IRACST – International Journal of Computer Networks and Wireless Communications (IJCNWC), ISSN: 2250-3501
Vol.3, No6, December 2013

End-To-End Flow Allocation and Channel Assignment in MC-MR Wireless Mesh Networks

C.Anbu Ananth
Assistant Professor in CSE
Annamalai University
Tamil Nadu, India

Dr.K.Selvakumar
Associate Professor in CSE
Annamalai University
Tamil Nadu, India

K.Manikannan
M.E Final Year**,**
Annamalai University
Tamil Nadu, India

***Abstract* - Wireless mesh networks with multi-channel multi-radio availability are attracting more and more attention from the research community because of its performance improvement and relatively low cost and complexity. It has been believed that the limited spectrum resource can be fully exploited by utilizing partially overlapping channels in addition to non-overlapping channels in 802.11b/g networks. In this paper focused on formulate the joint channel assignment and flow allocation problem for multi-channel multi-radio WMNs as a Mixed Integer Linear Program (MILP). It considers an objective of maximizing aggregate end-to-end throughput and minimizing queuing delay in the network, instead of the sum of link capacities. The static channel assignment algorithm incorporates network traffic information, i.e., it is load aware. MILP formulation takes into consideration several important network parameters such as the transmission power of each node, path loss information, the signal to interference plus noise ratio at a node, and the frequency response of the filters used in the transmitter and receiver.**

Index Terms - Channel assignment, End-to-end flow allocation, IEEE 802.11, partially overlapped channels, MILP, NS2.

I. INTRODUCTION

Wireless mesh networks (WMNs) are cooperative multi-hop, self-organizing, self-configuring, self-healing, and fault tolerant communication networks. The use of cooperative multi hopping technique helps the wireless nodes to route between node to node, node to multi-hop destination node, and node to base station, i.e., internet backhaul[13]. WMNs provide cooperate low up-front cost solution for high speed internet connectivity in urban and wilderness areas as compare to other technologies like wired and optical networks [1].

WMNs support MCMR scenarios which has further increased the overall throughput of the network. Mesh routers are equipped with two or more radios as each radio has its own MAC and Physical layer. Non overlapping frequency channels present in a single radio are further used to increase the throughput of the network. Multiple radios with multiple channels are available between the source and destination for communication enhancement [03]. In IEEE 802.11b/g, for example 2.4– 2.4835 GHz frequency band has been alienated into 13 channels each having the width of 22 MHz. It has only three non-overlapping channels as shown by the solid green, red and blue lines in the Figure 1. Recent studies have shown that the system throughput can further be increased when both non-overlapped channels and partially overlapped channels are used. An overwhelming number of recent as well as classical papers have studied the channel assignment problem, in association with several other related problems such as routing and congestion control, in great detail [04]. However, all these works only consider non-overlapping channels in their analysis. Our contributions in this work are as follows:

Study the problem of channel assignment and flow allocation in MC-MR WMNs. Unlike most of the previous studies consider the case when both non-overlapped and partially overlapped channels are used in the network.

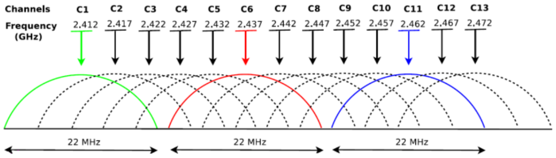

Fig.1. Available 13 partially overlapped channels in IEEE 802.11b/g networks.

This paper proposes a Mixed Integer Linear Program (MILP) formulation and study the performance of the problem under different objectives. The linear nature of the problem along with a low number of binary variables decreases the computational complexity of the problem. Many of the previous studies only consider maximizing the transport capacity of the network. However, this paper focuses on maximizing the aggregate end-to-end throughput and average queuing delay in the network. Given the topology of the WMN, propose a heuristic algorithm for the channel assignment and flow allocation problem to scale the solution to bigger networks.

II.RELATED WORK

A major problem facing multi-hop wireless networks is the interference between adjacent links. The throughput of a single-radio single-channel wireless network has been studied in [05,13]. The authors formalized it as a multi-commodity flow problem with constraints from conflict graph, which is NP hard, and gave an upper bound and a lower bound of the problem.

In [04,12], the authors show that the network capacity can be improved when both non-overlapped and partially overlapped channels are being used. They introduce the idea of the channel overlap factor for quantifying the overlap between two channels. The authors construct simple analytical and empirical models for interference that occurs in IEEE 802.11 networks and illustrate several schemes to incorporate partial overlapping channels in wireless ad hoc networks and WMNs. In [13], the authors consider a fixed MC-MR WMN and propose an MILP based static channel assignment scheme that maximizes the number of bidirectional links that can be activated simultaneously, subject to interference constraints.

To minimize the interference and to maximize the throughput, efficient algorithms for channel assignment are required in WMNs. In [06] the author proposed distributed algorithms that use local traffic load information for CA. But the proposal does not give the optimal solution within the constraints specified. In [07] proposed an efficient load balancing routing for WMNs. The authors try to maximize the network throughput by balancing traffic load. In [08] developed centralized CA and routing algorithms. The authors propose flow computation model independent of traffic demands to maximize the network capacity. Most of the work in the literature proposes heuristic CA algorithms based on fixed number of channels and radios [09].

III.METHODOLOGY

Consider an MCMR wireless mesh network and assume that N denotes the set of stationary nodes. There are K radios (K >1) in each node and C channels (C > K) are available for transmission in the network. The model use omni-directional antennas for communication at the physical layer.

The traffic demands of the end-to-end communication (T) sessions that exist in the network. Various traffic profiling techniques have been discussed in [11]. Each communication session is uniquely identified by a triple (i, j, t_{ij}), where i is the source, j is the destination, and t_{ij} is the aggregate traffic demand for the communication session between nodes i and j. It is use the fixed path routing for each flow (e.g., the shortest path). These alternate paths between a node i and node j, for an end-to-end communication session (i, j, t_{ij}), are represented by a binary variable $R^{e}_{ij,k}$ e $\in\varepsilon$, where k denotes the k^{th} path between node i and node j. In this case, the load on a link e, assuming link e is assigned channel c (equivalent to $f_{e,c}$), as determined by the routing algorithm and the demand of the flows is given by:

$$f_{e,c} = \sum_{(i,j,t_{ij})\in T} R^{e}_{ij,1} \times X_{ij,1} \qquad (1)$$

The total achieved throughput for a flow (i, j, t_{ij}) is denoted by x_{ij}. To support multi-path routing for each flow, assume that the traffic for a flow is infinitely divisible. Denote the achieved throughput on the k^{th} path between i and j as $x_{ij,k}$.

$$X_{ij} = \sum_{k} X_{ij,k} \qquad (2)$$

Consider an MCMR-WMN where both non-overlapped and partially-overlapped channels are being used. Two neighboring links (a, b), (c, d) $\in L$ are assigned to channels I and j, respectively. If the interference power of the transmission on link (a, b) causes the signal to interference plus noise ratio on link (c, d) to be below $SINR_{min}$, then the transmitter of link (a, b) is within the interference range of the receiver of link (c, d). That is,

$$\frac{G_{cd}\ P_c}{N_0 + [o]_{ij} G_{ad} P_a} < SINR_{\min} \qquad (3)$$

where N_0 denotes the thermal noise power. Without loss of generality, the path loss G_{cd} and G_{ad} using the Friis free space model [10].

$$G_{cd} = \frac{\alpha}{[r_{ad}]^{k}}$$

Where $r_{ad}$is the Euclidean distance between routers a and d, κ is the path loss exponent, and α is a constant which depends on the transmitter and receiver antenna gains and signal wavelength. By substituting into (3) and re-arranging the terms, link (a, b) interferes with link (c, d) then,

$$r_{ad} < \sqrt[k]{\left(\frac{\alpha P_a}{\frac{G_{cd}\ P_c}{SINR_{\min - N_0}}}\right)}[o]_{ij} \qquad (4)$$

Consider two links e = (a,b) and e' = (c,d). The Link Interference Matrix $LIM_{e,e'}$for these two links is a symmetric C × C matrix, with the entry in the i^{th} row and j^{th} column being 1 if link e interferes with link e', when e is assigned the channel i and e' is assigned the channel j. These interference relations can be determined using Eq. (5). Thus have:

$$[LIM_{e,e'}]_{ij} = \begin{cases} 1 \ if\ r_{cd} < F(c,a,b,i,j)\ or\ r_{ad} < F(a,c,d,i,j) \\ 0 \end{cases} \qquad (5)$$

3.1 MILP formulation

3.1.1 Channel assignment model

Now consider the static channel assignment problem, in a network with N nodes and E links. For a link e = (a,b) $\in$ ε, define a C ×1 zero-one[1] channel assignment vector w_e, where the i^{th} element of $\overline{w}_e$ is 1, if link e is assigned channel i, otherwise it is zero. Assume only one channel is assigned to each link e. were,

$$\sum_{i=1}^{c}[w_e]_i = 1 \ \forall\, e \in \varepsilon$$

The next constraint, which is an upper bound on the maximum number of channels that can be assigned to a node n, ensures that feasibility is not violated due to spurious allocations. The constraint on the maximum number of distinct channels that can be assigned to edges incident on a node n. Finally, using the definition of $\mathrm{LIM}_{e,e'}$The following condition for two links e = (a,b) and e' = (c,d) to interfere with each other:

$$[w_e]_i[LIM_{e,e'}]_{ij}[w_{e'}] = \begin{cases} 1 \text{ if links } e \text{ and } e' \text{ interfere} \\ 0 \text{ otherwise} \end{cases} \tag{6}$$

where $[\mathrm{LIM}_{e,e'}]_{ij}$ represents the entry in the *i*th row and *j*th column of $\mathrm{LIM}_{e,e'}$, and links e and e' are assigned channels *i* and *j*, respectively.

3.1.2 Flow rate at each link

Consider the fixed path routing scheme in MILP formulation. In this case, given the set of end-to-end communication sessions T , and the unique routing path for each flow, then calculate the aggregate load on a logical link e = (a,b), denoted by l(e), by substituting $x_{ij,1}$ with t_{ij} in Eq. (1), i.e.,

$$l(e) = \sum_{(i,j,t_{ij})\in T} R^{e}_{ij,1} \times t_{ij} \tag{7}$$

The channel assignment algorithm should ideally be able to support a major fraction of the demanded flow throughput, and the objective function (Obj1) to maximize the aggregate end-to-end flow allocations, i.e.,

$$\mathbf{Obj_1}: \ maximize = \sum_{(i,j,t_{ij})\in T} X_{ij} \tag{8}$$

In this model, if the ratio of the aggregate load on a logical link (l(e)) to the achieved throughput of the link ($f_{e,c}$) is large it leads to large queuing delays. A network with high queuing delays, is prone to congestion. Then also like to minimize the maximum of ratio of l(e) and $f_{e,c}$(Obj2) to reduce the chance of network congestion, while still managing the network capacity according to the aggregate load on each link, i.e.,

$$Obj_2: \ minimize\left(maximum\frac{l(e)}{f_{e,c}}\right) \equiv maximize\left(minimum\frac{f_{e,c}}{l(e)}\right) \tag{9}$$

These two conflicting objectives, by considering a weighted combination of the two objectives as this final objective function (Obj):

$$Obj: \ maximize\left(\psi \sum_{(i,j,t_{ij})\in T} X_{ij} + (1-)\left(\mathbf{minimum}\frac{f_{e,c}}{l(e)}\right)\right) \tag{10}$$

Summarize the Mixed Integer Non-Linear Program (MINLP) formulation for the channel assignment and flow allocation problem. Then convert this MINLP into a MILP using binary linearization techniques the linearization techniques are applicable only to the fixed path routing case. Given the optimal solutions for the channel assignment and flow allocation, assign the appropriate channels and interfaces to the nodes.

3.2 Heuristic algorithm for channel assignment and flow allocation

Given the network topology, the proposed MILP formulation solves the joint channel assignment and flow allocation problem. The linear nature of the proposed MILP formulation along with the less number of binary variables reduces the computational complexity of the problem. The proposed heuristic algorithm decouples the channel assignment from the flow allocation [09]. First find the channel assignment, and then perform flow allocation using the resultant channel assignment.

3.2.1 Channel assignment

The channel assignment algorithm is presented in Algorithm 1. In this algorithm, l(e) denotes the aggregate load on a link e, as defined in Section 4.3.l(e) denotes the aggregate load in the interference region of a link e. The set of links interfere with a link e as $E_1(e)$,

$$l_1(e) = l(e) + \sum_{e'\in\varepsilon} l(e') \times \left([w_e]_c[LIM_{e,e'}]_{cc}[w_{e'}]_c\right) \forall\, e \in \varepsilon \tag{11}$$

Consider all links e' $\in$ E, that could potentially interfere with link e, if e and e' were assigned the same channel c, while calculating $E_1(e)$.

The heuristic algorithm for channel assignment is polynomially bounded, with order O(E2C). This can be inferred from the following: in Algorithm, the loop in line 2 is executed until all the links are assigned a channel, i.e., E times. On entering the loop, there are two possibilities, (1) SatN is empty, and (2) SatN is not empty. In the former case, the complexity of first selecting the link, and then assigning a channel to it is O(EC). In the latter case, the link is assigned a channel in O(1) time. In the worst case, every time the loop is entered, SatN is empty. Thus, the order of the algorithm is $O(E^2C)$.

Algorithm : Channel Assignment Heuristic Algorithm

Input: AGraph G(N, ε), with *l(e)* and *l_1(e)* values $\forall\, e \in \varepsilon$

```
Output The channel assignmet: $\overline{w}_e \forall e \in \varepsilon$
Initialize $[w_e]_c = 0 \forall e \in \varepsilon, 1 \leq c \leq C;$
While $\exists a\ link\ e \in \varepsilon\ with\ [w_e]_c = 0 (\forall 1 \leq c \leq C)$ do
  if $SatN = \emptyset$ then
Select the edge e' with the highest $l(e) \times l_1(e)$ value;
Select the channel c with the least $W_1(e',c)$value;
 Set $[w'_e]_c = 1$ ;
 Update $[y_u]_c=1$ and $[y_v]_c=1$ where e'=(u,v);
  If Node u is saturated then
$SatN = SatN \cup \{u\};$
 End
 If Node v is saturated then
$SatN = SatN \cup \{v\};$
 End
   Else
   While $SatN = \emptyset$ do
     Let node $n \in SatN$ ;
       For all the links $e,$□ $e$ is not assigned a channel and
     n is one of its incident nodes do
       select c with the least $W_1(e',c)$ value among the
       channels already allocated to links incident at node n;
       set $[w_e]_c = 1$ ;
      if the other end node (n') of link e" is saturated,
      update $SatN = SatN \cup \{n'\};$
     end
$SatN = SatN \cup \{n'\}$
    End
  End
End
```

3.2.1 *Flow allocation*

MILP formulation reduces to an Linear Programming (LP) formulation. In this formulation, the values of $C_{e,e'}$e' ϵ ε, e≠e' are known in advance from the channel assignment. The LP can be solved in polynomial time, with an order $O(N_v^{3.5} L)$, where N_v is the number of variables and L is the number of bits of input to the algorithm. the complexity of the LP is $O((N^2)^{3.5}L)$ or $O(N^7L)$. The heuristic algorithm, consisting of the channel assignment algorithm and the flow allocation algorithm is polynomially bounded, and is of the order $O(E^2C + N^7L)$.

IV. SIMULATION SETUP

A network simulator is a software program that imitates the working of a computer network. The simulator can be used for traffic modeling of telecommunication networks, protocol modeling, modeling queuing networks, modeling multiprocessors and other distributed hardware systems, validating hardware architectures, evaluating performance aspects of complex software systems. NS2 needs the fixed parameter setup, they given below.

Table 1: Simulation Parameters

PARAMETER	VALUES
Channels	13
Mobile nodes	50 Nodes over 300m x 1500m
Reflection model	Two-ray ground reflection model
Data rate	11 Mbps
Transmission power	200 mW
SINR threshold	10 dB
Traffic model	UDP based CBR traffic
Routing protocol	Ad hoc On demand Distance Vector
Physical layer protocol	PHY 802.11
Packet size	512 bytes
Simulation time	900 sec

V. RESULT AND DISCUSSION

5.1 *MILP performance*

First study the performance of the MILP formulation, in terms of the aggregate throughput achieved and the average queuing delay in the network. Fig. 2, shows the achieved aggregate throughput and queuing delay for three different objective functions, with increasing number of channels, for network with loads.

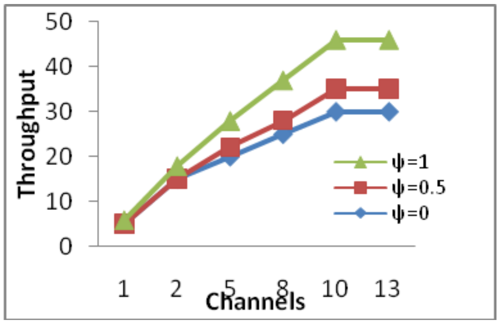

Fig. 2. Variation of throughput with number of channels

All the three objective functions considered effectively utilize the additional channels available by giving superior channel assignments. Show a steep increase in throughput with the addition of non-overlapped channels (C_N = 1 to C_N = 3). Note that, even when partially overlapped channels are introduced (C_N = 9 to C_N= 13), MILP formulation still gives progressively better channel assignments that are able to attain higher aggregate throughput in the network. This is possible, because formulation effectively utilizes the property of varying interference ranges to provide a channel assignment that makes efficient use of the available frequency spectrum. Note that from CN = 9 to CN = 13, then only introducing partially overlapped channels, without the use of any additional spectrum.

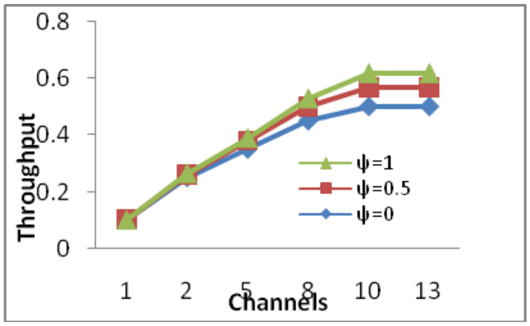

Fig. 3. Variation of queuing with number of channels

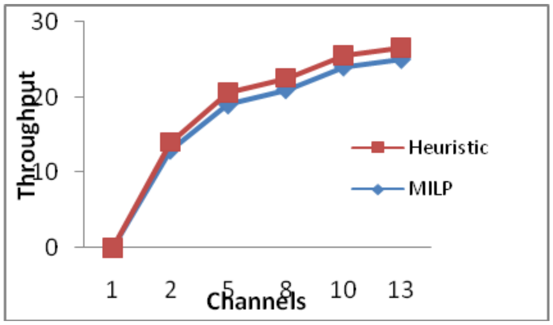

Fig. 4. Comparison of MILP and Heuristic

From the figure, show the rate of increase of the aggregate throughput with the addition of partially overlapped channels is higher for bigger networks. This stresses the importance of considering partially overlapped channels in bigger network topologies.

VI CONCLUSION

In this paper has proposed a joint channel assignment and flow allocation algorithm for MC-MR WMNs, when both non-overlapped and partially overlapped channels are being used. MILP formulation takes into consideration several important network parameters, such as the transmission power of each node, path loss information, the signal to interference plus noise ratio at a node, and the frequency response of the filters used in the transmitter and receiver. Considered maximizing aggregate end-to-end throughput and minimize queuing delay in the network, instead of the sum of link capacities. The heuristic algorithm performs on par with the optimal solution, with the worst case difference being about 13%.

For future work, then plan to study the performance of the proposed heuristic algorithm in real network scenarios. Also plan to consider other routing schemes in MILP formulation.

REFERENCES

[1]. Rahul Urgaonkar, Ram Ramanathan, Jason Redi, William N. Tetteh, “Channel Assignment in Dense MC-MR Wireless Networks: Scaling Laws and Algorithms”arXiv:1209.0676v1(2012).

[2]. H. L. Nguyen and U. T. Nguyen, “High-Performance Multicast Routing in Multi-Channel Multi-Radio Wireless Mesh Networks,” in Proc. of IEEE GLOBECOM’10, 2010.

[3]. S Avallone, IF Akyildiz, A channel assignment algorithm for multiradio wireless mesh networks. Comput. Commun. **31**(7), 1343–1353(2008).

[4]. B. F. Duarte, Zubair Md. Fadlullah, Athanasios V. Vasilakos, W. Arbaugh, On the Partially Overlapped Channel Assignment on Wireless Mesh Network Backbone: A Game Theoretic Approach,IEEE-6117767 June 2012.

[5]. K. Jain, J. Padhye, V. Padmanabhan, and L. Qiu, \Impact of interference on multi-hop wireless network performance," in *MobiCom*, 2003.

[6]. A. Raniwala and T. ckerChiueh, \On the Partially Overlapped Channel Assignment on Wireless Mesh Network Backbone: A Game Theoretic Approach," in *INFOCOM*, 2005.

[7]. YigalBejeranoSeung-jae, Han Amit Kumar, Efficient load-balancing routing for wireless mesh networks. Computer networks 2007;51;2450-66.

[8]. Stefano Avallonlan F, Akyildiz A. Channel assignment algorithm for multi-radio Wireless mesh networks. Computer Communications 2008;31;1343-53.

[9]. Yin Z, Li Z, Chen M., A novel channel assignment algorithm for multicast in multi-radio wireless mesh networks. In: Proceedings of IEEE ISCC’07, 2007.

[10]. Hongkun Li, Yu Cheng, Chi Zhou and WeihuaZhuang Routing Metrics for Minimizing End-to-End Delay in Multi-Radio Multi-Channel Wireless Networks,*INFOCOM*August 2010.

[11]. A. Mishra, E. Rozner, S. Banerjee, W. Arbaugh, Exploiting partially overlapping channels in wireless networks: turning a Peril into an advantage, in: Proceedings of the 5th ACM SIGCOMM Conference on Internet Measurement(IMC ’09), October 2009, pp. 1–6.

[12]. SurachaiChieochan, Student Member, IEEE, and EkramHossain, Senior Member, IEEE “Channel Assignment for Throughput Optimization in Multichannel Multiradio Wireless Mesh Networks Using Network Coding” IEEE transactions on mobile computing, vol. 12, no. 1, january 2013.

[13]. DjoharaBenyamina, AbdelhakimHafid, and Michel Gendreau “Wireless Mesh Networks Design — A Survey” IEEE communications surveys & tutorials, vol. 14, no. 2, second quarter 2012.