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A cooperative protocol for video streaming in dense small cell wireless relay networks

Dimitrios Kosmanos [a], Antonios Argyriou [a,*], Yanwei Liu [b], Leandros Tassiulas [c], Song Ci [b,d]

[a] Department of ECE, University of Thessaly, Volos 38221, Greece
[b] High Performance Network Lab, Chinese Academy of Sciences, Beijing 100190, China
[c] Department of Electrical Engineering, Yale University, New Haven, 06511 CT, USA
[d] University of Nebraska-Lincoln, Omaha 68046, USA

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ABSTRACT

The small-cell wireless network (SCN) paradigm is based on the deployment of low-power small cells close to the user so that spatial re-use is increased. Small cell base stations (SCBSs) can be connected either with a wired or a wireless backhaul link to the core network. However, since these SCBSs are expected to be deployed in significant numbers [1], the increased density creates not only new problems but also optimization opportunities. In this paper we work towards the full exploitation of the broadcast advantage that dense SCNs offer in order to improve the video quality of unicast streaming applications.

To accomplish our goal we design a protocol that exploits the broadcast channel in the neighborhood of each small cell by using the SCBSs opportunistically as a relay stations. Each SCBS can overhear packet transmissions both from the macro BS (MBS) and also from other SCBSs in its neighborhood. Furthermore, since a packet may be available at multiple SCBSs, we propose an algorithm for optimized relay selection that takes into account the content of each specific video packet. This algorithm selects jointly the optimal small cell relay and video packet for forwarding. Both the overhearing protocol and the relay selection algorithm use only passively collected information and require no explicit message passing. The evaluation of the two proposed sub-systems shows significant performance improvements under different key system configurations for the video content, the number of neighboring SCBS, and the type of the backhaul connection.

1. Introduction

High quality video streaming in wireless networks is one of the most popular mobile applications today. The widespread adoption of mobile devices that are capable of handling sophisticated video processing and high data-rate wireless communication algorithms is propelling this demand. The video traffic explosion in wireless networks is expected to accelerate even more the next few years [2]. To ensure high quality video streaming there is a need for more bandwidth. Even after compression, video is bandwidth-hungry and delay-sensitive. Thus, there is no fundamental way to bypass this problem except by providing more bandwidth. To ameliorate this problem in cellular networks, small cell base stations (SCBS) or small cell relay stations are deployed closer to the user in order to increase network capacity and spatial coverage respectively.[1] The envisioned cellular network configuration includes several SCBS with

* Corresponding author.
E-mail address: anargyr@ieee.org (A. Argyriou).

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[1] Note that the roles of a SCBS and relay station can be collocated in the same physical device.

overlapping coverage, while the typical macro base station (MBS) provides umbrella coverage [1,3]. Thus, besides the single SCBS node that a user may be associated to, neighboring SCBSs will also probably be reachable by the same user (see our topology in Fig. 1). But the dense deployment of these wireless networks can be exploited with even smarter ways so that they can increase the capacity, decrease delay, and minimize susceptibility to channel variations if they operate as relays. Although cooperative diversity with relays has been investigated considerably from a theoretical perspective, in the immediate future the prospects of being implemented are better than ever precisely because of the high demand for increased bandwidth and coverage. Many standards like LTE-A support relay-based transmission modes that have been shown to be practical [4].

In this paragraph we will try to highlight potential optimization opportunities in *dense SCNs* with simple examples. Consider the case of a wireless backhaul connection between the MBS and the SCBSs as illustrated in Fig. 1. The transmissions from the MBS can be overheard from the two target SCBSs within the cell. Now the question that has to be answered is which of the two SCBSs will transmit a packet from the first flow since they have both received it. Also assume that SCBS B_1 has been granted access to the channel and transmits the packet (according to one of the algorithms that we will propose). Due to the proximity of the two SCBSs, SCBS B_2 cannot transmit simultaneously with SCBS B_1. However, this does not prevent it from overhearing the transmission of packets from its neighbor, and remove it from its local buffer when user D_1 acknowledges it (this is handled by the second algorithm we propose in this paper). The same situation will occur if more SCBSs are deployed close to SCBS B_1, i.e., they can also overhear. When the SCBSs connect to the core network through a wireline backhaul, the network topology is similar only in this case SCBS B_2 can only overhear a packet transmission from SCBS B_1 and not the MBS. From the previous scenarios, we see that in dense SCNs there will be ample opportunities for collecting information from the neighborhood of each SCBS. In this paper we aim to exploit to the fullest these opportunities that arise from a fundamental property of a wireless channel which is its broadcast nature.

The first central idea of our proposal is to allow SCBSs to passively overhear data packets, so that several nodes have available the same information (packet). This means that the SCBS, who has the opportunity to transmit a packet, can do so by selecting from a higher number of candidate packets. The second central idea of this paper is to leverage these overheard packets that are available in the multiple SCBSs in order to obtain a diversity gain for the transmitted signals, but in a way that is aware of the video content of the packet that will be transmitted.

The previous ideas are implemented with two protocols/algorithms. Our concrete contributions that build incrementally one on top the other are

1. We propose a lightweight packet overhearing protocol for *dense SCNs* that operates between the SCBSs and is based on the concept of opportunistic communication. The cooperative protocol allows the SCBSs to overhear packets and ensures that duplicate video packet forwarding from different SCBSs is avoided.
2. After the previous protocol is applied and ensures that no duplicate packets are forwarded, our second contribution is an algorithm for video-aware optimized relay selection. Video-awareness is embedded in the relay selection process through a new utility metric that combines the importance of the video packet and the achievable data rate of a particular relay.

Our techniques are *fully distributed* and require no topology information and exchange of special messages between the relays. Only passively collected local measurements of the channel state are used at the relays.

2. Related work

Network cooperation for wireless video distribution has been investigated thoroughly. Digital network coding (NC) is a modern technique for packet-level cooperation and it was also studied as a scheme for improving the quality of wireless transmitted video. State-of-art wireless cooperative techniques at the network layer combine algebraic network coding and video transmission [5–7]. In these works the authors employ linear NC for mixing video packets before transmission to a multicast group of users. However, one assumption of wireless NC is that the coded broadcasted packets must be acknowledged by all the participating relays in order to improve the selection of coded packets. Nodes must exchange buffer maps (detailed information about precisely what packets they have) for ensuring decodability of the selected code and this has to take place between the destination nodes and intermediate relays [5]. Furthermore, NC is suitable for multicast delivery for maximizing the throughput gains, but in the setup that we adopt in this paper we do not consider multicast transmission. Due to the small-cell nature of the system configuration, the relays in Fig. 1 will be able to reach a small number of users/destinations that are located in their neighborhood and are unlikely to desire the same video flow. Therefore, SCBSs are not intended to help with the multicast traffic delivery to several nodes but are being deployed for the purpose of improving the performance of a single user/destination [3]. In [8] the authors considered video distribution in small cells but for the multicast case where all the users desired the same content. This is a possible scenario but the most prevalent case is the unicast streaming for each user that we focus in this paper [2].

Wireless cooperative transmission of video flows has been studied in the context of the lower layers of the protocol stack. The case of layered encoded video in conjunction with the novel PHY technique of distributed space–time coding (DSTC) was studied in [9]. DSTC was employed in that work in order to improve the decoding of the PHY symbols when multiple receivers are involved. One important issue that must be addressed in DSTC is that the relays must transmit simultaneously which means perfect synchronization is required. Also the authors of that work considered the transmission of a single video flow through multicast, but did not consider multi-user