Channel Allocation in 802.11-based Mesh Networks

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Presentation at Infocom 2006
Barcelona, Spain

Presentation Outline

- Motivation and Background
  - The 2P MAC protocol
- Channel allocation, channel subgraphs
- Optimal channel allocation
  - NP-completeness
  - Heuristics
- Discussion: P2MP links, further work
- Conclusion

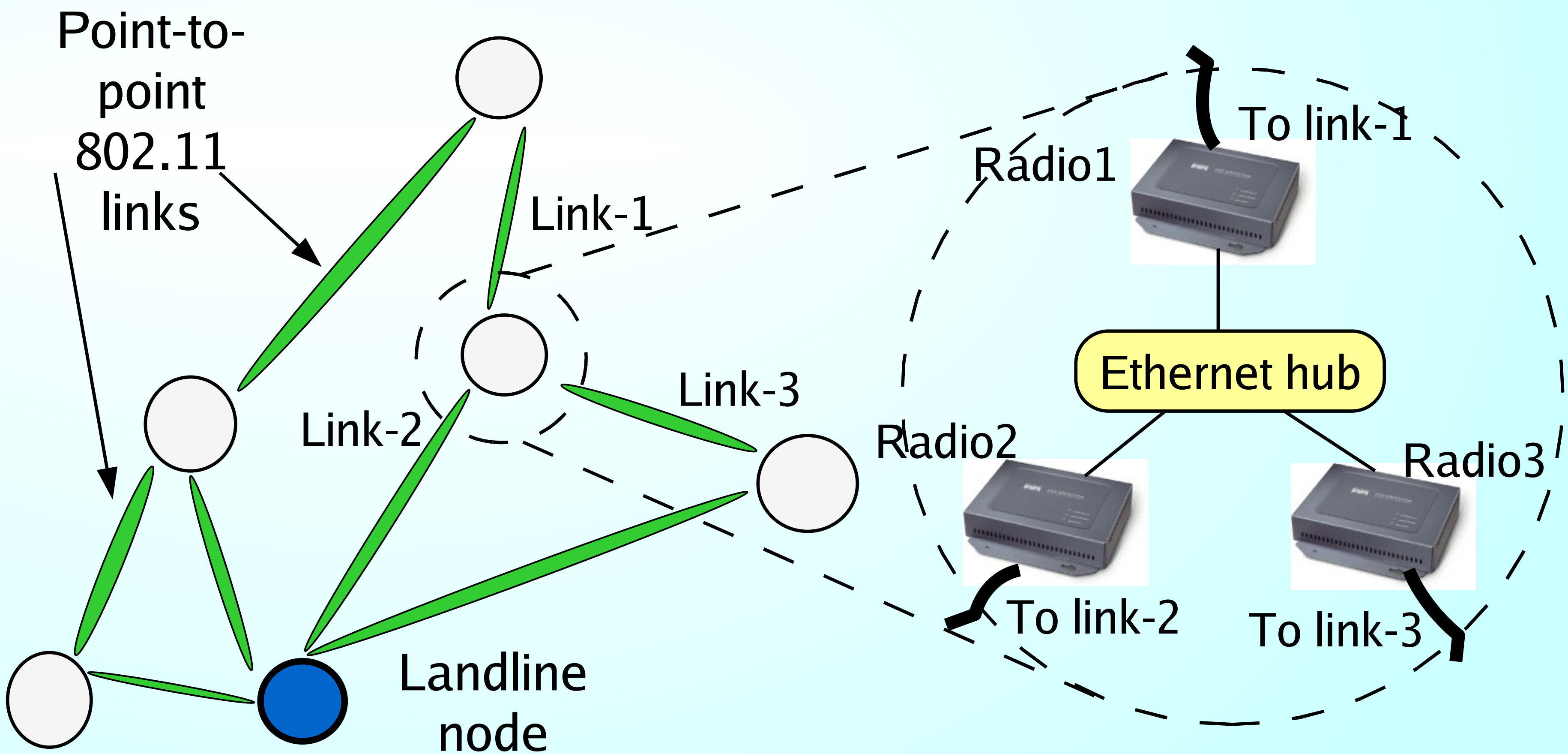
802.11 to Bridge the Digital Divide

- Low-cost equipment
- License-free spectrum
- Long-distance (10-100km) links
  - Directional antenna
  - MAC modifications
- Example deployments:
  - www.Djurslands.Net
  - Nepal wireless
  - Ashwini project, A.P., India

Src: http://nepalwireless.net/

The Ashwini Centre at Kasipadu, West Godavari, Andhra Pradesh, India

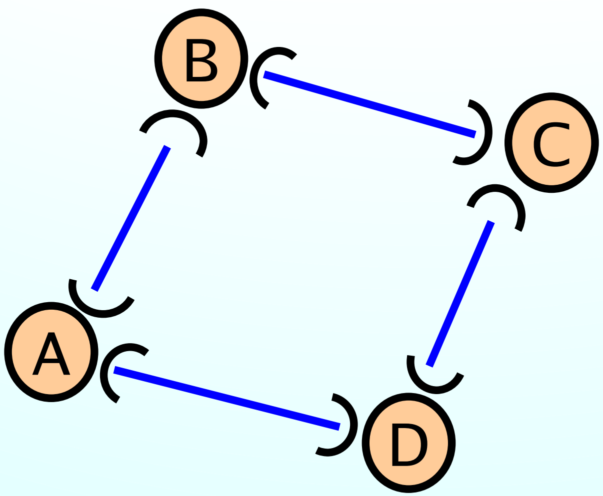
Network Model

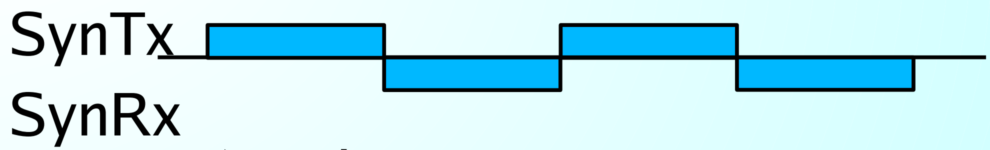


- Point-to-point links
- Multiple interfaces (radios) per node
- One directional antenna per link

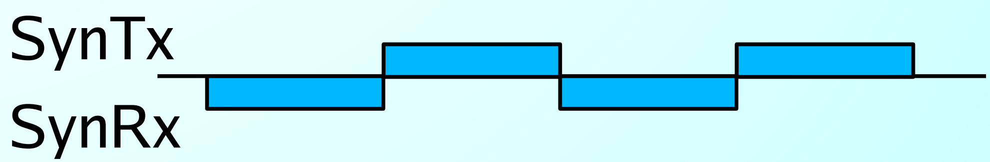
The 2P MAC Protocol

– Two phases: each node switches between SynRx and SynTx





a) Links: A-->B, A-->D, C-->B, C-->D



b) Links: B-->A, B-->C, D-->A, D-->C

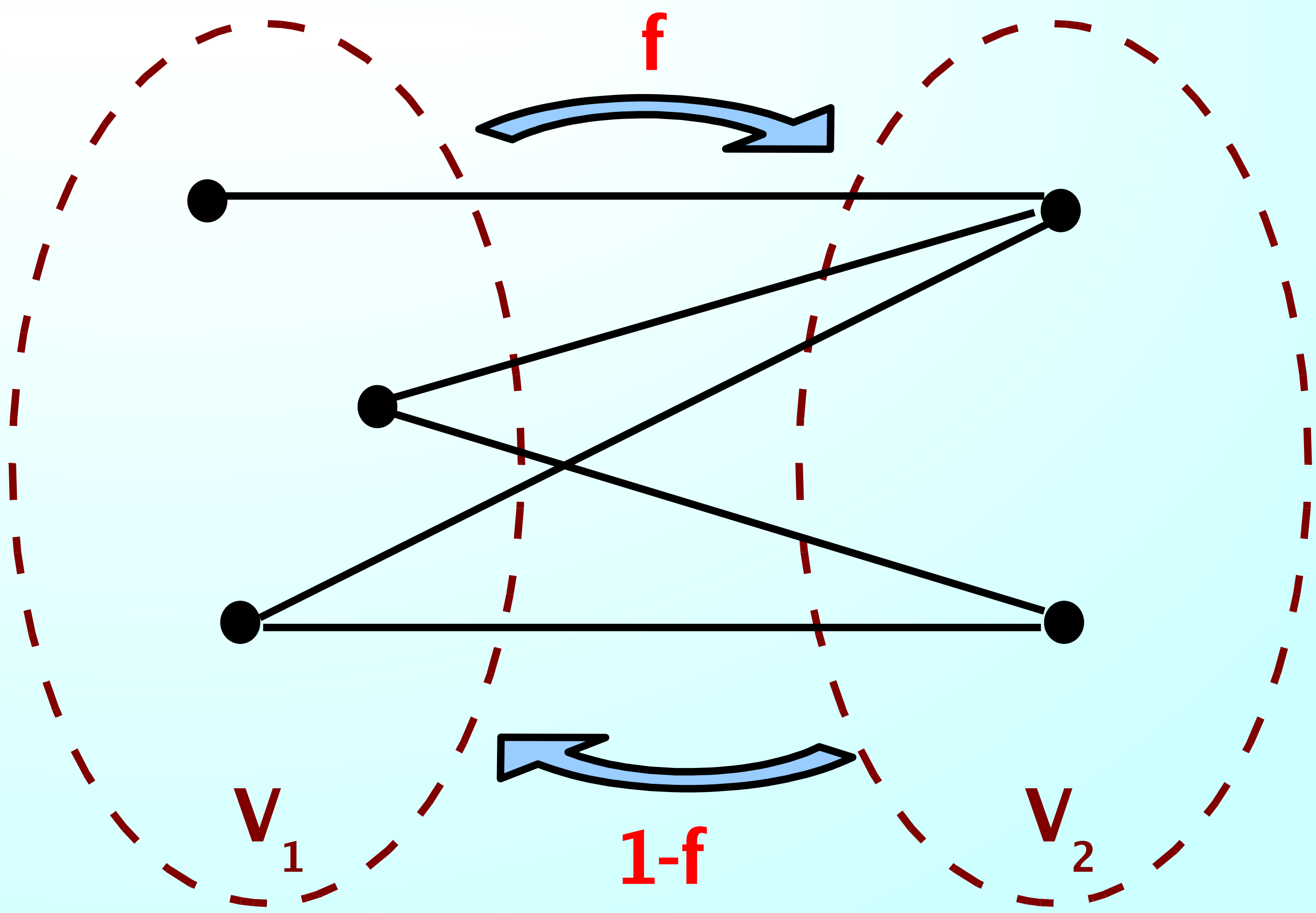
Note: diagram ignores system and propogation delays

– Single channel operation

– Topology has to be bipartite

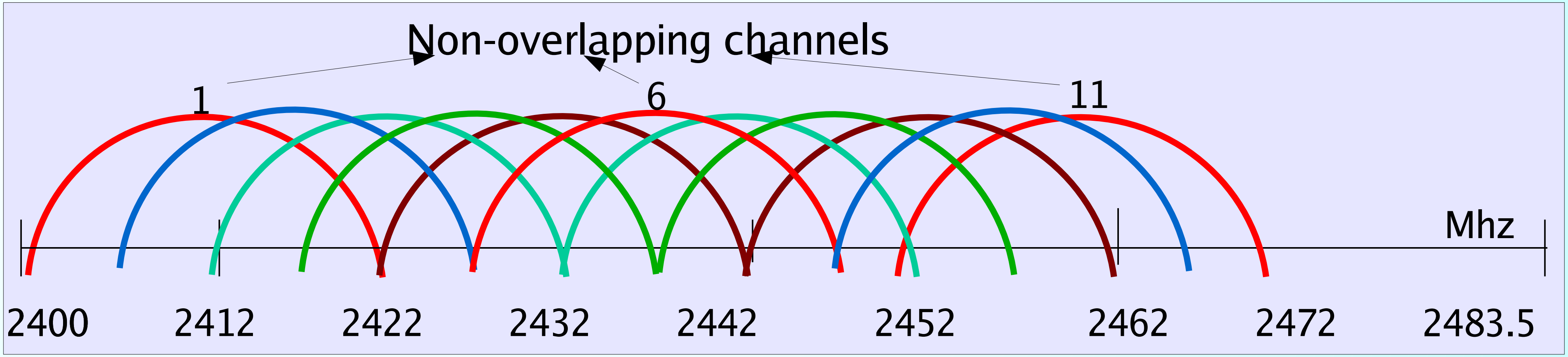
- “Design and Evaluation of a new MAC Protocol for Long-Distance 802.11 Mesh Networks”, Bhaskaran Raman and Kameswari Chebrolu, Mobicom 2005

2P Scheduling

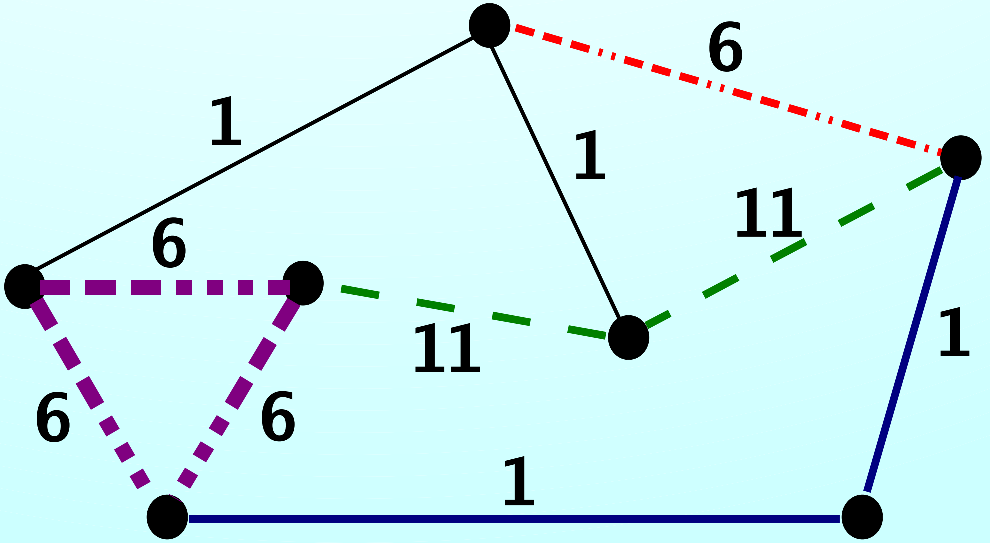


Bipartite graph, or a “channel subgraph”

Channel Subgraphs



802.11b/g have three non-overlapping channels



Channel subgraph: maximal subgraph with all links on the same channel

BP-proper Channel Allocation

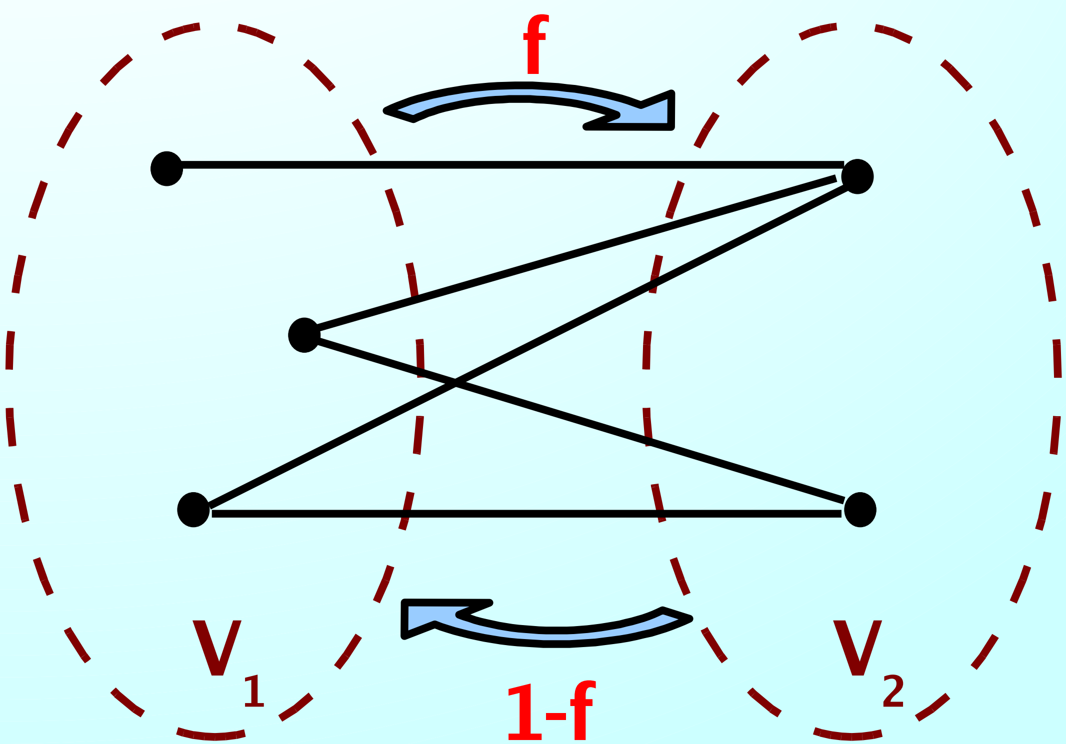
- BP-proper channel allocation: such that all channel subgraphs are bipartite
- Question: given a graph, does it have a BP-proper 3-edge colouring?
- If 6-edge-colourable, provably yes
  - 6-edge colouring using Vizing's approach
  - Merge alternate colours
  - Channel subgraphs will be paths or even cycles
- If graph is 8-vertex-colourable, provably yes
  - Thanks to Sundar Vishwanathan, CSE, IITB

Link Capacities

- Assumption: all links operate at max. rate
- Traffic on links may be asymmetric
- Focus of our work: accommodating this asymmetry
- Model: operator specifies a ***desired fraction (DF)*** of capacity in a particular direction
  - Note: $DF(v_1 \to v_2) + DF(v_2 \to v_1) = 1$
- The actual fraction of capacity an edge is allocated: ***achieved fraction (AF)***

Channel Allocation and Link Capacities

- Edges in a channel subgraph have the same AF



Zero-Mismatch Channel-Allocation (ZMCA)

- ZMCA definition:
  - Given a network and edge DFs,
  - BP-proper 3-channel allocation such that:

$$DF(\vec{e}_i) = AF(\vec{e}_i) \; \forall \text{ edges } e_i$$

  - That is: all edges e_i in each channel subgraph have the same $DF(e_i)$

NP-Completeness of ZMCA

- NP-Complete even if:
  - Delta <= 4
  - DFs chosen from {1/4, 1/3, 1/2, 2/3, 3/4}
- Proof outline:
  - Reduce 3SAT to ZMCA
  - Mimics proof of NP-Completeness of optimal edge-colouring problem
    - Ian Holyer, "The NP-Completeness of Edge-Colouring", SIAM J. COMPUTING, vol. 10, no. 4, Nov 1981.
  - Construct inverting, replicating, clause-testing components

Minimum-Mismatch Channel-Allocation (MMCA)

- MMCA definition: minimize $\sum_{e_i \in E} \left| DF(e_i) - AF(e_i) \right|$
- ZMCA NP-Complete => MMCA NP-hard
- Note: given a channel allocation, minimizing mismatch is trivial
  - Within a channel subgraph with edge DFs $f_i, i = 1..k$
  - Optimal f is one of $f_i, i = 1..k$
  - Optimal f for each channel subgraph is determined independently

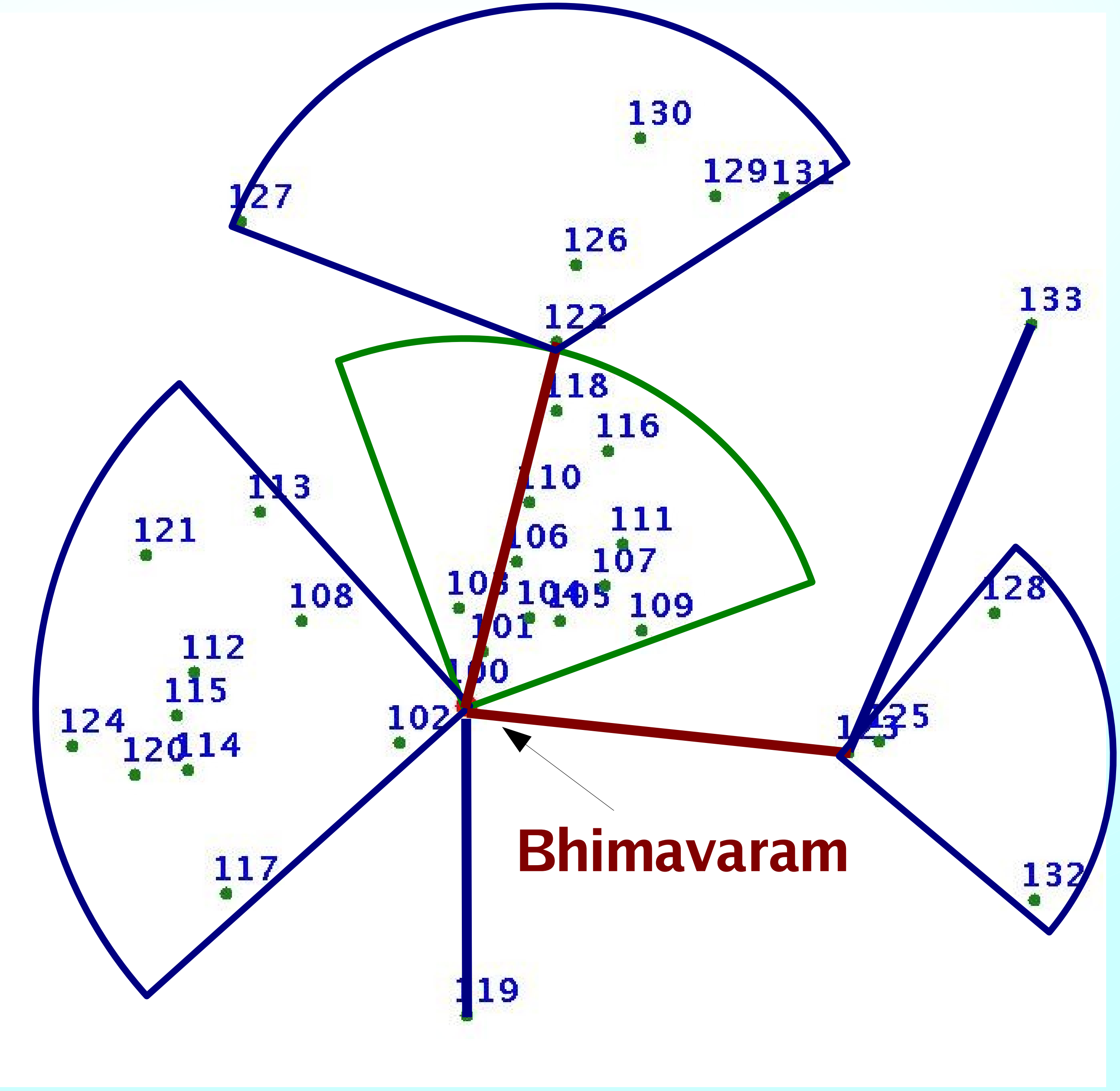
Heuristics for MMCA

- Steps: 6-edge-colouring, AF assignment
- Approach:
  - Heuristic for edge-colouring, edge-ordering in Vizing's algorithm
  - Get initial set of channel subgraphs
  - Uncolour channel subgraphs with large mismatch
  - Local exhaustive search to colour that subgraph
- Performance close to optimum

Related Work

- Packet radio network scheduling, bluetooth
  - Single channel of operation
  - Use STDMA scheduling (not 2P)

Discussion: Point-to-MultiPoint (P2MP) Links



- Ashwini network deployment (partial)
- Each village has a bandwidth reqmt.: 384 Kbps
- Specific times known too
- Can use this info to set DFs

Discussion: Further Work

- What if only two channels available?
  - One channel may be required for local coverage
- Practical complications:
  - Inter-link interference & channel assignment
    - Inter-link interference an important factor
  - Inefficiencies in 2P with large channel subgraph size
    - Minimize channel subgraph size

Conclusion

- 802.11 mesh networks becoming popular
  - We focus on planned networks with long-distance links
  - This work: channel allocation for desired link capacity
- Practical considerations add new dimensions to the problem
  - Experience will tell which direction is important to explore