Description of the Invited Tutorial for the meeting on the Design and Application of Random Network Codes (DARNEC 2015)

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Title: Resource allocation strategies for network-coded service delivery over LTE/LTE-A systems
Duration: 1 hour

Abstract

Network coding has the potential to significantly improve network reliability by mixing packets at a source node or at intermediate network nodes prior to transmission. In the first part of this talk, the concept of network coding will be quickly reviewed and extended to various cases including systematic, layered and sparse network coding. Performance expressions that describe the decoding probability of each case will be presented and discussed. The second part of the tutorial will use the derived performance expressions in resource allocation models, which can be easily adapted to the Long Term Evolution-Advanced (LTE-A) standard and its 5G features. More specifically, the idea of unequal error protection will form part of a resource allocation framework, whose objective can be either provider-centric or user-centric. In the former case, the provider can optimise the number of transmitted coded packets and the adopted modulation and coding scheme in order to offer a service to a minimum fraction of users without violating an existing service lever agreement. In the latter case, the aim is to maximise the ratio between the number of recoverable layers by the users (user's profit) and the total number of coded packet transmissions (provider's cost). The impact of the adopted network coding method on performance and the effect of sparse network coding on packet transmissions and decoding complexity will also be discussed.

Objectives

The tutorial consists of two parts. The first part will create links between communication theory and random matrix theory over finite fields and present a step-by-step methodology for obtaining theoretical expressions, which describe the performance of various network-coded systems. The objective of the second part is to build on the derived theoretical expressions, develop realistic resource allocation frameworks and consider LTE-A networks as a case of study in order to demonstrate the practical implication of network coding in real-world systems. The tutorial is suitable for graduate students and researchers from both academic and industrial sectors in the area of information theory, communication theory and networking.

Outline

Part I – Description and Performance Evaluation of Network-Coded Systems

- Fundamentals of Random Network Coding (RNC) – The concept and terminology of random network coding will be introduced and its two main types, namely inter-session and intra-session network coding, will be presented. Techniques for RNC decoding will be discussed and fundamental performance expressions that characterise the probability of successfully recovering a source message will be analysed.
- Systematic vs. non-systematic RNC – This subpart discusses the benefits of transmitting source packets that are not network-coded along with linear combinations of source packets. We derive analytical expressions for the success probability and prove that systematic RNC can both reduce decoding processing and achieve a success probability that is better or at least similar to that of non-systematic RNC, depending on the number of source packets in the original message.
- RNC for layered services – If a source message comprises packets of different priority layers or importance levels, the concept of "windowing" can be used to offer unequal error protection. We will focus on RNC using either non-overlapping windows or expanding windows, discuss their advantages and disadvantages and obtain expressions that accurately describe the decoding probability of each layer as well as the whole source message.

- Special structures of random linear matrices suitable for network-coded systems – The structure of random matrices over finite fields of size q plays a pivotal role in the design and performance of network codes. Specific 'constrained' designs will be considered, e.g. block angular matrices as well as matrices having a step structure, the probability of them being full rank will be examined and their application in window-based decoding and relay-aided networks will be presented.
- Sparse RNC – The literature usually assumes that network coding selects coefficients from a finite field of size q in a uniformly random fashion when source packets are combined. In this subpart, we consider the case of zero coefficients being selected with a higher probability than the remaining (q-1) coefficients and we present accurate bounds on the decoding probability of sparse RNC. Furthermore, we hint at the possibility of adjusting the sparsity of RNC as a means to trade transmit power for decoding speed. This claim is substantiated in Part II of this tutorial.

Part II - Resource Allocation Modelling for Network-Coded Systems

- 3GPP's Long Term Evolution-Advanced (LTE-A) – In the short-term, LTE-A is likely to play a leading role not only in 4G networks but also in the 5G ecosystem. In particular, the ability that LTE-A has of managing broadcast and multicast communications via the eMBMS frameworks are likely to be adopted into next-generation systems. In spite of its natural complexity, we will explain how the resources of the MAC and PHY layers can be mapped onto simple topologies in a bin-packing context and how the system's Service Level Agreements (SLAs) can be mapped onto a constraint set.
- Optimising with respect to the Internet Service Provider (ISP) or with respect to the users – ISP-centric optimisation and user-centric optimisation represent two extremes in the Operational Research applied to wireless networks. In this subpart, by referring to a fundamental economic principle, we will clarify how network coding could be integrated into the LTE-A stack and explain how hybrid strategies, which meet the desired SLAs constraints and are fair with respect to the ISP and the users, can be defined.
- Computationally efficient Sparse RLNC (S-RNC) strategies for ultra-reliable multicast services – In a network composed by low-end communication devices (e.g. wireless sensors), the optimisation of radio resources should not be our only concern. The computational requirements for the processing of the received information in order to recover the transmitted messages should also play a key role. In this subpart, we will adopt S-RNC and show how to model and optimise both the transmission parameters and the sparsity of the network code in order to minimise the processing footprint in the case of ultra-reliable services.

Short biography of the presenter

Ioannis Chatzigeorgiou (http://www.lancs.ac.uk/~chatzige/) is a Lecturer in Communications Systems at the School of Computing and Communications, Lancaster University (UK). He received the Dipl.-Ing. degree in Electrical Engineering from Democritus University of Thrace (Greece) in 1997, the MSc degree in Satellite Communication Engineering from the University of Surrey (UK) in 2000 and the PhD degree from the University of Cambridge (UK) in 2007. Prior to his appointment at Lancaster University, he held research positions at the University of Cambridge and the Norwegian University of Science and Technology (NTNU), supported by the Engineering and Physical Sciences Research Council (EPSRC) and the European Research Consortium for Informatics and Mathematics (ERCIM), respectively. He is the principal investigator on the EPSRC-funded project "R2D2: Rapid and Reliable Data Delivery" (http://www.lancs.ac.uk/~chatzige/R2D2/) that looks into theoretical and practical aspects of network coding and is a member of the COST Action IC1104. He has published 40 journal and conference papers on communication theory with an emphasis on forward error correction, relay-aided communications, cooperative networks and network coding.