Journal of Network Communications and Emerging Technologies (JNCET)
Volume 12, Issue 4, April (2022)

Developing an Algorithm to Reduce Interference for Coexisting "TV White Space" Users with Performance Enhancement and Making Handoff Decisions for End Users

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ABSTRACT

TV White Space is the unutilized spectrum that TV channels use to prevent interference amongst them. This unused spectrum can be used to provide broadband internet to secondary users (SU) if they don't cause interference to primary users (PU) that are TV channels. The resource should be used by SUs without interfering with one another for effective utilization of this spectrum. Therefore, an interference management algorithm is introduced in this paper for solving interference related issues between the SUs of TV White Space (TVWS). This is accomplished in three simple steps. In the first step, a group of SUs are identified that will not interfere with each other, second step will allocate distinct channels to each SUs group and finally the performance of each SU will be improved with the help of third step. The complexities of first and third stages have been minimized compared to the existing algorithms. Handoff decisions for end-users can be taken utilizing channel assignment matrices. The proposed scheme achieves better channel assignment with less complexity.

Index Terms – TV White Space, Channel Assignment, Cognitive Radio, Heterogeneous Networks, Channel Assignment Matrix.

1. INTRODUCTION

While designing a wireless system, it is important to take spectrum scarcity into account. We need to use the spectrum that is currently available for the available networks in a sharing process and at the same time it is important to increase the throughput delivered to the serving users [1].Cognitive radio technology is utilized to make the best use of the limited spectrum [2].Wireless sensor networks with cognitive radio capabilities can lessen the issue of spectrum scarcity [3].The primary task of cognitive radio networks is detecting the presence or absence of the primary users [4]. Television whitespace (TVWS) is one of the spectra that are underutilized. It comprises of Ultrahigh frequency (UHF) or Very High frequency (VHF) spectrum band which can be widely used to remove bandwidth problems. But these frequencies have been either liberated or are unusable due to regional prohibitions [5]. Therefore, Federal Communications Commission (FCC) has decided to divide wireless users into two groups: licensed to use the TV frequency bands (Primary users: PUs), unlicensed users (Secondary users: SUs). These Sus are capable of sensing the unused TV spectrum and can request the PUs to use them [6–8]. Any SUs capable of using TVWS (802.11af) can make excellent use of TVWS by coexisting without causing interference. As a result, a coexistence mechanism must be developed to allow heterogeneous networks to cohabit while minimizing interference. In the UK, the UHF TV bands extend from 470 MHz to 790 MHz [9]. This band is currently used for Digital Terrestrial TV (DTT) and Program Making and Special Events (PMSE). DTT spectrum allocation is static but PMSE is allocated as per requirement in different locations based on activity. From the figure 1 below we can see BTT, PMSE channels coexist between the frequency band 470 Hz to 790 Hz. To avoid internal interference many spectra are remained unused which increase the cost of the system. The usage of TVWS in an efficient way can reduce the wastage of the spectrum.

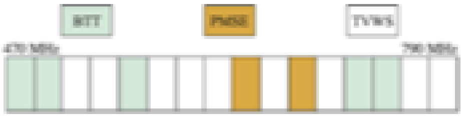

Figure 1 Use of UHF spectrum in a specific location

The TVWS spectrum band has sparked interest in the Dynamic Spectrum Access (DSA) community because of its excellent transmission characteristics [10, 11]. In a TVWS network, aggregate interference from numerous users, including both co-channel and adjacent channel interference from different channels, must be taken into account while allocating spectrum [12]. A coexistence management system over TVWS between multiple networks is established in our proposed architecture. The overall contribution of this paper includes:

•A new channel assignment algorithm is being developed with less complexities than the current one to avoid SUs interference to produce the same accurate result. As well as networks performance can be improved with the proposed algorithm.

•Some channel assignment matrices have been developed to assist end users in making handoff decisions while migrating from one network to another that is part of the TVWS allocation.

•The proposed scheme's throughput is compared to that of other existing four techniques using five TVWS channels and it is found that the proposed scheme is comparable with others.

The rest of the paper is segmented as follows. Section 2. discusses about related works. Section 3. shows overall system design. Section 4. provides a detailed description of the proposed methodology. Section 5 shows complexity analysis. Section 6 and 7 shows performance evaluation and simulation result. Section 8 presents conclusion.

2. RELATED WORK

In [13] they concentrated on secondary user assignment in cloud computing and voids detection in the radio spectrum. Non-interfering femtocells can operate with macro users on the same channel without interfering. A busy signal-based system has been developed in [14] which is proposed for the coexistence between two types of networks: IEEE 802.22 and 802.11af. A new combined power and bandwidth allocation approach was presented for TVWS in [15]. By optimizing both power and bandwidth allocation, their technique maximizes the amount of SUs of TVWS. In [16], they evaluated the IEEE 802.11 WLAN coexistence system and long-term evolution (LTE) and proposed a coexistence gap method. Coexistence interference between several heterogeneous networks is described in [17]. They created an analytical framework and computationally efficient technique for determining the best channel selection. In [18], categorization of the strategy that addresses TVWS spectrum in as well as a diversified coexistence of secondary networks that uses TVWS is proposed. In [19], they suggested two coexistence management methods for working on TVWS. However, the complexity of the situation is the source of the issue. It has the potential to improve performance at the cost of time and space.

3. SYSTEM DESIGN

Figure 2 Coexistence of PUs and SUs with the help of Database (GLDB)

Some regulations have been enforced worldwide to use geo-location database for the protection of PUs. In figure 2 a SU uses GLDB to determine the set of secondary frequency channels. This frequency channels can be used in a given area and at any given time [20]. For this reason, a GLDB is assigned to permit devices to access unoccupied bandwidth in a given area. This GLDB registers with SUs [21]. The SUs receives authentication from the database, allowing it to access the database. After then, the devices search the database for accessible channels based on its location. After receiving signals from SUs, the GLDB looks at area coordinates, device type, height of SUs and occupied channels for the PUs. The GLDB will then combine this data with the attributes of all nearby TV transmitters, such as antenna height, transmit power, and frequency of operation, to provide a list of accessible TVWS channels that the SU can use. The available TVWS channels are then assigned among the SUs in such a way that no two SUs can share the same TV channel. Therefore, these SUs can use the TVWS bandwidth without causing interference to the PUs [22, 23].

4. METHODOLOGY

Our main objective is to develop an interference free environment among the networks to reduce performance degradation. For this purpose, we have considered a graph G (figure 3) where the interference effect can be observed between the neighboring networks. Here, each vertex represents a network and connection or edge between the nodes is given based on the signal detection. If a node can detect the signal of another node, then it can be considered that they are adjacent.

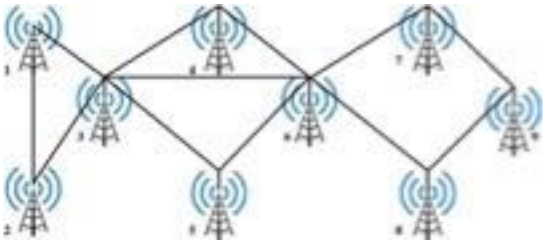

Figure 3 Network Topology

For example, from the figure 3, we can see that node 1 is adjacent with node 2 and 3, node 3 is adjacent with node 4,5 and 6, node 9 is adjacent with 7 and 8. In this way, we can consider all other adjacency cases. We have developed our system by using three steps.

4.1 Step 1: Subset Construction

The main purpose of this step is to develop subsets of networks. The subsets are developed in such a way that the networks in the subset can coexist with each other in the same bandwidth channel without creating interference. Let, P (i) denote the neighbors of network i. The neighbors of it are divided into subsets. These subsets can be reassigned with the same bandwidth channel. For example, we can consider node 3. The neighbors of node 3 will be divided into two subsets. First set P1(3) = {1,4,5} and second set P2(3) = {2,6}. The networks in each subset can use the bandwidth channel without causing interference.

```
1.  Enter the number of nodes
2.  Enter the number of edges
3.  Create a 2D array $E[i][j]$
4.  for $i=0$ to $N$ do
        $c[i]=1$
5.  for $j=0$ to $M$ do
        $q=1$
        if $c[E[j][0]] == c[E[j][1]]$ then
            if $c[E[j][1]] != q$ then
                $c[E[j][1]] = q$
            else
                $c[E[j][1]] = q + 1$
                $q++$
```

Algorithm 1 Subset Construction

In algorithm 1, first we take the number of nodes and number of edges of the corresponding graph as input. A two-dimensional array E[i][j] is used for keeping the information of adjacency nodes. Then we assign the color value of all the nodes to 1 by using an array c[i]. Here, N is the total number of nodes.

The loop in line 5 checks adjacency between the edges and the number of edges is declared to M. An integer q is declared to 1 which works as a flag value in our algorithm. Then, we check color value of the two adjacent nodes. In case of the same color value, we have changed the color value of one adjacent node to another value.

4.2 Step 2: Channel Assignment between Subsets

In this step, the total available bandwidth is distributed among the subsets of networks. Before distribution, priority is set to the subsets based on the requirement of bandwidth for each subset. When all of the available bandwidth has been used up or all of the subsets have been allotted bandwidth for at least once, the operation is come to a halt.

```
Sort the subsets based on priority
$L$=available TVWS bandwidth
$m$= no. of sets
$p=0$
for $i=0$ to $m - 1$ do
    if $p< L$ then
        Assign bandwidth to that set Update the value for $p$
    else
        No bandwidth will be allocated
```

Algorithm 2 Channel Assignment

The algorithm 2 is used to sort the subsets based on their priority and assign channels. This is a fixed channel assignment process. Here, L is an integer which is used to contain the total available bandwidth. m is another integer to set the number of subsets of networks present in our system. p is also an integer whose initial value is set 0 and can be used as a flag value. The loop used in the algorithm is used to assign bandwidth to the subsets one by one. After each assignment the value for p will be updated. The loop will continue until all of the available bandwidth has been used up or until each subset has been allotted with a single bandwidth assignment.

4.3 Step 3: Channel Reassignment

After performing algorithm 2, based on the available bandwidth step 3 is used to assign bandwidth among the subsets again. This step is used to increase performance of each subset. Here, maximum usage of bandwidth will be ensured. For giving priority to the subsets, here we consider the number of networks in each subset. Therefore, a sorting technique is used here to sort these subsets according to the number of networks in each subset. The maximum priority will be given to the subset which has the maximum number of networks. Following this rule, the priority will be given to the other subsets.

```
Count the number of networks in each subset
Sort the subsets based on the number of networks in each
while $p< L$ do
    for $i=0$ to $m - 1$ do
        if $p<L$ then
            Assign bandwidth to that set
            Update the value for $p$
```

In algorithm 3, first we count the number of networks in each subset. By using a while loop we perform this distribution. This procedure will be repeated until all of the available TVWS bandwidth has been consumed.

5. COMPLEXITY ANALYSIS

Table 1 shows the complexity analysis of our system with the existing systems. The complexity of algorithm 1 is O(m) where m is the total number of edges between the networks. In [22], this complexity is O(N + E) where, N is the total number of nodes and E is the total number of edges. In [19], this complexity is O(N3). Here, N is the total number of nodes of networks considered in the graph. They get the information about network adjacency from the spectrum broker. We store this information as a 2D array in our system. The complexity is exponential here, where as it is linear in our suggested method. The complexity of algorithm 2 is O(mlogm). The number of sets is defined by m. This is due to the fact that sorting operation of these sets takes mlogm time and channel assignment can only be done for m sets. As a result, complexity is (mlogm + m), which is represented as mlogm. The complexity in [19] is O(NC2). The total number of networks is N, and the total number of bandwidth slots available is C. O(mlogm) time is clearly superior to O(NC2) time. The complexity of algorithm 3 is O(m + k + L). The sorting technique requires m + k time and L is the total bandwidth which is available after performing the second algorithm. Here, m is the total number of subsets, k is an integer that is in a range between 1 to the highest number of networks in the considered set. For our considered graph, the value of k is between 1 to 5. Because subset 1 has a maximum of 5 networks. This algorithm complexity is solely dependent on output of algorithm 1 in our system. If we consider a strongly connected graph, then it is the worst case for the first algorithm. Because, all the sets will contain only one node. So, the value of k will be 1 to 1 which can be considered as 1. On the other hand, if we consider the best case for the first algorithm, which means all the nodes are isolated. Then, there will be only one set which will contain all the nodes. So, m = 1 and k will be some multiple of m. As TVWS is a limited resource and it can be available within a fixed region, there is a very low possibility that k's value will be high. Considering k as a constant and near to m, we can conclude that the complexity of the third algorithm is O(m + L). In [22], this complexity is O(nlogn + limit). Here, n denotes the number of sets of networks, and limit denotes the remaining bandwidth after Algorithm 2 is completed. The complexity of this algorithm in [19] is O(NA). After conducting algorithm 2, N signifies the total number of networks, and A denotes the remaining unassigned bandwidth.

Table 1 Complexity Analysis of our proposed methodology with different TVWS Algorithm

Algorithm	Proposed Methodology	[19]	[22]
Subset Construction	*O(m)*	*O(N + E)*	$O(N^3)$
Channel Assignment	*O(mlogm)*	*O(nlogn)*	$O(NC^2)$
Channel Reassignment	*O(m + L)*	*O(nlogn + limit)*	*O(NA)*

6. PERFORMANCE ANALYSIS

Here, we are considering a network scenario of M secondary users who are competing to access N TV white space spectrum channels, P primary users and Q is the total number of channels. This spectrum relation can be represented by the following equations:

$$Q = \sum_{p=1}^{P} PUD + \sum_{m=1}^{M} SUD$$

Legend: PUD-Primary User Demand; SUD- Secondary User Demand

Let us consider, $W=\{w(m,n)|w(m,n)\in\{0,1\}\}MXN$ the availability of channel as a matrix and the interference constraint $I=\{i(m,n,p)|i(m,n,p)\in\{0,1\}\}MXNXP$. The locations of the secondary users and the available free channel are not changeable. Let us consider, another matrix called channel assignment matrix , $C=\{C(m,n)|i(m,n)\in\{0,1\}\}MXN$. From the expression we can see that, c(m,n)=1 if channel n is entirely allotted to m secondary user or c(m,n)=0 if channel n is not fully allocated to m secondary user; otherwise, the value will be between 0 and 1 . Here, c must keep track of the interference constraint matrix and the channel availability matrix in this case.

7. SIMULATION RESULT

For simulation, we have used the CodeBlocks IDE to run the simulations, and our programming language is C++. The number of vertices, the number of edges between vertices, and the adjacency information between the vertices are all used as inputs. For describing our simulation result, we have considered a heterogeneous graph which is pictured in Figure 3. There are 9 heterogeneous networks in our considered graph with an unspecified number of users who are located within its range. In our considered graph, there are a total of 9 nodes and 12 edges.Table 2 shows the color values of all the nodes after performing algorithm 1. Here, Ci denotes the corresponding color number for node i. Based on the colors mentioned in the table, we can create three subsets. From the table we can see, color 1 is assigned to subset, S1 = {1, 4, 5, 7, 8}, color 2 is assigned to subset S2 = {2, 6, 9} and color 3 is assigned to subset S3 = {3}. Here, subset S1 has the maximum 5 networks, subset S2 has 3 networks and subset S3 has only 1 network. The networks in each subset can coexist with each other without causing interference which is the key feature for distributing the available TVWS bandwidth.

Table 2 Complexity Analysis of our proposed methodology with different TVWS Algorithm

Initial Color Value	Adjacent Nodes	Color Values of Each Node	No of Colors Used	Subset of Nodes Based on Colors
	1, 2	$C_1 = 1, C_2 = 2$		
	1, 3	$C_1 = 1, C_3 = 2$		

$C_1 = 1$	2, 3	$C_1 = 2, C_3 = 3$	3	Color 1 is assigned to nodes {1,4,5,7,8} Color 2 is assigned to nodes {2,6,9}. *Color 3 is assigned to node {3}*
$C_2 = 1$	3, 4	$C_3 = 3, C_4 = 1$		
$C_3 = 1$	3, 5	$C_3 = 3, C_5 = 1$		
$C_4 = 1$	3, 6	$C_3 = 3, C_6 = 1$		
$C_5 = 1$	4, 6	$C_4 = 1, C_6 = 2$		
$C_6 = 1$	5, 6	$C_5 = 1, C_6 = 2$		
$C_7 = 1$	6, 7	$C_6 = 2, C_7 = 1$		
$C_8 = 1$	6, 8	$C_6 = 2, C_8 = 1$		
$C_9 = 1$	7, 9	$C_7 = 1, C_9 = 2$		
	8, 9	$C_8 = 1, C_9 = 2$		

Following the discovery of these subsets of networks with the same color scheme, “channel assignment” and “channel reassignment” are used. Based on the overall bandwidth availability, three scenarios can be shown.

7.1 Case I

If there isn’t enough bandwidth, none of the subsets will be able to get the bandwidth they require to start their operation under TVWS. Assuming that, the total available TV white space bandwidth is 10 MHz, with N channels and S1’s requirement is 7 MHz, S2’s requirement is 3 MHz and S3’s requirement is 2 MHz. Priority will be given to S1 in the second algorithm’s channel assignment because its requirement is the highest. As a result, it will receive the total 7 MHz it requires from the available TVWS. For simplifying presentation, let N = 5 and each channel consists of 2 MHz. Then channel assignment matrix for Case-I can be represented as:

$$C_{5\times3} = \begin{bmatrix} S_1: & 1 & 1 & 1 & 0.5 & 0 \\ S_2: & 0 & 0 & 0 & 0.5 & 1 \\ S_3: & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Here, columns represent the white space channel which are assigned to utilize this unused spectrum and rows represent the set of secondary users which are ordered based on their priority. The percentage of channel assignment for different sets can be calculated from the above matrix. Let, w(I,j)∈[0,1] represents the percentage of a spectrum channel j assigned to network set i. First three channel is fully assigned to S1 but fourth channel is partially assigned to it. The total percentage of spectrum channel assigned S1 is w(1,3.5)= ((3.5×2))/10=0.70 or 70%. Similarly, we can calculate w(2,3.5)= ((1.5×2))/10=0.30 or 30% and w(3,0)= ((0×2))/10=0 or 0%.

7.2 Case II

If the bandwidth is insufficient, then some sets will only receive a portion of the bandwidth they require. Assume that the total available TVWS bandwidth is 15 MHz, with N channels, and that S1,S2 and S3 have bandwidth requirements of 7 MHz, 5 MHz, and 4 MHz, respectively. Let again, N = 5 and each channel consists of 3 MHz. The percentage of channel assignment to S1 is 46.6% ,S2 is 33.2% and S3 is 20%. There is no way to improve the network performance in Case-II because of bandwidth scarcity. So, channel assignment matrix for case II can be represented as:

$$C_{5\times3} = \begin{bmatrix} S_1: & 1 & 1 & 0.33 & 0 & 0 \\ S_2: & 0 & 0 & 0.66 & 1 & 0 \\ S_3: & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

7.3 Case III

If the bandwidth is sufficient, all sets will have access to it and will be able to improve their performance. Assuming that the total available bandwidth is 50 MHz, and the set S1,S2 and S3 requirements are 7 MHz, 6 MHz, and 5 MHz, respectively. Here, all sets achieved fractional assignment of channel. The percentage of channel assignment to S1 14%, S2 is 12% and S3 is 10%.There is still 32 MHz bandwidth left after channel assignment. As a result, channel reassignment can be used to increase performance. In this situation, the set with the greatest number of networks will be given first consideration. As a result, after completing algorithm 2, it will allocate bandwidth from the remaining bandwidth according to its requirements. Recalculating the percentage of channel assignment to theses sets for S1 is 28%, for S2 is 24% and for S3 is 12%.

$$C_{5\times 3} = \begin{bmatrix} S_1: & 0 & 0.2 & 0.5 & 0.4 & 0.3 \\ S_2: & 0 & 0 & 0.5 & 0.1 & 0.6 \\ S_3: & 0 & 0 & 0 & 0.5 & 0.1 \end{bmatrix}$$

For describing the significance of these matrices and corresponding channel assignment percentage to a set, we need to the consider two types of devices which are recognized by FCC. Mode-II device can geolocate itself and communicate with the regulatory database to obtain operational parameters and Mode-I for functioning, a slave device should be under the control of a master device. TVWS database provides TVWS bandwidth to mode-II device based on geolocation. After assigning corresponding channel to mode-II device, it provides service to mode-I device (802.11af). Finally, mode-I device helps end users to utilize these unused TVWS bandwidth. Our derived matrices and corresponding percentages of each subset of networks helps us to take decision about handoff. This can be termed as “spectrum handoff” for end users [24]. For example, case-I situation can be considered. S1 has gained the highest amount bandwidth and as a result its percentage of bandwidth gain is high. Then, subset S2 is assigned with the remaining bandwidth. Suppose, an end user enters a range where the S1 and S2 signals can be found. The end user must choose which bandwidth to use based on the percentage of available bandwidth. As a result, this end user reacts to the S1’s signal.

We compare our coexistence approach for diverse networks with the greedy channel assignment system in our simulation. This greedy system is a haphazard system which requires carrier aggregation and in baseline channel allocation scheme each network chooses one of the available TVWS channels independently. This decision is made based on the network access technology used. A network topology with 7 nodes is considered in the current [20] channel assignment mechanism. All users must be able to send and receive packets. They increase bandwidth through channel assignment augmentation. Spectrum allotment is a fixed assignment in this case. After a 24-hour channel query from the database, channel allocation may be adjusted [25].

The average throughput performance of our proposed scheme is then compared to that of greedy, baseline, and existing channel assignment schemes which is shown in chart 1. We compare the performance of various schemes for the same topology. In the greedy channel selection, the performance is very poor because of large interference and noise power. In the existing channel assignment scheme, the throughput is improved. Their scheme also gives support to channel aggregation properties based on more channels available. In our pro- posed scheme, bandwidth will be divided among the networks in such a way so that no interference will occur. When five channels are available, our methodology achieves near 14 MHz and 16 MHz average throughput gain without and with augmentation. However, in the existing scheme, the average throughput is around 6 MHz for the both with and without augmentation.

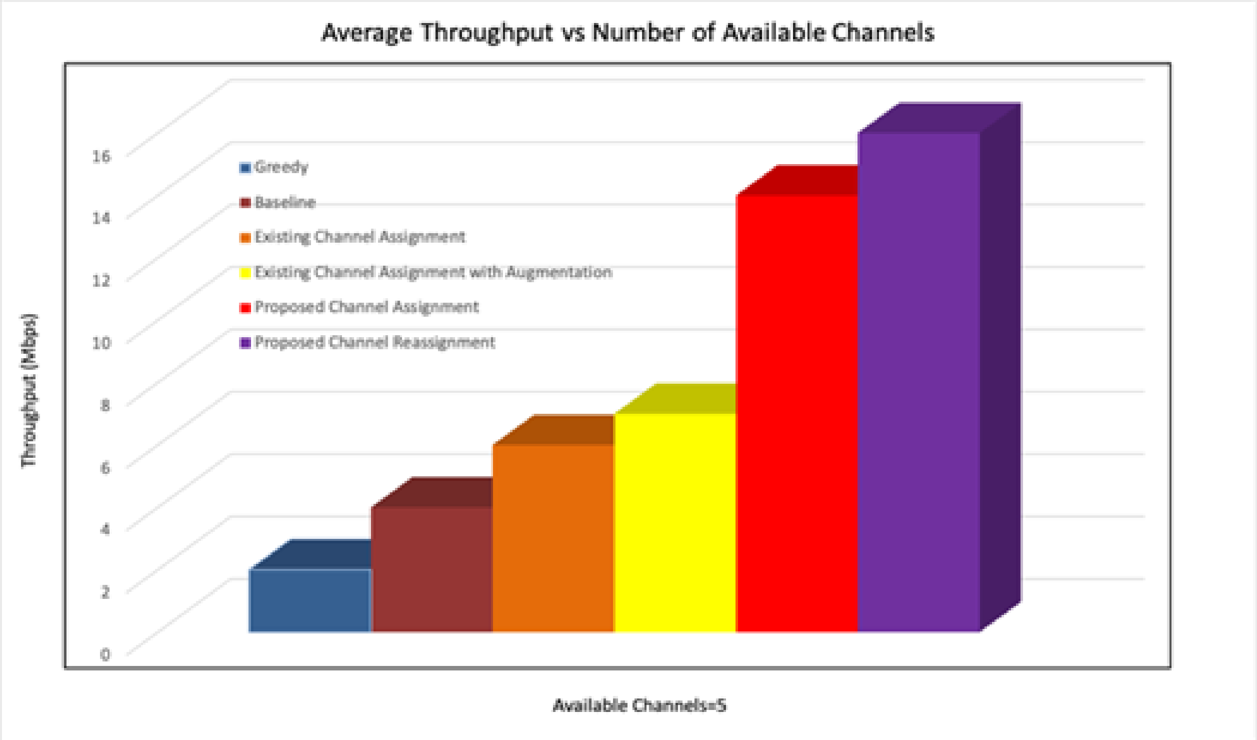

Chart -1: Average throughput of simulations considering five channels available

8. CONCLUSION

In this paper, we proposed a coexistence management approach for heterogeneous networks that share the TVWS in order to limit interference among the networks. It achieves a significant performance gain as well as less complexities than the existing work. These algorithms can be implemented at the central database systems that is used for TVWS. Our system, ensures a fair allocation of channels to these active networks. Moreover, percentage of channel allocation to the networks can take the decision of a handoff operation. The more the channels are available it will give the best performance.

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