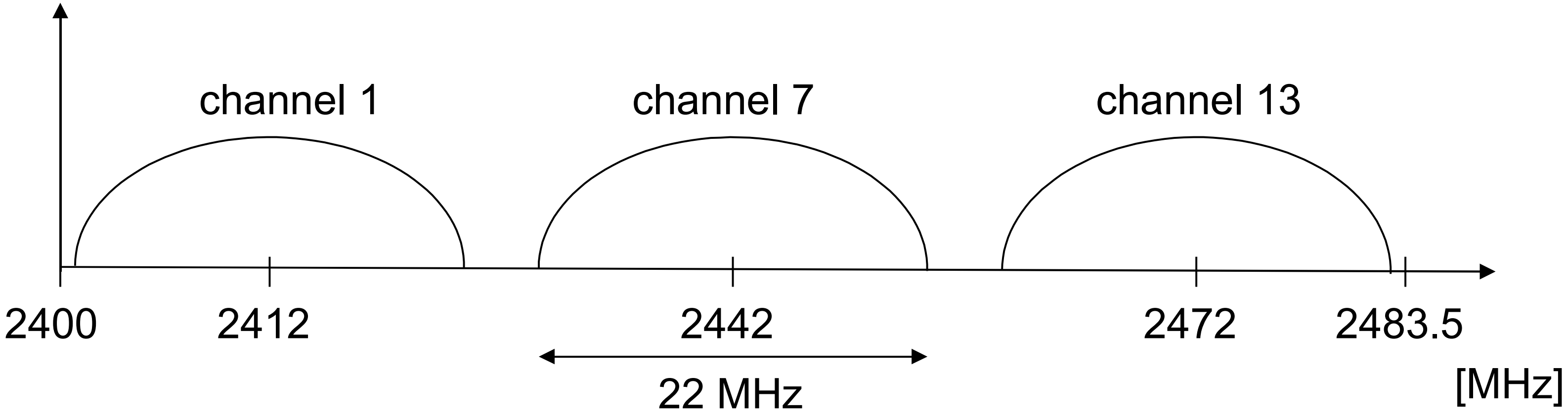
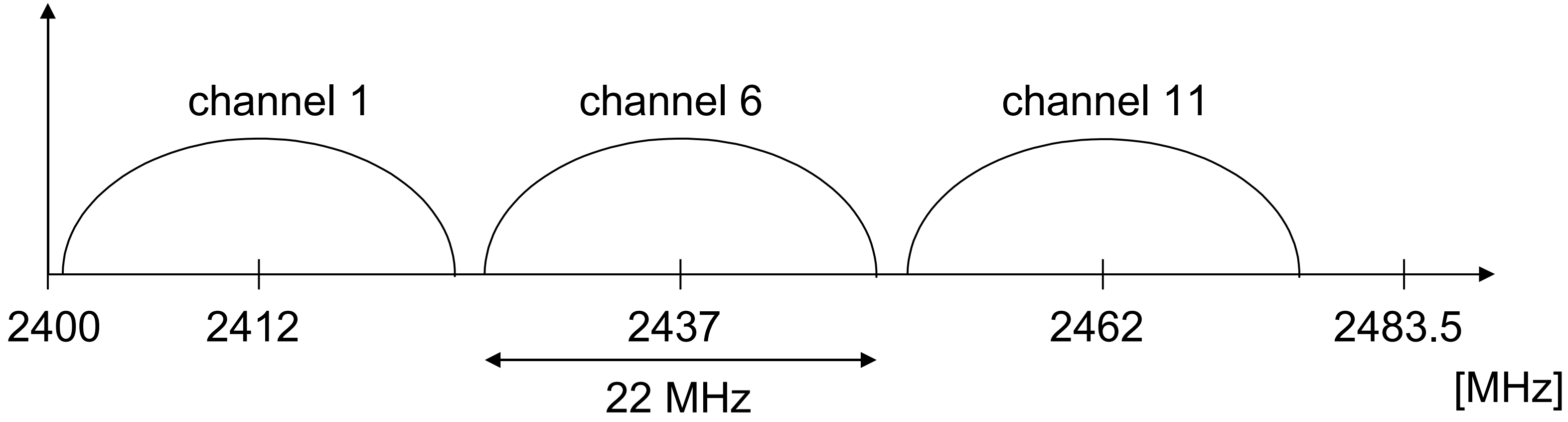
Channel Assignment and Channel Hopping in IEEE 802.11

Operating Channels for 802.11b

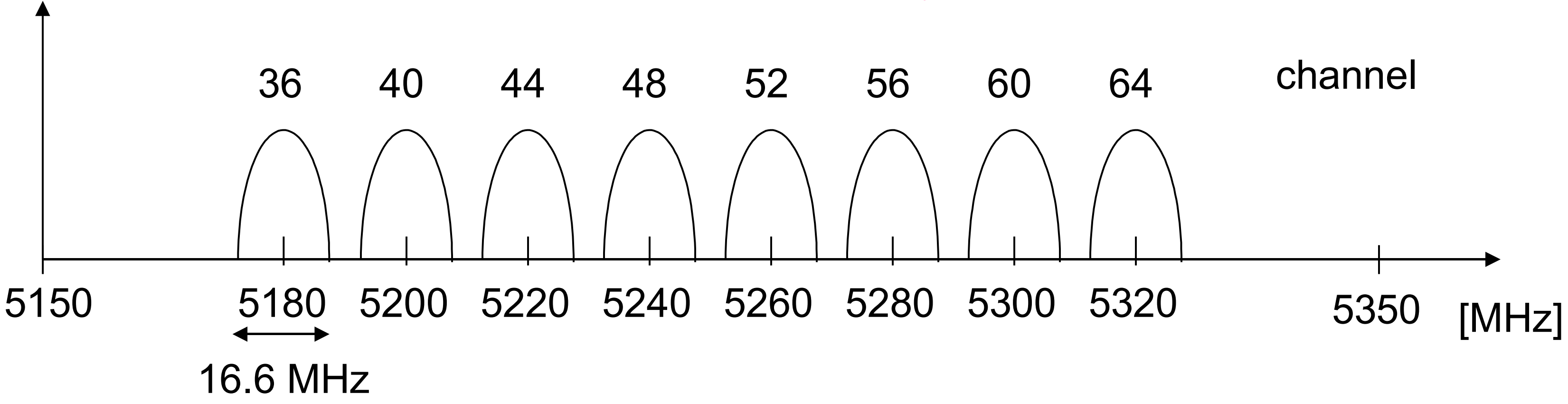
Europe (ETSI)

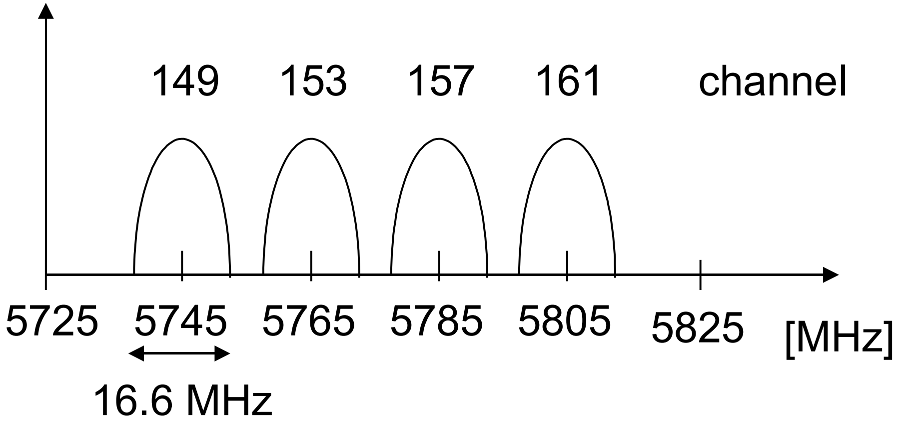


US (FCC)/Canada (IC)



Operating channels for 802.11a / US U-NII





center frequency =
5000 + 5*channel number [MHz]

SSCH: Slotted Seeded Channel Hopping for Capacity Improvement in IEEE 802.11 Ad-Hoc Wireless Networks

Victor Bahl, Ranveer Chandra, John Dunagan

Questions

- How to take advantage of channelization in multihop networks?

- Challenge:
  - Sender and receiver have to share a channel → all nodes on a multihop path use the same channel

Two Approaches

- Using multiple radios
- Using SSCH

SSCH

- Goal: Extend the benefits of channelization to ad-hoc networks

- SSCH (Slotted Seeded Channel Hopping)
  - Improve capacity in ad-hoc wireless multi-hop networks
  - Use a single radio
  - Do not use dedicated control channel
  - Do not require changes to 802.11

SSCH - Overview

- SSCH divides the time into equal sized slots and switches each radio across multiple orthogonal channels on the boundary of slots in a distributed manner
- Main Aspects of SSCH
  - Channel Scheduling
    - Self-computation of tentative schedule
    - Communication of schedules
    - Synchronization with other nodes
  - Packet Scheduling within a slot

SSCH - Desired Properties

- **No Logical Partition:** Ensure all nodes come into contact occasionally so that they can communicate their tentative schedule
- **Synchronization:** Allow nodes that need to communicate to synchronize
- **De-synchronization:** Infrequently overlap between nodes with no communication

Channel Scheduling - Self-Computation

- Each node use (channel, seed) pairs to represent its tentative schedule for the next slot.
- Seed: [1 , number of channels -1]. Initialized randomly.
- Focus on the simple case of using one pair
- Update Rule:

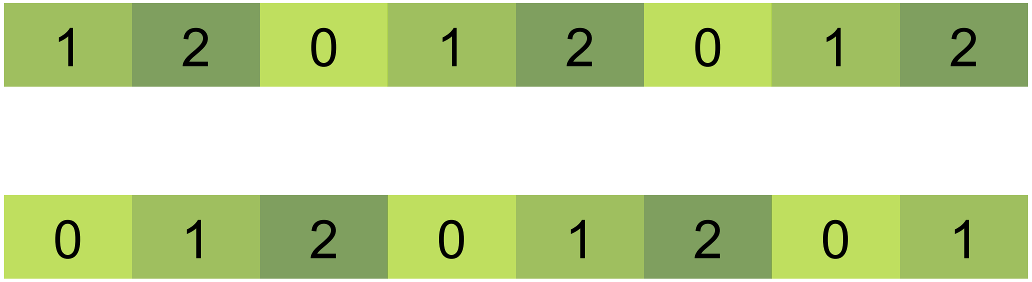
new channel = (old channel + seed) mod (number of channels)

A: Seed = 2	1	0	2	1	0	2	1	0
B: Seed = 1	0	1	2	0	1	2	0	1

Example: 3 channels, 2 seeds

Channel Scheduling - Logical Partition

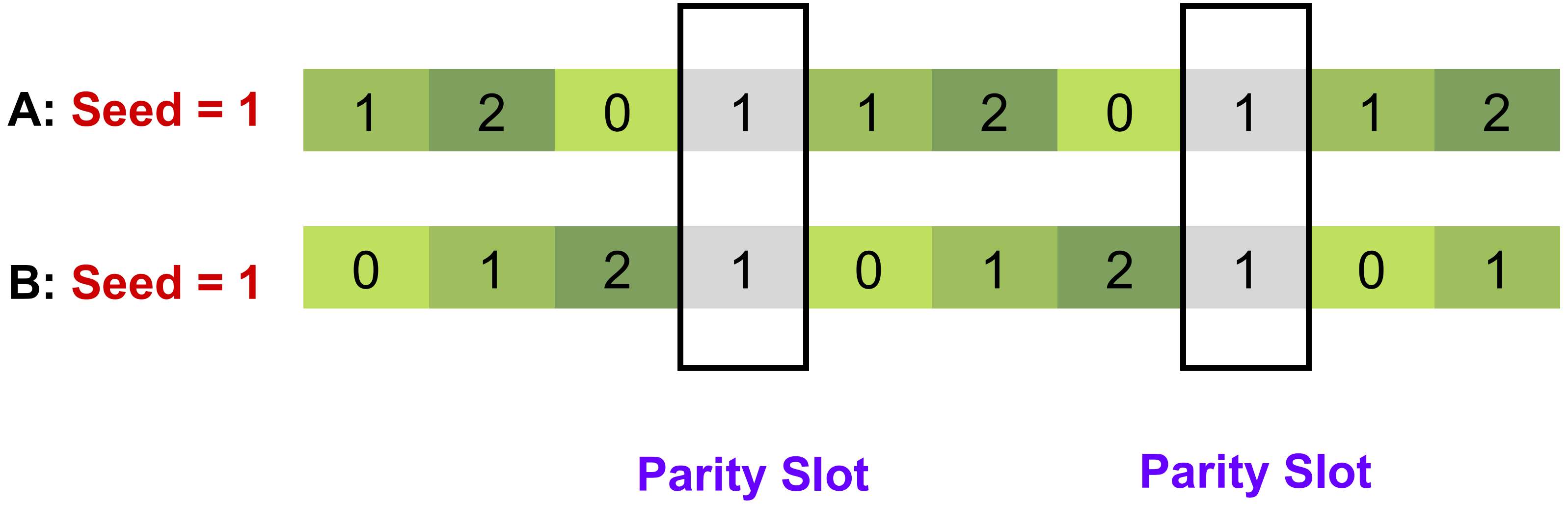
- Are nodes guaranteed to overlap?
  - Same channel, same seed (always overlap)
  - Same channel, different seed (overlap occasionally)
  - Different channel, different seed (overlap occasionally)
- Special case: Nodes may never overlap if they have the same seeds and different channels



A: **Seed = 1**	1	2	0	1	2	0	1	2
B: **Seed = 1**	0	1	2	0	1	2	0	1

Channel Scheduling – Solution to Logical Partition

- Parity Slot
  - Every (number of channels) slots, add a parity slot. In parity slot, the channel number is the seed.
  - Do not allow the seed to change until the parity slot



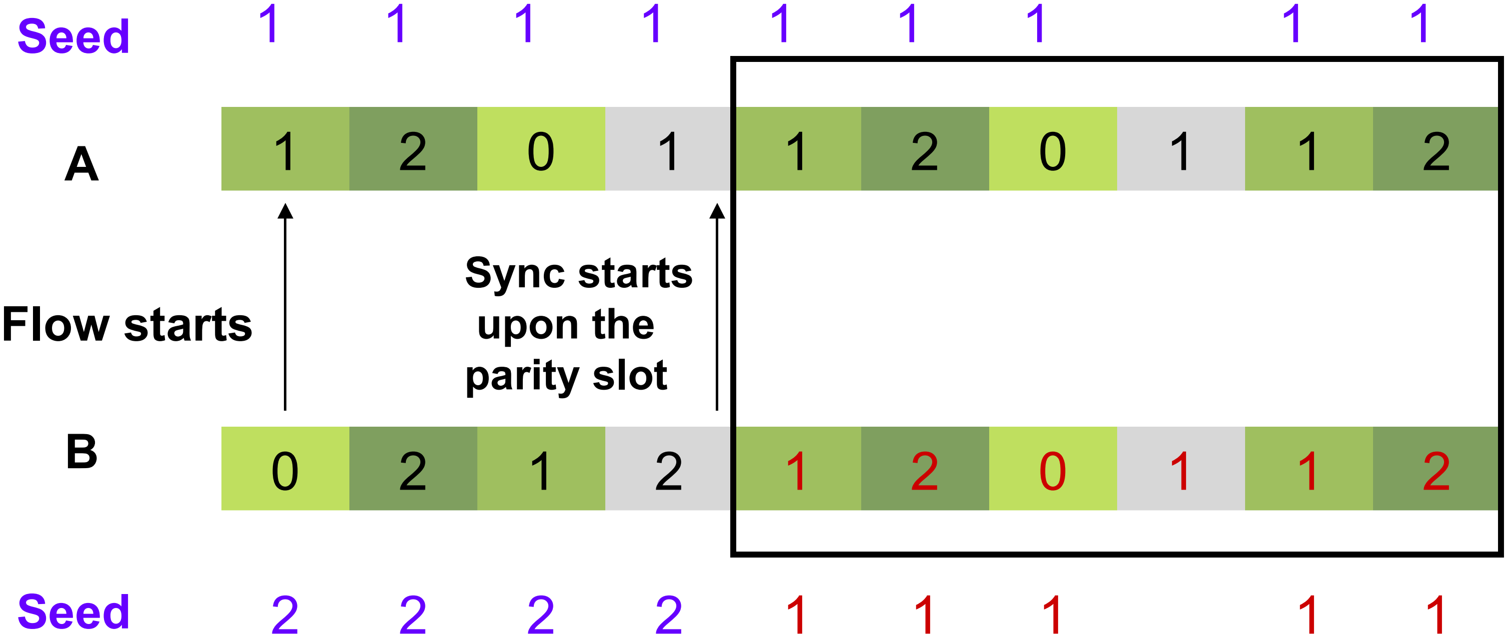
A: Seed = 1	1	2	0	1	1	2	0	1	1	2
B: Seed = 1	0	1	2	1	0	1	2	1	0	1

Channel Scheduling - Communication of Schedules

- Each node broadcasts its tentative schedule (represented by the pair) once per slot

Channel Scheduling - Synchronization

- If node B needs to send data to node A, it adjusts its (channel, seed) pair to be the same as A.



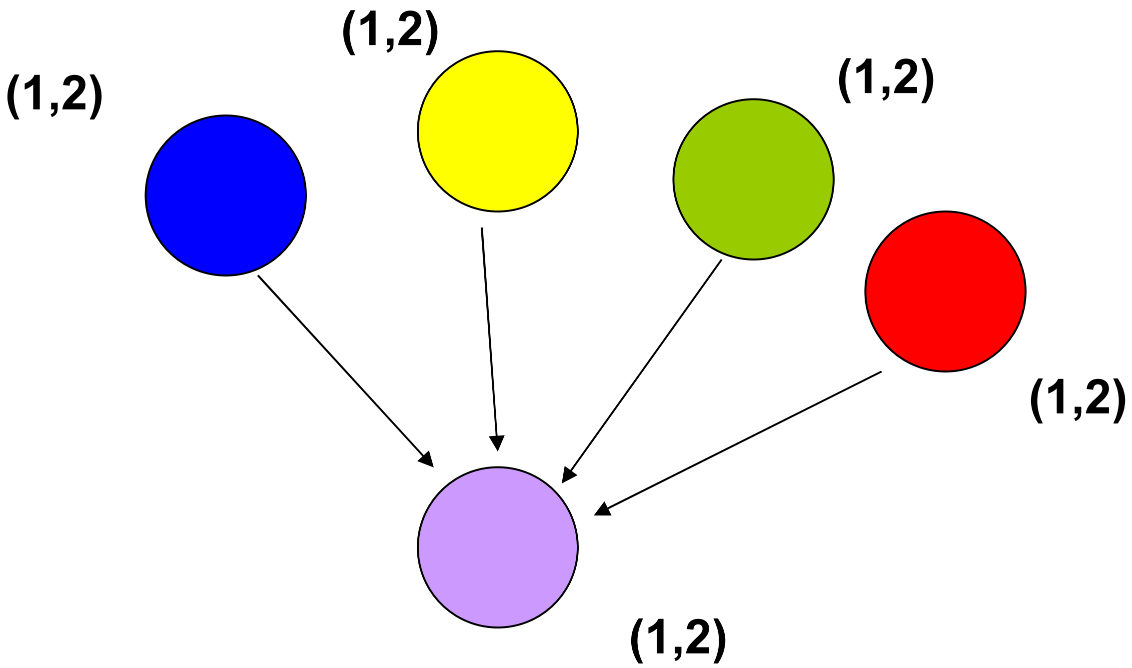
Seed	1	1	1	1	1	1	1		1	1
A	1	2	0	1	1	2	0	1	1	2
B	0	2	1	2	1	2	0	1	1	2
Seed	2	2	2	2	1	1	1		1	1

Flow starts

Sync starts upon the parity slot

Channel Scheduling - Channel Congestion

- It is likely various nodes will converge to the same (channel, seed) pair and communicate infrequently after that.



Channel Scheduling – Solution to channel congestion

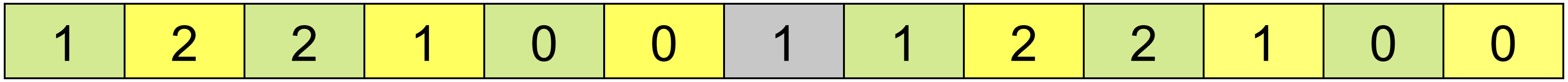
- De-synchronization
- To identify channel congestion: compare the number of the synchronized nodes and the number of the nodes sending data. De-synchronize when the ratio >= 2.
- To de-synchronize, simply choose a new (channel, seed) pair for each synchronized and non-sending nodes

Channel Scheduling – Synchronizing with multiple nodes

- Examples
  - a sender with multiple receivers
  - a forwarding node in a multi-hop network
- Solution: Use multiple seeds per node
  - Use one seed to synchronize with one node
  - Add a parity slot every cycle (= number of channels * number of seeds). The channel number of the parity slot is the first seed.
  - The first seed is not allowed to change until the parity slot.

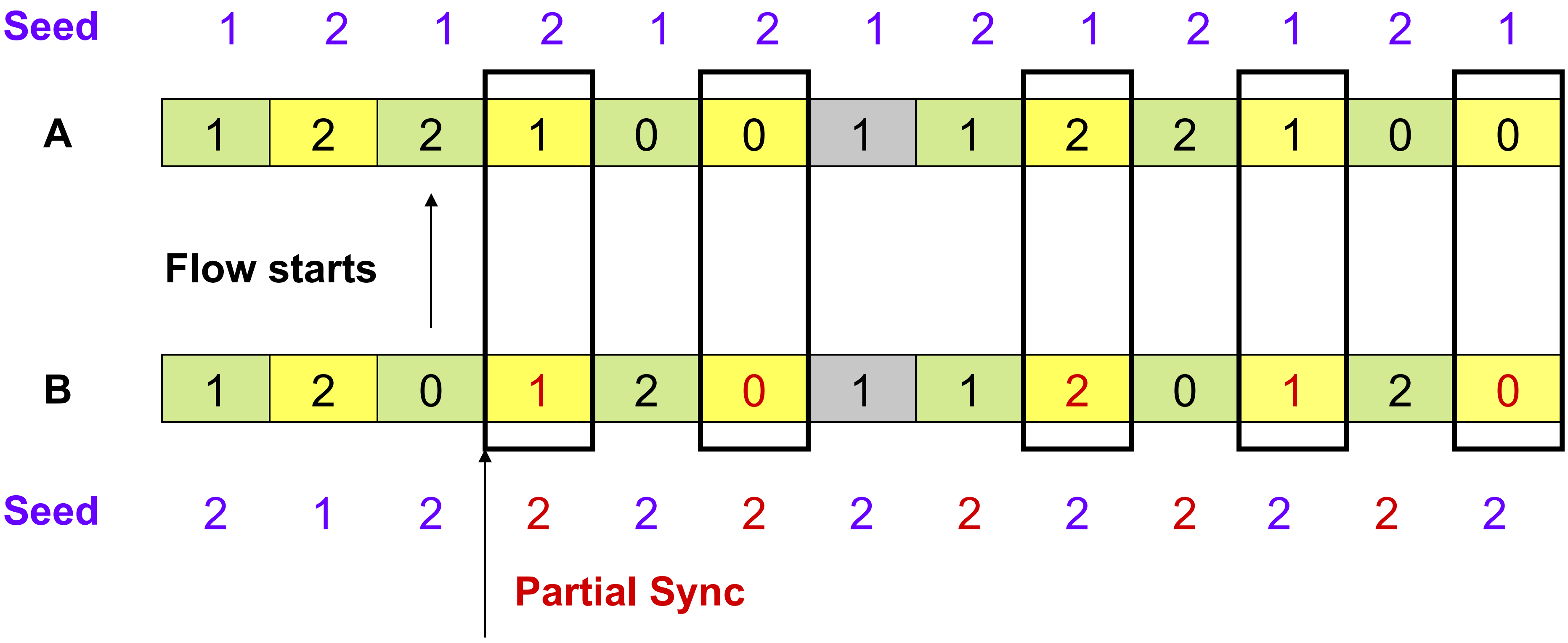
Green slots are generated by seed 1

Yellow slots are generated by seed 2



1	2	2	1	0	0	1	1	2	2	1	0	0

Channel Scheduling - Partial Synchronization



Seed	1	2	1	2	1	2	1	2	1	2	1	2	1
A	1	2	2	1	0	0	1	1	2	2	1	0	0
B	1	2	0	1	2	0	1	1	2	0	1	2	0
Seed	2	1	2	2	2	2	2	2	2	2	2	2	2

Flow starts

Partial Sync

Sync the second seed only

Packet Scheduling - Main Idea

- Send packets to receivers in the same channel and delay sending packets to receivers in other channels

Packet Scheduling - Basic Scheme

- Within a slot, a node transmits packets in a round robin fashion among all flows
- For a single flow, the packet is transmitted in FIFO order
- Failed transmission causes the relevant flow to be inactive for half a slot. An inactive flow does not participate the transmission unless there are no active flows.

Packet Scheduling – Absent Destination

- Problem: The destinations are in other channel
- Solution: Retransmission
  - Broadcast: 6 transmission
  - Unicast: Until successful or the cycle ends
- Question: Can SSCH distinguish
  - Destinations in other channels?
  - Failure because of bad channel condition or node crash
  - Collision

Evaluation

- Simulate in QualNet
- 802.11a, 54Mbps, 13 orthogonal channels
- Slot switch time = 80 μs
- 4 seeds per node, slot duration = 10ms
- UDP flows: CBR flows of 512 bytes sent every 50 μs (enough to saturate the channel)

Evaluation - Throughput (UDP)

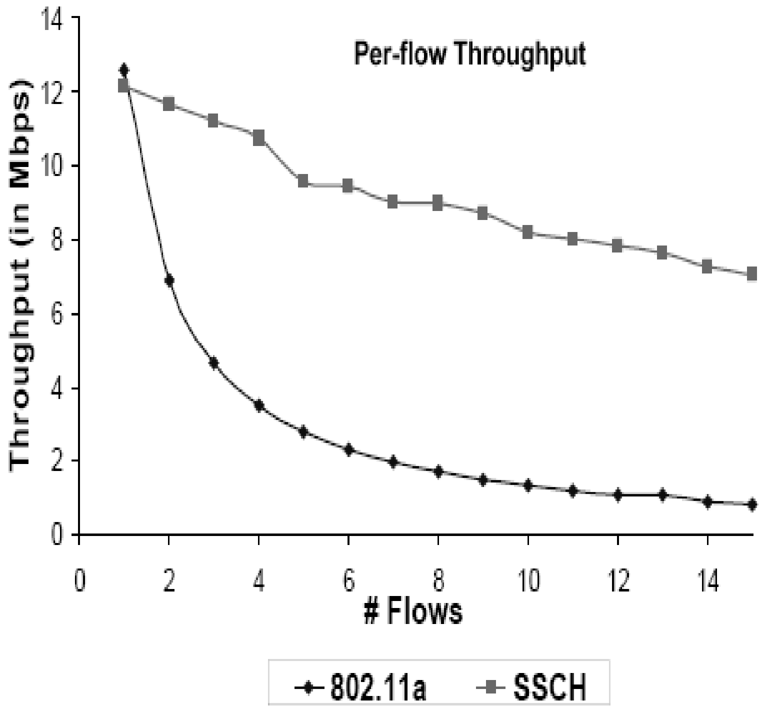


Figure 9: Disjoint Flows: The per-flow throughput on increasing the number of flows.

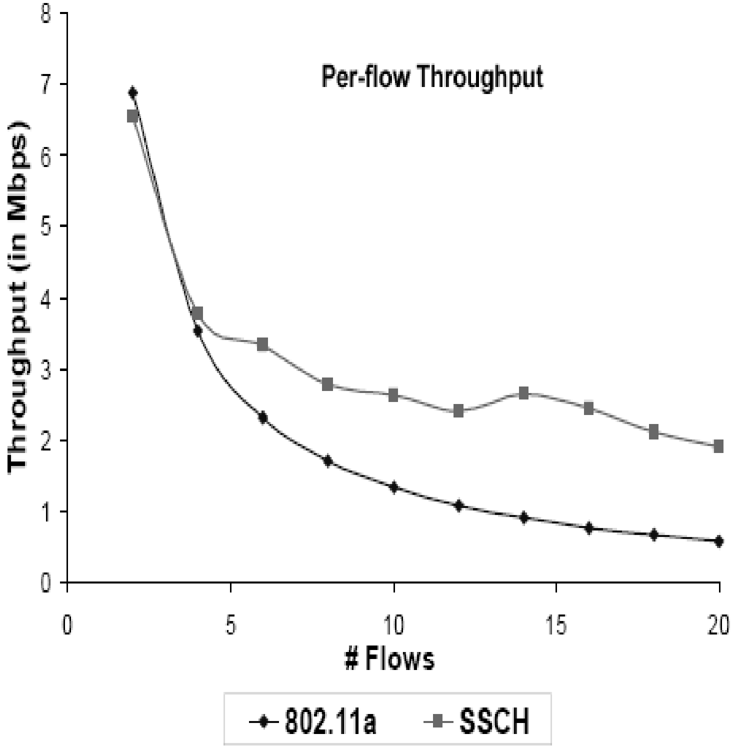


Figure 11: Non-disjoint Flows: The per-flow throughput on increasing the number of flows.

Evaluation – Multi-hop Mobile Networks

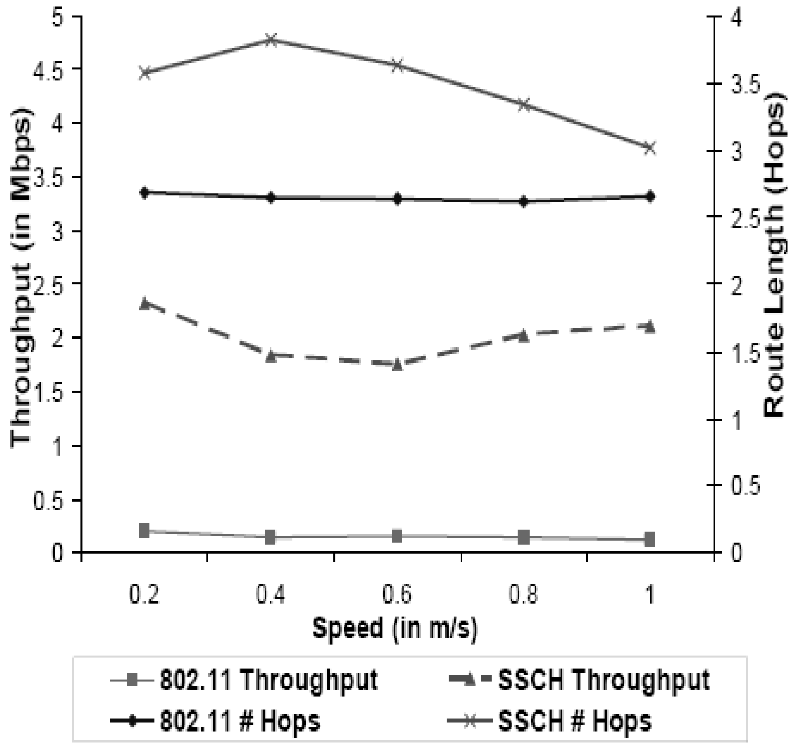


Figure 18: Dense Multi-hop Mobile Network: The per-flow throughput and the average route length for 10 flows in a 100 node network in a $200m \times 200m$ area, using DSR over both SSCH and IEEE 802.11a.

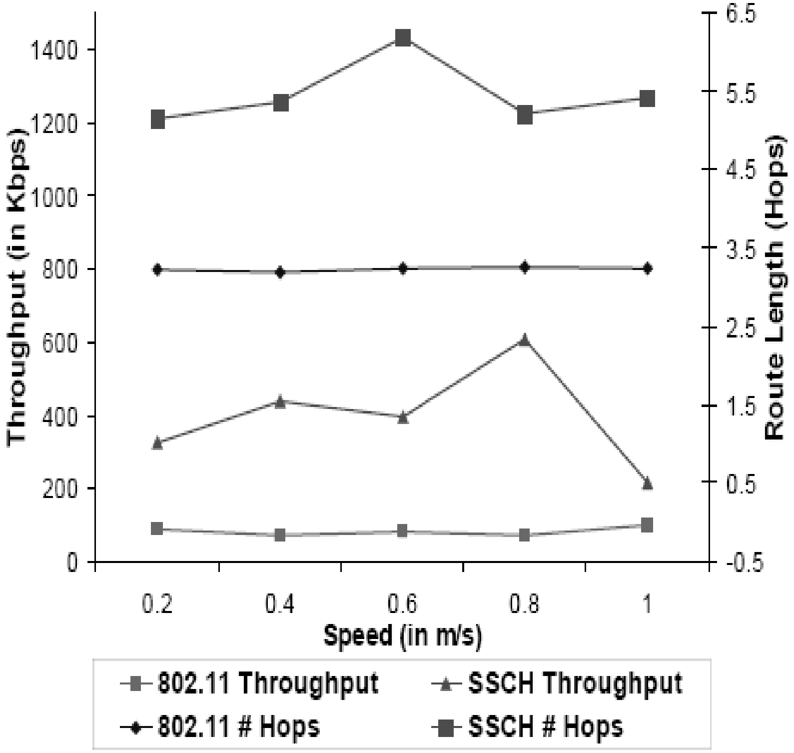


Figure 19: Sparse Multi-hop Mobile Network: The per-flow throughput and the average route length for 10 flows in a 100 node network in a $300m \times 300m$ area, using DSR over both SSCH and IEEE 802.11a.

Future Work

- Implementation over actual hardware
- Interaction with proactive routing protocols
- Interoperability with non-SSCH nodes
- Interaction with auto-rate adaptation scheme
- Interaction with TCP
- Study power consumption

Distributed Topology Control for Power Efficient Operation in Multihop Wireless Ad Hoc Networks

Roger Wattenhofer, Li Li,
Paramvir Bahl, Yi-Min Wang

Evaluation - Broadcast

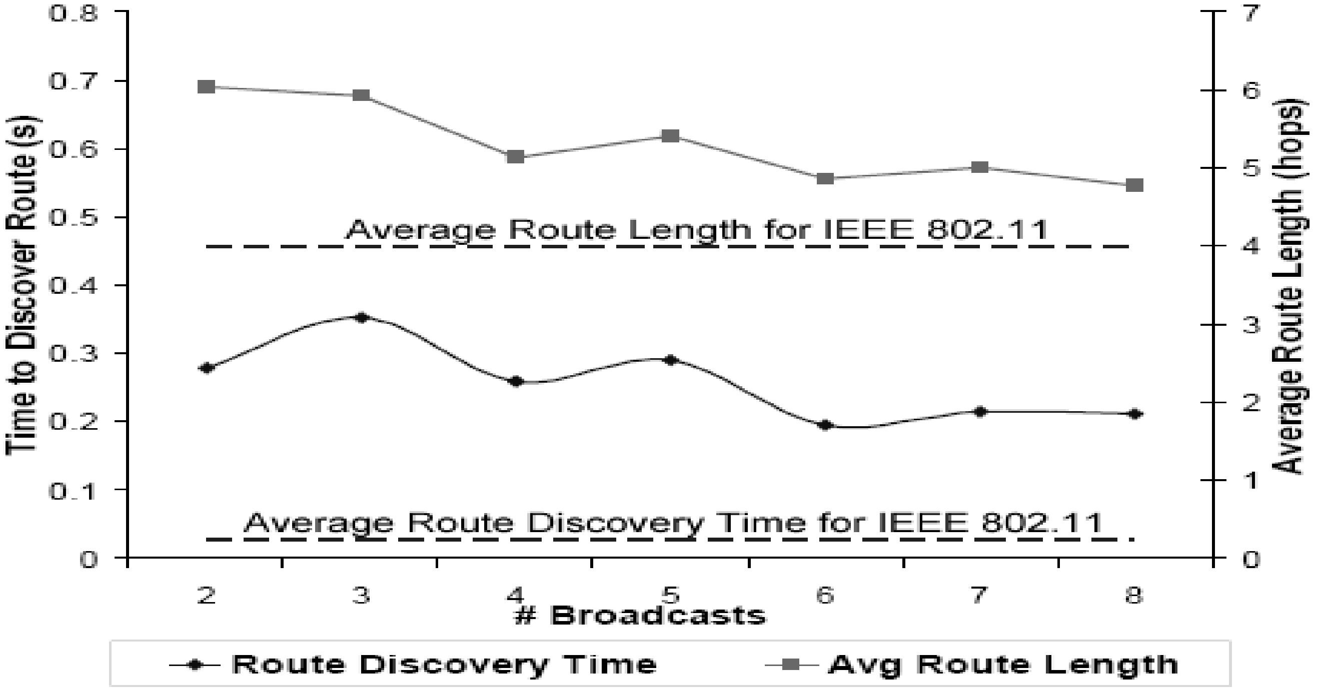


Figure 17: Impact of SSCH on Unmodified MANET Routing Protocols: The average time to discover a route and the average route length for 10 randomly chosen routes in a 100 node network using DSR over SSCH.

Introduction and Motivation

- Network lifetime limited by battery power
- Two choices
  - Increase battery power
  - Energy-efficient algorithms

Goal

- Minimize transmission power while maintaining network connectivity
  - Fully distributed algorithm
  - Use only local information
  - Simple to execute (feasible for sensors to run)

Cone-based Algorithm

- Cone-based topology control algorithm
  - Designed for multihop wireless ad hoc networks in 2-D
- Phase 1
  - Neighbor discovery process
- Phase 2
  - Redundant edge removal without disconnecting networks

Phase 1

- Each node u beacons with increasing power p, starting from min power
  - If node u discovers a new neighbor v, put v into N(u)
- Stop when for any cone with angle α, u has least one neighbor v or u hits max power
- To ensure symmetry
  - If node *u* puts v in its neighbor set, then node *v* also puts u in its neighbor set

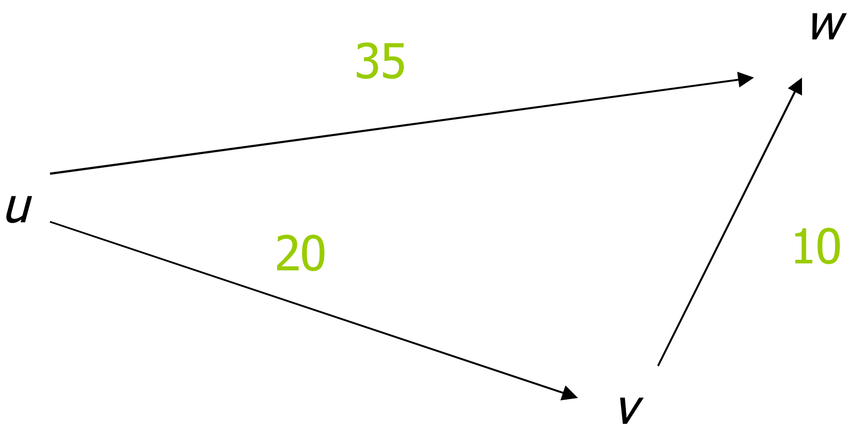
Phase 2

- Two nodes v, w
  - v, w in $N(u)$ and w in $N(v)$
  - $p(u,v) \leq p(u,w)$
  - $p(u,v) + p(v,w) \leq p(u,w)$
- Remove w from N(U) (and u from N(w))

Phase 2 (Cont.)

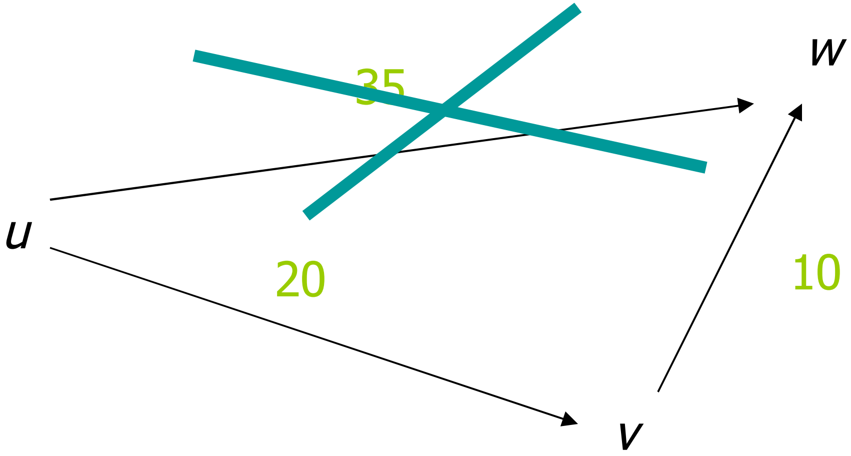
- Two nodes v, w
    - v, w in $N(u)$ and w in $N(v)$
    - $p(u,v) \leq p(u,w)$
    - $p(u,v) + p(v,w) \leq q * p(u,w)$ where $q \geq 1$
- Remove w from N(U) (and u from N(w))

Phase 2 (Cont.)



Which edge should be removed to minimize power usage?

Phase 2 (Cont.)



u transmitting to *v*

30 < 35

remove edge *u,v*

Phase 1

- Each node u beacons with growing power p
  - If node u discovers a new neighbor v, put v into N(u)
- Stop when for any cone with angle α, u has least one neighbor v or u hits max power

- Question: what is largest α that preserves network connectivity?

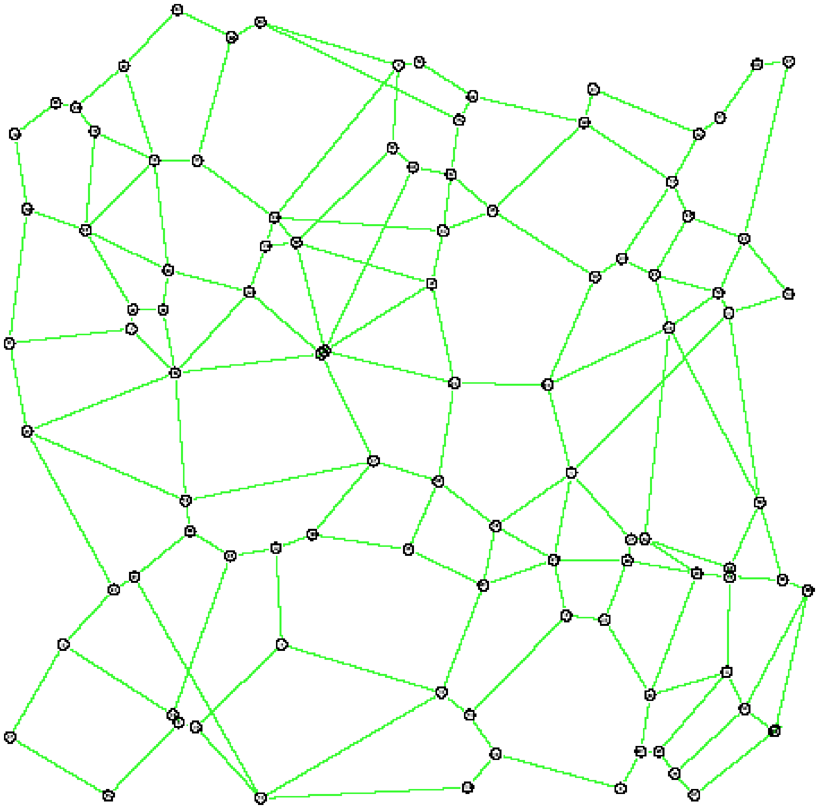
Main Result

- Let G' be the connectivity graph when each node uses max power
- Let G be the graph after applying phase 1 with $\alpha \leq 2\pi/3$
- If G' is connected → G is connected

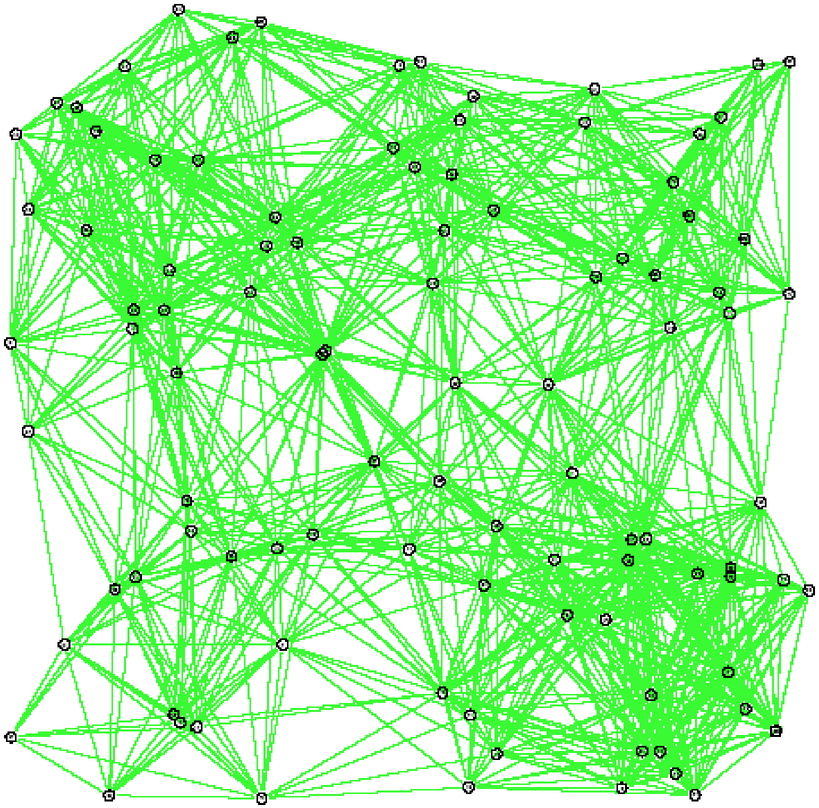
Simulation and Results

- 100 nodes
- Placed randomly in 1500 by 1500 rectangle
- Two-ray propagation model for terrestrial communications

Simulation and Results

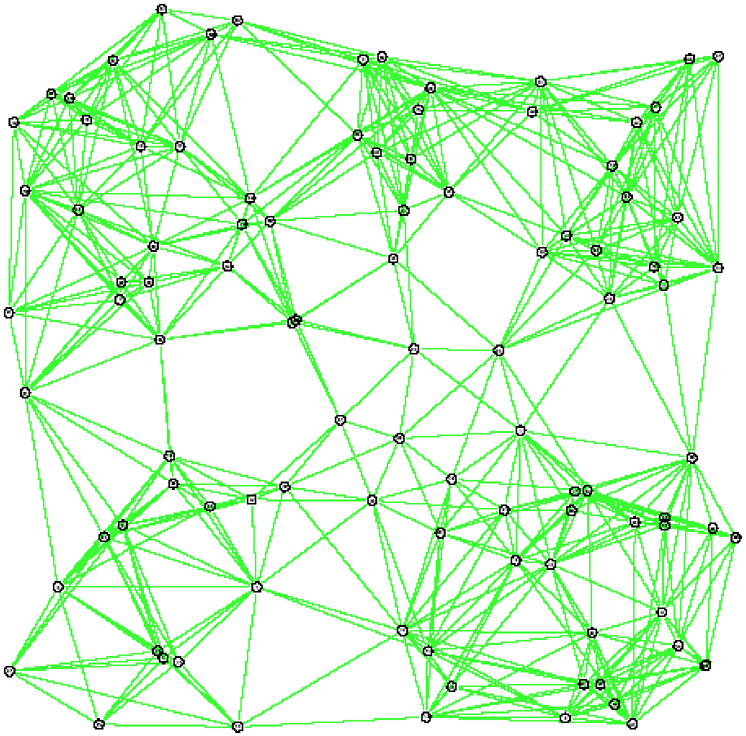


(e) R&M [3]

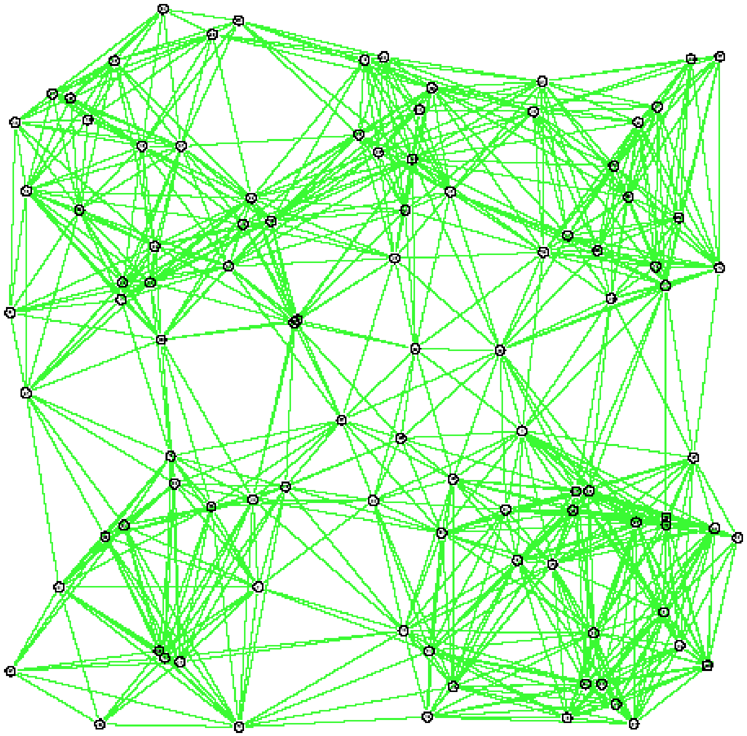


(f) Max Power

Simulation and Results

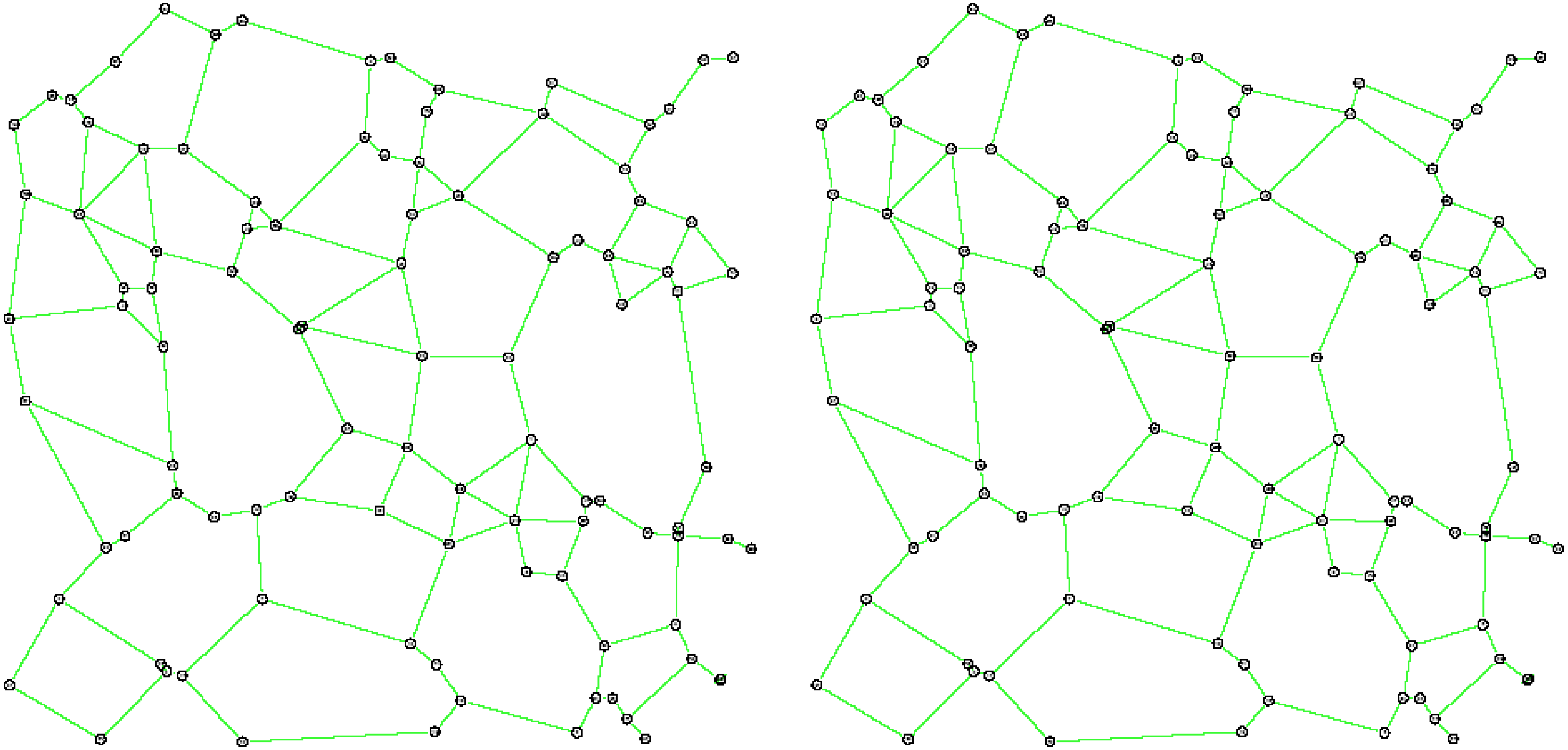


(a) Phase 1 Only $\alpha = 2\pi/3$



(b) Phase 1 Only $\alpha = \pi/2$

Simulation and Results



(c) Cone Based $\alpha = 2\pi/3$ (d) Cone Based $\alpha = \pi/2$

Simulation and Results

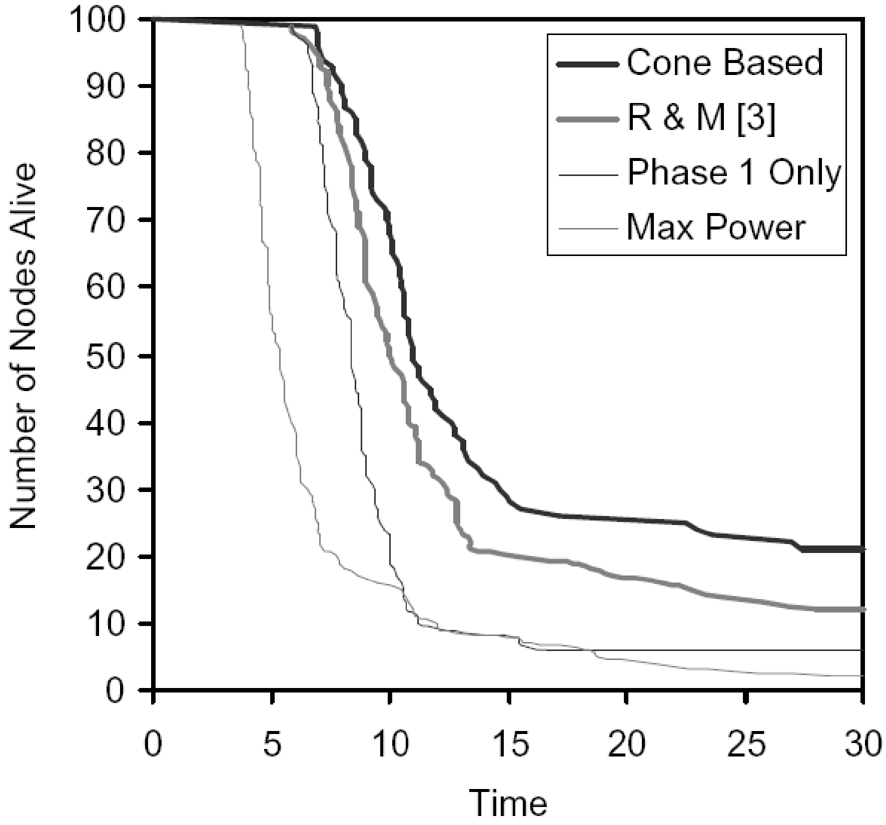


Fig. 5. Network lifetime

Simulation and Results

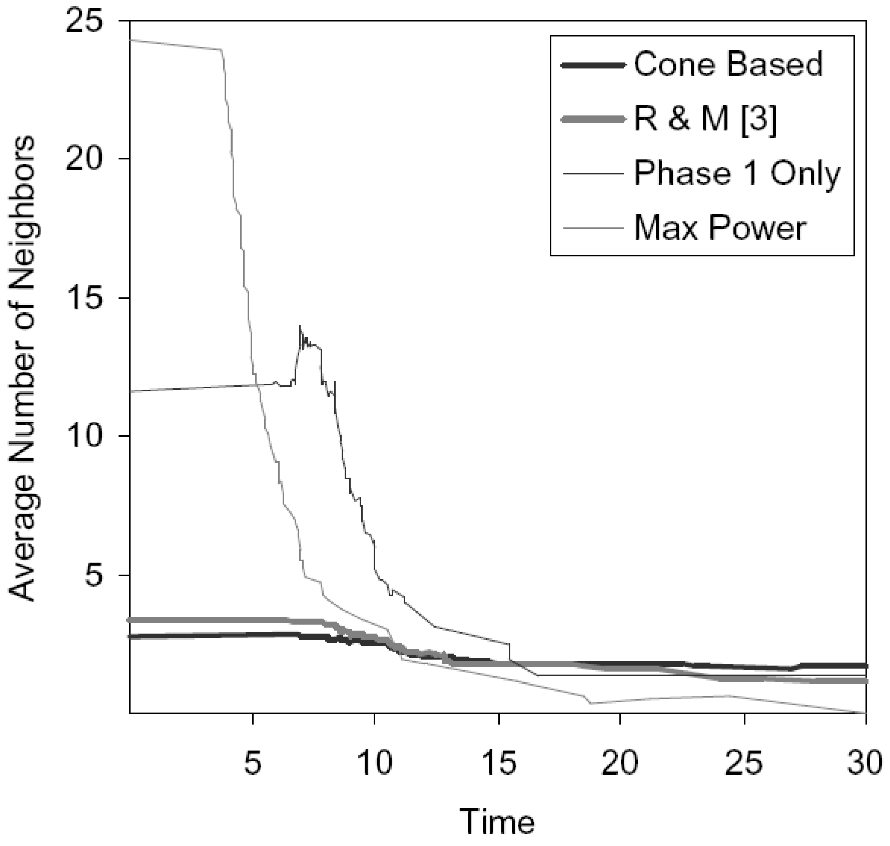
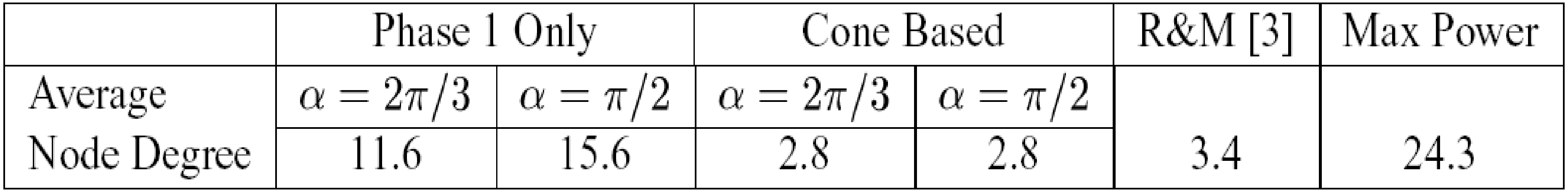


Fig. 6. Average node degree over time

Simulation and Results



	Phase 1 Only		Cone Based		R&M [3]	Max Power
Average Node Degree	$\alpha = 2\pi/3$	$\alpha = \pi/2$	$\alpha = 2\pi/3$	$\alpha = \pi/2$		
	11.6	15.6	2.8	2.8	3.4	24.3

TABLE I

AVERAGE DEGREE OF DIFFERENT TOPOLOGY CONTROL ALGORITHMS