A P2P Resource Sharing Algorithm (P2P-RSA) for 802.22b Networks

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ABSTRACT

IEEE 802.22 is a standard for Wireless Regional Area Network (WRAN) which uses cognitive radio techniques to exploit in an opportunistic way the white spaces in the TV frequency spectrum. In the last years 802.22b working group was approved by the IEEE 802 committee, at the aim to allow peer to peer communications in a 802.22 WRAN. One of the principal issue in this topic is the intra network resource sharing. In this paper we present a resource sharing algorithm based on spectrum reuse, the features of the proposed method are fairness and network capacity maximization.

Keywords

Cognitive Networks, 802.22b, frequency allocation, space-time codes, wireless regional area network, TV whitespace, spectrum reuse

1. INTRODUCTION

The increasing number of wireless network users, and the availability of various services and smartphone wireless applications, led inevitably to the growing request of spectrum resource. On the other hand there is a problem of resource inefficient usage, related to a static spectrum assignment policy. The classical spectrum assignment policy allocates to licensed users the frequency bands exclusively for specific services. The Federal Communications Commission (FCC) conducted a study to investigate the effective frequency utilization, demonstrating an inefficient usage of the spectrum. The band is not exploited with time continuity but there are temporal intervals during which the users are idle and the transmission channel is unused. As an example in New York City the maximum total spectrum occupancy is only 13.1% from 30 MHz to 3 GHz; in Washington the band occupancy is less than 35% for the radio spectrum below 3 GHz, [7].

Cognitive Network (CN) paradigm focuses on the idea to increase the spectrum utilization by allowing unlicensed users to exploit licensed spectrum during the inactivity period of licensed users, without causing harmful interferences each other. The core issue of a CN is based on the definition of Primary Users (PUs), Secondary Users (SUs) and spectrum holes. Spectrum hole, also called white space, is a region of space-time-frequency temporally unused for communication by licensed users. PUs are the licensed users which have the right to access a channel whenever they need. While SUs are unlicensed users who have the capability to sense the spectrum, and transmit on the available frequencies, spectrum holes, with the condition of not cause any harmful interference to the PUs. One of the most important challenge in this topic is to share the licensed spectrum without interfering with the transmission of the PUs, and among the same SUs.

IEEE 802.22 is a standard for Wireless Regional Area Network (WRAN) which exploits cognitive radio techniques using in an opportunistic way the white spaces in the TV frequency spectrum. IEEE 802.22 standard adopts a centralized topology with a Base Station (BS) and Customer Premise Equipments(CPEs) which are the SUs of the network. The centralized structure imposes that all the communications transit through the BS, also if they are among CPEs of the same WRAN. This model leads to a limited network capacity, because, in downlink transmission, a channel can be exploited by a CPE at a time slot. At the aim to overcome also this limitation a new working group, namely 802.22b, was approved by the IEEE 802 committee. In particular, the IEEE working group has introduced a standard which allows direct CPE to CPE communication stabilizing peer to peer (P2P)communication exploiting channels non-interfering with PUs, and reusing them multiple times, guaranteeing transmission not interfering each other.

A issue of this topic is the channel allocation problem which influences the network performance significantly in different features, as fairness, network capacity and interference. In this paper we propose a P2P Resource Sharing Algorithm (P2P-RSA) which holds all these characteristics, providing a spatial reuse mechanism. The main idea of the proposed method is based on the interference map; this is a method already introduced in literature but we exploit interference map and channel reuse in such away to maximize fairness without neglecting the network capacity. Note that, in literature, other works were proposed which focus on channel management in a cognitive P2P environment ([13],[12],[11] or [8]); but in these papers the number of available channels is variable while the bandwidth is always the same. In our

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work we have considered also the bandwidth, which, according to the 802.22 standard, can be equal to 6,7 or 8 MHz. Channels with different bandwidth have different weights in the network, allowing to transmit, in the same time, more or less data. Moreover our method compared with the proposed one in [12] is more fair, as demonstrated computing the Jain's index [6]. In [8] is proposed a resource sharing algorithm for P2P network which tries a trade off between fairness and network capacity, but the proposed solution is static which is not suitable in a cognitive environment. While in our paper a dynamic spectrum allocation method is presented.

The rest of the paper is organized as follows. In Section 1.2, an overview of the 802.22b working group is presented. In Section 1.3 our resource sharing algorithm is proposed. In Section 1.4, the performance is investigated through a simulation tool, and the results are compared with those obtained in [12]. Finally, Section 1.5 draws the conclusions.

2. 802.22B OVERVIEW

In this Section we show a brief overview of the latest update on IEEE 802.22 working group activities. IEEE 802.22 is a standard for WRAN, which exploiting cognitive radio techniques, allows the access to the TV frequency spectrum, in the specific TV channels from 54 to 862 MHz with a bandwidth of 6, 7 or 8 MHz. IEEE 802.22 WRAN has a centralized topology composed by one BS which manages CPEs, which are the SUs of the network. The BS is responsible of spectrum sensing, channel distribution among CPEs, and routing messages to the CPEs. The centralized topology of 802.22 WRAN makes the resource management very simple. On the opposite side there is a negative impact on the network capacity because every communication in the WRAN transits through the BS, both if the messages are addressed from CPE to the BS either if the communication is between CPEs of the same cell. This model leads to a limited network capacity, because, in downlink transmission, a channel can be exploited by a CPE at a time slot. Moreover, the coverage area of a WRAN is on the order of some kilometres [11], so the number of inter communications is very high. Therefore, the availability of WRAN peer to peer communication is necessary to improve the network performance, such as capacity, and energy consumption. So IEEE 802.22b was introduced, this standard supports direct communication between CPEs while the medium accesses control is managed by the BS. The purpose of this amendment is to enhance the MAC and PHY layer to accommodate broadband extensions and monitoring use cases for IEEE 802.22 devices operating is VHF/UHF TV broadcast bands, such as real-time, emergency broadband services or remote medical services, [1]. None of these use cases are implemented by the IEEE Std. 802.22-2011.

In the following main features of 802.22b standard are listed, [9] [1]:

- working in TV white spaces
- working in Very High Frequency (VHF)/Ultra High Frequency (UHF) TV broadcast
- enabling monitoring applications
- enabling peer-to-peer connection
- supporting very large number of CPEs, more than 512 devices in a network.
- supporting high reliability and QoS
- supporting real-time monitoring system with low latency, for channel sensing
- exploiting interface with various sensors, also to improve sensing ability
- supporting high data rate
- managing mechanisms to enable coexistence with other 802 systems.

CPE to CPE communication is an essential feature and key function of the smart grid or other applications based on IEEE 802.22b networks.

3. SPECTRUM ALLOCATION ALGORITHM

In this Section P2P-RSA is explained. The scenario is composed by a cognitive 802.22 network, composed by multiple CPEs and a BS, which is the responsible of the device channel access. Two CPEs are defined *overlapped* if the communication (transmitting or receiving) of the first CPE could interfere with the transmission of the second one and vice versa. Otherwise the CPEs could exploit the same channel. CPEs have to communicate with each other, but without a coordinator would create collisions. The transmissions may be coordinated in such a way to avoid harmful interference among the CPEs.

The main activities of the CPEs are three: sensing, communication with the BS, transmission according to the coordinator decisions. In a IEEE 802.22 network the sensing operation must be done periodically, with a period no larger then two second [10]. After this, CPEs convey their sensing results to the BS, named also coordinator. In particular each CPE communicates to the BS: I) its position II) resource request, III) available channels. The BS exploits these data for resource sharing optimization. Note that the amount of information exchanged among CPEs and the BS is exiguous; each device has to communicate only the channel availability, the CPE in interfering area and its requests. The concept of request will be clarified in the following. According to these data and implementing P2P-RSA, the coordinator determines the CPEs which are allowed to transmit and the respective channels to be occupied. This information is included in the *channel access map*, dispensed by the coordinator to the CPEs. With the channel access map the BS communicates to each CPE during which time slots and which channels they can exploit for the transmission.

The features of the introduced assignment policy are:

- reuse of the spectral frequencies;
- resource sharing with regards to the spatial diversity, i.e. the availability of some channels only for some users;

- resource sharing according to the time diversity, i.e. the variance over time of the channel availability;
- channel distribution according to the CPE spectrum demands.

To satisfy the firsts two points the coordinator needs to evaluate for each channel, the group of CPEs which are able to transmit simultaneously without causing interference, it has to create the interference map.

The coordinator elaborates the access plan to the resources and dispenses the channel access map to each CPE. The allocation process involves a maximum of 12 superframes; since the maximum time that a channel may be occupied by a secondary user is $2s$ [3], and the superframe duration is $160ms$ [5]. After this period a new sensing is necessary, and the coordinator has to implement again the channel allocation process according to the new topology information, if changes were registered.

To collect topology information BS uses a *overlay table*, while for the available resources and the spacial diversity a *channel table* is exploited. The *overlay table* and *channel table* have to be updated as soon as new information is received.

The *overlay table* is a square matrix, with size N, where N is the total number of CPEs in the network. The (i, j) element of the matrix is equal to 1 if the $CPEi$ and the $CPEj$ could interfere each other. While the *channel table* has the number of rows equal to the number of CPEs in the community, and a number of columns equal to the number of channels. The (i, j) element of the *channel table* is equal to 1 if the *channelj* is available for the $CPEi$.

As an example in tab.1 shows an *overlay table*.

Table 1: Overlay Table

	CPE1	CPE2	CPE3	CPE4	CPE5	CPE6
CPE1	1	0	0	1	0	1
CPE2	0	1	1	1	1	1
CPE3	0	1	1	0	1	0
CPE4	1	1	0	1	0	1
CPE5	0	1	1	0	1	0
CPE6	1	1	0	1	0	1

The *channel table* is created on the basis of the received sensing information. As an example, we suppose to have three available channels with different coverage area, which allow to build up the *channel table* shown in tab.2. In particular, we supposed that *channelA* is available only for $CPE1$, $CPE4$ and $CPE6$, *channelB* is available only for $CPE2$, $CPE3$ and $CPE5$, while the third channel covers all the network.

According to the contents of the *channel table* and *overlapping table*, the coordinator is able to elaborate the sets of CPEs which could transmit simultaneously without interfering each other. In the following these combinations are called clusters. The procedure to compute the clusters is:

Table 2: Channel Table

	ChA	ChB	ChC
CPE1	1	0	1
CPE2	0	1	1
CPE3	0	1	1
CPE4	1	0	1
CPE5	0	1	1
CPE6	1	0	1

- for each channel the coordinator has to examine which are the CPEs allowed to use it; i.e. for each *channel table* column the coordinator checks the elements marked with 1.
- Considering only this CPE set the BS computes the non-overlapped CPE groups.

In the exposed example $CPE1$, $CPE4$, and $CPE6$ are overlapped among them, then only one of these devices at a time can occupy the *channelA*. While more users can transmit simultaneously using the *channelC* without interfering each other. In tab.3 are shown all the possible channel assignments. Precisely, each column of the table is referred to a specific channel. Each row shows the possible groups of CPEs which can transmit simultaneously, without interfering each other, occupying the same channel, which is indicated on the top of the column.

Table 3: CPE Cluster

$Ch-A$	$Ch-B$	$Ch-C$
CPE1	CPE2	CPE1-CPE2
CPE4	CPE3	CPE1-CPE3
CPE6	CPE5	CPE1-CPE5
-	-	CPE3-CPE4
-	-	CPE3-CPE6
-	-	CPE4-CPE5
-	-	CPE5-CPE6

The coordinator creates the access map, which indicates the users able to transmit at a given moment. The map is created selecting for each channel a single CPE cluster which are allowed to occupy it for a superframe. The choice is taken with the aim to assign resources proportionally the requests, taking into account the spatial diversity. Before explaining the algorithm from a mathematical point of view, we show figure 1, where a schematic summary of the procedure of the protocol is shown.

CPEs send to the BS location, sensing and request information. The BS processes the first two information to compute overlay and channel table, and exploits these tables to compute the CPE clusters (as in table 3). Now BS implements the P2P-RSA, using as inputs the CPE clusters and requests, developing the channel access map, which is sent

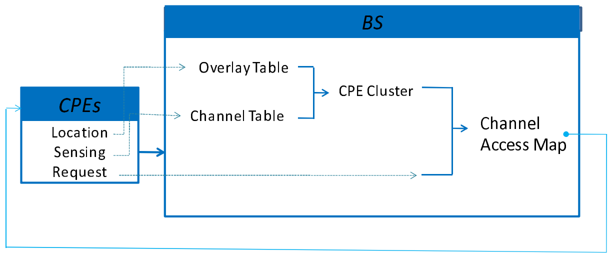

Figure 1: Algorithm Scheme.

to the CPEs to schedule their access to the spectrum. The protocol is dynamic because CPEs updates information every two seconds, and whenever it detects an environment change, as PU transmission or new requests.

The proposed resource sharing algorithm takes into account two different aspects: the resource already assigned to the user and the fairness of the allocation. The goal is to take the fairest choice among the ones which maximize the network total throughput. In the follow the policy is briefly explained, for more details see [2].

$CPEi$ communicated to the BS the resource request, req_i, which is the amount of data that $CPEi$ needs to transmit. According to the requests the coordinator computes the transmission probability p_i, by using the following formula:

$$p_i = \frac{req_i}{\sum_{j=1}^{N} req_j}, \tag{1}$$

where N is the number of CPEs in the network.

In the exposed case the set of CPEs which can transmit simultaneously without producing interference are illustrated in table 3. As an example in Tab.3, 7 different combinations are individuated for $channelC$, namely (CPE1-2), (CPE1-3), (CPE1-5), (CPE3-4), (CPE3-6), (CPE4-5), (CPE5-6). To define the $channelC$ access map the coordinator must choose one of the above sets to assign the resource. The criteria introduced in order to chose the best cluster among the available group for each channel, is the one which maximizes y, where:

$$y = \sum_{i=1}^{N} p_i \ln(n_i + 1). \tag{2}$$

Where n_i is the amount of data already transmitted by $CPEi$, with $n_i \geq 0$.

The function y was build as in eq.2 because it increases when the resources are assigned to the CPEs with higher requests: they have higher p_i, so increasing the corresponding n_i the global value of y will increase too. Moreover y has a logarithmic growth, for this reason y raises very fast with the first assigned superframes to the users with higher p_is. Subsequently, in the sum, the contributes of these will raise more slowly, because it is a logarithmic function, then, for increasing y, it is necessary to assign superframes to the CPEs with lower p_is. In particular is possible to demonstrate that in the optimal solution n_i is proportional to the related p_i, i.e. respects the resource request of CPEi. In [2] is proved that

$$\sum_{i=1}^{N} p_i \ln(n_i) \leq \sum_{i=1}^{N} p_i \ln(np_i), \tag{3}$$

which means that first and second member become equal when $n_i = n \cdot p_i$. Then $\sum_{i=1}^{N} p_i \ln(n_i)$ is maximized when $n_i = n \cdot p_i$. With reference to eq. 3, we can assert in the same way that $\sum_{i=1}^{N} p_i \ln(n_i + 1)$ is maximized when $n_i = n \cdot p_i$.

By applying the criteria exposed the P2P-RSA assigns resources to the CPEs in such a way to satisfy the required Quality of Service (QoS). In fact we proved that the resources guaranteed to each CPE depend on p_i. The procedure is repeated for each available channel. Note that in 2 n_i is the amount of data already transmitted, which depends on the number of time slots previously assigned and on the channel bandwidth exploited for the transmission.

4. PERFORMANCE EVALUATION

In this section numerical results are shown. In particular we have compared our algorithm with a method which, after computing the interference map aim to maximize the total throughput of the network as the method proposed in [12], named SIMBP(self-adapting interference map building protocol).

Results have been computed supposing a WRAN populated by 10, 20 and 30 CPEs randomly deployed, and supposing the availability of 1, 2 and 3 channels. The results obtained simulating P2P-RSA are illustrated by red lines, while the SIMBP results with green dotted lines.

In figure2 the Fairness Indexes (FIs) were computed whit the use of the Jain's index, for more details see [4]. The indexes were computed varying the number of available channels and users in the WRAN.

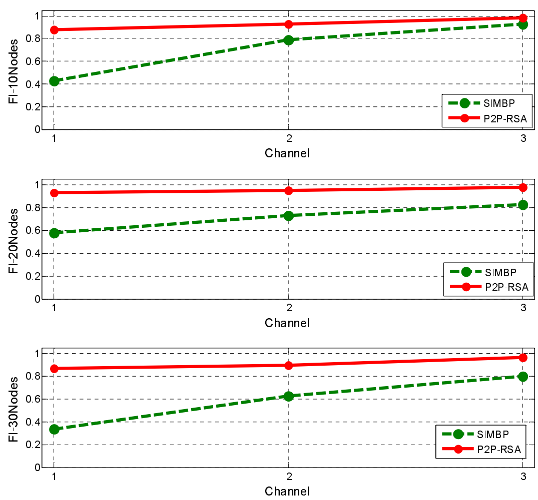

Figure 2: Fairness Index.

The results illustrated in figure 2 show that the proposed method is more fair then SIMBP. It is import to notice that the maximum value of Jain's index is 1, so figure2 demonstrates that P2P-RSA is a really fair resource sharing protocol.

In the same scenarios we computed the network capacity, as the total throughput of the WRAN. The results are shown in figure3.

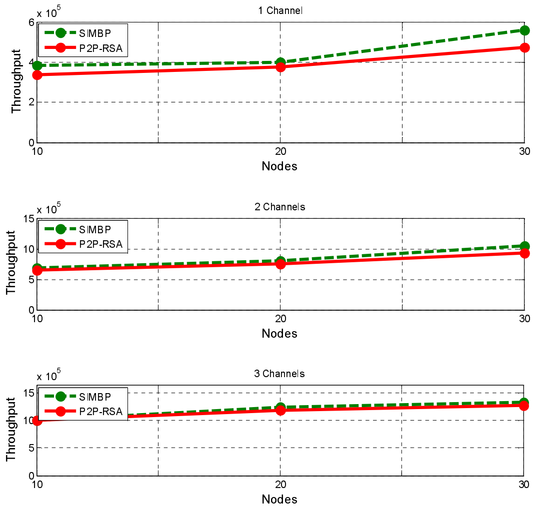

Figure 3: Network capacity.

As expected, in figure3 is shown that the network total throughput grows increasing the number of users and the available resources. It is interesting to note that SIMBP presents slightly better performances, but the gap with our algorithm decreases increasing the CPE and channel number of the WRAN. The first purpose of our algorithm was to create a fair resource sharing, figure 2 demonstrates that it was reached. Moreover, also the perspective of the spectral efficiency and network capacity has not been ignored, as shown in figure 3.

5. CONCLUSIONS

In this paper we focus on 802.22b WRANs. In particular we have addressed the resource management problem presenting a protocol named P2P-RSA. The purpose of the proposed resource sharing mechanism is to allow CPE to CPE communication avoiding interference among the same CPEs and PUs. The implementation is facilitated by the centralised structure of a 802.22 WRAN, composed by a BS and more CPEs. BS collects all the sensing results obtained by CPEs and manages the channel assignment, implementing the proposed P2P-RSA which allows the use of the same channel multiple times in the same frame. The algorithm's goals are fairness and sequentially network capacity. These objectives have been achieved as shown in the Section 1.4.

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