Noise Performance and Error Probability Measurement using Energy Balance

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ABSTRACT: *The echo effect in the reverse channel in CATV is measured and the outcome is presented with the dispersion properties results. The models and the distribution functions are explained with the properties and the signal to interference ration is also found out in the study. The inter-symbol and inter-channel interference in CATV with S-CDMA is explained. The noise performance and upper limit of the error probability is measured. The noise performance is recorded and the energy balance and network design are explained.*

Keywords: CATV, S-CDMA, Reverse Channel, DOCSIS, Dispersive Channel

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1. Introduction

There exist two main problems in the data transmission in the reverse channel in the cable television systems (CATV).

First of all, the reduced bandwidth (60MHz) constraints the capacity of the channel. Second, the level of the impulse and narrowband distortions in the bandwidth are relatively high, which leads to reduction of the noise performance.

In order to reduce the impact of both problems is proposed with the issuing of DOCSIS v.1.2 to use Synchronous Code Division Multiple Access (S-CDMA) in the reverse channel [4].

The standard DOCSIS 3.0 (Data Over Cable Service Interface Specification) defines the specifications of the third generation cable networks for high speed data transfer [1]. Unfortunately, there are few literature references that consist in-depth theoretical and system analysis of the possibilities of S-CDMA in the CATV [2-5].

The paper is focused on the research of the possibilities of the reverse channel for data transmission via S-CDMA. The echo effects lead to dispersion characteristics and violating of the orthogonality of the code sequences for CDMA. These effects lead to interchannel and intersymbol interferences and decrease the error probability in the system. Because of the random manner of the characteristics, the paper introduce statistic research of their dispersion characteristics. The distribution function and the statistical parameters of signal to interference ratio are investigated. The results of the analysis defines the model of the channel that describes the worst case for intersymbol interference (ISI) and interchannel interference (ICI). The defined adequate model of disperse channel will be used for accurate analysis of the noise performance and definition of the upper limit of the error probability.

The noise performance is a key characteristics, which is used in the energy design of the network and in the case of CDMA, when computing the capacity of the reverse channel. Besides the solving if these problems, with the knowledge of the noise performance it is possible to apply new methods and algorithms for signal and information processing, that can increase the capacity of the network.

2. CDMA CATV Networks Reverse Channel Model

The model of the dispersion reverse channel with S-CDMA is shown on Figure 1.

The following constraints, that do not worsen its quality, are introduced in the model:

1. The model is a channel in base band.

2. It is used direct spread spectrum (DSS) with orthogonal code sequences, described in the standard DOCSIS 3.0.

3. The echo effects are modeled with linear filter with random values of the time delay and the phase.

4. It is considered the worst case-without applying preequalizer in the transmitter of the cable modem (CM). The main idea is the whole processing for compensation of the ISI and ICI to be done in the cable modem termination system (CMTS). This approach for processing will increase the computational complexity of the CMTS, but the result will be increased capacity of the reverse channel. It is not necessary to transmit the coefficients for adjustment of the pre-equalizer.

5. It is taken into account the impulse response of raised cosine filter. In this case ISI and ICI take part on the input of the detector of the digital receiver of the CMTS.

6. There is ideal time, frequency and phase synchronization between the CM.

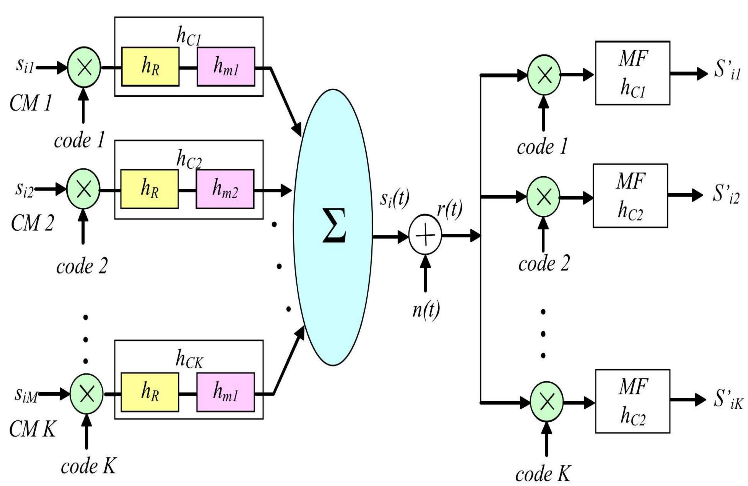

Figure 1. System model of dispersion reverse channel

The echo effects of the media for one subscriber or CM are modelled with linear digital filter with impulse response $h_c(t)$. $h_c(t)$. is the convolution of the impulse response of the raised cosine filter $h_R(t)$ and the impulse response of an linear filter modelling the echo effects $h_m(t)$.

$$h_c(t). = h_m(t).* h_R(t) \quad (1)$$

The characteristics of the dispersion channel $h_m(t)$ is different for each user. Besides this, the change of $h_m(t)$ is random and because of the stochastic setting on and off of the user CM. The dispersion characteristics are described in the standard DOCSIS and they are used for creation of the model of the reverse channel. In Table I are described the typipcal values of the parameters of the reflected signals [1]. The reflected components spread over several chips of the coded sequence for CDMA.

Relative amplitude [dBc]	Delay [chips]	Phase [rad]
-10	Uniform distribution {0 - 2.5}	Uniform distribution {0 - 2π}
-20	Uniform distribution {0 - 5}	Uniform distribution {0 - 2π}
-30	Uniform distribution {0 - 7.5}	Uniform distribution {0 - 2π}

Table 1. Echoes In Reverse Channel

The modulated symbols in baseband s_i are on the input of the block for spreading of the spectrum. In this block, the symbols are multiplied with orthogonal code sequence code *k* that is unique for the *k*-th user. It is assumed that *K* users are communication simultaneously with CDMA. The block h_R is the filter with optimal coefficients for minimum of ISI, but hmk models the echo effects for *k*-th reverse channel. h_m is different for each user. In the receiver of the CMTS, the signals of the CMs are summing, and $n(t)$ is the impact of additive white Gaussian noise (AWGN). For separation of the signals, the received signal $r(t)$ is correlated with the unique code sequences. The detector uses matched filter (MF).

3. Methodology of Research

The impulse response of the channel is derived according to Equation 1. The filter, forming the impulse responses for ISI minimization has roll-off factor $\alpha = 0.25$ [1, 5, 6]. For the research purposes it used discrete FIR filter with $h_R(k.\Delta t/T)$, $\Delta t/T$=0.25:

$$h_R(k) = \sin c\left(0.25\pi k\right)\frac{\cos\left(0.25\pi\alpha k\right)}{1-4\alpha^2 k^2 0.25^2}$$

$$k=-16..0..16. \quad (2)$$

The echo effects are modelled also with discrete FIR filter. It has coefficients with amplitude values, shown in Table 2. The phase of the delayed components is formed randomly with uniform distribution law. The time delay is changed with step a quarter of the chip $\Delta t/T = 0.25$. In Table 2 are described the parameters of the discrete echo channel, used in the research of the statistical characteristics.

The signal to interference ratio of the ISI is computed according to the equation:

$$S/I = \frac{|h_c(0)|^2}{\sum_{k=-p\ k\neq p}^{p}|h_c(k)|^2} \quad (3)$$

№	Impulse response $h_m(k.0,25)$
CH1	{1, 0.3162.exp[j.2.π.rand), 0.1.exp[j.2.π .rand], 0.0316.exp[j.2.π.rand]}
CH2	{1, 0, 0.3162.exp[j.2.π.rand], 0, 0.1.exp[j.2.π .rand], 0, 0.0316.exp[j.2.π.rand]}
CH3	{1, 0, 0, 0.3162.exp[j.2.π.rand], 0, 0, 0.1.exp[j.2.π.rand], 0, 0, 0.0316.exp[j.2.π.rand]}
CH4	{1, 0, 0, 0, 0.3162.exp[j.2.π.rand], 0, 0, 0 0.1.exp[j.2.π.rand], 0, 0, 0, 0.0316.exp[j.2.π.rand]}
CH5	{1, 0, 0, 0, 0, 0.3162.exp[j.2.π.rand], 0, 0, 0, 0 0.1.exp[j.2.π.rand], 0, 0, 0, 0, 0.0316.exp[j.2.π.rand]}
CH6	{1 0 0 0.1.exp[j.2.π.rand] $10^{-0.5}$.exp[j.2.π.rand] 0 0 0 0 0 0 0 $10^{-1.5}$.exp[j.2.π.rand]}
CH7	{1 0 0 0 $10^{-0.5}$. exp[j.2.π.rand] 0 0 0.1. exp[j.2.π.rand] 0 0 0 ($10^{-1.5}$)* exp[j.2.π.rand]}
CH8	{1 0 0 0 (10^-0.5). exp[j.2.π.rand] 0 0 0 0 0.1. exp[j.2.π.rand] 0 0 0 (10^-1.5). exp[j.2.π.rand]}

Table 2. Models of Reverse Channel

The number of the components of the discrete equivalent linear filter is $2p$+1.

4. Result of the Experiments

For the needs of the work is created a program model in MATLAB. It is used to investigate ISI in different channels. It is computed the S/I according to Eq.3. As a result of multiple experiments with random change of the phase of the reflected components according to Monte-Carlo method, is found the histogram of the S/I in [dB]. Eight different channels with characteristics, shown in Table 2, are investigated. They differ each other in the time delays of the reflected signals and they are chosen in order to achieve biggest values of the ISI.

The cumulative density distributions are computed together with the histograms. The statistical characteristics are defined as the mean, mean square deviation, minimu and maximum value. The results are summarized in Table 3.

The distribution of the probability density of the S/I ratio for some of the channels are shown on Figure 2 and Figure 4. The cumulative functions are shown on Figure 3 and Figure 5. The nuber of the channel is appointed on each figure.

№	S/I_{AVR} [dB]	Standard deviation $\sigma_{S/I}$ [dB]	$(S/I)_{min}$ [dB]	$(S/I)_{max}$ [dB]	$(S/I)_{90\%}$ [dB]
CH1	20.71	21.75	9.74	30.62	24.5
CH2	13.83	12.05	7.83	18.94	16.9
CH3	10.49	4.69	8.41	13.17	11.8
CH4	**9.54**	**-**	**-**	**-**	**9.54**
CH5	**10**	**-0.9939**	**9.22**	**10.53**	**10.42**
CH6	10.30	6.50	7.53	13.06	12.5
CH7	**9.64**	**0.47**	**8.76**	**10.60**	**10.3**
CH8	**9.6**	**-2.05**	**9.08**	**10.16**	**9.98**

Table 3

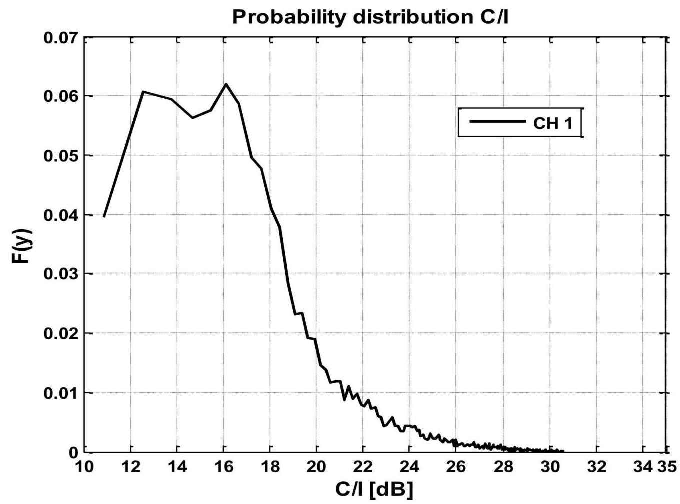

Figure 2

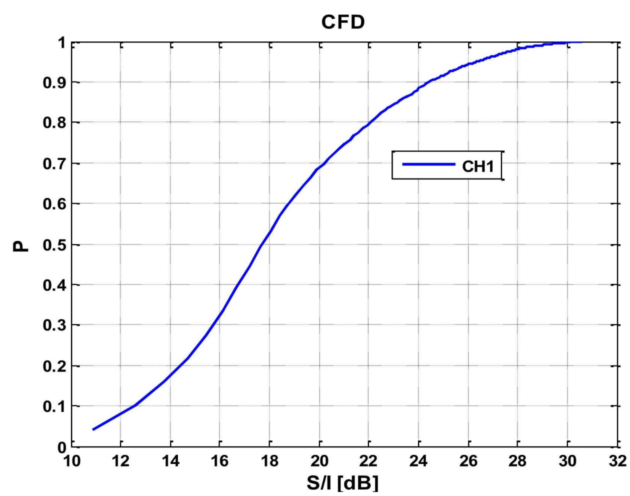

Figure 3

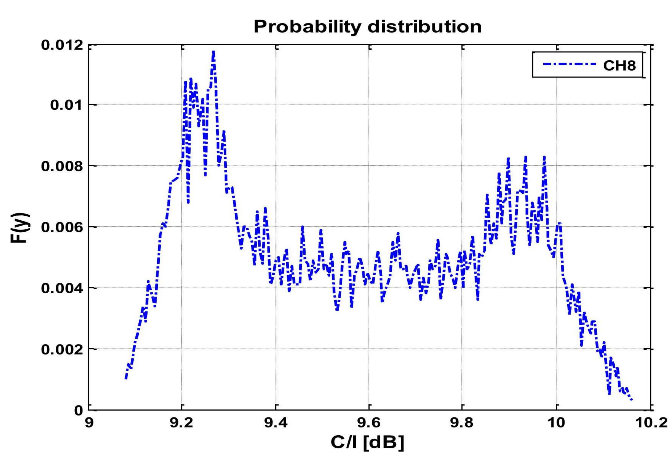

Figure 4

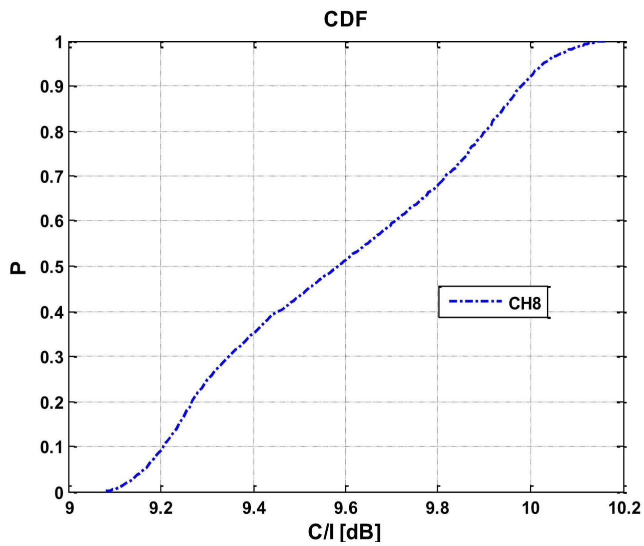

Figure 5

The dispersion characteristics of the reverse channel lead to two main effects:

1. Violating the orthogonality of the spreading codes and the appearance of the ICI.

2. Appearance of ISI in a single CDMA channel. Both effects reduce the noise performance of the communication system. This is the reason that must be chosen a model, that the level of the side lobes of the impulse response of the channel are maximum.

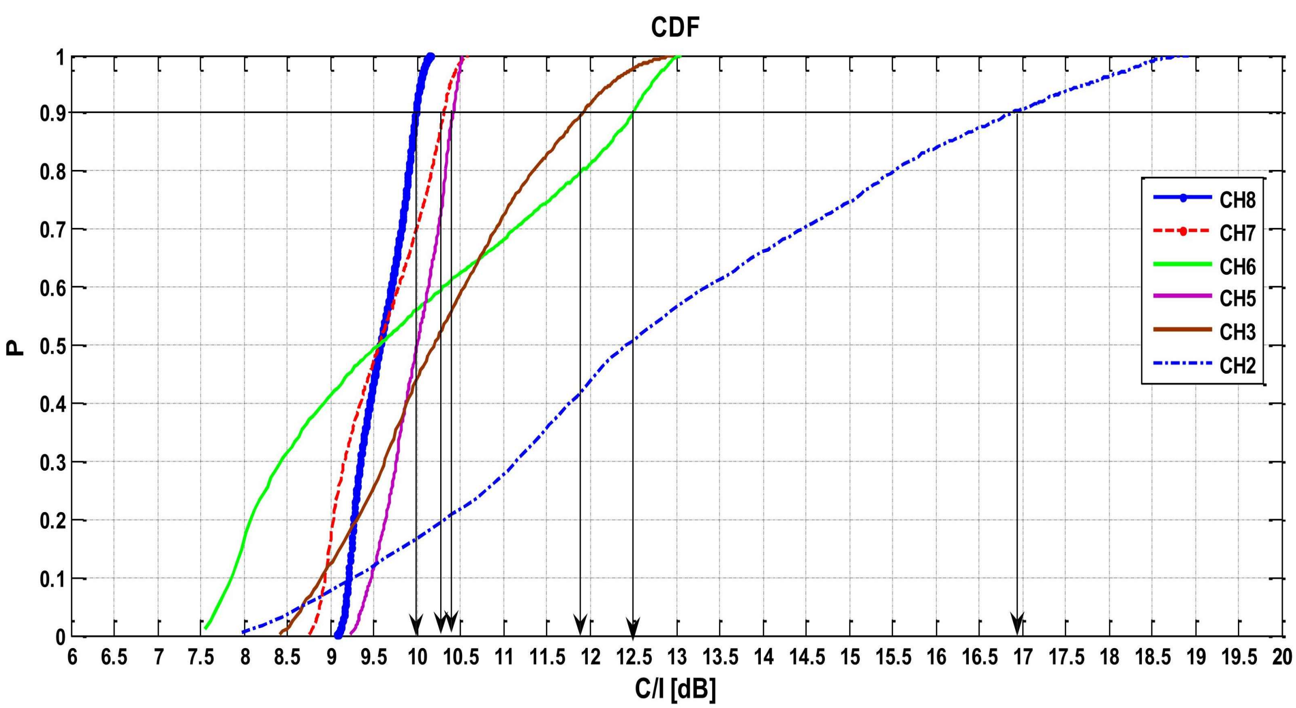

Figure 6

Figure 6 shows the cumulative function for the investigated dispersion channels on a common coordinate system. It is possible to define the value of the signal to noise ratio $(S/I)_{90\%}$, where in 90% of the time, S/I is less than this value. This threshold value is used for a criterion of the choice of channel that can be used in investigation of the noise performance of CDMA versus AWGN and the echo effects in the reverse channel.

The first criterion for a choice of the channel is defined as:

$$k = \arg_i\left[\min(S/I)_{i,90\%}\right] \quad (4)$$

In the last column of Table 3 are shown the results for $(S/I)_{90\%}$. It is chosen a channel that has minimum value of the $(S/I)_{90\%}$. As it is clearly seen CH8 has minimum value of

$(S/I)_{90\%}$ When choosing the channel, it must be taking into account the mean value of the S/I. The lower is this value, the higher is the mean probability in different random realizations of the characteristics of the dispersion channel. The aim is to investigate the worst case. The second criterion for choice of the channel is:

$$k = \arg_i\left\{\min[E(S/I)]_{i,90\%}\right\} \quad (5)$$

CH7 and CH8 satisfy this criterion. A good candidate is also CH3. In CH3, the S/I has minimum value and bigger dispersion, than in CH7 and CH8. CH4 should not be forgotten.

From the analysis, it is seen that best for modelling of the echo effects in the reverse channels are: CH3, CH4, CH7 and CH8.

5. Conclusion

The chosen models will be used for investigation of the noise performance of the dispersion reverse channel with CDMA in CATV. They can be used in definition of the upper limit of the error probability. The results from the investigation can be applied in a method for energy budget of the cable network and for definition of its capacity-the number of the users in the reverse channel.

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