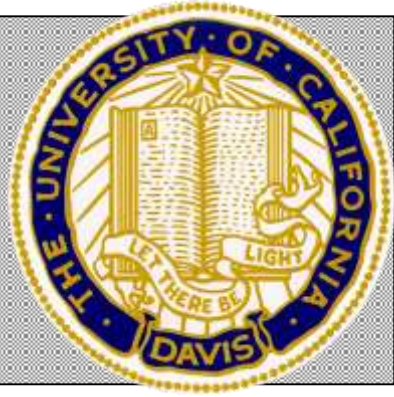

A Topology Control in Wireless Networks

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Network Design Problems

Complexity

Problem	Given	Minimize	w.r.t	s.t
CA	τ, $\lambda_{i,j}$	T	$C_{i,j}$	D
FA	τ, $C_{i,j}$	T	$\lambda_{i,j}$	$0 \le \lambda_{i,j} \le \mu C_{i,j}$
CFA	τ	T	$C_{i,j}$, $\lambda_{i,j}$	D
TCFA	-	T	τ, $C_{i,j}$, $\lambda_{i,j}$	D

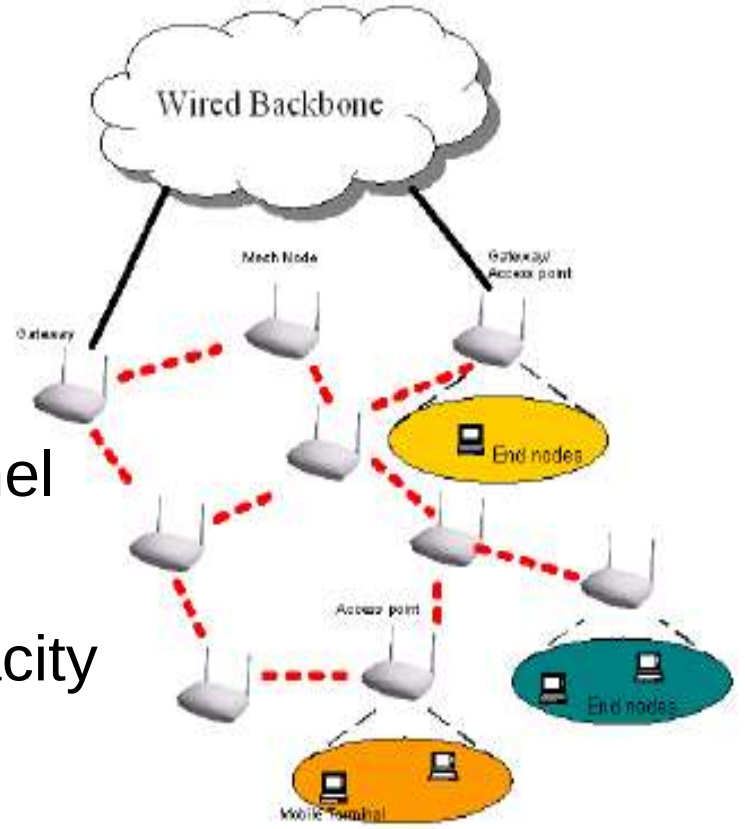
- τ = Network Topology
- $\lambda_{i,j}$ = flow on link (i,j)
- μ = average packet size
- $C_{i,j}$ = capacity of link (i,j)
- T = Average System Delay
- D = Maximum cost

$$\sum_{(i,j)\in E} d_{i,j}\left(C_{i,j}\right) = D$$

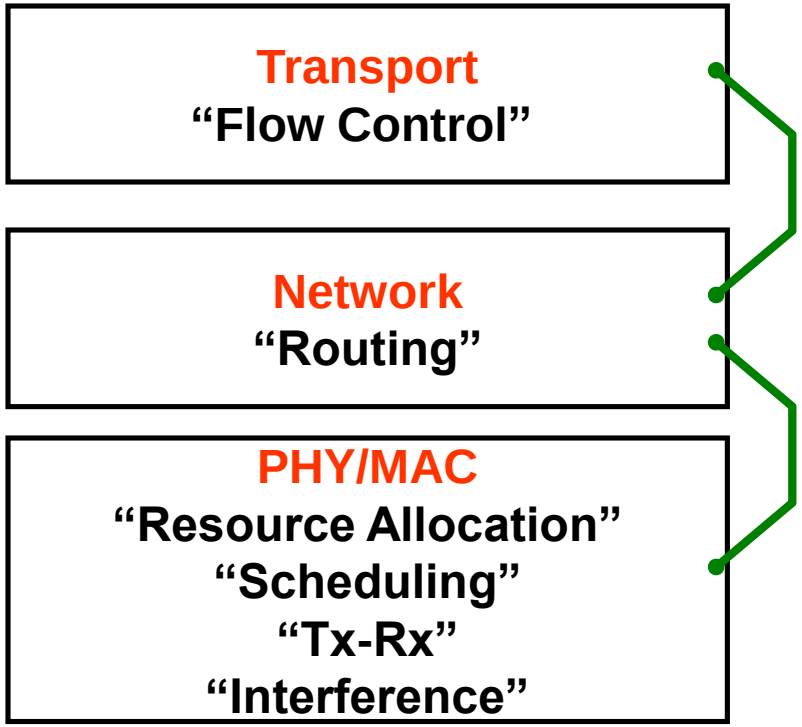
Ref: Channel, Capacity, and Flow Assignment in Wireless Mesh Networks Presentation, by Vishwanath Ramamurthi

In Wireless Mesh Network

- Each radio has a limited capacity
  - This can be used as a constraint instead of Cost Constraint
- Wireless Channel is a shared channel
- Interference limits the effective capacity



Cross-Layer Design



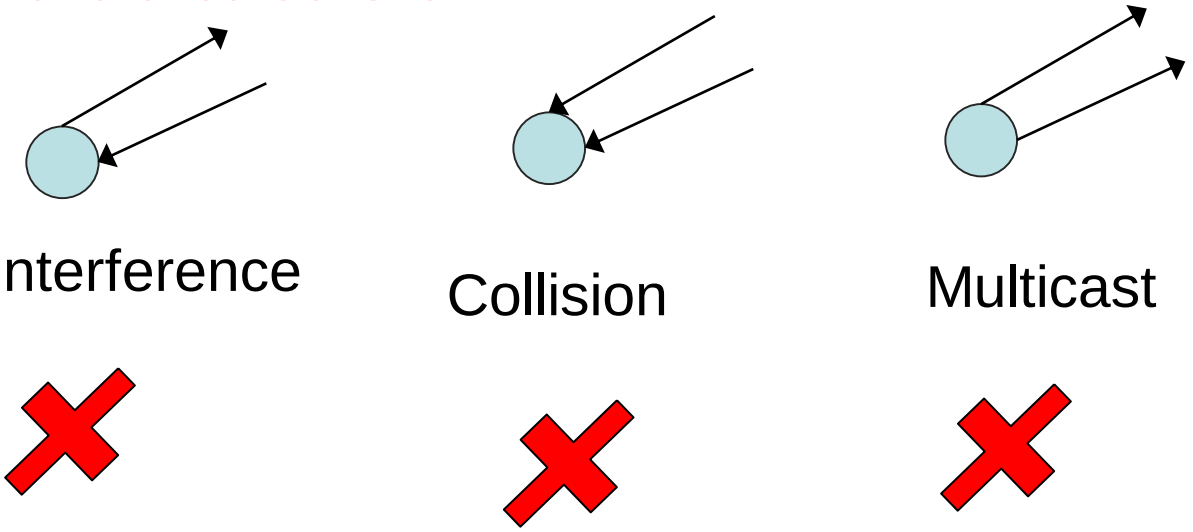
- CA in wireless network should also take into account Interference
- Interference depends on
  - Topology
  - PHY Layer technology
  - Antenna Beam pattern

- Benefits of Cross Layer Design
  - PHY layer limitations are considered
  - Network resources are utilized to the best possible extent

Ref: Channel, Capacity, and Flow Assignment in Wireless Mesh Networks Presentation, by Vishwanath Ramamurthi

Wireless Constraints

- Primary Interference Constraint:



- Signal-to-Interference-and-Noise Ratio (SINR) Constraint:

$$\frac{G_{(i,j)}P_{(i,j)}}{N_o + \sum_{(p,q)\in L_t} I_{(p,q,i,j)}P_{(p,q)}} \geq \beta$$

Ref: Channel, Capacity, and Flow Assignment in Wireless Mesh Networks Presentation, by Vishwanath Ramamurthi

Channel, Capacity, and Flow Assignment (CCFA)

- Given:
  - Network Topology, source-destination demands $\gamma_{s,d}$
  - Number of non-overlapping channels K
  - Number of Network Interface Cards (NICs) on each node q_i
- Minimize: T
- With respect to: $\{C_{i,j}\}$, $\{\lambda_{i,j}\}$, and $H_{i,j} \in \{1,\ldots,K\}$

Network Utility

- Efficiency of a WMN

$$\eta = \frac{\text{Total Throughput}}{\text{Total Demand}} = \frac{\gamma}{D} = \frac{\sum \gamma_{s,d}}{\sum D_{s,d}}$$

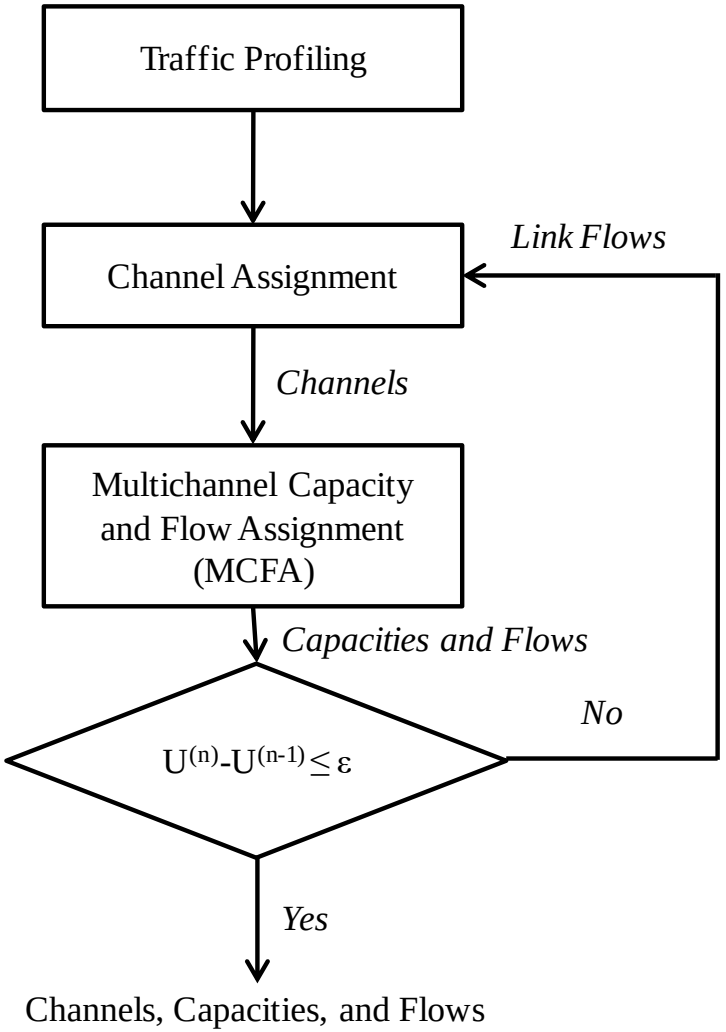
- Utility U is defined to include both throughput and delay

$$U = \frac{\eta^{Em}}{T}$$

- Em = " Throughput emphasis factor "
  - How much is throughput emphasized over delay
- Generalized version of Kleinrock's "Power" of a network

Ref: Channel, Capacity, and Flow Assignment in Wireless Mesh Networks Presentation, by Vishwanath Ramamurthi

Overall CCFA Algorithm



Topology CFA

- Given:
  - Number of nodes and their locations
  - Number of interfaces per node
  - Source-destination traffic demands $\gamma_{s,d}$
- Minimize: T
  - With respect to: $\{C_{i,j}\}$, $\{\lambda_{i,j}\}$, and τ
- Output:
  - Optimal Network Topology

Why Topology CFA in WMN?

	Fully connected	Tree	Star
No. of links	high	low	low
Reliability	high	low	low
Interference	high	low	high
Power	high	low	high

Algorithm

Step1: Start with a fully connected Network

Step2: Apply CCFA

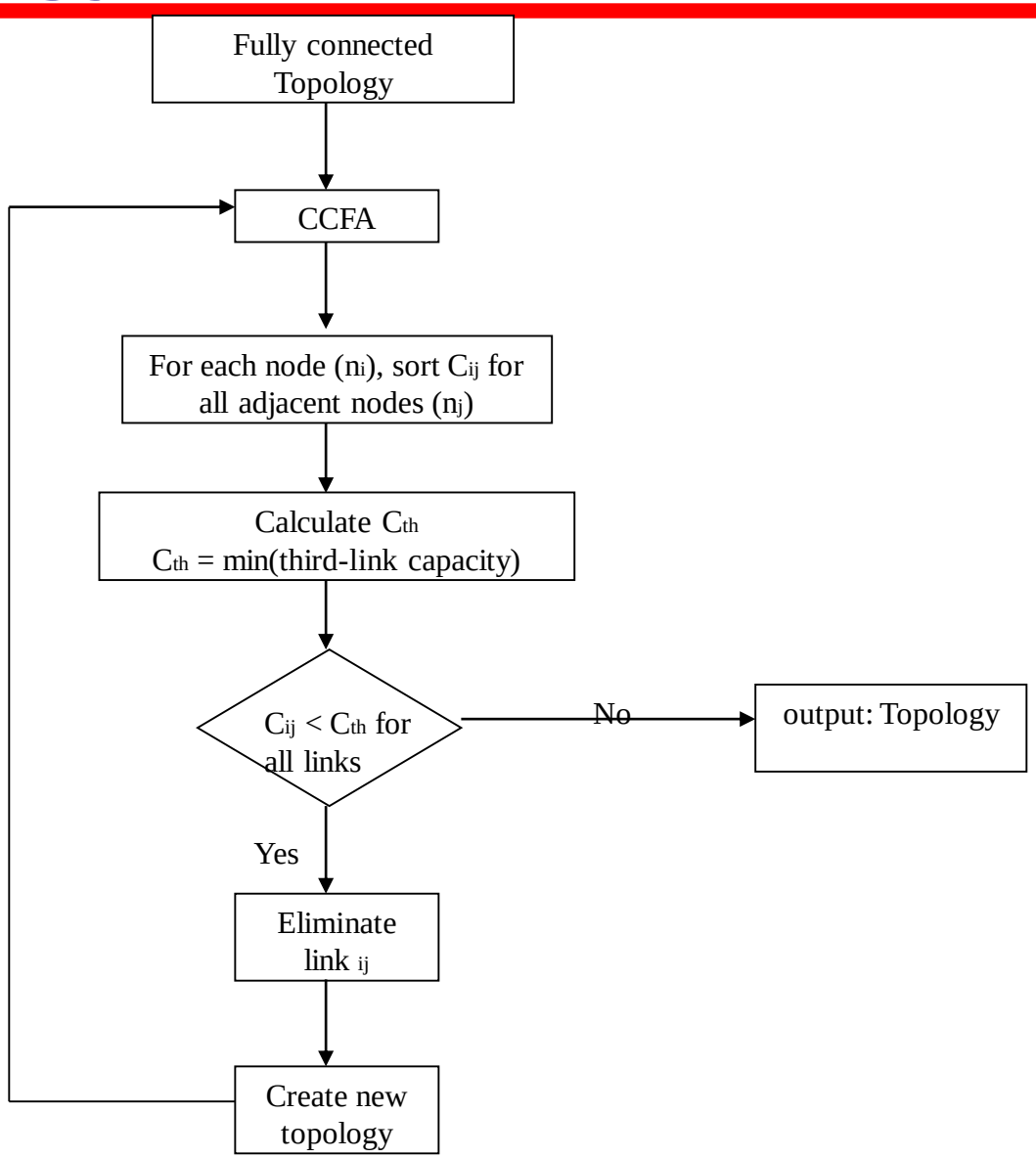
Step3: for each node n_i, sort (in a descending order) the outgoing-link capacities

Step4: Select the minimum third-link capacity among all nodes to be the value of the threshold capacity (C_{th})

Step5: Eliminate links with capacities less than a threshold ($C_{ij} < C_{th}$), create new topology. If no link is eliminated, then stop and output the topology

Step6: Redistribute the capacities and flows of the deleted links by repeating steps 2-5 (input topology for step 2 in each iteration will be changed)

Topology CFA

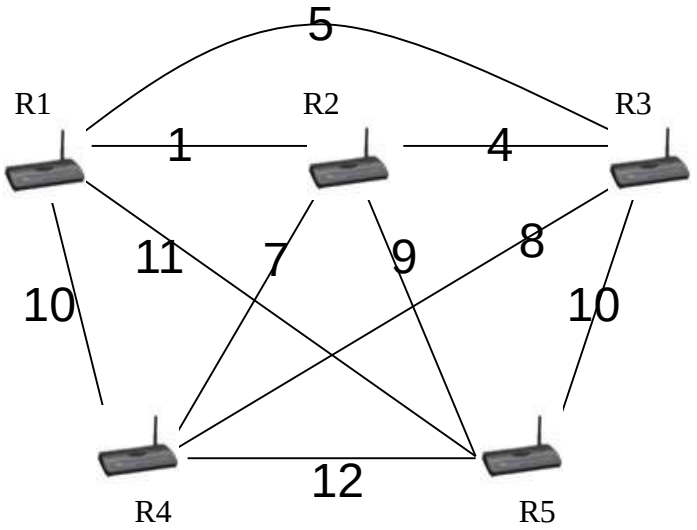


Threshold (C_{th})

- Maintain at least 2-connected network
- C_{th} has to be less than the second biggest link capacity adjacent to any node
- C_{th} is the third minimum link capacity among all nodes

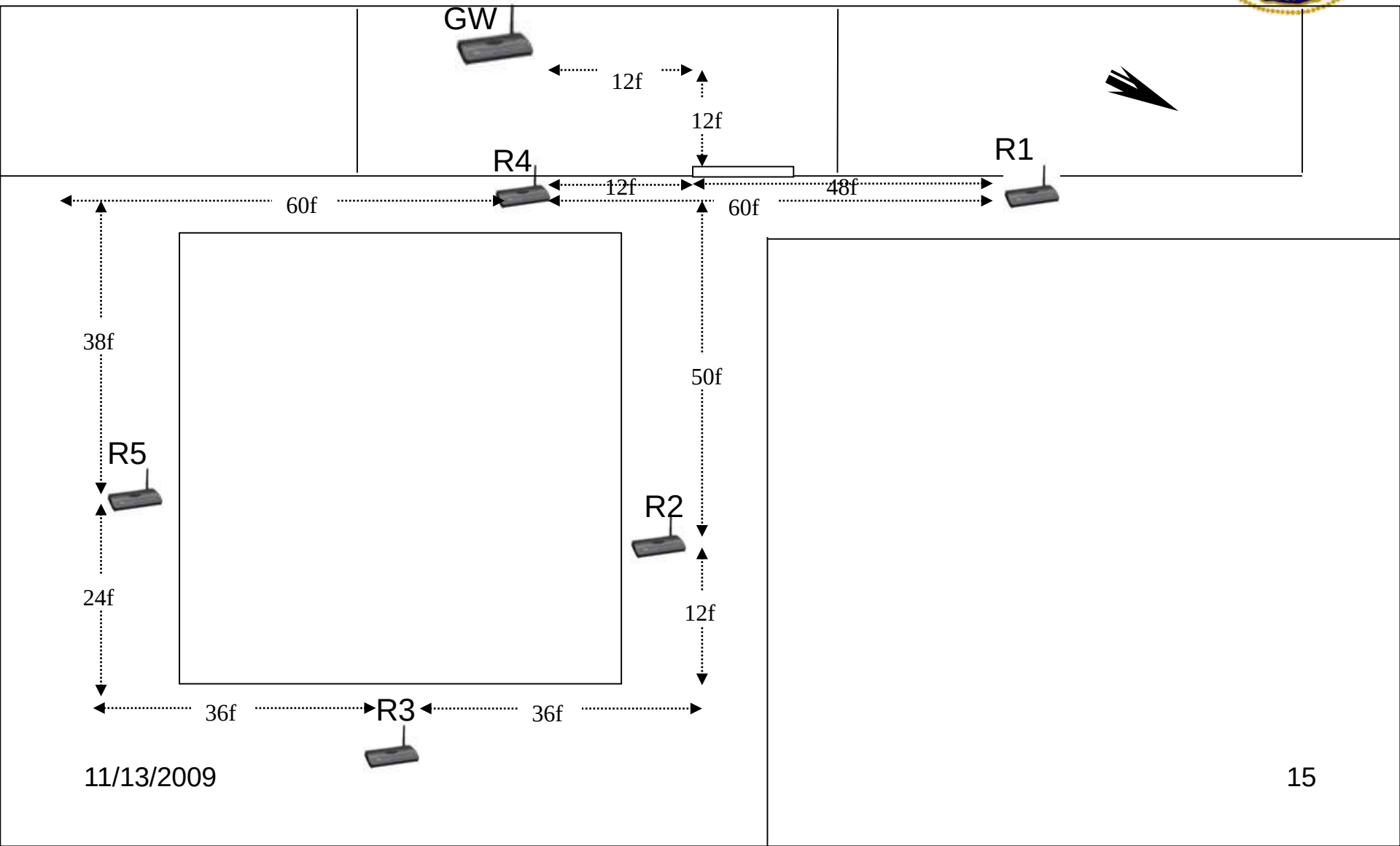
Threshold (Cth)

- R1
  - C15 = 11
  - C14 = 10
  - C13 = 5
  - C12 = 1
- R2
  - C25 = 9
  - C24 = 7
  - C23 = 4
  - C21 = 1

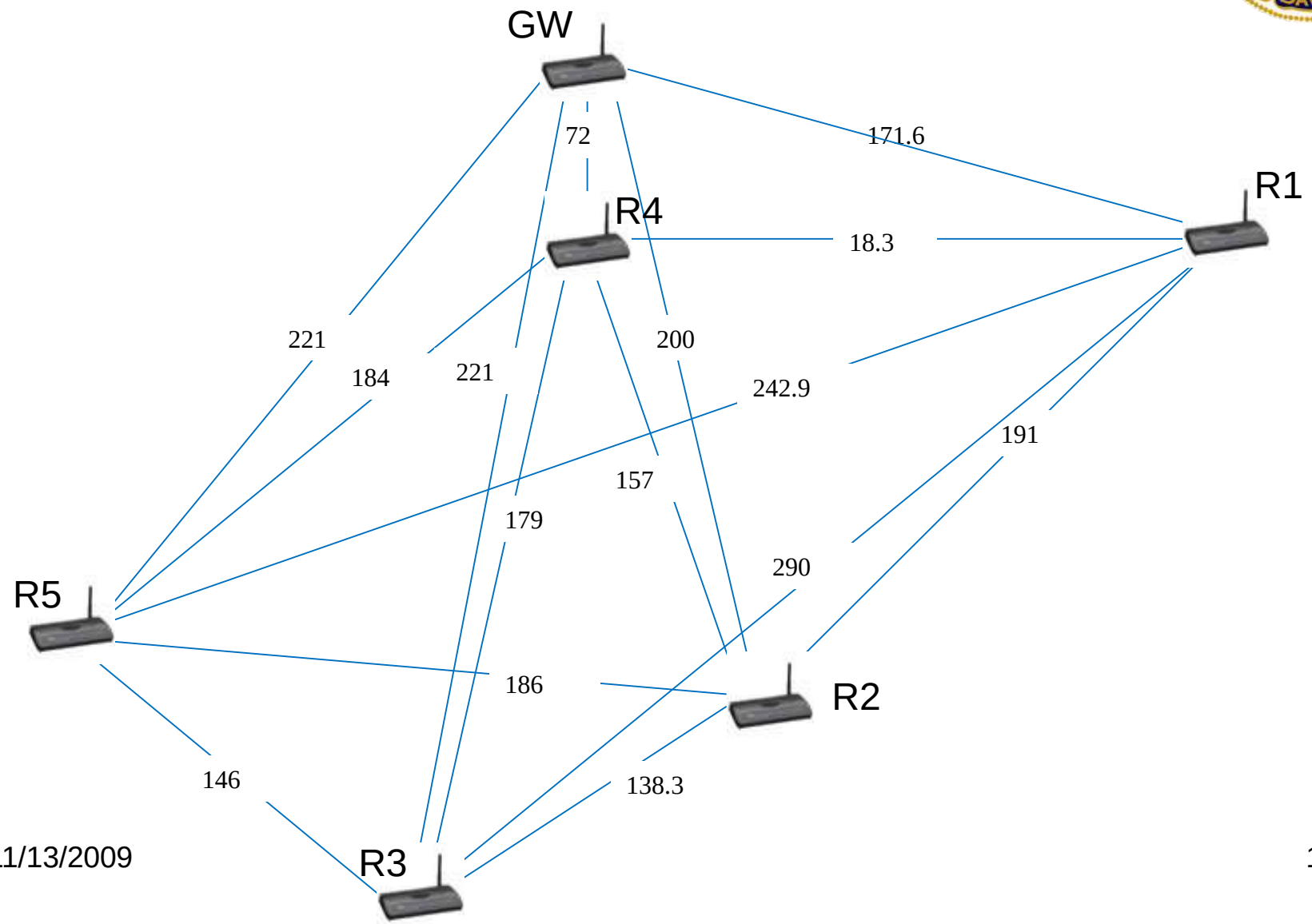


- R3
  - C35 = 10
  - C34 = 8
  - C31 = 5
  - C32 = 4
- R4
  - C45 = 12
  - C41 = 10
  - C43 = 8
  - C42 = 7
- R5
  - C54 = 12
  - C51 = 11
  - C53 = 10
  - C52 = 9

Testbed layout (Kemper Hall 2nd floor)

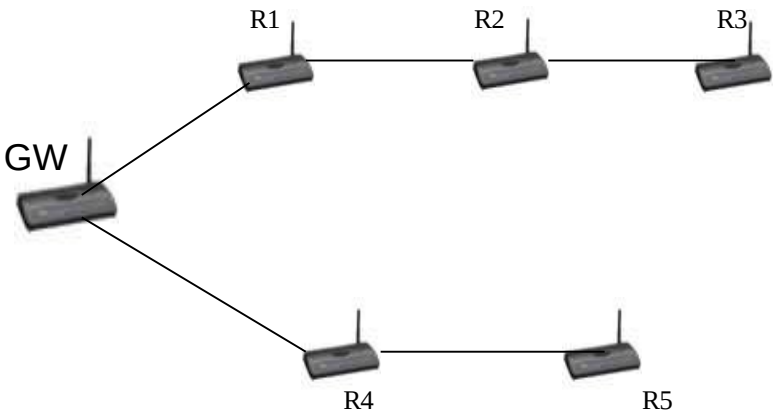


Testbed layout (distances)

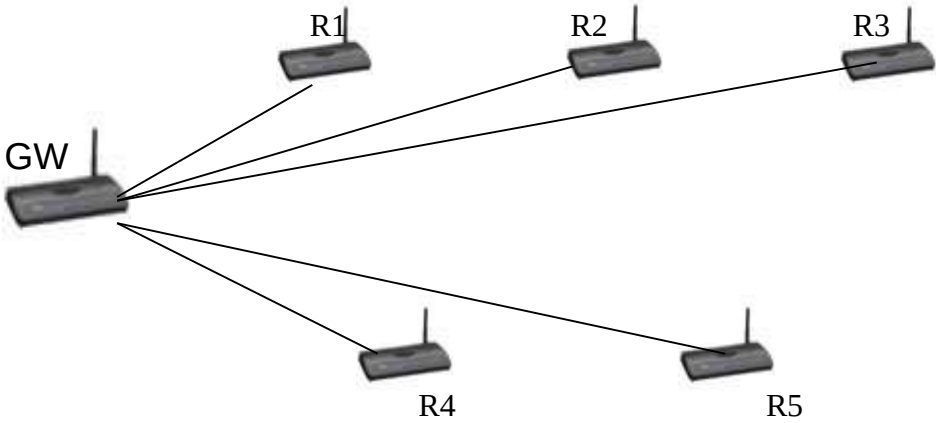


Tested Topologies

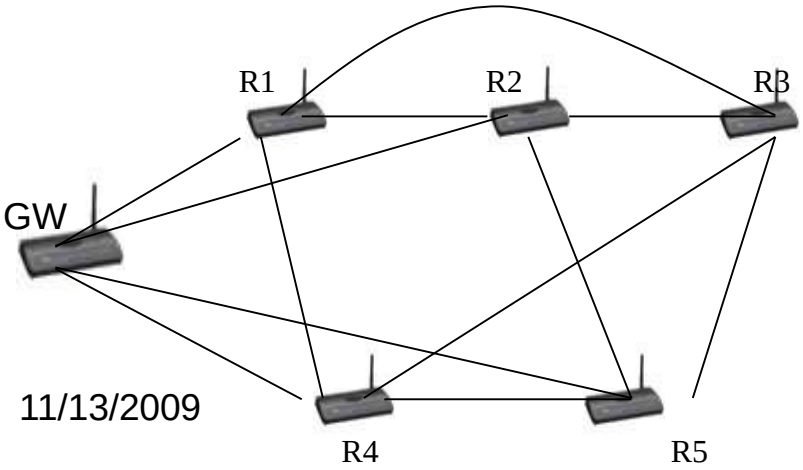
Tree Topology



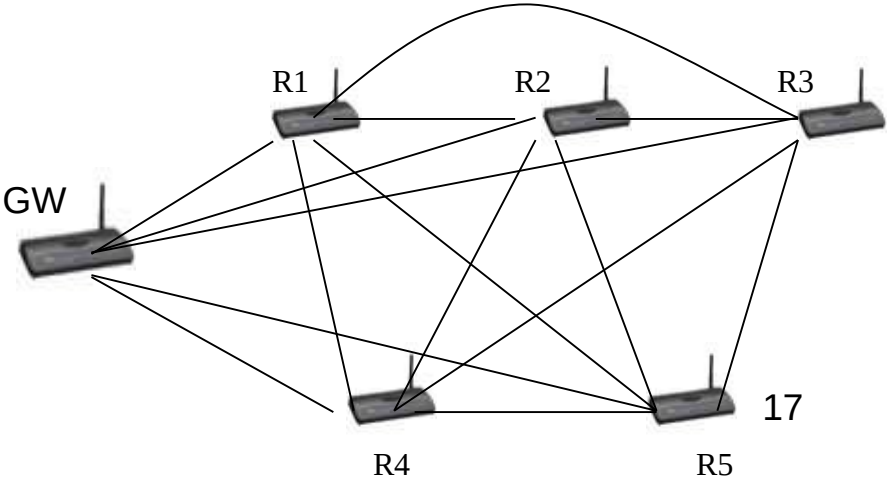
Star Topology



4-connected Topology

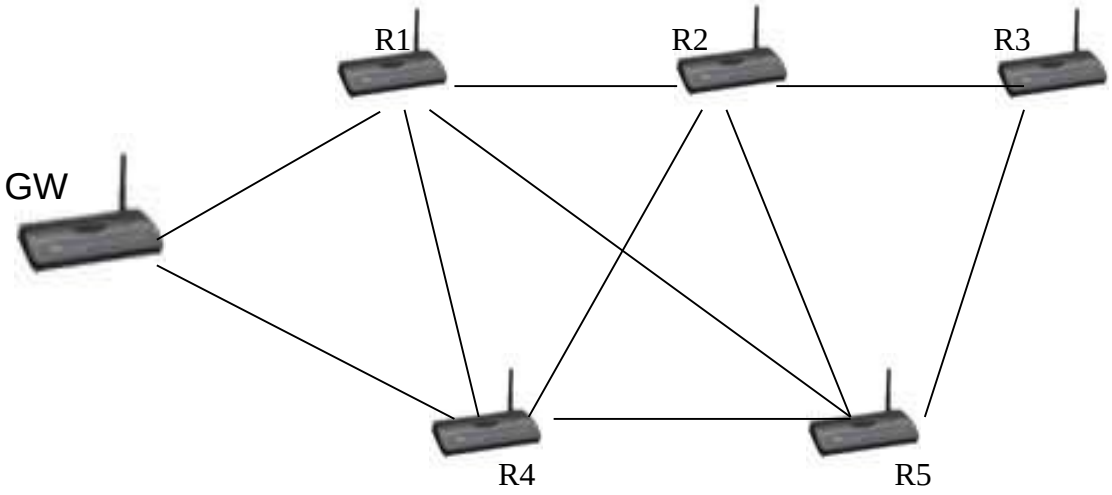


5-connected Topology



Tested Topologies

Option 2 Topology

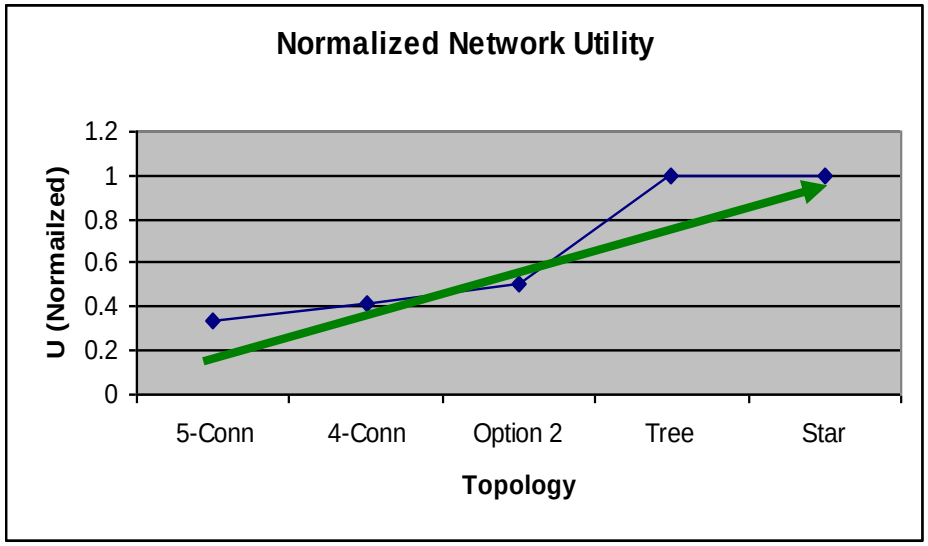


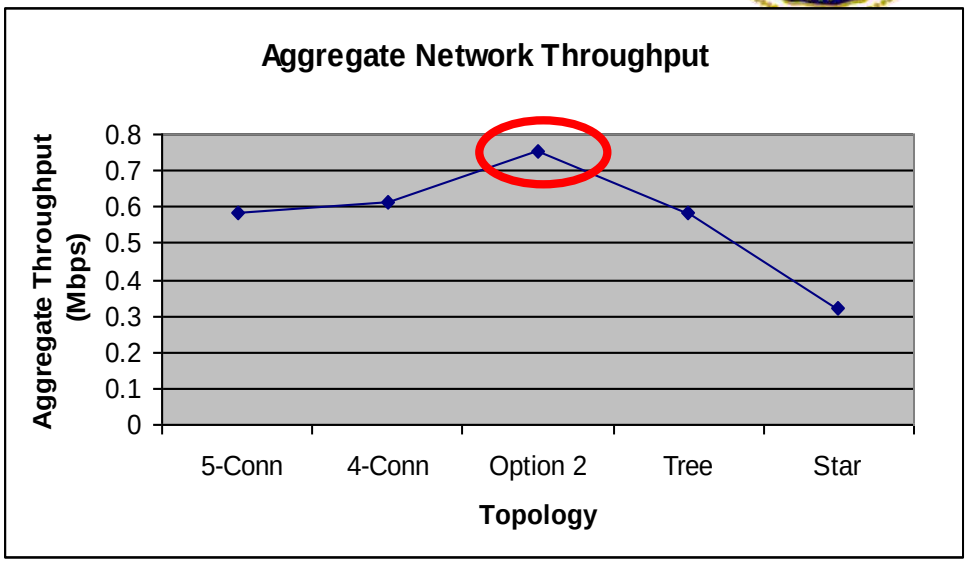
Assumptions

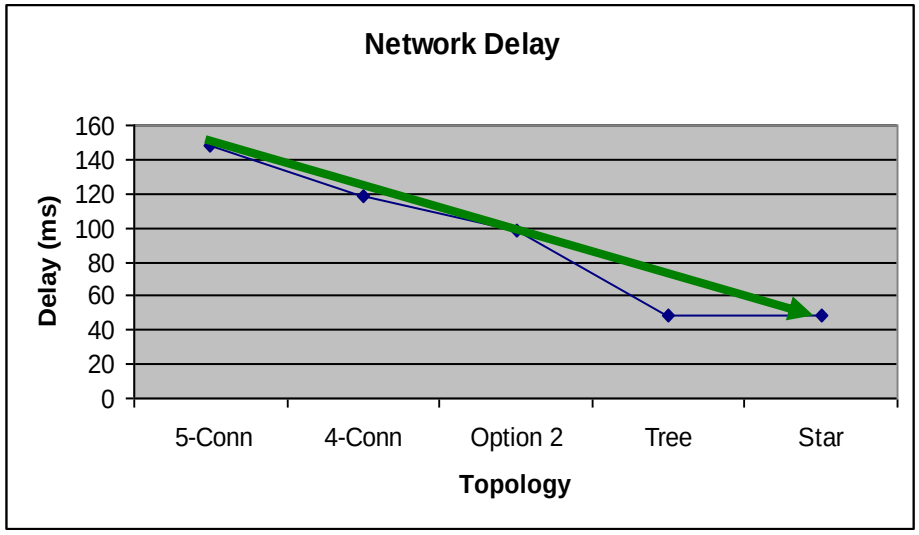
- All links are located within one interference range
- Single channel
- Single radio per node
- Traffic at each node follow the same pattern

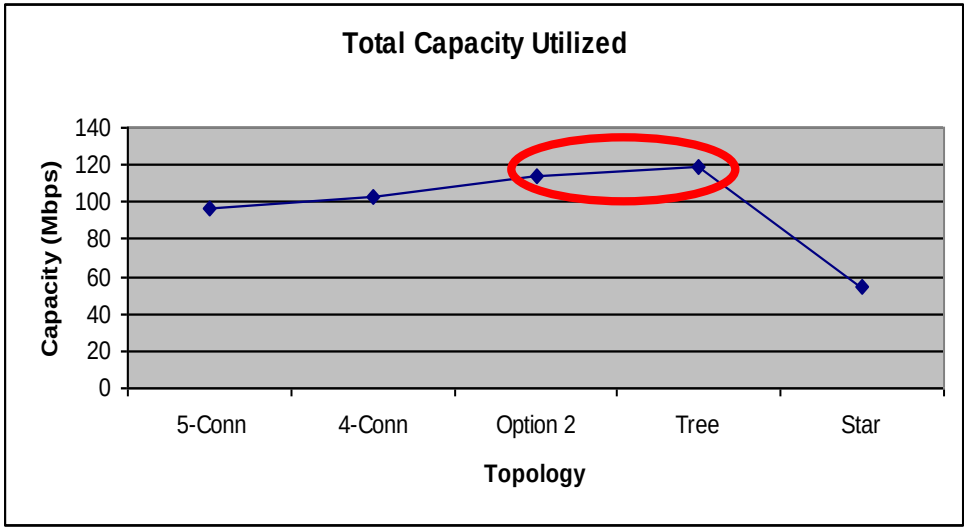
  (Du(i) = Dd(i) = xMbps)

Results (2Mbps)

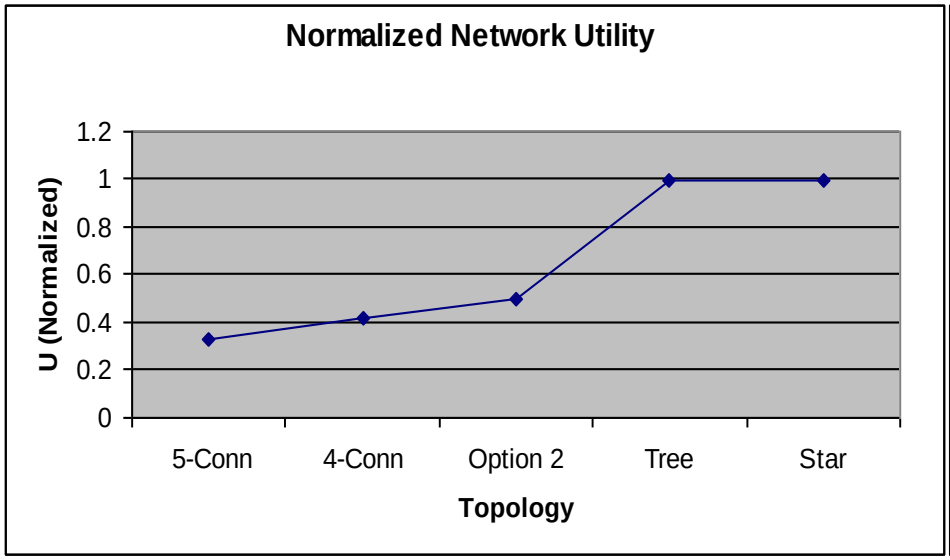


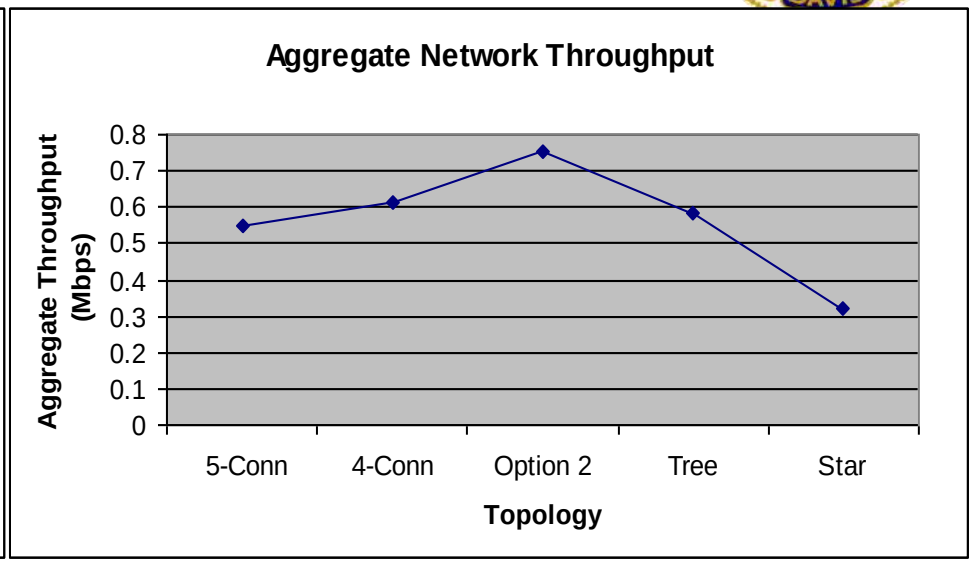


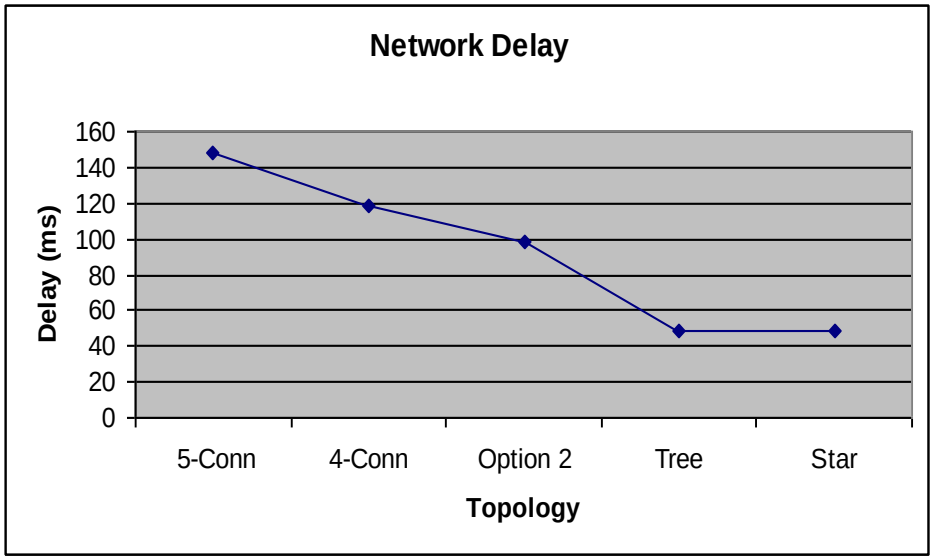


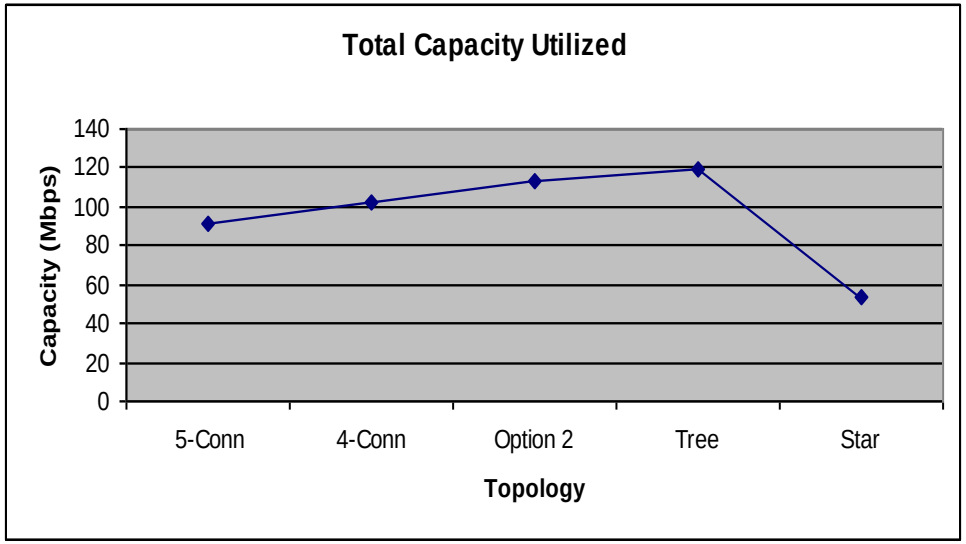


Results (12Mbps)

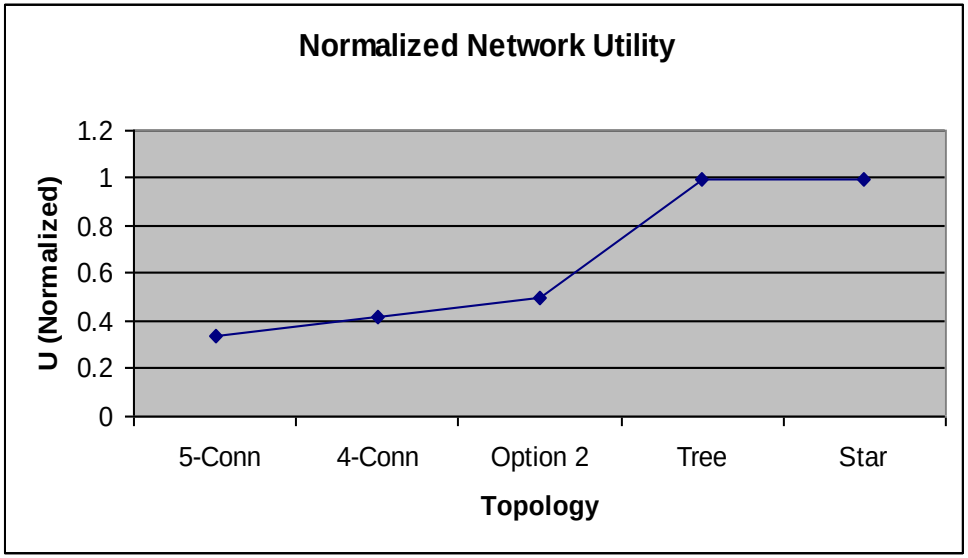


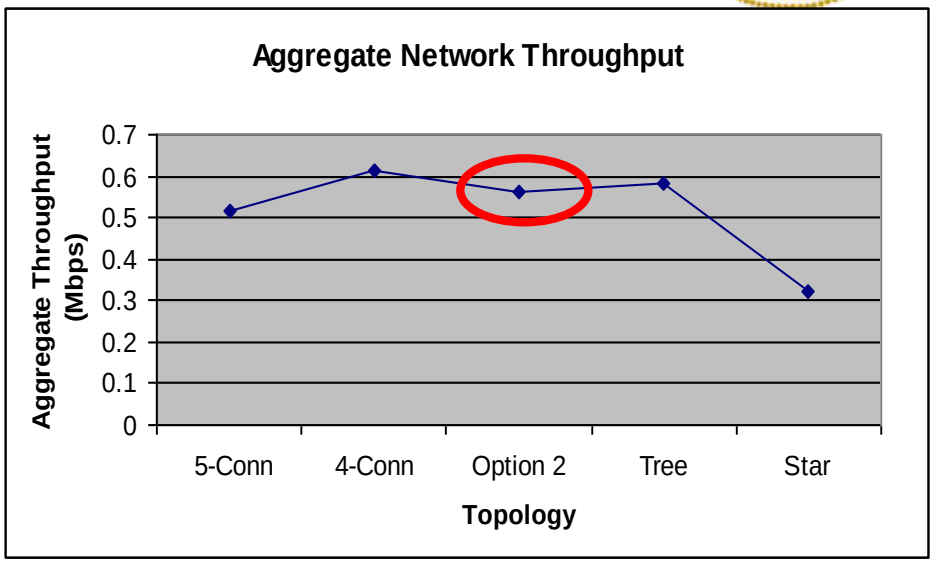


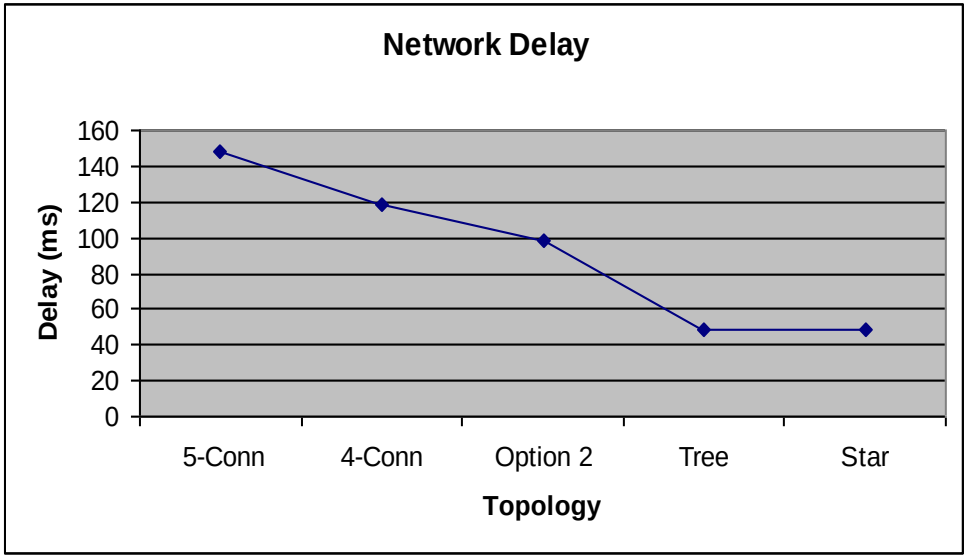


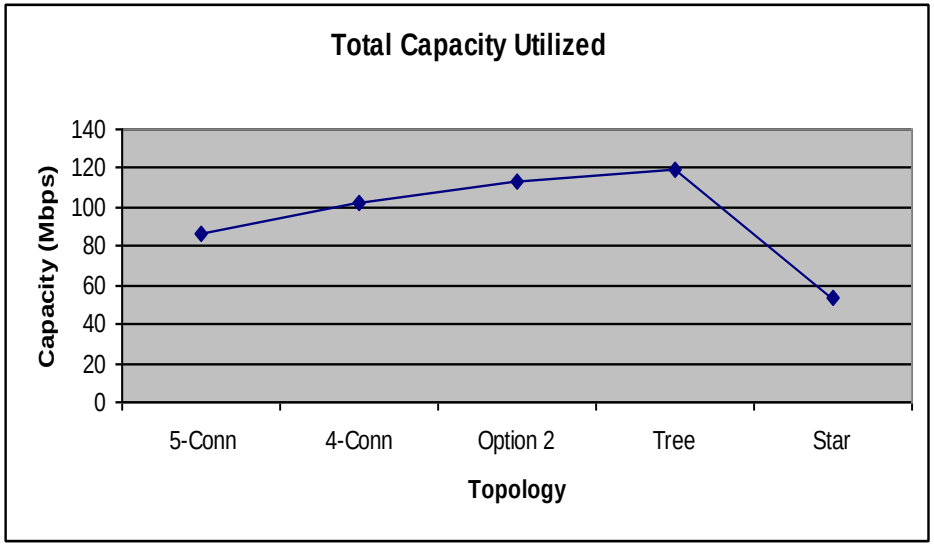


Results (54Mbps)



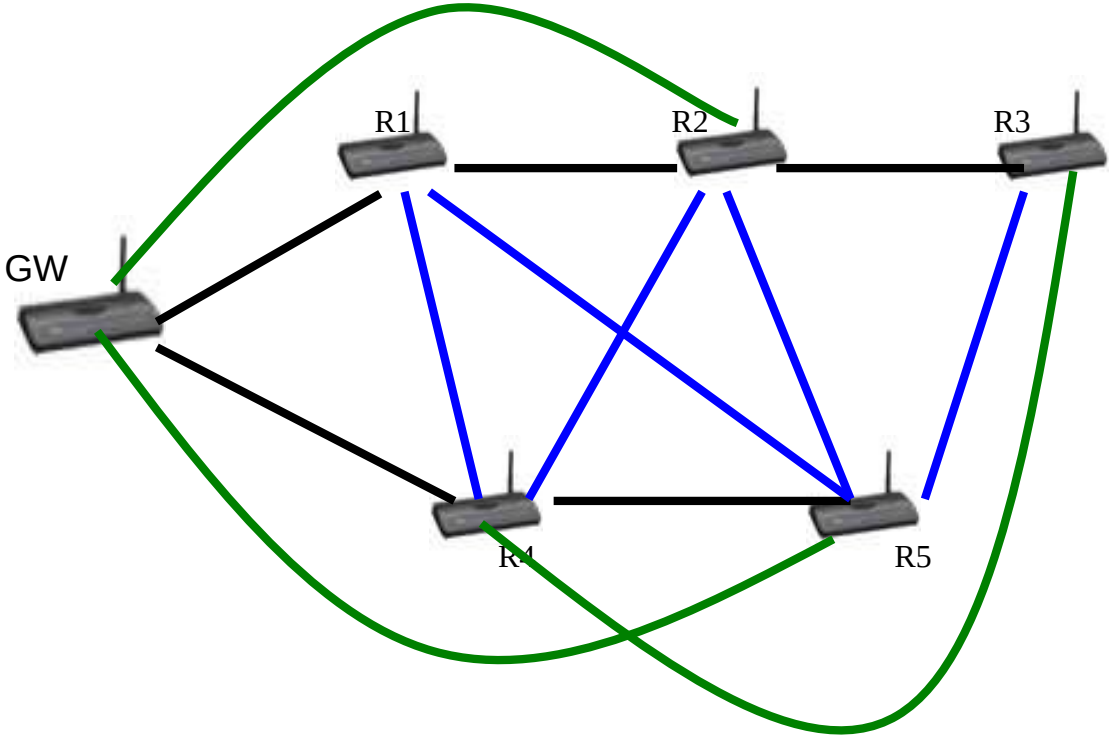




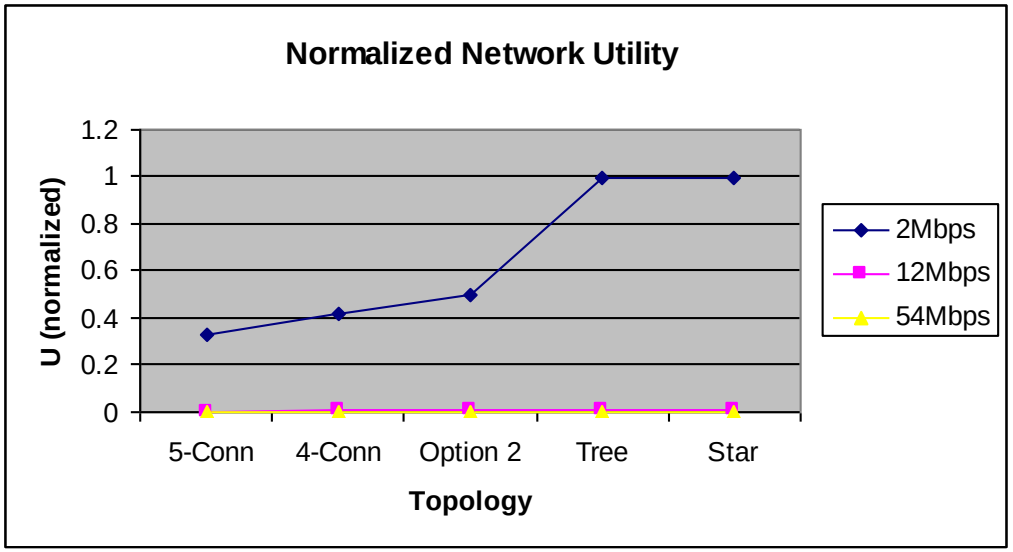


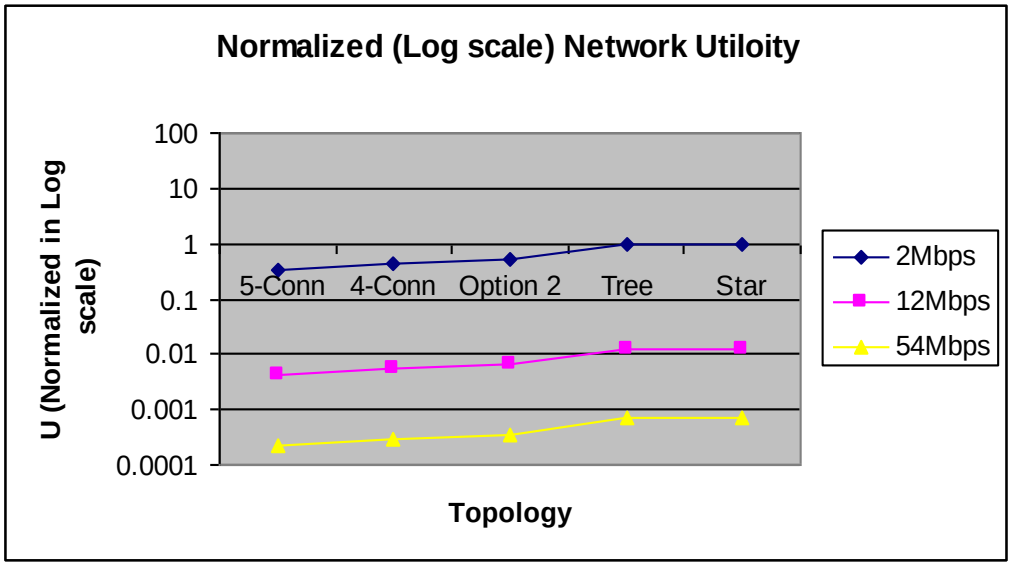
Tested Topologies

Option 2 Topology



Results


Normalized Network Utility
U (normalized)
1.2
1
0.8
0.6
0.4
0.2
0
5-Conn
4-Conn
Option 2
Tree
Star
Topology
2Mbps
12Mbps
54Mbps


Normalized (Log scale) Network Utiloity
U (Normalized in Log scale)
100
10
1
0.1
0.01
0.001
0.0001
5-Conn
4-Conn
Option 2
Tree
Star
Topology
2Mbps
12Mbps
54Mbps

What is next!

- Test the following cases:

  - varies number of radios (available capacity)
  - varies number of links
  - varies the transmission power
  - multi-channel

- Develop TCFA mathematical equations

Q&A

Thank you