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Throughput Enhancement for WLAN TV White Space in Coexistence of IEEE 802.22

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Abstract

This paper proposes an algorithm for coexistence in TVWS between IEEE 802.22 and IEEE 802.11af by equal opportunity without increased delay time and decreased throughput, for each of them. Also, an investigation has been conducted for the coexistence problem between the 802.22 and the IEEE 802.11af systems, in the TV White Spaces (TVWS). IEEE 802.22 and IEEE 802.11af are two typical standards envisioned to be widely adopted in the future. However, these two standards are heterogeneous in both power level and PHY/MAC design; as a result coexistence challenge is there. The main focus of this paper is to design a co-channel coexistence scheme for the IEEE 802.22 customer-premises equipment's (CPEs) as well as the IEEE 802.11af systems. In this paper, the challenges are identified to enable the co-channel coexistence of the IEEE 802.22 and the IEEE 802.11af systems. Afterwards, an algorithm is proposed for coexistence, depending on frame times. The algorithm is applied in two networks in three cases, depending on the amount of transmitting data. The simulation results suggest that the proposed solution has increased the throughput and decreased the waiting time by a noticeable way for IEEE 802.11af.

Keywords: IEEE 802.11af, Interference, TDMA, TVWS, White-Fi

1. Introduction

When you submit your paper print it in two-column format, including figures and tables. In addition, designate one author as the "corresponding author". This is the author to whom proofs of the paper will be sent. Proofs are sent to the corresponding author only. The TV broadcasting spectrum is seen as one of the first opportunities to adopt and implement innovative and more efficient Dynamic Spectrum Access (DSA) models supported by cognitive radio technology[6]. With the transition to digital TV (e.g. June 2009 in the USA), considerable amount of vacant spectrum have been generated in the TV spectrum. This group of non-contiguous vacant channels is collectively known as TV White Spaces (TVWS)[12]. The IEEE 802.22 WG has been developing a standard for Wireless Regional Area Networks (WRAN) in the TVWS[4]. Recently, the IEEE 802.11 WG has initiated development of an amendment (IEEE 802.11.af) to the IEEE 802.11 wireless local area network (WLAN) standard[1] to operate in the TVWS. The IEEE 802.11 working group will be known by the IEEE 802.11 Wireless Local Area Network (WLAN) standards[7]. IEEE 802.22 is the first standard for devices to operate on TVWS, providing a cell radius of up to 100 km. A new version has been released in July 2011. IEEE 802.11af is also referred to as White-Fi or super Wi-Fi and targeted at providing local area coverage. These two standards are both envisioned to have wide applications in the future[8]. However, these standard heterogeneities are in operating powers and sensitivities and

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protocol stack[9,15]. To enable coexistence of heterogeneous system on TVWS, the IEEE 802.19.1 protocol[10] requires all the networks operating on TV white spaces to have a common interface to access the coexistence database and the channel allocation will be scheduled by a centralized entity called coexistence manager. Recently in[11], two standard independent mechanisms are proposed to provide an information exchange platform for heterogeneous TVWS standards. Both of the proposed mechanisms required either a coexistence database or the use of multiracial cluster head equipment. On the other hand[12], the two problems of coexistence (Hidden Terminal to IEEE 802.22 and Exposed Terminal to 802.11af) can be solved by proposed busy tone frame work, but this tone decreases the throughput of IEEE 802.11. In[13], a new paradigm is proposed which is called Cooperative Busy Tone (CBT), that enhances the mutual observe ability between ZigBee and Wi-Fi. However, in TVWS it is not practical for the devices to transmit a higher power due to the regulation. The IEEE 802.15.2[14] proposed an adaptive frequency hopping (AFH). However, AFH is ineffective at Wi-Fi hotspots where the entire 2.4 GHz spectrum is congested by multiple WLAN cells configured to orthogonal channels. The proposed framework is to minimize the mutual interference for coexisting networks. It is only applicable to static. Another approach is called SWIFT (a Split Wideband Interferer Friendly Technology). Prior work avoids narrowband devices by operating below the noise level and limiting itself to a single contiguous unused band. However, this requires learning the reactions of the other systems. To make assumptions for the throughput and delay time, this is an important parameter in coexistence and also, another work operates at the application layer.

The main focus of this work is to resolve problem regarding the coexistence between IEEE 802.22 and IEEE 802.11 by proposing an algorithm, depending on a frame time scheme. The basic idea of this algorithm gives IEEE 802.22 an opportunity to send at a specific frame time and after frame time finishes, the IEEE 802.11 sends at a specific frame time (two networks send by equal opportunity). The proposed algorithm has been applied in three cases: when IEEE 802.22 sends high traffic and IEEE 802.11 sends low traffic, IEEE 802.22 and IEEE 802.11 both sends medium traffic and IEEE 802.22 sends low traffic and IEEE 802.11 sends high traffic. To know the waiting time (Delay) for each of the two networks in all three cases to enable coexistence without deteriorating the throughput of IEEE 802.11 and IEEE 802.22. In summary, three major contributions have been done.

By analyzing the heterogeneity of the IEEE 802.22 and the IEEE 802.11af standards, the coexistence challenges between these two systems are identified. To enhance the IEEE 802.11af TVWS throughput and delay time with presence of IEEE 802.22, we a new algorithm has been proposed based on frame time scheme. A demonstration is done with the numerical simulation that the delay time of IEEE 802.11 can be decreased and the throughput also can be increased while both networks has the equal sending opportunity, with the proposed frame time scheme.

The rest of this paper is organized as follows: Related works are further reviewed in detail in Section II and in Section III, we the coexistence problem has been identified between the two systems. The proposed frame time based coexistence framework is demonstrated in section IV. Section V presents the numerical results. The conclusion is summarized in Section VI.

2. Coexistence Problem in TVWS

The two standards 802.22 and 802.11af are different at almost all levels in the protocol stack (as shown in Figure 1). Due to the heterogeneities of the 802.22 and 802.11af systems, it is challenging to enable their coexistence. The two networks are heterogeneous in operating powers and sensitivities. The transmission power of 802.22 can be as high as 4W (36 dBm) and the reception sensitivity can be as low as -97 dBm. On the other hand, 802.11af tends to use much lower transmission power of 100 mW (20dBm) and its sensing threshold is usually -64 dBm. 802.22 stan-

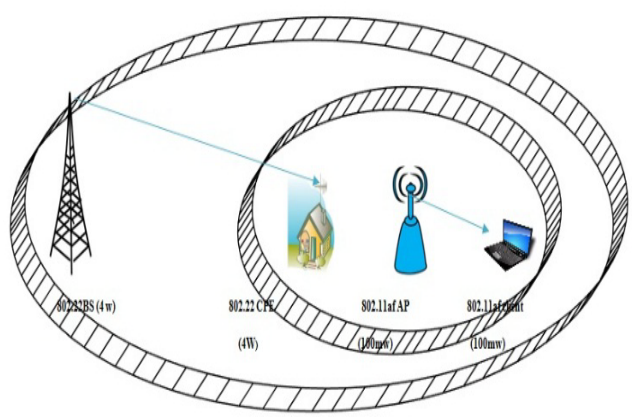

Figure 1. Coexistence between IEEE 802.22 and IEEE 802.11 in TVWS.

dards adopts the point to multi-point architecture and has a TDMA-like MAC while the 802.11af is expected to use CSMA at MAC[3]. Since the reception threshold of 802.11af is much higher than that of the 802.22 receiver, it is possible that the 802.11af transmitter cannot detect the existence of a faraway 802.22 transmitter and thus becomes a hidden terminal to the 802.22 receiver.

3. Proposed Busy Tone and Frame Based Coexistence Frame

In this section, the busy-tone and frame time based coexistence framework is proposed for the IEEE 802.22 and the IEEE 802.11af systems' assumptions and then the design is present.

3.1 Simulation Setup

Consider one IEEE 802.22 BS and one CPE in the simulation. The network topology is shown in Figure 2. One IEEE 802.11af AP and one IEEE 802.11af client both are randomly generated. In the MAC layer, a simplified version of the MAC protocols is implemented. For the IEEE 802.22 network, nodes transmit without carrier sense the channel (TDMA). For the 802.11af network, nodes transmit after carrier sense (CSMA). In the physical layer, the power is considered as 36 dBm for IEEE 802.22 and 20 dBm for IEEE 802.11af. In the simulation the traffic load is varied for both of the networks from zero to 1.0, and two different algorithms are applied. One of these algorithms uses the technique of busy tone and another algorithm uses the technique of frame time. Data rate and frame size are used to calculate the delay of both networks. The two algorithms are applied in three cases:

- When CPE transmitting data with high traffic load 0.9 at the same time 802.11 sends low traffic load 0.1.
- When CPE transmitting data with medium traffic load 0.5 and at the same time IEEE 802.11 is with medium traffic load 0.5.
- When CPE transmitting data with low traffic load 0.1 at the same time IEEE 802.11 is with high traffic load 0 .9.

Two algorithms applied on these three cases to find the best algorithm to improve the performance of each of the networks to coexist in TVWS, and then compared the delay of the two algorithms for each network under the scenarios:

- IEEE 802.11 throughput when coexistence with IEEE 802.22 if algorithm one is used.
- IEEE 802.11delay when coexistence with IEEE 802.22 if algorithm one is used.
- IEEE 802.22 delay when coexistence with IEEE 802.11 if algorithm one is used.
- IEEE 802.11 delay when coexistence with IEEE 802.22 if algorithm two is used.
- IEEE 80.22 delay when coexistence with IEEE 802.11 if we use algorithm two.

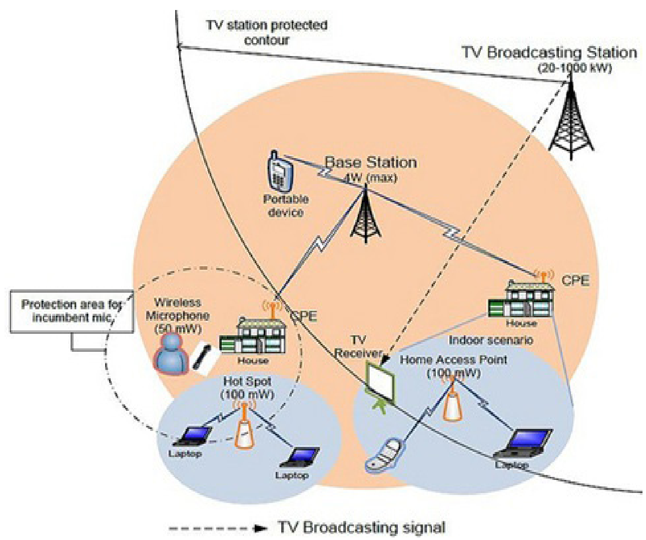

Figure 2. Coexistence scenario.

3.2 Coexistence Algorithms

3.2.1 Algorithm one (based on a busy-tone Scheme Implemented on the IEEE 802.22 CPEs.)

When the IEEE 802.22 transmits to CPE, at the same time the CPE sends power of 100mw (busy tone). In this case, the IEEE 802.11 cannot transmit due to the presence of busy tone. So, every time try to send prevent from transmission (denial of service), and thus IEEE 802.11 cannot send without the CPE sends all data or all frames. To find out the effect of this algorithm in general on IEEE 802.11 the throughput is calculated in three cases:

Case 1: IEEE 802.11 only occupying the entire channel as in equation (1).

$$T_{(only)} = Ge - G \quad (1)$$

Case2: IEEE 802.11 and IEEE 802.22 coexistence with busy tone as in equation (2)

$$T_{(w/BT)} = p\left(w/BT\right).T_{only} \quad (2)$$

Case 3: when IEEE 802.11coexistence with IEEE 802.22 without busy tone, where T is throughput, G is traffic load.

$$T_{(w_0/BT)} = p\left(w_0/BT\right).T_{only} \quad (3)$$

Where, T(w/BT) is throughput with busy tone, $T(w_0/BT)$ is throughput without busy, tone, p(w/BT) shows probability with busy tone $p(w_0/BT)$. In order to calculate the delay of IEEE 802.11, it is necessary to know the waiting time which can be expressed in equation (4).

$$\text{Delay of 802.11 (with busy tone)} = \frac{\text{Throughput of IEEE 802.22 (with busy tone)}}{\text{data rate IEEE 802.11}} \quad (4)$$

While calculating the delay of CPE, it is observed that the delay is equal zero because the CPE do not wait; at any time receive data from IEEE 802.22 sends a busy tone. Although, it can be seen that, the IEEE 802.11 is waiting too much even the CPE send all frames. Therefore, it is summarized that this algorithm decreases the throughput of IEEE 802.11.

3.2.2 Algorithm two (frame time Scheme Implemented in 802.22 CPE)

This proposed algorithm is based on frame size for each of the CPE and IEEE 802.11 (as in Figure 3). In this case there is a specific frame time for each network, so the IEEE 802.11 do not wait until CPE send all the data or frames but wait for a specific frame time and then transmission chance move to the IEEE 802.11. It is noted in this algorithm that the sending technique is a variable between two networks. Also, it is found that IEEE 802.11 wait for a specific number of frame duration of CPE and also CPE wait for a specific number of frame duration of IEEE 802.11. It is clear that, this algorithm reduces the waiting time of IEEE 802.11 which leads to reduce the delay. So, the outcomes when the frame number of 802.11 is less than or equal frame number of CPE as in equation (5), and when the frame number of IEEE 802.11 is more than frame number of CPE as represented in equation (6), (7) and (8).

$$\text{Delay of IEEE 802.11} = \text{frame number of IEEE 802.11} \left(1536 \times 10^{6}\right) \quad (5)$$

$$\text{Delay of IEEE 802.11} = \text{frame number of CPE} \times 10^{3} \quad (6)$$

$$\text{Delay of CPE} = \text{frame number of CPE} \times 10^{3} \quad (7)$$

$$\text{Delay of CPE} = \text{frame number of IEEE 802.11} \times \left(1536 \times 10^{6}\right) \quad (8)$$

The impact of this algorithm on each of the two networks will be observed by using the frame time in the three cases (high traffic, medium traffic, low traffic) and how the algorithm improves the performance of IEEE 802.11 and reduces the waiting time of IEEE 802.11 and also at the same time it doesn't reduced the CPE performance. In addition, it is noted that the performance of the two networks is very close to equal.

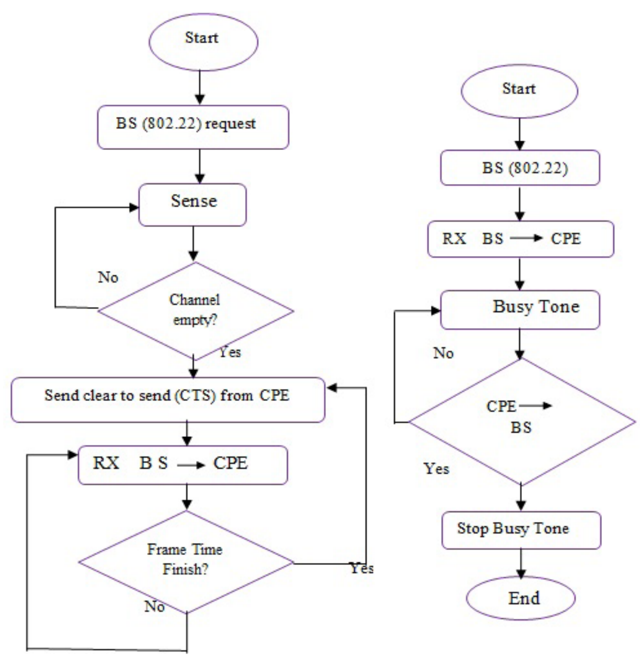

Figure 3. Proposed enhanced algorithm.

4. Result Analysis

In this section, Math Lab is used for the simulation to show the numerical performance of the proposed coexistence algorithm. Figure 4 and Figure 5, both demonstrates the effect of busy tone in IEEE 802.11 when co-existence exists with IEEE 802.22, in three cases (high, medium and low traffic).

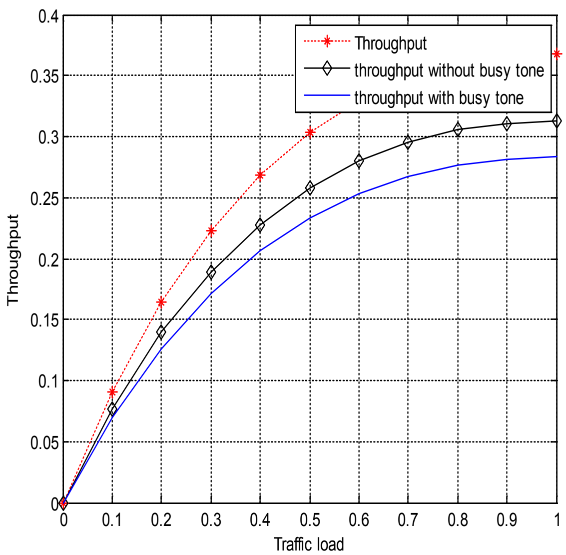

Figure 4. Representation of busy tone throughput.

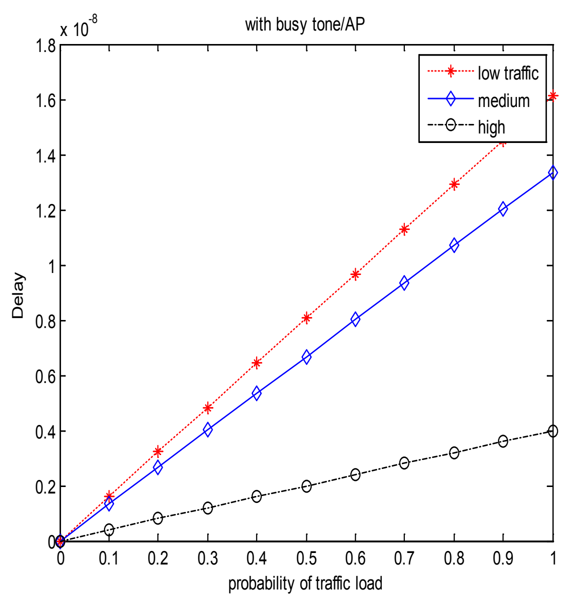

Figure 5. Representation of busy tone throughput with coexistence.

Figure 4 shows that when using the busy tone scheme, IEEE 802.11 is only occupying the entire channel and the throughput equal 0.37 in this case. The throughput of IEEE 802.11 while coexisting with 802.22 is equal 0.28. In case when IEEE 802.11 and IEEE 802.22 coexist without busy tone, the throughput is equal to 0.32. So, it can be noted that while using busy tone, the throughput of IEEE 802.11 is deteriorated by a noticeable way.

It can be seen in Figure 5 that when IEEE 802.11 sends a traffic load of 0.1 and IEEE 802.22 sends a traffic load of 0.9, the waiting time of 802.11 is very long (1.62 x 108), even though IEEE 802.22 sends all data or frames. In the second case, IEEE 802.11 and IEEE 802.22 both send a traffic load of .5. So, the waiting time decreases (from 1.62 x 108 to 1.38 x 108) because the traffic loads of 802.22 decreases from 0.9 to 0.5. It is found out that the waiting time of IEEE 802.11 equals the transmission time of IEEE 802.22 to transmit all data. While IEEE 802.11 send traffic load of 0.9 and IEEE 802.22 send traffic load of 0.1, it can be considered the best case for IEEE 802.11. This is because the IEEE 802.11 waits for a short period of time (.4 x 108) and IEEE 802.22 sends low traffic Therefore, it sends a busy tone for a short period and after that IEEE 802.11 is able to send the data. In the aspect of IEEE 802.22 delay, it has been found out that the IEEE 802.22 does not wait for any time period but receives data momentarily from any base station that can re transmit this data by sending busy tone. So, this work does not contain any figure of delay for IEEE 802.22.

4.1 Results of Algorithm two (frame times Scheme)

Here, analysis will be done with the result of second algorithm which depends on frame time with an intension to know how this algorithm improves the delay on IEEE 802.11. Figure 6 shows different results for the delay when send 0.9 traffic loads is sent from 802.11 and 0.1 traffic load from IEEE 802.22. It can be seen that the value of traffic load is (.4 X 107) and if IEEE 802.11 sends the same amount of data from 802.11, the value of delay is equal to 1.38. In the last case it is noted that this algorithm has improved the delay time when IEEE 802.11 sends 0.1 traffic load and IEEE 802.22 sends 0.9 traffic load. In this case, an improvement of .14 X 107 is noted.

Figure 7 shows the result of delay in three cases: when IEEE 802.11 sends data higher than IEEE 802.22 (0.9 to 0.1), when IEEE 802.11 sends data equal to 802.22 (both 0.5) and finally if IEEE 802.11 sends data lower than IEEE 802.22 (0.1 to 0.9). In these cases the values of the delay are in order (.4, 1.38 and .14) and it can be noted that this values are the same values if the second algorithm is applied in the case of access point.

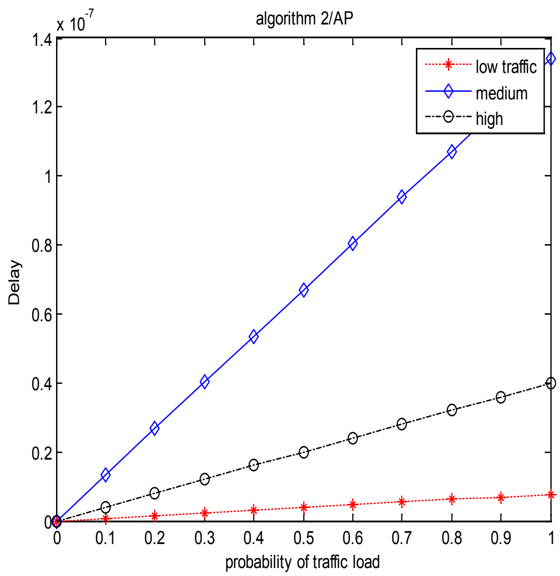

Figure 6. The effect of frame time scheme in IEEE 802.11 (algorithm 2/AP).

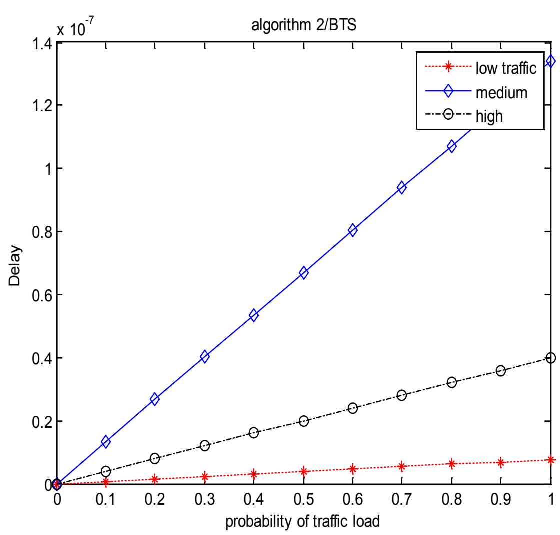

Figure 7. The effect of frame time scheme in IEEE 802.11 (algorithm 2/BTS).

5. Conclusion

It can be observed that the paper has investigated the coexistence challenges, and thereby, proposed an enhanced algorithm in order to mitigate such challenges. From the assessment, it is found that after implementing the first algorithm, the throughput of IEEE 802.11 decreases because of not sending any data when IEEE 802.22 sends all data. As a result, this algorithm increases the waiting time of IEEE 802.11, however waiting time of IEEE 802.22 equals to zero. While implementing the second algorithm, it can be observed that the waiting time of IEEE 802.11 decreases in a clear manner, meanwhile the waiting time of IEEE 802.22 does not increase by a noticeable way and therefore, it is conclusive that the proposed algorithm improves the throughput and delay time of IEEE 802.11.

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