An improved 3GPP reconfigurable turbo decoder for flat Rayleigh fading channels

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Abstract

It is well known that in a turbo decoder extrinsic information increases with every iteration. In published literature it is shown that there are different techniques which improve the performance of Soft Output Viterbi Algorithm (SOVA) and max-log-Maximum A Posteriori (MAP) turbo decoding algorithms by applying a scaling factor at the extrinsic information. Most of these techniques give good Bit Error Rate (BER) and Frame Error Rate (FER) performance results, but the drawback is increased complexity for the turbo decoder. Following well known techniques and using 3rd Generation Partnership Project (3GPP) parameters for flat Rayleigh fading channels, this paper shows that for a reconfigurable SOVA/log-MAP turbo decoder, a common constant scaling factor can improve BER and FER performance significantly.

Keywords

Cognitive radio, 3GPP, Turbo coding

I. INTRODUCTION

During the past few years, turbo codes have attracted attention because of the large coding gains they can achieve in an additive white Gaussian noise (AWGN) channel [1, 2]. They are used already as a channel coding scheme in a number of mobile systems, one being 3GPP (third generation partnership project) for high data rates. 3GPP represents the most important 3G mobile communication standard today. Scaling of the extrinsic information is essential in a turbo decoder and according to the published literature the goal is to find the less complex technique that gives the best performance results.

Cognitive or software or reconfigurable radio generally represents signal processing elements of the radio interface implemented in software, which can be reconfigured either in the same mobile standard or between different mobile communications standards. An initial approach and analysis can be found in [3, 4]. In this paper we investigate the turbo decoder scaling technique which was proposed in [5], however considering flat Rayleigh fading channels instead of AWGN channels.

The structure of this paper is as follows: section II presents a literature review on turbo decoder scaling techniques and an overview of the reconfigurable SOVA/log-MAP turbo decoder. Subsequently, section III presents the technique we use to scale the extrinsic information of the turbo decoder and additionally presents the specifications of the simulation model to be used. The proposed scaling method is verified through simulations in section IV and finally we conclude in the last section.

II. LITERATURE REVIEW FOR TURBO DECODER SCALING TECHNIQUES – RECONFIGURABLE SOVA/LOG-MAP TURBO DECODER

In [6] and [7] it is explained that when SOVA is used as the soft input – soft output (SISO) turbo decoding algorithm, scaling of the extrinsic information is necessary. Particularly, the scaling method proposed in [6] limits the maximum value of the extrinsic information to a threshold value, which is determined by simulation. In [7] it is shown that SOVA suffers from two distortions: overoptimistic soft outputs, and correlation between the intrinsic and extrinsic information. Performance is degraded substantially by the first type of distortion but only mildly by the second. Therefore, according to [7], only the first type of distortion should be considered. The
solution to the first distortion problem is to multiply the extrinsic information by a scaling factor, which must be calculated for each decoder stage and recalculated for each new frame.

In [8] it is shown that a fixed scaling factor gives better performance compared to the method proposed in [7], while [9] proposes two scaling methods for a SOVA turbo decoder. In the first one the extrinsic information is scaled by a constant value, which is determined by simulation. The values of 0.5, 0.6, 0.7, 0.8 and 0.9 are evaluated. In the second scaling method the extrinsic information is also scaled by a constant value. This value increases with the number of iterations. Both of these factors are determined by simulation. Although this method is less complex than [7], suitable numbers have to be found in advance for the range of the signal-to-noise ratio (SNR) values used.

A similar but less complex method for SOVA is proposed in [10]: for SISO decoder 1 of the turbo decoder the scaling factor \( s_1 \) is calculated using the method of [9], but with \( s_2 \) a constant. The value of \( s_2 \) that gives the best performance is found to be 0.6. With this method the performance is almost the same as reported in [9], while the complexity is halved.

In [11] it is shown that for 3GPP standard, using max-log-MAP turbo decoding algorithm, the application of a scaling factor in the calculation of the extrinsic information can improve performance by 0.2 to 0.4 dB in AWGN and uncorrelated Rayleigh fading channels. The scaling factor is constant and equal to 0.7 and it is determined by simulation.

Reconfigurable systems represent reconfigurable functionalities of the radio interface. Considering turbo decoding function in battery powered devices like 3GPP mobile terminals, it would be desirable to choose the optimum decoding algorithm for each application. The two main candidate algorithms to be used in a SISO decoder are SOVA and log-MAP algorithms. In [3] and [5] it is shown that the two algorithms share common operations and it makes sense to consider a reconfigurable SOVA/log-MAP turbo decoder.

III. SCALING THE EXTRINSIC INFORMATION – SIMULATION MODEL

The simulation model is shown in Figure 1, and it considers a carrier frequency of 2 GHz. Firstly, it is assumed that 1,000,000 information bits are transmitted, which are grouped into frames whose length \( k_f \) is in the range of \( 40 \leq k_f \leq 5114 \). For a particular transport channel, every Time Transmission Interval (TTI) the data with the characteristics specified in a transport format of the transport channel (transport block set size or \( k_f \) bits), is turbo encoded (\( K = 4 \) and \( c_r = 1/3 \)) at the transmitter [12, 13].

No tailing bit scheme is applied to the two recursive systematic convolutional encoders of the turbo encoder: each time it is assumed that they start encoding from the all-zeros state. After turbo encoding and block interleaving using the 3GPP parameters, the bits are binary phase shift keying (BPSK) modulated and transmitted through the mobile channel. At the receiver the received values are not quantized, therefore floating point arithmetic is used. It is also assumed that the turbo decoder uses 8 iterations. Figure 2 presents a simplified diagram of the turbo decoder that neglects the details of interleaving and deinterleaving.

![Figure 1. Simulation model](image-url)
As can be seen in Figure 2, the extrinsic information sequence $I_i^{(s)}$ for decoder $i$ for every symbol $k$ is calculated as follows:

$$I_i^{(s)} = \left( \frac{A_i^{(s)}}{2} - I_i^{(0)} - z_i^{(0)} \right) s$$

where the term $s$ denotes the proposed scaling factor.

Therefore, using the same concept as in [5], in the following section it is shown that even in the case of a reconfigurable SOVA/log-MAP decoder for a flat Rayleigh fading channel, scaling of the extrinsic information is possible, applying a common scaling factor to both SOVA and log-MAP algorithms.

### IV. SIMULATION RESULTS

Our simulation results are obtained using a flat Rayleigh fading channel. Firstly, the best common scaling factor for SOVA and log-MAP algorithms is evaluated. Subsequently, two sample frame lengths are examined in order to show the effect of the chosen scaling factor on BER and FER performance compared to the standard algorithms ($s = 1$): a short length of 100 bits and the maximum frame length for 3GPP (5114 bits) [3].

#### A. Best scaling factor evaluation

For a frame length of 5114 bits, in order to find the best common scaling factor the values 0.5, 0.6, 0.7, 0.8 and 0.9 are examined for the reconfigurable SOVA/log-MAP turbo decoder. Similarly, to [16] we choose these values because the scaling factor for SOVA is almost always between approximately 0.5 and 0.9. Our results show that the same happens for log-MAP.

Using the flat Rayleigh fading channel model, simulation results are presented in the figures below for the different scaling factors assuming the following parameters: $R_b = 128$ kbps (equivalent to a symbol rate $R_s$ of 384 Kbaud), mobile speed 100 km/h (normalised fade rate $f_d T_s = 0.00048$ with Doppler frequency $f_d = 185.1$ Hz) and TTI 80 msec.

**Figure 2. Simplified turbo decoder diagram showing the scaling operation**

**Figure 3. BER performance for 3GPP turbo code evaluating the best scaling factor using a flat Rayleigh fading channel with 100 km/h mobile speed, log-MAP algorithm, frame length of 5114 bits**

**Figure 4. FER performance 3GPP turbo code evaluating the best scaling factor using a flat Rayleigh fading channel with 100 km/h mobile speed, log-MAP algorithm, frame length of 5114 bits**
Figure 3 presents the BER performance for the different scaling factors for log-MAP algorithm. At a BER of $10^{-3}$ a performance gain of 0.15 dB is seen using $s = 0.7$ or $s = 0.8$ compared to $s = 0.5$, while compared to $s = 0.6$ the gain is 0.04 dB. This means that $s = 0.7$ or $s = 0.8$ are the best choices in terms of BER.

If the FER performance is considered (Figure 4), at a FER of $10^{-1}$ a performance improvement of 0.5 dB is seen using $s = 0.8$ compared to $s = 0.5$, while compared to $s = 0.7$ or $s = 0.9$ the gain is 0.06 dB. Therefore, the best scaling factor in terms of FER is $s = 0.8$ followed by $s = 0.7$ and $s = 0.9$.

For SOVA, the BER performance for the different scaling factors is presented in Figure 5. At a BER of $10^{-3}$ the improvement using $s = 0.5$ or 0.6 instead of $s = 0.9$ is 0.2 dB, while compared to $s = 0.7$ it is 0.1 dB. Therefore, considering BER the highest performance gain is given by $s = 0.5$ and $s = 0.6$ followed by $s = 0.7$.

![Figure 5. BER performance of 3GPP turbo code evaluating the best scaling factor using a flat Rayleigh fading channel with 100 km/h mobile speed, SOVA algorithm, frame length of 5114 bits](image)

![Figure 6. FER performance of 3GPP turbo code evaluating the best scaling factor using a flat Rayleigh fading channel with 100 km/h mobile speed, SOVA algorithm, frame length of 5114 bits](image)

Considering FER performance, as shown in Figure 6, at a FER of $10^{-1}$ there is 0.4 dB gain by using $s = 0.6$ compared to $s = 0.9$, while there is 0.05 dB gain compared to $s = 0.7$ and $s = 0.5$. Thus, the best factor in terms of FER is $s = 0.6$ followed by $s = 0.7$ and $s = 0.5$.

As the above results show, it is obvious that even in the case of a flat Rayleigh fading channel for a reconfigurable SOVA/log-MAP decoder a common scaling factor with value 0.7 is the best choice considering BER and FER performances.

### B. Performance gain of the improved decoder for 100 km/h mobile terminal speed – Diversity

Having shown that $s = 0.7$ is the optimum common scaling factor choice for the reconfigurable SOVA/log-MAP decoder, this section presents the performance gain compared to $s = 1$ for different mobile channels and for two frame lengths. A data rate of 128 kbps (equivalent to a symbol rate of 384 Kbaud) and a TTI of 80 msec are used in the simulations.

In the following figures the performance of the simulated system for mobile speed 100 km/h (normalised fade rate $f_d T_f = 0.00048$) for the different scaling factors and two frame lengths is stated. The corresponding Doppler frequency for this speed is $f_d = 185.1$ Hz.
On a radio channel fading can be measured in terms of diversity, which provides two or more channels or branches for the same information signal. Thus, order-2 diversity represents two branches. Three different diversity techniques exist: space, frequency or time, with space diversity being the most popular [14]. It is well known that the uncoded flat Rayleigh fading channel has a slope of –1 (or 10 dB/decade), while the uncoded flat Rayleigh fading channel with order-2 diversity has a slope of –2 (or 20 dB/decade). It is interesting to note in Figures 7 and 8 that the turbo coded flat Rayleigh fading channel using a 100-bit frame length has a slope of approximately 10 dB/decade which is the same like the uncoded flat Rayleigh fading channel slope.

For 100 bits frame length, Figure 7 shows an improvement of 0.2 dB for log-MAP at a BER of $10^{-3}$. The improvement for SOVA is 0.3 dB at the same BER. At an FER of $10^{-1}$ for the same frame length, as Figure 8
shows, the FER improvement for SOVA is 0.3 dB, which is the same as the BER improvement. At the same FER there is no improvement for log-MAP.

For a large frame length and at a BER of $10^{-3}$, Figure 9 shows an improvement of 0.25 dB for log-MAP. At the same BER using SOVA the improvement is the same as with log-MAP, 0.25 dB. In terms of FER (Figure 10), it can be seen that at an FER of $10^{-1}$ the improvement for log-MAP is 0.13 dB, while for SOVA the improvement is 0.7 dB.

C. Performance gain of the improved decoder for 250 km/h mobile terminal speed

Here, a mobile speed of 250 km/h (normalised fade rate $f_d T_s = 0.0012$) is considered, while the corresponding Doppler frequency is $f_d = 462.9$ Hz. The performance of both algorithms with the different scaling factors is shown below.

Figure 11 illustrates that for a frame length of 100 bits at a BER of $10^{-3}$ for log-MAP there is an improvement of 0.25 dB. For SOVA there is a gain of 0.7 dB at the same BER. Figure 12 shows that for the same frame length and at FER=$10^{-1}$ for SOVA the improvement compared to the standard algorithm is 0.4 dB. For log-MAP there is no improvement at the same FER.

For a large frame, as Figure 13 illustrates, the improvement with the proposed scaling factor is 0.12 dB at a BER of $10^{-3}$ for log-MAP. For SOVA the improvement is 0.82 dB at the same BER. In terms of FER for a large frame Figure 14 shows that at an FER of $10^{-1}$ the gain compared to the standard algorithm is 0.11 dB for log-MAP, while for SOVA it is 0.5 dB.

If we compare Figures 9 and 13 it can be observed that for large frames as the mobile speed increases the BER improvement decreases for log-MAP (from 0.25 to 0.12 dB), while for SOVA the improvement increases (from 0.25 to 0.82 dB). Furthermore, for both speeds, the improvement is less for 100-bit frames compared to 5114-bit frames, as expected.
V. DISCUSSIONS AND CONCLUSIONS

Cognitive radio and reconfigurable structures – technologies have gained considerable attention the last decade, due to the plethora of new technologies. In this paper it is shown that it is possible to improve the performance of a reconfigurable SOVA/log-MAP turbo decoder for 3GPP mobile communications standard by applying a constant scaling factor to the extrinsic information.

In [5] it was shown that it is possible to improve the performance of a reconfigurable SOVA/log-MAP turbo decoder by applying a constant scaling factor to the extrinsic information for AWGN channels. More specifically, our work in [5] showed that a scaling factor equal to 0.7 is the optimum choice for both SOVA and log-MAP among the possible value range (0.5 to 0.9). The proposed scaling factor is constant over all frame lengths and iterations, and so can be implemented in a reconfigurable SOVA/log-MAP turbo decoder for 3GPP with minimum cost. In this paper we followed similar approach as in [5] for flat Rayleigh fading channels and we were able to verify the previous results.

Using the proposed scaling factor for AWGN channels in [5] in terms of BER, the performance, compared to the standard algorithms, improves up to 0.45 dB for SOVA and up to 0.15 dB for log-MAP. In terms of FER the performance improves up to 0.48 dB for SOVA and up to 0.13 dB for log-MAP. In the case of uncorrelated Rayleigh fading channels according to [11] the BER improves up to 0.2 dB for log-MAP and up to 0.5 dB for SOVA. The FER improves up to 0.12 dB for log-MAP and up to 0.6 dB for SOVA.

In this paper for flat Rayleigh fading channels our simulation results shows that the BER improves up to 0.25 dB for log-MAP, whereas the improvement for SOVA can be up to 0.82 dB. For log-MAP the FER can be improved up to 0.13 dB, while for SOVA the FER improves up to 0.7 dB. It is also observed that for large frame lengths as the mobile speed increases the BER improvement decreases for log-MAP, while for SOVA the improvement increases.

REFERENCES


