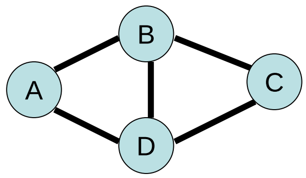
Approaches to Use Multiple Channels

- Number of radio interfaces per node
  - Single
  - Multiple
- Legacy compatibility
  - Use COTS 802.11-based hardware (need multiple interfaces).
  - Use 802.11, but not COTS hardware.
  - Minor extensions to 802.11.
  - Almost new protocol.
- Channel assignment
  - Static or quasi-static (need multiple interfaces).
  - Dynamic (switch channel in packet time-scale).

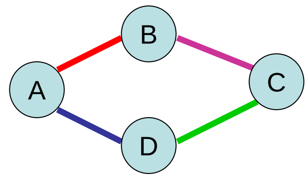
Multi-Radio Approach

- Use COTS 802.11 interfaces.
- Multiple interfaces per node.
  - 802.11 interfaces are quite affordable.
  - Power is usually not an issue.
- Static solution.
  - Interfaces are bound to channels statically.
  - No need for fast channel switching.

Channel Assignment Problem



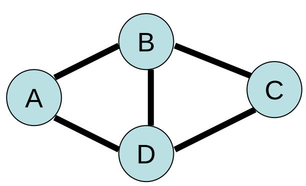
1 channel
1 interface



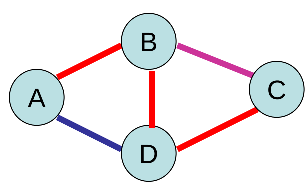
4 channels,
2 interfaces

- Channel assignment can control topology.
- Two nodes can communicate when they have at least one interface in common channel.

Channel Assignment Problem



1 channel
1 interface



4 channels,
2 interfaces

- Channel assignment can control topology.
- Two nodes can communicate when they have at least one interface in common channel.

Channel Assignment Problem

- Similar to a graph coloring problem, except that ..
  - We are given some number of colors (channels).
  - We are looking for coloring with least conflicts.
- Need to model interference.

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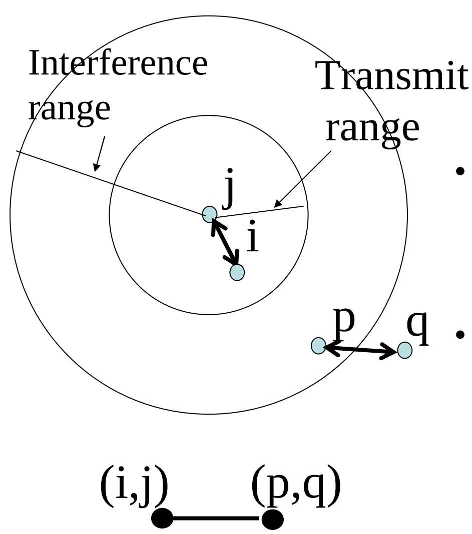
Representing Interference



- Use conflict graph. [Jain-et-al-Mobicom-03]
- Link in network graph = node in conflict graph.
- Edge in conflict graph denotes "interference."

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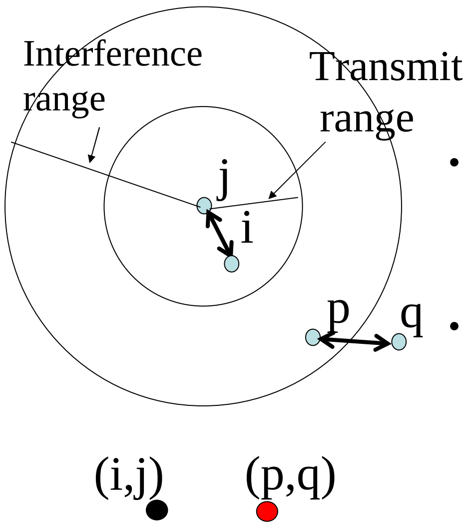
Representing Interference



- Use conflict graph. [Jain-et-al-Mobicom-03]
- Link in network graph = node in conflict graph.
- Edge in conflict graph denotes "interference."

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Channel Assignment Problem

- k channels (colors). r (r < k) interfaces on each network node.
- Assign colors to ALL nodes in the conflict graph such that the max degree is minimized.
  - Also, average degree, max. independent set are good metrics.
- Constraint: total no. of colors at a network node <= r.
- NP-complete problem. Heuristic approaches in literature. [Raniwala-et-al-MC2R-04, Marina-Das-Broadnets-05]

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Joint Channel Assignment and Routing

- We considered a channel assignment technique that is "topology preserving"
  - Assigns channels to all links that exist in a single channel network.
- Not necessary. Some links can be "routed around."
  - Also conflicts can be "weighted."
- Solve channel assignment and routing jointly in a network flow maximization framework.

[Alicherry-et-al-MobiCom-05, Kodialam-et-al-MobiCom-05]

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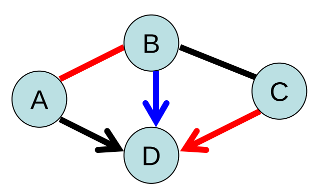
Approaches with Single Interface



- Sender switches to the channel to use. Easy.
- Receiver must know what channel to switch to in order receive. Hard.
- Several broad approaches:
  - Set up recurring appointments.
  - Negotiate channel before transmission.
  - Receive always on a pre-determined channel.

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1. Setting up Recurring Appointments

- Each node switches channels synchronously in a pseudo-random sequence so that all neighbors meet periodically in the same channel.
- Spreads usage over all channels.
- No rendezvous to select channels.
- Can use 802.11.
  - But interfaces must be capable of fast synchronous channel switching.

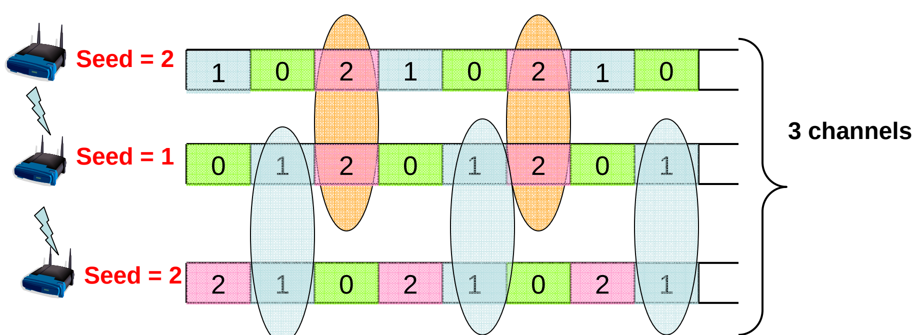
[Bahl-Chandra-Dunagan-MobiCom-04]

SSCH: Slotted Seeded Channel Hopping

Divide time into slots: switch channels at beginning of a slot

New Channel = (Old Channel + seed) mod (Number of Channels)

seed is from 1 to (Number of Channels - 1)



[Bahl-Chandra-Dunagan-MobiCom-04]

2. Negotiate Channel Before Transmission

- Two approaches.
- Meet periodically at a pre-determined channel to negotiate channels for the next phase of transmissions.
  - Can use minor variation of 802.11.
- Use a separate control channel and interface.
  - Need new MAC protocol.

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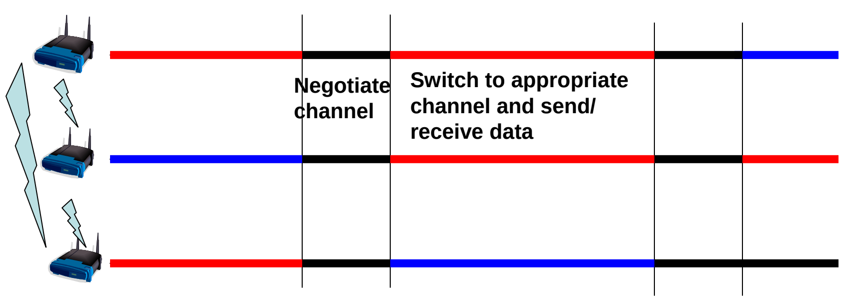
MMAC: Synchronous Rendezvous



- Meet periodically at a pre-determined channel to negotiate channels for the next phase of transmissions.
  - Can 802.11 time synch used to implement power save mode.

[So-Vaidya-MobiHoc04]

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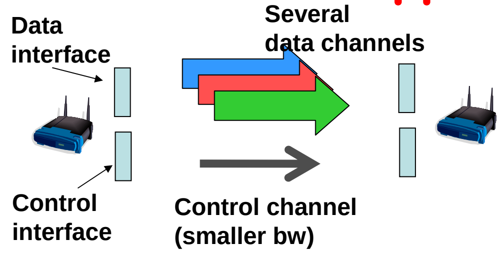
Control Channel Approach



RTS {channel list} on control channel. Lists free channels at sender.

CTS {channel} back on control channel.

RES {channel} on control channel

DATA/ACK on selected channel.

Every node hearing CTS{channel} or RES{channel} sets up NAV for that channel.

[Wu-et-al-WCNC-00]

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3. Receive on Pre-Determined Channel

- Assign a channel (quiescent channel) to each node
  - No feasibility constraint related to topology.
  - Can change with traffic in a course time-scale.
- Always listen to own quiescent channel.
- Switch to receiver's channel before transmission.
- No time synchronization. No control channel, interface. But deafness possible (new channel state unknown).

[Shacham-King-IEEE-TC-87]

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Fairness Issues

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Fairness

- Many views of fairness. Can happen in any layer.
- Issues unique for mesh networks happen..
  - In the MAC layer.
  - In the interface between MAC and packet forwarding.

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Fairness in Random Access MAC

- Quite fundamental. MAC attempts to provides packet level fairness; not flow level fairness.
- So-called "capture" phenomenon.
  - Happens even on Ethernet. Property of binary exponential backoff (BEB) algorithm.
  - The winner of two contending flows has a higher chance to win later contentions.
  - Reason: Each packet competes afresh. Backoff interval on the packets for winning flow stays smaller.

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New Problems with 802.11

- Interference levels are different at different links.
  - Because neighborhoods are different.
- Highly interfered flows can be drowned easily.
  - Harder to be fair.
- We will discuss two basic problems:
  - Information asymmetry.
  - Flow in the middle problem.

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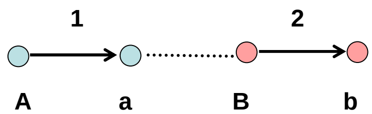
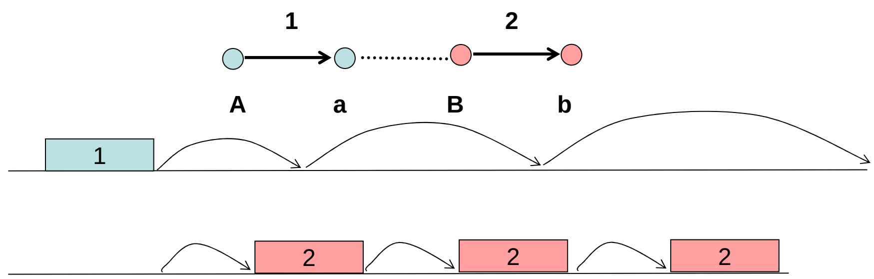
Information Asymmetry



- The senders of two contending flows may have different sets of information.
- Example:
  - Sender of flow 2 is aware of flow 1 (via CTS , e.g.).
  - Sender of flow 1 is not aware of flow 2.

[Gambiroza-et-al-Mobicom-04] 57

Information Asymmetry



- Flow 2 knows how to contend.
- Flow 1 is clueless – it is forced to timeout and double its contention window.
  - Eventually may be forced to drop packet.
  - Large access delay may also cause overflow in the interface queue.

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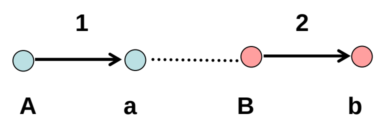
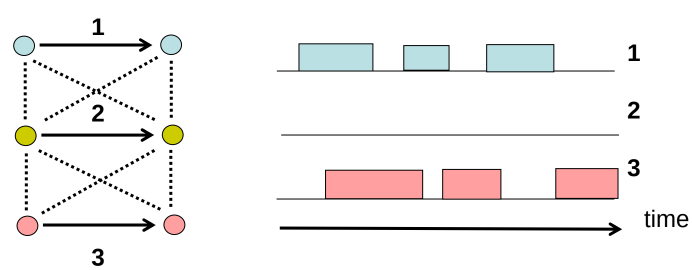
Information Asymmetry



- Happens even when RTS/CTS are not used.
- Flow 1 collides at a. Flow 2 is successful.
- Downstream links still suffer.
- Information asymmetry can be solved by receiver-initiated protocols.
  - Receiver "invites" transmissions when free. [Talucci-et-al-PIMRC-97, Garcia-Luna-Aceves-Tzamaloukas-Mobicom-99]

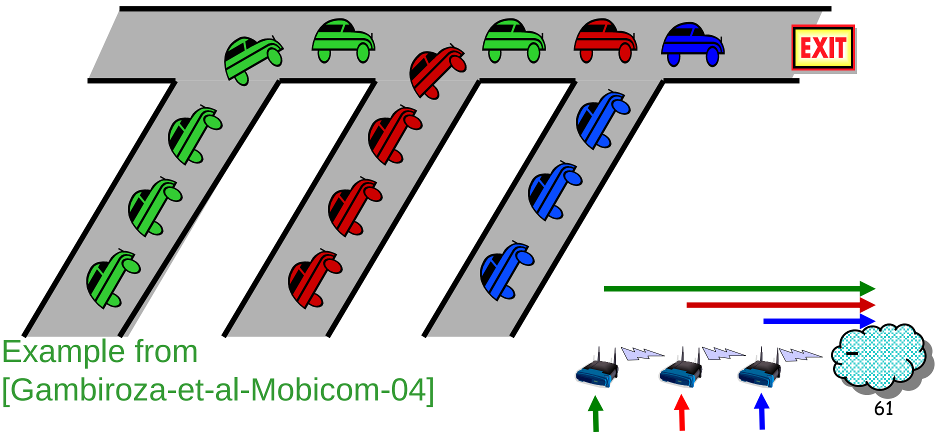
Flow-in-the-Middle Problem



- A flow (2) contends with several flows (1,3) that do not contend with each other.
  - Typically a flow in the middle.
- May suffer from lack of transmission opportunity.

Fairness Problem above MAC

- Mixing of local and forwarded traffic.
- Similar to a parking lot scenario.



Example from
[Gambiroza-et-al-Mobicom-04]

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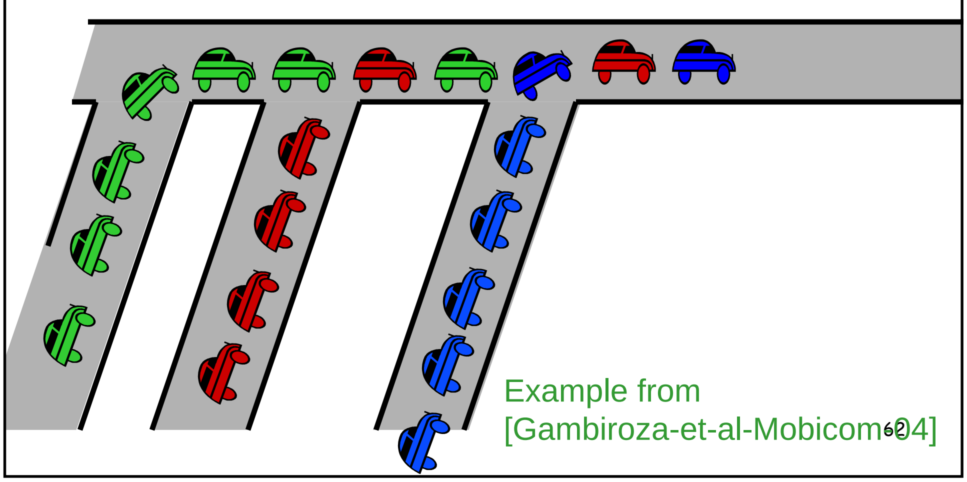
Parking Lot Example



Example from
[Gambiroza-et-al-Mobicom-04]

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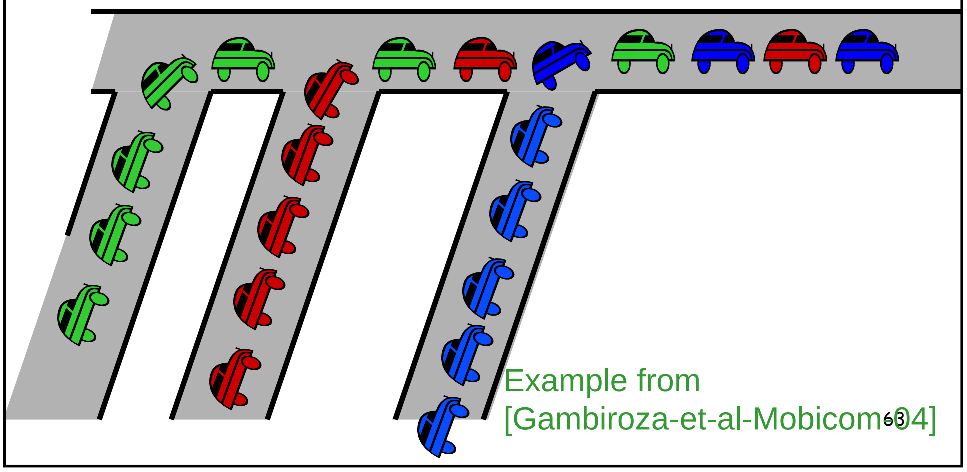
Parking Lot Example



Example from
[Gambiroza-et-al-Mobicom04]

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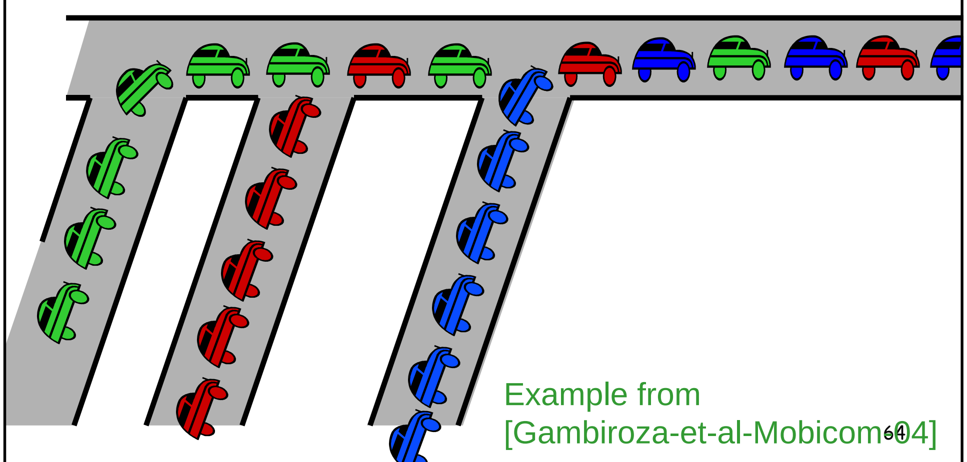
Parking Lot Example



Example from
[Gambiroza-et-al-Mobicom04]

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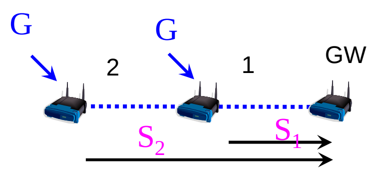
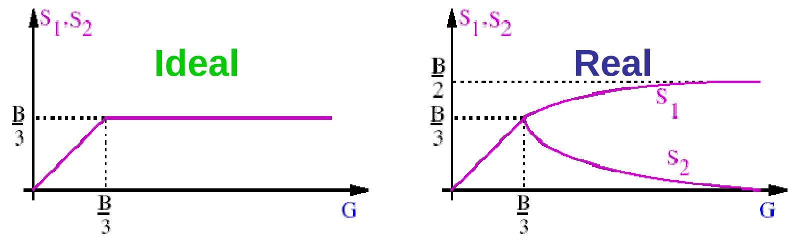
Two Node Analysis



- S2 needs two transmissions; S1 needs one transmission.
- MAC allows only one transmission in the neighborhood at one time.



[Jun-Sichitiu-Wireless-Comm-Mag-03]

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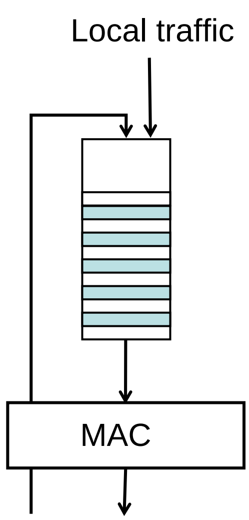
Two Node Analysis



- At high load the locally generated traffic fills up the queue at a faster rate than forwarded traffic.

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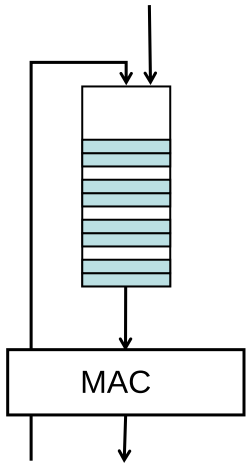
Two Node Analysis



- At high load the locally generated traffic fills up the queue at a faster rate than forwarded traffic.

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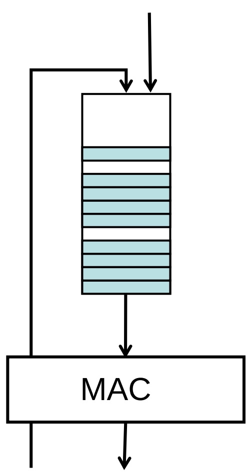
Two Node Analysis



- At high load the locally generated traffic fills up the queue at a faster rate than forwarded traffic.
- Solution: Rate control for local traffic.
- But need to calculate the fair shares.

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Addressing Fairness Problems

- Rate limiting above MAC layer
  - Compute "fair" link flow rates. [Huang-Bensaou-Mobihoc-01]
  - Packets for different flows are passed on to MAC only when "eligible." [Sarkar-Tassiulus-IEEE-TAC-05]
  - Legacy MAC OK.
- New MAC protocols
  - Use additional "coordinations" to control transmissions. [Kanodia-et-al-Mobihoc02, Luo-et-el-IEEE-TMC-04]
  - Essentially distributed scheduling.
- Both topics of active research!

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