Near Optimal Channel Assignment for Interference Mitigation in Wireless Mesh Networks

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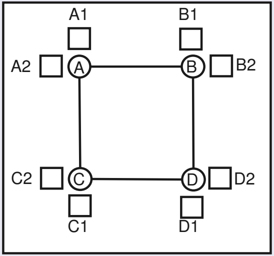
Wireless Mesh Networks (WMNs)

A Promising Technology

MRMC WMNs

- Multi-hop relaying is a primary characteristic of Wireless Mesh Networks (WMNs).
- Wireless transmissions give rise to transmission conflicts, when transmission is occurring on overlapping channels.
- The adverse impact of prevalent interference caused by transmission conflicts devours the network capacity of MRMC WMNs.
- Interference mitigation techniques include channel assignment (CA) to radios, link-scheduling, routing and beam-forming through directional antennas.

2*2 Grid MR WMN



Role of CA schemes in WMNs

- Interference → Most debilitating factor in network performance.
- Minimizing interference in WMNs is a primary objective.
- Mainly achieved through a prudent channel assignment (CA) scheme, which
  - Enhances network capacity.
  - Reduces end-to-end latency.
  - Reduces data packet loss.
- Optimality is a desired yet elusive goal in real-time deployments.

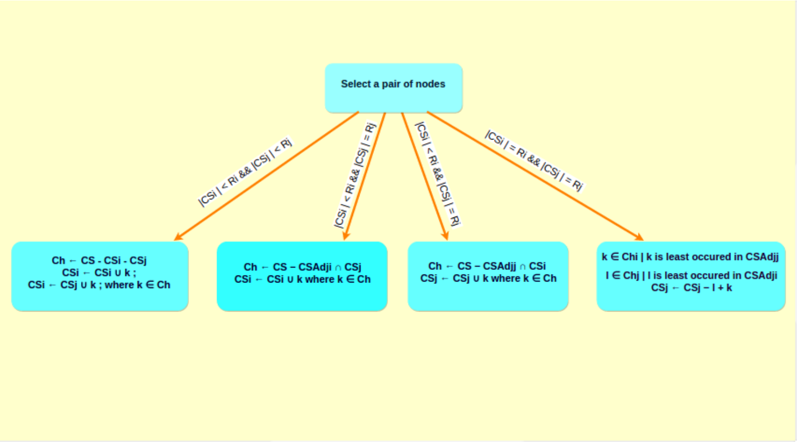
Terminology

- Network topology is given by $G_{WMN} = (V_{WMN}, E_{WMN})$, V_{WMN} denotes nodes in the WMN, and E_{WMN} denotes links in the WMN.
- CS denotes the set of available channels.
- CS_i represents the set of channels that are assigned to the radios on i^{th} node.
- cs_{max} is the maximum number of available orthogonal channels.
- R_i represents the maximum number of radios on node i.
- $|CS_i|$ denotes the cardinality of the set CS_i.

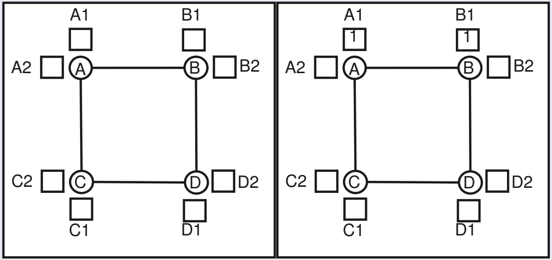
Why another CA?

- CA in WMNs is an NP-Hard problem.
- Many algorithms have been proposed, which have high computational overhead and perform worse as compared to brute force(BF).
- For real-time deployments, optimality is a desired yet elusive goal.
- Proposed NOCAG algorithm, is a heuristic with less computational overhead and performs as good as BF.

Proposed NOCAG algorithm



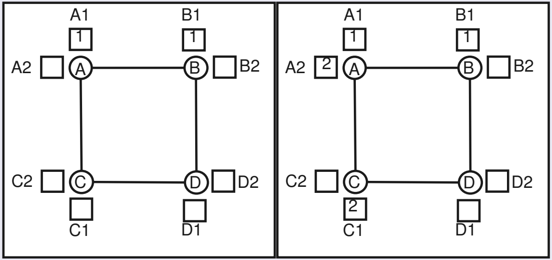
Walk Through Example
Step 1



- Chooses nodes A and B
- Assigns channel 1 to radios A_1 and B_1.

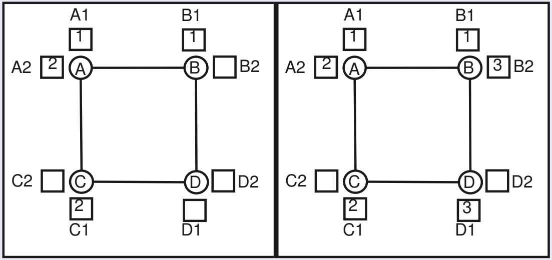
Walk Through Example

Step 2



- Chooses nodes A and C
- Assigns channel 2 to radios A_2 and C_1.

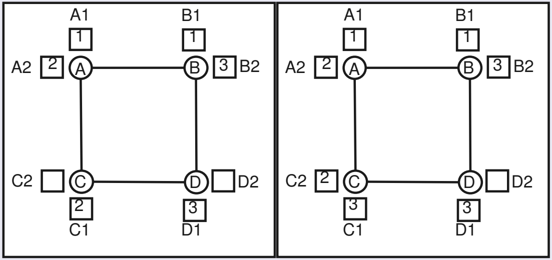
Walk Through Example
Step 3



- Chooses nodes B and D.
- Assigns channel 3 to radios B_2 and D_1.

Walk Through Example

Step 4



- Chooses nodes C and D.
- Assigns channel 3 to radios C_2.

Time Complexity Analysis

- For a $n \times n$ grid, let m be the total number of nodes i.e., $m = n^2$.
- Let k be the average number of radios on each node and c be the number of available channels.
- Time complexity BFCA is $O(c^{(m*k)})$.
- NOCAG chooses each node at a time and for each node it considers only its adjacent nodes.
  - Maximum number of adjacent nodes can be 4.
  - In the worst case it checks all c available channels.
- Time complexity for NOCAG is $O(4 * m * c)$ i.e., $O(m * c)$.
- For regular WMNs $c << m$.
- So the time complexity is as low as $O(m)$.

MILP Model

- Throughput of the network is considered as a flow problem in a graph.
  - Nodes in the network as the vertices in the graph.
  - Links in the network as the edges in the graph.
  - Max. capacity of the link is analogous to the maximum flow the corresponding edge can carry.
- A MILP model is developed to solve the problem flow problem.
- Model calculates the maximum achievable throughput in the network theoretically.
  - I.e., maximum achievable flow in the analogous graph.
  - Constraints and flow equations are described below.

MILP Model

- Variables Used:
  - $flow(i, j)$ - variable denoting the amount of data flowing from node i to node j, on the link connecting i and j and its value is 0 if the nodes are not connected.
  - $C(i, j)$ - the maximum rate at which the link between node i and node j can transfer the data.
  - Rad_{max} - number of maximum radios on any node.
  - int - represents an intermediate node in a path from source to sink.

MILP Model

- Constraints:
  - $Continuity$: At any intermediate node data incoming is equal to data outgoing.
  - $Flow$: The flow on any link is non negative.

$$flow(i,j) \geq 0$$

- Objective: To maximize the flow in the network.

$$Max.Flow = Maximize \sum_{k} y_k \tag{1}$$

  - y_k is the throughput of flow between a source-sink pair.
  - k denotes the source-sink pairs in the network.

$$y_k = \frac{1}{|P^k|} \sum_{i} P_i^k \tag{2}$$

  - P_i^k denotes i^{th} possible path between source-sink pair k.

$$\begin{aligned}\max P_i^k &= \min\{flow_{max}(source, int_1), \ldots, \\ &\qquad flow_{max}(int_n, sink)\} \\ &= \min\{C(source, int_1), \ldots, C(int_n, sink)\}\end{aligned} \tag{3}$$

$$Max.Flow = \max \sum_k y_k = \sum_k \frac{1}{|P_i^k|}\Big(\sum_i \max P_i^k\Big) \tag{4}$$

Test Scenarios & Evaluation Procedure

Simulation Parameters

ns-3 Simulation Parameters

Parameter	Value
Available Orthogonal Channels	3
Transmitted File Size	5 MB
Maximum 802.11g/n Phy Datarate	54 Mbps
Maximum Segment Size (TCP)	1 KB
Packet Size (UDP)	512 Bytes
MAC Fragmentation Threshold	2200 Bytes
RTS/CTS	Enabled
TCP NS-3 Protocol	BulkSendApplication
UDP NS-3 Protocol	UdpClientServer
Routing Protocol Used	OLSR
RTS/CTS (TCP)	Enabled
RTS/CTS (UDP)	Disabled
Rate Control	Constant Rate (54Mbps)

Theoretical Metrics

Cumulative X-Link-Set Weight ($CXLS_{wt}$)[2]

- Considers statistical characteristics and spatial proximity of links for interference estimation.
- Computed by finding all the X-links present in the topology and assigning them a weight based on the CA .
- $CXLS_{wt}$ is the sum of weights of all the X-links.

Channel Fairness Analysis

- It is a good idea to use all the available channels evenly.
- For this statistical evenness of the channels is calculated.
- Simply the number of links which communicate on a particular channel should almost be the same for all the channels.

$CXLS_{wt}$ Metric

Grid /CA	NOCAG	BF	EIZM[10]	CCA[3]
3x3	14	15	11	8.5
4x4	34	36	28.5	15
5x5	62	68	50.5	33
6x6	98	107	67.5	60.5
7x7	142	151	96	83

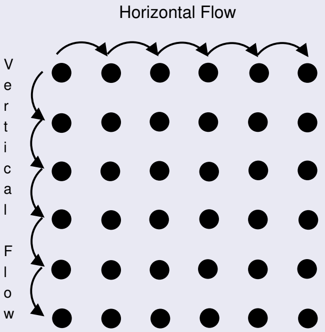
Channel Fairness Analysis

Grid/CA	NOCAG	BF	EIZM	CCA
3x3	06:06:06	06:06:06	07:05:06	08:01:09
4x4	09:11:12	11:11:10	11:09:12	16:08:08
5x5	15:17:18	16:17:17	16:15:19	25:07:18
6x6	22:24:26	24:24:24	21:21:30	36:12:24
7x7	31:33:35	33:33:32	32:28:38	47:13:38

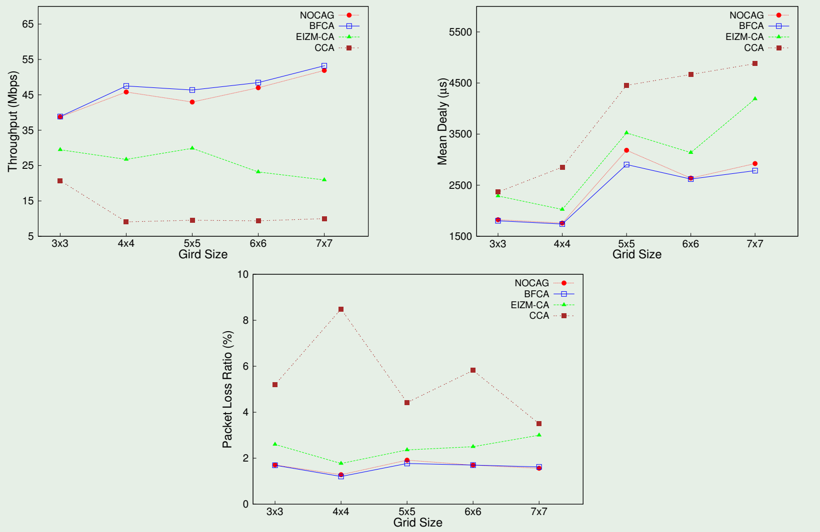
Test scenario

- We develop a test scenario that includes each and every node for data transmission in the WMN.
- Consider a $n \times n$ grid, we establish $2n$ concurrent flows, n vertical flows and n horizontal flows.
- Setup ensures that the nodes are exhaustively involved in data transmission ideal to assess the performance of the CA.

6x6 Grid WMN



Experimental Results



Throughput in Mbps

Grid Size	MILP Max. Value	BF Exp. Value	NOCAG Exp. Value
3×3	54.6	38.87	38.74
4×4	72.8	47.50	45.80
5×5	91	46.36	42.97
6×6	109.2	48.46	47.00
7×7	127.4	53.21	51.90

Conclusions

- Computational overhead is linear in terms of the number of nodes in the network.
- A very high performance hike is observed and is very close to the brute force CAs and much better than existing CAs.
- Channel Fairness is better than compared to existing CAs and is very close to BFCA.
- Algorithm is intelligent and is easy to implement.

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Thank You

QUERIES ?