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Multi-Channel Scheduling with Optimal Spectrum Channel Hole Filling (MCS-OSHF) for Cognitive Radio Wireless Networks

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Multi-Channel Scheduling with Optimal Spectrum Channel Hole Filling (MCS-OSHF) for Cognitive Radio Wireless Networks

N. Shribala [α], Dr. P. Srihari [σ] & Dr. B. C. Jinaga [ρ]

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I. Introduction

Wireless communication systems are emerging much faster in terms of performance and efficiency, and the public radio spectrum bands do not have the scope of service for such advancements, as the bands were already licensed to the service providers earlier. Despite that, still there are many licensed spectrum bands that are underutilized in the spatial domain and also time domain [1].In order to utilize the unutilized spectrum band as opportunistic access for improving the efficiency of the spectrum usage, Cognitive Radio (CR) solutions are providing quality solutions. [2][3]. Spectrum and Channel sensing methods are introduced to handle one of the key issues envisaged with CR is about the protection of Primary Users (PUs) from any kind of interference resulting from Secondary Users (SUs) communications.

In the case of opportunistic access, SU shall identify any idle channels for the service, and can utilize the channel, but the crux is that irrespective of whether it focuses on the idle channel, still it has to ensure that current channel and additional channels are sensed. Only in such conditions, when a PU channel appears, SU can recover immediately the service channel. During the process of channel sensing, SU can't communication with other channels.

As per IEEE 802.16e Worldwide Interoperability for Microwave Access (WiMax) [4], the system allows the mobile station to perform channel scanning, by allowing mobile station to cut the communication with the base station, the efficacy of the process for QoS can be assured. But, in the case of IEEE 802.11 WLAN [5], such process is not facilitated unlike WiMax, and hence there shall be issues of packet losses and disruptions emerging due to channel scanning. To achieve the system with minimal QoS disruption, the interface of SU equipped with WLAN models has to be designed effectively.

This paper proposes the model of channel sensing scheduling which ensures interests of PUs are addressed, with the emphasis on sensing the channels only during the pre-defined time schedule, whilst managing the QoS for SUs for the delay and packet loss issues. As the interests of the PUs have to be given priority, certain level of SUs QoS may not be satisfied in the model.

In the further sections of this report, the emphasis is on, the literature pertaining the subject is discussed in section 2 and in section 3, the inputs related to proposed model of QoS-aware multichannel scheduling that has Optimal Spectrum Hole Filling model is proposed. Section -4 depicts the experimental results, and is followed by Section 5 with conclusion of the proposed model.

II. Related Work

Medium-Access-Control (MAC) protocols are adapted in using the DSA scheme for CRNs. In the case of MAC protocol, there are usually two phases predominantly, as contention phase and data transmission phase. In the contention phase, SUs rather than focusing on the common control channel shall focus on the idle licensed channels, through which successful SUs which shall take over the idle channels in the transmission phase. There is numerous protocol solutions defined in for MAC protocols. [6]-[9].

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In [6], distributed MAC protocol was proposed which comprise the SUs having common channels for forming groups and for multiple groups some SUs performing as gateways. The data is transmitted by SUs using the data based on their success in the contention phase.

In the distributed MAC protocol proposed by Chen et al [7], SUs shall form clusters that are controlled by a group leader for each cluster, which conducts the contention and data transmission process. Also in another model proposed in [8], the distributed multi-channel MAC protocol was proposed in which SU pair gets the opportunity to sense and access during the contention phase, and use the available channels for the hardware constraint. In the case of distributed multi-channel MAC discussed in [9], all the available access channels that are sensed using the sensing policies are accessed by the SU paid during the contention phase.

In all the aforesaid conditions, there is high quantum of control overheads as the SUs usually contend in random manner for channels, certainly the outcome shall be much lower with the MAC protocols. [10] -[15]Whereas in the case of DSA that are implemented using scheduling algorithms that can achieve higher throughput. DAS system has the process in which at the beginning of every slot, information regarding bandwidth requirement is collected from the SUs by scheduler and it is broadcasted to common control channels. From the received schedule, the SUs access the corresponding channels for the slot time that is remaining, and the model is defined as slot-based scheduling schemes.

[10] Proposes the scheduling algorithm which is based on integer linear programming (ILP), which is a unique channel user pair that is activated for varied time instants within the slot. Models in [11] –[15] presents numerous scheduling algorithms which can support in maximizing the transmission capacity for the SUs which are presented. In the scheduling algorithm discussed in [11], certain factors like the fairness, traffic demand to the SUs, link capacity, and Signal-to-interference-and-noise ratio (SINR) are considered. Whereas, in [12], the factors like fading, interference, and packet waiting times are considered, unlike [13] in which the focus is upon throughput, maximum frequency and packet waiting time. In [14], that achieves proportional fairness for SUs, focus on packet waiting time and the interference caused due to SU to the PUs receiver, but in [15], the model focus on assigning the idle channels to SUs depending on if the signal-to-noise ratio (SNR_ shall be used at the receiving SU which could be highest for any given channel.

The information exchange taking place by the scheduler in the slot based scheduling schemes are even comprised in the scheduling overhead for the SUs in the beginning. Considerable quantum of slot time is lost in the communication to the scheduling overhead due to low bandwidth in the common control channel and because of such model, the effective transmission to the data channels are getting reduced and are constraining the throughput achievable. Also, the scheduling overhead works on increasing the number of channels that can work on SUs, and not any of the aforesaid [10]-[15] shall focus on issuing of scheduling overhead.

Review of the earlier models and the literature reflect that the scheduling overhead could majorly impact the system performance, and hence such issues have to be addressed in the scheduling scheme design.

III. Multichannel Scheduling with Spectrum Hole Filling for Cognitive Radio Networks:

The proposed model of Multichannel scheduling with Optimal Spectrum Hole Filling (MCS-OSHF), has emphasis on medium access control strategy which shall function in Spectrum Access Controller. The key objective in the model is about QoS aware and also on dynamic channel allocation for different data-frame size that are to be transmitted in cognitive Radio wireless Networks which could enable the spectrum hole usage. The term spectrum hole usage can be defined as idle time amidst the schedules for sequence that is observed in a channel under Primary User levels. MCS-OSHF model presents the multichannel scheduling for hierarchy, and the following are the key processes adapted.

- The CR nodes shall assemble the varying size data-frames that are to be transmitted.
- For every data-frame in the transmission queue, a specific control frame shall be sent to the spectrum access controller, which shall inform to common controller, the requirement of each of the data-frame.
- Message mainly comprise the inputs like channel time, size of the data-frame, requisite bandwidth and the tentative time for transmission that is essential for reaching the spectrum access controller.
- The data-frame arrival time shall be calculated as the aggregate value of cumulative average time taken for a data-frame to reach the possible spectrum access controllers and the process-time (time taken for analyzing the message frame)

Let $\rho_{mf}(w_i)$ seen as process-timefor analyzing acontrol frame mf for a specificdata-frame w_i .

Let $a\tau_{mf}(w_i)$ seen as control frame arrival time mf atspectrum access controller ap . The time taken by the data-frame tentatively for transmission time w_i to reaching an access point ap , the outcome is estimated as:

$$\tau_{w_i} = \frac{\sum_{j=1}^{|AP|} \tau_{w_i}(ap_j)}{|AP|}$$

// |AP| shall be spectrum access controllers of count that is observed as w_i with the average of the tentative arrival times of a data-frame w_i atspectrum access controller ap is estimated as follows:

$a\tau_{w_i} = a\tau_{mf}(w_i) + \rho_{mf}(w_i) + \tau_{w_i}$ // the cumulative value of arrival time $a\tau_{mf}(w_i)$ of the message frame mf , process time $\rho_{mf}(w_i)$ and tentative transmission time τ_{w_i} of the data-frame w_i .

As per the message evaluated from Data-frame mf of data-frame w_i , the spectrum access controller shall schedule channels using proposed model of MCS-OSHF.

a) MCS-OSHF Scheduling Strategy

In MCS-OSHF, the channel scheduling for respecttive data-frame w_i is carried out as:

The selection criteria for the channels are that of desired bandwidth and the ones that are idle for time slot transmission expected. If none of the channel exists in such criteria, under considering other such conditions like, the arrival time of a data-frame and the channel scheduling time is not being sync, or in the case where the multiple channels meet scheduling criteria, or multiple data-frames arriving with same criteria, or if less number of channels are identified with desired criteria, in such conditions, the data-frame segmenting and channel allocation shall be carried out by MCS-OSHF.

However, the data-frame transmission time w_i if realized to be much lesser than the available transmission time frame for a target channel, and also if the opportunity for a channel usage is found to be extremely high, in such conditions the following processes are performed by the spectrum access controller.

The process of scheduling an infrequent channel, with the extremely high transmission time frame shall be adapted rather than desired transmission time frame for data-frame w_i .

In case of failing to trace a channel with the given criteria, selection of the infrequent channel sets that has some kind of lower time frame that the desired time frame for the data-frame w_i , in order to aggregate the transmission time slots for the selected channels, which shall be greater than desired transmission time frame.

Also segments the data-frame w_i multiple data-frames as to each partition in the data-frame shall transmit by one of the channels, from the set of channels that are selected.

Also, if the spectrum access controller do not achieve the schedule under above criteria, channels with idle times are selected which could meet the criteria for transmission time frame w_i

In the case of idle time frame is not found sufficient, then the data-frames are segmented in to minimum number of data-frames, so as the new data-frames shall be transmitted using the minimum channels that are compatible with the idle time slots.

Also, in the instances where the spectrum access controllers fail to schedule channels using any of the above criterions, then the data-frame is buffered and in frequent intervals the attempts are made to schedule. Despite of such process, if the scheduling fails within the lifetime of data-frame, then such data-frames are dropped and acknowledgment to CR nodes are sent about failure.

Mathematical notations and the process flow algorithm for MCS-OSHF model has been depicted in the following section.

b) Pseudo representation of scheduling algorithm

MCH: Begin

1. Let mf_i be the control frame representing the data-frame w_i to be transmitted by spectrum access controller ap_j ,
2. $oc \leftarrow \phi$
   //representation of optimal channel initialized to null
3. $oc = selectOC(a\tau_{w_i}, db_{w_i}, etf_{w_i}, |w_i|, \{C\})$
   //finding the optimal channel and passing parameters are varying size data-frame arrival time $a\tau_{w_i}$, desired bandwidth db_{w_i} , expected transmission time frame etf_{w_i} , data-frame size $|w_i|$ and vector of channels available $\{C\}$
4. If ($oc \neq \phi$) Begin //optimal channel found for varying size data-frame w_i
5. channel oc scheduled tovarying size data-frame w_i
6. *Exit*
7. End // of condition in line 4
8. Else Begin //of condition in line 4
9. Set $ocl \leftarrow \phi$
   // ocl is the set of optimal channels initialized to null, which contains selected optimal channels to transmit multiple segments of data-frame w_i
10. Set $s(w_i) \leftarrow \phi$
    // $s(w_i)$ represents the set of data-frame segments formed from the varying size data-frame w_i that initialized with ϕ
11. $< o\ l, s(w_i) >= MCList(w_i, \{C\})$
    // finding the set of optimal channels to transmit data-frame segments of data-frame w_i
12. If $(ocl \neq \phi \,\&\, s(w_i) \neq \phi)$ Begin

13. For-each $ws \leftarrow s(w_i)$ & $oc \leftarrow ocl$ Begin
14. Schedule oc to ws
15. End //of iteration in line 13
16. Exit // since scheduling completed
17. End //of condition in line 12
18. Else Begin
19. $< ocl, s(w_i) >= SCHF(w_i, \{C\})$
20. If $(ocl \neq \phi \,\&\, s(w_i) \neq \phi)$ Begin
21. For-each $ws \leftarrow s(w_i)$ & $oc \leftarrow ocl$ Begin
22. Schedule oc to ws
23. End //of iteration in line 21
24. Exit // since scheduling completed
25. End // of condition in line 20
26. Varying size data-frame loss inevitable
27. End //of condition in line 18
28. End //of condition in line 8
29. End // of the function

c) *Pseudorepresentation of channel selection algorithm*

$selectOC(a\tau_{w_i}, db_{w_i}, etf_{w_i}, |w_i|, \{C\})$ Begin

1. $ec \leftarrow \phi$ // vector of eligible channels is set to ϕ
2. $oc \leftarrow \phi$ // resultant optimal channel set null initially
3. Foreach $c \leftarrow \{C\}$ begin
4. if $(itf_s(c) + \lambda) > (a\tau_{w_i} - \varphi)$ Begin //channel c is not idle by the arrival time of data-frame, here $itf_s(c)$ is the next idle frame start time of channel c, λ and φ are elapsed time thresholds respective to idle time frame start time and data-frame arrival time respectively.

a. *continue //to next iteration of line* 3

5. End // of the condition in line 4
6. Else Begin //of condition in line 4

b. $ec \leftarrow c$ // move channel c to vector ec

7. End //of condition in line 6
8. $ritf_{\min} \leftarrow \infty$ // represents minimal residual idle time frame set to ∞ initially
9. $rbw_{\min} \leftarrow \infty$ // represents minimal residual bandwidth set to ∞ initially
10. For-each $\{c \exists c \in ec\}$ begin

a. $ritf = ((itf_e(c) - itf_s(c)) - (ttf_{w_i} + \varphi)$

b. $rbw = bw_c - (db_{w_i} + \beta)$ // residual bandwidth observed for channel c to transmit data-frame w_i with desired bandwidth $(db_{w_i} + \beta)$, here β is elapsed threshold of the bandwidth desired.

c. $if\,(0 < ritf < ritf_m) \wedge (0 < rbw < rbw_m)$ begin

   i. $ritf_m \leftarrow ritf$
   ii. $rbw_m \leftarrow rbw$
   iii. $oc \leftarrow c$

d. End // of condition in line a

11. End //of iteration in line 10
12. Return oc
13. End //of the function

d) *Pseudo representation of data-frame segmenting and Multiple Channels selection Algorithm*

1. $MCList(w_i, \{C\})$:Begin
2. $ocl \leftarrow \phi$ //optimal channel list initialized with null
3. $s(w_i) \leftarrow \phi$ //varying size data-frame segment list initialized with null
4. For-each $c \leftarrow \{C\}$ begin
5. if $(itf_s(c) + \lambda) > (a\tau_{w_i} - \varphi)$ Begin //channel c is not idle by the arrival time of data-frame, here $itf_s(c)$ is the next idle frame start time of channel c, λ and φ are elapsed time thresholds respective to idle time frame start time and data-frame arrival time respectively.

a. continue //to next iteration of line 4

6. End // of the condition in line 5
7. Else Begin //of condition in line 5

b. $ec \leftarrow c$ // move channel c to vector ec

8. End //of condition in line 7
9. Sort ec in descending order of $|itf|$ // sorting the eligible channels in descending order of their idle time frame size.
10. For-each $\{c \exists c \in ec\}$ begin

a. $ocl \leftarrow c$

b. $s(w_i) \leftarrow w_i$

// w_i is the segment of the data-frame w_i such that $[(((itf_e(c) - itf_s(c)) - (ttf_{w_i} + \varphi)) > 0] \wedge [(bw_c - (db_{w_i} + \beta)) > 0]$

a. $w_i \leftarrow w_i - w_i$

11. $if\,(w_i \equiv \phi)$ Begin
12. Break // the loop in line 10
13. End //of the condition in line 11
14. Return $< ocl, s(w_i) >$
15. End // of the function

e) *Pseudo representation of data-frame segmenting and multiple channels with spectrum channel holesalgorithm*

1. $SCHF(w_i, \{C\})$:Begin
2. $ocl \leftarrow \phi$ // indicates optimal channels list for idle time usage, which initialized with null
3. $s(w_i) \leftarrow \phi$ //varying size data-frame segment list bsl initialized with null
4. Sort channels in ascending order of buffer time between data-frame arrival time and channel idle time frame start time.

The buffer time of the data-frame w_i under channel c can be measured as

$b_{w_i}(c_i) = (itf_s(c_i) + \lambda) - (a\tau_{w_i} + \varphi)$

5. For-each $c \leftarrow \{C\}$ begin

a. $ocl \leftarrow c$

b. $s(w_i) \leftarrow w_i$

// w_i is the segment of the data-frame w_i such that

$[(((itf_e(c) - itf_s(c)) - (ttf_{\square w_i} + \varphi)) > 0] \wedge$

$[(bw_c - (db_{\square w_i} + \beta)) > 0]$

c. $w_i \leftarrow w_i - \square w_i$
6. $if\,(w_i \equiv \phi)$ Begin
7. Break // the loop in line 5
8. End //of the condition in line 6
9. Return $< ocl, s(w_i) >$
10. End //of the function

Towards performing the channel scheduling, MCS-OSHF focus on tracking possible optimal channel (Sec 3.3), and in the instance of failure, attempts the further selection criteria like the minimal number of idle channels (3.4), and the process as detailed in the aforesaid section (3.5). Process of segmenting is carried out on the basis of demand, thus leading to minimal overhead. In the instances of MCS-OSHF failing to schedule any of the channels, the failure acknowledgment is communicated to CR nodes after dropping the data-frames.

IV. Experimental Setup and Empirical Analysis

Using the simulation study the performance of proposed model of MCS-OSHF is assessed in comparison to the benchmarking models like QoS-aware Channel Sensing Scheduling (QCSS) [16] and the other model of Novel Spectrum Scheduling Scheme (NSSS) [17]. Using the NS2 simulation methods, CR based wireless network is simulated and the metrics used in the simulation process is detailed in the following tabulation (table.1)

Table1: Metrics for Simulation

No of cognitive radio nodes as users	50
The range of Varying size data-frame generation threshold	32KB to 512KB
Number of spectrum access controllers	8
Usage of elapsed threshold values	0.05% of actual
Channels per spectrum access controller	16
Simulation time	12 minutes
Bandwidth Range	512MB to 1536MB

There is huge deviation in the varying size data-frames that are formed in the data size of 10GB to 25GB. In the range of 32kb to 512kb, there is variation in the data-frame size. In the comparison of model to QCSS [16] and NSSS [17], performance of OCA-UTI is assessed using QoS metrics – data-frame loss against transmission data - frame loads (see figure -1), and also the transmission throughput that is achieved in data frame load (see figure-2). Also the process overhead that is observed in the transmission data-frame load (see figure-3) is also depicted.

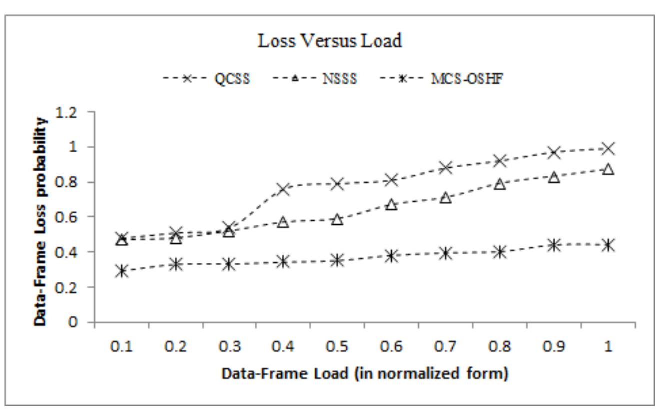

Figure 1: Varying size data-frame Loss vs. Varying size data-frame Load

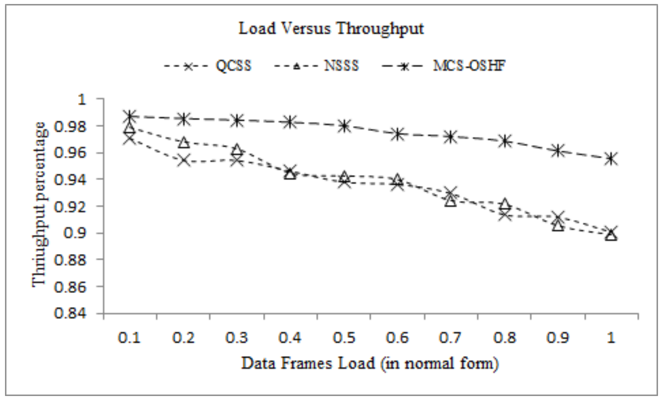

Figure 2: Throughput vs. varying size data-frame Load

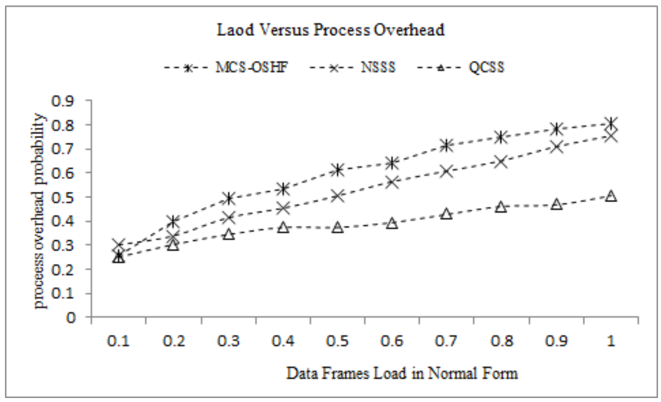

Figure 3: varying size data-frame load vs. Process overhead

The quantum of data-frame loss in correlation to data-frame load is depicted in Figure.1 and it is imperative that the data-frame load is normalized amid the value of 0 and 1 that depicts the number of data-frames per second. The study reflects that MCS-OSHF shall certainly reduce the data-frame loss compared to the other models opted for simulation. (See Figure-1). However, in terms of multiple channel selection, and the process of data-frame segmentation too, MCS-OSHF still leads the minor process overhead rather than the other two models considered in the study. (See figure 3).For achieving the maximum throughput using the minimal data-frame loss, such mechanism is certainly tolerable.

V. Conclusion

MCS-OSHF (Multichannel scheduling with spectrum hole filling) model is focused on improving the channel scheduling protocol for CR based wireless networks. The emphasis in the model is about maximizing optimal channel allocation for better throughput and also minimal transmission loss of data-frames. Using the hierarchical approach which facilitates the optimal idle channel, using a specific process, in terms of following the order in the hierarchy the process of data-frames scheduling is carried out. From the detailed experimental studies that are carried out in comparison with other such models like NSSS and QCSSS, the inputs from the study depict much more efficient performance from the proposed model compared to the other two models. In terms of futuristic study or expansion of the model, emphasis shall be on minimize the process overhead, and in the other way, model could be developed for optimal channels allocation by preempting the allotted channels, which could support in rescheduling towards achieving stable throughput and minimal loss of data-frames in CR based wireless networks.

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