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Self-Concatenated Coding for Wireless Communication Systems

by

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BEng., MSc

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This thesis is dedicated to

my beloved parents (Rafi and Nilum), grandmothers
and parents-in-law
for their love and prayers
my lovely wife Ayesha
for her tremendous patience, love and care
and my adorable daughter Sarah
for making my days brighter with her smile and lovely actions
with all my heartfelt gratitude, appreciation and love $\cdots$

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

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In this thesis, we have explored self-concatenated coding schemes that are designed for transmission over Additive White Gaussian Noise (AWGN) and uncorrelated Rayleigh fading channels. We designed both the symbol-based Self-Concatenated Codes considered using Trellis Coded Modulation (SECTCM) and bit-based Self-Concatenated Convolutional Codes (SECCC) using a Recursive Systematic Convolutional (RSC) encoder as constituent codes, respectively. The design of these codes was carried out with the aid of Extrinsic Information Transfer (EXIT) charts. The EXIT chart based design has been found an efficient tool in finding the decoding convergence threshold of the constituent codes. Additionally, in order to recover the information loss imposed by employing binary rather than non-binary schemes, a soft-decision demapper was introduced in order to exchange extrinsic information with the SECCC decoder. To analyse this information exchange 3D-EXIT chart analysis was invoked for visualizing the extrinsic information exchange between the proposed Iteratively Decoding aided SECCC and soft-decision demapper (SECCC-ID). Some of the proposed SECTCM, SECCC and SECCC-ID schemes perform within about 1 dB from the AWGN and Rayleigh fading channels' capacity. A union bound analysis of SECCC codes was carried out to find the corresponding Bit Error Ratio (BER) floors. The union bound of SECCCs was derived for communications over both AWGN and uncorrelated Rayleigh fading channels, based on a novel interleaver concept. Application of SECCCs in both UltraWideBand (UWB) and state-of-the-art video-telephone schemes demonstrated its practical benefits.

In order to further exploit the benefits of the low complexity design offered by SECCCs we explored their application in a distributed coding scheme designed for cooperative communications, where iterative detection is employed by exchanging extrinsic information between the decoders of SECCC and RSC at the destination. In the first transmission period of cooperation, the relay receives the potentially

erroneous data and attempts to recover the information. The recovered information is then re-encoded at the relay using an RSC encoder. In the second transmission period this information is then retransmitted to the destination. The resultant symbols transmitted from the source and relay nodes can be viewed as the coded symbols of a three-component parallel-concatenated encoder. At the destination a Distributed Binary Self-Concatenated Coding scheme using Iterative Decoding (DSECCC-ID) was employed, where the two decoders (SECCC and RSC) exchange their extrinsic information. It was shown that the DSECCC-ID is a low-complexity scheme, yet capable of approaching the Discrete-input Continuous-output Memoryless Channels's (DCMC) capacity.

Finally, we considered coding schemes designed for two nodes communicating with each other with the aid of a relay node, where the relay receives information from the two nodes in the first transmission period. At the relay node we combine a powerful Superposition Coding (SPC) scheme with SECCC. It is assumed that decoding errors may be encountered at the relay node. The relay node then broadcasts this information in the second transmission period after re-encoding it, again, using a SECCC encoder. At the destination, the amalgamated block of Successive Interference Cancellation (SIC) scheme combined with SECCC then detects and decodes the signal either with or without the aid of *a priori* information. Our simulation results demonstrate that the proposed scheme is capable of reliably operating at a low BER for transmission over both AWGN and uncorrelated Rayleigh fading channels. We compare the proposed scheme's performance to a direct transmission link between the two sources having the same throughput.

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DECLARATION OF AUTHORSHIP

I, **Muhammad Fasih Uddin Butt**,

declare that the thesis entitled

Self-Concatenated Coding in Wireless Communication Systems

and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, this is always clearly attributed;
- where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- parts of this work have been published as: [1–9].

Signed: *Muhammad Fasih Uddin Butt*
Date: 23rd June 2010

List of Publications

Journal Papers:

1. **M. F. U. Butt**, R. A. Riaz, S. X. Ng and L. Hanzo, "Near-Capacity Iterative Decoding of Binary Self-Concatenated Codes Using Soft Decision Demapping and 3-D EXIT Charts", to appear in IEEE Transactions on Wireless Communications.

2. **M. F. U. Butt**, R. A. Riaz, S. X. Ng and L. Hanzo, "Distributed Self-Concatenated Coding for Cooperative Communications", to appear in IEEE Transactions on Vehicular Technology.

3. S. X. Ng, **M. F. U. Butt** and L. Hanzo, "On the Union Bounds of Self-Concatenated Convolutional Codes", IEEE Signal Processing Letters, vol. 16, pp. 754-757, September 2009.

4. R. A. Riaz, **M. F. U. Butt**, S. Chen and L. Hanzo, "Generic z-domain discrete-time transfer function estimation for ultra-wideband systems", IET Electronics Letters, Vol. 44, 2008, pp. 1491-1492.

5. R. A. Riaz, R. G. Maunder, **M. F. U. Butt**, S. X. Ng, S. Chen and L. Hanzo, "EXIT-Chart Aided 3-Stage Concatenated Ultra-WideBand Time-Hopping Spread-Spectrum Impulse Radio Design", in IEEE Transactions on Vehicular Technology, vol. 58, no. 9, pp. 5320-5324, 2009.

Conferences Papers:

1. **M. F. U. Butt**, S. X. Ng and L. Hanzo, "EXIT Chart Aided Design of Near-Capacity Self-Concatenated Trellis Coded Modulation Using Iterative Decoding", in Proceedings of the 67th IEEE Vehicular Technology Conference (VTC-2008 Spring), pp. 734-738, May 2008.

2. **M. F. U. Butt**, R. A. Riaz, S. X. Ng and L. Hanzo, "Near-Capacity Iteratively Decoded Binary Self-Concatenated Code Design Using EXIT Charts", in Proceedings of the IEEE Global Communications Conference, GLOBECOM '08, (New Orleans, USA), Nov/Dec 2008.

3. **M. F. U. Butt**, R. A. Riaz, S. X. Ng and L. Hanzo, "Distributed Self-Concatenated Codes for Low-Complexity Power-Efficient Cooperative Communication", in Proceedings of the IEEE Vehicular Technology Conference (VTC-2009 Fall), Anchorage, Alaska, September 2009.

4. R. A. Riaz, **M. F. U. Butt**, S. X. Ng, S. Chen and L. Hanzo, "Near-Capacity UWB Impulse Radio Using EXIT Chart Aided Self-Concatenated Codes", in Proceedings of the IEEE Vehicular Technology Conference (VTC-2009 Fall), Anchorage, Alaska.

5. R. A. Riaz, R. G. Maunder, **M. F. U. Butt**, S. X. Ng, S. Chen and L. Hanzo, "Three-Stage Concatenated Ultra-Wide bandwidth Time-Hopping Spread-Spectrum Impulse Radio using Iterative Detection", in Proceedings of the IEEE ICC'09, 14-18 June, Dresden, Germany, June 2009.

6. R. A. Riaz, **M. F. U. Butt**, S. Chen and L. Hanzo, "Optimized Irregular Variable Length Coding Design for Iteratively Decoded UltraWideBand Time-Hopping Spread-Spectrum Impulse Radio", in Proceedings of the IEEE Vehicular Technology Conference (VTC-2009 Spring), Spain, April 2009.

7. **M. F. U. Butt**, R. Zhang, S. X. Ng and L. Hanzo, "Superposition Coding Aided Bi-directional Relay Transmission Employing Iteratively Decoded Self-Concatenated Convolutional Codes", in Proceedings of the IEEE Vehicular Technology Conference (VTC-2010 Spring), Taipei, Taiwan, May 2010.

8. Nasruminallah, **M. F. U. Butt**, S. X. Ng and L. Hanzo, "H.264 Wireless Video Telephony Using Iteratively-Detected Binary Self-Concatenated Coding", in Proceedings of the IEEE Vehicular Technology Conference (VTC-2010 Spring), Taipei, Taiwan, May 2010.

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