Centralized Caching and Delivery of Correlated Contents over a Gaussian Broadcast Channel

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Abstract—Content delivery in a multi-user cache-aided broadcast network is studied, where a server holding a database of correlated contents communicates with the users over a Gaussian broadcast channel (BC). The minimum transmission power required to satisfy all possible demand combinations is studied, when the users are equipped with caches of equal size. A lower bound on the required transmit power is derived, assuming uncoded cache placement, as a function of the cache capacity. A centralized joint cache and channel coding scheme is proposed, which not only utilizes the user's local caches, but also exploits the correlation among the contents in the database. This scheme provides an upper bound on the minimum required transmit power for a given cache capacity. Our results indicate that exploiting the correlations among the contents in a cache-aided Gaussian BC can provide significant energy savings.

I. INTRODUCTION

Thanks to the decreasing cost and increasing capacity of memory available at mobile devices, *proactive caching* has been considered as a low-cost and effective solution to today's exponentially growing mobile data traffic [1]–[3]. Proactively storing popular contents in cache memories distributed across the network during off-peak traffic periods can greatly reduce both the network congestion and the latency during peak traffic hours. *Coded caching* [2] further exploits the broadcasting nature of wireless delivery and the contents available in users' local cache memories to create multicasting opportunities, even when the users request distinct files, which further boosts the benefits of caching. The significant gains of coded caching over traditional uncoded caching schemes have inspired numerous studies, among which [4]–[15] are most related to this paper.

Delivering correlated contents over an error-free shared cache-aided link is considered in [4]–[9]. In [4], correlation among an arbitrary number of files in a caching system is exploited by identifying the most representative files, which are then used as references for compressing the remaining correlated files. A two-file system is studied in detail in [7], where the files are initially compressed using Gray-Wyner source coding, and an optimal caching scheme is derived for the two-receiver network. This scheme is generalized to more files in [6], which is shown to be optimal for large cache

sizes. Arbitrary numbers of users and files are considered in [5], where each file is modeled as a collection of subfiles, each of which is shared by a different subset of files. In [9] a caching scheme is proposed, which exploits correlation by performing on-demand compression during delivery, resulting in a scheme that is robust to dynamic changes in a correlated library. Cache-aided content delivery is studied in [16] with a source coding perspective, where users request different quality lossy versions of the files in the library. More recently, [11]–[15], and others have relaxed the assumption of a shared error-free bit-pipe from the server to the users by replacing it with noisy BCs in the traditional setting of uncorrelated files. In [14] the authors consider a total memory budget, and optimize the cache assignment with respect to the channel capacity for degraded BCs. In [12] the benefits of caching and coded delivery are studied from the perspective of energy-efficiency in Gaussian BCs.

In this paper, we consider the degraded Gaussian BC model studied in [12], but we assume that the files in the library can be arbitrarily correlated as modeled in [5]. We evaluate the performance in terms of the minimum transmission power required to satisfy any demand combination, called the *peak power* in [12] as it represents the power required to satisfy the worst demand combination. We derive a lower bound on the minimum required transmission power assuming uncoded cache placement, and an upper bound that employs superposition coding and power allocation when delivering coded contents over the BC. Through numerical simulations, we show that the proposed correlation-aware joint caching and channel coding scheme reduces the transmission power significantly compared to schemes that are correlation-ignorant.

Notations: $\mathbb{R}$ is the set of all the real values, while $\mathbb{R}^+$ denotes the set of all the positive real values. The set of integers $\{i, \ldots, j\}$, where $i \leq j$, is denoted by $[i:j]$, and for $q \in \mathbb{R}^+$, the set $[1:\lceil q \rceil]$ is denoted shortly by $[q]$. For sets $\mathcal{A}$ and $\mathcal{B}$, we define $\mathcal{A}\backslash\mathcal{B} \triangleq \{x : x \in \mathcal{A}, x \notin \mathcal{B}\}$, and $|\mathcal{A}|$ denotes the cardinality of $\mathcal{A}$. $\binom{j}{i}$ represents the binomial coefficient if $j \geq i$; otherwise, $\binom{j}{i} = 0$. For event E, $\mathbb{1}\{E\} = 1$ if E is true; and $\mathbb{1}\{E\} = 0$, otherwise.

II. SYSTEM MODEL

Consider a wireless server that holds a database of N correlated files, denoted by $\mathbf{W} = (W_1, \ldots, W_N)$, which have

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web diary of a wimpy kid is a 2010 american comedy film directed by thor freudenthal and based on jeff kinney s 2007 book of the same name the film stars zachary gordon and robert capron devon bostick rachael harris steve zahn and chloë grace moretz also have prominent roles it is the first installment in the diary of a wimpy kid film series