Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 3, April : 2024

VLSI IMPLEMENTATION OF TURBO ENCODER AND DECODER FOR MIMO-OFDM SYSTEMS USING MAXIMUM-A-POSTERIORI APPROACH

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Abstract
It is important to note that Turbo codes and MIMO-OFDM, which stands for Multiple-Input Multiple-Output Orthogonal Frequency Division Multiplexing, are two techniques that are utilized in contemporary wireless communication systems. Turbo codes are distinctly powerful error correction codes that offer tremendous overall performance about ensuring that channel mistakes are avoided. Wireless communique standards together with 3G (UMTS), 4G (LTE), and 5G NR (New Radio) all make substantial use of them during their implementation. Using a concatenated structure, rapid codes are composed of two or more thing codes and an iterative interpreting algorithm. Turbo codes are used to encode records. This iterative deciphering technique contributes to the success of overall performance that is near superior. So, this work offered a MIMO-OFDM system this is based on Turbo codes. The transmitter on this gadget is equipped with multiple antennas, and the receiver is likewise equipped with multiple antennas respectively. Each transmit antenna is accountable for its very own unbiased operation of the rapid encoder and decoder (TED), which ends inside the generation of more than one coded bitstreams. Over-frequency department multiplexing (OFDM) is then used to modulate those coded bitstreams, with each antenna transmitting a subset of subcarriers. The OFDM approach is used to demodulate the indicators which have been acquired from all the antennas at the receiver, which leads to a couple of bitstreams being acquired. In the following step, the Maximum-a-Posteriori (MAP) based totally faster deciphering algorithm is utilized to decode these bitstreams. The manner of decoding is performed in an iterative way, with smooth records being given and obtained between the factor decoders based on the dependability of the bits which have been obtained. The error correction capability of the Turbo codes is stepped forward the usage of this iterative technique. The outcomes of the simulation display that the turbo encoder that turned into proposed led to a discount in the complexity of the hardware in assessment to other strategies.
Keywords— Multiple-Input Multiple Output, Orthogonal Frequency Division Multiplexing, Turbo encoder, Lookup Tables.

1. Introduction

The implementation of efficient error correction and redundancy strategies is necessary in order to guarantee the reliability of communication in MIMO-OFDM systems. When it comes to contemporary wireless communication, it is necessary to ensure that information is transferred reliably despite the presence of background noise. To accomplish this, redundant bits are inserted into information bit streams utilizing a strategic approach. One method, which is referred to as Automated Repeat Request (ARQ) [1], includes the utilization of redundancy solely for the purpose of identifying faults and prompting the sender to resend information, which contributes to the transmission of data that is reliable. Forward Error Correction (FEC) [2], which is another method that involves redundancy, is designed to identify, and correct errors in the information, thereby removing the requirement for that information to be retransmitted. On the other hand, this comes at the expense of increased transmission rates, which in turn necessitates expansion of the bandwidth available. The substantial benefits, such as a significant

reduction in Signal-to-Noise Ratio (SNR), which is also referred to as Coding Gain, are sufficient to justify this trade-off.
For wireless systems, low-power transmission is essential for extending the life of the battery and reducing the amount of interference caused by co-channels. Concurrently, one of the most important performance criteria is to succeed in achieving high data rates. According to the theory of coding, increasing the length of the codeword or the memory of the encoder can bring the channel capacity closer to its limit. However, this comes with difficulties in code selection [3] and the development of real-time decoders due to the complexity of the problem. The robust error correction method known as turbo codes [4] provides dependable communication with a bit error rate (BER) that is relatively close to the boundaries of the Shannon limit. The construction of these codes involves the parallel concatenation of recursive systematic convolutional codes that come from two different sets. When compared to convolution codes, turbo codes have a relatively minor impact when the constraint length is increased. However, this results in a significant increase in coding even when the coding rate is reduced. Several aspects of multiuser detection are complemented by turbo decoding [5], which comes close to reaching the Shannon limit in terms of performance. Turbo equalization, which employs soft decisions on signals for iterative equalization and channel estimation, has been shown to be effective in combating selective fading. Recent works have brought attention to the simplicity that can be achieved through frequency-domain processing, which offers improvements for various types of multiple access (FDMA, TDMA [6], CDMA [7], or OFDM [8]). In the realm of VLSI implementation for MIMO-OFDM systems, the incorporation of turbo encoder and decoder through the use of the MAP approach becomes of the utmost importance [9]. To accomplish this, the established principles must be translated into hardware design, the architecture must be optimized for efficient processing, and the requirements of real-time communication in wireless environments must be satisfied. Because the MAP approach [10] improves both the system's reliability and its performance, it is an approach that is highly desirable for the implementation of robust communication in MIMO-OFDM systems.
The following is the organizational structure of the remaining parts of the article: A survey of the relevant literature, along with some objections, was found in section 2. Within Section 3, a comprehensive study of the MAP-TED that has been developed is presented. The information on the proposed MAP-TED is included in Section 4, which provides the simulation information. At this point, the article is complete with section 5.

2. Literature Survey

During the course of their research, Urrea and colleagues [11] suggested the utilization of an interleaver for the purpose of implementing tiny Parallel Turbo Codes (PTC) with short block lengths on the order of 64, 128, and 256 bits. In order to be more specific, the objective is to design an interleaver that, while simultaneously ensuring proper data transmission in an effort to reduce the bit error rate (BER), generates decorrelation in the external input information to parallel recursive convolutional encoders. An approach that was presented by Yang et al. [12] for the development of a fully parallel turbo decoder that makes use of FPGA was described. Specifically, they included information on the overall processing and structural composition of the decoder hardware implementation within this proposal. A further explanation was provided regarding the architecture of the algorithm block processing unit as well as the interleaving module.
Within the framework of Duffing chaotic maps, Urrea and colleagues [13] developed an interleave that is centered on the concept. This particular interleave has an advantage over other strategies that are comparable due to the fact that it is deterministic. It was asserted that the performance results were outstanding, and it was also stated that the BER values for 64 bits were outstanding. In the process of evaluating the performance of turbo codes, the bit error rate (BER) is frequently utilized, and the lengths that are utilized for this evaluation are typically between 64 and 512 bits. With the intention of utilizing short block length Turbo codes, Salija et al. [14] proposed a revolutionary new method of decoding that is both performance-improved and reliability-based. This method is intended for specific applications.

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ISSN: 0970-2555
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In this work, we apply the suggested method to a variety of Turbo encoder structures in order to conduct an in-depth evaluation of the approach that was suggested. Both 3GPP LTE and CCSDS Turbo codes are involved in the construction of these Turbo encoder structures. The choice of those homes was based totally at the unequalled qualities and characteristics that distinguish them from other homes.
For VLC and 5G networks, the multiple get entry to method known as SCMA, which stands for sparse code a couple of get entry to, is a way that has the potential to be applied. It turned into suggested through Murugaveni et al. [15] that this method be applied within the field of seven mild conversation, further to programs for 5G and the Internet of Things. Furthermore, in assessment to Power Domain-Non-Orthogonal Multiple Access (PD-NOMA), it demonstrates superior performance in both the spectrum area and the strength efficiency domain.

3. Proposed Methodology

This phase offers an in-depth analysis of the proposed MIMO-OFDM programs which might be the focus of the MAP-TED system, which has been delivered. Within the context of information transmission, MAP-TED operates in a manner that is each methodical and complex to guarantee dependable errors correction. To generate encoded records immune to mistakes, the MAP-TED encoder entails the use of Recursive Systematic Convolutional (RSC) encoders on the side of interleaving. To simulate the situations that exist inside actual time, this statistic is sent through a loud channel in a simulated transmission. The technique of interpreting includes the information which has been encoded being divided into segments and then fed into RSC-MAP decoders. These decoders are characteristic in an iterative way, making use of interleaving and engaging in records exchange to enhance mistakes correction. Despite mistakes that were delivered sooner or later of transmission, the goal is to correctly reconstruct the records that turn out to be to start with transmitted.

A. *MAP-TED encoder*

The block diagram of the proposed MAP-TED encoder, which makes use of an RSC encoder with direct input, was found in Figure 1. The method begins with the records that is input, that is then considered with the aid of the RSC1 encoder.

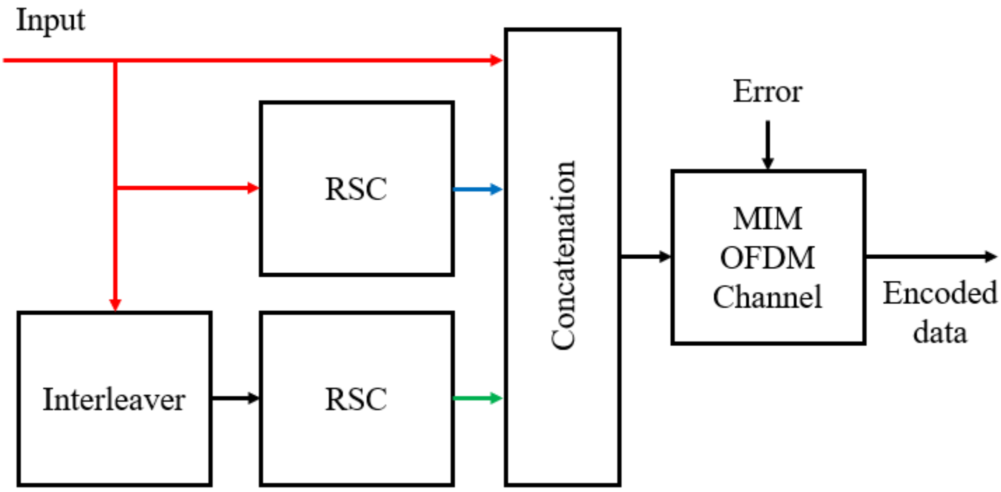

Fig. 1. Proposed MAP-TED encoder block diagram.

A technique of interleaving is performed at the output of RSC1 before it's far sent via the RSC2 encoder. Data that has been encoded is created by way of concatenating the outputs of RSC1 and RSC2 which have been produced as a result, at the side of the preliminary enter. An error-correcting code known as the RSC encoder is a type of code that encodes enter bits in a methodical way even as simultaneously incorporating feedback from bits that have been encoded inside the past. The interleaving step provides a further layer of complexity to the encoding system, which is already complicated by way of the reality that there are RSC encoders (RSC1 and RSC2) working together in coordination. The bits are rearranged thru the system of interleaving to lessen the effect of burst mistakes that occur during transmission. Following that, the encoded statistics is despatched thru the MIMO-OFDM channel for transmission. The representation of this channel considers the existence of errors, more specifically Additive White Gaussian Noise (AWGN). The output of the encoder is a representation of the data after it has been transmitted through this noisy channel, which highlights the potential errors that may have been introduced during transmission.

Presented in the following manner is the step-by-step operation.

Step 1: Entering the Data: The input data, which serve as a representation of the information that is going to be transmitted through the communication system, is where the process starts.

Step 2: Encoder for the RSC1: The RSC1, which happens to be a recursive encoder, is responsible for the systematic encoding of the input data. Utilizing feedback from bits that have been encoded in the past is what recursive encoding is all about. There is redundancy in the encoded data that is generated by RSC1 to facilitate error detection and correction.

Step3: Interleaver involves interleaving the output from RSC1. Interleaving takes the bits of encoded data and rearranges them to spread out any burst errors that may occur while the data is being transmitted. This data transfer strengthens the system's resistance to mistakes styles through improving its robustness.

Step 4: The records that has been interleaved is then sent via the second one RSC encoder, which is observed by the fourth step. Since this encoder consists of additional redundancy into the interleaved data, the machine's error-correction capabilities are similarly progressed.

Step 5: Concatenation is the process by which the outputs of the RSC1 encoder and the RSC2 encoder, along with the initial input data, are combined to form the final encoded data. The data that has been concatenated is now prepared to be transmitted through various channels.

Step 6: MIMO-OFDM is the channel that is used to transmit the encoded data. This channel is modeled to include the presence of errors in the form of AWGN. The channel presents the data that is being transmitted with noise as well as the possibility of errors.

Step 7: Output from the Encoder: The final output is a representation of the data after it has been transmitted through the MIMO OFDM channel, considering the effects of errors and noise.

B. *MAP-TED decoder*

Figure 2 depicts the interpreting technique this is applied inside the MAP-TED decoder this is being proposed. Data that has been encoded is divided into three streams: the first circulation incorporates the encoded data that became at first encoded, the second one flow consists of facts from RSC1, and the 1/3 circulation contains records from RSC2. This record is then sent to two RSC-MAP decoders for processing. Both the authentic encoded statistics and the facts from RSC1 are processed with the aid of Decoder 1, while Decoder 2 processes the interleaved encoded statistics as well as the facts from RSC2. Iterative surroundings are brought between Decoder 1 and Decoder 2, with interleavers and deinterleavers performing the facilitation of this environment. It is possible for the 2 decoders to proportion data with each other via this iterative technique, which results in an improvement in the errors-correction skills. The steps of interleaving and deinterleaving are extremely crucial in this manner due to the fact they permit the decoders to take benefit of the advantages of diversity and make it less complicated for them to correct a variety of errors. Finally, the output of Decoder 1 represents the decoded records, which, in a super global, must be same to the statistics that became to start with enter without any mistakes. This demonstrates that the MAP-TED decoding scheme that was proposed is effective.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 3, April : 2024

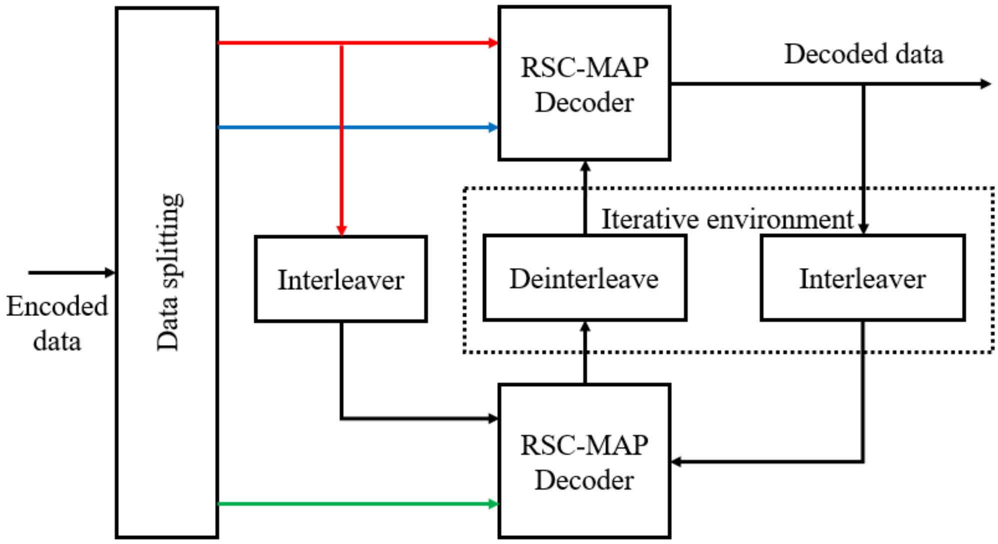

Fig. 2. Proposed MAP-TED decoder block diagram.

The operational process, damaged down into steps, is as follows:

Step 1: Data Splitting The procedure of information splitting is liable for the technology of encoded information, RSC1 facts, and RSC2 records while a hit.

Step 2: The RSC-MAP Decoder 1 takes as inputs each the unique encoded information and the RSC1 facts. A deciphering set of rules referred to as RSC-MAP is applied to decode the records that became at the beginning encoded and to correct any mistakes that had been because of the channel.

Step 3: Interleaved encoded data and RSC2 statistics are both inputs for the RSC-MAP Decoder 2, which is the 1/3 step in the procedure. Utilizes the interleaving and deinterleaving method to use RSC-MAP decoding to the interleaved encoded facts and correct any errors which could have occurred.

Step 4: Both interleavers and deinterleavers are used to facilitate the advent of an iterative environment this is situated between the 2 decoders. Before sending records to the RSC-MAP Decoder 2, the interleaver is applied to rearrange the bits for the information. The RSC-MAP Decoder 2 is followed through the deinterleaver, that's used to reorder the bits. This helps the exchange of data among the decoders and improves mistakes correction.

Step 5: The interleaved statistics and the RSC2 records are subjected to an iterative procedure between the RSC-MAP Decoder 1 and the RSC-MAP Decoder 2 in the 5th step of the iterative environment protocol. Through the facilitation of facts change and the enhancement of the interpreting method, this iterative surroundings contributes to the development of errors correction.

Step 6: Deciphering the Data: The data that has been decoded is represented with the aid of the very last output from RSC-MAP Decoder 1, which should preferably be free of any mistakes that have been brought during the transmission via the channel.

4. Simulation Results

In this section, a comprehensive simulation analysis of the MAP-TED system that has been proposed is presented. Simulations are carried out in this location with the assistance of the Xilinx-Vivado software tool. The result of the simulation is depicted in Figure 2, which includes the clk and rst as primary inputs, data_in as an 8-bit data input, and enc_out as a 32-bit MAP-TED encoded output, which includes errors. Lastly, the output of the MAP-TED decoder is the output that is free of errors.

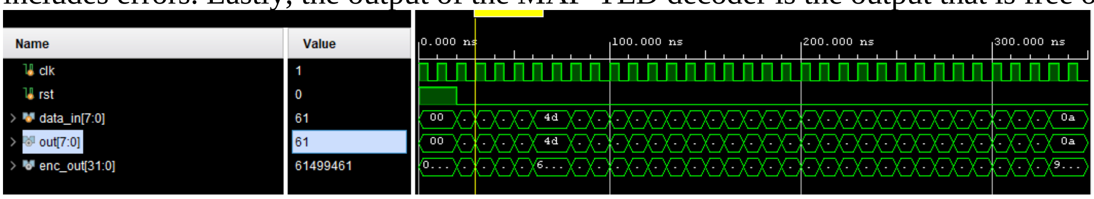

Fig. 3. Simulation output

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 3, April : 2024

The utilization of resources for the proposed MAP-TED implementation is illustrated in Figure 4, which provides insights into the matter. "LUTs" is an abbreviation that stands for "Look-Up Tables," which are essential elements that are found in digital circuits. Since only 16 of the 78,600 available LUTs are utilized in this scenario, it can be concluded that the design is relatively simple in terms of the amount of logic that is involved. Input/Output Blocks, also known as IoBs, play a role in connecting the design to external devices. The utilization of 49 out of 250 IoBs indicates that these resources are utilized in a moderate manner. To maximize the effectiveness of the design and make the most of the resources that are at one's disposal, it is essential to visualize the utilization of the available space.

Resource	Utilization	Available	Utilization...
LUT	16	78600	0.02
IO	49	250	19.60

Fig. 4. Design summary.

In the realm of digital design, setup time is an essential metric that denotes the minimum amount of time that must pass before a signal is able to become stable before the subsequent clock edge. In Figure 5, the total delay of 7.436 nanoseconds is broken down into its component parts: logic delays, which account for 3.5 nanoseconds, and net delays, which account for 3.9 nanoseconds. This information is essential for ensuring that signals are stable and valid at the input of the flip-flops, as well as for meeting timing requirements and avoiding violations of setup time.

Unconstrained Paths - NONE - NONE - Setup

Name	Slack	Levels	Routes	High Fanout	From	To	Total Delay	Logic Delay	Net Delay	Requirement	Sou
Path 1	∞	3	2	24	rst	out[7]	7.437	3.500	3.937	∞	inpu
Path 2	∞	3	2	24	rst	out[6]	7.111	3.496	3.615	∞	inpu
Path 3	∞	3	2	8	data_in[1]	out[0]	7.025	3.500	3.526	∞	inpu
Path 4	∞	3	2	8	data_in[1]	out[1]	7.024	3.480	3.544	∞	inpu
Path 5	∞	3	2	24	rst	out[5]	6.999	3.520	3.479	∞	inpu
Path 6	∞	3	2	24	rst	enc_out[27]	6.999	3.376	3.623	∞	inpu

Fig. 5. Setup Time summary.

Figure 6 provides a concise summary of hold time, which refers to the minimum amount of time that a signal must be held stable after the clock edge. There is a total delay of 2.064 nanoseconds, making up 1.328 nanoseconds of logic delay and 0.736 nanoseconds of net delay. The effective management of hold times is absolutely necessary in order to avoid the corruption of data and to keep the signals' integrity intact while the clocking process is being carried out.

Tcl Console | Messages | Log | Reports | Design Runs | Power | DRC | Timing

Inter-Clock Paths
Other Path Groups
User Ignored Paths
Unconstrained Paths
NONE to NONE
Setup (10)
Hold (10)

Unconstrained Paths - NONE - NONE - Hold

Name	Slack	Levels	Routes	High Fanout	From	To	Total Delay	Logic Delay	Net Delay	Requirement	Sou
Path 11	∞	3	2	8	data_in[0]	enc_out[3]	2.064	1.328	0.736	-∞	inpu
Path 12	∞	3	2	8	data_in[1]	enc_out[1]	2.155	1.358	0.797	-∞	inpu
Path 13	∞	3	2	8	data_in[1]	enc_out[0]	2.202	1.394	0.809	-∞	inpu
Path 14	∞	3	2	8	data_in[0]	enc_out[5]	2.237	1.413	0.824	-∞	inpu
Path 15	∞	3	2	8	data_in[0]	enc_out[7]	2.256	1.370	0.885	-∞	inpu
Path 16	∞	3	2	8	data_in[0]	enc_out[4]	2.260	1.374	0.885	-∞	inpu

Fig. 6. Hold Time summary.

Figure 7 provides a comprehensive overview of the power utilization that is included in the MAP-TED design that is being proposed. Within the context of power consumption, both dynamic and static components are broken down in detail. There are contributions from signals, logic, and I/O Blocks that are further broken down into the dynamic power, which is 14.852uW all together. The amount of power that is lost out of the circuit when it is in a static state is 0.226 uW, which is referred to as static power. The total power utilization of 15.1 uW offers a comprehensive understanding of the power requirements, which is helpful in optimizing power consumption and taking efficiency into consideration during the design design process. Applications in which power consumption is a primary concern, such as those involving energy-efficient systems or devices powered by batteries, require this information in order to function properly.

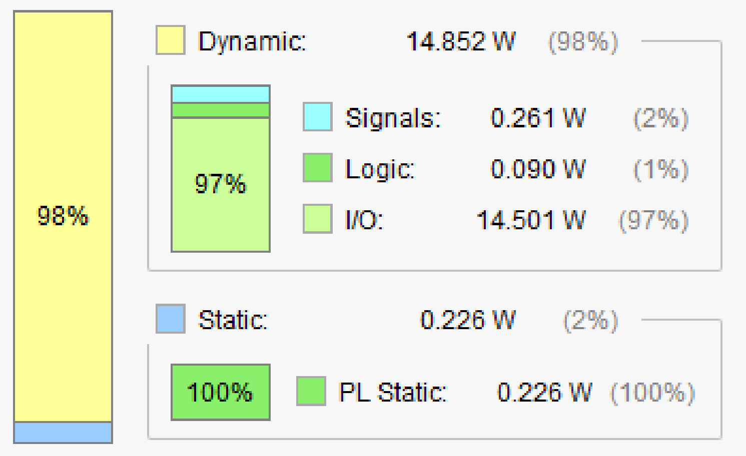

Fig. 7. Power summary

It is clear from looking at Table 1 that the proposed system demonstrates a significant improvement in terms of resource utilization when compared to the system that is currently in place. According to the number of LUTs, the proposed system makes use of sixteen LUTs, whereas the current system makes use of thirty-five LUTs. Consequently, this represents a significant decrease of 54.3%. To a similar extent, the proposed system makes use of 49 IoBs, whereas the system that is currently in place makes use of 76 IoBs. The improvement in this case amounts to a significant reduction of 35.5% in the amount of IoB usage. These reductions are illustrative of the effectiveness and optimization that the proposed system has achieved in terms of making better use of the resources provided by the hardware.

Table. 1. Area performance comparison.

Resource	Existing System	Proposed System
LUTs	35	16
IoBs	76	49

5. Conclusion

To ensure the transmission of data in a reliable manner even when channel-induced errors are present, the MAP-TED that has been proposed incorporates a sophisticated error-correction mechanism. The encoder uses RSC encoders that incorporate interleaving to encode the input statistics before its transmission thru a MIMO-OFDM channel with simulated transmission mistakes. When it comes to decoding, the MAP-TED decoder makes use of RSC-MAP decoders, each of that is chargeable for handling a different element of the encoded data. The mistakes-correction capabilities are advanced via the iterative technique that occurs between those decoders. This process is made viable with the resource of interleavers and deinterleavers, which ensures that the unique facts is recovered in a reliable and correct manner. The MAP-TED system is designed to offer a dependable solution for conversation systems which may be running in hard environments. This is accomplished using a scientific encoding and iterative deciphering method, which targets to reduce mistakes which may be added throughout transmission itself. A comprehensive approach to blunders correction is confirmed by using the tool that has been proposed. This technique combines the advantages of recursive encoding, interleaving, and iterative deciphering on the way to attain excessive fidelity in all components of information recuperation.

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