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.
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

Select a pair of nodes

\[ \text{Ch} \rightarrow \text{CS} - \text{CSI} - \text{CSj} \]
\[ \text{CSI} \rightarrow \text{CSI} \cup k ; \]
\[ \text{CSI} \rightarrow \text{CSj} \cup k ; \text{where } k \in \text{Ch} \]

\[ \text{Ch} \rightarrow \text{CS} - \text{CSAdj} \cap \text{CSj} \]
\[ \text{CSI} \rightarrow \text{CSI} \cup k \text{ where } k \in \text{Ch} \]

\[ \text{Ch} \rightarrow \text{CS} - \text{CSAdj} \cap \text{CSI} \]
\[ \text{CSj} \rightarrow \text{CSj} \cup k \text{ where } k \in \text{Ch} \]

\[ k \in \text{Ch} | k \text{ is least occurred in } \text{CSAdj} \]
\[ I \in \text{Chj} | I \text{ is least occurred in } \text{CSAdj} \]
\[ \text{CSj} \rightarrow \text{CSj} \cup I + k \]
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.
    \[
    \text{flow}(i, j) \geq 0
    \]

- **Objective:** To maximize the flow in the network.
  \[
  \text{Max. Flow} = \text{Maximize } \sum_k y_k
  \]

- \(y_k\) is the throughput of flow between a source-sink pair.
- \(k\) denotes the source-sink pairs in the network.
  \[
  y_k = \frac{1}{|P^k|} \sum_i P^k_i
  \]

- \(P^k_i\) denotes the \(i^{th}\) possible path between source-sink pair \(k\).
max \( P_i^k \) = \min \{ flow_{max}(source, int_1), \ldots, \\
flow_{max}(int_n, sink) \} \\
= \min \{ C(source, int_1), \ldots, C(int_n, sink) \} \tag{3}

Max. Flow = \max \sum_k y_k = \sum_k \frac{1}{|P_i^k|} \left( \sum_i \max P_i^k \right) \tag{4}
# Test Scenarios & Evaluation Procedure

## Simulation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available Orthogonal Channels</td>
<td>3</td>
</tr>
<tr>
<td>Transmitted File Size</td>
<td>5 MB</td>
</tr>
<tr>
<td>Maximum 802.11g/n Phy Datarate</td>
<td>54 Mbps</td>
</tr>
<tr>
<td>Maximum Segment Size (TCP)</td>
<td>1 KB</td>
</tr>
<tr>
<td>Packet Size (UDP)</td>
<td>512 Bytes</td>
</tr>
<tr>
<td>MAC Fragmentation Threshold</td>
<td>2200 Bytes</td>
</tr>
<tr>
<td>RTS/CTS</td>
<td>Enabled</td>
</tr>
<tr>
<td>TCP NS-3 Protocol</td>
<td>BulkSendApplication</td>
</tr>
<tr>
<td>UDP NS-3 Protocol</td>
<td>UdpClientServer</td>
</tr>
<tr>
<td>Routing Protocol Used</td>
<td>OLSR</td>
</tr>
<tr>
<td>RTS/CTS (TCP)</td>
<td>Enabled</td>
</tr>
<tr>
<td>RTS/CTS (UDP)</td>
<td>Disabled</td>
</tr>
<tr>
<td>Rate Control</td>
<td>Constant Rate (54Mbps)</td>
</tr>
</tbody>
</table>
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.
### $CXL_{Sty} \text{ Metric}$

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>3x3</td>
<td>14</td>
<td>15</td>
<td>11</td>
<td>8.5</td>
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<tr>
<td>4x4</td>
<td>34</td>
<td>36</td>
<td>28.5</td>
<td>15</td>
</tr>
<tr>
<td>5x5</td>
<td>62</td>
<td>68</td>
<td>50.5</td>
<td>33</td>
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<td>6x6</td>
<td>98</td>
<td>107</td>
<td>67.5</td>
<td>60.5</td>
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<tr>
<td>7x7</td>
<td>142</td>
<td>151</td>
<td>96</td>
<td>83</td>
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</table>
## Channel Fairness Analysis

<table>
<thead>
<tr>
<th>Grid/CA</th>
<th>NOCAG</th>
<th>BF</th>
<th>EIZM</th>
<th>CCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>3x3</td>
<td>06:06:06</td>
<td>06:06:06</td>
<td>07:05:06</td>
<td>08:01:09</td>
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<tr>
<td>4x4</td>
<td>09:11:12</td>
<td>11:11:10</td>
<td>11:09:12</td>
<td>16:08:08</td>
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<tr>
<td>5x5</td>
<td>15:17:18</td>
<td>16:17:17</td>
<td>16:15:19</td>
<td>25:07:18</td>
</tr>
</tbody>
</table>
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.
Experimental Results

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Experimental Results

- Throughput (Mbps)
- Mean Delay (µs)
- Packet Loss Ratio (%)

Grid Size: 3x3, 4x4, 5x5, 6x6, 7x7

Comparisons:
- NOCAG
- BFCA
- EIZM-CA
- CCA

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<table>
<thead>
<tr>
<th>Grid Size</th>
<th>MILP Max. Value</th>
<th>BF Exp. Value</th>
<th>NOCAG Exp. Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3×3</td>
<td>54.6</td>
<td>38.87</td>
<td>38.74</td>
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<tr>
<td>4×4</td>
<td>72.8</td>
<td>47.50</td>
<td>45.80</td>
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<tr>
<td>5×5</td>
<td>91</td>
<td>46.36</td>
<td>42.97</td>
</tr>
<tr>
<td>6×6</td>
<td>109.2</td>
<td>48.46</td>
<td>47.00</td>
</tr>
<tr>
<td>7×7</td>
<td>127.4</td>
<td>53.21</td>
<td>51.90</td>
</tr>
</tbody>
</table>
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.
References I


References II


THANK YOU
Intro

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