Joint Channel and Network Coding: A Survey

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Abstract:
The high and variable BER and packet loss in the wireless networks due to the unreliable nature of wireless channel, interference, link failure, fading and shadowing wireless link considers the main problems to implement a reliable wireless network. Packet loss and packet drop probability are the most important performance measures for real-time applications. In order to address these problems, improve the performance of wireless network, and make it more reliable, several joint networks coding with channel coding (JNCC) scheme are proposed. This combination assists in complete exploitation of the spatial variability and redundancy in both channel and network codes. The JNCC technique is proposed in order to reduce the bit error rate (BER) over wireless multi-access channel with low SNR and increases the PDR over multi-access wireless channel. Recently, many active studies jointly design network-channel codes to fully exploit the redundancy in both channel and network codes. In this paper, we aim at providing a comprehensive survey of the most important and notable research directions in joint channel and network codes techniques.

Keywords: Network Coding, Channel Coding, Joint Channel Network, LDPC

1. Introduction

In a wireless network, the packet is dropped if the retransmitted information is still erroneous and this is a waste of bandwidth and time, which leads to bad performance for networks [1], [2], [3]. In addition, packets can be lost due to errors, congestion in a queue due to high traffic, collision, hidden nodes, and the link failures. The problem of packets dropped becomes more critical in real time applications such as video conference and remote control in a wireless sensor network (WSN) [4]. In addition to the channel coding, a wireless network coding (WNC) has been considered as a promising solution with its capability of improving the quality of service (QoS) performance of wireless networks by retrieving the packet lost. In a traditional store-and forward network, packets are forwarded hop-by-hop along the intermediate routers from a source to a receiver. An intermediate node forwards the packets as it receives through a predefined path. WNC is a recent field of information theory that allows the intermediate nodes instead of simply forwarding data, to generate new packets by combining packets received on their incoming ports before sending the combined data on its output links to increase the capacity and throughput of each link (path), and increase the packet delivery ratio (PDR).

The aims of channel coding and network coding techniques have retrieved the original information. Channel coding is used for point-to-point communication over a single channel, and it uses the error correction coding to improve the error performance of the wireless link. It is implemented at the physical layer to recover erroneous bits through redundant parity check bits added inside a packet. The error retrieval capability for channel coding depends on the specific coding and the amount of redundant bits. An erasure correction coding can be used to handle lost packets on the end-to end connection level that uses redundant packets to recover the original information at the network layer for end-to-end communication.

Traditional network coding allows the intermediate nodes to generate a redundant network-coded packet [5], [6]. Joint channel-network coding provides reliable communication and achieves a better performance for a network communication system instead of the case when channel and network codes are designed separately [7], [8], [9], [10], [11], [12]. Recently, many authors proposed design for channel-network codes to exploit the benefits of channel and network codes in recovering the original information. On the other hand, the demand for real time applications and multimedia applications has increased due to the rapid increase in the number of wireless network users. In addition, providing high-speed and reliable services with the ability to access video over the Internet and share large files in wireless mesh networks is the fundamental challenge due to the interference and unreliable nature of wireless link (i.e., variable link qualities), which causes packet losses and link failures. Moreover, some applications cannot use automatic repeat-request (ARQ) when the packet is lost, because the original packets are no longer available in the source. For example, most of the television cameras immediately forget the information as soon as they are sent and cannot resend the original packets.

The remainder of this paper is structured as follows. In section II, we present background of channel coding and network coding. In section III, the related work of joint channel and network coding is presented. Finally, we conclude the paper in section V.

2. Background

A. *Channel Coding:*

Channel coding is an error-control technique used to provide robust data transmission through imperfect channels by adding redundancy to the data. There are two important classes of channel coding methods namely, block and convolutional coding. In information and coding theory, error detection and correction are techniques that enable the reliable delivery of digital data over unreliable communication channels. Error detection and correction especially in a high reliability and high data rate wireless network applications have been receiving considerable attention and have become an important part of networking and data communications. Best networks communication must be able to transfer data from source to destination or from one node to another node with complete accuracy and reliability. Therefore, for reliable networks, it is desirable to detect and correct the error at the destination node without need to send a retransmit request again to the sender node. By using the error detection and correction techniques the network performance will improve by increasing the throughput and PDR and decreasing the BER and end-to-end delay. Examples of the channel codes are Hamming, Reed-Solomon (RS), Turbo, and Low Complexity Parity Check (LCPC) codes.

B. *Considerations of Selecting the Channel Code Scheme:*

Selecting channel coding scheme for a practical application is not an easy task. In fact, many factors it needs to take into account: error detection and correction capability, decoding complexity, error types, signal power constraints and processing latency. However, no single channel coding scheme works for all applications. In Shannon's theorem, the longer the code, the better the error correcting performance. On the other hand, longer code means higher decoding complexity and larger processing latency. The decoding process dominates the overall computational cost of an error control system. In real time application, large amounts of latency are not preferred. Therefore, we have to make a trade-off between the performance and complexity when selecting the channel code scheme. The ensemble average bound on uncorrected error probability can give us an estimate of how the performance and the complexity are related.

C. *Network Coding:*

Network coding considers a new transmission paradigm that proved the strength in optimizing of network resources. Network coding is a new approach introduced into the theory of information science to increase the transmission capacity and improve throughput of a network [13]. It enables better resource utilization and achieves the max flow, which is the theoretical upper bound of network resource utilization, by allowing a network node such as a router to encode its received data before forwarding it. Network coding is considered as a generalization of conventional store-and-forward routing techniques. Contrarily, traditional coding techniques are referred to as source-based coding, where only source node encodes packets [13], [14], [15]. In this case, each node is implemented with network coding function instead of simply forwarding the packets of information to the destination; the nodes of a network take several packets and encode them together into a single coded packet before forwarding. This can be used to achieve the maximum possible information flow in a network.

Recent research has proven that network coding has great potential to improve network throughput, reduce delay, and improve robustness in multi-hop wireless networks by exploiting the intrinsic broadcast nature of wireless communication and the native physical-layer coding ability by mixing simultaneously arriving radio waves at relay nodes [16], [17]. In traditional networks based on the store and forward, packets are forwarded hop-by-hop along the routers from a source to a destination. In this case, intermediate node forwards the packets without analyzing it.

Linear Network coding (LNC) has been proposed as an effective technique to increase the network bandwidth-efficiency [5], and throughput [17]. NC gives intermediate nodes the ability of randomly encoding different packets received previously into one output packet. LNC is one research area that able to enhance the reliability and efficiency of network communications systems. In LNC, packets transferred through a network are viewed as symbols in finite field GF (q) on which their arithmetic operations are defined, where q denotes the size of finite field. Each coding node has two or three input links and one or two output links. Coefficients are assigned to input links of coding nodes. Each input link has one coefficient. These coefficients are randomly generated and selected from the Galois Field GF(q). These coefficients are grouped together which refer to as the coding vector. This coding vector was used to encode the native packets at the source node and to retrieve native packets at the receiver nodes [6], [14].

In order to retrieve native packets, receiver nodes need to know the coding vector of the coded packets they received. Chou et al. [18] proposed a method of embedding the coding vector in the header of the coded packet in order to deliver coding vectors to the receiver nodes. The main problem in LNC is, if some error occurs in the coding vector (coefficients) through the transmission or it is lost due to the unreliable nature of wireless link, interference or link failure. In this case, the receiver cannot retrieve the native packets, as it does not have the correct coefficients. In LNC system, the transmission was assumed to be in ideal channel with no error, no packet loss and no link failure.

3. Related Work

In wireless networks, network error correcting codes have other interesting research topics, such as joint network channel coding. Joint network and channel coding provide reliable communication and achieves better BER performance in a wireless network instead of the case when channel and network codes are designed separately. Recently, many researchers proposed design for joint channel and network codes to exploit the benefits of channel and network codes in recovering the original information. For example, Tran et al. [7] have presented a proposed joint network and channel coding technique to increase the bandwidth efficiency of a single hop wireless network such as WLAN or WiMAX networks. The results showed that the proposed technique could increase the bandwidth efficiency for both broadcast and unicast scenarios in a single hop wireless network.

Further, in [19] an extension of the relay channel model, namely two-way relay channel has been proposed and introduced. The two-way relay channel consisted of two users who wanted to communicate to each other with the help of one relay. Time-division two-way relay channel without power control was considered. A joint network-channel coding method for the two-way relay channel model was described. The channel codes were used at both users, whereas, a network code was used at the relay node. Hausl and Dupraz [8] have proposed joint network channel coding based on turbo codes for two-way relay channels and a multi-access relay channel. The proposed system with a distributed turbo code for the relay channel was compared with a system which used separate network-channel coding for the multiple-access relay channel. Simulation results confirmed that joint network-channel coding outperformed separate network-channel coding.

Qiang et al. [9] have presented a joint network and channel coding (JNCC)strategy with retransmissions for two canonical network elements, broadcast channel with receiver side information (BC-SI) and orthogonal multiple access channel with correlated sources (MAC-CS). The network throughput by applying the renewal ward theorem was quantified. The proposed JNCC strategy outperformed conventional separate network and channel coding (SNCC) strategy with random linear network coding (RLNC). Bao and Li [20] presented a general framework that merges channel coding and network coding. Liu et al. [21] have proposed a joint network channel coding algorithm for wireless relay communications in order to reduce the BER over the wireless multi-access channel with low SNR. LDPC was applied as channel code to work together with network coding in the relay node. Joint network-channel decoding was applied at the destination nodes. The channel message with higher SNR was chosen as the received information. The proposed network model was able to support network coding well with low system BER. However, the scheme required more hardware resource due to the usage of relay node. On the other hand, the improvement of the proposed system depended on higher power consumption and more collaboration complexity.

Thobaben [22] proposed a joint network and channel coding scheme for multiuser ARQ. Network coding was employed to combine retransmissions to several users in a packet based wireless system. The proposed JNCC approach significantly outperformed the conventional MU-ARQ. Qiang et al. [23] proposed a joint network and channel coding (JNCC) strategy by exploiting ARQ, receiver side information (RSI)and correlated sources. Wireless multicast network with multiple sources, relays and destinations were considered. A multi-hop decode-and-forward relay protocol was adopted, in which two canonical sub networks were relevant, namely broadcast channel with receiver side information (BC-RSI) and orthogonal multiple access channel with correlated sources and receiver side information (MAC-CS-RSI). A closed form expression of network throughput by applying the renewal-reward theorem was derived to measure the performance of the proposed JNCC strategy with ARQ. Analytical results demonstrated that the proposed JNCC strategy outperformed, in terms of network throughput, the conventional separate network and channel coding strategy with random linear network coding. In [24], the authors proposed the time-division multiple access relay channel (MARC) with the low-complexity compress-and-forward-based transmission scheme that consists of a scalar quantization of log-likelihood ratios (LLRs), followed by a suitably defined network code. The information bottleneck method (IBM) for designing the LLR quantizers is used. S. J. Johnson et al., [25] investigated the joint network and channel coding schemes in case the relay nodes in the networks are not capable of performing channel coding operations. The authors examined three different decoding strategies: independent network-then-channel decoding, serial network and channel decoding, and joint network and channel decoding.

Guo et al. [10] have proposed a practical non-binary joint network channel coding (NB-JNCC) for multi-path multi-hop communication in large scale wireless networks. The authors combined NB-LDPC channel coding from [26] and random linear network coding [15], [27], [28] through iterative joint decoding. NB-JNCC operates over a high order Galoisfield, and therefore it can be directly combined with high order modulation without needing any bit-to-symbol conversion or its inverse. Simulation results showed the significant performance improvement of NB-JNCC over other schemes. Yu and Zhaoyang [11] employed a joint network-channel coding with a specially designed rate less code which conducted both the channel coding and network coding simultaneously to enhance the link robustness and the system throughput. They considered an asymmetric time division multiple access relay system consisting of two sources, relay and destination. Simulations showed that the proposed JNCC scheme outperformed other JNCC schemes on the BER and throughput performances.

Hernaez et al. [12] proposed a novel joint non-binary network-channel code forth time-division decode-and-forward multiple access relay channel (TD-DF-MARC).They designed a joint-network-channel code which did not perform channel coding on the bits which were already network-coded; this helped reducing the complexity at the relay node without compromising performance. The relay linearly combined the coded sequences from the source nodes. Simulation results showed that the proposed scheme outperformed other schemes. K. Christian et al. [29] have been considered a binary channel coding on a binary symmetric channel (BSC) and q-ary RLNC for erasure correction in a star network. The authors analyzed the joint design of channel coding on the physical layer and random linear network coding on the link layer for a star network topology. In [30], a new joint source channel network coding (JSCNC) using Quasi Cyclic Low-Density Parity Check (QCLDPC) code is proposed for a sensor network with two source nodes communicating correlated information to multiple destination nodes. A joint iterative channel-network decoder for use at the base station in a system employing a Diversity Network Code (DNC)is presented [31]. The proposed scheme is based on hybrid soft/hard message passing between constituent low-complexity low-density parity-check (LDPC) decoders. The authors in [32] proposed a Joint Channel Network Coding (JCNC) scheme applied to Multiple Access Relay Channel (MARC) for correlated sources.

Table 1: Chronology of Research Activities

Reference	**Summary of Work Performed**
(Hausl and Hagenauer, 2006)	An extension of the relay channel model, called two-way relay channel had been proposed and introduced. Time-division two-way relay channel without power control was considered.
(Hausl and Dupraz, 2006)	A joint network-channel coding based on turbo codes was proposed to use for the multiple-access relay channel. Simulation results confirmed that joint network-channel coding outperformed separate network-channel coding.
(Tran et al., 2008)	A joint network and channel coding technique to increase the bandwidth efficiency of a single hop wireless network such as WLAN or WiMAX networks was presented. Simulation results showed that the proposed technique could increase the bandwidth efficiency for both broadcast and unicast scenarios in a single-hop wireless network.
(Qiang et al., 2009)	A joint network and channel coding (JNCC) strategy was proposed, with retransmissions for broadcast channel with receiver side information (BCSI)and orthogonal multiple access channel with correlated sources (MACCS).
(Thobaben, 2010)	A joint network and channel coding scheme for multi-user ARQ was proposed. The proposed JNCC approach outperformed the conventional MUARQ significantly.
(Liu et al., 2011)	A joint network-channel coding algorithm for wireless relay communications was proposed, in order to reduce high BER over the wireless multi-access channel with low SNR. LDPC was applied as channel code to work together with network coding in the relay node.
(Qiang et al., 2011)	A joint network and channel coding (JNCC) strategy was proposed by exploiting ARQ, RSI, and correlated sources. Wireless multicast network with multiple sources, relays, and destinations was considered. A multi-hop decode-and-forward relay protocol was adopted.
(Guo et al., 2012)	Non-Binary Joint Network-Channel Coding (NB-JNCC), for reliable multipath multi-hop communication scheme was proposed. NB-JNCC combined non-binary irregular LDPC channel coding and random linear network coding through iterative joint decoding.
(Yu and Zhaoyang, 2013)	An asymmetric time division multiple access relay system consisting of one relay and one destination was considered. The channel conditions and message lengths of the two sources were allowed to be different.

(Hernaez et al., 2013)	Joint non-binary network-channel codes for the time-division decode-and forward multiple access relay channel (TD-DF-MARC) was proposed. The relay linearly combines the coded sequences from the source nodes. Simulation results showed that the proposed scheme outperformed other schemes.
(K. Christian et al., 2014)	The authors analyzed the joint design of channel coding on the physical layer and random linear network coding on the link layer for a star network topology.
(Christian et al. et al., 2014)	Propose a binary channel coding on a binary symmetric channel (BSC) and q-ary RLNC for erasure correction in a star network.
(P. Jesy and P. P. Deepthi, 2014)	Proposed joint source channel network coding (JSCNC) using Quasi Cyclic Low-Density Parity Check (QCLDPC) code for a sensor network.
(H. King and M. F. Flanagan, 2016)	Presented a joint iterative channel-network decoder for use at the base station in a system employing a Diversity Network Code (DNC).
(Y. Zid, et al., 2017)	Proposed a joint channel network coding (JCNC) scheme applied to Multiple Access Relay Channel (MARC) for correlated sources.

4. Concluding Remarks

In this survey paper, an overview of the recent researches on joint network coding with channel coding is provided. Wireless networks communications suffer packet losses due to the detrimental effect of fading of wireless channels and link failures. Motivated this problem, joint network coding with channel coding (JNCC) scheme is proposed, to provide reliable packet transmission in wireless networks applications. JNCC technique combines a one channel coding with network coding. The related work shown that the research field of JNCC is receiving anupsurge of interest in the research community. However, research in that field is still at its start, and fundamental and open issues need to be still addressed for the practical application.

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