MRC) and equal gain combining (EGC) have been chosen as coherent techniques. Being PSM an orthogonal modulation, also two non-coherent techniques have been taken into account: absolute combining (AC) and absolute combining with power estimation (AC+PE). Non-coherent approaches cannot be used with PAM, due to the fact that the polarity of the pulse is required for the detection of the databit. The number of selective Rake branches used at the receiver is optimized for single user case for different receiver algorithms and modulation schemes, as already studied in [6].

3. Simulation Results

The simulations have been performed for several UWB system configurations (physical layers) using different numbers of interfering users in order to have a varying cumulative power for MAI. The processing gain (PG) has been selected to be 127 (21 dB), that is, the same length of the Gold codes. This leads to an approximate data rate of 16 Mbps. It is important to say that for TH systems the match between PG and length of the code is of no particular importance, since in this approach the spreading sequence gives information of the position of each pulse inside every sub-frame. Then, the cross-correlation properties of the codes have no direct effect on the degradation of the signal. Both AWGN and modified SV fading channel have been used for performance evaluation. Due to paper length constraints, only some of the results will be shown in the figures, although a comprehensive discussion will be given in the following sections.

3.1 AWGN results

Fig. 1 shows BER results as a function of SNR for PAM in DS spreading for the synchronous and asynchronous approach with different number of active users in the system. The asynchronous systems outperform the synchronous ones of approximately 1 and 2 dB in the 3-user and 10-user case, respectively. This can be justified by the correlation properties of the Gold codes [4], which worsen the performance of the system when all the users are aligned.

In Fig. 2, the results for UWB TH-PAM are depicted. In this case, synchronous and asynchronous systems show the same performance, differently from the DS case. As a matter of fact, in TH approach, a data bit is composed by a sequence of UWB pulses separated by silent time gaps. Then, the perfect alignment of the users is not going to worsen the performance, since the separation of the single pulses composing a single data bit is given by the spreading code, resulting in a real low value of the average cross-correlation.

For PSM, the 4th and 5th derivatives of the Gaussian pulse are used for transmitting data bit "0" and "1", respectively. The other system assumptions remain the same as presented in the previous cases. In both TH- and DS-PSM, the presence of two interfering users does not affect the studied link performance. When the number of interfering users increases, one can notice a common behaviour in the performance of both concepts. For the same number of users in the system, asynchronous DS-PSM gives the best performance and the corresponding synchronous system performs the worst. TH-concept is located in the middle of the previous ones, not showing any difference between synchronous and asynchronous case, as previously said in PAM case.

Table 1 shows the required SNR values for 10 and 30 user cases to reach the 10^{-3} BER level when different modulation schemes are used.

Table 1. Required SNR values for different physical layers to achieve 10^{-3} BER-level for asynchronous (a) and synchronous (s) case in AWGN channel.

a/s [dB]	TH-PAM	DS-PAM	TH-PSM	DS-PSM
10 users	7.7 / 7.7	7.6 / 9.8	8.3 / 8.3	8.0 / 10.4
30 users	10.6 / 11.1	10.3 / -	13.7/ 14.7	10.6 / -

3.2 SV results

Simulation results in SV model have been produced for different possible configurations, depending on the channel type, detection technique, synchronicity or asynchronicity of the system. Refer to [6] for more information on detection techniques.

As in AWGN case, the difference between DS-PAM in asynchronous and synchronous case (Fig. 3 and 4, for SV1, Fig. 5 and 6 for SV3) is still present. The difference in performance is furthermore increased, as depicted in Table 2. On the other hand, TH-PAM (Fig. 7 and 8) keeps the same performance behaviour in synchronous and asynchronous approach, although it shows worse results than DS-PAM. Figs. 9 and 10 show the results for DS-PSM for synchronous and asynchronous case, respectively, using non-coherent detection systems.

Generally, DS-PSM (Figs. 9 and 10) does not give any reasonable loss in performance passing from asynchronous to synchronous, as we would expect from the AWGN results and from the behaviour of the above mentioned PAM in SV channel. As it can be seen in Table 2, while DS-PAM loses 3 dB in MRC case, no loss is noticed for DS-PSM in neither coherent nor non-coherent schemes. The same trend is seen in SV3, although a small difference leading to better performance of asynchronous schemes is noticed for a high loaded system (30 to 60 users).

The TH-PSM behaviour does not differ sensibly from the TH-PAM already depicted. In TH we have worse performance than in DS systems, which case are more evident in PSM case. In coherent systems, using MRC decoding for a target BER of 10^{-2} we have, in single user case, an E_b/N_0 of 8 and 11 dB for PAM and PSM, respectively. Thus, the difference between this modulation schemes is exactly the same in SV and AWGN channels.

No big discrepancies have been noticed when comparing the performance of the coherent and non-coherent schemes. Keeping fixed all the other parameters (synchronicity and channel type) we have noticed that in all cases they give the same relative results. From best to worse, the schemes are MRC and EGC, AC+PE and AC, also matching the results obtained in [6].

Finally, it is interesting to notice that TH-PAM systems show a general higher performance loss in all cases compared to DS-PAM. This is in contrast to what was happening in AWGN case, where the results give similar values, at least for the asynchronous case. The same behaviour can also be noticed in TH-PSM results. Thus, this loss must be caused by both the particular way of allocating the TH codes and the intersymbol interference, which in a multipath fading channel creates a high interference among the different users.

Table 2. Required SNR values for different physical layers to achieve 10^{-2} BER-level for asynchronous (a) and synchronous (s) case in SV-1 channel.

a/s [dB]	DS-PAM	DS-PSM
10 users MRC	9/12	15/15
10 users EGC	10.5/15	17.5/17.5

4. Conclusions

This paper studies the ultra wideband link system performance in the presence of multi-user interference. The MAI users are modelled using exactly the same signal structure that is used in the link under interest. Also, the powers of the interfering users are equal.

Results show that in both AWGN and fading channel the DS systems performance shows sensibly different results in case we choose synchronous or asynchronous transmission. This is due to the correlation properties of the chosen codes. This problem does not occur in systems using TH spreading since the different users are less overlapped in time. In this case, then, the synchronism of the user does not sensibly worsen the performance, although, the presence of multipath components lowers down this gain.

In the fading channel TH systems show a general high performance loss in all cases compared to DS, in contrast to what happens in AWGN case, where results are closer. Thus, we can conclude that the allocation of the TH codes creates a higher interference among the different users in a multipath fading channel, leading to a challenge in the optimization of the spreading codes in such environment. If comparing the corresponding TH and DS concepts, DS gives the better results.

5. Acknowledgements

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6. References

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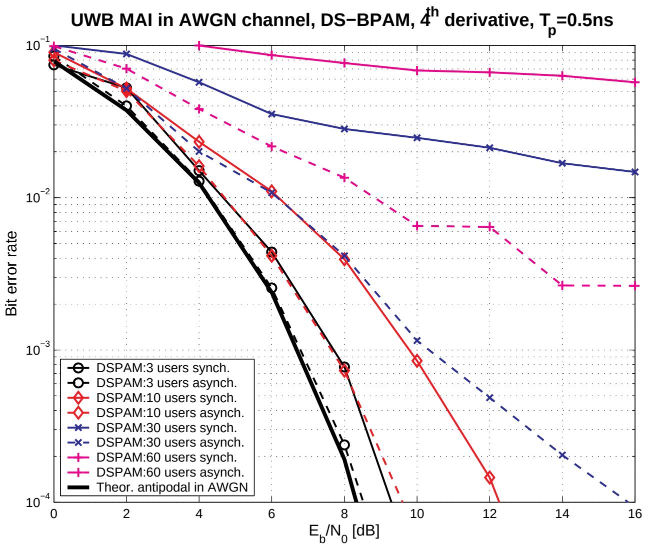

Figure 1. BER in AWGN channel for DS-PAM.

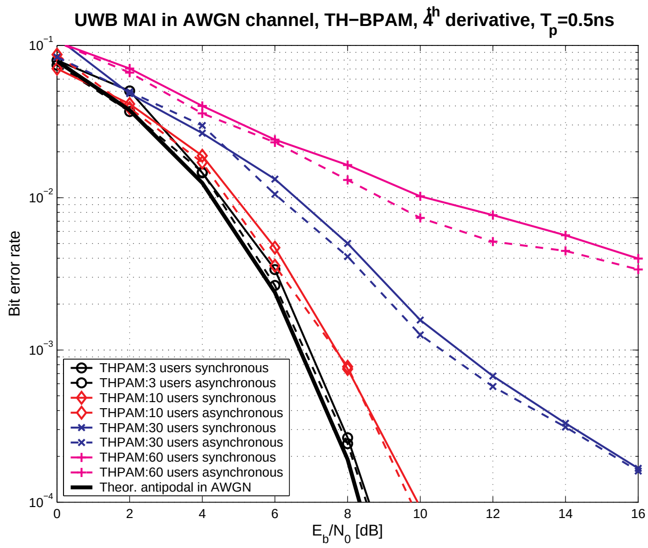

Figure 2. BER in AWGN channel for TH-PAM.

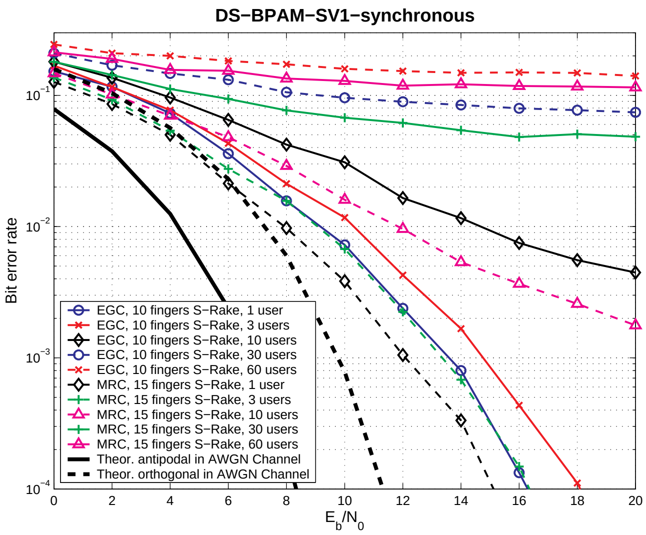

Figure 3. BER in SV-1 channel for DS-PAM: coherent systems, synchronous case.

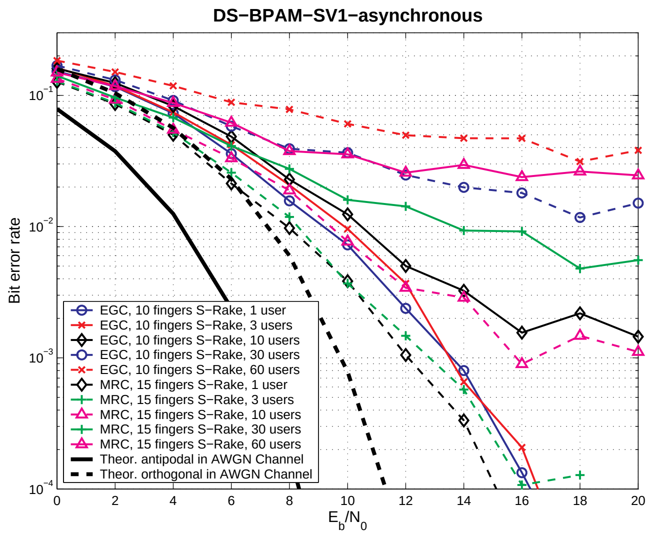

Figure 4. BER in SV-1 channel for DS-PAM: coherent systems, asynchronous case.

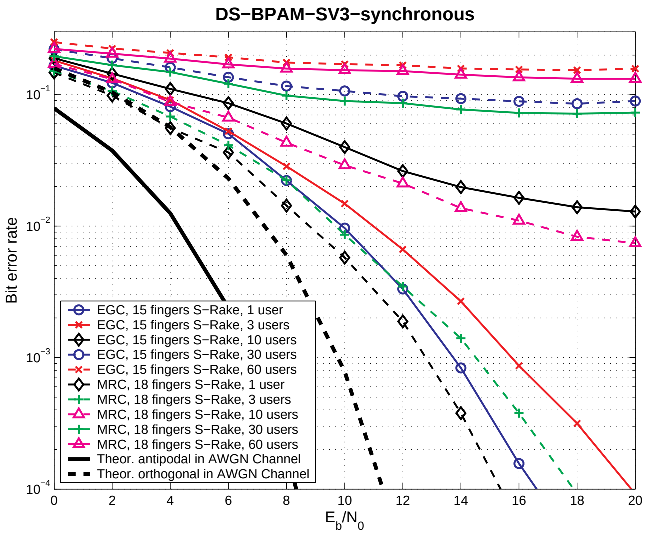

Figure 5. BER in SV-3 channel for DS-PAM: coherent systems, synchronous case.

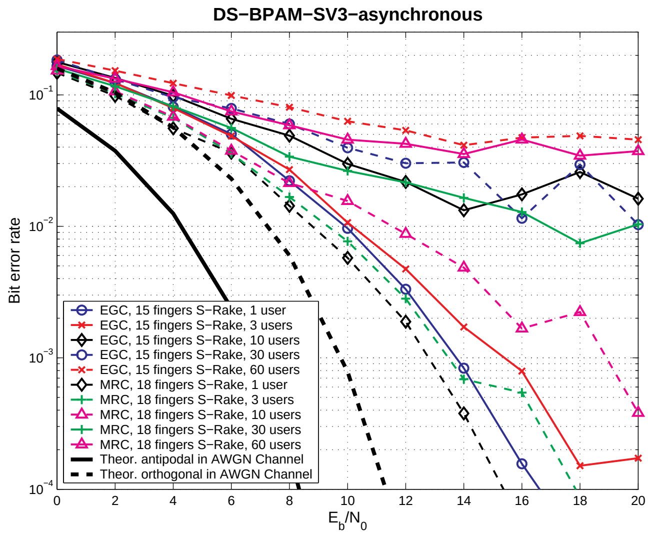

Figure 6. BER in SV-3 channel for DS-PAM: coherent systems, asynchronous case.

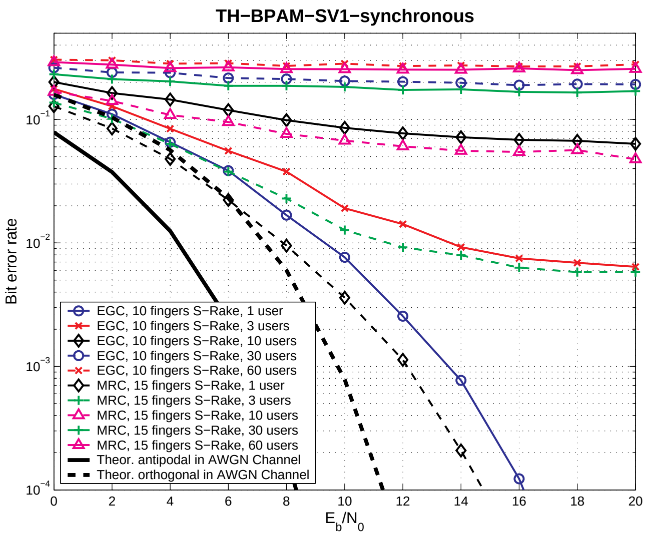

Figure 7. BER in SV-1 channel for TH-PAM: coherent systems, synchronous case.

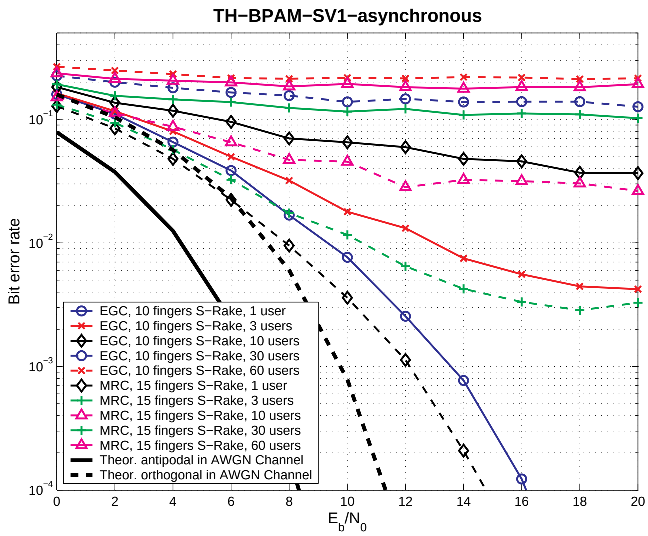

Figure 8. BER in SV-1 channel for TH-PAM: coherent systems, asynchronous case.

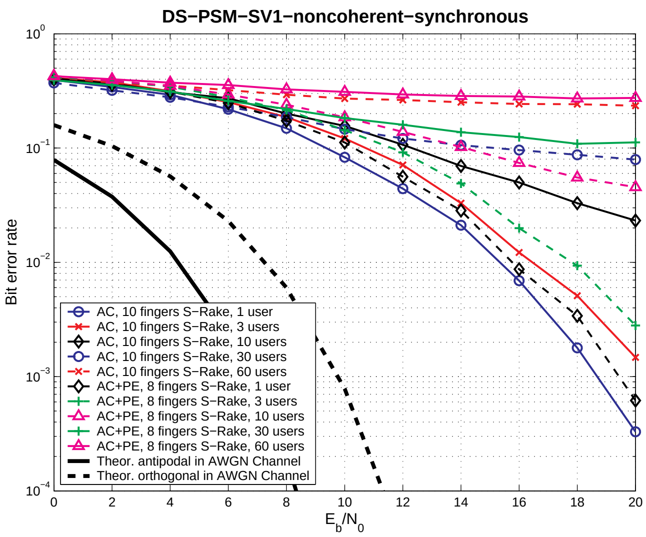

Figure 9. BER in SV-1 channel for DS-PSM: non-coherent systems, synchronous case.

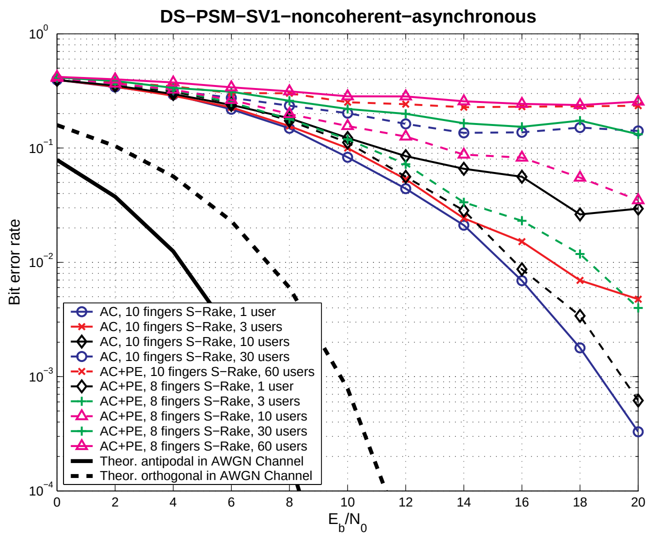

Figure 10. BER in SV-1 channel for DS-PSM: non-coherent systems, asynchronous case.