SPECTRUM SENSING APPROACH BASED ON QOS REQUIREMENTS IN WHITE-FI NETWORKS

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ABSTRACT

Cognitive Radio (CR) technology opens the door for the opportunistic use of the licensed spectrum to partially address the issues relevant to the limited availability of unlicensed frequencies. Combining CR and Wi-Fi to form the so called White-Fi networks, has been proposed for achieving higher spectrum utilization. This paper discusses the spectrum sensing in White-Fi networks and the impacts that they have on the QoS of typical applications. It also reports the analysis of such impacts through various simulation studies. We also propose such a sensing strategy that can adapt to the IEEE 802.11e requirements. The proposed strategy aims to enhance overall QoS while maintaining efficient sensing. Simulation results of the proposed mechanism demonstrate a noticeable improvement in QoS.

KEYWORDS

Cognitive Radio, Spectrum Sensing, White-Fi, IEEE 802.11af, IEEE 802.11e, QoS.

1. INTRODUCTION

Traditionally, the radio spectrum is statically divided into frequency bands, most of which are licensed to organizations and companies usually referred to as primary users (PUs). A small number of frequency bands are unlicensed including the unlicensed Industrial, Scientific, and Medical (ISM) bands, which are used by a variety of indoor and short-range wireless communication systems, such as Wi-Fi, Bluetooth, and Zigbee. These free unlicensed frequencies are not sufficient to handle the rapidly growing number of wireless devices using these unlicensed bands. Also, modern applications running on these devices demand more bandwidth. These modern applications usually involve multimedia communications, e.g., media streaming, video conferencing, and interactive gaming. One of the promising solutions to increase radio frequency spectrum availability to these wireless devices is to add the Cognitive Radio (CR) capability to such devices. With CR capability, a wireless device can operate opportunistically, as a Secondary User (SU), over licensed frequency channels when they are unused, i.e., White Spaces (WS) or spectrum holes in the licensed bands. Television (TV)bands are the most attractive frequency ranges for such opportunistic use of the spectrum by SUs. This because the TV bands show high availability of WSs and their schedule use by the PUs can be obtained through Geolocation Database (GDB) services[1]. Moreover, the TV spectrum is located below 1 GHz. Compared to the higher ISM bands, these frequencies offer more desirable propagation characteristics. An IEEE-802.11 protocol with CR capability is often referred to as CR Wi-Fi, White-Fi, Wi-Fi Like or IEEE-802.11af. The IEEE 802.11af is the first draft standard for CR networks based on IEEE

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802.11 to operate in TV WS[2]. The White-Fi devices can operate either in ISM channels or TV WSs based on the IEEE 802.11af standard. Figure 1 shows the main approaches for assessing the potential operation bands along with their related basic conditions and required actions.

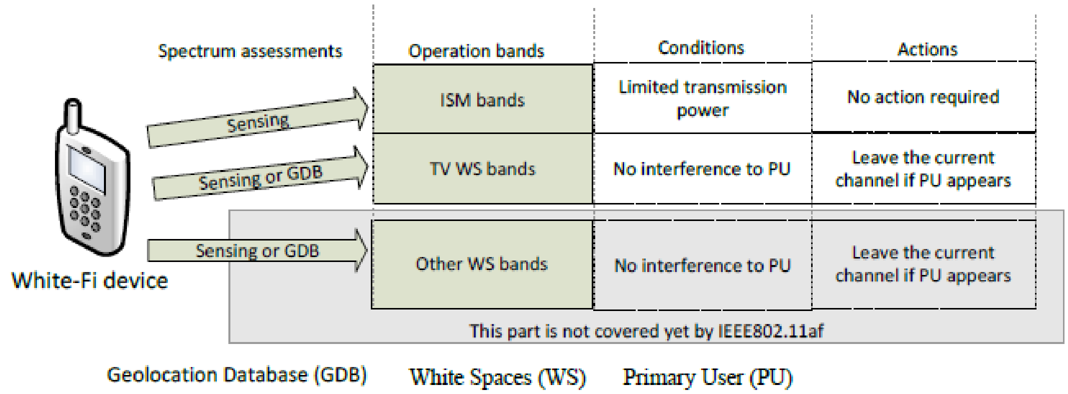

Figure 1. White-Fi potential operation bands and their required conditions and actions

Primarily, the CR capabilities and requirements are established at the Physical (PHY) and Medium Access Control (MAC) layers of wireless systems. Spectrum sensing is one of the most important functions in CR to identify the available spectrum holes and to protect the PU from interference. Conducting sensing has its impact on transmission delays and throughput. The Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism is used in wireless devices based on various 802.11 standards to share the ISM bands[3]. The concept is that a Wi-Fi device checks the channel occupancy before transmitting over it. Typically, this checking is accomplished by using a simple sensing technique, e.g., Energy Detection (ED), where the energy of the channel is measured and compared to a predefined threshold. If the measured energy level exceeds the threshold, the channel is in use by another device; otherwise, it is idle.

The remaining parts of this article are organized as follows. In section 2,some of the previous related work are reviewed andcompared to the contributions of this study. Correlation between QoS requirements and sensing is discussed in Section 3.Then the impacts of sensing duration on QoS are identified and analyzed by simulations in Section 4. In Section 5,the proposed solution for enhancing QoS in White-Fi networks by selecting sensing strategy based on QoS requirements is demonstrated. Conclusions and future works are described in Section 6.

2. RELATED WORK AND MOTIVATIONS

The success of White-Fi technology highly depends on the QoS level that it can offer for various communication applications. Although the QoS in CR networks, in general, has drawn more attention recently, White-Fi networks have received a minor portion of that attention. Articles that have been published to study QoS issues in White-Fi networks based on sensing are related to our work in this paper. The most related work is that where the sensing duration and its effect on QoS are considered.

The effect of the sensing duration on the access delay of an SU was analyzed when the Request-to-Send/Clear-to-Send(RTS/CTS)mechanism was enabled for spectrum access in[4]. The optimal sensing length was formulated as a function of the false alarm and miss detection probabilities and the number of SUs contending for the same access point. The ED was assumed as the sensing method and the maximum sensing duration used for analysis was 25ms.The sensing was only conducted at the beginning of the contention period and before sending an RTS packet. The study found that the access delay of an SU depends on the sensing length, and its optimal value varies based on the number of contending SUs. The relation and the possible trade-off between the spectrum sensing duration and achievable throughput of SUs were addressed in several studies[5, 6]. The approximated analytical formulation of the optimally saturated throughputs for multiple SUs based on CSMA/CA mechanism was proposed in[14]. The discrete-time Markov chain was used to model this formulation for different false alarm probabilities and a varying number of SUs. Their numerical results showed the significant role of sensing in improving the SUs throughputs and how the saturated throughput was affected by the sensing false alarm probability. Their analysis was approximate and under typical parameters as their primary aim was to conduct an initial study on the performance of CR techniques used in 802.11-based networks. In another similar study by other authors, the authors' aim was to find the optimal sensing duration that achieves the maximum throughput under unsaturated traffic conditions in[6].The discrete-time Markov chain model was used by the authors to model their proposed MAC structure for analyzing the performance of SUs. The sensing was conducted by SUs only at the beginning of the contention period when one access point and several SUs exist. The optimal sensing duration was investigated within the range of 0.5 ms to 3 ms for different number of SUs (5, 10, 15 and 20) of the various queuing probabilities and contention window sizes. Other conditions, such as the false alarm probability, detection probability and single-to-noise ratio (SNR), were assumed constant and the same for all SUs. Under the aforementioned assumptions, the optimal sensing duration was found to be around 2 ms for all the simulated scenarios under certain assumptions and conditions[6]. Therefore, an optimal sensing duration can be found for maximum throughput under unsaturated traffic conditions.

The studies mentioned above were solely based on the use of ED as their sensing method and relatively small sensing length. Practically, the ED method performs poorly in low SNR environments and cannot distinguish between PU signals and other SU signals. The use of higher accuracy sensing methods implies the need of longer sensing. In our study, a wider range of sensing durations is considered to reflect the potential use of more complex sensing methods.

3. CORRELATION BETWEEN QOS REQUIREMENTS AND SENSING

The IEEE 802.11e standard is proposed to enhance QoS in IEEE 802.11 networks [7]. As applications have different requirements, in 802.11e, the frames belonging to different applications are prioritized with one of the eight user priority (UP) levels. In contrast, previous IEEE 802.11 standards use the Distributed Coordination Function (DCF) mechanism at MAC layer where the best-effort service is provided equally to all traffic streams from different applications to access the medium. In IEEE 802.11e, the Hybrid Coordination Function (HCF) is used for prioritizing traffic streams to enhance QoS on top of the DCF. The HCF accommodates two medium access methods, i.e., a distributed contention-based channel access mechanism, called Enhanced Distributed Channel Access (EDCA), and a centralized polling-based channel access mechanism, called HCF Controlled Channel Access (HCCA). Based on the UP, the EDCA defines four Access Categories (AC); voice (AC_VO), video (AC_VI), best-efforts (AC_BE) and background (AC_BK). These categories are assigned different priorities ranging from highest to lowest respectively. The category AC_VO has top priority and is usually given to traffic carrying voice information. It is followed by the AC_VI category for video traffic and then the AC_BE category for data traffic. The category AC_BK has the lowest priority and is usually assigned to unnecessary data traffic.

Each AC has a Contention Window (CW) that has a specified minimum size and maximum size, i.e., CW_{min}[AC] and CW_{max}[AC]. Also, an Arbitration Inter-frame Space (AIFS) value and a Transmit Opportunity (TXOP) interval are used to support the QoS prioritization [8]. Instead of using fixed Distributed Inter-Frame Space (DIFS), also called DCF inter-frame space, the AIFS[AC] value is a variable value calculated based on the AC. For instance, possible valuesfor AIFS[AC] are; AIFS[AC_BK], AIFS[AC_BE], AIFS[AC_VI] or AIFS[AC_VO]. The AIFS value determines the time that a node defers access to the channel after a busy period and before starting or resuming the back-off duration. Hence, the time for a station to wait for the channel to become idle before it starts sending data is calculated based on the AC category of the data AC [9]. However, the Short Inter-frame Space (SIFS) value is used as the shortest Inter-frame Space (IFS) value for transmitting high priority frames, such as DATA Acknowledgment frames. Therefore, the higher priority frames access the operational channel earlier than other frames in the same transmission queue.

White-Fi users and SUs based on other different wireless technologies may coexist in the same available WSs. Under this situation, a White-Fi user needs to distinguish between three types of users, i.e., the PU, the other White-Fi users and the other non-White-Fi SUs. The simple sensing methods, e.g., ED, cannot distinguish between these different signals. Although advanced sensing, such as Matched Filter Sensing (MFS) method, may distinguish between signals when prior information about these signals is available, higher sensing duration is required.

In the case of White-Fi, increasing sensing duration will impact the effectiveness of the IEEE802.11e standard on improving QoS in IEEE802.11 networks. The impact of the sensing operation should be investigated under different settings of the associated parameters. For the frames belonging to the categories of AC_VI and AC_VO, the AIFS, and CW values are set smaller than for the frames of the categories AC_BE and AC_BK, to reduce the delays. In White-Fi networks based on sensing, increasing sensing duration for more accurate sensing can result in compromising the IEEE 802.11e mechanism, as shown by the simulation results in the following sections.

4. SIMULATION STUDIES: IMPACTS OF SENSING DURATION

To study effects of sensing function on the frame transmission delays that impacts the QoS of applications running on a White-Fi device, a simulation tool Modeler 18.0 from Riverbed (formerly Opnet) [10] is used. Modeler 18.0 supports different types of applications and network traffics. However, CR networks are not implemented yet in Modeler 18.0. Hence, we have customized the standard Wi-Fi node to include a sensing function with different sensing periods to simulate the behavior of a White-Fi node. The settings of some common parameters of all simulation scenarios are shown in Table 1. The IEEE 802.11e is supported in all scenarios with the settings illustrated in Table 1. Simulations are conducted under different sensing durations and for different application categories. The main three types considered are the voice traffic, video conferencing traffic and email traffic. The result values are captured under bucket mode with a sample mean of 100 values per a result statistic. In the Bucket mode, the data is collected at all of the points over the time interval or sample count into a “data bucket” and generates a result from each bucket. The wireless delay, simply called delay in this article, represents the end-to-end delay of all the data packets that are successfully received by the MAC layer and forwarded to the higher layer in a node. The media access delay is the sum of delays, including queuing and contention delays of all frames transmitted via the MAC layer.

For each frame, the media access delay is calculated as the duration between the time when the frame is placed in the transmission queue until the time when the frame is sent to the physical layer for the first time. On other words, the media access delay is the time of processing a packet at the MAC layer. For a voice application, voice traffic is generated as IPv4 unicast traffic flows between the nodes. For generating email and video conferencing traffic, a server is used to run these applications in the infrastructure network scenarios.

Table 1 Simulation parameters settings

Parameter	value
Data rate	26 Mbps / 240Mbps
Buffer Size	256000 bits
Maximum Transmitter A-MSDU size	3839 bytes
Maximum Acceptable A-MSDU size	8191 bytes
EDCA Parameters:	
Voice:	CW_{min}= ($PHYCW_{min}$ + 1) / 4-1 CW_{max}= ($PHYCW_{min}$ + 1) / 2-1 AIFSN = 2 TXOP = One MSDU
Video:	CW_{min}= ($PHYCW_{min}$ + 1) / 2-1 CW_{max}= $PHYCW_{min}$ AIFSN = 2
Best Effort:	CW_{min}=$PHYCW_{min}$ CW_{max}=$PHYCW_{max}$ AIFSIN=3
Background:	CW_{min}=$PHYCW_{min}$ CW_{max}=$PHYCW_{max}$ AIFSIN = 7

4.1. Analyzing the sensing duration effect on different type of applications

In this subsection, the effect of sensing duration is analyzed for various applications. Three scenarios are implemented for that purpose; voice scenario, email scenario and video scenario. The sensing is conducted for all frames except response frames in all scenarios. For voice scenario, four nodes Ad Hoc network are used. Moreover, IPv4 unicast voice traffic is generated amongst all the four nodes. Several simulations are conducted for different sensing durations from 1 ms to 300 ms. Also, the simulation is run when the sensing is neglected, i.e., 0 ms. The average delay for each of the sensing duration starts to increase sharply from the beginning till the 900 seconds of simulation time. It becomes more stable afterward for all sensing durations.

In the email scenario, an email server is added for simulating heavy email traffic between the server and other four nodes. Instead of operating as an ad hoc network in the previous scenario, the network in this scenario operates in an infrastructure mode with the server also acting as an AP. Several simulations are run under different sensing periods from 1 ms to 300 ms. The simulated operation time of the network is an hour for each of these sensing durations. The average measured delay is 0.35 seconds when the sensing length is 300 ms. The average delay is between 0.3 and 0.1 seconds for sensing durations between 250 ms and 100 ms while it is less than 0.1 seconds for sensing lengths less than 50 ms. These results show that the delay is less with heavy email traffic than the voice traffic.

The video application scenario is similar to the email application one, except that the added server is used for providing video conferencing application to the other four nodes. The server is used to generate high-resolution video conference traffic between the four nodes through the server. The simulations are conducted for different sensing durations from 1 ms to 300 ms. The average delay in this scenario has not exceeded 0.1 seconds even when the sensing length is 300 ms. The average delay in this scenario does not follow proportional relation between the average delay and sensing duration.

4.2. Observations and comparisons

The comparison between the three traffic types; voice, email, and video, clearly illustrates that the voice traffic experience the highest average delay as shown in Figure1. Compared to the other traffics, the voice traffic is more sensitive to the length of the sensing period. The average delay in email traffic is proportional to the length of the sensing duration, but with a smaller slope. Thus, the email traffic is less affected by the sensing duration than voice traffic. Moreover, email applications are not sensitive to delay. The video traffic is less sensitive to sensing length compared to the other traffics and the average delay and the sensing duration is not in a constant proportionality relation. The results in Figure1 demonstrate that the same sensing strategy has different effects on the traffics from different applications.The diverse traffics used in these scenarios follow different aggregation settings. It can also be seen in Figure1 that sensing durations less than 50 ms cause an average delay of fewer than 0.2 seconds, which is acceptable in several applications. However, a longer sensing time could be required for achieving higher sensing accuracy. Although IEEE802.11e was enabled in the simulations, the results show that the voice and video traffic gain no benefit from it because of the impact of extended sensing time. Therefore, sensing duration and frequency should be conducted in a way that preserves the aim of improving QoS of different applications by using IEEE802.11e. In the next section, our proposed solution for enhancing QoS is discussed and evaluated by simulations.

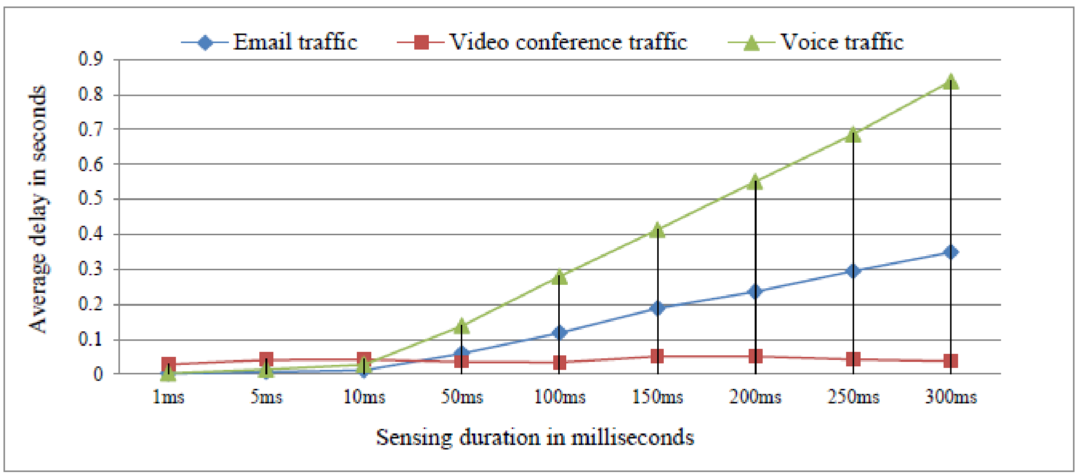

Figure1. Comparison between the average delays of different applications traffics for different sensing durations

5. Selecting The Proper Sensing Strategy For Enhancing QoS

The ED method is commonly used for sensing on CSMA/CA based networks because of its simplicity and low overhead. However, in a CR environment, the main ED drawback, in particular, is its inability to recognize PU signal among other signals, reduce its effectiveness. The MFS method can overcome this drawback and provide higher detection accuracy at the cost of more sensing time, complexity and power consumption. Therefore, the sensing method should be selected during operation by trading off between the sensing requirements and its implications. Such approach imposes that the White-Fi device supports a set of different effective sensing techniques where each one of these methods is suitable for a particular set of operation requirements.

Towards enhancing QoS in White-Fi networks, a mechanism of selecting the proper MAC operation settings and sensing strategy that suits the QoS application requirements is proposed.

The required QoS for different applications is classified into four levels based on the four ACs in IEEE 802.11e as shown in Table 2. The sensing strategies are classified into four types; Coarse (C), Moderate (M), Fine (F) and Extra Fine (EF) sensing. Each sensing type will be conducted based on the AC of the frame to be transmitted as shown in Table 2. The proposed sensing duration S_d range for each sensing type is chosen based on our previous study and classification of different sensing methods [11]. In the C sensing type, the sensing duration S_d is less or equal 1 ms to give higher priority to AC_VO frames with less impact on the delay. However, the sensing method that can be used within this short time is the blind sensing method, such as ED. Consequently, the C sensing type cannot distinguish between PU and other SU signals, and poor accuracy is expected at low SNR. Under the M sensing type, the sensing methods that can be used for an S_d larger than 1 ms up to 5 ms are similar to those used in the C sensing type with a slight improvement in sensing accuracy, particularly at low SNR. Therefore, AC_VI frames have less priority than AC_VO to win the contention window and more delay is predicted. For the F sensing type, the sensing duration S_d is larger than 5 ms up to 50 ms. Thus, sensing methods that can differentiate PU singles from other signals can be used. On the one hand, the F sensing type enables more utilization of WSs. On the other hand, it causes higher delay. In addition, conducting F sensing before AC_BE frames maintains the desired priority of these frames. As AC_BK frames have the lowest priority, EF sensing should be carried out before them for a sensing duration S_d larger than 50 ms. In the EF sensing type, sophisticated sensing methods can be used to achieve high sensing accuracy even under low SNR. Hence, higher spectrum utilization can be achieved under the cost of higher delay. When F and EF sensing recognize the appearance of PU in the current WS channel, the White-Fi device must scan for other vacant channels and leave the currently occupied one. Otherwise, when the current channel is found busy by other SUs, the device can continue use and share the current channel with other SU.

Table 2 Sensing strategy based on frame access category

Frame Access Categories	**QoS requirements**	**Sensing type**	**Sensing duration (S_d) in ms**	**Sensing characteristics**
Voice (AC_VO)	Highest priority (low latency, e.g., voice call, audio streaming)	Coarse (C) sensing	$S_d \leq 1$	Only blind sensing can be used. Cannot distinguish between PU and SU. Poor performance in low SNR.
Video (AC_VI)	Second highest priority (e.g., video conferencing, streaming)	Moderate (M) sensing	$1 < S_d \leq 5$	More advanced sensing methods but still not capable of distinguish between PU and SU. Moderate sensing accuracy.
Best Effort (AC_BE)	Low priority (traffic less sensitive to latency, e.g. web surfing)	Fine (F) sensing	$5 < S_d \leq 50$	Some sensing methods that can distinguish between PU and SU can be used. High sensing accuracy.
Background (AC_BK)	Lowest priority (no strict latency) (e.g., print jobs, email, etc.)	Extra Fine (EF) sensing	$S_d > 50$	Sensing methods that can distinguish between PU and SU can be used. High sensing accuracy even in low SNR.

In the case of C and M sensing, the sensing outcome cannot be certain about the PU presence. Hence, as long as the appearance for the PU is not certain, other factors should be considered before conducting handoff procedure to another available channel.

5.1 Evaluation of the sensing selection strategy

In this section, we demonstrate the QoS enhancement that can be achieved by considering the application requirements in selecting the proper sensing strategy. Two scenarios were implemented to compare between fixed sensing approach and selecting the proper sensing based on the QoS requirement approach. The network in both scenarios was the same with four nodes and one server. Three applications, i.e., voice, video and email, were configured to run simultaneously on all nodes for both scenarios. The simulated environment was implemented to reflect a real-life scenario where the wireless device is used to run simultaneously IP telephony voice application, high resolution video conferencing and heavy load email application. The sensing was conducted for all frames except response frames in both scenarios. The nodes in the first scenario were implemented with the same sensing strategy in Section.4.1.Hence, fixed sensing duration was used for all different AC frames. In the second scenario, the nodes were implemented to use different S_d based on the AC of the frame to be sent as proposed in Section 5.

The first scenario was simulated under four different sensing durations in each run where the sensing duration was changed to one of these values: 1 ms, 5 ms, 50 ms and 100 ms. As each one of these values fallen in different sensing type proposed in Table 2. In the second scenario, the nodes were implemented to select S_d based on the AC of the frame, such as S_d = 1 ms for AC_VO, S_d = 5 ms for AC_VI, S_d = 50 ms for AC_BE and S_d = 100 ms for AC_BK. The achieved average throughput for BE frames shown in Figure 3demonstrates that the sensing based on selection approach can achieve higher throughput compared to fixed sensing approach even when the sensing duration is fixed to 1 ms. The average media access delay that was experienced by voice frames is illustrated in Figure 4. The sensing based on selection experienced average media access delay less than the fixed sensing when the sensing length was 50 ms or 100 ms. The fixed approach with low sensing duration, e.g., 1 ms or 5 ms, resulted in less medium access delay but with less achieved average throughput compared to the sensing based on selection. Moreover, the fixed small sensing duration most likely results in inefficient sensing and less protection to PU signals that may not comply with requirements. Therefore, the proposed sensing based on selection approach can enhance the archived QoS of White-Fi devices based on spectrum sensing.

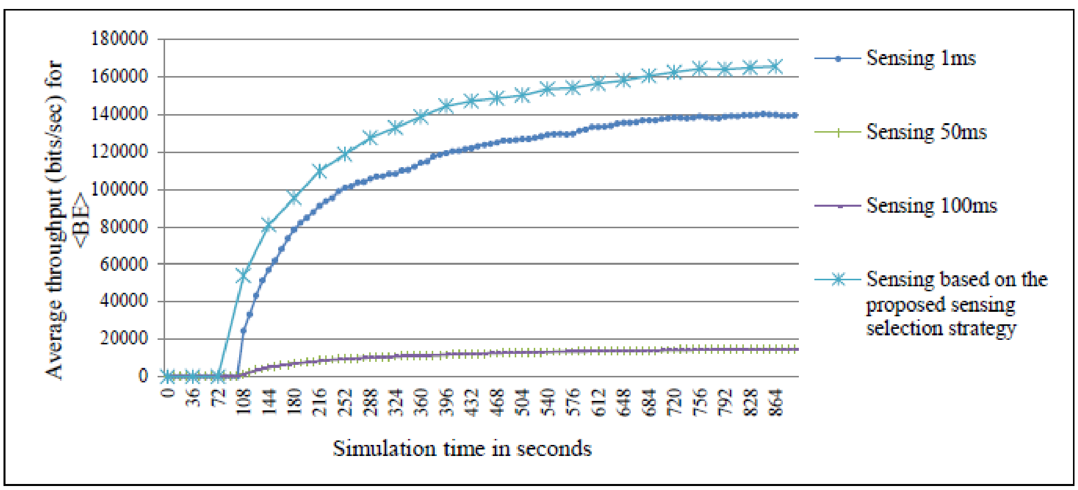

Figure 3. Average throughput for different sensing strategies when voice, video and email applications are running

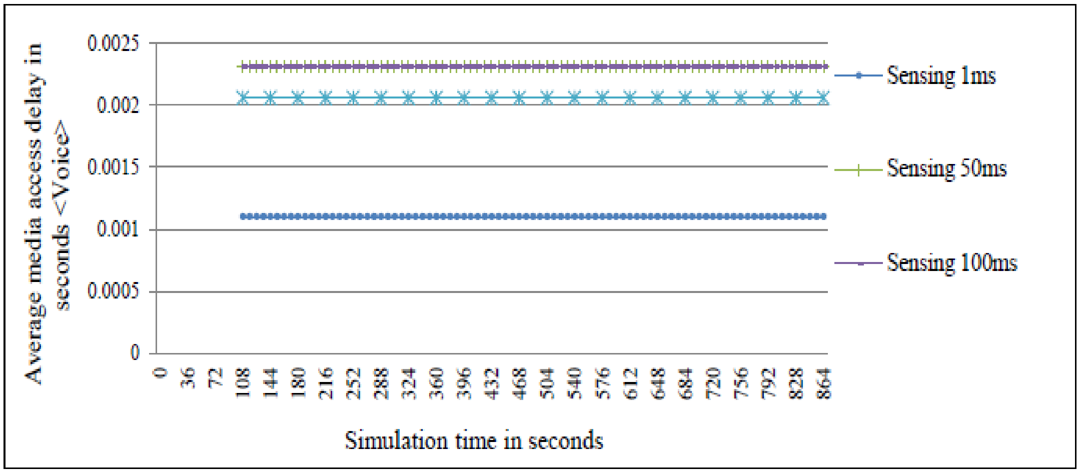

Figure 4. Average voice application media access delay for different sensing strategies when voice, video and email applications are running

6. CONCLUSIONS AND FUTURE WORK

Increasing sensing duration is required to achieve advanced sensing accuracy in CR networks. In this work, we studied the need of different sensing durations and its impact on QoS of various applications in the White-Fi networks. Our simulation results show that voice traffic is more affected by the sensing operation than video and email traffics. That means the IEE802.11e mechanism performs poorly when sensing duration is increased for higher accurate sensing. To address this issue, a sensing approach that selects the sensing parameters based on the 802.11e frames categories is proposed. The proposed sensing strategy resulted in QoS improvement while attempting to preserve higher PU protection and spectrum utilization. Our future research is aiming to develop our sensing strategy by considering more factors for better performance.

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