# IRMA: Integrated Routing and MAC Scheduling in Multihop Wireless Mesh Networks

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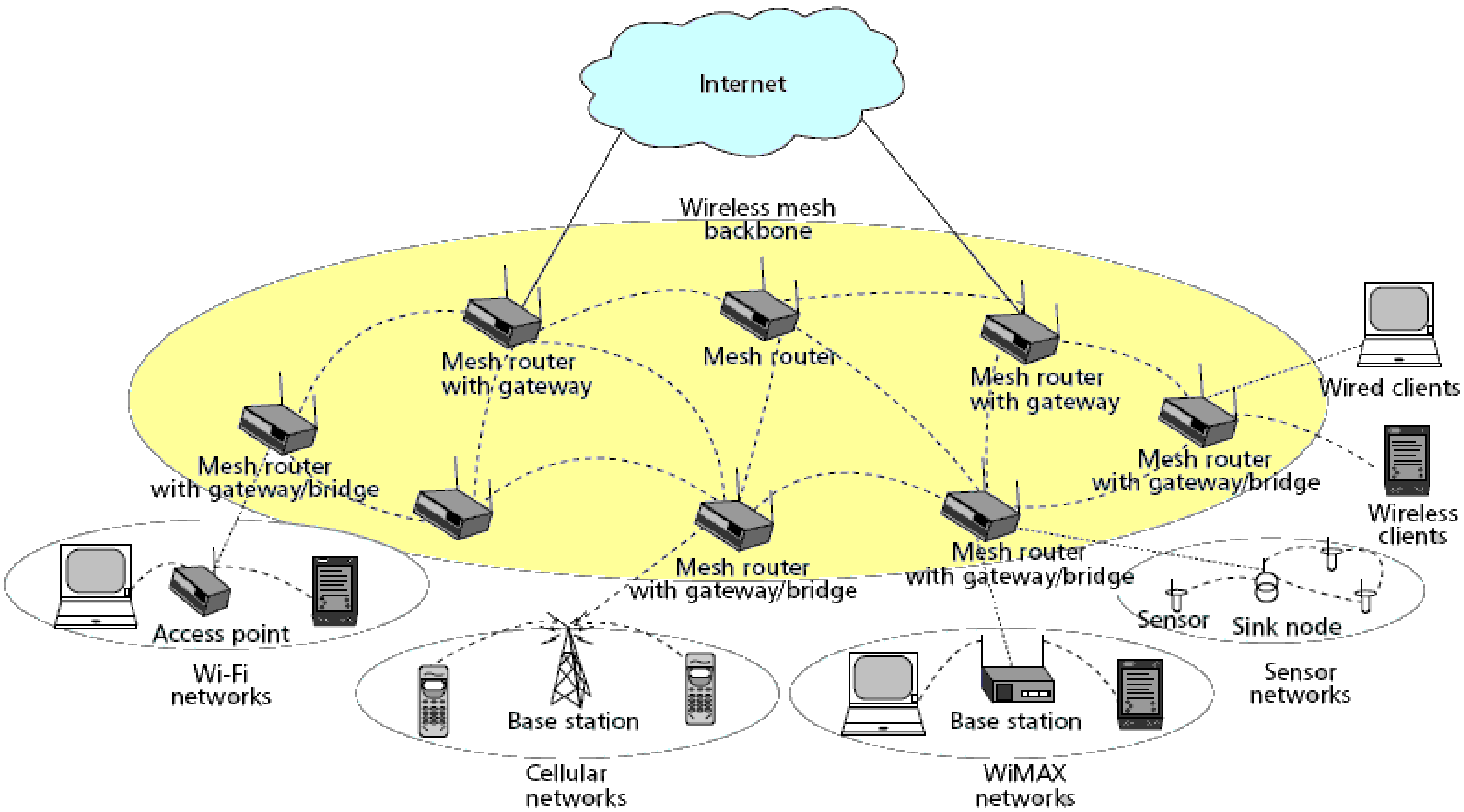
# WMN (Wireless Mesh Network)




- Mesh routers form a core network serving as an infrastructure for clients

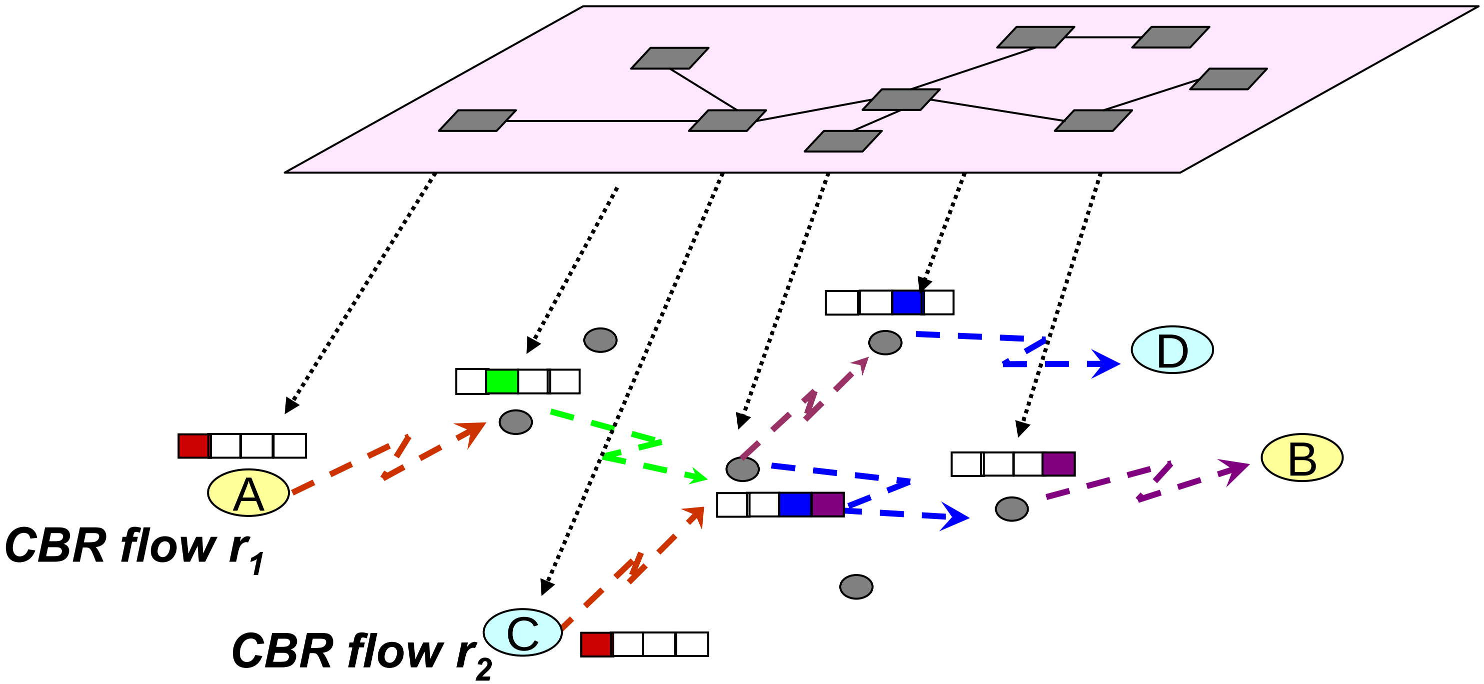
Picture from: "A survey on wireless mesh networks", *IEEE Comm. Magazine*.

# Motivations for IRMA Design

- WMN is different from ad-hoc and sensor networks
  - Minimal mobility, no power consumption constraints.
  - Performance focus: resource (channel) utilization efficiency
- Problems with layered approaches (802.11 + AODV, etc. …)
  - The performance of 802.11 MAC degrades with the increasing number of clients and number of hops
  - Routing protocols not take care of wireless characteristics.
- Cross-layer designs
  - Incorporate MAC/PHY parameters (e.g. link loss rate, bandwidth) into routing metrics, do not solve MAC inefficiency directly.
- Our approach: IRMA
  - Merge routing and MAC layer into an integrated component
  - Optimize MAC/routing parameters to maximize the end-to-end system throughput with multi-hop flows

# IRMA Concept

IRMA determines good routes and schedules together

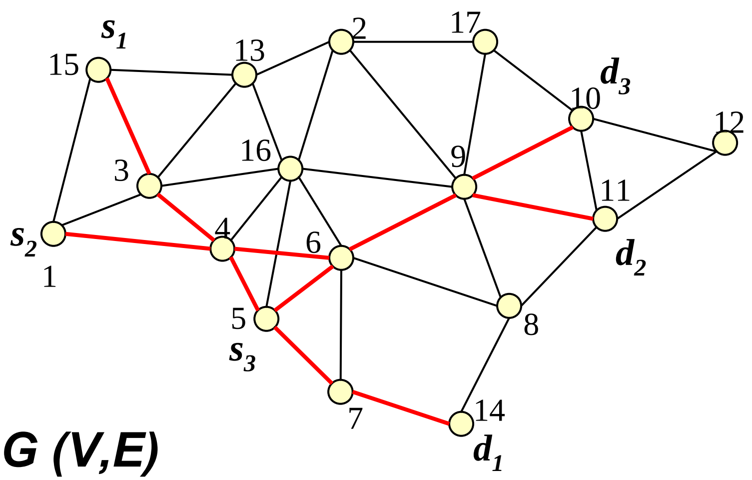



- Link transmissions are scheduled at different timeslots (shown as different colors)
- Eliminate interference and maximize spatial reuse

# Theoretical background

- Maximize end-to-end throughput : multi-commodity network flow problem (linear programming)
- Interference-free scheduling: coloring problem (graph theory)
  - Finding maximal independent set in the conflict graph

# LP Formulation of Integrated Routing and MAC Scheduling (1)




***G (V,E)***

***M*** concurrent flows from ***s*** to ***d***

***L:*** link set selected as paths

***r:*** offer-load/demands for each flow

$$Maximize \quad \sum_{i=1}^{M} f_i$$

**Subject to:**

1) Flow conservation

$f_i$ keeps same along the path for $< s_i, d_i >$

2) Link capacity

$$f(e) = \sum_i f_i \le BW(e), \text{ for each } e \in L$$

**+**

Constraints for *link conflict* based on "conflict graph" in interference model

3) Fairness tradeoff

$$qr_i \le f_i \le r_i \quad 0 \le q \le 1$$

# LP Formulation of Integrated Routing and MAC Scheduling (2)

- Find the analytical throughput bounds
  - Min-hop routing + link Scheduling
    - The path for each <s, d> is known as the min-hop path.
  - Joint routing/scheduling
    - Single path routing, but path is uncertain.
    - Mixed integer programming problem

  (*Method is similar to the LP optimization method presented in [ K. Jain et. al. 03]* )
- Observations and conclusions from previous and our LP analysis
  - It's NP-hard to find all link conflict constraints in LP formulation.
  - Possible optimal routing paths can be found to yield better throughput than min-hop paths
  - Optimal solution needs global knowledge
- Our contribution: Offline Optimization ⇨ Online algorithms

# Interference-free Scheduling

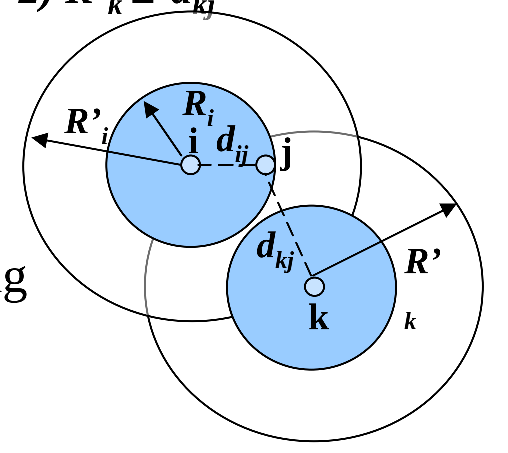
- Protocol Model of Interference

  Transmission range: ***R***
  Interference range: ***R'***
  ***Conditions for a successful transmission:***

  1) $d_{ij} \le R_i$

  2) any node k, such that $d_{kj} \le R'_k$ is not transmitting

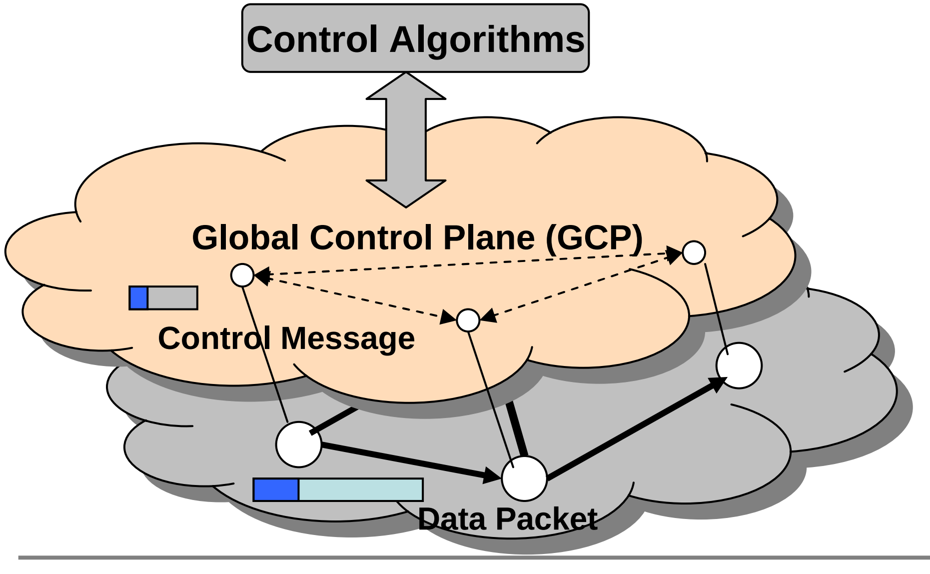
***Unsuccessful transmission***
***1) $d_{ij} \le R_i$***
***2) $R'_k \ge d_{kj}$***

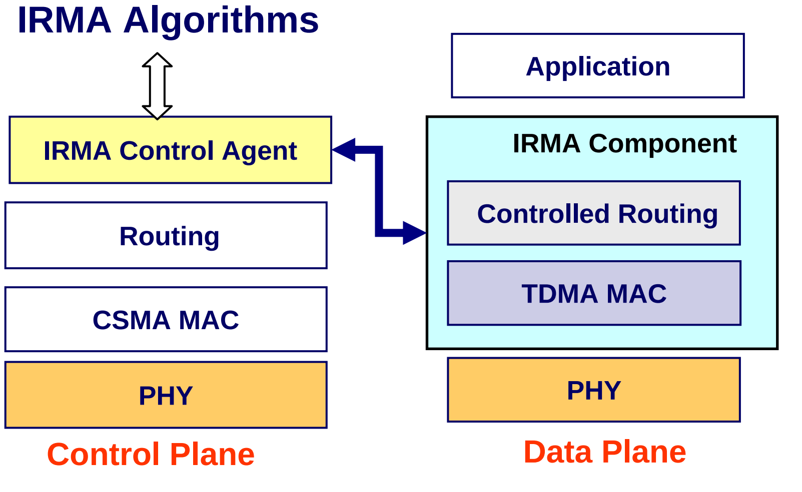



- Scheduling requires
  - to know exactly whose interference affect whom
  - node distance to be known or measured. *Not practical!*
- Our proposed solutions
  - Using a "k-hop" range to approximate the interference range
  - Using a control radio to reach all interfering hidden nodes.

# IRMA System Model

- Global control plane and data plane
  - All control signaling on a separate plane
  - Each node uses another radio interface over a dedicated control channel
  - Parameters of IRMA component in data plane is determined by control algorithms

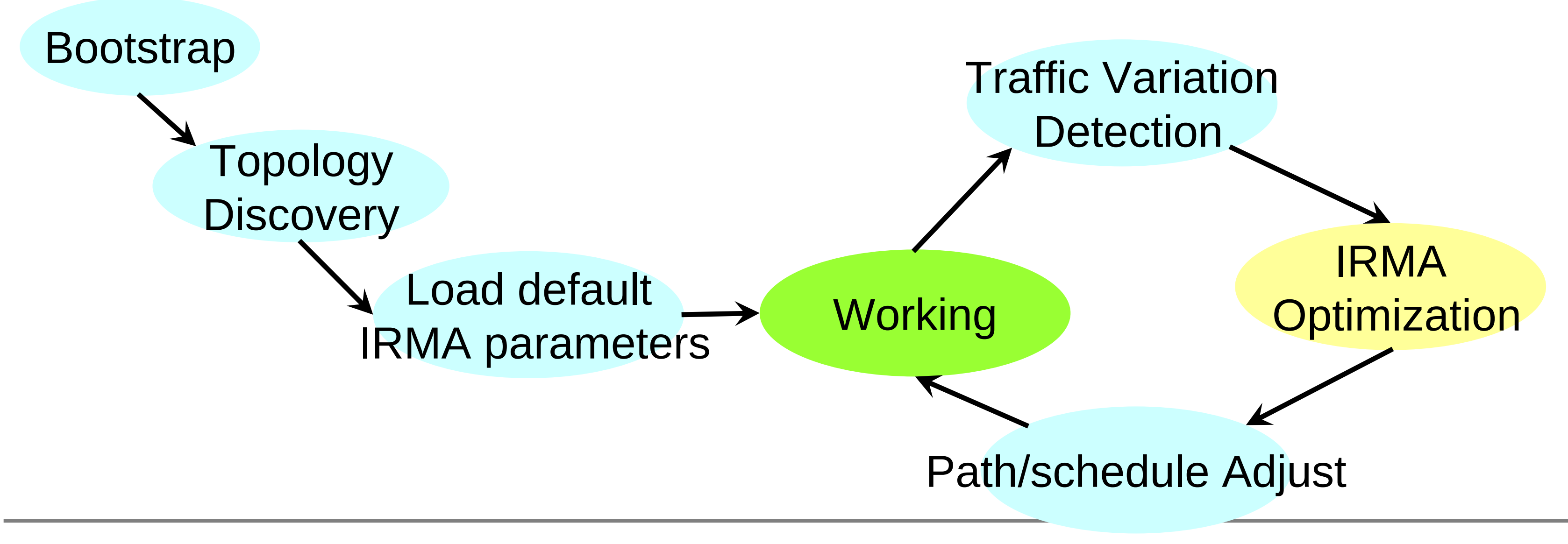



Protocol stacks in IRMA system

# IRMA System Control Cycle

- A central control entity running in one of the nodes, discovering global topology and link bandwidth information
- Control Cycle:
  - Detection and report of new or changed traffic demands.
  - IRMA optimization determine the paths and conflict-free TDMA schedules for each node.
  - IRMA components (Routing and MAC) transform and work with the new working parameters to ensure QoS.



# IRMA Algorithms: IRMA-MH

- MH (Min-hop) routing
- TDMA link scheduling based on the path selection
- Inputs of the algorithm:
  - Topology (G(V,E))
  - Traffic Profile (source-destination, bandwidth requirement) and
  - Interference-index *k*
  - TDMA frame length T (Number of slots in a frame)
- Output: route selection and MAC TDMA slot assignments

IRMA-MH Algorithm:

1. *Find the shortest route with hop metric*
2. *For each link e in each flow $F_i$, assign earliest available slot x for this link as long as it does not conflict with the links already scheduled in this slot x*
3. *Repeat step 2 until all bandwidth requirements are fulfilled or no more slots are available.*

# IRMA-BR

- Min-hop routes are not optimal, cause local congestions
- Better paths can be found and yield higher throughput than MH paths
- Joint TDMA Link Scheduling and Bandwidth Aware Routing (BR)

IRMA-BR Algorithm:

1. *Sorting the flow in ascending order by bandwidth requirements*
2. *For each flow $F_i$, i= 1,2 …, M*
   *a) Generate link Metric based on available "free" TDMA Slots*
   *b) finding shortest path for flow $F_i$ with the "bandwidth" metric.*
   *and assign conflict-free TDMA slots for this flow*

# Performance Evaluation

- Implement the GCP and IRMA algorithms in ns-2.28
- Introduce the calculation of aggregated interference signal strength
- A separate control radio and channel in GCP

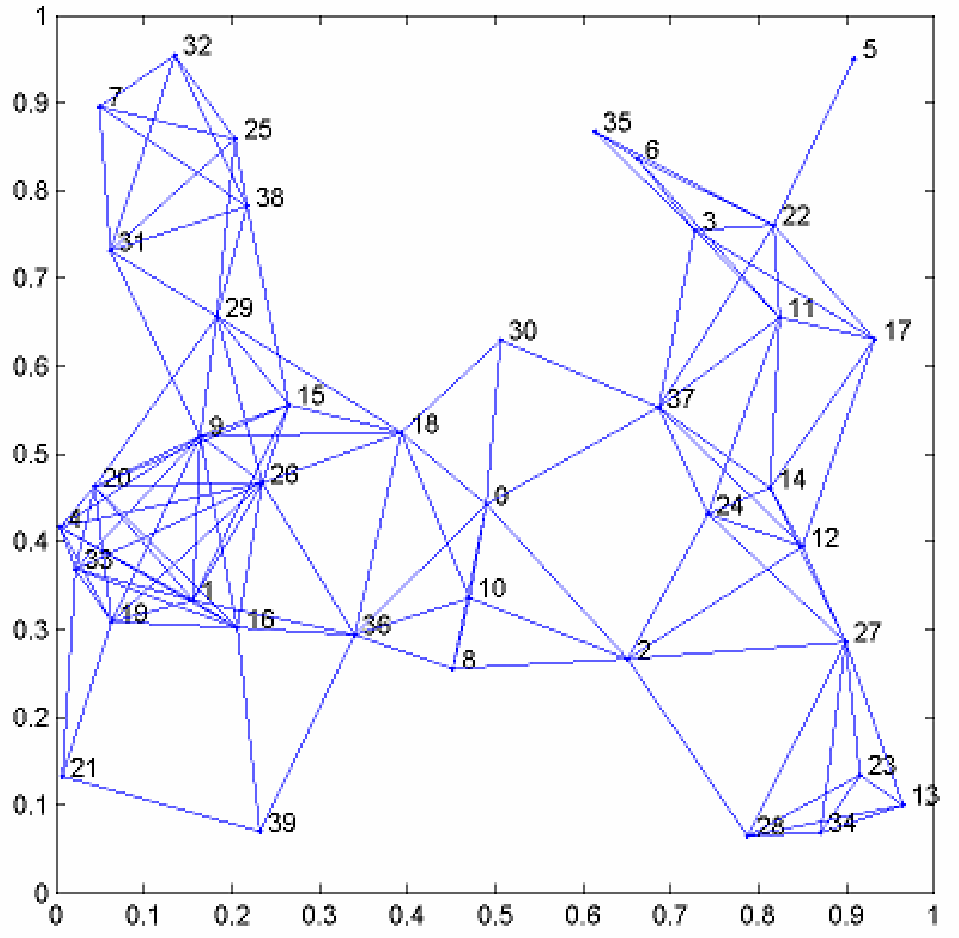
- Compare the performance
  - IRMA algorithms
  - Analytical bounds solved by LP
  - Baseline approaches
    - DSDV+802.11
    - AODV+802.11

Simulation Parameters

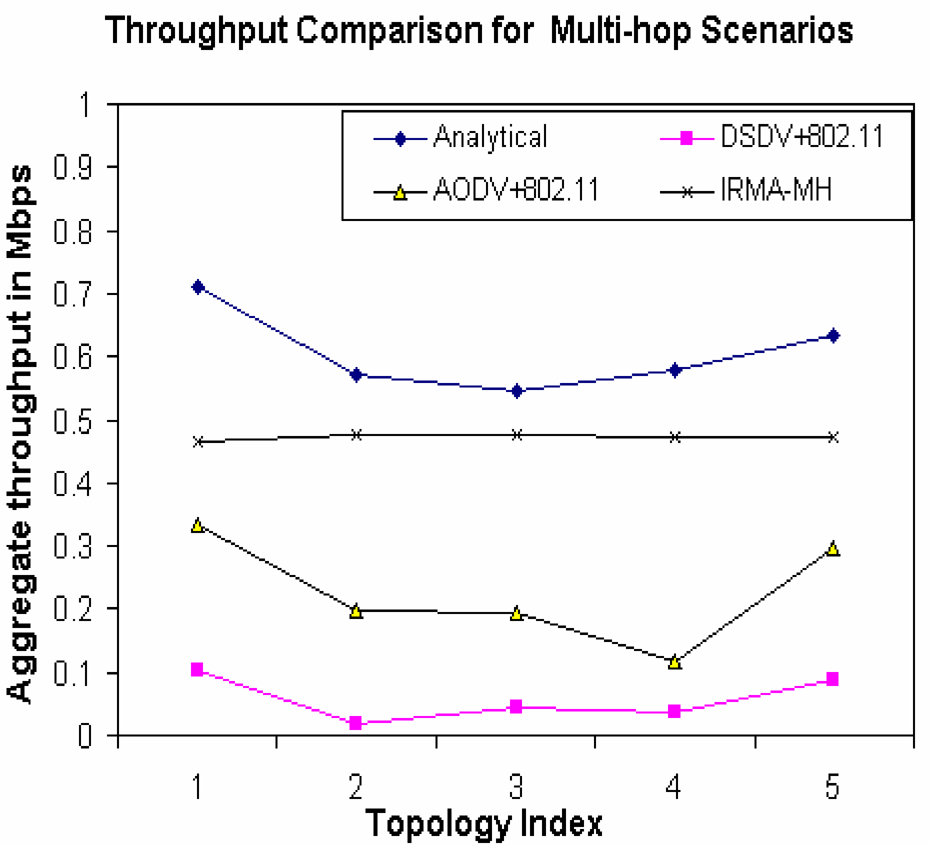
| | |
|---|---|
| Topology size | 1000x1000 $m^2$ |
| TX range | 250m |
| Data channel rate | 1Mbps |
| Control Channel rate | 100kbps |
| SINR threshold | 10 dB |
| Propagation Model | TwoRayGround |
| Path loss index | 4 |
| MAC slot duration | 8.4 msec |
| Slots per frame | 20 |

Based on $SINR_{thresh}$, 2-hop interference model is adopted in IRMA

# A Typical Simulation Topology



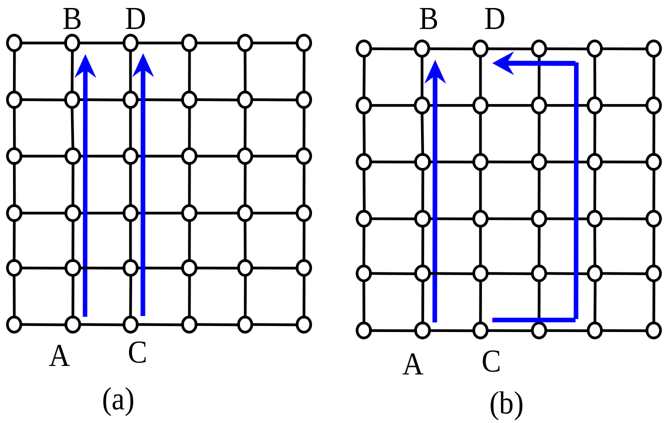
# Performance of IRMA-MH algorithm



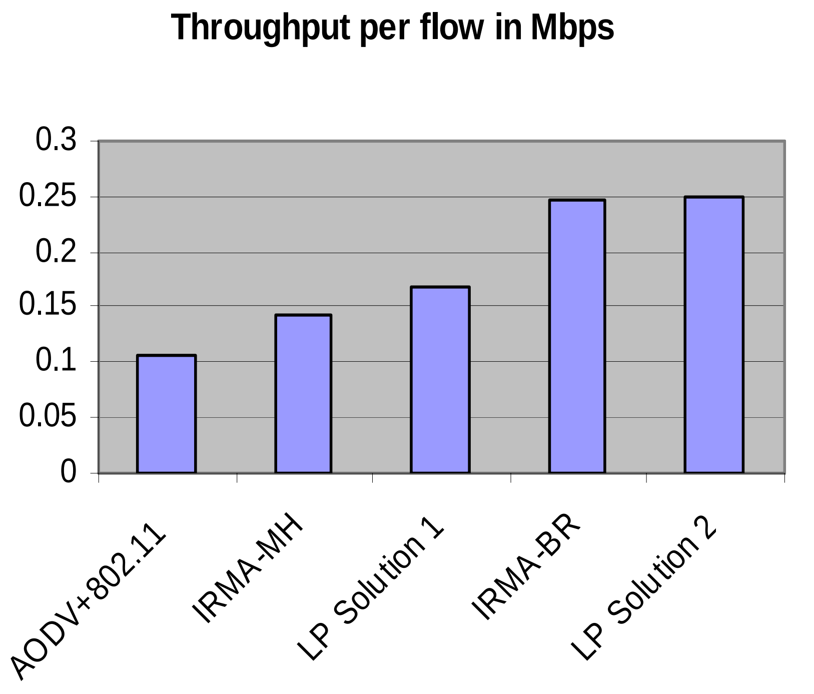

- 5 Multi-hop flows
- Average Hop length: 3.22

- IRMA-MH algorithm supports much higher throughput (200%-400%) than baseline scenarios with conventional approaches
- Resource utilization is more efficient with conflict-free TDMA scheduling

# IRMA-MH vs. IRMA-BR




**Different routes used by (a) IRMA-MH and (b) IRMA-BR in a 6x6 grid for two vertical flows**




- IRMA-BR algorithm chooses a detour path to route around possible congested areas by using available bandwidth measurement as metric

# Evaluation of the Signaling Overhead

Overhead Statistics

- Baseline: RTS/CTS + routing overhead
- IRMA: All control signaling in GCP

Simulation Topology:

- 4x4 grid
- 10 random start/end traffic sessions
- Traffic duration: exponential distributed.
- Results normalized by end-to-end throughput

| Scheme | normalized overhead |
|---|---|
| IRMA-MH | 1.499% |
| AODV+802.11 | 6.1962% |
| DSDV+802.11 | 7.0517% |

- IRMA approach reduce signaling overhead as well as improve throughput performance

# Conclusion and Future Work

- We proposed IRMA for wireless mesh networks and discussed:
  - Interference-free scheduling
  - Realistic system model
  - Online algorithms
- Simulation results show that IRMA design improve end-to-end throughput significantly with modest signaling overhead
- Fundamental need to integrate routing and MAC scheduling for wireless mesh network design
- Ongoing and Future Work
  - Distributed IRMA algorithms
  - Extension to Multi-Channel Multi-Radio (MCMR) Mesh Networks
  - CSMA/TDMA overlay MAC emulation and ORBIT validation

# Questions & Answers