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Three schemes for wireless coded broadcast to heterogeneous users

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A B S T R A C T

We study and compare three coded schemes for the single-server wireless broadcast of multiple description coded content to heterogeneous users. The users (sink nodes) demand different numbers of descriptions over links with different packet loss rates. The three coded schemes are based on the LT codes, growth codes, and randomized chunked codes. The schemes are compared on the basis of the total number of transmissions required to deliver the demands of all users, which we refer to as the server (source) delivery time. We design the degree distributions of LT codes by solving suitably defined linear optimization problems, and numerically characterize the achievable delivery time for different coding schemes. We find that including a systematic phase (uncoded transmission) is significantly beneficial for scenarios with low demands, and that coding is necessary for efficiently delivering high demands. Different demand and error rate scenarios may require very different coding schemes. Growth codes and chunked codes do not perform as well as optimized LT codes in the heterogeneous communication scenario.

1. Introduction

1.1. Motivation

In the past decade, the development of wireless networks has provided a fertile soil for popularization of portable digital devices, and the digital distribution of bulk media contents. This, in return, is stimulating new leaps in wireless communication technology. Today, devices retrieving digital video content in the air vary from 1080p HDTV sets to smartphones with 480 × 320-pixel screen resolution. Under assorted restraints in hardware, power, location, and mobility, these devices experience diverse link quality, differ in computing capability needed to retrieve information from received data streams, and request information of varied granularity. Consequently, a transmission scheme designed for one type of users may not be as suitable for another even if they demand the same content.

Today's technology implements a straightforward solution of separate transmissions to individual users, that is, multiple unicasts. Nonetheless, the key question is whether it is possible to deliver all users' demands with fewer data streams and less traffic. Especially in transmitting bulk data through wireless channels or over other shared media, reducing the amount of traffic is vital for reducing collision/interference, which in turn will also positively affect the quality of the channel in use. An additional concern in the environment conscious world is, of course, energy.

There is no surprise then that the problem of delivering more efficient service to a heterogeneous user community has attracted a great deal of both technical and academic interest. On the source coding side, layered coding (e.g. [1,2]) and multiple description coding [3] have been widely studied as solutions to providing rate scalability. In particular, with multiple description coding, a user is able to reconstruct a lower-quality version of the content upon receiving any one of the descriptions,

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and is able to improve the reconstruction quality upon receiving any additional description. Thus, the users' content reconstruction quality is commensurate with the quality of their connection. On the channel coding side, rateless codes [4,5], or fountain codes, can generate a potentially infinite stream of coded symbols that can be optimized simultaneously for different channel erasure rates as long as the users have uniform demands.

In this work, we explore an achievable efficiency of serving users having heterogeneous demands while using a single broadcast stream. Whereas the information theoretical aspect of the problem is of interest and under investigation (see for example [6] and references therein), we focus on three practical coding schemes and explore their suitability for the described communications scenario. Two important features that make codes suitable for such scenarios are (1) the ability to support partial data recovery and (2) the ability to efficiently adapt to different channel conditions. Based on these desirable features, we chose to investigate three candidates: LT [4], growth [7], and chunked [8,9] codes. In this paper, we are particularly interested in the *total number of source transmissions* needed to deliver the demands of all users. This quantity determines the amount of required communication resources, and also translates to the amount of time required for delivery. In the streaming of temporally-segmented multimedia content that is delay-constrained, it is important for the source to finish transmitting a segment as soon as possible so as to proceed to the next one. Some other performance measures of interest are addressed in [10].

1.2. Main results

We compare three coding schemes and their variations for broadcasting to heterogeneous users: users suffer different packet loss rates and demand different amounts of data. The coding schemes discussed include:

1. optimized LT codes, with or without a systematic phase, that is, one round of transmission of the original uncoded packets;
2. growth codes; and
3. chunked codes.

We also compare these schemes to a reference scheme for the heterogeneous scenario based on time-shared broadcast of degraded message sets [11]. We find that including a systematic phase is significantly beneficial towards delivering lower demands, but that coding is necessary for delivering higher demands. Different user demographics result in the suitability of very different coding schemes. Growth codes and chunked codes are not as suitable to this communication scenario as are optimized LT codes.

1.3. Organization

The rest of the paper is organized as follows. Section 2 introduces the model of wireless broadcasting of multiple description coded content to heterogeneous users. Section 3 introduces the coding schemes of interest, and provide theoretical characterization of code performance. In particular, the LT codes are optimized both with and without a systematic phase. In Section 4 we provide numerical and simulation results of the achievable server delivery time, and discuss the suitability of these coded schemes for broadcast to heterogeneous users. The last section concludes.

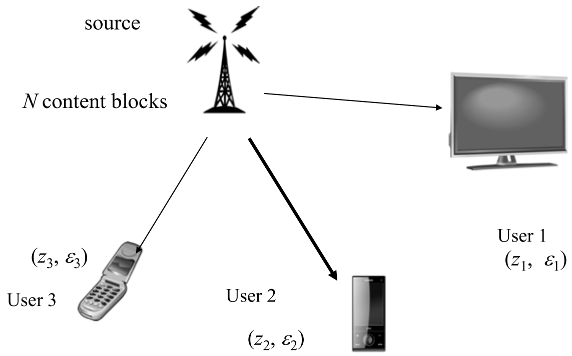

Fig. 1. Network model.

2. System model

Consider a wireless single-hop broadcast network consisting of a source (server) node holding content for distribution, and l sink (user) nodes waiting to retrieve the content from the broadcast stream aired by the source, as shown in Fig. 1. Suppose the content held at the source node is multiple description coded into N descriptions, using, for example, one of the coding schemes described in [12] or in [13], and each description is packaged into one packet for transmission. Each packet is represented as a binary vector of length b, and denoted with ξ_j for $j = 1, 2, \ldots, N$. A low-quality version of the content can be reconstructed once a user is able to recover any description. The reconstruction quality improves progressively by recovering additional descriptions, and depends solely on the number of descriptions recovered, irrelevant of the particular recovered collection.

The source broadcasts one packet per unit time to all the sink nodes in the system. However, the sinks are connected to the source by lossy links, and at every sink, a packet either arrives at the sink intact or is entirely lost. Such an assumption is practical if we only consider data streams at the network level or higher. Under the multiple description coding assumption, a sink node can choose to demand a smaller number of descriptions rather than wait to collect all N. This may not only shorten its own waiting time but also reduce the system burden. The demand of a sink node is characterized by the number of descriptions it needs to reconstruct the content within the desired distortion constraint.

Sink nodes are characterized by parameter pairs (z_i, ϵ_i), $i = 1, 2, \ldots, l$, describing their demands and link qualities:

- $z_i \in \{1/N, 2/N, \ldots, 1\}$ is the fraction of content demanded by user i, that is, each node demands z_iN distinct descriptions.