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Survey on Delay Analysis of Multichannel Opportunistic Spectrum Access MAC Protocols

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Abstract — *In this paper we provide a comprehensive delay and queuing analysis for two baselines medium access control protocols for multi-user cognitive radio networks with homogeneous users and channels and investigate the impact of different network parameters on the system performance. In addition to an accurate Markov chain, which follows the queue status of all users, several lower complexity queuing theory approximations are provided. Accuracy and performance of the proposed analytical approximations are verified with extensive simulations. It is observed that using an Aloha-type access to the control channel, a buffering MAC protocol, where in case of interruption the CR user waits for the primary user to vacate the channel before resuming the transmission, outperforms a switching MAC protocol, where the CR user vacates the channel in case of appearance of primary users and then compete again to gain access to a new channel. The reason is that the delay bottleneck for both protocols is the time required to successfully access the control channel, which occurs more frequently for the switching MAC protocol. It is thus shown that a clustering approach, where users are divided into clusters with a separate control channel per cluster, can significantly improve the performance by reducing the competitions over control channel.*

I. INTRODUCTION

Opportunistic spectrum access (OSA) communication models [1], implemented by cognitive radios (CR), offer both the capacity to decrease the communication infrastructure expenses by using the vacant portions of the spectrum and to improve the quality of wireless communications by permitting wireless CR nodes1 to switch to a better channel when the channel quality is not satisfactory. These notable features have made cognitive-radio based wireless networks a technology of choice for incoming wireless technologies. Frequent spectrum handovers along with new requirements such as spectrum sensing and spectrum decision distinguish a cognitive radio network from its predecessors. New medium access control (MAC) protocols which take into account the inherent nature of cognitive radios are thus indispensable. For this aim, several medium access protocols have been proposed in the literature [2]–[4]. Different protocols may differ in details such as the existence of a common control channel, contention management, number of radios required for the nodes and sensing algorithm (please see [5], [6] and references therein for a detailed survey of CR MAC protocols). However, what is common in most of the proposed protocols is the spectrum management and channel handover, which can be broadly classified as either staying on the same channel (buffering) or switching to a new channel (switching) in case of PU appearance.

Those two extreme possibilities are representative because any other policy will also be a combination of those two baseline policies. We thus provide a comprehensive delay analysis and comparison for two baseline medium access control protocols discussed in [6], [7] which in turn provide performance bounds for other MAC protocols. Related Work: In the literature, most of the attention has been focused on the throughput analysis of different medium access protocols in the presence of saturated traffic (e.g., [2]– [4], [6]–[8]), while little work has been done on delay and jitter analysis. Throughput analysis provides an upper bound for the performance of the network, which can be used for evaluation and comparison purposes of different protocols. However, delay analysis and packet level performance evaluation are required to investigate how a protocol, along with its parameter settings, behaves for delay-sensitive applications, such as multimedia communications [9], [10]. Further, for cognitive radio networks, which consist of alternating operating and interruption periods, throughput analysis in the presence of saturated traffic is often insensitive to the period lengths while packet delay for unsaturated traffic varies significantly [11]. It is therefore crucial to possess delay analysis tools to assess the performance of cognitive networks, which is the motivation for this paper.

Advances in wireless communication systems have significantly increased the demand for more transmission capacity. The unlicensed portions of the frequency spectrum (e.g., the ISM bands) have become increasingly crowded. At the same time, the FCC has recently reported that licensed bands are vastly underutilized. To overcome spectrum scarcity, licensed spectrum bands need to be more intelligently utilized. For this purpose cognitive radios (which are based on programmable-radio platforms) have been proposed to allow opportunistic spectrum access for unlicensed users. A CRN has unique characteristics that distinguish it from a traditional wireless communication network. The latter allocates spectrum statically, resulting in spectrum wastage, and has a fixed radio functionality. In contrast, a CRN dynamically utilizes the available spectrum and adapts its operating parameters (e.g., carrier frequency, number of channels to use, etc.)

according to the surrounding environment. In an environment where several licensed primary radio networks (PRNs) are operating, a network of CR users that co-exist with PR users needs to exploit the underutilized portion of the spectrum. In this case, the crucial challenge is how to allow CR users to share the licensed spectrum with PR users without degrading the performance of the PR users.

In this paper, CR users are allowed to communicate opportunistically while probabilistically guaranteeing the performance of PR users. Our key performance measure is the "outage probability" (*pout*) of a PR user, defined as the fraction of time during which the total interference power at a PR receiver exceeds the maximum tolerable interference. It should be noted that interference modelling in wireless networks was previously studied under the assumption of an infinite user population, operating within an unbounded Field.

For example, assumed that nodes are distributed according to a Poisson distribution, and characterized the distribution of the interference for an idealized infinite-size network operating within an infinite field. No multipath fading was considered. It is easy to show that their model leads to total interference whose mean and variance are infinite. Such a model cannot be applied in our work, as we consider a finite number of users. The rest of the paper is organized as follows. Approach and Objectives: The focus of this work is the spectrum handover and interruptions which occur in opportunistic spectrum access. Our objective in this paper is thus to fill the delay analysis gap. From the spectrum management and channel handover point of view, staying on the same channel after an interruption or switching to a new channel can be considered as the two extreme possibilities and are thus representative. We extend the throughput analysis in the presence of saturated traffic for buffering and switching policies presented in [6], [7], and provide a comprehensive delay analysis in the presence of unsaturated traffic with an arrival process and assuming a queue (buffer) for the users. Note that the models described in those papers are not detailed MAC models for practical purposes. The intent is rather to have models with enough details, yet general enough, to use as baseline reference models for families of MAC protocols and investigate the effect of different parameters, specially the parameters related to channel handover, on the throughput of a cognitive radio network. In this paper, we have the same objective for the delay analysis and thus only relax the saturated traffic assumption and keep the same other assumptions and modelling details to analyze the average delay. Some simplifying assumptions are therefore made to keep the analysis complexity tractable. In the first part, a buffering MAC model [6], [7], in which a node stays on the channel in case of interruptions until the transmission of the packet is finished, is investigated. In the second part, a switching MAC model [7], where the node leaves the interrupted channel and participates in a new reservation competition every time that an interruption occurs, is investigated.

II. RELATED WORK

One of the key challenges to enabling CR communications is how to perform opportunistic medium access control while limiting the interference imposed on PR users. Recently, several attempts were made to develop MAC protocols for CRNs (e.g., [8]–[16]). Existing work on spectrum sharing/access protocols can be classified according to their architecture (centralized or decentralized), spectrum allocation behaviour (cooperative or non-cooperative), and spectrum access technique (overlay or underlay) [2]. The IEEE 802.22 working group is in the process of standardizing a centralized MAC protocol that enables spectrum reuse by CR users operating on the TV broadcast bands [17]. In [12]–[14] centralized protocols were proposed for coordinating spectrum access. For an ad hoc CRN without centralized control, it is desirable to have a distributed MAC protocol that allows every CR user to individually access the spectrum. DC-MAC [18] is a cross-layer distributed scheme for spectrum allocation/sensing. It provides an optimization framework based on partially observable Markov decision processes, with no insights into protocol design, implementation and performance. In [19], the authors proposed a decentralized channel-sharing mechanism for CRNs based on a game theoretic approach under both cooperative and non-cooperative scenarios.

However, they did not propose an operational MAC protocol. No guarantee on the performance of PRNs was considered. Before closing, we note that a number of multi-channel contention-based MAC protocols were previously proposed in the context of CRNs (e.g., [8]–[11]). The CRN MAC protocol in [8] jointly optimizes the multi-channel power/rate assignment, assuming a given power mask on CR transmissions. How to determine an appropriate power mask remains an open issue. DDMAC [9] is a spectrum sharing protocol for CRNs that attempts to maximize the CRN throughput through a novel probabilistic channel assignment algorithm that exploits the dependence between the signal's attenuation model and the transmission distance while considering the prevailing traffic and interference conditions. AS-MAC [10] is a spectrum-sharing protocol for CRNs that coexist with a GSM network. CR users select channels based on the CRN's control exchanges and GSM broadcast information. Explicit coordination with the PRNs is required. In [16], the authors developed a spectrum aware MAC protocol for CRNs (CMAC). CMAC enables opportunistic access and sharing of the available white spaces in the TV spectrum by adaptively allocating the spectrum among contending users. To the best of our knowledge, COMAC is the first CRN MAC protocol that provides a soft guarantee on the performance of PR users without assuming a predefined interference power mask. Opportunistic spectrum access communication Models is Implemented By Cognitive Radios (CR) [1]. In Opportunistic Spectrum Access the large amount of growth in a wireless service causes overly conjunction Occurred in spectrum. The allocated current state means usable frequencies have been occupied [4].To Avoid this collusion by permitting wireless CR nodes1 to switch to a better channel when the channel quality is not satisfactory. These notable features have made cognitive radio based wireless networks a technology of choice for incoming wireless technologies. Frequent spectrum handovers along with new requirements such as spectrum sensing and spectrum decision distinguish a cognitive radio network from its predecessors. New medium access control (MAC) Protocol which take into account the inherent nature of cognitive radios are thus in dispensable. For this aim. The licensed spectrum band are needed to be Utilized More Intellegently,For this Purposed Cognitive Radios Was Proposed to Allow Opportunistic Spectrum Access For Unlicensed Users [1]-[3]. It Offers the capacity to decrease Communication Infrastructure spend by using the Empty Portion Of The Spectrum and to Improve the quality of Wireless communications by permitting wireless Cognitive radio Nodes (CR Nodes)switch to another better channel whenever the channel quality was not good, not satisfactory. these feature have made by Cognitive Radio based wireless network technologies [1].There are some issues like The deal with sensing and accessing the strategies that Combine Identification of Opportunity and Exploitation. Second issue is the Synchronization Of Transmitter & Receiver, Which is Unique to Medium Access Control (MAC) In Opportunistic Spectrum Access OSA Network[4].Media Access Control Protocol is very Important in the Ad-Hoc Cognitive Network. A Cognitive Medium Access Control (CMAC) Protocol for Multiple Channel Wireless Network is Proposed In Which Operate all Over Multiple Channel & It Also Able to Deal Perfectly with the Dynamic Resource Availability[2].Several medium access protocols have been proposed in the literature different protocols may differ in details such as the existence of a common control channel.

Contention management number of radios required for the nodes and sensing algorithm.However, what is common in most of the proposed protocols is the spectrum management and channel handover ,which can be broadly classified as either staying on the same channel (buffering) or Switching to a new channel(switching)in case of PU appearance. Those two extreme possibilities are representative because any other policy will also be a combination of those two baseline policies. We thus provide a comprehensive delay analysis and comparison for two baselines medium access control protocols discussed in which in turn provide performance bounds for other MAC protocols.

Data Approach and Objectives

The focus of this work is the spectrum handover and interruptions which occur in opportunistic spectrum access. Our objective in this paper is thus to fill the delay analysis gap. From the spectrum management and channel handover point of view, staying on the same channel after an interruption or switching to a new channel can be considered as the two extreme possibilities and are thus representative. We extend the throughput analysis in the presence of saturated traffic for buffering and switching policies presented in and provide a compressive delay analysis in the in the presence of understand traffic with an arrival process and assuming a queue(buffer)for the users. Note that the models described in those papers are not detailed MAC models for practical purposes.

The intent is rather to have models with enough details, yet general enough, to use as baseline reference models for families of MAC protocols and investigate the effect of different parameters, specially the parameters related to channel handover, on the throughput of a cognitive radio network. In this paper, We have the same objective for the delay analysis and thus only the saturated traffic assumption and keep the same other are therefore made to keep the analysis complexity tractable, In The first part, a Buffering MAC Model in which a node stays on the Channel In The Case Of Interruptions Until the Transmission Of the Packet is finished, is investigated. In the second part, a switching MAC model, where the node leaves the Interrupted Channel And participates in a new reservation competition every time that an interruption occurs, is investigated.

Preliminary of Open Spectrum System

Current fixed allocation of radio spectrum results in significant underutilization of spectrum resources. The concept of open spectrum system aims to make flexible use of these radio spectrum resources. With a given open spectrum system, some spectrum bands are of interest for *primary users* and *secondary users*. Primary users possess the licenses of these spectrum bands which are granted by Government. Normally, these primary users are legacy systems previously deployed in an area; however, the actual utilization of their spectrum may be quite low. Since little spectrum is available in this area, new spectrum-based communication systems cannot be deployed. However, with the help of open spectrum, these new systems named secondary users are able to request the opportunistic usage of these spectrum bands from the primary users. Secondary users can only use the spectrum on a lease or non-interference basis. Both primary users and secondary users can benefit from open spectrum system: primary users may generate extra revenue from the leasing contract, while secondary users can enable the communication which is not possible previously.

The operations of secondary devices usually have two stages: sensing and transmission. In this paper, we assume the sequential execution of these operations. During sensing stage, PHY-layer sensing and MAC-layer sensing are used to detect the primary users and protect their service quality. PHY-layer sensing adapts modulation schemes and parameters to measure and detect the primary users' signals on different channels while MAC-layer sensing is to determine when and which channel the secondary user should sense. MAC-layer sensing decision is the main focus in this paper. After the information of spectrum has been collected in the sensing stage, actual data transmission can be conducted on the channels not used by primary users during the transmission stage.

III. SYSTEM MODEL

In this section, we provide a summary of the two generic multi channels OSA MAC protocols for which derive the delay analysis under unsaturated traffic in later sections. More details on those protocols, as well as their throughput performance under saturated traffic, can be found in [6], [7]. It is assumed that there are N homogeneous nodes in an adhoc cognitive radio network and M OSA channels where one channel is the dedicated control channel and the remaining MC = M □1 similar channels are used for data transmission. Without loss of generality and for notation simplicity, we assume that the N nodes have intended receivers that are not part of those nodes. A maximum of smax = min (N;Mc) links might thus simultaneously exist. We also use a packet capture model whereby a transmission during an available timeslot is successful, with probability _ for the data channels and probability _C for the control channel. is a function of the fading model (outage probability) and sensing errors (miss detections resulting in collisions with PU). Channel availability (PU appearance) and packet captures are assumed to be independent.

To model the unsaturated traffic, a geometric (Bernoulli) arrival process is assumed for all nodes with a probability of packet arrival in a timeslot the packet length L is given in the number of timeslots required to transmit the packet and has a geometric distribution with parameter q. A node is in the busy state when it has a reserved data channel for transmission, otherwise the node is in the idle state (with an empty or non-empty packet queue). After the sensing period, if the control channel is available, the g idle nodes with a non-empty packet queue attempt to reserve a channel using an Aloha-type competition over the control channel. That is, each of the g nodes will transmit in the timeslot a reservation request with a probability p over the control channel. The competition is successful if only one reservation request is transmitted and it is correctly received. It is therefore important to distinguish the event of success in competition, which depends solely on the number of competing users, from the event of success in reservation, which depends also on the status of channels. In case that a node is successful in reserving a channel, it starts transmitting one packet in the reserved channel from the beginning of the next timeslot. Other nodes cannot make any interference on the reserved channel, but fading, sensing errors and PU activities may interrupt the transmission.

An exception is when all channels are occupied in this timeslot. If a channel is released at the end of this timeslot, it will be assigned to the successful node in competition; otherwise the successful node in competition is unsuccessful in reserving a channel and returns for a new competition in the next timeslot. It is therefore important to distinguish the event of success in competition, which depends solely on the number of competing users, from the event of success in reservation, which depends also on the status of channels. In case that a node is successful in reserving a channel, it starts transmitting one packet in the reserved channel from the beginning of the next timeslot. Other nodes cannot make any interference on the reserved channel, but fading, sensing errors and PU activities may interrupt the transmission. Two baseline MAC protocols are considered in this paper. In the buffering MAC protocol [6], a node stays on its reserved channel, even when it becomes occupied by PUs, until the packet is entirely transmitted. In each timeslot, a successful transmission therefore occurs with probability = (1-pc). For the buffering MAC protocol, the (enlarged) packet service time X therefore consists of a reservation period of length XR followed by a transmission time XT which consists of successful transmission, unsuccessful transmission and unavailable timeslots, until the entire packet is transmitted. In the switching MAC protocol [7], a node that senses it channel occupied by PUs leaves the channel and returns to the idle state to participate in the competition to reserve a new channel in this timeslot.

For the switching MAC protocol, the (enlarged) packet service time X therefore consists of several reservation periods and the successful transmission and unsuccessful transmission timeslots required to transmit the entire packet. For both MAC protocols, once the packet transmission is terminated, the node releases the channel and returns to the idle state. It will enter the competition at the next timeslot if it has another packet in its queue. A service-resume transmission model is assumed for both MAC protocols where the remaining part of the packet is transmitted after each interruption. Note that for this model, we consider the general packet concept of a block of data to be transmitted, itself composed of smaller identifiable parts. As an example, a packet in this model can be a MAC jumbo frame composed of smaller frames. Naturally, if an interruption occurs, there will be no need to retransmit the smaller frames which have already been delivered. Note that due to the packet length geometric distribution model, the delay analysis is similar for a service repeat model where the entire packet must be retransmitted after each interruption.

CONCLUSION

Hence, from this paper Delay and queuing analysis for a multimode network with homogeneous users and an Aloha-type medium access model was provided. In buffering recovery policy where the CR node waits for the primary user to vacate the channel and continues the transmission on the same Channel In switching policy where after the appearance of primary user, a channel handover occurs. To reserve a data channel is the major bottleneck in Aloha, so any approach which decreases the number of competitors, such as having fewer but longer packets and node clustering, improves the performance. It was observed that access to the control channel to reserve a data channel is the major bottleneck in Aloha, so any approach which decreases the number of competitors, such as having fewer but longer packets and node clustering, improves the performance. The probability of medium access in Aloha should also be adjusted carefully to have the minimum delay.

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