Computer Communications 86 (2016) 49–56

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

OM^{2}DNC: Opportunistic Max^2-Degree Network Coding for wireless data broadcasting[☆]

Hui Tian, Kui Xu*, Jian Wang, Youyun Xu, Dongmei Zhang, Wei Xie

College of Communications Engineering, PLA University of Science and Technology, Nanjing 210007, China

ARTICLE INFO

Article history:
Received 28 April 2015
Revised 15 December 2015
Accepted 22 February 2016
Available online 2 March 2016

Keywords:
Wireless data broadcasting system
Opportunistic network coding
Opportunistic retransmission
Joint network and RSC decoding

ABSTRACT

In wireless broadcasting systems, multiple retransmissions are commonly employed to guarantee the correct reception of each packet. The traditional hybrid automatic retransmission request protocol retransmits one packet per slot. Hence, a large amount of retransmissions is required to correctly receive all the packets, which leads to low spectrum efficiency. In this paper, we propose an Opportunistic Max^2-Degree Network Coding (OM^{2}DNC) based wireless broadcasting (WBC) protocol. Specifically, to reduce the overall number of retransmissions, lost packets of different user equipments (UEs) are combined by performing Max-Degree network coding (NC) at the access node. Then, NC combined packets are broadcasted by utilizing the Max-Degree based opportunistic retransmission protocol. At each UE, the lost packet can be recovered by using the proposed joint network recursive systematic convolution decoder. Theoretical analyses and simulation results show that the average number of transmissions performance of the proposed OM^{2}DNC based WBC protocol outperforms that of the traditional NC based WBC protocols.

1. Introduction

Next generation broadband wireless access (BWA) networks such as WiMAX and Long Term Evolution (LTE) are expected to provide efficient, affordable and ubiquitous internet access for data multimedia broadcasting applications such as stock price, real-time traffic and weather information, high-definition (HD) digital television (TV) video streaming and video conferencing. To ensure users' satisfaction, the Quality of Service (QoS) provided by BWA networks should be comparable to that of wired data broadcasting networks. Although the QoS framework for the next generation BWA networks has been designed to support the requirements of multimedia applications, the inherent error-prone nature of the wireless channel often results in high packet error rate (PER) and hence degrades the system reliability. To transmit information reliably over wireless channel, many approaches are employed, such as Forward Error Correcting (FEC), Automatic Retransmission reQuest (ARQ) and Hybrid Automatic Retransmission reQuest (HARQ) [1]. Among these approaches, FEC suffers from low transmission efficiency and ARQ faces large delay and low throughput caused by severe fading channel. HARQ, which combines both FEC and ARQ techniques, can contribute to an efficient utilization of the available resources.

1.1. Motivation and related work

HARQ has now become a fundamental tool of BWA networks, as it can significantly improve the reliability of wireless link. However, HARQ still encounters challenge in wireless broadcasting applications. As identical information is transmitted from one source to many receivers, it is impossible for each receiver to successfully receives all packets all the time. The traditional HARQ protocol retransmits one packet per slot.[1] Therefore, HARQ[2] may require large amount of retransmissions in broadcasting scenario to ensure

---

[☆] This work is supported by Major Research Plan of National Natural Science Foundation of China (no. 91438115), National Natural Science Foundation of China (nos. 61301165 and 61371123), Jiangsu Province Natural Science Foundation (BK2012055), Special Financial Grant of the China Postdoctoral Science Foundation under grant (no. 2015T81079), China Postdoctoral Science Foundation (2014M552612) and Jiangsu Postdoctoral Science Foundation (no. 1401178C).

* Corresponding author. Tel.: +86 25 13611587232.
E-mail address: lgdxxukui@126.com (K. Xu).

[1] We use the term packet because no matter what exactly is retransmitted in a particular HARQ protocol, a Protocol Date Unit (PDU) in MAC layer is produced and delivered to PHY layer, a resource block (or slot, in LTE the length of a resource block is 500 us) of system must be allocated to the terminal. Therefore in the view of channel occupation, both traditional HARQ (that retransmits information bits and redundancy bits) and HARQ with Incremental Redundancy (HARQ-IR) (that retransmits only redundancy bits) need to retransmit at least one packet.

[2] Though advanced HARQ schemes, i.e., HARQ-IR and HARQ with Chase Combine (HARQ-CC) [2], achieve significant performance improvement, the potential of being combined with network coding makes traditional HARQ Type-I scheme a better choice. For this reason, in this paper we mainly focus on traditional HARQ

http://dx.doi.org/10.1016/j.comcom.2016.02.013
0140-3664/

correct reception for every packet in all the receivers, which leads to low bandwidth efficiency. In order to improve the transmission efficiency for wireless broadcasting (WBC) system, recently, network coding (NC) [3–7] has been applied to WBC system. By broadcasting, we refer to the scenario where a common sender serves multiple receivers[3] with the same information. In NC based WBC scenario, lost packets or additional naive packets are NC combined before transmitted. According to the way NC combined packets are utilized, we could divide existing NC based WBC schemes into two types, i.e., *wait-and-decode network coding* (WDNC) [7–10] and *instantly decodable network coding* (IDNC) [14–20].

1.1.1. WDNC based WBC

Typical WDNC applications include fountain codes and random linear. For WDNC based WBC, received packets that are not instantly decodable are stored for future decoding opportunity [7–10]. With WDNC, perfect throughput could be achieved, however, the receivers can decode all the lost packets only if they have received sufficient number of mixed packets, this kind of retransmission strategy usually has a greater computational complexity and incurs additional delay. In recent work, the trade-off between performance, delay and complexity is addressed to facilitate the application of network coding in multimedia services [11,12].

1.1.2. IDNC based WBC

IDNC refers to that the received packets are decoded only at their reception instant and cannot be stored for future decoding. For XORing NC based WBC, NC is performed on lost packets which are carefully selected to ensure the decodability at the receiver [14–19]. A dual-XOR HARQ retransmission scheme for wireless broadcasting is proposed in [21], which introduces an additional XOR operation between two lost packets from the individual receiver. In [22], a XORing network coding combining (XNCC) and distributed Turbo coding based type-III HARQ protocol is proposed for wireless broadcasting system. The broadcasting efficiency can be significantly improved by introducing the network and channel coding gain. The above literatures [8–10,14–19,21] address the problem of NC based retransmission for WBC system. Unfortunately, different lost packets are NC combined and retransmitted without considering the *degree* of each NC packet.

1.2. Contributions

In this paper, an Opportunistic Max^2-Degree Network Coding (OM^{2}DNC) based WBC protocol is proposed to improve the overall system spectrum efficiency. At the access node (AN), lost packets of different user equipments (UEs) are combined by performing Max-Degree NC. Then, NC combined packets are broadcasted by utilizing the Max-Degree based opportunistic retransmission protocol. At each UE, the lost packet can be recovered by using the proposed joint network recursive systematic convolution (RSC) decoder (JNRD). Theoretical analyses and simulation results show that the average number of transmissions (ANTs) performance of the proposed OM^{2}DNC based WBC protocol is superior to that of the maximum clique selection algorithm (MCSA) [16], traditional index NC (INC) [15] protocol and XNCC [22] protocol in severe fading channels.

2. System model and parameters

We consider a WBC system, where a wireless AN[4] broadcasts a frame of λ packets to a set $\mathcal{R}=\{R_1,R_2,\ldots,R_M\}$ of M UEs within its coverage, and the UEs try to receive packets transmitted from BS. BS adopts TDMA protocol to broadcast these packets. During a TDMA slot, only one packet could be transmitted. In total, λ TDMA time slots are needed to broadcast λ data packets, and this λ time slots is referred to as *Broadcast Phase*. After decoding packets, UEs send feedback to report whether packets have been successfully decoded. After *Broadcast Phase*, BS starts *Retransmission Phase*, in which the BS retransmits packets and UEs send feedback to request retransmission of lost packets until all the packets are correctly received.

2.1. Mathematical description

2.1.1. Signal transmission

We assume that the original WBS frame $\mathbf{A}$ consisting of λ information vectors, i.e., $\mathbf{A}=\{\mathbf{a}_1,\mathbf{a}_2,\ldots,\mathbf{a}_\lambda\}$. A transmission information vector could be denoted by the XORing of a set of original. Let $\mathcal{C}$ denote the *candidate set*, which is defined as an index set of original packets that can be XORing NC combined. For the information vector set $\mathbf{A}_\mathcal{C}=\{\mathbf{a}_i \mid i\in\mathcal{C}\}$, the AN combines all the information vectors by using NC, i.e., $\mathbf{a}_\mathcal{C}=\mathbf{a}_i\oplus\mathbf{a}_j\oplus\cdots\oplus\mathbf{a}_k$, where $\oplus$ denotes the XOR operator. Specially, for broadcast phase, the candidate set is the corresponding original information vector itself. The information vector is encoded by the RSC encoder yielding the codeword $\mathbf{b}_\mathcal{C}=\mathrm{RSC}(\mathbf{a}_\mathcal{C})$, where $\mathrm{RSC}(\,\cdot\,)$ denotes the RSC encoder. The code bits $b_\mathcal{C}(i)$ are mapped to symbols $x_\mathcal{C}(i)\in\mathbb{X}$ of the modulation alphabet $\mathbb{X}$ and broadcasted to the UEs. In case of block fading channel, the received signal vector at the lth UE can be expressed as

$$\mathbf{y}_{l,\mathcal{C}}=h_l\sqrt{P_s}\mathbf{x}_\mathcal{C}+\mathbf{n}_l \tag{1}$$

where $\mathbf{x}_\mathcal{C}$ denotes the transmitted signal packet and $\mathbf{n}_l$ is the noise vector whose elements are identically independent distributed (i.i.d) zero-mean Gaussian random variables with variance $\sigma^2_{n_l}$. P_s denotes the BS's transmission power. The coefficient h_l, $\forall\{l\}$ denotes complex zero-mean circular symmetric Gaussian distributed variable with variance $\sigma^2_{h_l}$, i.e., $h_l\sim\mathcal{CN}(0,\sigma^2_{h_l})$.

2.1.2. Signal reception

After receiving packets, UEs try to decode these packets, and whether a packet is decoded successfully can be determined by calculating the CRC bits attached in the tail of the packet. We assume that the information vector $\mathbf{a}_i$ is lost at the lth UE. Based on the received NC combined signal $y_{l,\mathcal{C}}(m)$, the LLRs for the participating coded bit $b_i(n)$ can be calculated as [23],

$$\begin{aligned}L^l_{\mathrm{Dem}}(b_i(n))&=\mathrm{sign}\left(\hat{x}^m_{\mathcal{C}\backslash\{i\}}(n)\right)\ln\frac{\Pr\left\{b_i(n)=0|y_{l,\mathcal{C}}(m),\hat{h}_{l,\mathcal{C}}\right\}}{\Pr\left\{b_i(n)=1|y_{l,\mathcal{C}}(m),\hat{h}_{l,\mathcal{C}}\right\}}\\&=\mathrm{sign}\left(\hat{x}^m_{\mathcal{C}\backslash\{i\}}(n)\right)\ln\frac{\sum_{x\in\mathbb{X},b_i(n)=0}\exp\left(-\frac{\left|y_{l,\mathcal{C}}(m)-\hat{h}_{l,\mathcal{C}}\sqrt{P_s}x\right|^2}{\sigma^2_{n_l}}\right)}{\sum_{x\in\mathbb{X},b_i(n)=1}\exp\left(-\frac{\left|y_{l,\mathcal{C}}(m)-\hat{h}_{l,\mathcal{C}}\sqrt{P_s}x\right|^2}{\sigma^2_{n_l}}\right)}\end{aligned} \tag{2}$$

where $\hat{h}_{l,\mathcal{C}}$ is the estimate of the channel coefficient $h_{l,\mathcal{C}}$ [25], $\mathrm{sign}(\cdot)$ denotes the sign function, $\backslash$ denotes the relative complement (also termed as set difference) operator, $\mathrm{sign}(\cdot)$ denotes the sign function, $\hat{x}^m_{\mathcal{C}\backslash\{i\}}(n)=[x_{\mathcal{C}\backslash\{i\}}(n)]_m$ denotes the modulated signal portion of $x_{\mathcal{C}\backslash\{i\}}(n)$ associated with the coded bit

---

Type-I scheme where unsuccessfully received packets (information bits and redundancy bits) are threw away without further use.

[3] The number of receivers should not be too large for the threat of feedback implosion problem. For the scheme for broadcasting scenario with massive receivers, see [20].

[4] Such as a base station (BS) in a LTE or WiMAX cell.