Strategies for Blind Transport Format Detection Using Cyclic Redundancy Check in UMTS WCDMA

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Abstract

Cyclic redundancy check (CRC) bits that are conventionally used for error detection have recently found a new application in UMTS WCDMA standard (specifically, "blind transport format detection") for message length detection of variable-length message communications. Co-worked with the inner convolutional code, it was demonstrated that the CRC bits can simultaneously detect the receiver-unaware length of a message block without much degradation in its error detection capability. In this work, we introduce two novel decoding strategies for joint decoding of the convolutional and the CRC code. Two previous strategies are also quoted for comparison. Simulation results on their error performance and computational complexity are given.

Index terms - CRC, WCDMA, variable-length message, length detection, blind transport format detection

1 Introduction

It is common in communication systems that the length of transmitted message blocks varies. Additional length information is thus necessary for the receiver to de-block the message. To achieve a reliable transmission, an error correcting code is often used to protect the message. A fixed number of CRC bits are attached at the end for a possible retransmission in case uncorrected channel errors occur.

In a variable message-length communication system, the transmission of message-length information requires additional system overhead. In some specific applications, the data rate is quite low such that the transmission of additional length information becomes an inefficient system burden. An example is the AMR 12.2 kbps mode of UMTS WCDMA, in which the transmission overhead for message length may be as large as 3 kbps, which consumes almost 25% of the 12.2 kbps data rate. In such case, detection of message length through the attached CRC bits with the help of inner convolutional code decoder as shown in Fig. 1 becomes a potential system alternative.

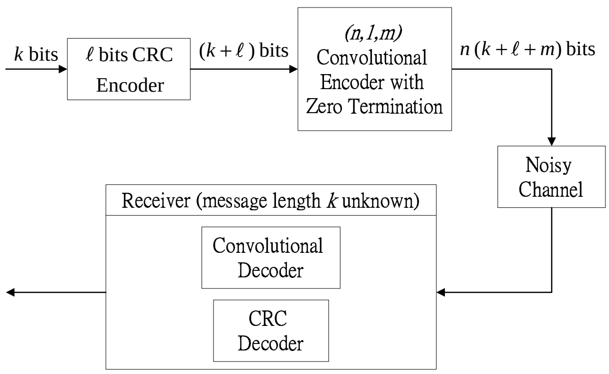

Figure 1: Block diagram of the "blind transport format detection" for a communication system with unknown message length. The message length k that is chosen from the candidate message-length set $\mathcal{K} = \{k_1, k_2, \ldots, k_p\}$ is assumed unknown to the receiver. The receiver thus must detect the message length through the attached CRC bits with the help of convolutional decoder.

Assume that the message length k is chosen uniformly from a candidate message-length set $\mathcal{K}$ of finite size p, where $\mathcal{K} = \{k_1, k_2, \cdots k_p\}$ is pre-negotiated between the transmitter and the receiver. As shown in Fig. 1, the k-bit message block is first CRC-

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encoded by an ℓ-bit CRC encoder, and then convolutional encoded by an $(n, 1, m)$ convolutional code. Additional m zeros are attached after CRC encoded message block to terminate the trellis of convolutional codes. The resultant frame structure is summarized in Fig. 2.

Variable Length User Data (length $k \in K$)	CRC bits (ℓ bits)	Tail bits (m bits)	Empty

Figure 2: Frame structure for "blind transport format detection" in UMTS WCDMA System.

The underlying concept for message-length detection is as follows. A length $\hat{k}$ is accepted as a legitimate candidate length by the receiver, only when the all-zero state on the decoding trellis of the convolutional code gives the largest path metric among all nodes at the same trellis time index $(\hat{k}+\ell+m)$, and meanwhile, the CRC test applied to the convolutional decoded block of $(\hat{k}+\ell)$ bits is passed. Here, our system presumes that the path metric of the best (e.g., maximum-likelihood) codeword is the largest among all codewords.

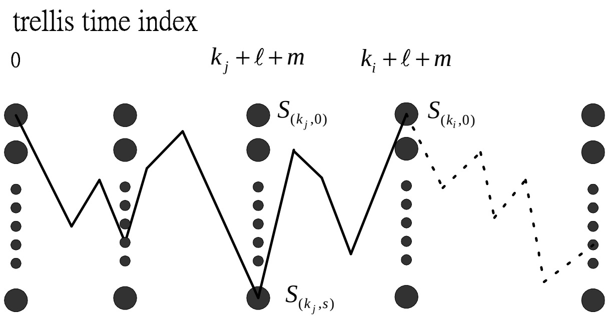

Figure 3: Sample of trellis diagram of the convolutional code. The solid line draws the correct path that corresponds to the codeword transmitted.

To make it clear, a sample trellis diagram is illustrated in Fig. 3. It can be seen from the figure that the trellis path at trellis time index $(k_i+\ell+m)$ shall end at the all-zero state $S_{(k_i,0)}$ because of the attached m zero bits, where k_i is the true message length. As $k_j < k_i$ is an incorrect length, the survivor path ending at the all-zero state $S_{(k_j,0)}$ shall have smaller path metric than the survivor path ending at state $S_{(k_j,s)}$ under error-free transmission. By comparing the metrics of the survivor paths at each trellis level, one should be able to find the legitimate candidate message length k_i.

In [2], it is proposed to test the legitimacy of the candidate message length in terms of the variable:

$$\delta(k_i) = -10 \log \left(\frac{\lambda_0(k_i) - \lambda_{\min}(k_i)}{\lambda_{\max}(k_i) - \lambda_{\min}(k_i)} \right), \qquad (1)$$

where $\lambda_0(k_i)$, $\lambda_{\max}(k_i)$ and $\lambda_{\min}(k_i)$ are respectively the zero-state, the maximal and the minimal path metrics among all survivor paths at the trellis time index $(k_i + \ell + m)$. Obviously, the range of $\delta(k_i)$ is $0 \le \delta(k_i) \le +\infty$, where $\delta(k_i) = 0$ if $\lambda_0(k_i) = \lambda_{\max}(k_i)$ and $\delta(k_i) \triangleq +\infty$ if $\lambda_0(k_i) = \lambda_{\min}(k_i)$.

In noiseless transmission, $\delta(k_i)$ corresponding to the true message length k_i equals zero. For candidate message length k_j other than the true message length, $\delta(k_j) \ge 0$. In fact, the probability of $\delta(k_j) = 0$ (which may incur a possible wrong estimate of the true message length) is equal to $2^{-\min\{m,|k_i-k_j|\}}$ under error-free transmission.

In noisy transmission, $\delta(k_i)$ may be larger than zero, even if k_i is the true message length. In order not to exclude the true message length at the receiver end, it is proposed in [2] to relax the test of *finding the survivor with the largest metric*, which is equivalent to the test of whether $\delta(k_i) = 0$ or not, to the threshold test of whether $\delta(k_i) < \Delta$ or not. Specifically, if $\delta(k_i) < \Delta$, the Viterbi decoder traces back the trellis, and outputs the decoded $(k_i+\ell)$ bits for further CRC checking. If the CRC check is also passed, a legitimate message length is found.

By considering their nature, we classify the error events into two categories: *detected error* and *undetected error*. The former concerns the case that none of the lengths in $\mathcal{K}$ can pass both the δ-function threshold test and the CRC test. The latter considers that at least one length in $\mathcal{K}$ passes both tests, but either the claimed length is wrong or a wrong message block with correct length is resulted.

2 Previous Decoding Strategies

In this section, we introduce two decoding strategies proposed by NTT DoCoMo in [2] and [4].

The first decoding strategy, which is proposed in [2], searches only one legitimate message length. The entire decoding process is ended right after the first legitimate message length is found or when all possible length candidates are exhausted.

For clarity, we list the first decoding strategy below (cf. Fig. 4):

1. Set a fixed threshold Δ, and set $i = 1$.
2. Calculate $\delta(k_i)$ according to Eq. (1).
3. If $\delta(k_i) < \Delta$, then the Viterbi decoder traces back from the all-zero state at trellis time index $(k_i + \ell + m)$, and outputs the decoded block with $(k_i + \ell)$ bits; else, go to step 5.
4. If the block with $(k_i + \ell)$ bits passes the CRC test, a legitimate message length k_i is found and the decoding process is terminated.
5. If $i < p$, then set $i = i + 1$ and go to step 2; else, the received frame is declared to be in error.

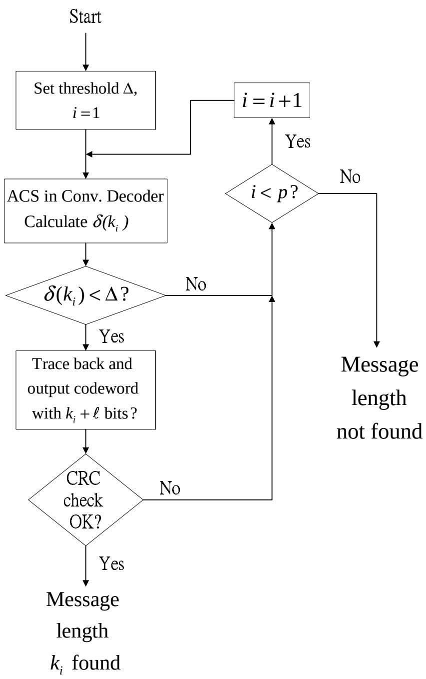

Figure 4: Flow chart of the first decoding strategy proposed in [2].

The second decoding strategy is from [4]. Unlike the first one, the second decoding process is not ended after the appearance of the first legitimate message length. It continues to search for other legitimate message lengths until all lengths in $\mathcal{K}$ are examined. In the end, if more than one legitimate message lengths are found, the strategy proposes to output the one with the lowest δ-function value.

Again, the algorithm of the second decoding strategy is listed below for clarity (cf. Fig. 5):

1. Set a fixed threshold Δ. Let the current best δ-function value $\delta_{\min} = \Delta$, and set the current best legitimate message length $\hat{k} = 0$. Also, set $i = 1$.
2. Calculate $\delta(k_i)$ according to Eq. (1).
3. If $\delta(k_i) < \Delta$, then the Viterbi decoder traces back from the all-zero state at trellis time index $(k_i + \ell + m)$, and outputs the decoded block with $(k_i + \ell)$ bits; else, go to step 6.
4. If the block with $(k_i + \ell)$ bits does not pass the CRC test, go to step 6.
5. If $\delta(k_i) < \delta_{\min}$, set $\delta_{\min} = \delta(k_i)$ and $\hat{k} = k_i$.
6. If $i < p$, set $i = i + 1$ and go to step 2.
7. If $\hat{k} \neq 0$, a legitimate message length $\hat{k}$ is found; else, the received frame is declared to be in error.

3 Novel Decoding Strategies

In the second decoding strategy, the decoder traces back the trellis, and examines the CRC validity as long as $\delta(k_i) < \Delta$, even if $\delta(k_i)$ is greater than the current best δ-function value $\delta_{\min}$. Such design introduces unnecessary overhead. With the knowledge of $\delta_{\min}$, namely the best δ-function value up to the current length under tests, we found that the system inefficiency due to unnecessary tracebacks and CRC test can be simply eliminated by adopting a dynamic threshold, rather than a fixed one. To be specific, we propose to update Δ by $\delta(k_i)$ if length k_i can pass both the δ-function threshold test and the CRC test. In such way, the number of unnecessary tracebacks and CRC tests can be reduced. This results in the third decoding strategy below (cf. Fig. 6).

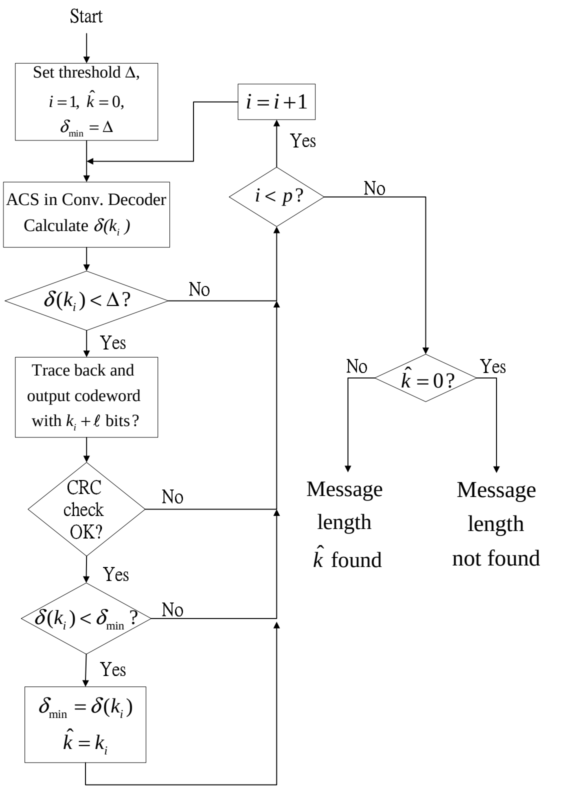

Figure 5: Flow chart of the second decoding strategy proposed in [4].

1. Set an initial threshold Δ. Let the current best legitimate message length $\hat{k} = 0$. Also, set $i = 1$.

2. Calculate $\delta(k_i)$ according to Eq. (1).

3. If $\delta(k_i) < \Delta$, then the Viterbi decoder traces back from the all-zero state at trellis time index $(k_i+\ell+m)$, and outputs the decoded block with $(k_i + \ell)$ bits; else, go to step 5.

4. If the block with $(k_i + \ell)$ bits passes the CRC test, set $\Delta = \delta(k_i)$ and $\hat{k} = k_i$.

5. If $i < p$, set $i = i + 1$ and go to step 2.

6. If $\hat{k} \neq 0$, a legitimate message length $\hat{k}$ is found; else, the received frame is declared to be in error.

The main idea of the second and the third decoding strategies is to find the best legitimate message length with the lowest δ-function value. Since, no matter which decoding strategy is employed, the evaluation of the δ-function value for every length in $\mathcal{K}$

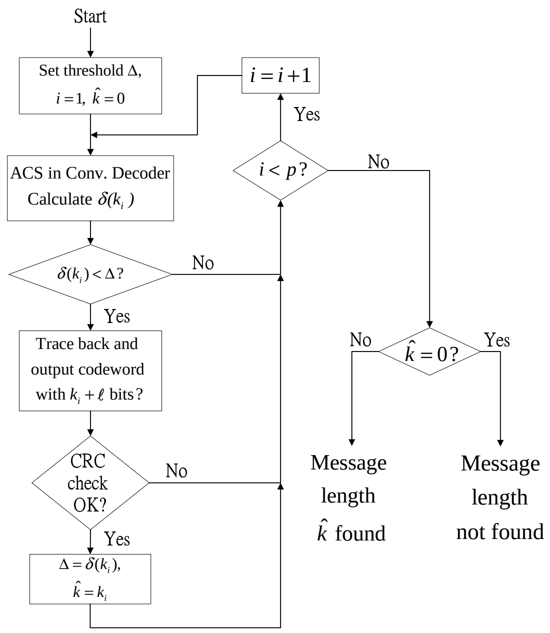

Figure 6: Flow chart of the third decoding strategy.

is unavoidable, we further propose the forth decoding strategy to minimize the number of tracebacks in the Viterbi decoder. Our idea is to first evaluate and store all δ-function values for all length candidates. Then, sort them according to ascending δ-function values. The next step is to perform tracebacks and the CRC test starting from the one with the lowest δ-function value until the first legitimate message block is found or all length candidates are exhausted.

For clarity, we list the forth decoding strategy in the following (cf. Fig. 7):

1. Evaluate $\delta(k_i)$ for $1 \le i \le p$ according to Eq. (1).

2. Sort lengthes in ascending order of δ-function values. In other words, $\delta(k_{(1)}) \le \delta(k_{(2)}) \le \cdots \le \delta(k_{(p)})$, where $k_{(i)}$ is the message length corresponding to the i-th smallest δ-function value.

3. Set $i = 1$.

4. The Viterbi decoder traces back from the all-zero state at trellis time index $(k_{(i)}+\ell+m)$, and outputs the decoded block with $(k_{(i)} + \ell)$ bits.

5. If the CRC test for the block with $(k_{(i)}+\ell)$ bits is passed, a legitimate message length $k_{(i)}$ is found, and the decoding process is terminated.

6. If $i < p$, set $i = i + 1$ and go to step 4; else, the received frame is declared to be in error.

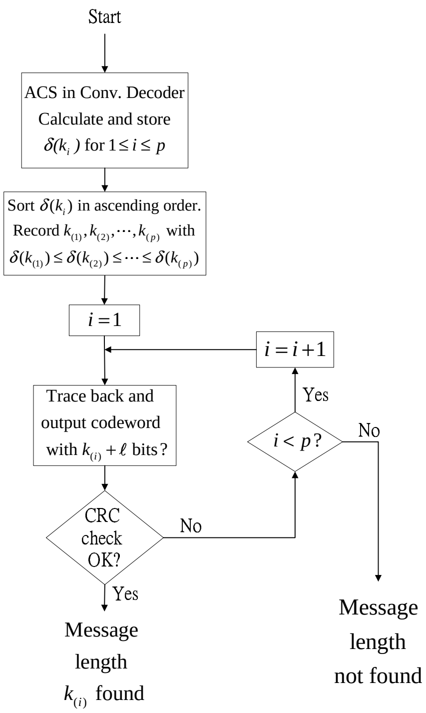

Figure 7: Flow chart of the forth decoding strategy.

4 Simulation Results and Comparison

In this section, the simulation results for antipodal transmission over the AWGN channel are presented. The candidate message length set is $\mathcal{K} = \{39, 42, 49, 55, 58, 61, 65, 75, 81\}$. The true message length k is uniformly chosen from $\mathcal{K}$. The message block of k bits is first used to generate 8 CRC bits, where the CRC generator polynomial is $g(x) = x^8 + x^7 + x^4 + x^3 + x + 1$. These 8 CRC bits are then attached after the message block in reversed order.[2] The whole $(k + \ell)$-bit CRC coded block is convolutional encoded using a $(2, 1, 8)$ convolutional encoder with generator polynomial $[561, 753]$ (in octal). Additional 8 zeros are attached to make certain that the trellis terminates at the all-zero state. Our simulation setting follows Table B.1 in Annex B in [5].

[2]Attaching CRC bits after the message block without any modification will introduce high undetected error rate, especially when the surmised message length k' is within ℓ-vicinity of the true message length k, i.e., $|k - k'| < \ell$. It was demonstrated that attaching CRC bits in reversed order can flatten the undetected error rate to a constant value [3, 6].

The simulation results for the block error rate (BLER), the detected error rate (DER) and the undetected error rate (UER) for different initial threshold Δ and different decoding strategy are shown in Fig. 8. Notably, BLER = UER + DER. The average number of tracebacks in the convolutional decoder is summarized in Fig. 9.

First, we remark on the BLER for different initial threshold Δ_{init} and different decoding strategies. Referring to Subfigs. 8(a), 8(b) and 8(c), the BLER is high when the uncoded SNR is low. This is because at low SNR, the joint decoder frequently fails to find any legitimate message length. As the SNR increases, the BLER approaches a floor value. Similar results are also shown in [2].

The DER, as depicted in Subfigs. 8(d), 8(e) and 8(f)), decreases fast as the SNR grows, and is almost indifferent with respect to the decoding strategies. It can also be observed that the DER decreases as Δ increases.

From Subfigs. 8(g), 8(h) and 8(i), we note that the UER decreases at a markedly slower speed than the DER. Contrary to DER, the UER increases as Δ increases. However, the impact of Δ choice on the UER becomes negligible when the SNR is high for the second and the third decoding strategies.

In summary of all subfigures, the DER dominates the BLER at low SNR, and the UER dominates the BLER at high SNR.

As pointed out in [2], the reason why the first decoding strategy proposes to terminate the decoding process after the appearance of the first legitimate message length is to avoid a large UER. From Subfig. 8(g), the first decoding strategy does offer a smaller UER if the initial threshold is small, namely 1 in this case. However, Δ should not be too small especially at low SNR; otherwise, the probability of detection will suffer. We may say that the higher the Δ is, the better the DER and the BELR will be at low SNR. In addition, the performance of the first decoding strategy is very sensitive to the choice of the initial threshold Δ. Figure 8(a) indicates that when the SNR is less than 3 dB, the best Δ that minimizes the BLER is actually 3. When the SNR is between 3 dB and 4 dB, the best Δ reduces to 2. The best Δ becomes 1 when the SNR is larger than 4 dB. Therefore, if the exact SNR is unknown to the receiver, how to choose an appropriate Δ to minimize the BLER becomes an essential problem for the first decoding strategy.

The BLER, the DER and the UER for the second and the third decoding strategies are the same. When being compared with the first decoding strategy, the influence of the initial threshold Δ on the BLER greatly reduces. In fact, the BLER, the DER and the UER almost remain intact as long as the initial threshold Δ is sufficiently large.

The forth decoding strategy completely eliminates the impact of the choice of the initial threshold Δ. The BLER of the forth decoding strategy outperforms those of all other decoding strategies almost at all SNRs.

Next, we examine the decoding complexity for different decoding strategies.

The complexity difference between the second and the third decoding strategies is the number of tracebacks in the convolutional decoder. For both decoding strategies, the number of traceback increases as the initial threshold Δ increases; however, the third decoding strategy that dynamically adjusts the threshold Δ significantly reduces the number of tracebacks. For example, when $\Delta = 3$ and SNR=5 dB, the average number of tracebacks for the second decoding strategy is 2.94, while that of the third decoding strategy is only 1.32.

As anticipated, the forth decoding strategy needs much less number of tracebacks in the convolutional decoder than the other strategies. For example, when SNR equals 5 dB, the average number of tracebacks for the forth decoding strategy is 1.07, while the average number of the second (resp. third) decoding strategy is 2.94 (resp. 1.32). Although the forth decoding strategy requires additional memory and computation work for storing and sorting the nine δ-function values, the reduction in the number of tracebacks is more than enough to compensate the additional computation work.

5 Conclusion

Cyclic redundancy check, when it is collaborated with the inner convolutional code, has recently been used in UMTS WCDMA system for message length detection of variable-length message communications. Two tests, δ-function threshold test and CRC test, are performed to search for the legitimate message length. Two novel decoding strategies are proposed to jointly decode the convolutional and the CRC codes. Simulation results show that the error performance and the computational complexity can be greatly improved by the two novel decoding strategies.

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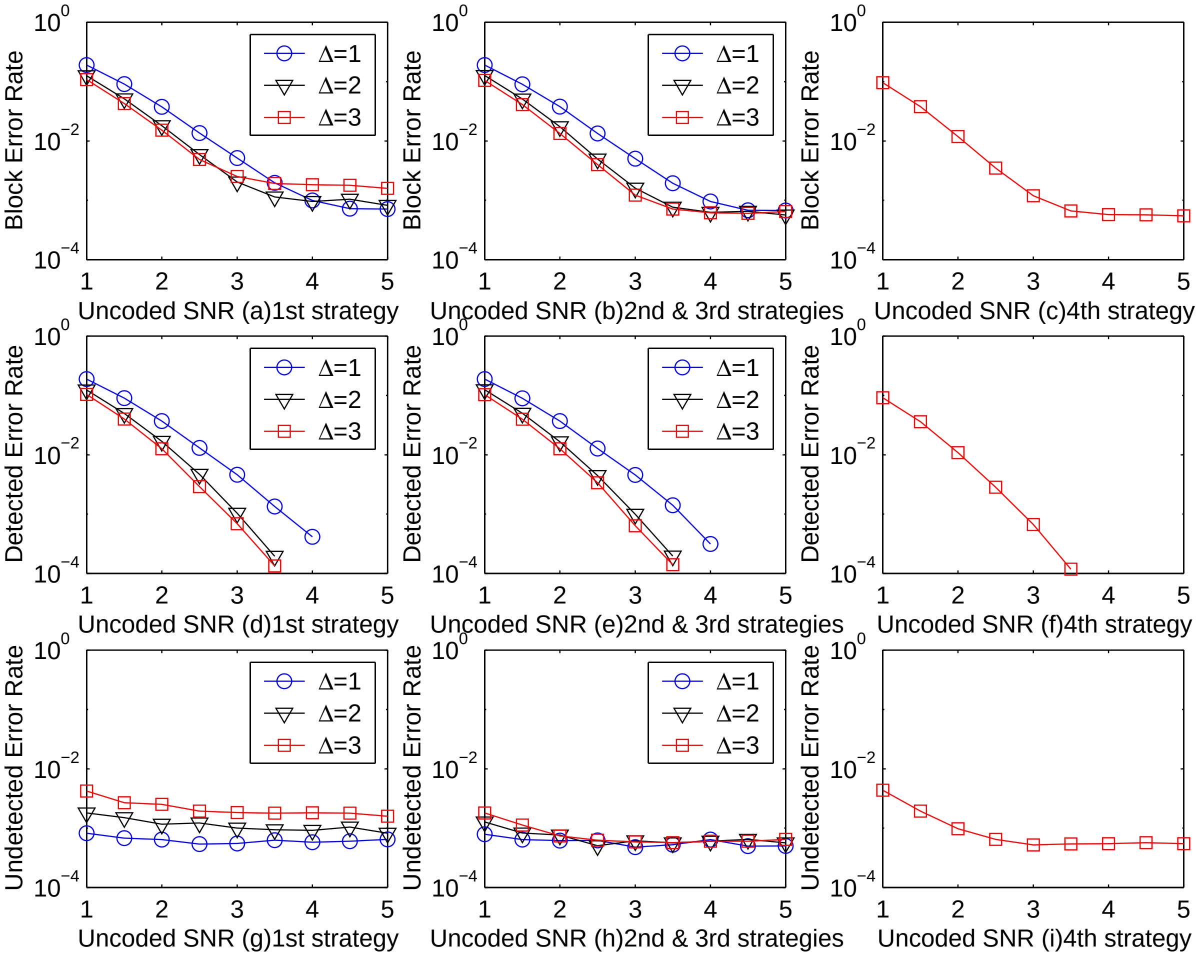

Figure 8: Simulation results for BLER, DER and UER under different decoding strategies.

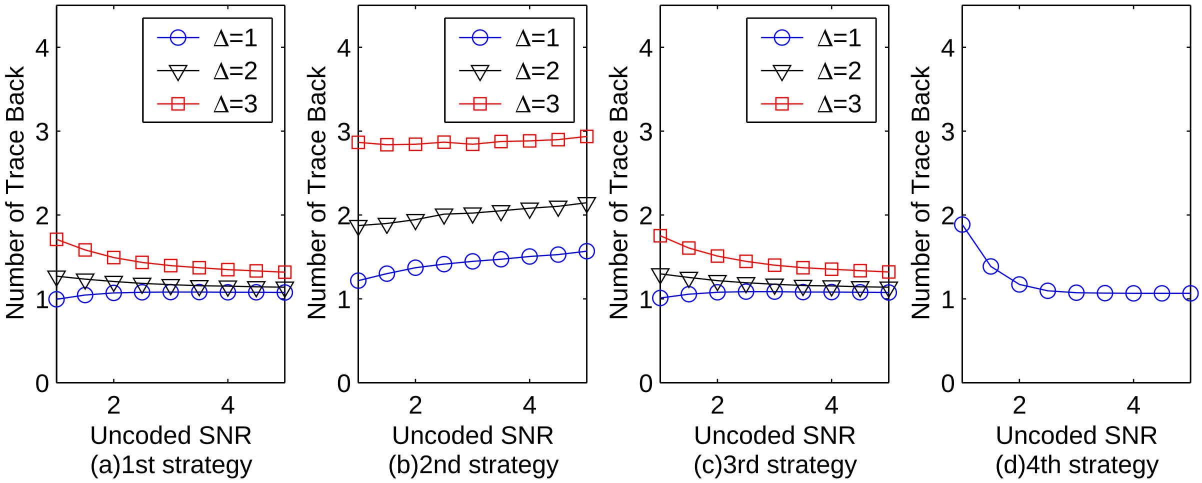

Figure 9: Simulation results for the number of tracebacks in the convolutional decoder.