# A NOVEL GENERATIVE MODEL FOR THE CHARACTERIZATION OF DIGITAL WIRELESS CHANNELS WITH SOFT DECISION OUTPUTS


Cheng-Xiang Wang[1,2]
[1]Faculty of Engineering and Science
Agder University College
Grooseveien 36, N-4876 Grimstad
Norway

Wen Xu[2]
[2]Department of Mobile Phone Development
Siemens AG
Grillparzerstr. 10-18, D-81675 Munich
Germany

Matthias Pätzold[1]
[1]Faculty of Engineering and Science
Agder University College
Grooseveien 36, N-4876 Grimstad
Norway



## ABSTRACT

To speed up simulations for the performance evaluation of error control strategies, there is a need of developing error models for digital wireless channels. In this paper, uncoded enhanced general packet radio service (EGPRS) systems with typical urban (TU) channels and rural area (RA) channels are adopted to provide target soft error sequences. A realistic deterministic process based generative model (DPBGM) is then proposed for the modeling of the underlying digital channels with soft decision outputs. Simulation results demonstrate that the proposed DPBGM can approximate very well the statistical behavior of the target soft error sequences with respect to the soft error-free run distribution (SEFRD), soft error cluster distribution (SECD), soft error burst distribution (SEBD), soft error-free burst distribution (SEFBD), block error probability distribution (BEPD), and soft decision symbol distribution (SDSD). An attractive advantage of the suggested model is its capability to generate also hard bit error sequences by using a quantizer. The verification made by the simulated frame error rates (FERs) and residual bit error rates (RBERs) of coded EGPRS systems further confirms the reliability of the novel DPBGM.


## I. INTRODUCTION

In digital wireless communication systems, the effect of the channel impairments tends to introduce distortion into the transmission process in such a way that errors are grouped together in bursts. Thus, it is necessary to employ proper error control strategies in order to obtain the required quality of service. For the effective "control" of errors through coding techniques, the study of the statistical structure in error occurrences is a prerequisite. Error models for characterizing burst error statistics have therefore been developed, based on either a descriptive approach [1] or a generative approach [2]. A generative model allows a fast generation of long error sequences compared with a descriptive model, which often obtains target error sequences by computer simulations of the overall communication link.

In the literature, most of the generative models [2–6] can only simulate the occurrence of binary or hard bit errors. It is widely accepted that the use of soft decision decoding algorithms can greatly improve the performance of channel coding schemes. In this framework, the hard bit generative models become useless. Recently, hidden Markov models [7–9] and chaos models [9] were presented for the simulation of digital wireless channels with soft decision outputs. In [10–14], sum-of-sinusoids based deterministic processes [15] were successfully applied to develop generative models capable of producing binary error sequences. The aim of this paper is to develop a realistic DPBGM which allows us to generate soft error sequences with desired burst error statistics. It is important to mention that the proposed DPBGM is such a general model that it also has the capability to produce binary error sequences by simply adding a quantizer. The accuracy of the suggested modeling approach is further validated by the close agreement of the performance simulations of coded EGPRS systems obtained from the target and generated error sequences.

## II. THE DESCRIPTIVE MODEL AND RELEVANT BURST ERROR STATISTICS

In this paper, EGPRS systems were adopted as the reference transmission systems. The underlying digital channels all include a Gaussian minimum shift keying (GMSK) modulator, a propagation channel with co-channel interference, a GMSK demodulator, and a Viterbi equalizer, which delivers 4-bit soft decision outputs. The transmissions were carried out in time-division multiple access (TDMA) bursts of 116 bits with a transmission rate of $F_s$ =270.8 kb/s. Let us refer to the deployed propagation channels as NAMEx, where NAME is the name of the particular channel, and x is the vehicle speed in km/h [16]. Also, no frequency hopping (NFH) or ideal FH (IFH) can be used. Here, IFH implies perfect decorrelation between TDMA bursts [16]. In this paper, four propagation channel profiles as specified in [16] will be considered, namely, TU3 IFH, TU3 NFH, TU50 NFH, and RA275 NFH. The target soft error sequences of length $N_t = 15 \times 10^6$ were produced at carrier-to-interference ratios (CIRs) of 5 dB, 7 dB, 8 dB, 9 dB, 11 dB, 13 dB, 15 dB, 17 dB, 19 dB, 21 dB, 23 dB, and 25 dB. A soft error sequence is represented here by a sequence of integers ranging from -8 to +7. A negative integer indicates an error bit, while a nonnegative integer stands for a correctly received bit. The absolute value of an integer shows the reliability of the decision.

In order to make statistical assessments of soft error sequences, some new terms and relevant burst error statistics pertaining to soft decision outputs have to be introduced. For reasons of consistency, we will consider the following terms for soft error sequences analogous to the definitions used for hard bit error sequences [13, 14]. A soft gap is defined as a string of consecutive nonnegative integers between two negative integers, having a length equal to the number of nonnegative integers. A soft error cluster is a region where the negative integers (errors) occur consecutively and has a length equal to the number of negative integers. A soft error-free burst is defined as a sequence of nonnegative integers with a length of at least $\eta$ bits, where $\eta$ is a positive integer. A soft error burst is a sequence of integers beginning and ending with a negative integer, and separated from neighboring soft error bursts by soft error-free bursts. With the above terms in mind, the following burst error statistics will be investigated:

1) $P(m_+)$: the SEFRD, which is the probability that a negative integer is followed by at least $m_+$ nonnegative integers.
2) $P(m_-)$: the SECD, which is the probability that a nonnegative integer is followed by $m_-$ or more negative integers.
3) $P_{EB}(m_e)$: the SEBD, which is the cumulative distribution function (CDF) of soft error burst lengths $m_e$.
4) $P_{EFB}(m_{\bar{e}})$: the SEFBD, which is the CDF of soft error-free burst lengths $m_{\bar{e}}$.
5) $P(m,n)$: the BEPD, which is the probability that a block of $n$ bits will contain at least $m$ errors.
6) $P(S)$: the SDSD, which is the CDF of soft decision symbols $S \in [-8,+7]$.

To avoid a bit-by-bit processing of a soft error sequence, it is sensible to compress the error data by listing the successive soft error burst lengths and soft error-free burst lengths. Consequently, a soft error burst recorder $\mathbf{EB}_{rec}$ and a soft error-free burst recorder $\mathbf{EFB}_{rec}$ are obtained. Here, $\mathbf{EB}_{rec}$ is a vector which keeps a record of successive soft error burst lengths, while $\mathbf{EFB}_{rec}$ records successive soft error-free burst lengths. Let us denote the minimum value as $m_{B1}$ and the maximum value as $m_{B2}$ in $\mathbf{EB}_{rec}$. By analogy, the minimum value and the maximum value in $\mathbf{EFB}_{rec}$ are denoted as $m_{\bar{B}1}$ and $m_{\bar{B}2}$, respectively. For the derivation of the generative model in Section III, it is convenient to further define the following quantities:

1) $\mathcal{N}_{EB}$: the total number of soft error bursts, which equals the number of entries in $\mathbf{EB}_{rec}$.
2) $\mathcal{N}_{EFB}$: the total number of soft error-free bursts, which equals the number of entries in $\mathbf{EFB}_{rec}$.
3) $N_{EB}(m_e)$: the number of soft error bursts of length $m_e$ in $\mathbf{EB}_{rec}$. Apparently, $\sum_{m_e=m_{B1}}^{m_{B2}} N_{EB}(m_e) = \mathcal{N}_{EB}$ holds.
4) $N_{EFB}(m_{\bar{e}})$: the number of soft error-free bursts of length $m_{\bar{e}}$ in $\mathbf{EFB}_{rec}$. Similarly, $\sum_{m_{\bar{e}}=m_{\bar{B}1}}^{m_{\bar{B}2}} N_{EFB}(m_{\bar{e}}) = \mathcal{N}_{EFB}$ holds.
5) $\mathcal{R}_B$: the ratio of the mean value $M_{EB}$ of soft error burst lengths to the mean value $M_{EFB}$ of soft error-free burst lengths, i.e., $\mathcal{R}_B = M_{EB}/M_{EFB}$.
6) $\mathbf{EBS}_i$: a vector which records soft decision symbols corresponding to each entry of $\mathbf{EB}_{rec}$. Clearly, $i = 1, 2, \ldots, \mathcal{N}_{EB}$. Note that $\mathbf{EBS}_i$ indicates the infrastructure of the corresponding soft error burst.
7) $\mathbf{EFBS}_j$: a vector which records soft decision symbols corresponding to each entry of $\mathbf{EFB}_{rec}$. Similarly, $j = 1, 2, \ldots, \mathcal{N}_{EFB}$.

## III. The Generative Model

It is commonly accepted that the second order statistics of fading envelope processes are closely related to the statistics of burst errors. This suggests the potential of developing generative models by using fading processes.

The idea of the proposed generative model is to derive directly from a deterministic process a soft error burst length generator and a soft error-free burst length generator. However, the employed deterministic process $\tilde{\zeta}(t)$ has to be properly parameterized and sampled with a certain sampling interval $T_A$. The sampled deterministic process $\tilde{\zeta}(kT_A)$, where $k$ is a nonnegative integer, is then followed by a threshold detector. Soft error-free bursts are produced at the model's output if the level of $\tilde{\zeta}(kT_A)$ is above a given threshold $r_{th}$. The lengths of the generated soft error-free bursts equal the numbers of samples in the corresponding inter-fade intervals of $\tilde{\zeta}(kT_A)$. On the other hand, when the level of $\tilde{\zeta}(kT_A)$ falls below $r_{th}$, then this implies the occurrence of soft error bursts. The soft error burst lengths equal the numbers of samples in the corresponding fading intervals of $\tilde{\zeta}(kT_A)$. Consequently, a soft error burst length generator $\widetilde{\mathbf{EB}}_{rec}$ and a soft error-free burst length generator $\widetilde{\mathbf{EFB}}_{rec}$ are obtained. For the generative model, we use similar notations to those introduced in Section II by simply putting the tilde sign on all affected symbols, i.e., we write $\tilde{m}_{B1}$, $\tilde{\mathcal{N}}_{EFB}$, $\tilde{N}_{EB}(m_e)$, etc.

### A. The Parametrization of the Deterministic Process

We determine the parameters of the deterministic process as follows. The level-crossing rate (LCR) $\tilde{N}_\zeta(r_{th})$ at the chosen threshold $r_{th}$ is adapted to the desired occurrence rate $R_{EB} = \mathcal{N}_{EB}/T_t$ of soft error bursts. Here, $T_t = N_t/F_s$ denotes the total transmission time of the reference transmission system. Also, the ratio $\tilde{\mathcal{R}}_B$ of the average duration of fades (ADF) $\tilde{T}_{\zeta_-}(r_{th})$ at $r_{th}$ to the average duration of inter-fades (ADIF) $\tilde{T}_{\zeta_+}(r_{th})$ at $r_{th}$ is fitted to the desired ratio $\mathcal{R}_B = M_{EB}/M_{EFB}$. Moreover, in order to detect most of the level crossings and fading intervals at deep levels, i.e., $r_{th} \ll 1$, the sampling interval $T_A$ must be chosen sufficiently small. Let us consider the following continuous-time deterministic process [15]

$$\tilde{\zeta}(t) = |\tilde{\mu}_1(t) + j\tilde{\mu}_2(t)| \qquad (1)$$

where

$$\tilde{\mu}_i(t) = \sum_{n=1}^{N_i} c_{i,n} \cos(2\pi f_{i,n} t + \theta_{i,n}) \ , \quad i = 1, 2 \ . \qquad (2)$$

In (2), $N_i$ defines the number of sinusoids, $c_{i,n}$, $f_{i,n}$, and $\theta_{i,n}$ are called the gains, the discrete frequencies, and the phases, respectively. By using the method of exact Doppler spread (MEDS) [15], the phases $\theta_{i,n}$ are considered as realizations of a random generator uniformly distributed over $(0, 2\pi]$, while $c_{i,n}$ and $f_{i,n}$ are given by $c_{i,n} = \sigma_0\sqrt{2/N_i}$ and $f_{i,n} = f_{max}\sin[\pi(n-1/2)/(2N_i)]$, respectively. Here, $\sigma_0$ is the square root of the mean power of $\tilde{\mu}_i(t)$ and $f_{max}$ is the maximum Doppler frequency.

When using the MEDS with $N_i \geq 7$, it has been shown in [15] that the LCR $\tilde{N}_\zeta(r)$ of $\tilde{\zeta}(t)$ is very close to the LCR $N_\zeta(r)$ of a Rayleigh process, which is given by

$$N_\zeta(r) = \sqrt{\frac{\beta}{2\pi}} p_\zeta(r) \ , \quad r \geq 0 \qquad (3)$$

where $\beta = 2(\pi\sigma_0 f_{max})^2$ and

$$p_\zeta(r) = \frac{r}{\sigma_0^2} \exp(-\frac{r^2}{2\sigma_0^2}) \ , \quad r \geq 0 \qquad (4)$$

denotes the Rayleigh distribution. It can also be shown that the ADF $\tilde{T}_{\zeta_-}(r)$ and the ADIF $\tilde{T}_{\zeta_+}(r)$ of $\tilde{\zeta}(t)$ approximate very well the desired quantities $T_{\zeta_-}(r)$ and $T_{\zeta_+}(r)$, respectively, of a Rayleigh process. They can be expressed as

$$T_{\zeta_-}(r) = \sqrt{\frac{2\pi}{\beta}} \frac{\sigma_0^2}{r} \left[ \exp(\frac{r^2}{2\sigma_0^2}) - 1 \right] , \quad r \geq 0 \tag{5}$$

$$T_{\zeta_+}(r) = \sqrt{\frac{2\pi}{\beta}} \frac{\sigma_0^2}{r} , \quad r \geq 0 . \tag{6}$$

Consequently, the ratio $\tilde{\mathcal{R}}_B$ can be determined as follows

$$\tilde{\mathcal{R}}_B = \frac{\tilde{T}_{\zeta_-}(r_{th})}{\tilde{T}_{\zeta_+}(r_{th})} \approx \frac{T_{\zeta_-}(r_{th})}{T_{\zeta_+}(r_{th})} = \exp(\frac{r_{th}^2}{2\sigma_0^2}) - 1 . \tag{7}$$

Now, the task at hand is to find a proper parameter vector $\mathbf{\Psi} = (N_1, N_2, r_{th}, \sigma_0, f_{max}, T_A)$ in order to fulfill the following conditions: $\mathcal{R}_B = \frac{T_{\zeta_-}(r_{th})}{T_{\zeta_+}(r_{th})}$ and $R_{EB} = N_\zeta(r_{th})$. To solve this problem, we first choose reasonable values for $N_1$, $N_2$, and $r_{th}$, e.g., $N_1 = 9$, $N_2 = 10$, and $r_{th} = 0.09$. Then, performing $\mathcal{R}_B = \frac{T_{\zeta_-}(r_{th})}{T_{\zeta_+}(r_{th})}$, $\sigma_0$ can be calculated according to the following expression

$$\sigma_0 = \frac{r_{th}}{\sqrt{2 \ln(1 + \mathcal{R}_B)}} . \tag{8}$$

With the help of the relation $R_{EB} = N_\zeta(r_{th})$, $f_{max}$ is given by

$$f_{max} = \frac{\mathcal{N}_{EB}}{\sqrt{\pi}\sigma_0 T_t p_\zeta(r_{th})} \tag{9}$$

which can finally be simplified as

$$f_{max} = \frac{\mathcal{N}_{EB}(1 + \mathcal{R}_B)}{T_t\sqrt{2\pi \ln(1 + \mathcal{R}_B)}} . \tag{10}$$

It is clear that $f_{max}$ is completely determined by $\mathcal{N}_{EB}, \mathcal{R}_B$, and $T_t$, but not influenced by $r_{th}$ and $\sigma_0$. Concerning the selection of the sampling interval $T_A$ for small values of $r_{th}$, the following value

$$T_A \approx \frac{4}{\sqrt{5\pi}} T_{\zeta_-}(r_{th}) \sqrt{-1 + \sqrt{1 + 10q_s/3}} \tag{11}$$

has turned out to be suitable [17]. Here, $q_s$ is a very small quantity determining the maximum measurement error of the LCR. This implies that the probability of undetectable level crossings at $r_{th}$ is not larger than $q_s$. Using (5), (11) can explicitly be expressed as

$$T_A \approx \frac{4\sigma_0[\exp(\frac{r_{th}^2}{2\sigma_0^2}) - 1]}{\sqrt{5\pi} r_{th} f_{max}} \sqrt{-1 + \sqrt{1 + 10q_s/3}} . \tag{12}$$

By using the obtained parameter vector $\mathbf{\Psi}$, a sampled deterministic process $\tilde{\zeta}(kT_A)$ is generated within the necessary time interval $[0, \tilde{T}_t]$, i.e., $kT_A \leq \tilde{T}_t$. Here, $\tilde{T}_t = T_t\tilde{N}_t/N_t$ with $\tilde{N}_t$ denoting the required length of the generated soft error sequence. The total numbers of the generated soft error busts $\tilde{\mathcal{N}}_{EB}$ and soft error-free bursts $\tilde{\mathcal{N}}_{EFB}$ can be estimated from $\tilde{\mathcal{N}}_{EB} = \lfloor \frac{\tilde{N}_t}{N_t} \mathcal{N}_{EB} \rfloor$ and $\tilde{\mathcal{N}}_{EFB} = \lfloor \frac{\tilde{N}_t}{N_t} \mathcal{N}_{EFB} \rfloor$, respectively. Here, $\lfloor x \rfloor$ stands for the nearest integer to $x$ towards minus infinity. In this manner, a soft error burst length recorder $\widetilde{\mathbf{EB}}_{rec}$ with $\tilde{\mathcal{N}}_{EB}$ entries and a soft error-free burst length recorder $\widetilde{\mathbf{EFB}}_{rec}$ with $\tilde{\mathcal{N}}_{EFB}$ entries are derived.

## B. *The Mappers*

We have found that the obtained recorders $\widetilde{\mathbf{EB}}_{rec}$ and $\widetilde{\mathbf{EFB}}_{rec}$ are not suitable to directly generate an acceptable SEBD and SEFBD, respectively. A proper procedure is required to adapt the distributions of soft error burst lengths and soft error-free burst lengths of the developed generative model to those of the descriptive model. Two mappers are therefore introduced, which map the lengths of the generated soft error bursts and soft error-free bursts to the corresponding desired lengths, as explained subsequently. The idea of the mappers is to modify $\widetilde{\mathbf{EB}}_{rec}$ and $\widetilde{\mathbf{EFB}}_{rec}$ in such a way that $\tilde{N}_{EB}(m_e) = N'_{EB}(m_e)$ and $\tilde{N}_{EFB}(m_{\bar{e}}) = N'_{EFB}(m_{\bar{e}})$ hold, respectively. Here, $N'_{EB}(m_e)$ equals $\lfloor \frac{\tilde{N}_t}{N_t} N_{EB}(m_e) \rfloor$ or $\lfloor \frac{\tilde{N}_t}{N_t} N_{EB}(m_e) \rfloor + 1$ for different soft error burst lengths $m_e$ in order to fulfill $\sum_{m_e=m_{B1}}^{m_{B2}} N'_{EB}(m_e) = \tilde{\mathcal{N}}_{EB}$. Similarly, $N'_{EFB}(m_{\bar{e}})$ equals $\lfloor \frac{\tilde{N}_t}{N_t} N_{EFB}(m_{\bar{e}}) \rfloor$ or $\lfloor \frac{\tilde{N}_t}{N_t} N_{EFB}(m_{\bar{e}}) \rfloor + 1$ for different soft error-free burst lengths $m_{\bar{e}}$ to satisfy $\sum_{m_{\bar{e}}=m_{\bar{B}1}}^{m_{\bar{B}2}} N'_{EFB}(m_{\bar{e}}) = \tilde{\mathcal{N}}_{EFB}$. Note that the resulting SEBD $\tilde{P}_{EB}(m_e)$ will be close to the desired SEBD $P_{EB}(m_e)$, since $\tilde{N}_{EB}(m_e)$ is almost proportional to $N_{EB}(m_e)$. Also, the resulting SEFBD $\tilde{P}_{EFB}(m_{\bar{e}})$ will match well the desired one $P_{EFB}(m_{\bar{e}})$.

Next, we will only concentrate on the procedure of properly modifying $\widetilde{\mathbf{EB}}_{rec}$. The same procedure applies also to $\widetilde{\mathbf{EFB}}_{rec}$. For each soft error burst length value $m_e$ ($m_{B1} \leq m_e \leq m_{B2}$), we first find the corresponding values $\ell^1_{m_e}$ and $\ell^2_{m_e}$ ($\tilde{m}_{B1} \leq \ell^1_{m_e},\ \ell^2_{m_e} \leq \tilde{m}_{B2}$) in $\widetilde{\mathbf{EB}}_{rec}$ to satisfy the following conditions

$$\sum_{l=\ell^1_{m_e}}^{\ell^2_{m_e}-1} \tilde{N}_{EB}(l) \quad < \quad N'_{EB}(m_e) \tag{13}$$

$$\sum_{l=\ell^1_{m_e}}^{\ell^2_{m_e}} \tilde{N}_{EB}(l) \quad \geq \quad N'_{EB}(m_e) . \tag{14}$$

Let us define

$$N_{\ell^2_{m_e}} = N'_{EB}(m_e) - \sum_{l=\ell^1_{m_e}}^{\ell^2_{m_e}-1} \tilde{N}_{EB}(l) . \tag{15}$$

Clearly, $\sum_{l=\ell^1_{m_e}}^{\ell^2_{m_e}-1} \tilde{N}_{EB}(l) + N_{\ell^2_{m_e}} = N'_{EB}(m_e)$ holds. This indicates that if we map all soft error burst lengths between $\ell^1_{m_e}$ and $\ell^2_{m_e} - 1$, while only $N_{\ell^2_{m_e}}$ soft error burst lengths of $\ell^2_{m_e}$ in $\widetilde{\mathbf{EB}}_{rec}$ to $m_e$, then $\tilde{N}_{EB}(m_e) = N'_{EB}(m_e)$ will be satisfied. Note that $\ell^1_{m_{B1}} = \tilde{m}_{B1}$ and $\ell^2_{m_{B2}} = \tilde{m}_{B2}$ hold. In summary, the mapper for the soft error burst length generator works as follows: if $l$ ($\ell^1_{m_e} \leq l < \ell^2_{m_e} - 1$) samples of the deterministic process are observed in a fading interval, then a mapping $l \to m_e$ is first performed and afterwards a soft error burst with length $m_e$ is generated.

## C. *The Generation of Error Sequences*

From the modified recorders $\widetilde{\mathbf{EB}}_{rec}$ and $\widetilde{\mathbf{EFB}}_{rec}$, a suitable approach is necessary to enable the generation of soft error sequences. For generating soft error bursts, we first have to find all vectors $\mathbf{EBS}_i$ corresponding to a soft error burst length $m_e$ in $\mathbf{EB}_{rec}$. Then, for all soft error bursts with the same length $m_e$ in $\widetilde{\mathbf{EB}}_{rec}$, we randomly choose an underlying infrastructure (soft decision symbols) from all possible vectors $\mathbf{EBS}_i$. With such a vector $\mathbf{EBS}_i$, a soft error burst of length $m_e$ is generated. By analogy, for the generation of soft error-free bursts, we need first to locate all vectors $\mathbf{EFBS}_j$ corresponding to a soft error-free burst length $m_{\bar{e}}$ in $\mathbf{EFB}_{rec}$. Afterwards, the underlying infrastructure of a soft error-free burst with the same length $m_{\bar{e}}$ in $\widetilde{\mathbf{EFB}}_{rec}$ is at random selected from all possible vectors $\mathbf{EFBS}_j$. In this manner, a soft error-free burst of length $m_{\bar{e}}$ is produced. The resulting soft error sequence is simply the combination of consecutively generated soft error bursts and soft error-free bursts. The block diagram of the obtained generative model is depicted in Fig. 1. We stress that, although the simulation set-up phase (determining the parameters and designing the mappers) of the DPBGM requires relatively long time, the simulation run phase (generation of soft error sequences) is fast. This is due to the fact that the DPBGM generates directly soft error burst and soft error-free burst lengths instead of bit sequences. Since a binary error sequence is simply a quantized version of a soft error sequence, the suggested DPBGM in Fig. 1 with a quantizer will generate binary error sequences. Therefore, this novel DPBGM can be considered as a general model which includes the previously presented DPBGM in [14] for generating only binary error sequences as a special case.

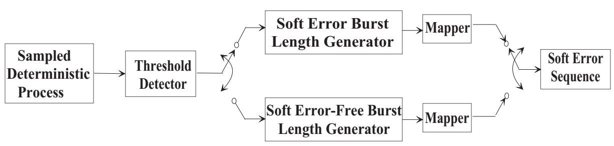


Fig. 1. The block diagram of the proposed DPBGM.

## IV. Simulation Results and Discussions

For brevity of presentation, only the simulation results for the EGPRS system with the TU3 IFH channel will be presented in this section. Other results are omitted here. Soft error sequences of length $\tilde{N}_t = 20 \times 10^6$ were generated by using the proposed DPBGM. The bit error rates (BERs), the SEFRDs, the SECDs, the SEBDs and SEFBDs with $\eta = 800$, the BEPDs with blocks of 116 bits ($n$=116) per TDMA burst, and the SDSDs calculated from the generated error sequences were compared to those of the target error sequences. Fig. 2 depicts the simulated BERs of the uncoded EGPRS system with the TU3 IFH channels obtained from both the descriptive model and the DPBGM. As examples, the CIRs of 9 dB and 19 dB were selected, which correspond to the typical BERs of $5.3841 \times 10^{-2}$ and $4.7936 \times 10^{-3}$, respectively. In case of CIR=9 dB, the ratio $\mathcal{R}_B = 0.73865$ and $\mathcal{N}_{EB} = 4263$ soft error bursts were obtained. With $q_s = 0.01$ and $\tilde{T}_t = 73.846$ s, the chosen parameter vector for the corresponding deterministic process was $\mathbf{\Psi} = (9, 10, 0.09, 0.0856, 71.785$ Hz, 0.71593 ms). For CIR=19 dB, $\mathcal{R}_B = 0.093488$ and $\mathcal{N}_{EB} = 2006$ hold. The chosen parameter vector was $\mathbf{\Psi} = (9, 10, 0.09, 0.21288, 52.841$ Hz, 0.30635 ms). Figs. 3–5 show the corresponding SECDs, the BEPDs, and the SDSDs of the descriptive model and the DPBGM, respectively. The results for the SEFRDs, SEBDs, and SEFBDs of both models are not shown here since they are very close to each other. As expected, all these curves for the DPBGM have very excellent agreements with the target ones.

To further illustrate the accuracy of the DPBGM, we applied it to the performance evaluation of a coded EGPRS system with the TU3 IFH channel. The modulation and coding scheme 3 (MCS3) [16] was chosen as a practical example. Fig. 6 illustrates the resulting radio link control (RLC) data FERs of the coded EGPRS system with hard and soft decoding algorithms obtained from the descriptive model and the DPBGM. Here, one frame includes 4 TDMA bursts. It is clear that the FERs obtained from the DPBGM coincide very well with those obtained from the descriptive model. The same conclusion holds for the RLC data RBERs, which are demonstrated in Fig. 7. The RBER is the ratio of the number of errors detected over the frames defined as “good” to the number of transmitted bits in the “good” frames [16]. It is worth mentioning that the obtained DPBGM has also been successfully applied to the EGPRS systems with the TU3 NFH, TU50 NFH, and RA275 NFH channels. All the simulation results are quite satisfactory. In this manner, the reliability of the proposed DPBGM, as well as its applicability to coding systems evaluation, is validated.

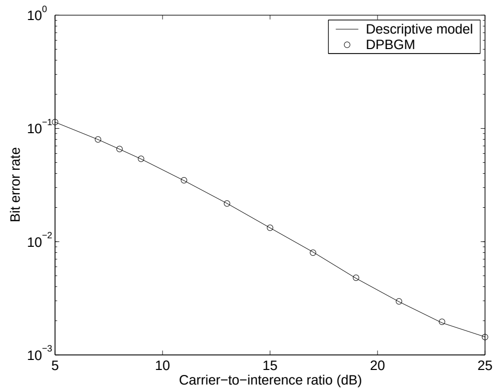


Fig. 2: The BERs of the uncoded EGPRS system with the TU3 IFH channel obtained from the descriptive model and the DPBGM.

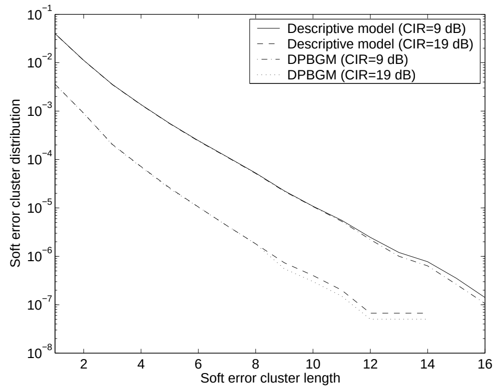


Fig. 3: The soft error cluster distributions of the descriptive model and the DPBGM (CIR=9 dB and CIR=19 dB).

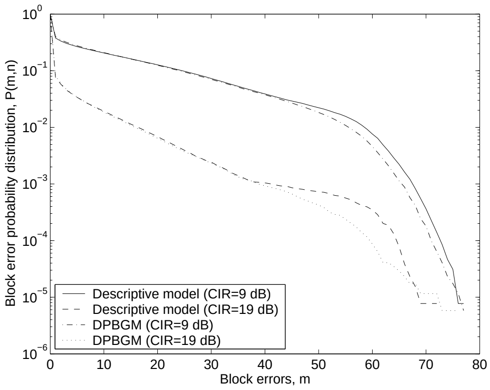


Fig. 4: The block error probability distributions of the descriptive model and the DPBGM (CIR=9 dB and CIR=19 dB).

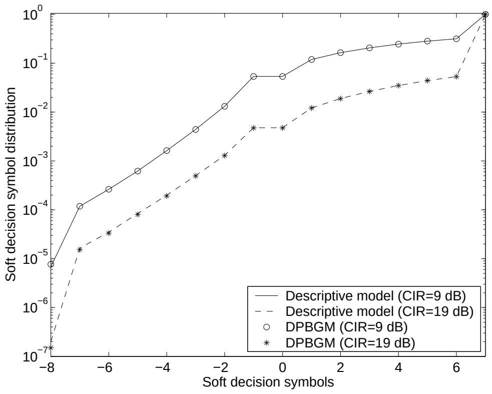


Fig. 5: The soft decision symbol distributions for the descriptive model and the DPBGM (CIR=9 dB and CIR=19 dB).

## V. Conclusions

In this paper, we have shown that deterministic processes are applicable to the modeling of digital wireless channels with soft decision outputs. The developed fast soft bit generative model is simply a properly parameterized and sampled deterministic process followed by a threshold detector and two parallel mappers. With an additional quantizer, the proposed DPBGM is also capable of generating hard bit error sequences. The reliability of the suggested DPBGM is confirmed by the excellent match of all interested burst error statistics to those of the underlying descriptive model, as well as performance simulations of coded EGPRS systems obtained from the target and generated error sequences.

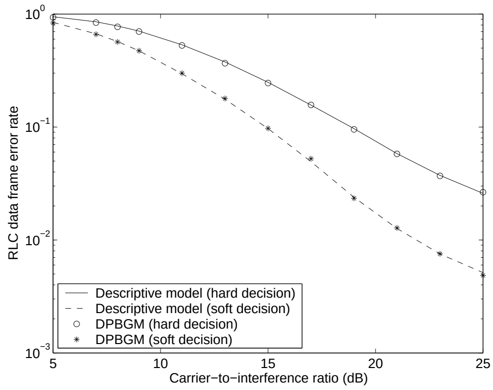


Fig. 6: The RLC data FERs of the coded EGPRS system with hard and soft decision decoding algorithms obtained from the descriptive model and the DPBGM.

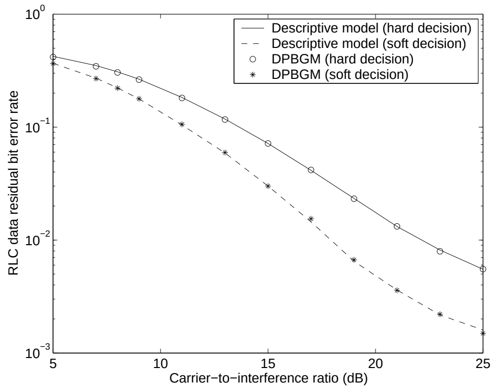


Fig. 7: The RLC data RBERs of the coded EGPRS system with hard and soft decision decoding algorithms obtained from the descriptive model and the DPBGM.

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