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A fuzzy admission control scheme for high quality video delivery over underlay cognitive radio

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ABSTRACT

In much of the traditional tight admission control algorithms for video cognitive users in cognitive networks, cognitive users are admitted sequentially based on the strict quality of service and interference constraints imposed on the cognitive and primary users respectively. The sequential admittance of cognitive users may impose some form of the queuing delay for time-sensitive cognitive users which may be unacceptable. On the other hand, traditional admission control schemes do not consider the quality of experience (QoE) of video users for admitting newly incoming ones. For addressing these issues and obtaining a more flexible quality-centric admission control policy by which the admission system can admit eligible cognitive users in parallel, and to cope with uncertainties in the acceptable levels of the video quality for different cognitive users (which may use different software/hardware with different capabilities) and interference levels imposed on the primary users, a soft admission control (SAC) technique (named FQAC) is proposed by which the admission probability level for the parallel cognitive users can intelligently be controlled based on some linguistic input variables. Numerical analysis has been performed to validate the efficiency of the proposed quality-aware SAC mechanism.

1. Introduction

Cognitive radio networks (CRN) are designed to use the potentially unused wireless spectrum holes in the licensed band. The CRNs are categorized into two different groups which are *underlay* CRNs and *overlay* CRNs. In underlay CRNs which are the topic of interest in this work, there is no need for sophisticated spectrum/bandwidth estimation techniques (in contrast with overlay CRNs). But, in underlay CRNs there always exists some interference which is imposed on licensed primary users (the users of the primary network or PUs) from unlicensed secondary/ cognitive ones (the users of secondary network or CUs).

Mitigating the imposed interference from CUs on PUs is always an important challenging research area especially in the underlay CRNs. In the case that CUs are broadband applications such as video, suppressing the CU-induced interference becomes even more challenging. In such scenarios, the admission and power control mechanisms must be designed such that while guaranteeing the stringent and hard quality requirement of secondary users, make the interference power for the primary users below a target value. Compared with overlay CRNs, the underlay cognitive radio benefits from extremely simplified senders/receivers because it does not need sophisticated spectrum estimation techniques.

Broadband multimedia content delivery over wireless networks has been converted to a reality by the emerging 3G or 4G technologies and responded to the increasing momentum in the network user demands. The emerging high-speed wireless access technologies and the requirements of different wireless applications are expected to create a huge demand on spectral resources in the next generation wireless networks. Achieving high spectrum utilization is, therefore, one of the most critical research objectives in designing wireless communication systems today.

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In fact, as discussed in a report by the Federal Communication Commission (FCC) on spectrum usage, the spectrum utilization varies from 15% to 85%, depending on the geographical area [1]. Therefore, there is an increasing interest in developing efficient methods for spectrum management and sharing. Cognitive radio is a new paradigm in wireless communications to enhance utilization of limited spectrum resources. It is defined as a radio that is able to utilize available side information, in a decentralized paradigm, in order to efficiently use the radio spectrum left unused by licensed systems. CRN techniques exploit spectrum opportunities in space, time, frequency while protecting PUs from excessive interference due to spectrum access from the CUs. Meanwhile, Code Division Multiple Access (CDMA) has been adopted as multiple access technology for 3G and beyond due to its advantages such as universal frequency reuse, soft hand-off, inherent diversity, and high spectrum efficiency [2]. Multimedia services over IP-based CDMA wireless networks will be one of the key applications in the cognitive radio field.

Quality of experience (QoE) is an essential feature associated with successful video content delivery to the end-users. The main concern of most telecommunication operators about their video-based services is because of video service assurance. Quality of experience ties together user perception, experience and expectations to application and network performance, typically expressed by quality of service parameters. Quantitative relationships between QoE and Quality of Service (QoS) are required in order to be able to build effective QoE control mechanisms onto measurable QoS parameters. Against this background, the work proposed in [3] introduces a generic formula in which QoE and QoS parameters are connected through an exponential relationship, called IQX hypothesis. The formula relates changes of QoE with respect to QoS to the current level of QoE, is simple to match, and its limit behaviors are straightforward to interpret. It validates the IQX hypothesis for streaming services, where QoE in terms of the subjective Mean Opinion Scores (MOS)[1] [4] is expressed as functions of loss and reordering ratio, the latter of which is caused by jitter. They conclude that the IQX hypothesis is a strong candidate to be taken into account when deriving relationships between QoE and QoS parameters.

The requirements of a specific set of QoS parameters (delay, jitter, packet loss, etc.) must be guaranteed for each real-time traffic transmitted over such wireless networks. However, for most real-time applications of wireless networks, intrinsic and possibly large levels of interference or collisions in the physical or link layers caused by radio transmission, media access protocols or time-varying topological changes provides challenging issues in guaranteeing these stringent QoS requirements.

Admission control (AC) mechanisms are investigated in networks to guarantee the desired levels of quality for existing network users by blocking the unwanted newly arriving ones. In other words, AC is a validation process in communication systems where a check is performed before a connection is established to see if current resources are sufficient for the proposed connection. Admission control should guarantee that all links receive their required QoS throughout their lifetime. Therefore, admission control should consider the long-term traffic conditions as well as transmission and interference conditions of both existing and the new links.

The AC problem in CRNs not only needs to provide quality guarantees for the admitted CUs, but also it should guarantee the interference constraints of CUs on the primary network. Generally, in a wireless network, there always exists a tradeoff between two types of error that should be considered in the admission process. Type I errors occur when a new user is accepted incorrectly and cause excessive interference and hence outage of the ongoing users. Type II errors occur by tight admission rules which results in blocking. In a CRN, loose constraint in admitting new CUs which is referred to as *all-admission* may cause excessive interference on PUs or other CUs. On the other hand tight admission rules lead to low utilization of opportunities and high blocking probability (the probability that the required level of quality cannot be offered). The former leads to violation of the PUs interference constraints and the latter will increase the outage probability (the probability that the mobile station is outside the service coverage area, or affected by interference) of current CUs [5].

An admission control in an underlay CRN based on single or multiple link removal has been investigated in [6]. This method includes two phases: power control and links removal. In the first phase, the steady state powers of all CUs are determined. Then, in the second phase, one or multiple CUs are removed based on an interference measure values until the remaining subset of CUs fulfill the Quality of Service (QoS) requirement and the interference threshold of primary network, the interference measure definition is based on the similar work in [7], where the users have been removed gradually from network until the remaining set of CUs could be supported. In [8] different revenues have been considered for CUs. Then, the problem is how to find a subset of CUs such that the total revenue output of the network is maximized. For this purpose the problem is formulated in the optimization theory framework to maximize the CUs revenue subject to the interference constraint on the PU and QoS requirement of CUs.

These works and most of the existing, e.g. [6,8–10], however try to choose the best subset of CUs which can fulfill the two constraints of the underlay scheme, the interference temperature on PUs and QoS of CUs, regardless of their order of arrival. That is, the admission procedure has been simultaneously done for a set of N CUs. Therefore, there is no guarantee on satisfying interference limits of the PUs or the QoS of current CUs during the admission process. Furthermore, these schemes result in zero blocking and high outage probability for cognitive networks. However, in a real scenario of wireless networks, simultaneous arrival of users is a rare event and typically follows a statistical distribution in time.

In [5], the authors consider the arrival process of CUs which better models the real scenarios. In their model, some of the new arriving CUs may suffer blocking and consequently, with non zero blocking probability of

[1] The MOS is a subjective measure for the perceived video quality [4].