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SASMS: Spectrum Allocation Scheme under Multi-transceiver Structure in CogMesh Network

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***Abstract*—A novel spectrum allocation scheme in a centralized scenario with the support of multi-transceiver structure of CMR (cognitive mesh router) in CogMesh network is proposed. Traditional MR (mesh router) in WMN (wireless mesh network) is no longer met the demand of the development of wireless communication in the field of dynamically utilizing vacant spectrum holes. Therefore, MR is reconstructed into CMR with a multi-transceiver structure. CMR inherits some good merits from MR and add some special function, such as learning, aggregation, allocation and etc to better adapt to dynamic spectrum scenario. In the paper, CMR can use the proposed SASMS to allocate vacant spectrum bands for SMCs (secondary mesh client), which access the CMR with one hop. Besides, the scheme is designed according to the different spectrum scenario and constraint by the average minimum back-off delay of each SMC to guarantee the relatively small end-to-end delay and the equilibrium of each transceiver. From the simulation, the outstanding performance gain will be got in the term of decreasing SMC's back-off delay through a theoretical approach and the Qualnet.**

***Index Terms*—CogMesh; CMR; SMC; back-off delay; spectrum allocation; SASMS.**

I. Introduction

CogMesh network[1,2,3,4], as a mode of CRN (cognitive radio network), aims to enable a uniform service platform by seamlessly integrating heterogeneous wireless networks through the utilization of advanced cognitive and adaptive technologies under a mesh structure[3]. It can enable SMCs to effectively sense and dynamically utilize some unlicensed spectrum bands that PUs (primary user) doesn't need. CogMesh network can significantly improve the capacity of utilizing the spectrum through CR technology and supply maintenance for client accessing to the network. Above all, CogMesh network can simultaneously support heterogeneous networks, such as Wi-Fi, WiMAX, Wi-media, Cellular network, Blue tooth, WSN[5] .est. The most important advantage is that it is a well-knit with current wireless technology.

Indeed, we familiar with WMN (wireless mesh network) for its mesh structure. The core of mesh structure is its special topology, which is centralized within a BSS and distributed among the BSSs, or in the other word, distributed within a DS (distributed system), which is the backbone network of WMN comprised of multiple MRs.

CogMesh network inherits some merits from WMN, such as scalability, heterogeneity and etc. However, there are still some substantial differences between the both.

Difference of clients. In WMN, the difference among nodes is the functionality, such as portal node, AP node, MC (mesh client) and etc. In CogMesh network, the differences among nodes are not only in the above aspects, but also in the possession of spectrum. MC and MR (mesh router) should be called as SMC and CMR for the yielding to the PU (primary user) when it comes. Moreover, SMC can't yield any interference to PU according to spectrum etiquette. From an application perspective, CR allows a single radio to provide a wide variety of functions, acting as a cell phone, broadcast receiver, GPS receiver, wireless data terminal, etc.[8] Meanwhile, CMR is also a management module, which is responsible for monitor and adjust the state of network. The functionality of SMC and CMR is undergoing an profound changes.

Uniform control plane. CogMesh network is a network which applies uniform control plane under mesh structure. SMC equips with spectrum-agile radio, applies with CR technology, and switches vertically among different networks. CMR also equips with spectrum-agile radio to supply multiple available channels for multiple SMCs. From this perspective, we believe that CMR will have a more complex structure to fulfill the target. In WMN, it doesn't allow different nodes in different networks communicate directly with each other. However, it needs the MR's coordination and forwardness. For example, in WMN, broadly speaking, it is impossible for a cell phone in cellular network communicates with a sensor node in WSN (wireless sensor network). However, in CogMesh network, such talk will be built up due to the multi-functionality of SMC and the CMR.

Revolution of protocol stack. In WMN, all the nodes are running the layer-based protocol. Though the application of cross layer design can significantly improve the efficiency of the network, it can not meet the demand of CogMesh network any more. In CogMesh, a kind of context-aware engine along with protocol stack, which can be traditional protocol stack or reconfigurable stack, is proposed. Meanwhile, the design of CogMesh network must be the combination of loosely-coupled among the heterogeneous networks and closely-coupled within a specific network. It guarantees the CogMesh to fully adapt or predict the change of dynamic

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scenario.

Challenges of spectrum management. WMN adopts a fixed spectrum allocation scheme, which is simple in management. The question of it is, if a WLAN client moves out of the network covering range and lack the forward of the other same nodes, it will immediately become blind. In CogMesh network, such kind of problem will be solved easily due to dynamically utilizing the spectrum band and the multiple functionality of each SMC.

The main and fundamental reason of the above differences is the way of utilizing the spectrum. Such difference changes the structure and functionality of node in CogMesh network. There are two kinds of node in CogMesh network: SMC and CMR. Most of SMCs are mobile while CMRs are stationary with sufficient power supply. CMR plays a significant role of offering service for multiple networks and controlling the state of the whole network. Moreover, it doesn't constrained by the power, processing capacity and volume. Therefore, the structure and its functionality are the significance of the paper.

With the support of the CMR, we focus on the centralized scenario and primarily consider a spectrum allocation problem with the constraint with end-to-end delay time. Facing the problem, SASMS algorithm is proposed.

The structure of the paper is shown as follow: we first introduce the merits and the status quo of CogMesh and key points of the paper. We then illustrate the motivation of the paper and then introduce the metrics of our network scenario and spectrum allocation method. Next, we specifically introduce the function of CMR and SMC and spectrum allocation scheme. We then give our allocation example and simulation analysis. Finally, we summarize the paper.

II. Motivation

In CogMesh network, spectrum is under change. [9] classified the changing spectrum into 3 types: static, dynamic and opportunistic (highly dynamic). The available spectrum bands that each SMC sensed is different from each other. The spectrum heterogeneity contains more than one available spectrum band. However, in most circumstances, each SMC can only tune to only one channel. Such allocation is indeed an uneconomic approach. If we enable a node to equip with a multi-transceiver structure, the left channel can also be reserved to meet the dynamic spectrum scenario. Moreover, in dynamic spectrum scenario, practically, the highly dynamic spectrum environment requires per packet transmission solutions since a channel may probably not be utilized for whole flow duration. Therefore, in such cases inefficiency of handling changing spectrum bands will lead to link failure and network clogging. Therefore, packet transmission duration must shorter than the time duration of the changing spectrum. Excluding the spectrum sensing period, the time duration is comprised of three parts: transmission delay, propagation delay and backoff delay. The transmission time is determined by packet size. The propagation time is determined by propagation environment. They are relatively smaller parts compared with backoff delay.

To our common sense, clients which failed to compete for channel must back-off for the sake of protecting the successful data transmission of their own and others'. Furthermore, back-off will reduce the chance for clients to evenly utilize the channel and increase the delay. For a system using EB-M back-off scheme, a packet will be dropped beyond M (e.g. M=6) attempts. Meanwhile, [6] proved the decreasing of single node's throughput while the nodes' density increasing, no matter how the channel will be split into sub-channels.

Delay is an important metric about the QoS of different traffic. In some delay-sensitive traffic, it needs the successive transmission with non-stop. If the channel the traffic utilized is not available during the transmission, the node must initiate another round of sensing. Time from hang up to retransmission in another channel is the wasted time. The fact that dynamic access with artificial intelligence is under research can't be deny. However, it needs a large amount of statistical information and *priori* information.

To not use all the available channels is equivalent to not using the entire available spectrum, which in turn is equivalent to artificially limiting the achievable bandwidth[7]. That is to say, more different channels should be used simultaneously to fully explore the spectrum. However, SMC is exclusive in using spectrum, while to extensively using the spectrum requires enough active SMCs. Therefore, how to make a balance between the above two aspects is our main task in the paper.

Above all, the question will be converted to spectrum allocation scheme designing problem running in CMR under dynamic spectrum scenario. We consider this problem from both hardware and software perspectives. First, we believe that there exists two SMCs can make traffic simultaneously through using two different bands even they are in interference range of each other. Therefore, a multi-transceiver structure of CMR is proposed. Each transceiver operates on different frequency band from one to another. These frequency bands are allocated by spectrum

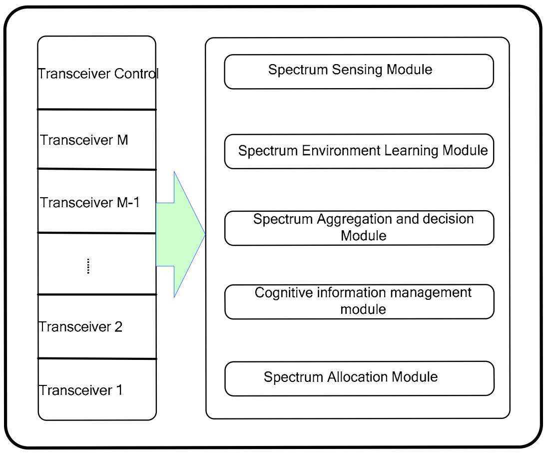

Figure.1 CMR structure

allocation module in CMR. Meanwhile, each transceiver enables to sustain different data rate and different power level. Second, it is an NP-complete problem for CMR to select proper channel for itself and SMC from all the available frequency bands. Many unavoidable disadvantages, if we choose to solve it in ergodic algorithm, are hard to adapt the dynamic spectrum environment. Therefore, the approach we choose to solve the problem requires quicker convergence and smaller computations. SASMS is proposed to adapt the changing spectrum scenario.

III. Design and Implementation of SASMS

A. CMR structure

SASMS assumes a CCC (common control channel) to intersect the controlling messages with SMCs and other CMR. Based on the above analysis, CMR can be multi-transceiver structure. We assume M+2 transceivers in CMR. One of them is specific for CCC. The left M+1 transceivers are spectrum-agile radio. There is still a specific transceiver of the left which should link with other CMR to compose the backbone network.

CMR keeps its original AP (access point) function, which is responsible for offering service and linking backbone network. The special functionality of CMR is not only the multi-transceiver structure but also the five main modules mentioned before, which suits for CogMesh network. There are spectrum sensing module, spectrum learning module, spectrum aggregation and decision module, cognitive information management module, spectrum allocation module. The enrichment of these modules will greatly pave the way of utilizing spectrum and enhancing the performance of CogMesh network.

- ***Spectrum sensing module.*** Spectrum sensing module is the fundamentals of CMR. The sensing ability decides which channel is free or not. Meanwhile, the channels that spectrum sensing module sensed is different from each other in central frequency, bandwidth, SNR, interference and etc.
- ***Spectrum aggregation module.*** It will recertify or modify the sensing information from SMC within its covering range. Providing the most reliable sensing result is the primary target.
- ***Spectrum environment learning module.*** The module should incorporate history and *priori* information and current sensing result to adaptively decide or even to predict which channel to use, when to use and how long it can be used. Moreover, it has the power to tell the level of spectrum environment: static or dynamic.
- ***Cognitive information management module.*** The module charges for storage and inquiry of cognitive information. It is a huge data base of real time information of dynamic and historic spectrum environment.
- ***Spectrum allocation module.*** Allocating the decided spectrum band to each transceiver and SMC is the main task. This module works on CCC. It will intersect the real-time information with SMCs.

In the paper, CMR and SMC intersect control messages with each other on the *M+1*th transceiver, which operates on CCC (common control channel). Transceivers 1 to M in CMR are responsible for communicating with SMCs. The *M+2*th transceiver is proprietary for communicating among CMRs that doesn't be considered in the paper.

CMR keeps a main stack which stores data from all the transceivers and M+2 stacks which store data to M+2 transceivers. Data from any transceiver will be directly moved into main stack for schedule. Then, CMR forwards traffic data to the destination through its operating transceiver.

SASMS is actually a scheduling scheme beyond more than one single transceiver. We believe that in each transceiver there are multiple choices for its own protocol.

B. Network Model

We consider a centralized scenario with one CMR and N SMCs. K available channels can be used. Each SMC accesses the CMR with one-hop. Several PUs are located randomly. They have channels available different from one to another. Any SMC which locates within the covering range of PU can't use the channel that the specific PU operates on according to the spectrum sensing result.

Let $U = \{u_1, u_2, \cdots, u_i, \cdots u_N\}$ denotes the active SMC set. SOP^i_{SMC} denotes the spectrum sensing result of the ith SMC. The terms in SOP^i_{SMC} is different from one to another, which determined by the SMC's sensing result. SMC can offer dedicated sensing result. Therefore, CMR will get comprehensive spectrum sensing result of each SMC after they upload their own SOP sets.

The target of SASMS is to deduce the backoff delay of each SMC. See (1). Its essential objective is to provide more opportunity for SMC to utilize the spectrum.

$$\min . \frac{1}{N}\left(\sum_{i=1}^{N} delay_i\right) \tag{1}$$

where $delay_i$ denotes the backoff delay time of the ith SMC.

C. The Operation of SASMS

The fundamental questions that SASMS has to solve are two questions: which channels do CMR utilize and which channel dose SMC utilize.

Actually, the above questions should be solved according to the spectrum environment and traffic load of each transceiver in CMR. In the paper, SASMS is comprised of three parts: SASMS_A, SASMS_B and SASMS_C. SASMS_A is responsible for choosing channels, which used for CMR. SASMS_B is responsible for choosing channel, which used for SMC in relatively static spectrum scenario. SASMS_C is responsible for choosing channel, which used for SMC in dynamic spectrum scenario. The policies of them will be described particularly in the next section.

SASMS starts from an evenly distributed state, whose SMCs in each transceiver are equilibrium, which is guaranteed by SASMS_A and SASMS_C. With the time going, the traffic load among different transceivers may probably un-equilibrium for the traffic termination of SMC.

At the time, some smaller-scaled adjustment should be carried to adjust the traffic load of each transceiver without disturbing the transmission of other nodes. It just relate to several SMCs without disturbing the others' communication. Such scheme is called SASMS_B. When CMR is running SASMS_B, the performance will be predicted. If the performance will no longer be satisfied, SASMS_C will be initiated.

The above stable state will be broke again when some new SMCs request to join the network. CMR is on the wait-to-allocate state at the time. CMR must firstly check there is any intersection between the frequency bands which operate on CMR and the SOP set of SMC. If there is, CMR starts SASMS_B. Otherwise, it equals to reallocation approach, which will be described in SASMS_C.

In highly dynamic spectrum scenario, the quitting and joining action are frequent. Therefore, SASMS_C scheme will be initiated immediately and directly. Most importantly, when PU comes or the current channel deteriorates, SASMS_C will also be initiated immediately and directly. The FSM (finite state machine) of SASMS is shown in Figure. 2

D. The Specifications of SASMS

As described above, we implement SASMS in three parts: SASMS_A, SASMS_B and SASMS_C. Meanwhile, in the paper, we consider that the traffic of all the SMC is the same to facilitate the analysis. The work related to different traffic of each SMC will be our next step work.

Let us re-clarify the problem we face about SASMC. The standpoint of solving the problem, which described in (1), is the related to each SMC. The basic requirement of allocation is the lesser computation and more precise. With them each node in CogMesh network can acquire fast adaptability. Appointing SMC the dedicated channel to use need as little time as possible.

Considering the pair of CMR and SMCs, the number of transceivers in CMR is fixed, while the available channels in CMR may probably larger than the number of transceivers. Which M channels should CMR to choose in the centralized scenario? On the other aspect, the available channels of SMC may probably more the one, which one to choose? Therefore, we solve them in two parts naturally.

1) SASMS_A

The target of SASMS_A is to choose M channels that CMR to utilize. Let $D=(d_{ij})_{N\times K}$, d_{ij} =1 or 0 represents *i*th SMC can use *j*th band or not. Therefore, $r_j=\sum_{i=1}^{N} d_{ij}$ means the number of SMC which detect the *j*th band. The bigger the value of r_j is, the more probably that the *j*th channel is likely to be used in the view of SMC. That equals to the jth channel can sustain more SMCs. However, if we choose the jth channel, more SMCs may use it. The consequence of it is larger end-to-end delay time. Therefore, each channel that

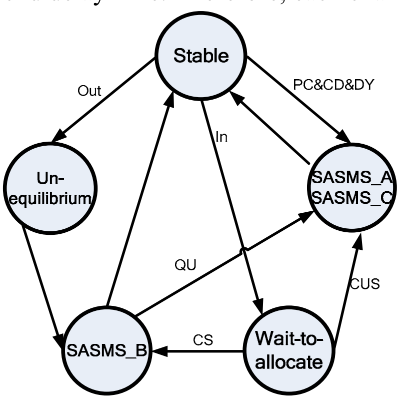

Figure.2 Finite State Machine chart (out: SMC quits. In: SMC join. QU: quality un-satisfied. PC: primary user is about to come. CD: channel deteriorates). DY: dynamic spectrum scenario. CS: condition satisfied. CUS: condition un-satisfied, whose condition means there exists intersection between channel sets in CMR and channel sets in SMC.)

CMR can use should be quantized, which was shown as (2)

$$\vec{Q}=\frac{\vec{W}}{\vec{R}} \quad (2)$$

$\vec{W}=(W_1,W_2,\cdots,W_j,W_K)$ and $\vec{R}=(r_1,r_2,\cdots,r_j,r_K)$ denote the evaluation of each channel(e.g., capacity) and the choosing cost of each channel separately.

We believe that the chosen M channels should supply resources for each SMC as evenly as possible. The most evenly resources SMC will be got, the best performance all the SMCs will achieve in a micro perspective. Therefore, it is formulated as follows:

$$min \quad Z(\vec{X})=\max(\vec{Q}.*\vec{X})-\min(\vec{Q}.*\vec{X}) \quad (3)$$

$$s.t. \quad \sum_{j=1}^{K} d_{ij}\cdot x_j \ge 1 \quad i=1,2,\cdots N \quad (4)$$

$$x_j\in\{0,1\} \quad j=1,2,\cdots K \quad (5)$$

$\vec{X}$ is a sector comprised of M 1 and K-M 0 which represent to choose or not to choose the channel. Actually, this is a *set-covering problem and NP-complete*. $\vec{X}$ represents the channels that CMR should utilize.

The channels that CMR hold are the channels that SMCs should utilize. Which one should a specific SMC choose is a tough problem. The number of the overlapping part between SOP_{SMC}^{i} and the channels that CMR hold may probably more than one. The target that SASMS_B and SASMS_C achieved is to appoint one SMC one channel. Equilibrium methodology is still adopted. Making all the SMCs evenly got the most evenly resources in the selected M channels is the final result. It still is a NP problem.

2) SASMS_B

When a single SMC's traffic terminates, it actually a comparatively static events in a time sequence. The termination of a single SMC will not make effect on the other

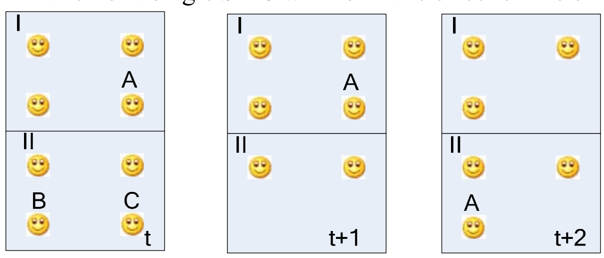

Figure.3 The variation of traffic load in different transceivers

SMCs. It is unnecessary to reallocate the spectrum for the other SMCs. Some small-scaled adjustment needs to initiate. E.g. at time t, transceiver I and transceiver II are evenly used. At time t+1, two SMC B and C in transceiver II release the channel and the two transceivers are unevenly used. At time t+2, to solve the problem, CMR just need to enable SMC A in transceiver I to operate on transceiver II.

In SASMS_B, CMR should statistic η in each transceiver, which shown in (6). η represents the traffic load level of each transceiver. In static spectrum scenario, when a new SMC want to join CMR, CMR will appoint it the transceiver with the lowest η value.

$$\eta = {AT_b}/{AT_i} \quad (6)$$

AT_b and AT_i are the accumulated busy time and accumulated idle time, which are acquired by the statistic value of CMR.

3) SASMS_C

In dynamic spectrum scenario, the topology is under fiercely changing. CMR needs a fast and adaptive optimized method to offer service for SMCs. During the spectrum changing, SASMS_A and SASMS_C is tightly coupled. The primary target of them is to make a proper decision at the most shortest time duration. After running SASMS_A, a matrix which is identify the correspondence of channels decision in CMR and their original SMCs, will be acquired. The structure of vector $\vec{X}$ should be emphasized again. The ones means the channels can be used. Therefore, extracting all-zero row from the matrix, a $M \times N$ matrix will be got. The problem of appointing a SMC a proper channel will be formulated as follows:

$$\min \quad \sum_{i=1}^{N}\sum_{j=1}^{M} q_{ij} x_{ij}$$

$$s.t. \quad \sum_{i=1}^{N} x_{ij} \cdot w_{ij} \le W_j \qquad (7)$$

$$\sum_{j=1}^{M} x_{ij} = 1 \qquad i = 1, 2, \cdots, N \qquad (8)$$

$$x_{ij} \in \{0,1\} \qquad j = 1, 2, \cdots, M \qquad (9)$$

where $q_{ij} = \sum_{j=1}^{M} r_{ij} \Big/ \sum_{i=1}^{N} r_{ij}$, which represents the cost of each item in matrix. w_{ij} means the minimum resource requirement of *i*th SMC in *j*th channel. It is fixed due to the above hypothesis of the same traffic of each SMC. W_j has a tight relationship with the quality of channel. The problem described above is a NP-hard problem, which will also be solved through GA approach.

To fully utilize the spectrum, channel capacity should be considered comprehensively. If SASMS doesn't consider it, that is to say to ignore W_j, SASMS is about to change into BUSA (balancing user-based spectrum allocation algorithm). BUSA considers there are the most evenly number of SMCs in each transceiver.

IV. Simulation

In a circular area with radius 300m, there are 10 different frequency bands available. 4 PU operate on different channel. The cover range of PU is 200m. The transmission range of SMC is 300m. CMR equipped with 6 transceivers, 4 of them equipped with IEEE 802.11b physical module. IEEE 802.11 MAC is adopted. In application layer, CBR with packet size 512 bytes is adopted. The overall simulation time is 60s. 10 to 50 nodes which locate randomly are simulated.

Simulation is comprised of two parts. First is the comparison between SASMS scheme and single transceiver applied with IEEE802.11 MAC in theoretical approach[7] and simulation in Qualnet with the metric of end-to-end delay. Second is the comparison between SASMS and BUSA in end-to-end delay.

In Figure.4, end-to-end delay and backoff delay increase with the node number increasing. SASMS scheme has a lower delay than the single transceiver applied with IEEE 802.11 MAC scheme. It is mainly because CMR has multiple transceivers. The gap between the dash line and the solid line is the transmission delay and the propagation delay.

In Figure.5, SASMS has lower end-to-end delay than BUSA. It tells the fact that SASMS has a better adaptability than BUSA in dynamic spectrum scenario. Moreover, treating channels the same way is not the proper approach to enhance the spectrum utilization ratio.

V. Conclusion And Future Work

In this paper, a brand new structure of CMR under CogMesh network is proposed. To decrease the backoff delay in each SMC, an algorithm using GA is proposed to adapt the traffic loads among multi-transceivers and different spectrum scenario. Moreover, SASMS results the average end-to-end delay of each SMC decreasing. The same traffic type is the hypothesis in SASMS. The different traffic type of SMC is about to research in the future work.

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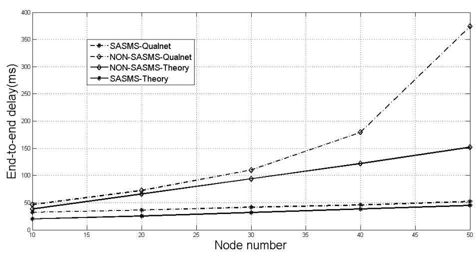

Figure. 4 Comparison between SASMS and Non-SASMS. Solid line is the comparison of backoff delay in theoretical way. Dash line is the comparison of end-to-end delay in Qualnet.

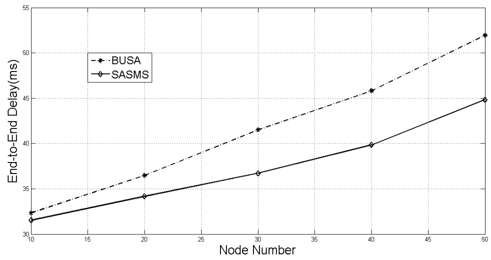

Figure. 5 Comparison between SASMS and BUSA in end-to-end delay using Qualnet.