University of Padua
Department of Information Engineering

Final Project of the source coding course

Algorithms for encoding and decoding CD-quality audio signals by means of DPCM technique and Golomb procedure.

Author:
Lorenzo Gasparollo

July 25, 2018

Contents

Abstract

In this project is presented a procedure for encoding and decoding CD-quality audio signals (16 bit/sample) by means of the DPCM technique combined with Golomb coding procedure. At the beginning there is a recall of the key notions, then is presented a list of considerations regarding a possible solution to the assigment. Finally, simulation's results obtained from the comparison between different configuration of the DPCM scheme are presented.

1 Motivation: differential coding and audio

Differential coding is a lossy technique. The principle idea in differential coding is to exploit the correlation of source's samples in order to predict each sample based on its past and only encode and transmit the differences between the prediction and the sample value.

Why using a diffential coding scheme for the compression of an audio track?

In acoustic, the "resonance" generated by the sounds leads to some sort of the "redundancy" (The sound repeats itself). This, in accordance to our intuition, implies also a repetition from a numerical point of view.
Contrary to memoryless scalar quantization, the redundancy of a source, e.g. **statistical correlation**, can be conveniently exploited to increase the coding efficiency.

2 DPCM technique

The differential pulse code modulation (DPCM) system is a differential encoding system. DPCM system consists of two major components, the **predictor** and the **quantizer** and it can be, open or closed loop. We will focus on the second one, as it will be treated throughout the report.
Block diagram of a DPCM coding scheme can be represented as follows:

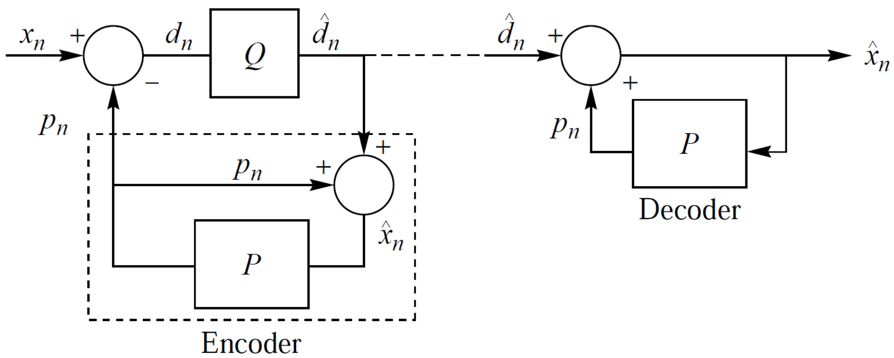

Figure 1: Block diagram of a DPCM coding scheme

where x_n,$\hat{x_n}$,p_n d_n,$\hat{d_n}$ denote respectively the source, its quantized version and prediction, the prediction error and its quantized version. A fundamental property of the DPCM coding scheme is that the quantization error on the residual d_n equals the reconstruction error on the source sample x_n, namely:

$$\begin{cases} d_n = x_n - p_n \\ \hat{x_n} = \hat{d_n} + p_n \end{cases} \Rightarrow d_n - \hat{d_n} = x_n - p_n \tag{1}$$

In other words, the distortion on the samples x_n equals the distortion on the residual d_n, thus, for a given predictor, the performance of the DPCM coding scheme can be derived from the quantizer characteristics.

Let's see the kind of quantization and prediction that will be attacked in this project.

2.1 Quantization

Lossy coding in practice consists of a quantization procedure. There exists several quantization methods, but in following we will consider a **scalar**, **uniform**, **non adaptive quantizer**, i.e., a quantizer in which:

- each input sample is quantized individually.
- the step size Δ is constant.
- the quantizer does not adapt itself to the input statics (It only considers the maximum value of the source, as we will see later.).

2.2 Prediction

DPCM gain its advantage by the reduction in the variance and dynamic range of the difference sequence. Variance's reductions depends on how well the predictor can predict the next symbol based on the past reconstructed symbols. There exists many ways in which the source x_n can be estimated.
In the following we will consider a optimal linear predictor.

2.2.1 Optimal linear prediction

Let x_n be a stationary zero mean discrete time random process. Let's consider the N order linear predictor defined as follows:

$$\hat{x}_n = \sum_{k=1}^{N} a_k x_{n-k} \tag{2}$$

It can be showed that the Optimal (in the sense of MMSE) linear predictor can be obtained for:

$$a = R^{-1} r_c \tag{3}$$

where, by indicating $r_j = r_{-j} = \mathbb{E}[x_n x_{n-j}]$:

1. a is the N dimensional vector containing $\{ \ a_i \ \}_{i=1}^{N}$
2. R is a $N \times N$ Toepliz matrix such that: $R_{1,j} = r_{j-1}$, $j = 1, \ldots$,N.
3. r_c is the N dimensional vector containing $\{ \ r_i \ \}_{i=1}^{N}$

The performance of a predictor is usually evaluated by the **prediction gain** in dB defined as:

$$G_{P(dB)} = 10 \log_{10} \frac{\sigma_x^2}{\sigma_d^2} \tag{4}$$

3 Golomb coding

Golomb coding is a lossless data compression method, generally used for encoding natural numbers.

Golomb coding uses a tunable parameter m to divide an input value n into two parts: q, the result of a division by m, and r, the remainder. The quotient is sent in unary coding, followed by the remainder in truncated binary encoding.
The pseudo-code is reported in the following:

Algorithm 1 Golomb coding

procedure GOLOMB ENCODING
- $M \leftarrow$ m value
- $N \leftarrow$ *quotient of N/m*
- $r \leftarrow$ *reminder of N/m*
- *encQ* $\leftarrow$ *concat(q-length string, 0)*
- **if** *M is power of 2* **then** $encR \leftarrow bin(r)$, so $\log_2(M)$ bits are needed. (Rice code)
- **else**
  - $b \leftarrow \lceil \log_2(M) \rceil$
- **if** $r < 2^b - m$ **then** $encR \leftarrow bin(r)$ using b-1 bits
- **else**
  - $encR \leftarrow bin(r + 2^b - m)$ using b bits
- $codeword \leftarrow concat(encQ, encR)$

3.1 Choice of m

The choice of m depends on the statistical distribution of the integer values which have to be coded, i.e. on the corresponding Bernoulli $\{\ B(p),\ (p = \mathbb{P}\ [\mathrm{X} = 1])\ \}$ process associated. A reasonable choice is the median.
A typical choice is:

$$m = \lceil \frac{-1}{\log_2(p)} \rceil \tag{5}$$

4 Work on the Assignment

The system is the composition of 2 techniques: a lossy compression (Quantization) and a loss-less compression (Golomb coding).

We will consider a simple DPCM-closed loop system (C1) and a system with a basic version of the forward adapted predictor (C2).

4.1 DPCM (C1)

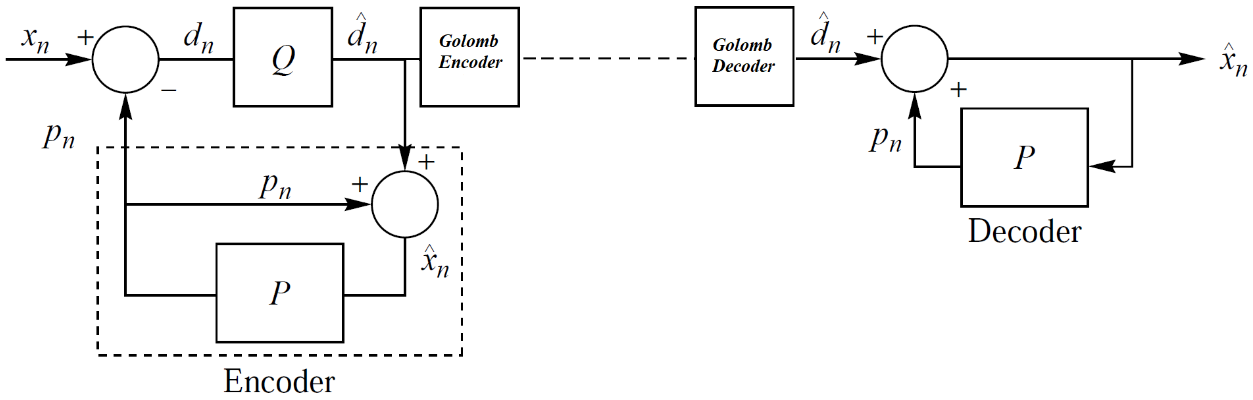

Figure 2: Block diagram of the system

Considerations for the quantizer and the predictor

- In Sec. 2.2.1 we have assumed the source as a stationary zero mean discrete random process. In general an audio signal is not zero mean. We thus have to normalize the input signal, by subtracting this latter by its mean μ, which can be estimated before the encoding procedure.
- Under uniform quantization, Δ has been calculated:
  - for the PCM system as:
  $$\Delta(B) = 2\frac{|\max(x_n)|}{2^B} = \frac{|\max(x_n)|}{2^{B-1}},\ B > 1 \tag{6}$$
  - for the DPCM system as:
  $$\Delta(N, B) = 2\frac{|\max(d_n)|}{2^B} = \frac{|\max(d_n)|}{2^{B-1}},\ B > 1 \tag{7}$$

  where B is the number of bit used in the quantizer. It is worth noticing that, in the DPCM, Δ depends also (indirectly, by d_n) on the predictor order N.
- In practice it is not possible to know a-priori the the distribution of the source and so the $\{\ r_i\ \}_{i=1}^{N}$. Nevertheless, given M data points, r_k can be estimate as follow:

$$\hat{r}_k = \frac{1}{M-k}\sum_{i=1}^{M-k} x_i x_{i+k}\ ,\ 0 \le k < M \tag{8}$$

Considerations for the Golomb encoder

- d_n is assumed to be distributed as a two side geometric distribution. Golomb encoding can be used also for negative integers by mapping values as:

$$x^* = \begin{cases} 2|x| & x \ \geq 0 \\ 2|x| - 1 & otherwise \end{cases} \tag{9}$$

Let's call d_n^* the positive version of d_n through the previous map. We assume to be distributed according to a geometric r.v. G(p) of parameter p. Since:

$$N \sim G(p) \Leftrightarrow \mathbb{P}[N = n] = p^n(1 - p) \quad , n \in \mathbb{N} \Rightarrow p = 1 - \mathbb{P}[N = 0] \tag{10}$$

we pick the estimate:

$$p^* = 1 - \frac{\sum_{n=0}^{nSamp} \mathbb{1}_{\{0\}}(d_n^*)}{nSamp} \tag{11}$$

4.2 DPCM (C2)

Motivation: the equations used to obtain the predictor coefficients were derived based on the assumption of stationarity.
However this strong assumption is not true: different segments have different characteristics. While the source output may be locally stationary over any significant length of the output, the statistics may vary considerably. In this situation, it is better to adapt the predictor to match the local statistics. In forward adaptive prediction, the input is divided into segments or blocks.
The system is depicted in Figure 3.

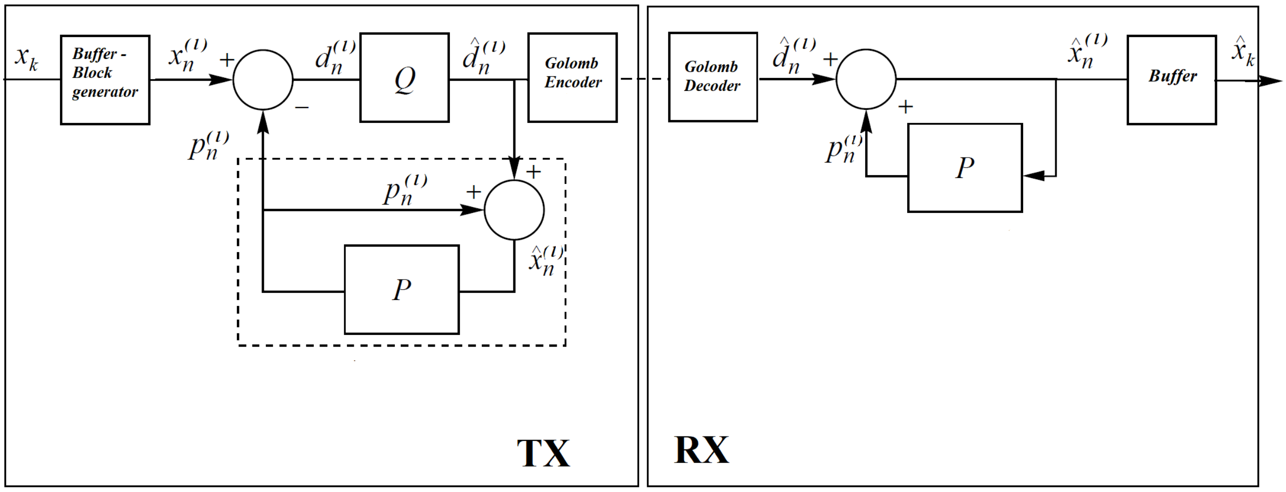

Figure 3: Block diagram of the system

Considerations:

- We can apply the same rationale as the non-adaptive scheme, just by considering $x_n^{(l)}$ as the input source of the non-adaptive scheme.

- The autocorrelation for each block can be estimated by assuming that the sample values outside each block are zero. For a block length of M, the autocorrelation function for the l^{th} block is be estimated by:

$$\hat{r_k}^{(l)} = \frac{1}{M - k} \sum_{i=(l-1)M+1}^{lM-k} x_i x_{i+k} \ , \ 0 \leq k < M \tag{12}$$

Since each block is assumed to be stationary, we pose $\hat{r_k}^{(l)} = \hat{r}_{-k}^{(l)}$ for $0 \leq$ k $<$ M , $\forall$ l.

- It's worth noticing that since we're compressing CD audio, we're doing an off-line operation and we don't need fast performances. Thus, the choice of a forward adaptation is legitimate.

4.3 Matlab map

- *main.m*: is used to coordinate the various functions. At the beginning this function loads the desired audio file (via the RADIO.m function). It is possible to select the Window size to be considered in the computation (array bSec). Then it follows a simulation, for different block sizes, order of predictors, and quantization bits. Performance indicators are finally computed.
- *EACF.m*: is used in order to estimate the autocorrelation function.
- *PCOEFF.m*: is used in order to calculate the predictor's coefficients.
- *GENC.m*: implements the golomb encoder.
- *GDEC.m*: implements the golomb decoder.
- *PCM.m:* is used for the quantization.
- *GMAP.m, GMAPI.m*: functions that implement the direct and inverse operation of eq. (9).
- *PIND.m*: is used to compute the performance indicators.
- *RAUDIO.m*: load an audio file (It is possible to select the duration of the track as well as its start.)

5 Results

Firstly, it will be presented results obtained with a simple PCM.
Then, results by means of DPCM technique and Golomb coding will be presented and compared with the previous ones.
Simulations will take into account different degrees of freedom which can be summarized as:

- type of scheme: **(C1)** or **(C2)**.
- predictor order **(N)**.
- quantization bits **(B)**.
- Genre of music.

For DPCM (C1) and DPCM (C2) it has been set the window size of 200ms and 30000 ms, respectively.

The chosen tracks are represented in the following figure:

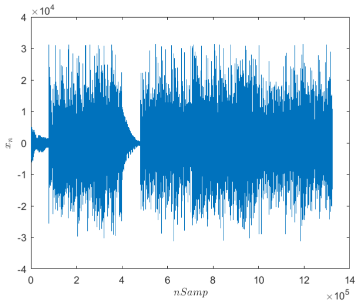

Figure 4: Caprice No 5.

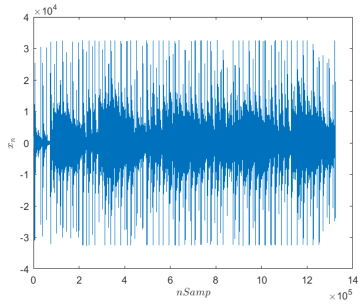

Figure 5: Identikit.

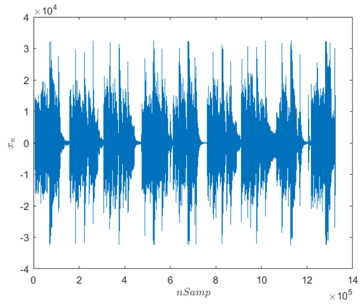

Figure 6: Am Gone.

Let's see each one of them in more detail.

5.1 Paganini: caprice No 5

Number of seconds considered: 30s.
Sampling frequency: 44100 Hz.

PCM

B	H(X)	SNR [dB]
2	0,2317786813	1,1162497997
3	1,1577824354	5,6995573044
4	2,3478221893	12,2087087631
5	3,5333266258	19,2160511017
6	4,6546840668	26,1719799042
7	5,7219147682	32,8564071655
8	6,7558989525	39,277015686
9	7,7706251144	45,5194892883
10	8,7749605179	51,6564102173
11	9,7722129822	57,732673645
12	10,7639856339	63,7842254639
13	11,7512340546	69,828956604
14	12,7321882248	75,8629989624
15	13,7018499374	81,8823394775

DPCM (C1)

N	G_P [dB]	$\sigma^2(\hat{d}_n)$
1	22,2866821289	269580,393091334
2	27,7477760315	76661,7494444404
4	28,1748867035	69481,2791795584

B	H(dn)			SNR		
	N =1	N = 2	N = 4	N =1	N = 2	N = 4
2	0,0017861718	0,0027882634	0,002828287	22,3477401733	27,4246425629	27,8501338959
3	0,0572257377	0,0350803137	0,0408027768	22,8155784607	28,0400276184	28,4865760803
4	0,481862545	0,2286308855	0,2640154064	25,1172676086	29,9559192657	30,4970569611
5	1,4799213409	0,7561225295	0,8501390219	30,1776847839	33,4175109863	34,1263999939
6	2,6823227406	1,6621793509	1,8183400631	36,8095855713	38,1862068176	39,1810798645
7	3,8564240932	2,8221194744	2,9933178425	43,8653907776	44,3760147095	45,5509338379
8	4,9631576538	4,0017447472	4,1644763947	50,7378540039	51,355255127	52,5670585632
9	6,0219407082	5,1180496216	5,2706842422	57,3492202759	58,2683639526	59,4318084717
10	7,0516338348	6,1828198433	6,3294425011	63,7247657776	64,9353713989	66,0543670654
11	8,0640687943	7,2153129578	7,358757019	69,9436264038	71,3431472778	72,4379043579
12	9,066693306	8,2292842865	8,3704299927	76,0692138672	77,5790481567	78,6502838135
13	10,0626535416	9,2324533463	9,3722438812	82,1507415771	83,7053222656	84,7749710083
14	11,0540409088	10,22838974	10,3671007156	88,1993255615	89,7940063477	90,8506011963
15	12,0402135849	11,2175426483	11,3557825089	94,2416229248	95,850692749	96,9011306763

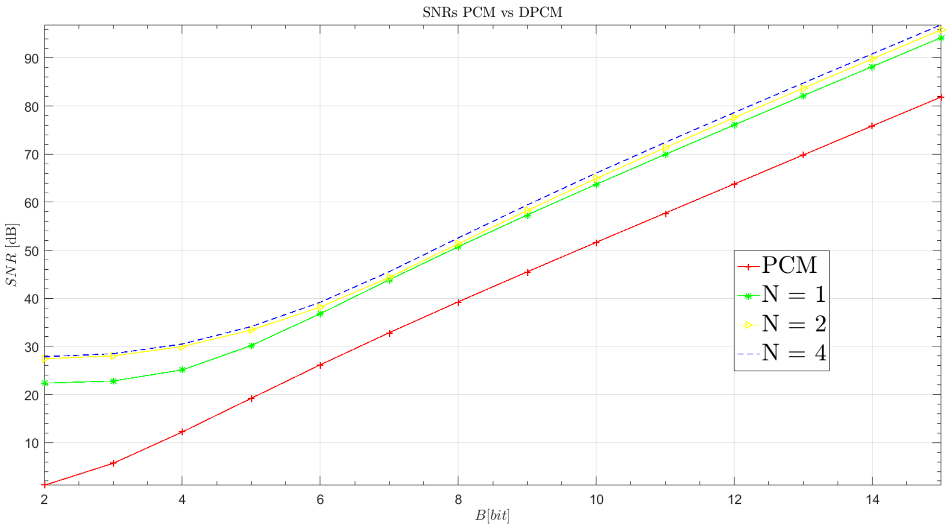

Figure 7: SNR as a function of the number of bits B used by the quantizer for the PCM scheme and the DPCM (for N = 1,2,4.)

B	R			D		
	N =1	N = 2	N = 4	N =1	N = 2	N = 4
2	1,0005124717	1,0000491308	1,0000483749	266641,125	76166,4453125	69078,0390625
3	1,0381783825	1,0022373394	1,0021662887	205426,28125	71074,0703125	64910,375
4	1,3213779289	1,0341519274	1,036334845	80813,953125	51191,078125	46823,23828125
5	2,2008941799	1,2230748299	1,2422947846	20061,70703125	23709,568359375	21047,892578125
6	3,4781640212	1,8547097506	1,9186870748	4163,8056640625	7167,1201171875	6131,3212890625
7	4,8374693878	3,0789221466	3,152138322	878,4412841797	1649,4399414063	1381,8381347656
8	5,9969281935	4,7359493575	4,315250189	189,764175415	347,0688476563	290,5213623047
9	7,2212252457	5,8996205593	6,0681602419	42,1117362976	76,4707107544	64,1456451416
10	8,265973545	7,2652962963	7,1610808768	9,7311468124	16,8035411835	14,1383972168
11	9,2480929705	8,344675737	8,3499773243	2,3289217949	3,7678091526	3,1852686405
12	10,2791050642	9,4850438398	9,4815555556	0,5691244006	0,8814067245	0,7466350198
13	11,2847838246	10,5056439909	10,5508609221	0,1406688094	0,2125953287	0,1803979427
14	12,2976553288	11,5428231293	11,5360823885	0,0349525698	0,0521701612	0,0442954823
15	13,3122237339	12,5078790627	12,5410529101	0,008711583	0,0129027944	0,0109679988

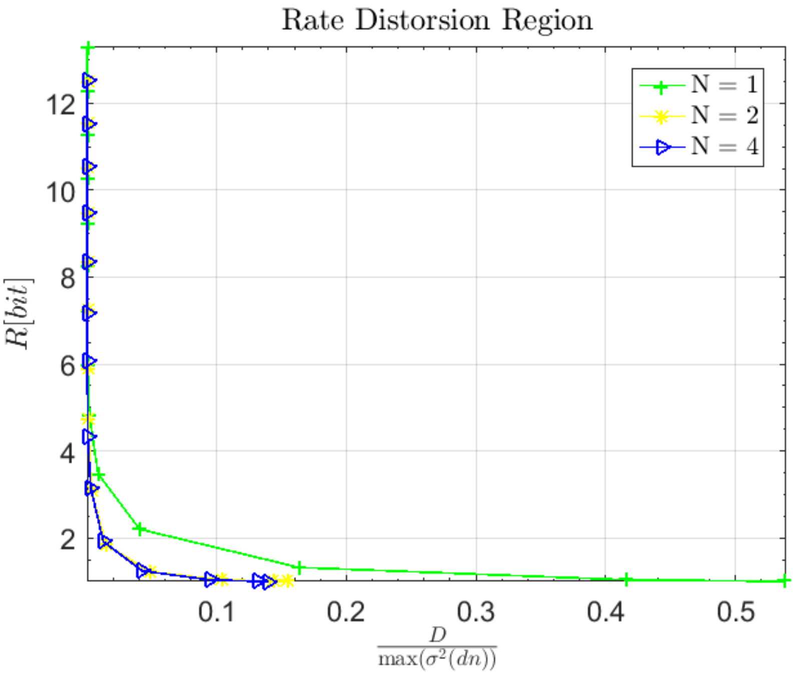

Figure 8: Comparison between points achieved by (DPCM scheme with Golomb coding) with different predictors(for N = 1,2,4.)

DPCM (C2)

N	G_P [dB]	$\sigma^2(\hat{d}_n)$
1	22,2897	269388,95
2	27,8214	75372,83
4	28,4503	65212,006

B	H(dn)			SNR		
	N =1	N = 2	N = 4	N =1	N = 2	N = 4
2	0,0016920528	0,0023076925	0,0017735835	22,3550605774	27,6306648254	28,4405250549
3	0,057063967	0,0332974419	0,0366546176	22,8224639893	28,2095718384	29,0231361389
4	0,4815563262	0,2308196127	0,2557528615	25,1245307922	30,1839160919	31,039680481
5	1,4790432453	0,7607904673	0,8352579474	30,1795768738	33,7860794067	34,7441368103
6	2,6813700199	1,6379448175	1,7725166082	36,8081970215	38,6207199097	39,7973175049
7	3,8554217815	2,7553160191	2,9177572727	43,8658332825	44,587688446	45,9911346436
8	4,9618897438	3,9272592068	4,0852589607	50,7385101318	51,3775978088	52,8302612305
9	6,021086216	5,0520782471	5,2005124092	57,358127594	58,2755279541	59,7111854553
10	7,0502939224	6,1247329712	6,2663912773	63,7358436584	64,9909133911	66,3921279907
11	8,0629901886	7,1620416641	7,2992181778	69,9538497925	71,4370193481	72,804397583
12	9,0654821396	8,1791639328	8,3133459091	76,0726089478	77,7021942139	79,0417404175
13	10,0615167618	9,1839962006	9,3163375854	82,1510467529	83,8542175293	85,1749801636
14	11,0528087616	10,180727005	10,3119335175	88,2032470703	89,9435424805	91,2657165527
15	12,0389575958	11,1705150604	11,3012104034	94,2384262085	95,9994812012	97,3106460571

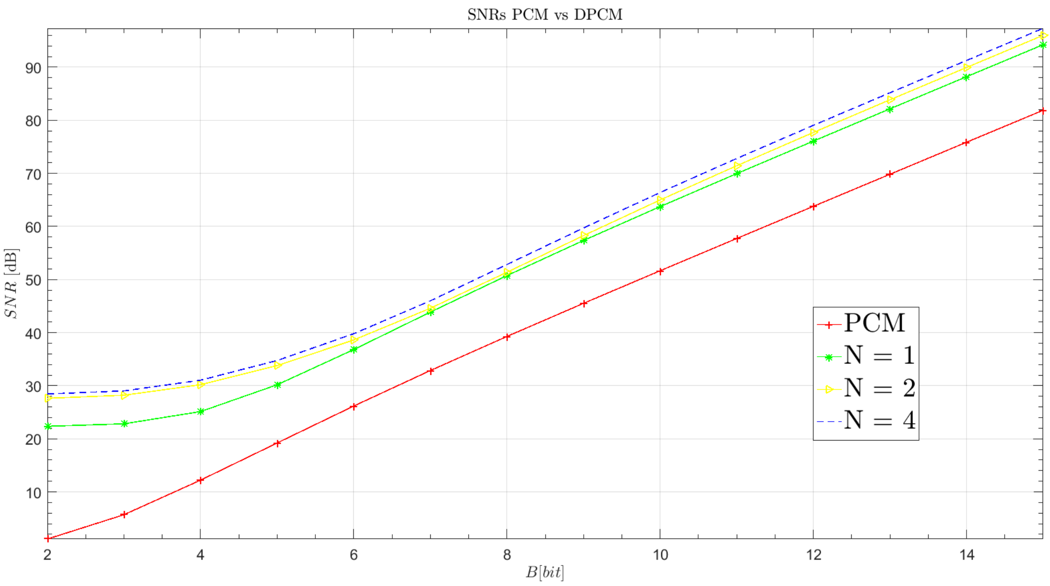

Figure 9: SNR as a function of the number of bits B used by the quantizer for the PCM scheme and the DPCM (for N = 1,2,4.)

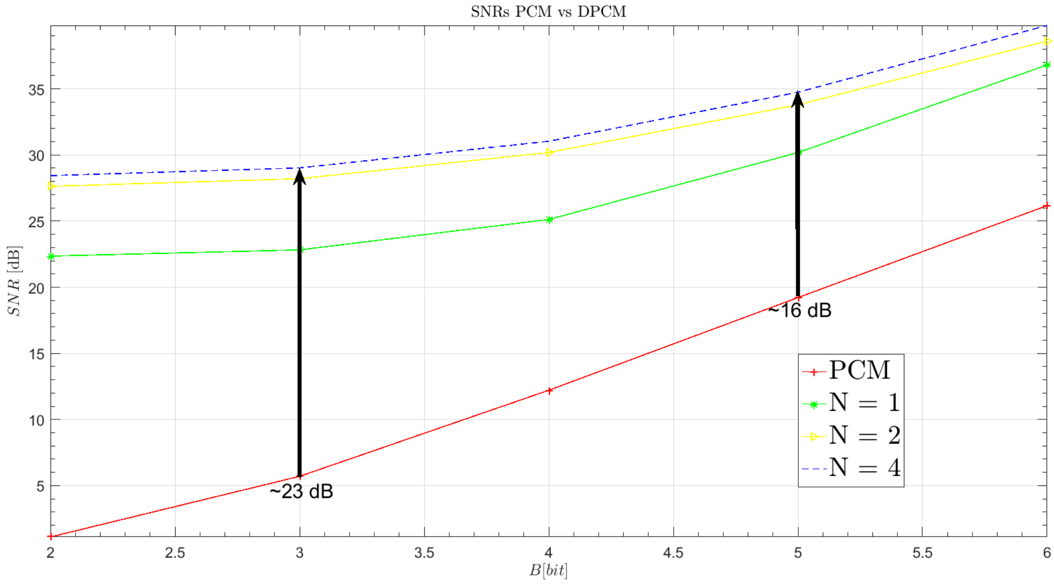

Figure 10: Detail: SNR as a function of the number of bits B used by the quantizer for the PCM scheme and the DPCM (for N = 1,2,4.)

B	**R**			**D**		
	N =1	N = 2	N = 4	N =1	N = 2	N = 4
2	1,0004353741	1,0000861678	1,0000498866	266784,5625	74733,046875	64840,390625
3	1,0349138322	1,0036326531	1,0027702192	208879,40625	68322,2421875	60587,55078125
4	1,3062426304	1,0498851096	1,0470891912	83837,1484375	45943,1328125	41768,44921875
5	2,1607014361	1,2933628118	1,295845805	20998,494140625	19370,25	17328,63671875
6	3,434574452	2,0484610733	2,0666046863	4364,8212890625	5459,779296875	4735,0322265625
7	4,7746727135	3,2882585034	3,3107558579	918,731262207	1222,9930419922	1038,9693603516
8	5,9330861678	4,5036500378	4,5366341648	198,6814880371	259,829864502	220,4487457275
9	7,1520400605	6,3520060469	6,4032947846	44,0284042358	58,1842918396	50,3125190735
10	8,1970166289	7,4450249433	7,8402358277	10,1655960083	12,8334541321	11,3610963821
11	9,2191844293	8,867138322	9,1736749811	2,4299602509	2,8949878216	2,5578906536
12	10,2716311413	9,9061473923	10,2155623583	0,5936872363	0,6783174872	0,5974795818
13	11,2774875283	10,9262025699	11,3073665911	0,1465854943	0,1638370305	0,1438656896
14	12,3239584278	11,9658684807	12,35487226	0,0364355855	0,0402158462	0,0352171659
15	13,5128518519	13,0011466364	13,4176628874	0,0090859272	0,0099818818	0,0087260734

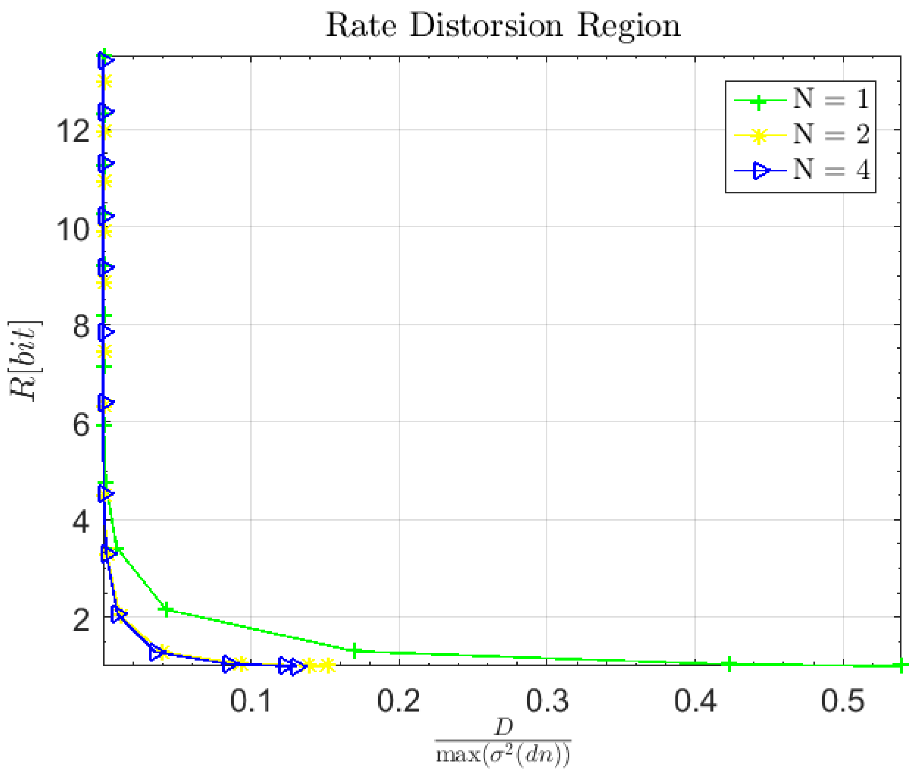

Figure 11: Comparison between points achieved by (DPCM scheme with Golomb coding) with different predictors(for N = 1,2,4.)

5.2 Radiohead: Identikit

Number of seconds considered: 30s.
Sampling frequency: 44100 Hz.

PCM

B	H(X)	SNR [dB]
2	0,2988416255	2,6616206169
3	0,9997423887	6,1125922203
4	2,1566488743	12,0383815765
5	3,3747375011	19,0401363373
6	4,5198559761	26,1638069153
7	5,5970110893	32,8183746338
8	6,6427044868	39,3431625366
9	7,663664341	45,6383857727
10	8,6744861603	51,8009986877
11	9,6795806885	57,887336731
12	10,6812257767	63,954536438
13	11,6797790527	69,9902648926
14	12,6751432419	76,0214691162
15	13,6647415161	82,0434570313

DPCM (C1)

N	G_P [dB]	$\sigma^2(\hat{d}_n)$
1	26.1427	1.2846e+05
2	28.8829	0.6835+e05
4	30.9252	0.4271+e05

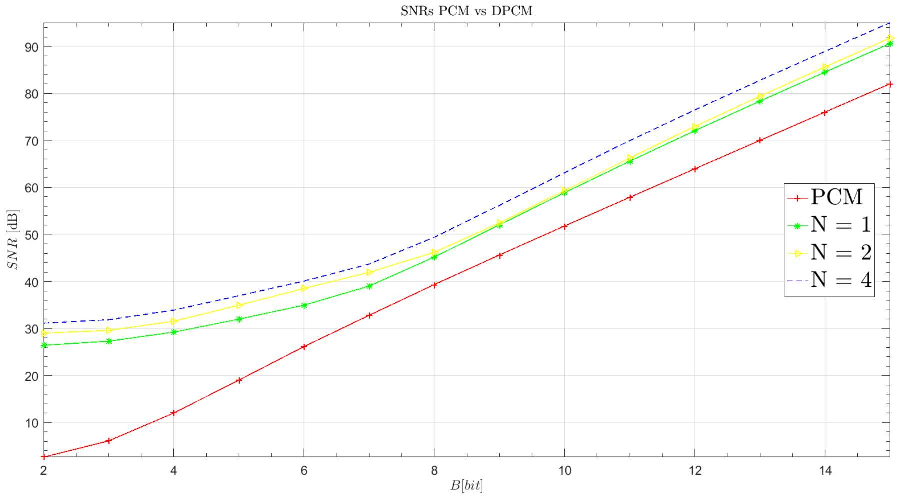

Figure 12: SNR as a function of the number of bits B used by the quantizer for the PCM scheme and the DPCM (for N = 1,2,4.)

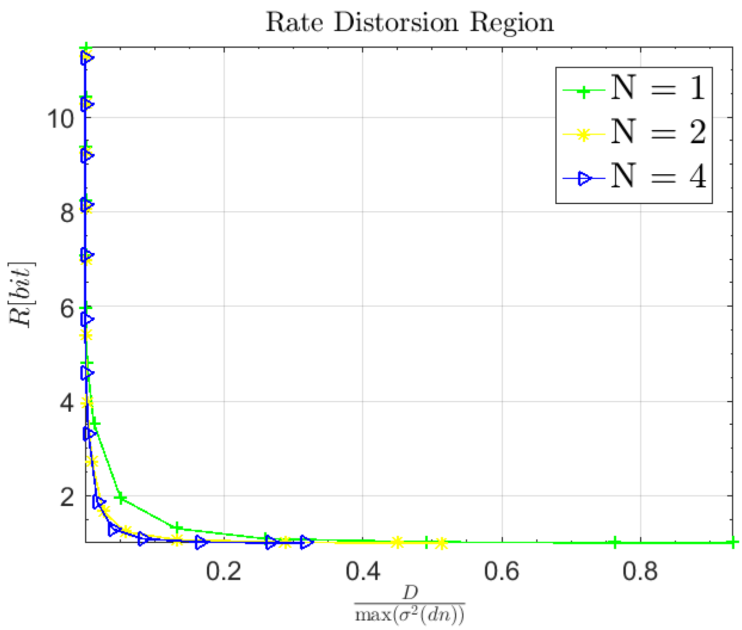

Figure 13: Comparison between points achieved by (DPCM scheme with Golomb coding) with different predictors(for N = 1,2,4.)

DPCM (C2)

N	G_P [dB]	$\sigma^2(\hat{d}_n)$
1	26.1579	1.2801e+05
2	28.9477	0.6734+e05
4	31.8349	0.3464+e05

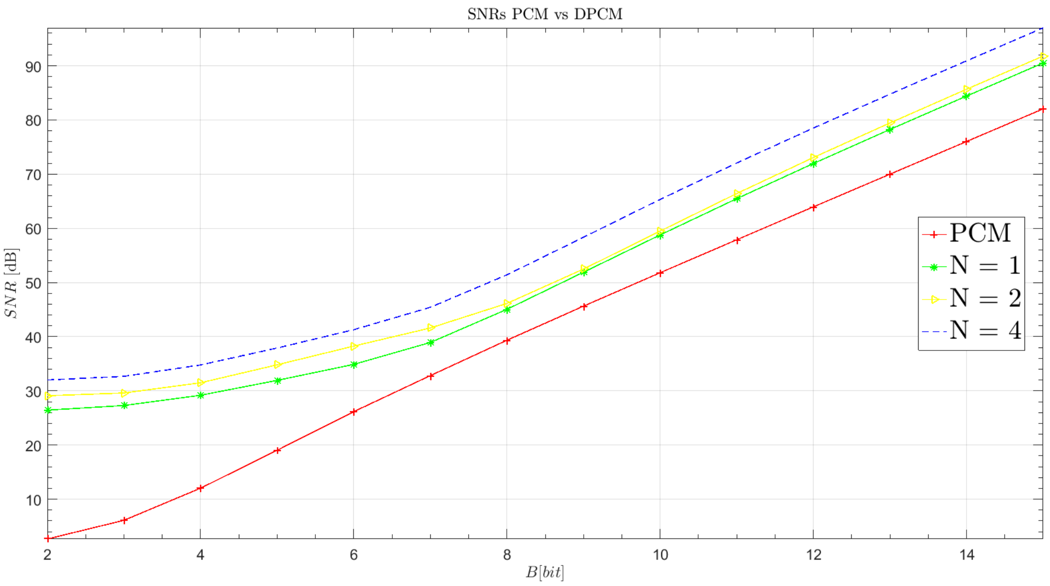

Figure 14: SNR as a function of the number of bits B used by the quantizer for the PCM scheme and the DPCM (for N = 1,2,4.)

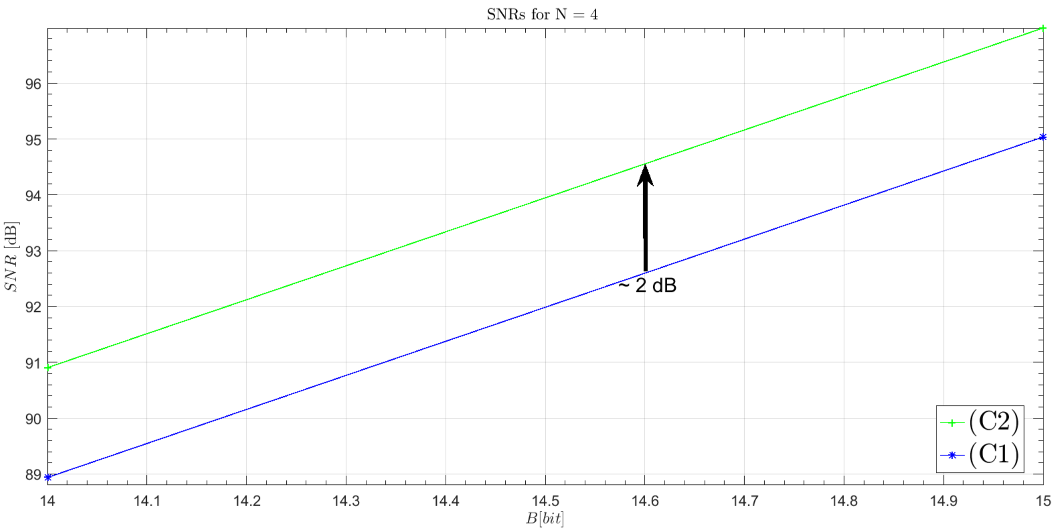

Figure 15: Detail: SNR for DPCM (C1) and DPCM (C2) with N = 4.

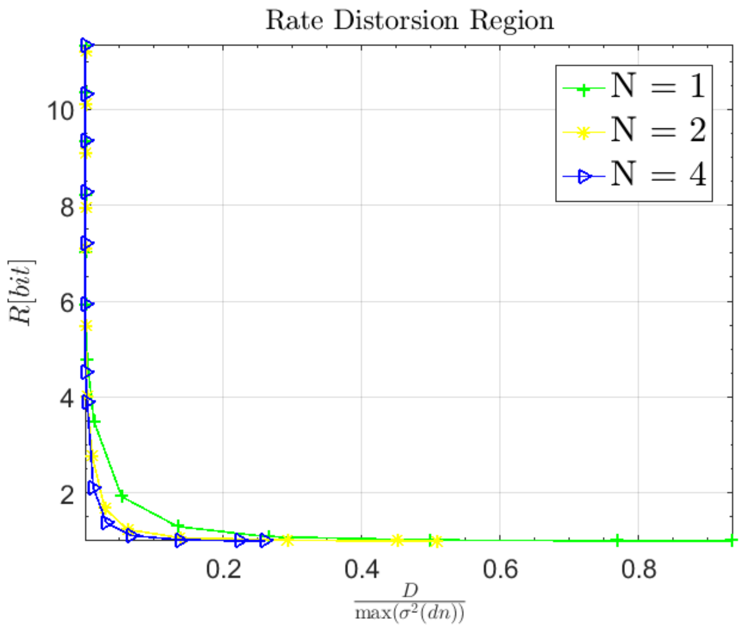

Figure 16: Comparison between points achieved by (DPCM scheme with Golomb coding) with different predictors(for N = 1,2,4.)

5.3 Adult Jazz: Am Gone

Number of seconds considered: 30s.
Sampling frequency: 44100 Hz.

PCM

B	H(X)	SNR [dB]
2	0,1719210744	1,1225020885
3	0,9466127753	5,2521276474
4	2,0355200768	11,6188602448
5	3,1484029293	18,3028621674
6	4,234972477	24,8896522522
7	5,2946305275	31,2756252289
8	6,3435349464	37,5384025574
9	7,3862957954	43,8908615112
10	8,4141073227	50,1792449951
11	9,4303007126	56,3451805115
12	10,4400129318	62,4846191406
13	11,4441041946	68,5839385986
14	12,4425106049	74,6488876343
15	13,4339084625	80,688331604

DPCM (C1)

N	G_P [dB]	$\sigma^2(\hat{d}_n)$
1	18.9251	4.9452e+05
2	19.8465	3.9998+e05
4	20.4408	3.4883+e05

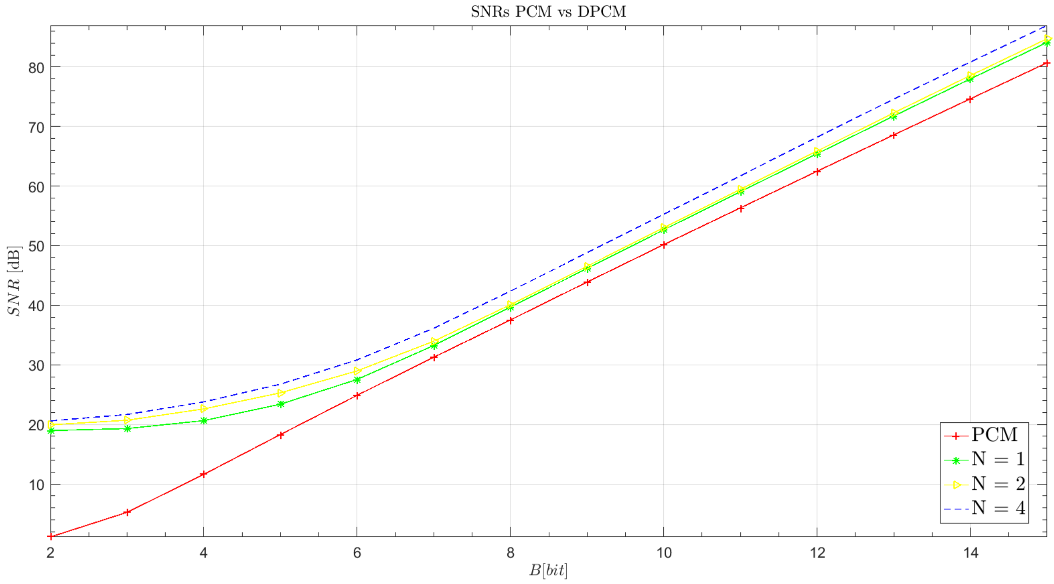

Figure 17: SNR for DPCM (C1) and DPCM (C2) with N = 4.

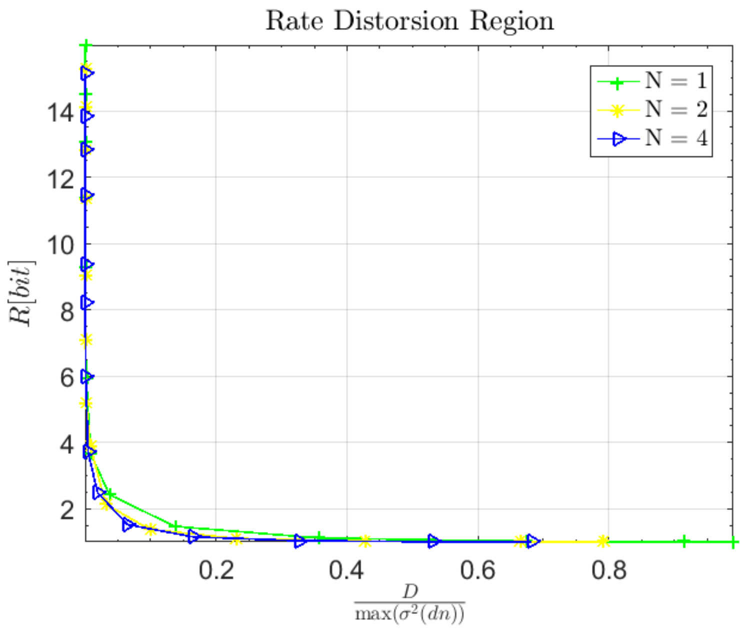

Figure 18: Comparison between points achieved by (DPCM scheme with Golomb coding) with different predictors(for N = 1,2,4.)

DPCM (C2)

N	G_P **[dB]**	$\sigma^2(\hat{d}_n)$
1	19.0104	4.8490e+05
2	20.7638	3.2382+e05
4	21.8413	2.5268+e05

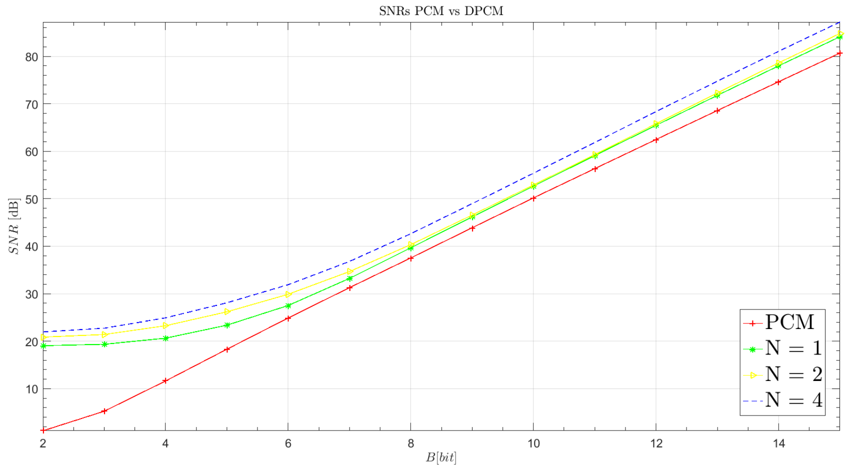

Figure 19: SNR for DPCM (C1) and DPCM (C2) with N = 4.

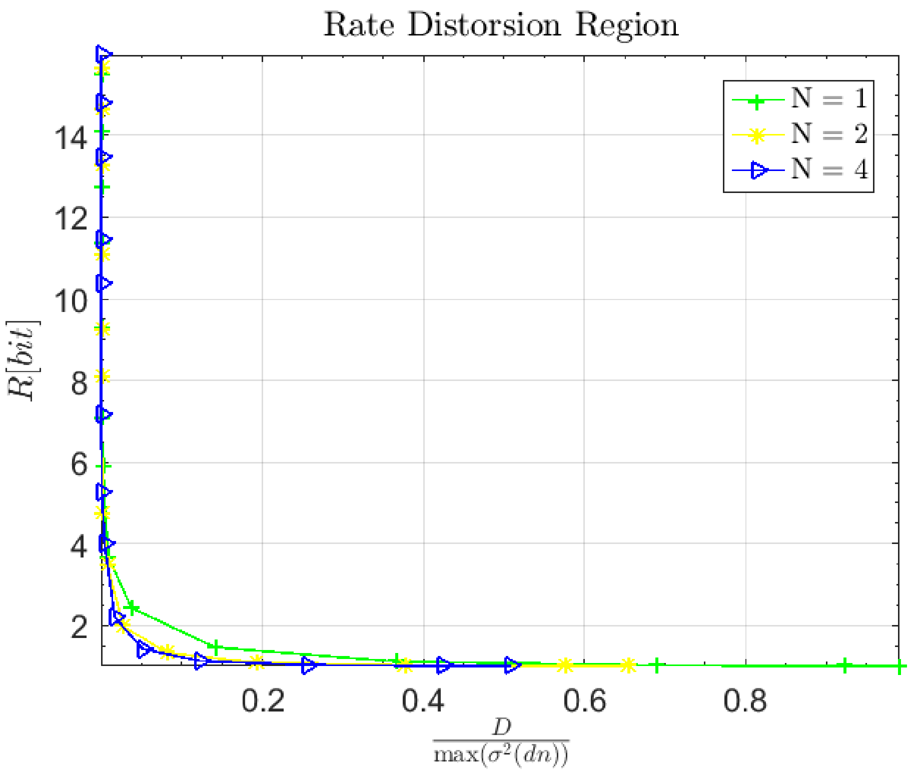

Figure 20: Comparison between points achieved by (DPCM scheme with Golomb coding) with different predictors(for N = 1,2,4.)

5.4 Considerations about PCM, DPCM (C1) and DPCM(C2)

Let's consider the following quantities:

- **SNR avg GAIN using X wrt Y** = avg(SNR using X - SNR using Y)
- **Rate avg GAIN using (C2) wrt (C1)** = avg(R using X - R using Y)

From the following *'metrics'* we can state that for:

1. **Caprice No 5**:

   Both DPCM (C1) and (C2) considerably outperform PCM in terms of SNR.

SNR avg GAIN using (c2) wrt PCM [dB]		
N = 1	N = 2	N = 4
12,91	15,27	16,48

   DPCM (C2) slightly outperforms DPCM (C1) in terms of SNR.

SNR avg GAIN using (C2) wrt (C1)[dB]		
N = 1	N = 2	N = 4
0,0041	0,1691	0,4433

   DPCM (C1) outperforms DPCM (C2) in terms of average length per codeword.

Rate GAIN using (C2) wrt (C1)[bit]		
N = 1	N = 2	N = 4
-0,013	-0,226	-0,4012

   This may explained by the fact that Rate estimation depends on both d_n but also on the Golomb encoding procedure. Intuitively, the more samples we have, the more precise the estimate of the median will be, leading to a better estimate of m, and, consequently, to a shorter average length.

2. **Identikit:**

   Both DPCM (C1) and (C2) considerably outperform PCM in terms of SNR.

SNR avg GAIN using (C2) wrt PCM [dB]		
N = 1	N = 2	N = 4
10.6779	15,27	16,48

   DPCM (C1) slightly outperforms DPCM (C2) in terms of SNR for N = 1,2.

SNR avg GAIN using (C2) wrt (C1) [dB]		
N = 1	N = 2	N = 4
-0.0884	-0.0196	1.6295

   DPCM (C1) outperforms DPCM (C2) for some values and vicerversa in terms of average length per codeword.

Rate avg GAIN using (C2) wrt (C1) [bit]		
N = 1	N = 2	N = 4
-0.0381	0.0131	-0.1200

3. **Am Gone:**

Both DPCM (C1) and (C2) outperform PCM in terms of SNR, but not as much as the previous cases.

SNR avg GAIN using (C2) wrt PCM [dB]		
N = 1	N = 2	N = 4
5.2353	6.4355	8.5580

DPCM (C2) slightly outperforms DPCM (C1) in terms of SNR.

SNR avg GAIN using (C2) wrt (C1) [dB]		
N = 1	N = 2	N = 4
0.0110	0.3471	0.5779

DPCM (C1) outperforms DPCM (C2) for some values and vicerversa in terms of average length per codeword.

Rate avg GAIN using (C2) wrt (C1) [bit]		
N = 1	N = 2	N = 4
0.0871	-0.0899	-0.1167

Finally, with the following detail it is possible to better see how, for big values of B, the DPCM (C2) reacts to different genre of musics and different linear predictor orders.

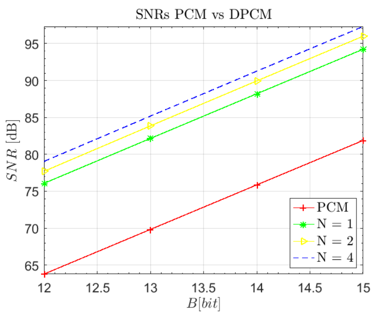

Figure 21: Caprice No 5.

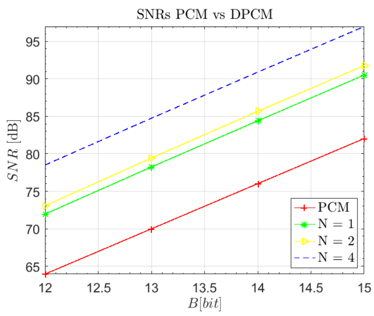

Figure 22: Identikit.

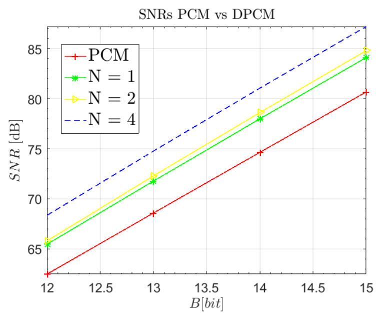

Figure 23: Am Gone.

6 Conclusions

In this report, a short motivation as well as a recall of the key notions is given. DPCM scheme is presented in two different configuration [(C1) and (C2)]. Results have been analyzed for different songs and different schemes, according to several performance indicators (SNR, R/D, etc ...). In almost all the cases the DPCM (C2) with N = 4 yields to the best result in terms of SNR. In some cases DPCM (C1) slightly outperforms (C2) in terms of average codeword length. Eventually, as compression, in this context, is an off-line operation, it is possible to chose one of the two configuration, according to a certain purpose (maximize SNR or minimize the average codeword length).