Video over Cognitive Radio Networks: When Compression Meets the Radios

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1. Introduction

Video content delivery over wireless networks is expected to grow drastically in the coming years. The compelling need for ubiquitous video content access will significantly stress the capacity of existing and future wireless networks. To meet this critical demand, the Cognitive Radio (CR) technology provides an effective solution that can exploit co-deployed networks and aggregate underutilized spectrum for future video-aware wireless networks.

CR was motivated by the FCC's spectrum measurements, where a significant amount of the spectrum are found to remain underutilized [1, 2]. A CR is an advanced radio device that enables dynamic spectrum access (DSA). It represents a paradigm change in spectrum regulation and access, from exclusive use by *licensed*, or, *primary* users to sharing spectrum and allowing dynamic access for *unlicensed*, or, *secondary* users, with the objective of enhancing spectrum utilization and achieving high throughput capacity.

The high potential of CRs has attracted substantial interest. The mainstream CR research has focused on developing effective spectrum sensing and access techniques (e.g., see [1-4]). Although considerable advances have been achieved, the important problem of guaranteeing application performance has not been well studied. We find video streaming can make excellent use of the enhanced spectrum efficiency in CR networks. Unlike data, where each bit should be delivered, video is loss-tolerant and rate-adaptive. They are highly suited for CR networks, where the available bandwidth depends on primary user transmission behavior. Graceful degradation of video quality can be achieved as spectrum opportunities evolve over time.

We investigate the challenging problem of video over CR networks. Although having high potential, this problem brings about a new level of technical challenges. The extra dimension of dynamics on channel availability and the additional uncertainty from spectrum sensing and access make it a challenging task to deliver video data with stringent QoS requirements. Built upon our prior research, we address this problem with a cross-layer optimization approach, which leads to effective distributed algorithm design with performance guarantees. The manifold design trade-offs, multifarious network dynamics, limited network resources and, on the other hand, video's tight QoS constraints make the proposed approach highly suited for "squeezing" the most out of the spectrum whitespaces. The proposed approach can be adapted for video streaming over traditional cellular networks and wireless mesh networks with CR-enabled devices as well.

2. Video Multicast in Infrastructure-based CR Networks

CR is an evolving concept with various network models and levels of cognitive functionality [1-3]. IEEE 802.22 Wireless Regional Area Networks (WRAN) is the first CR standard for refarming broadcast TV bands, where a base station (BS) controls medium access for customer-premises equipments (CPEs) [5]. We first consider multicasting scalable videos in such an infrastructure-based CR network. The spectrum consists of N channels, each allocated to a primary network. The CR network is co-located with the primary networks, where a CR BS seeks spectrum opportunities for multicasting multiple video streams, each to a group of secondary subscribers.

The problem is to exploit spectrum opportunities for minimizing video distortion, while keeping the collision rate with primary users below a prescribed threshold. We consider fine-grained-scalability (FGS) and medium grain scalable (MGS) videos. Unlike prior work on wireless video [6], the challenge stems from dynamic channel processes, the need to predict future channel status under the presence of sensing errors, and tightly coupled design choices for partitioning, adaptive modulation, and real-time scheduling of video data. Further, there is also a need to accommodate heterogeneity and achieve fairness among groups of users. Such a problem necessitates joint design of spectrum sensing and access, adaptive modulation, scheduling, and rate adaptation for concurrent videos. The dynamic network environment and the large number of multicast users also make low complexity algorithms highly appealing.

We model the problem of CR video multicast over the licensed channels as a mixed integer nonlinear programming (MINLP) problem. We then develop a sequential fixing algorithm and a greedy algorithm to solve the MINLP, while the latter has a low computational complexity and a proved optimality gap. For more details, see [7].

3. Video over Multi-hop CR Networks

We also tackle the problem of video over multi-hop CR networks, e.g., a wireless mesh network with CR-enabled nodes. This problem is more challenging than the problem in Section 2 due to the lack of infrastructure support. Consider a multi-hop CR network that is collocated with K fixed primary networks (e.g., multiple cells in a traditional cellular network) allocated with N licensed channels. CR users non-intrusively exploit spectrum opportunities in the licensed bands for streaming multiple unicast video streams. The objective, again, is three-fold: (i) to maximize the overall video quality, (ii) to achieve fairness among the concurrent video sessions, and (iii) to bound interference to primary users.

We assume each secondary user is equipped with two transceivers. To model and guarantee end-to-end video performance, we adopt the *amplify-and-forward* approach for video data transmission, which is well-studied in the context of cooperative communications [8]. This is equivalent to setting up a "virtual tunnel" through a multi-hop multi-channel path. In addition to allowing a neat formulation of the multi-hop video streaming problem, this approach also satisfies video's needs for low latency, low jitter, and high bandwidth. The challenging problem, however, is how to set up the virtual tunnels, while the available channels at each relay evolve over time due to primary user transmissions. The lack of centralized control also calls for distributed algorithms. Various design factors, such as spectrum sensing and sensing errors, spectrum access and primary user protection, video quality and fairness, channel scheduling and path selection, should be considered.

We first obtain an MINLP problem formulation. The MINLP problem is first solved using a centralized sequential fixing algorithm, which provides upper and lower bounds for the achievable video quality. We then apply dual decomposition to develop a distributed algorithm and prove its optimality and convergence conditions. Please see [9] for more details.

4. Conclusions

Although considerable advances have been achieved in CR research, the important problem of guaranteeing application performance has not been well studied. We investigate the problems of optimized video streaming under two wireless network architectures: (i) an IEEE 802.22 WRAN-like, infrastructure-based CR network where the base station coordinate spectrum sensing and access, and (ii) a multi-hop CR network, such as a wireless mesh network with CR-enabled nodes. This research demonstrates the feasibility and significant potential of enabling content-rich video services in emerging CR networks.

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