Response Letter for EURASIP Journal on Wireless Communications and Networking JWCN-D-17-00004

Design of Adaptive Constellations and Error Protection Coding for Wireless Network Coding in 5-node Butterfly Networks

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May 30, 2017

We would like to thank all the reviewers for their valuable comments and suggestions. We first reply to the most common and important questions and then we answer the individual questions and comments individually.

1 Common Questions and Corresponding Answers

- CQ1: *Lacking novelty compared to [1].*
- A1: Compared with the conference version [1], the major contributions and differences of this submitted manuscript are summarized as follows:
    1. We introduce additional performance analysis results for constellations in an uncoded system and an in-depth discussion of the observed results.
    2. We extend the section dealing with the adaptive constellation design in an uncoded system and we supplement additional HW evaluation results for the adaptive system in the whole range of observed channel SNRs. Again a close agreement between between the analytic and measurement results is shown.
    3. We show how the channel coding can be integrated into the proposed constellation design, including the cut-set bound analysis of proper source transmission rates, which provides a hint for the setup of all channel encoders' rates in the system.
    4. We evaluate numerically the performance of the resulting adaptive modulation-coding scheme for a wide range of channel conditions in the WBN and we emphasise the performance gains with respect to the uncoded system.
    5. We perform a simple robustness analysis, demonstrating that the proposed modulation and coding strategy is viable even in the case when the real world condition induce some deviations from the mathematical system model assumed in the paper.
    6. We conducted a comparison with the state of the art reference scenarios (traditional network coding and routing) for the proposed channel coded adaptive constellation design.
- CQ2: *Better reference scenario.*
- A2: We definitely agree that the zero throughput uncoded QPSK reference scenario is not a very good to demonstrate the performance gain of the proposed constellation design. Although, the 2-step scenario does not offer other state of the art solution, we decided to consider a comparison with traditional network coding and routing strategies. These strategies require 3 steps and therefore some attention is required to provide a fair comparison with the proposed 2-step framework. We added a completely new section 7.4 into the manuscript dedicated to this comparison with the conventional techniques.

  Within this new section, we shown that the HW implementation of the proposed adaptive constellation design outperforms the reference scenarios even with the relaxed assumption (pre-rotation off). In addition we shown that the performance of the proposed framework is even above the corresponding reference theoretical limits.

- CQ3: *Typos and Formatting Issues*
- A3: The manuscript was carefully proofread by native speaker for typos. Regarding the formatting issues, we searched and corrected the issues we found. Nevertheless, we should stress that the manuscript will be transformed to the EURASIP template prior publishing and there will be time for final tuning of these issues.
- CQ4: *Generalization of the proposed Adaptive Constellation Design*
- A4:

Reviewer 1

- Q: *The weak aspect of this paper is that the current paper is a small variation of a previous paper by the authors. The authors should further highlight the difference of this paper.*
- A: See A1
- *The authors should edit the paper more carefully. For example, in Figure 5, the references are missing. Please go over the whole the paper and make sure similar issues do not exist*
- A: See A3

Reviewer 2

- Q: *Since this work builds upon previous work on the application of wireless network coding to the WBN, novelty is slightly lacking*
- A: see A1
- Q: *The proposed scheme appears to be quite specific to the WBN, I wonder if it is possible to generalize to other similar networks where linear codes yield a good performance.*
- A: See A4. We should stress that the proposed constellation design covers both wireless network coding and processing the signal from multiple stages. Join generalization of both techniques in the way we did would be extremely challenging, because of time synchronization, pre-rotation, etc. Also note that our approach is basically a practical instance of a well known theoretical principle with application of WNC to approximately equal power levels and interference cancellation on significantly different power levels. So that its generalization in theoretical level is already known.
- Q: *The authors should also provide more insight or intuition on the design of the constellation and explain why the challenges to apply to other linear networks.*

- A: The intuition beyond the design could be partly found in [1]. Particularly, the idea is to consider bit streams that are divided among individual power levels. We need to define 1) the scale of individual levels, 2) the constellation element for all levels. Obviously, this design would differ for basic and superposed streams:

  1. In case of superposed stream, we need to have both source streams decodable and thus we need some kind of orthogonality. This orthogonality is achieved by considering real and imaginary axis of the constellation space.
  2.

  Our solution considers the simplest possible constellation element (BPSK at given level)

- Q: *It might be useful to the reader to add a figure for the butterfly network in the setting of algebraic network coding for comparison.*
- A: see A2
- Q: *It might be useful to the reader to add a figure for the butterfly network in the setting of algebraic network coding for comparison.*
- A: see A2
- Q: *Since real world networks are usually more complicated, I think it would be really interesting if this systematic design can be generalized to all linear network coding schemes (e.g. random linear network coding).*
- A: see A2
- Q: *If it cannot be easily generalized, it could be helpful to explain what are the difficulties in applying it to other coding schemes.*
- A:
- Q: *It might be useful to the reader to add a figure for the butterfly network in the setting of algebraic network coding for comparison.*
- A:
- Q: *Might be helpful if mention beforehand that the nomenclature is given at the end of the paper (For example, HW is throughout the paper and its definition is only given at the end of the paper).*
- A: The nomenclature is placed according to the EURASIP-author's guidelines.

Reviewer 3

- Q: *In figure 6, 7, 8, 9, the reference scheme using QPSK always has a zero throughput, which demonstrates that this reference modulation scheme does not work at all in WBN under the proposed SNRs. Then the proposed communication scheme is claimed to have performance enhancement for* *sure. However, logically, this only demonstrates that the proposed algorithm gives positive throughput in WBN instead of not working. But it is not enough to say it gives a "performance enhancement" comparing with a previous working scheme. So it would be better if the author can further compare some other modulation schemes which can also give some positive throughput in WBN.*

- A: See A2. Considering the two time slot communication, there is indeed no state of the art solution for joint decoding, that is the constellation design in sources such that the relay would reliably jointly resolve data[1] from both sources. We thus decided to claim the performance of the proposed $N_b = 0$, $N_s = 2$ compared to the zero throughput QPSK as the throughput gain. Nevertheless, the reviewer has point that it is unfair to claim the performance of the proposed $N_b = 1$, $N_s = 1$ constellation as throughput gain compared to zero-throughput QPSK, because a conventional wireless network coding with BPSK would give a nonzero throughput in this case. We therefore drop this claim from our Figures 6-9 in manuscript (check Figure 1).

- Q: *As far as we know, according to the 3GPP protocol, there is a Channel Quality Index (CQI) vs. modulation format table, which suggests the modulation scheme with respect to difference SNR range. According to this table, for example, for the SNR varying from 6dB to 20dB, the protocol suggests using 16QAM and 64QAM instead of QPSK. In WBN, it could be different from 3GPP, but I suggest the author to test some other reference modulation format and compare the difference.*

- A: The channel quality index is 3-dimensional (MAC, BC and HSI) in our case and we have it basically presented in the manuscript in form some cuts shown in figures. Its comparison with P2P case can be conducted in multiple ways (e.g. one can consider 4-step conventional P2P), but we solve again the problem two-step versus 4-step stage (see A2).

- Q: *Although, in the future work, the authors have mentioned the fading channel case, it would still be better that the case of fading channels or of longer communication distance could be simulated and experimented. AWGN channel seems to be too ideal. If some initial results on the fading channel case can be added into the paper, it would be better.*

- A: TODO (possible to play with in the tutorial)

- Q: *The robustness analysis is important, and the authors have done some simulations on this aspect. However, it would be more appreciated if a hardware experiment can be done on this aspect.*

- A: We fully understand and agree that the robustness analysis deserves further deep investigation. Nevertheless we provided some basic analysis including the hardware experiment within our work (check Figure 17 in manuscript) giving quite promising results. A more detailed investigation is suited rather for a standalone work than for this resubmission.

[1] We assume uncoded data in this context only.

- Q: *In Fig. 15, the throughput enhancmence for the coding scheme is shown. It is interesting to see that the throughput enhancment has some "peak" and "valley" as the Îş_MAC increases. If possible, please give some explanation. Or this is just a random instance that happens to be shown by the hardware experiment, that is also fine.*

- A: The explanation here is quite straightforward, as it follows from the steep gradients of the uncoded throughput as function of SNRs shown in Figure 10. On the other hand the coded throughput as a function of SNRs is much smoother (Figure 14) and therefore their difference induces peeks and valleys

- Q: *There are also some minor context error or typos found*

- A: See A3

2 Major Changes Summary

- New section 7.4 containing a more advanced comparison of the proposed framework with the state of the art strategies.

- Redrawn Figures (see changes in Figures 1 and 2).

References

[1] Pavel Prochazka, Tomas Uricar, David Halls, and Jan Sykora. Relaying in butterfly networks: Superposition constellation design for wireless network coding. In *Proc. IEEE Int. Conf. on Commun. (ICC)*, pages 1–7, London, UK, to appear 2015.

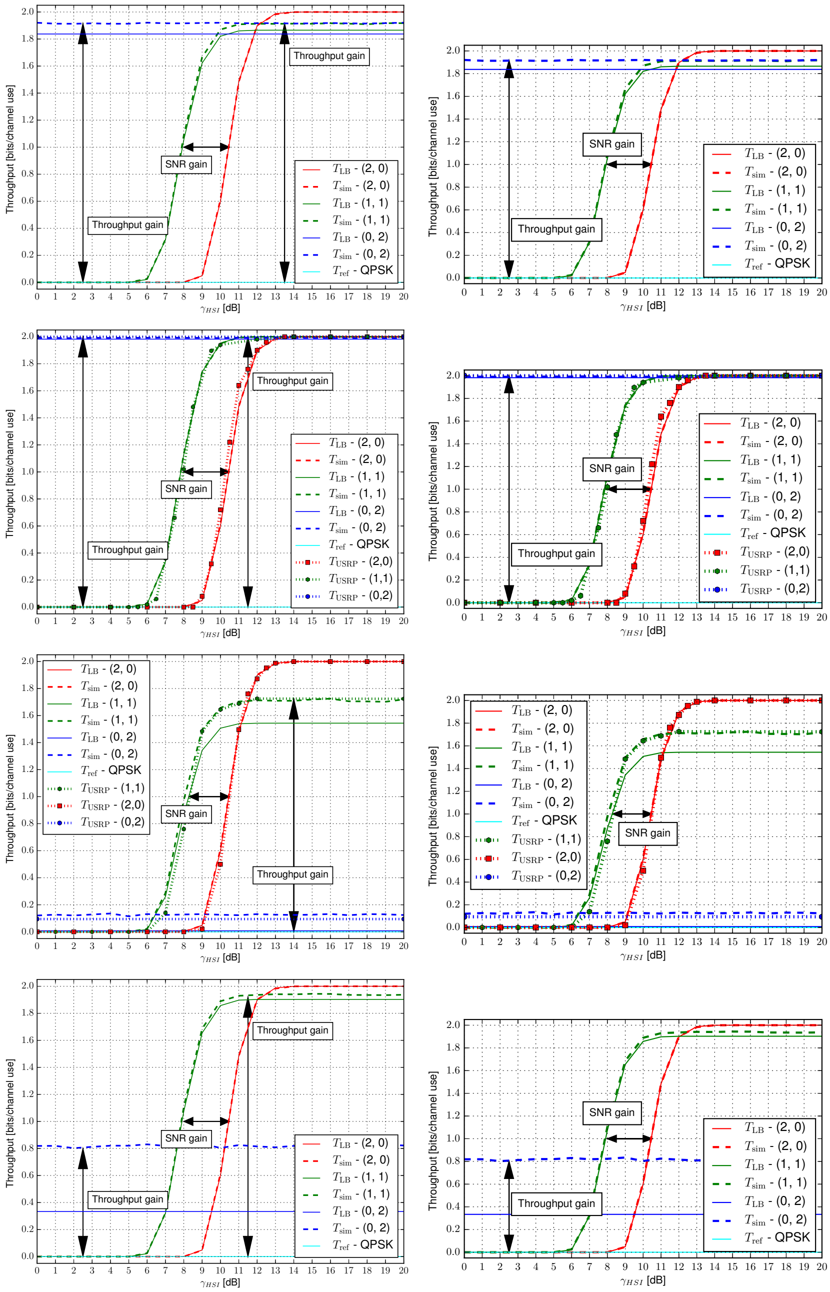

Figure 1: Uncoded throughputs (old versions left, new versions right).

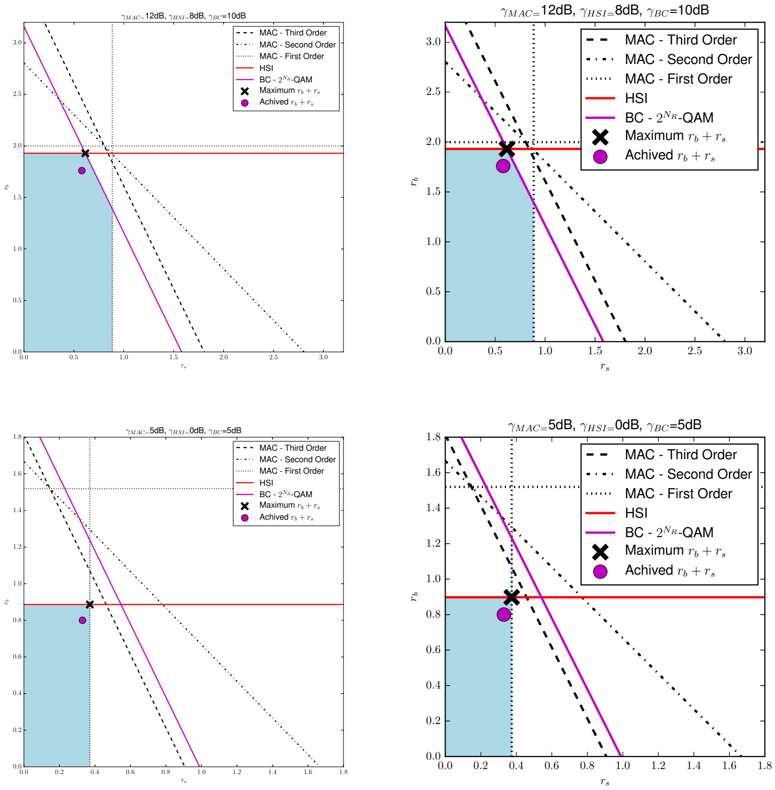

Figure 2: Enlarged fonts – Figure 13 in the manuscript (old versions left, new versions right).