Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Turbo Code Comparison (TCC v TPC)**
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Re:	Invitation to submit PHY Proposals 802.16.3-00/24
Abstract	A comparison of convolutional code based Turbo Codes (TCC) and Turbo Product Codes (TPC) is provided over a range of spectral efficiencies.
Purpose	To initiate a request for a more detailed proposal regarding the use of TCC for the physical layer of 802.16.3.
Notice	
Release	
Patent Policy and Procedures	

Comparison of Turbo-Convolutional Codes and Turbo Product Codes for QPSK-64QAM Channels

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1.0 Summary

A comparison of Turbo Convolutional Codes (TCC) and Turbo Product Codes (TPC) demonstrates that TCC provide the best forward error correction performance over the range of spectral efficiencies under consideration by 802.13.3. Under the various functional requirements specified for 802.16.3, this greater forward error correction performance will translate into a more robust, high capacity, system.

2.0 Reference Model and Code Description

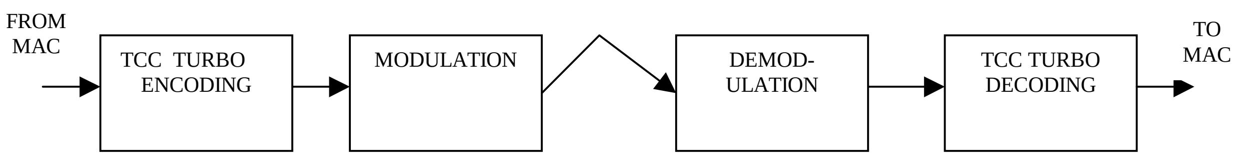


Figure 1.

Turbo Coding is performed on the information to be transmitted and the resulting coded information is transmitted via the selection modulation scheme. After demodulation, the resulting receive information is iteratively decoded and passed to the MAC layer.

The encoding is performed according to the following diagram:

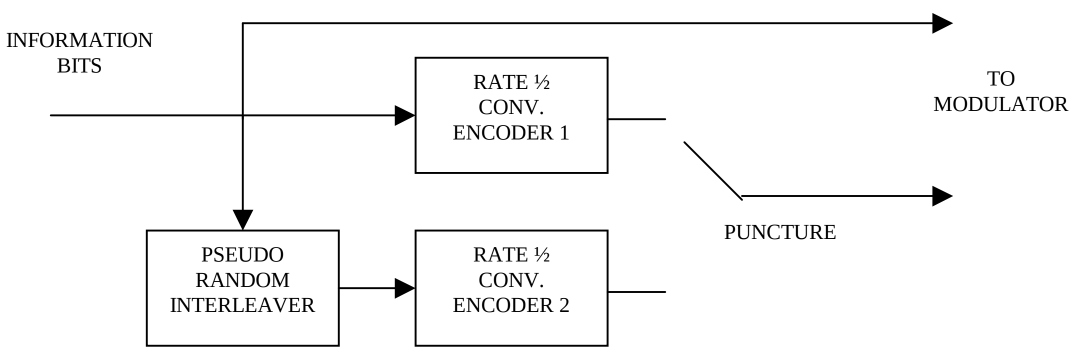


Figure 2.

Punctured rate range from rate 1/3 to rate 9/10, with a suggested set of rate being ½, 2/3, ¾, 5/6, and 8/9. Other rate constituent codes may also be employed.

3.0 Relation to existing standards.

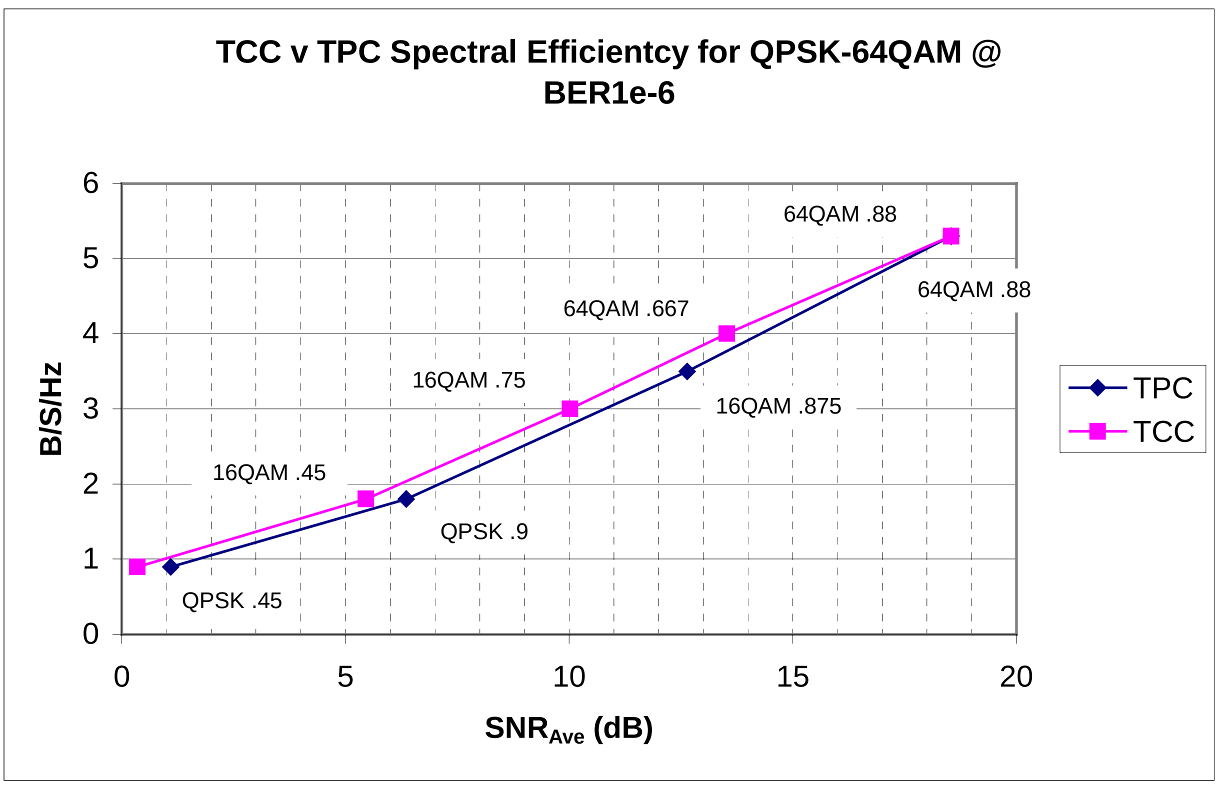
The TCC scheme presented resembles the Turbo Codes used in 3GPP (W-CDMA) and 3GPP2 (CDMA2000) with some enhancements. The enhancements include a generatable interleaver that provides both higher performance and which may be decoded in parallel for very high data rates. Additionally, sixteen state constituent codes have been selected. It is believed that eight state codes will be suitable for the target BER's, however, sufficient testing had not been performed at the time of submission.

As 802.16.3 comes closer to selecting a modulation scheme some additional modifications to the code may be made based on the selected scheme and channel model.

4.0 Benefits of the Proposal

Graph 1 provided below is a comparison of the spectral densities achieved for various code-modulation scheme combinations for TCC's and TPC's. As shown, the TCC provides superior error correction performance relative to TPC at virtually all operating points. At the few operating points where the TCC scheme is not superior, it is virtually identical to the TPC. With respect to the other codes proposed, including a different TPC scheme as well as trellis coded modulation, the performance gains of TCC is typically 3dB or more providing enormous performance gains in terms of data throughput, coverage area, and frequency reuse.

Figure 1. TCC v TPC Spectral Efficiency



Higher spectral efficiency is demonstrated for TCC across virtually the entire area of interest.

The TPC data is taken from 802.16.1c-00/45. The frame size for the TCC is 15842 and the frame size for the TPC is listed at 16K. Thus, the TCC used an ~ 3% smaller frame, which is to the advantage of the TPC.

The TCC points were selected to maximize spectral efficiency for a given SNR, which is a specified requirement in Section 5.4 of the 802.16.3 functional requirements document. It is assumed that 802.16.1c=00/45 did the same as it was submitted in response to the Initial PHY Proposal Call for Contributions (802.16.3-00/14).

SNR vs. Spectral Efficiency graphs are an excellent method for evaluating the FEC portion of any PHY proposals, and we suggest that they be included in future PHY submissions where FEC is of particular interest.

Although the final definition of 802.16.3 is unknown, the requirements document specifies the need for efficient frequency reuse. (Sections 2, 5, 5.9 and M3 as well as the evaluation criteria). For systems dealing with frequency reuse issues powerful FEC coding has dramatic capacity effects. This is because powerful FEC coding not only decreases the required SNR for the receiving system, but it also reduces the necessary transmit power of other systems thereby reducing the major source of jamming. This is why heavy frequency reuse schemes such as CDMA always employ the most powerful FEC available, and therefore selected a convolutional turbo code based solution. (This does assume the use of some transmit power control mechanism such as that used in 802.16.1).

Depending on the degree of frequency reuse, increases in system sensitivity can result in a corresponding increases in system performance. That is, a 3dB increase in sensitivity will result in double the system capacity, and a 1dB increase in sensitivity will result in a 25% increase in system capacity. While the level of reuse for 802.16.3 will probably be less than that of a CDMA system, any significant degree of frequency reuse creates a strong incentive for powerful FEC.

The performance increase of Turbo Convolutional Codes relative to TPC is most dramatic at lower code rates, although as demonstrated above the advantages are present over virtually all spectral densities. This advantage at low code rates is particularly useful for small packets containing control information, for which error free transmission is of critical importantance. In many instances it is important to provide extra high encoding for such control packets, and Turbo Convolutional Codes can provide more than 1dB Eb/No performance enhancement over TPC for these rates. This eliminates the need to provide an alternative coding technique for control packets.

Turbo Convolutional Codes also present the lowest implementation risk. By virtue of their use in various standards including 3GPP, 3GPP2 as well as DVB-RCS, Turbo Convolutional Codes will be the most widely known and used form of iterative codes. The large numbers of papers and other documentation generated with respect to Turbo Convolutional Codes will ensure wide availability of TCC related devices and IP.

5.0 Drawbacks of the Proposal

Iterative decoders are more complex than non-iterative decoders. Therefore, the digital decoder portion of the receive system will be more costly for a turbo code based solution. Overall, the total cost of the system should decrease due to savings in other areas such as amplifiers and other analog components. Additionally, the increase in system capacity and coverage should increase value far in excess of the cost. Actual device cost estimates can be provided upon request.

The additional complexity of Turbo Decoder introduces between 1N-3N delay, where N transmit time of a frame. For a minimum data rate of 2 Mbit/Sec a 16 Kbit frame can be transmitted in less than 20ms even with more than 2N delay. An 8 Kbit frame may be used if rates less than 2Mbit/Sec are expected.

6.0 Intellectual Property

Turbo Convolutional Codes were invented by France Telecom and have been patented. France Telecom has demonstrated willingness in the past to non-discriminatory licensing of Turbo Codes on reasonable terms and conditions.

iCODING agrees to comply with the IEEE IPR policy should the final standard incorporate iCODING IPR.

7.0 PHY Evaluation Table

1. Meets System Requirements

The proposed TCC scheme provides the high spectral efficiency and frequency reuse, while also meeting the latency and other system requirements. The coding scheme can be used with single carrier or OFDM modulation schemes. We therefore submit that the applicable system requirements are met.

2. Channel Spectrum Efficiency

A set of proposed modulation-code rate combinations have been provided that provide the highest level of channel spectrum efficiency across most of the range of modulation scheme contemplated. Spectral efficiency for 256QAM can be provided if our request for a more detailed submission is granted.

3. Simplicity of Realization

Turbo Convolutional Codes have been adopted by several standards bodies for extremely high volume applications ensuring the widespread use and availability of Turbo Convolutional Code devices and Intellectual Property. The adopting standards are for consumer based products, for which cost is of critical importance.

In general, while iterative codes do provide additional cost in the area of the digital processing portion of the system, these costs are substantially offset by reductions in the performance requirements of other components including amplifiers as well as overall increases in system performance. Thus, we believe the proposal meets the evaluation criteria.

A. SS cost optimization

The use of a turbo encoder in the SS could be used in a variety of ways. One of which is to reduce overall SS cost by decreasing the necessary transmit power. Alternatively, increases in data throughput or distance from the base station could be achieved. The cost of a turbo encoder would have minimal impact on the SS cost.

The use of a turbo decoder in the SS would add some cost to the SS. Estimates of the cost for data rates of 100Mbit/Sec or less would be $20 (Assuming reasonable market penetration) initially, with that cost decreasing rapidly over time. Thus, the proposal meets the SS cost optimization evaluation criteria.

B. BS cost optimization

The use of a turbo decoder in the base station would provide a modest increase in cost, but would allow the SS to transmit using less power.

The use of turbo encoder(s) would add minimal cost to the base station, but it would allow for greater throughput capacity and lower transmit power. Using lower transmit power will enable higher frequency reuse thereby increasing overall system capacity. Thus, the proposal meets the BS optimization evaluation criteria.

C. Installation Cost

Turbo Codes should have no effect on installation costs

4. Spectrum Resource Flexibility

Turbo Codes of various rates have been proposed allowing for flexible resource usage. Additionally, the turbo code can be easily configured for different frame sizes if necessary.

5. System Spectrum Efficiency

Turbo Convolutional Codes provide the greatest reduction in the transmit power necessary for successful communications. This in turn reduces cell-to-cell interference as well as interference between SS. The reduction in interference allows for the highest level of frequency reuse and therefore overall system capacity.

6. System Service Flexibility

Turbo Convolutional Codes can be configured for a wide range of frame length (and therefore latencies) as well as code rates. Thus, turbo codes should not prevent introduction of new services.

7. Protocol Interfacing Complexity

Turbo Convolutional Codes posses the same basic characteristics of other FEC coding techniques and therefore present no unique interface challenges. The larger frame sizes typically used for Turbo Convolutional Codes may present some delay problem for control information so smaller and more highly coded control packets may be required.

8. Reference System Gain

More information about the chosen modulation scheme is necessary for system gain estimates, however, whatever scheme is chosen Turbo Convolutional Codes should enable that system to perform at the highest overall system performance.

9. Robustness to Interference.

Turbo Convolutional Codes are able to withstand the highest level of noise and therefore should have the highest resistance to interference.

10. Robustness to Channel Impairments.

Turbo Convolutional Codes typically degrade at least no worse than other coding scheme relative to channel impairments.

11. Robustness to Radio Impairments.

Turbo Convolutional Codes typically degrade at least no worse than other coding scheme relative to radio impairments.

12. <u>Support of Advanced Antenna Techniques</u>

    Turbo Convolutional Codes typically benefit at least as well as other coding scheme relative to advanced antenna techniques.

13. <u>Compatibility with Existing Relevant Standards and Regulations</u>

    The Turbo Convolutional Code proposed is from the same family of codes as that used in 3GPP and 3GPP2, but has some enhancements which make it incompatible.

8.0 Misc

Based on this submission, iCODING asks that:

1. iCODING be requested to submit a more detailed proposal during the next 802.16 meeting.
2. PHY proposals be asked to prepare SNR vs. Spectral Efficiency Graphs.