Switched Multistage Vector Quantizer

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Abstract

This paper investigates the use of a new hybrid vector quantizer called switched multistage vector quantization (SWMSVQ) technique using hard and soft decision schemes, for coding of narrow band speech signals. This technique is a hybrid of switch vector quantization technique and multistage vector quantization technique. SWMSVQ quantizes the linear predictive coefficients (LPC) in terms of the line spectral frequencies (LSF). The spectral distortion performance, computational complexity and memory requirements of SWMSVQ using hard and soft decision schemes are compared with split vector quantization (SVQ) technique, multistage vector quantization (MSVQ) technique, switched split vector quantization (SSVQ) technique using hard decision scheme, and multi switched split Vector quantization (MSSVQ) technique using hard decision scheme. From results it is proved that SWMSVQ using soft decision scheme is having less spectral distortion, computational complexity and memory requirements when compared to SVQ, MSVQ, SSVQ and SWMSVQ using hard decision scheme, but high when compared to MSSVQ using hard decision scheme. So from results it is proved that SWMSVQ using soft decision scheme is better when compared to SVQ, MSVQ, SSVQ and SWMSVQ using hard decision schemes in terms of spectral distortion, computational complexity and memory requirements but is having greater spectral distortion, computational complexity and memory requirements when compared to MSSVQ using hard decision.

Keywords: Linear predictive coding, Hybrid vector quantizers, Product code vector quantizers, Code book generation.

1. INTRODUCTION

Speech coding is a means of compressing digitized speech signal for efficient storage and transmission, while maintaining reasonable level of quality. Most speech coding systems were designed to support telecommunication applications, with frequency contents band limited between 300 and 3400Hz, i.e., frequency range of narrow band speech coding. In telecommunication applications speech is usually transmitted at 64 kbps, with 8 bits/sample and with a sampling rate of 8 KHz. Any bit-rate below 64 kbps is considered as compression. This paper deals with switched multistage vector quantizer, it is used in linear predictive coding (LPC) for quantization of line spectral frequencies (LSF) [1-2]. This technique is a hybrid of switch vector quantization technique and multistage vector quantization technique [3-7]. Switched multistage vector quantization is a lossy compression technique. As quality, complexity and memory requirements of a product affects the marketability and the cost of the product or services. The performance of SWMSVQ is measured in terms of spectral distortion, computational complexity and memory requirements. Switched multistage vector quantizer involves the connection of the vector quantizers in cascade where the difference between the input vector and quantized vector of one stage is given as an input to the next stage, each stage of the vector quantizer consists of codebooks connected in parallel. In this work two codebooks are connected in parallel so as to maintain a tradeoff between the switch bits and the number of codebooks to be searched at each stage of the quantizer i.e., when only two codebooks are connected in parallel with soft decision scheme the input vector is quantized by using the two codebooks connected in parallel, with hard decision scheme the input vector is quantized in only one of the two codebooks connected in parallel [7]. As only one bit is required for the two switches in both the soft and hard decision schemes, there can be an improvement in the spectral distortion performance with soft decision scheme when compared to the hard decision scheme. The aim of this article is to examine the performance of switched multistage vector quantizer and to compare its performance with other product code vector quantization schemes like split vector quantization [7-8], multistage vector quantization, switched split vector quantization and multi switched split vector quantization.

2. SWITCHED MULTISTAGE VECTOR QUANTIZER

The generation of the codebooks at different stages of switched multistage vector quantizer is shown in Figure 1.

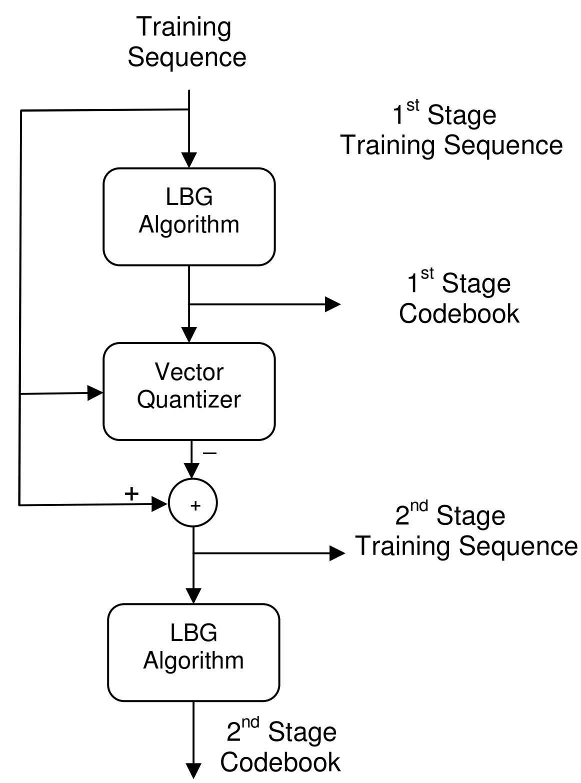


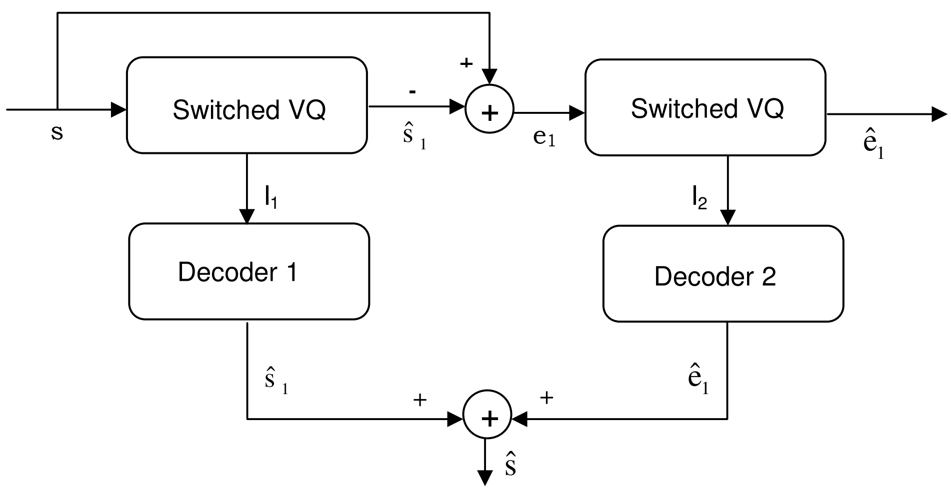
Figure1. Codebook Generation at different stages

The basic idea of switched multistage vector quantizer is to use n stages and m switches. With m switches at each stage of the vector quantizer, the performance of quantization has been improved by decreasing the computational complexity and memory requirements. For a particular switch the generation of codebooks at different stages is shown in Figure 1.

- Initially the codebook at the first stage is generated by using the Linde, Buzo and Gray (LBG) algorithm [9] by using training set of line spectral frequencies (LSF) as an input [10-**1**2].
- Secondly the difference vectors at the input of the second stage are generated by using the training sets of the first stage and the codebooks generated at the first stage of the quantizer.
- The training difference vectors at the input of the second stage are used to generate the codebooks of the second stage.
- The above process can be continued for the required number of stages for generating the codebooks.

An n x m Switched Multistage vector quantizer is shown in Figure 2. Where n corresponds to the number of stages, m corresponds to the number of switches. SWMSVQ involves the following steps

- Each vector 's' to be quantized is switched from one codebook to the other connected in parallel at the first stage of the quantizer so as to obtain the quantized vectors.



(I_i denotes the index of i^{th} quantizer)

Figure2. Block Diagram of Switched Multistage Vector Quantizer

- Extract the quantized vector with minimum distortion from the set of quantized vectors at the first stage i.e. $\hat{s}_1$ = Q[s].
- Compute the quantization error resulting at the first stage of quantization and let the error be $e_1 = s - \hat{s}_1$.
- The error vector at the first stage is given as an input to the second stage so as to obtain the quantized version of the error vector i.e. $\hat{e}_1 = Q[e_1]$.

This process can be continued for the required number of stages. Finally the quantized vectors from each stage are added up and the resulting vector will be the quantized version of the input vector 's' given by $\hat{s} = Q[s] + Q[e_1] + Q[e_2] + ...$. Where Q[s] is the quantized version of the input vector at the first stage, Q [e_1] is the quantized version of the error vector at the second stage and Q [e_2] is the quantized version of the error vector at the third stage and so on.

3. SPECTRAL DISTORTION

In order to objectively measure the distortion between the quantized and un quantized outputs a method called the 'spectral distortion' is often used in narrow band speech coding. For an i^{th} frame the spectral distortion, SD_i (in dB) between the quantized and un quantized vectors is given by [13]

$$SD_i = \sqrt{\frac{1}{(f_2 - f_1)} \int_{f_1}^{f_2} \left[10\log_{10} S_i(f) - 10\log_{10} \hat{S}_i(f)\right]^2 df} \; (dB) \quad (1)$$

Where $S_i(f)$ and $\hat{S}_i(f)$ are the LPC power spectra of the unquantized and quantized i^{th} frame respectively. The frequency f is in Hz, and the frequency range is given by f_1 and f_2. The frequency range used in practice for narrow band speech coding is 0-4000Hz. The average spectral distortion SD [13] is given by

$$SD = \frac{1}{N} \sum_{n=1}^{N} SD_i \quad (2)$$

Frames having spectral distortion greater than 1dB are called as outlier frames. The conditions for transparent speech coding are.

- The mean of the spectral distortion (SD) must be less than or equal to 1dB.
- The number of outlier frames having spectral distortion greater than 4dB must be zero.
- The number of outlier frames having spectral distortion between 2 to 4dB must be less than 2%.

4. COMPLEXITY AND MEMORY REQUIREMENTS

The computational complexity of a switched multistage vector quantizer using hard decision scheme is given by

$$Complexity_{SWMSVQ\ HARD} = \sum_{j=1}^{P} \left(4n\left(2^{b_m} + 2^{b_j}\right) - 2 \right) \quad (3)$$

The computational complexity of a switched multistage vector quantizer using soft decision scheme is given by

$$Complexity_{SWMSVQ\ SOFT} = \sum_{j=1}^{P} \left(\left(4n2^{b_m} - 1\right) + \left(\sum_{k=1}^{Pl} 4n2^{b_{jk}} - 1 \right) \right) \quad (4)$$

The memory requirements of a switched multistage vector quantizer using hard decision scheme is given by

$$Memory_{SWMSVQ\ HARD} = \sum_{j=1}^{P} n\left(2^{b_m} + 2^{b_j}\right) \quad (5)$$

The memory requirements of a switched multistage vector quantizer using soft decision scheme is

$$\text{Memory}_{\text{SWMSVQ SOFT}} = \sum_{j=1}^{P}\left(\left(n2^{b_m}\right)+\left(\sum_{k=1}^{Pl} n2^{b_{jk}}\right)\right) \tag{6}$$

Where
n is the dimension of the vector
b_m is the number of bits allocated to the switch vector quantizer
b_j is the number of bits allocated to the j^{th} stage
m = 2^{b_m} is the number of switching directions
P is the number of stages
b_{jk} is the number of bits allocated to the j^{th} stage k^{th} codebook
Pl is the number of codebooks connected in parallel at each stage

5. RESULTS AND DISCUSSION

Table1. Spectral distortion, Complexity, and Memory requirements for 3-Part Split vector quantization technique

Bits / frame	SD(dB)	2-4 dB	>4dB	Complexity (kflops/frame)	ROM (floats)
24	1.45	0.43	0	10.237	2560
23	1.67	0.94	0	8.701	2176
22	1.701	0.78	0.1	7.165	1792
21	1.831	2.46	0.2	5.117	1280

Table2: Spectral distortion, Complexity, and Memory requirements for 3-stage multistage vector quantization technique

Bits / frame	SD(dB)	2-4 dB	>4dB	Complexity (kflops/frame)	ROM (floats)
24	0.984	1.38	0	30.717	7680
23	1.238	1.2	0.1	25.597	6400
22	1.345	0.85	0.13	20.477	5120
21	1.4	1.08	0.3	15.357	3840

Table3: Spectral distortion, Complexity, and Memory requirements for 2- switch 3-part switched split vector quantization technique using hard decision scheme

Bits / frame	SD(dB)	2-4 dB	>4dB	Complexity (kflops/frame)	ROM (floats)
24	0.957	1.06	0	8.78	4372
23	1.113	1.29	0.14	7.244	3604
22	1.119	0.52	1.3	5.196	2580
21	1.127	1.3	0.56	4.428	2196

Table4: Spectral distortion, Complexity, and Memory requirements for 2- switch 3-stage switched multistage vector quantization technique using hard decision scheme

Bits / frame	SD(dB)	2-4 dB	>4dB	Complexity (kflops/frame)	ROM (floats)
24	0.93	1.4	0	15.594	3900
23	1.131	0.83	1.12	13.034	3260
22	1.134	0.42	1.56	10.474	2620
21	1.163	1.16	0.38	7.914	1980

Table5: Spectral distortion, Complexity, and Memory requirements for 2- switch 3-stage switched multistage vector quantization technique using soft decision scheme

Bits / frame	SD(dB)	2-4 dB	>4dB	Complexity (kflops/frame)	ROM (floats)
24	0.91	0.56	0.81	3.111	780
23	0.87	1.05	0.31	2.791	700
22	1.1	1.45	0.63	2.471	620
21	1.18	0.6	1.89	2.151	540

Table6: Spectral distortion, Complexity, and Memory requirements for a 3-stage 2-switch 3-part multi switched split vector quantization technique using hard decision scheme

Bits / frame	SD(dB)	2-4 dB	>4dB	Complexity (kflops/frame)	ROM (floats)
24	0.0322	0	0	0.9	396
23	0.0381	0	0	0.836	364
22	0.0373	0	0	0.772	332
21	0.0377	0	0	0.708	300

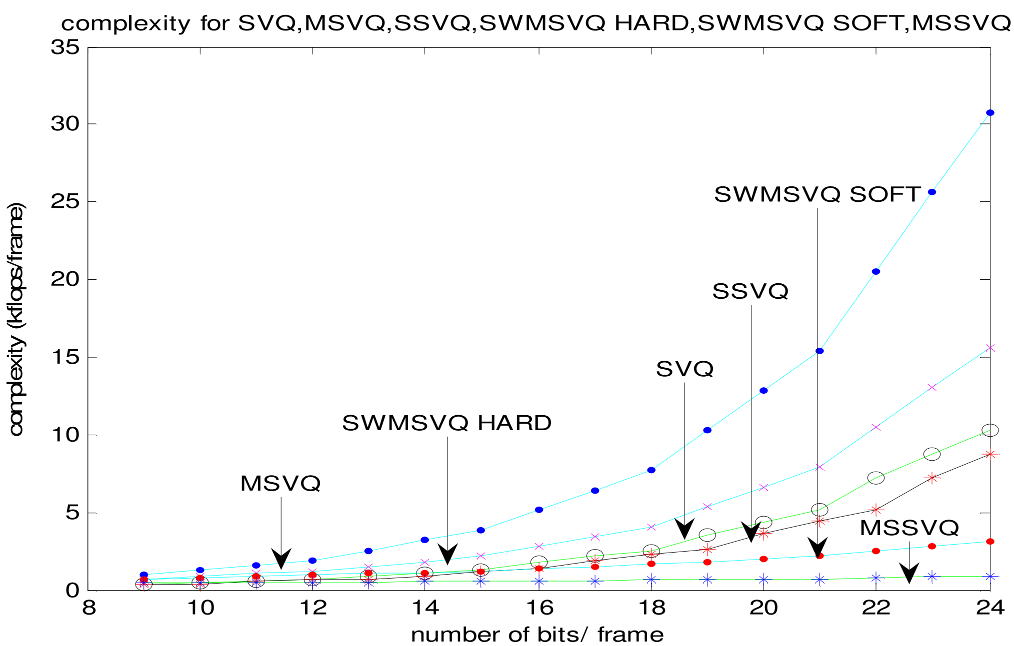


Figure.3. Complexity for SVQ, MSVQ, SSVQ Hard, SWMSVQ Hard, SWMSVQ Soft and MSSVQ Hard

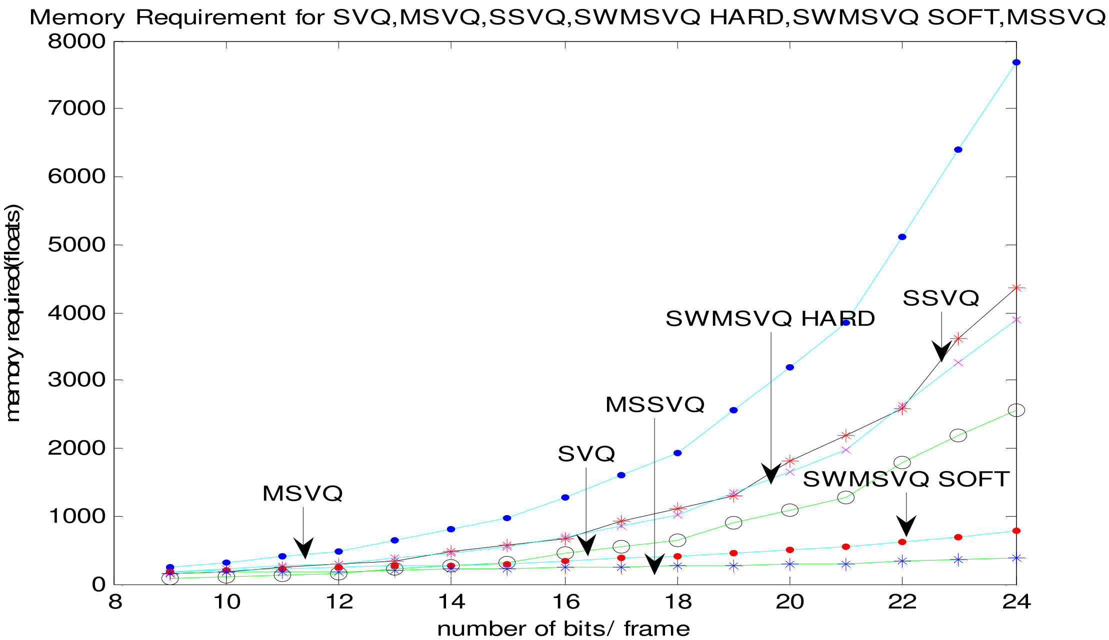


Figure.4. Memory requirements for SVQ, MSVQ, SSVQ Hard, SWMSVQ Hard, SWMSVQ Soft and MSSVQ Hard

Tables 1 to 4 shows the spectral distortion measured in dB, computational complexity measured in Kilo flops/frame, and memory requirements (ROM) measured in floats at various bit-rates for a 3-part split vector quantizer, 3-stage multistage vector quantizer, 2-switch 3-part switched split vector quantizer using hard decision scheme, 2-switch 3-stage switched multistage vector quantizer using hard and soft decision schemes and 3-stage 2-switch 3-part multi switched split vector quantizer using hard decision scheme. From Tables 1 to 4 and from Figures 3 & 4 it can be observed that SWMSVQ using soft decision scheme has less spectral distortion, computational complexity and memory requirements when compared to SVQ, MSVQ, SSVQ using hard decision scheme, and SWMSVQ using hard decision scheme but with a slight increase in spectral distortion, computational complexity and memory requirements when compared to MSSVQ using hard decision scheme. For SWMSVQ using hard decision scheme the spectral distortion is less when compared to SVQ, MSVQ, and SSVQ using hard decision scheme but with a slight increase in spectral distortion when compared to SWMSVQ using soft decision scheme and MSSVQ using hard decision scheme. The computational complexity of SWMSVQ using hard decision scheme is less when compared to MSVQ, and the memory requirements are less when compared to MSVQ and is in a comparable manner with SSVQ using hard decision scheme.

6. CONCLUSION

From results it is proved that SWMSVQ using soft decision scheme provides better trade-off between bit-rate and spectral distortion, computational complexity, and memory requirements when compared to all the product code vector quantization techniques except for MSSVQ using hard decision scheme. So SWMSVQ using soft decision scheme is proved to be better when compared to SVQ, MSVQ, SSVQ and SWMSVQ using hard decision scheme, and is having comparable performance when compared to MSSVQ using hard decision. The advantage with soft decision scheme is, with increase in the number of stages or codebooks per stage or splits per codebook the number of available bits at each stage, codebook, split gets decreased there by the computational complexity and memory requirements gets decreased, but the disadvantage is that there will be a limit on the number of stages, codebooks per stage and on the number of splits.

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