Chapter 32
MAC and PHY–Layer Network Coding for Applications in Wireless Communications Networks

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ABSTRACT

Network coding (NC) is a promising technique recently proposed to improve network performance in terms of maximum throughput, minimum delivery delay, and energy consumption. The original proposal highlighted the advantages of NC for multicast communications in wire-line networks. Recently, network coding has been considered as an efficient approach to improve performance in wireless networks, mainly in terms of data reliability and lower energy consumption, especially for broadcast communications. The basic idea of NC is to remove the typical requirement that different information flows have to be processed and transmitted independently through the network. When NC is applied, intermediate nodes in the network do not simply relay the received packets, but they combine several received packets before transmission. As a consequence, the output flow at a given node is obtained as a linear combination of its input flows. This chapter deals with the application of network coding principle at different communications layers of the protocol stack, specifically, the Medium Access Control (MAC) and physical (PHY) Layers for wireless communication networks.

INTRODUCTION

Network coding represents one of the main topic for future communication technology. It permits to maximize the information flow in the network, leading an increased throughput with low complexity increase. NC concept can be applied to different layers of the protocol stack. Traditional NC has been proposed at the network level of wired systems. However, in some cases the achievable gains with this approach are limited (Liu, 2006). For this reason NC has been extended also to other communication layers in order to exploit link-layer or physical layer information, especially when used in wireless networks.

Despite the underlying theory of NC is attractive, many practical aspects need still to be addressed in order to understand the actual performance and benefits of this technique in wireless communications. In particular, large part of the works in the literature considers wireless links reliable like the wired ones. However, the propagation medium is very different and should be carefully addressed: theoretical concepts need to be revised and adapted to real environments. After a state of the art review, some open research issues concerning with link reliability and wireless propagation channel are addressed in this chapter and deeply investigated considering NC integration at different protocol stack layers, namely MAC and PHY.

MAC layer NC (MAC-NC) schemes are based on the features provided by this layer - basically (un)acknowledged communications - and do not require to identify the sessions to which packets fragments belong to, while effectively managing the resources. Likewise, Physical Layer NC (PLNC) schemes are inspired by the basic NC principle to remove the constraint that different information flows have to be transmitted in separated channels. In particular, for PLNC schemes the definition of efficient approaches concerning cancellation or detection of collided packets at the final receiving ends is the main design goal.

For both approaches this chapter offers a critical review of the state of the art and then outlines new solutions that overcome classical methods.

The MAC-NC has been adopted to achieve better performance for connection oriented services, i.e., acknowledged communications, in terms of end-to-end packet delay in the presence of lossy links. The focus is usually on a network model where source nodes broadcast packets to a group of two or more sink nodes over error prone wireless channels. Three different alternatives have been considered in order to assure a reliable data multicasting, namely: a classical random linear network coding (RLNC) scheme, a linear network coding combined with a basic ARQ or, alternatively, with a soft combined ARQ scheme. Performance comparisons provided by means of analytical and numerical results clearly highlight that the best solution is to adopt the last alternative.

In addition, it has been investigated the feasibility of applying MAC-NC to unreliable wireless communications scenarios (i.e., without explicit acknowledgment of packet reception outcome) in which the transmitted power level of different network nodes is optimized with the aim of minimizing the number of NC packets transmitted on a link basis, thereby lowering the end-to-end delay and the overall power consumption.

Also PLNC has been addressed. One of the most interesting topic concerning the PLNC deals with the Two-Way Relay Network (TWRN) where a pair of nodes exchange information through a third node with relaying function. The two main approaches of PLNC coding are Amplify and Forward (AF) and Decode and Forward (DF). Generally the latter approach works better in AWGN (Additive White Gaussian Noise) channel because the noise is not forwarded by the relay. However in actual multipath fading channels this approach has several limitations due to channel variations that have impacts on the relay demodulation, the knowledge of the channels involved in the communication and the power balancing to name a few. In this chapter the attention is

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