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Modified algorithm of dynamic frequency hopping (DFH) in the IEEE 802.22 standard

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Abstract. IEEE 802.22 Cognitive Wireless Regional Area Networks is a first standard of wireless terrestrial system relying on cognitive radio concept and operating as an opportunistic system in the vacant unoccupied frequency spaces of the licensed TV-frequency band. Concept of the proposed standard assumes special functionality to protect the operation of the primary licensed subscribers. Dynamic Frequency Hopping is the mechanism for providing connectionless operation of Wireless Regional Area Networks systems while ensuring protection of transmissions from the primary users. During its operation regular time gaps appear on the involved frequency channels. This paper introduces the concept of the efficient reuse of the vacant frequency resources appearing when using the Dynamic Frequency Hopping mode. The scheme for consecutive-parallel inclusion of the new Dynamic Frequency Hopping Communities-members in the Dynamic Frequency Hopping mode is presented. The proposed approach allows significantly decrease time of inclusion the new members into a new Dynamic Frequency Hopping Communities.

Keywords: IEEE 802.22 standard, Dynamic Frequency Hopping (DFH), WRAN, DFHC, DFH scheme.

1 Introduction

Limitations in number of available for communications frequency bands is a problem as number of various wireless systems grow rapidly. This makes researchers to focus on optimizing the utilization efficiency of the currently licensed bands. During the last decade investigation of opportunistic access approaches based on the usage of cognitive radio have been conducting [1]. In the opportunistic channel access approach secondary (unlicensed) users are equipped with cognitive radios, which allow them to transmit on the licensed bands while the primary users are inactive. The IEEE Work Group 802.22 (802.22 WG) proposed the first standard of the new wireless air interface [2], based on Cognitive Radio principle [3]. The IEEE 802.22 standard specifies the protocol for using the TV-frequency band by the secondary users. Globally, the standard uses band from 54 to 862 MHz. The network of devices allowed to use the TV band is referred as Wireless Regional Area Network or WRAN. A good overview of the standard is presented in [4]. The different aspects of the standard can be found in [2], [5], [6].

In paper we propose the concept of using an unoccupied frequency resources, which appear in a typical DFH schemes [7] for increasing the number of active secondary users. It also presents the new Dynamic Frequency Hopping Community scheme. The main contribution of this article is that proposed approach allows more efficient parallel inclusion of several WRAN members into DFH schedule.

The paper is structured as follows. Section II provides state of the art. The DFH mode is described in Section III. Section IV presents the proposed approach for vacant frequency-time DFH resources usage. Modifications to the DFHC scheme are presented in Section V. Finally, Section VI concludes the paper.

2 Related work

One of the key problems that is crucial for the IEEE 802.22 standard [8], [9] — the simultaneous satisfaction of two requirements: high quality of service (QoS) providing by WRAN services and reliable spectrum sensing for licensed subscribers protection. In [2] has been described the mechanism for reliable sensing in base operations mode using one frequency channel. It is defined to stop data transmission periodically, because spectrum sensing has to be performed during predefined time periods. To avoid connection interruptions the alternative operation mode named Dynamic Frequency Hopping (DFH) proposed for the IEEE 802.22 standard in [10]. In [11] using simulations it was shown that DFH mode can reduce the collision with incumbent users and achieve higher throughput. DFH mode allows both to transmit WRAN's data and to perform spectrum sensing simultaneously. To enable the effective frequency usage and avoid WRAN connection interruptions while spectrum sensing the so-called Dynamic Frequency Hopping Community (DFHC) was proposed in [7]. This approach assumes that several neighbor WRANs work in the DFH coordinated mode being organized in the DFHC. The main idea of DFHC is that neighboring WRANs are collaborating when assigning frequency channels for DFH and coordinate the execution of corresponding dynamic frequency hopping operations.

3 Dynamic frequency hopping (DFH)

The IEEE 802.22 standard defines that WRAN should continuously use a channel in the operating mode for no longer than 2 seconds. Between two subsequent operation phases WRAN must sense for the presence of licensed subscribers [2]. WRAN devices must be able to recognize digital TV signal (DTV) with levels up to -116 dB with maximum error probability equals of 0.1 [12]. The analysis of the well-known technologies shows that this procedure spends dozens of milliseconds per channel [13]. For example, DTV sensing on 6 MHz requires around 100 ms per channel. However, the IEEE 802.22 standard requires maximal delays to be less than 20 ms to provide satisfactory Quality of Service for delay sensitive applications such as VoIP [12]. Thus the it was proposed to apply DFH in the IEEE 802.22 [2]. WRAN in the DFH mode changes frequency channel for transmission among all available channels. Fig. 1 presents an example of DFH principle for the case of three WRANs.

Fig. 1. An example of three WRANs

In DFH mode N WRANs operate under $N + 1$ vacant channels. Fig. 1 shows an operation of DFH phase shifting process [7], [2] for $N = 3$ neighbor WRANs over $N + 1 = 4$ available channels, where OP – operation phase is a time slot of fixed duration when WRAN transmits and receives data. Each WRAN shifts its DFH OPs on the QT — Quiet Time relatively to the shift of previous WRAN. QT intervals are used for a channel sensing. It means that QT must be not less than minimum time required for the reliable sensing. For instance, WRAN2 shifts the execution of its operation by one QT period relatively to WRAN1 operation, while WRAN3 by the one period, relatively to WRAN2. This approach allows to support continuous connection for every WRAN while preserve necessary sensing for incumbents presence to protect licenced subscribers.

Thus, the group of N interfering WRANs can operate over $N + 1$ channels as long as the duration of one operation phase is more than $N \cdot QT$.

4 The proposed approach for vacant frequency-time DFH resource usage

The DFH scheme causes time gaps of $t_{vac} = OP - N \cdot QT$ every $N \cdot (OP + (QT - 1))$ due to the phase shifting operation. The interval between the first and the last WRANs in the DFH mode is much more than QT and it equals $t_{vac} = OP - 2QT$. We emphasize this vacant resource in Fig. 2 as "VACANT", taking into account two more sensing steps: after OP WRAN3 is finishing and before OP WRAN1 is starting.

We propose to use these vacant frequency-time resources for additional WRAN, which will operate with interruptions. This method can suit for the cases when one of the $N + 1$ channels is occupied by a licensed device. Then, WRAN with the lowest priority should switch to a mode with interruptions for the time when channel remains unavailable. Fig. 2 illustrates this example, demonstrating WRAN4 operating over vacant intervals.

Fig. 2. Illustration of a vacant resources in the DFH phase shifting process

Generally, when one has N WRANs and $N + 1$ available channels, the vacant frequency-time slots, which appear in the group of channels, can be described within the expressions given below.

Time of the k -th operation phase beginning:

$$T_{start} = N \cdot QT + OP \cdot k. \quad (1)$$

Time of the k -th operation phase ending:

$$T_{end} = OP - QT + OP \cdot k = OP \cdot (k + 1) - QT. \quad (2)$$

Duration of the vacant operation phase (OP_{vac}) is then:

$$\begin{aligned} OP_{vac} &= T_{end_k} - T_{start_k} = OP \cdot k + OP - QT - OP \cdot k - \\ &- N \cdot QT = OP - (N + 1) \cdot QT. \end{aligned} \quad (3)$$

The interruption time between transmissions:

$$\begin{aligned} QT_{vac} &= T_{start_{k+1}} - T_{end_k} = N \cdot QT + OP \cdot (k + 1) - \\ &- OP \cdot (k + 1) + QT = (N + 1) \cdot QT. \end{aligned} \quad (4)$$

Therefore in vacant intervals, which appear in $N + 1$ channels in DFH mode, data transferring can be executed by one more WRAN. In this case, time of transferring in one interval is $OP_{vac} = OP - (N + 1) \cdot QT$, and connection interruption between operation intervals is $QT_{vac} = (N + 1) \cdot QT$.

5 Modifications to the DFHC scheme

5.1 Dynamic Frequency Hopping Community

According to the definition proposed in [7], Dynamic Frequency Hopping Community — is a nonempty group of neighbor WRANs, which supplies coordinated DFH opera-

tions to avoid interference spectrum sensing. DFHC consists of one arbiter WRAN and usually several member WRANs. The *DFHC-arbiter* is responsible for maintaining the membership in the group, construction of DFH schedules and the distribution of that information to all members of the group. DFHC members provide all the necessary information about their neighbors and the available channels to the arbiter, i.e. sensing results and watch for neighbor WRAN channels utilization [7].

Every DFH schedule has its time to live (TTL hereinafter), which is counted and distributed by the arbiter. Each member can use the channel, constructed by the DFH scheduler, during this time. Arbiter periodically refreshes and broadcasts the information about the schedule to group's members. The new schedule starts right after the time when the previous one is completed. The new one's has to be confirmed by all the group members. If any member does not receive this information before the previous schedule is completed, it cannot operate anymore in the DFH mode and switches to the non-hopping operation mode.

In general, the updating of the schedule can be organized in two ways: either by starting the new schedule when the TTL of the previous one has elapsed or by consecutive joining of all members to the new schedule [7].

Fig. 3. Consecutive switching for inclusion of new DFHC-member

5.2 Shortcomings of the standard scheme for new DFHC-members inclusion

The first approach ensures collision avoidance during the schedule switching. Even if some of the group members do not get the information about the new model, they still cannot continue to operate by using the old schedule after TTL has expired. However, this approach is not flexible enough in terms of distribution of the new schedule during the execution time of the previous schedule. It could cause conflicts: if someone does not get the updated schedule and still works with the old one [7].

This problem can be avoided by using serial switching of DFH schedules. This method assumes inclusion of each member to the new schedule by the arbiter individually. Members are chosen from those, who are not yet scheduled. This allows to avoid collisions between the operating and new unscheduled devices. The arbiter checks whether WRANs are switched or not by sensing the channel. In this case, even if some members do not switch to the new schedule, all scheduled members can use the new model without causing any collisions [7].

Consider for example dynamic scheduling of the new DFHC-member as shown in Fig. 3 (old schedule is illustrated as well). At first, all members are switched to the new schedule. It means that their OPs shift on one QT period on channel 4. Additionally, OPs of the first channel shortens on one QT during the switching time. When all members have switched to the new schedule, there is enough space for including a new member (the last OP in the channel 4). The main advantage of this method is that it does not cause collisions between old and new DFH schedules.

Fig. 4. Consecutive including of two new WRAN in a standard way

However, when it is necessary to include in the new schedule several new members, one will face with significant delays. Thus, using shown above approach, $T_{add2} = T_1 + T_{cyc} + T_2$ is needed for consecutive inclusion of two new members. Where T_1

is the time of the first member inclusion, T_{cyc} is the time of one updated schedule full cycle, T_2 — time of the second member including. The shown above arguments, which are defined as follows:

$$T_1 = N \cdot (OP + QT). \quad (5)$$

$$T_2 = (N + 1) \cdot (OP + QT). \quad (6)$$

$$T_{cyc} = (N + 1) \cdot OP + t_{vac} - QT = (N + 1) \cdot OP + OP - (N - 1) \cdot QT - QT = (N + 2) \cdot OP - N \cdot QT. \quad (7)$$

Fig. 4 provides an example illustrating the consecutive inclusion of two new WRAN into the existing schedule takes considerable time. Also when the number of DFHC-members is increasing this value grows as well. Thus, if in Fig. 4 WRAN4 inclusion takes about 3 OP, WRAN5 takes more than 4 OP and so on. Besides, before each new member inclusion it is necessary to wait for the full schedule updating cycle. To optimize the WRAN inclusion process and decreases the inclusion delays we propose the consecutive-parallel scheme for the members inclusion in the following subsection.

5.3 Solution: consecutive-parallel scheme of new DFHC-members inclusion

Fig. 5. Illustration of consecutive-parallel scheme for members switching

The core of the proposed method is that at the beginning all members of the DFHC shift their schedules on $K \cdot QT$ in one of channels (e.g. channel one in Fig. 5), where K is the number of new members, which must be included into the DFHC. The same way [7], in the first channel OPs are shorten on QT during inclusion time. Using this method, it is possible to decrease the inclusion time in comparison with the standard consecutive

scheme (Fig. 3). Thereby time for the inclusion of the last new-added WRAN for the proposed consecutive-parallel scheme is determined as:

$$T_K = N \cdot (OP + QT) - QT. \quad (8)$$

An example for the consecutive-parallel inclusion of two new WRANs is shown in Fig. 5.

Comparison of the last new-added WRAN inclusion time for the standard scheme (5), (6), (7) and the proposed one (8) is shown in Fig. 6. The following parameters values were used during the estimation:

- Duration of one QT is 0.1 sec;
- Duration of one OP is 2 sec;
- Initial number of DFHC group members is 3.

Fig. 6. Comparison of the inclusion time for the last new members in both schemes

Fig. 6 shows that the proposed scheme requires less time for inclusion of new members even starting from two WRANs. Moreover the time of inclusion proposed this scheme is permanent. Such behavior of the proposed algorithm is due to the fact that all members of the DFHC shift their schedules on $K \cdot QT$.

6 Conclusion

This article discussed efficiency of DFH mechanism for 802.22 WRAN. Standard scheme causes appearance of time gaps on involved in DFH operation frequency channels. It was shown that these resources can be used for operation with partly connection interruptions of one extra WRAN. Another drawback in DFHC inclusion scheme was detected. The more effective consecutive-parallel scheme of WRANs inclusion was proposed. Introduced approach may significantly decrease DFHC transition time. Thus, extensions proposed in the paper allow to increase the efficiency of DFH standard schemes within insignificant growth of complexity.

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