Complexity Comparison of Iterative Channel Estimation, Equalization and Decoding for GSM Receivers[1]

Hailong Cui, Predrag B. Rapajic

School of Electrical Engineering and Telecommunications
The University of New South Wales, Sydney, Australia

***Abstract*--** **In this paper we present the trade off between complexity and performance of 4 different types of GSM receiver: Conventional training sequence channel estimation receiver, iterative channel estimation feedback from equalizer, iterative channel estimation plus iterative equalization and decoding, and combination of iterative channel estimation and Iterative equalization and decoding. The combination of iterative channel estimation and iterative equalization and decoding has the best trade off among the receivers with iterative processes. It has about 1.3 dB gain over conventional receiver using training sequence estimation only.**

A. INTRODUCTION

Intersymbol Interference (ISI) caused by multi-path propagation is a significant problem in digital mobile communication system. In addition, the channel characteristic is time varying due to the movement of the mobile station relative to its surrounding. In a time division multiplex access (TDMA) system like GSM, the receiver must be able to estimate the channel and compensate for channel distortion adaptively. The performance of this compensation is largely determined by the accuracy of the channel estimation. In a conventional GSM receiver, the channel impulse response (CIR) is estimated using the known training sequence transmitted as a midamble in each burst. Feeding back the estimated data output from the equalizer or decoder as an extended training sequence can improve the accuracy of the estimated CIR. Which is called iterative channel estimation (ICE) [1].

The channel encoder and ISI channel can be treated as a serially concatenated coding scheme, the decoding principle of Turbo Code [2] can be used to perform iterative equalization and decoding [3]. Four different types of GSM receiver with these techniques were introduced. The complexity of implemented these receivers and the corresponding performances are compared here in terms of number of operations required in receiving one GSM block.

This paper is organized as follows: in section 2, we introduce the configuration of four candidate GSM receivers employing various iterative schemes. Their complexity analysis is presented in section 3. Simulation results of bit error rate (BER) performance are presented in section 4, and the conclusion is made in section 5.

B. CANDIDATE GSM RECEIVERS

The typical structure of the GSM digital receiver is shown in Figure 1. The channel impulse response (CIR) is estimated by a known training sequence or data sequence transmitted as a midamble in each GSM burst. The channel is estimated using channel sounding (CS) [4] or least square (LS) [5] techniques, and this estimated CIR is used in equalization process to eliminate the impact of Intersymbol Interference (ISI). After de-interleaving, the decoder estimates the original message sequence. In this paper, we consider receivers which employ maximum a posteriori probability (MAP) [6] algorithm for equalization and either maximum likelihood sequence estimation (MLSE) [7] or MAP estimation in the decoder. The MAP algorithm is a soft-in soft-out (SISO) algorithm, which is well suited to iterative receiver schemes.

1st. Conventional Training Sequence Receiver (TS)

In conventional training sequence receiver, the channel impulse response was estimated by the known training sequence stored at the receiver. MLSE or MAP is used to perform equalization and MLSE implemented by Viterbi algorithm to perform decoding. The output from the MAP equalizer will be soft value, which can improve the performance of decoder.

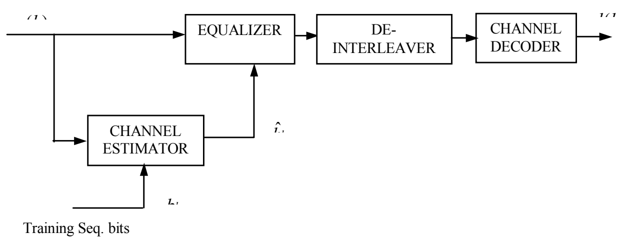

Fig 1. Conventional GSM receiver [1]

[1] This work was supported by Bell Labs, Lucent Technologies.

2nd. Iterative Channel Estimation from Equalizer (EQ-ICE)

The effectiveness of the Equalization depends on the accuracy of the reliability of the estimated CIR. In order to get more accurately estimation, the equalization output can be feedback to the channel estimator to perform Iterative Channel Estimation (ICE), the performance is further improved using soft decision feedback [8] This configuration is shown in Figure 2.

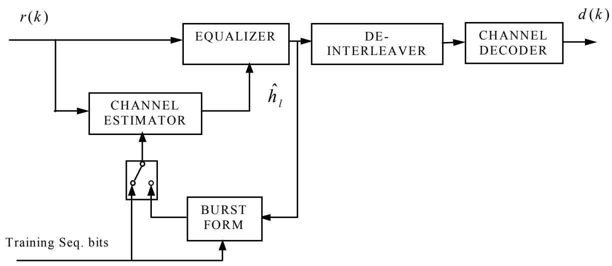

Fig 2. Iterative channel estimation feedback from equalizer [1]

3rd. Iterative Channel Estimation plus Iterative Equalization and Decoding (EQ-ICE+Turbo)

In GSM, the channel encoder and ISI channel can be viewed as a serially concatenated coding scheme, so the decoding principle of Turbo Code can be used to perform Iterative Equalization and Decoding [3]. So in this configuration there are two iterative processes: One for channel estimation and the other for equalization and decoding.

4th. Turbo Iterative Channel Estimation (Turbo-ICE)

As an extension to the EQ-ICE+Turbo receiver as described above. These two iterative processes can be combined to perform Turbo Iterative Channel Estimation. The output from the APP decoder were fed back to the channel estimator to re-estimate the channel, using the improved CIR and the extrinsic information as a priori knowledge, the APP equalizer will get improved data estimation.

MAP algorithm is used to perform these iterative processes. In order to reduce the complexity, a simplification of MAP algorithm: Max-Log-MAP [9] algorithm is used instead MAP in these receiver schemes. All the iterative processes can be performed any times without delay restriction [10]. One iterative process is performed for each in our comparison.

C. COMPLEXITY COMPARISON

The complexity is evaluated by the total operation needed in receiving one GSM block. The interleaving and de-interleaving processes are ignored in this complexity calculation. Channel sounding is used as channel estimation algorithm for both training sequence estimation and iterative channel estimation. The operation needed for one GSM burst is shown in Table 1. For soft decision feedback [8], a look up table used to convert the log likelihood ration (LLR) of each transmitted data into soft values.

Operation	Channel Sounding		
	Training Sequence Estimation	Iterative Channel Estimation	
		Hard Decision Feedback	Soft Decision Feedback
Multiplication	$M_{CIR}L_t$	$M_{CIR}(L_B - M_{CIR})$	$M_{CIR}(L_B - M_{CIR})$
Addition	$M_{CIR}(L_t - 1)$	$M_{CIR}(L_B - M_{CIR} - 1)$	$M_{CIR}(L_B - M_{CIR} - 1)$
Look-ups			$L_B - M_{CIR} - 26$

M_{CIR}: Number of estimated channel impulse response taps.

L_t : Number of training sequence bits used in channel estimation.

L_B: Length of a GSM normal burst excludes guard bits.

Table 1. The Complexity of Channel Sounding

Equalization is performed burst by burst and the decoding is taken when it receives the whole speech block. So the equalization and decoding complexity are estimated in term of the number of operation needed for equalizing one burst and decoding one speech block. Table 2 gives the complexity of Viterbi equalizer and decoder used in conventional training sequence receiver.

Operation	Viterbi Equalizer for GSM	Viterbi Decoder for GSM
Addition	$(M+2)\ 2^M(L_B+M)$	$8\ 2^K(L_{C1}+K)$
Multiplication	$(M+1)\ 2^M(L_B+M)$	$4\ 2^K(L_{C1}+K)$
Max Operation	$2^M\ (L_B+M)$	$2^K\ (L_{C1}+K)$

M : Memory Length of the ISI channel $M = M_{CIR} - 1$

L_B: Number of bits in one GSM normal burst excludes guard bits.

K : Memory length of the channel encoder for GSM.

L_{C1} : Length of Class1a bits in one GSM speech block.

Table 2. Complexity of Viterbi equalization and decoding

Max-Log-Map is used to perform iterative channel estimation, equalization and decoding. The operation required for equalizer and decoder is presented in Table 3.

Operation	Max-Log-MAP Equalizer				
	Branch Transition Probability γ Calculation	Forward Process α Calculation	Backward Process β Calculation	Log Likelihood Function	Total (Approximation)
Addition	$2(M+3)\ 2^M\ (L_B+M)$	$2\ 2^M\ (L_B+M)$	$2\ 2^M\ (L_B+M)$	$5\ 2^M\ L_B$	$(2M^2+10M+10L_B+2ML_B)\ 2^M$
Multiplication	$2(M+3)\ 2^M\ (L_B+M)$				$(2M+6)(L_B+M)\ 2^M$
Max Operation		$2^M\ (L_B+M)$	$2^M\ (L_B+M)$	$2\ 2^M\ L_B$	$(4L_B+2M)\ 2^M$

L_B: Number of bits in one GSM normal burst excludes guard bits.

M: Memory Length of the ISI channel. $M = M_{CIR} - 1$

Operation	Max-Log-MAP Decoder					
	Branch Transition Probability γ Calculation	Forward Process α Calculation	Backward Process β Calculation	Log Likelihood Function (Info Bits)	Log Likelihood Function (Coded Bits)	Total (Approximation)
Addition	$4\ 2^K\ (L_{C+1}+K)$	$2\ 2^K\ (L_{C1}+K)$	$2\ 2^K\ (L_{C1}+K)$	$5\ 2^K\ L_{C1}$	$2\ 2^K\ L_{C1}$	$(13L_{C1}+6K)\ 2^K$
Multiplication	$6\ 2^K\ (L_{C1}+K)$					$6(L_{C1}+K)\ 2^K$
Max Operation		$2^K\ (L_{C1}+K)$	$2^K\ (L_{C1}+K)$	$2\ 2^K\ L_{C1}$	$4\ 2^K\ L_{C1}$	$(8L_{C1}+2K)\ 2^K$

K: Memory Length of Channel Encoder for GSM

L_{C1}: Length of Class1a bits in one GSM speech block

Table 3. Complexity of Max-Log-MAP Equalizer and Decoder

The number of process times required in receiving one GSM speech block is shown in Table 4. One iteration is investigated for each configuration because the simulation result in [3][12] show that most of the improvement is achieved by the first iteration. The GSM speech block are divided into 8 sub-block and interleaved into 8 GSM burst, only receiving the first speech block required equalization of 8 burst. For the other speech block, 4 sub-block data have been equalized in the previous 4 bursts due to the interleaving process [11]. In our simulation:

. Estimated channel impulse response taps: $M_{CIR} = 5$

. Memory Length of the ISI channel $M = M_{CIR} - 1 = 4$

. Channel Encoder Memory of GSM: $K = 4$

. Length of one GSM Normal Burst: $L_B = 148$

. Length of training sequence used in channel estimation: $L_t = 16$

. Length of coded Class 1 bits in one speech block: $L_{C1} = 378$

In Table 5 we give the exact number of operation required for each type of GSM receiver in receiving one GSM speech block. Max-log-MAP is used in conventional GSM receiver to perform equalization.

RECEIVER TYPE	Number of Operation in Receiving one GSM Speech Block					
	TS Channel Estimation	Iterative Channel Estimation	Equalization		Decoding	
			Viterbi	Max-Log MAP	Viterbi	Max-Log MAP
TS	4	0		4	1	
EQ-ICE	4	4		8		1
EQ-ICE+Turbo (N iteration)	4	4		4(2+N)		1+N
Turbo-ICE (N-iteration)	4	4N		4(1+N)		1+N

TS: Training Sequence Only Receiver using Max-log-MAP equalization.

EQ-ICE: Iterative Channel Estimation Feedback from Equalizer.

EQ-ICE + Turbo: Iterative Channel Estimation Feedback from Equalization plus Iterative Equalization and Decoding.

Turbo-ICE: Iterative Channel Estimation Feedback from Decoder with Iterative Equalization and Decoding.

Table 4. Configuration of different receiver schemes

Operation	RECEIVER TYPE						
	TS	EQ-ICE		EQ-ICE+TURBO (1 Iteration)		TURBO-ICE (1 Iteration)	
		Hard Decision	Soft Decision	Hard Decision	Soft Decision	Hard Decision	Soft Decision
Addition	238652	432536	432536	686468	686468	511364	511364
Multiplication	160960	312236	312236	485100	485100	426732	426732
Max Operation	44512	125312	125312	212224	212224	173824	173824
Look-ups			976		976		976

Table 5. Complexity of different receiver schemes

D. SIMULATION RESULT

The simulation was done over EQ50 channel model provided by ETSI [11], it is an equalization test channel with vehicle moving at a speed of 50 km/h. The result shown in Figure 3 is using soft decision feedback for iterative channel estimation. From the simulation result of [8], we know that soft decision feedback has about 0.15 dB gain than hard decision only at a cost of some extra look-ups. Compared with EQ-ICE+Turbo in 2.3, Turbo-ICE has better performance and less cost. It has about 0.4-dB gain than EQ-ICE and a little more complexity. Without doubt, it is the best one among these 3 configurations (EQ-ICE, EQ-ICE+Turbo, and Turbo-ICE) when we trade off the complexity and performance. Compared with conventional training sequence receiver, Turbo-ICE has 1.3 dB gain and about 3 times complexity in implementation.

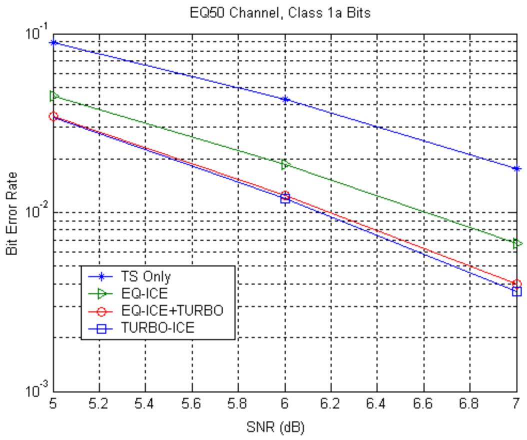

Fig 3. Performance of different receiver schemes

E. CONCLUSION

In this paper we investigated four different GSM receiver schemes and their complexity in implementation. Three kind of iterative processes have been studied: iterative channel estimation, iterative equalization and decoding, and combination of iterative channel estimation, equalization and decoding. Among these 3 configurations, the combination of iterative channel estimation, equalization and decoding has the best performance and complexity trade off. Using Channel Sounding channel estimation with soft decision feedback, it has about 1.3 dB gain over conventional training sequence receiver for class 1a bits in GSM. Similar improvement was also found for class 1b and class 2 bits.

F. ACKNOWLEDGEMENT

The authors wish to say thanks to Dr. Chris Nicol, Dr. Linda Davis, Dr. Graeme Woodward and Dr. Bing Xu for their support in this work.

G. REFERENCES

[1]. Carlo Luschi, Magnus Sandell, Paul Strauch, Ran-Hong Yan, "Iterative Channel Estimation, Equalization and Decoding", Internal paper of Lucent Technologies, Document NO. BL01131L-990225-04TM, 1999.

[2]. C. Berrou, A. Glavieux, and P. Thitimajshima, " Near shannon limit error-correcting and decoding: Turbo-codes (1)," in International Conference on Communications (ICC), pp.1064-1070, IEEE, May1993.

[3]. G. Bauch, V. Franz, " Iterative Equalization and Decoding for theGSM-system", Vehicular Technology Conference, 1999. VTC 1999 -Fall. IEEE VTS 50th, Volume: 5, pp.2954-2958, 1999.

[4]. G.L. Turin, " Introduction to spread-spectrum antimultipath techniques and there application to urban digital radio", Proceeding IEEE, vol.68, pp.328-353, March 1980.

[5]. L. Scharf, "Statistical signal processing: Detection, estimationand time series analysis", Addison-Wesley, 1991.

[6]. L. Bahl, J. Cocke, F. Jelinek, and J. Raviv, " Optimal Decoding of Linear Codes for Minimizing Symbol Error Rate", IEEE Trans. Inform. Theory, vol. IT-20, pp284-287. Mar 1974.

[7]. G. D. Forney, Jr., "Maximum Likelihood Sequence Estimation of Digital Sequences in the Presence of Intersymbol Interference", IEEE Trans. Inform. Theory, vol. IT-18, pp. 363-378, May 1972.

[8]. Sandell, M.; Luschi, C.; Strauch, P.; Yan, R, "Iterative Channel Estimation Using Soft Decision Feedback ", Global Telecommunications Conference, 1998. GLOBECOM 1998. The Bridge to Global Integration. IEEE , Volume: 6 , 1998,pp. 3728 –3733.

[9]. P. Roberson, E. Villebrun, and P. Hoeher, " A Comparison of Optimum and Sub- Optimum MAP Decoding Algorithms Operating in the Log Domain", in Proc. ICC '95, June 1995, pp. 1009-1013.

[10]. ETSI, GSM Recommendation 03.05, Digital cellular telecommunication system; Technical performance objectives, August 1996.

[11]. ETSI, "Digital cellular telecommunications system; Radio transmission and reception," GSM 05.05 version8.4.0, 1999.

[12]. Petermann, T.; Kuhn, V.; Kammeyer, K.-D. "Iterative blind and non-blind channel estimation in GSM receivers" Personal, Indoor and Mobile Radio Communications, 2000. PIMRC 2000. The 11th IEEE International Symposium on, Volume: 1,2000, pp.554-559