Self-Organizing TDMA MAC for Mobile Ad-hoc Network

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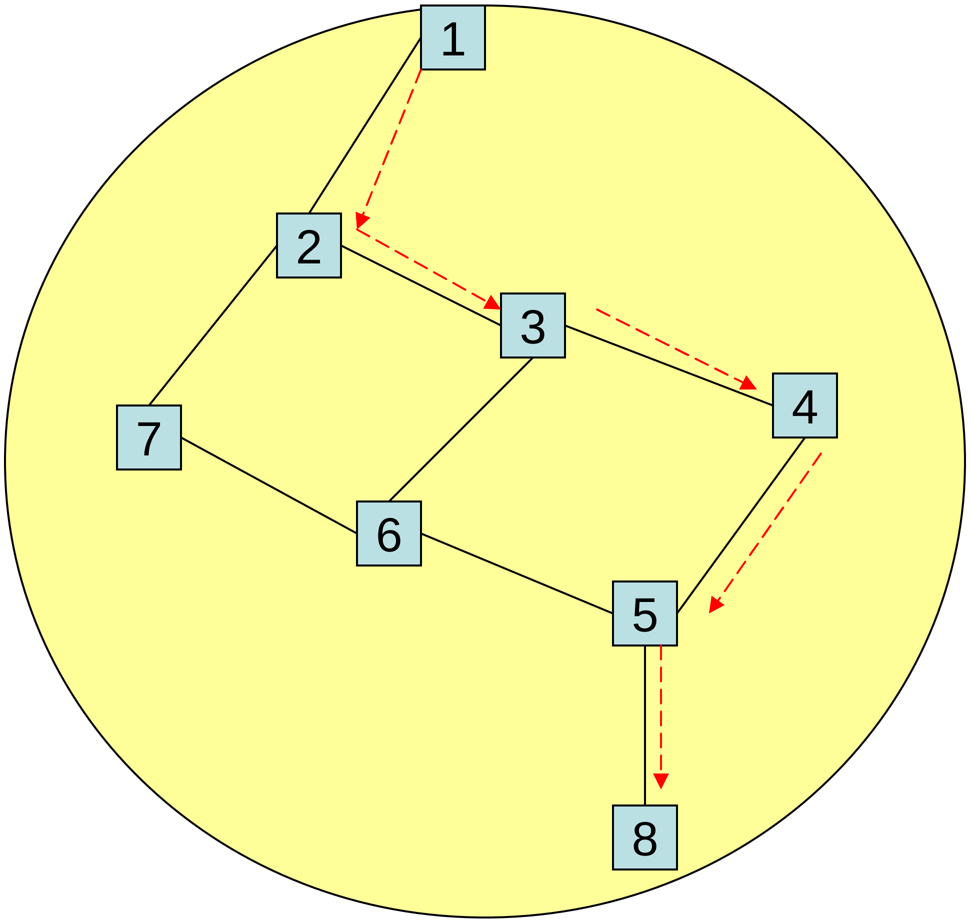
Contents

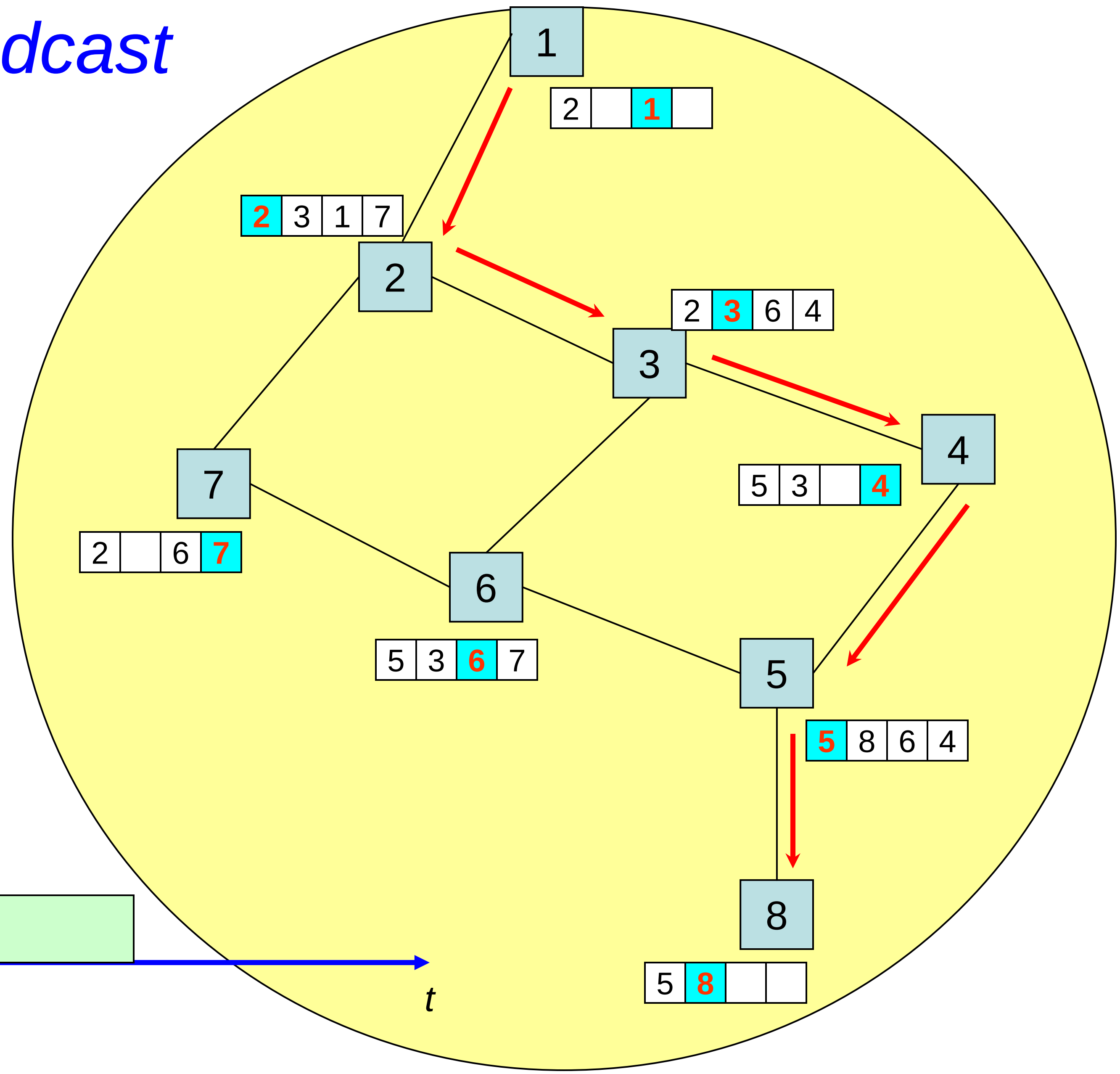
- Motivation
- Related Work
- My Design Scheme
- Demo Specification

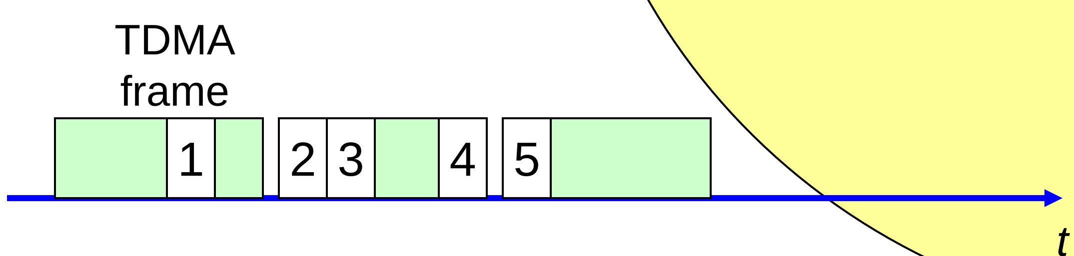
Mobile Ad-hoc Network

- 802.11 MAC+ Multi-hop Routing
  - Delay could be extremely large
  - MAC is not efficient, Stop-and-Wait
  - Hidden Terminal
  - MAC is simple, leave complexity to routing



TDMA Broadcast scheduling

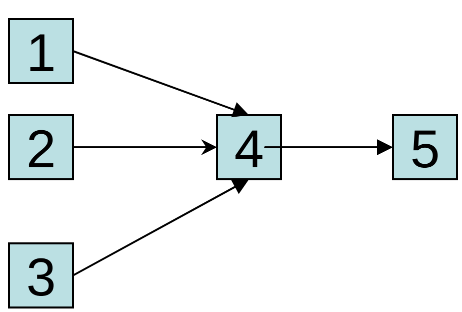


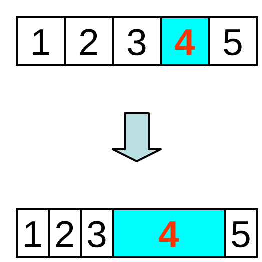


Advantages

- Time-bounded packet transmission
- Solve hidden terminal problem
- TDMA MAC provide valuable information for Routing
  - Discovery neighbor nodes
  - Helpful to determine link metric (bandwidth, delay)
  - Quick response to topology change
  - Dynamical bandwidth adjust

Example: Congestion Control





Centralized .vs. Distributed

- Traditional TDMA Scheme
  - TDMA cellular network (IS-136) or 802.11 DCF
  - Centralized node (base station) has global info
  - Scale problem
  - Global time sync or polling
- Distributed TDMA
  - Each node is equal, runs same algorithm to build schedule without global knowledge
  - Appropriate for Forwarding node MAC Design?
  - Broadcast scheduling is suitable for provide QoS for real-time broadcast, multicasting packets, also for unicast if immediate ACK is not needed.
  - Link scheduling for uni-cast.

Self-Organizing Distributed TDMA Design Goals

- No central control --- being ad-hoc
- No global information exchange in MAC
  - Cost too much when network is large
- Distributed algorithm
  - Running at each node, converge to a feasible local schedule
- No separate reservation channel
  - Need another radio, or channel switching
- No global time sync
  - Add extra weight (GPS) and cost to handheld mobile devices
- Adaptive to topology change and bandwidth adjustment
- Scalability is a tradeoff .vs. Optimality

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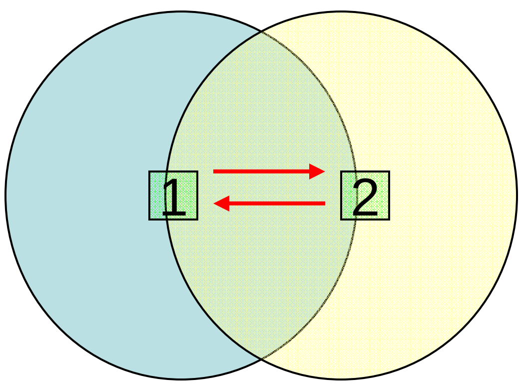
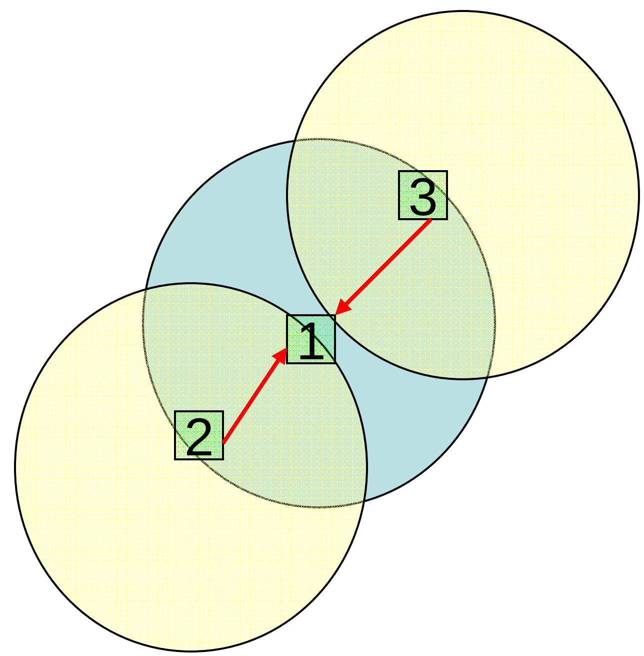
Collision (Schedule Conflict)

- Primary Interference (do more than one thing at one time)
  - Type I Collision --- Transmitting while receiving
  - Type II Collision --- Receiving from multiple Neighbors
- Secondary Interference (exposed terminal, CDMA)

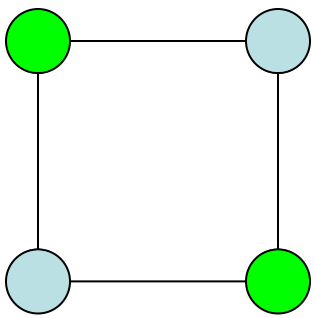




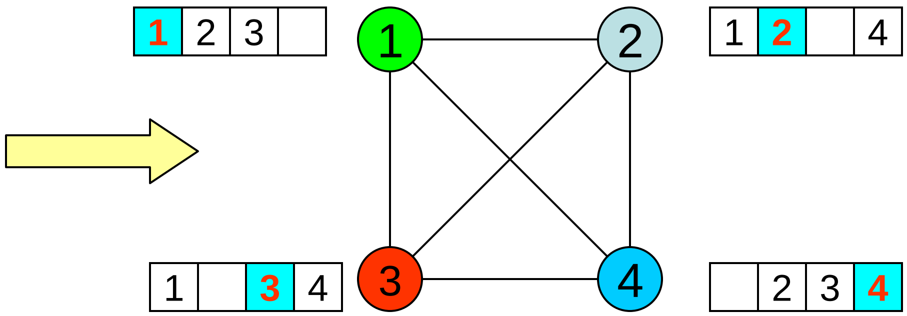
Note: exposed terminal is regarded as Type I collision in broadcasting Scheduling

Graph Theory: Vertex Coloring

- An Undirected Graph *G(V,E)* with Vertex and edges
- No edges connecting two Vertexes with same color
- How many colors do we need?



Original Topology



Connecting Nodes 2-hops away

Note:

- NP-Complete Problem
- Point to Point Link Scheduling (Oriented Graph, Edge Coloring)

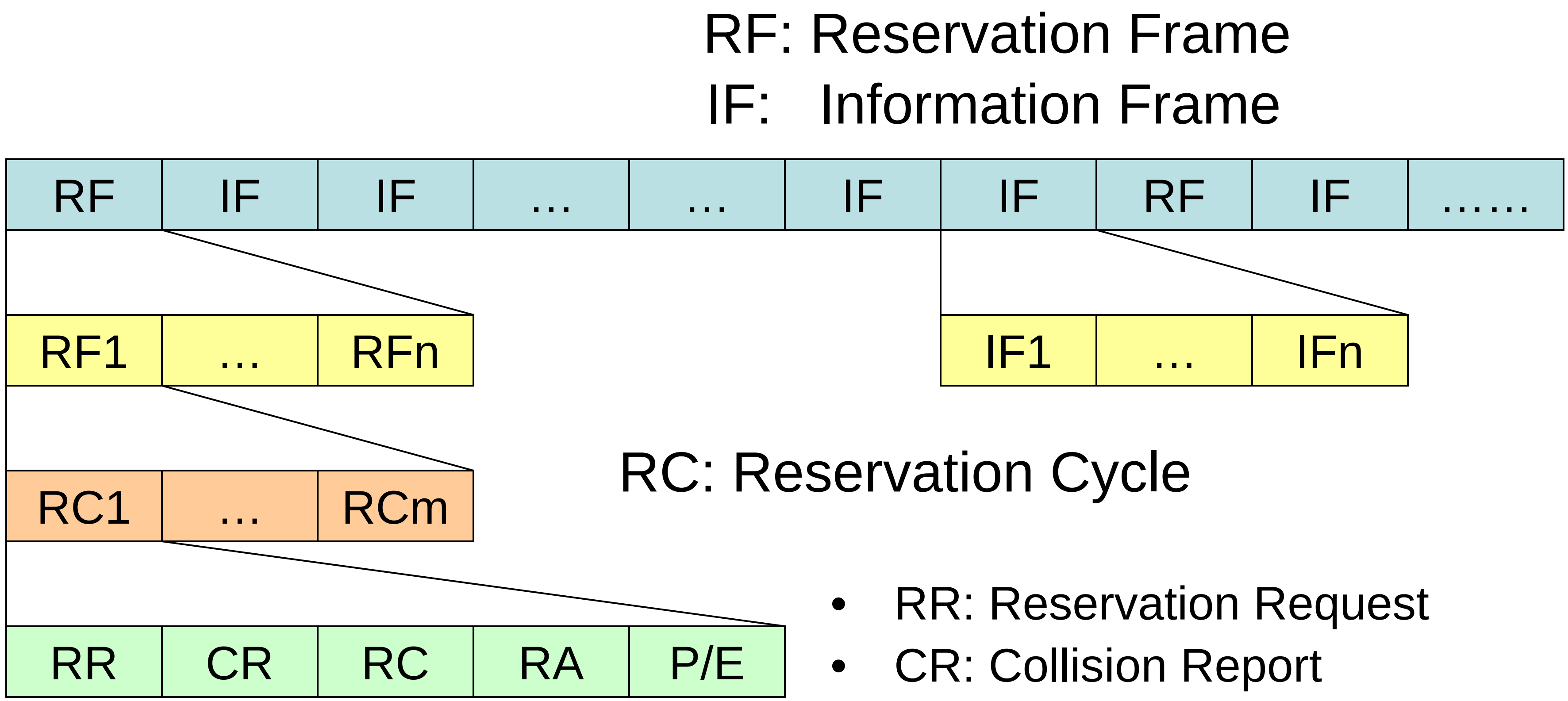
Algorithm to Find Near-optimal Coloring scheme

- Lower bound: $D(G) + 1$
- Heuristic approach
- Centralized algorithm with a global knowledge
  - RAND algorithm: nodes are colored in a random ordering in a greedy fashion.
- Only useful for a fixed topology in a global sense

Recent work on Distributed Algorithm

- FPRP(Five Phase Reservation Protocol)
  - A Five-Phase Reservation Protocol (FPRP) for Mobile Ad Hoc Networks Chenxi Zhu , M. S. Corson **Wireless Networks** September 2001 Volume 7 Issue 4
- Features
  - Single Channel TDMA-based Broadcast Scheduling
  - Fully distributed, parallel algorithm
  - Only local conversation is needed
  - Nodes Keep perfect global timing for synchronization

Brief introduction to FPRP



- RR: Reservation Request
- CR: Collision Report
- RC: Resv. Confirm
- RA: Resv. Ack
- P/E: Packing /Elimination

Performance & Drawback?

- How quick It will converge?
  - $R = N / D_{max}$
  - M: Number of Cycles
- Comments
  - If M is dynamic, it may never converge when R is ~1, some nodes will never settle down
  - Global Timing (A potential central commander?)
  - Fixed share of Reservation Slot
  - Potential Deadlock for Type 1 collision, because RR is synced.
  - Contention-based (high-connectivity, high failure rate?)
  - Global reset every N info frames
  - Noiseless Channel, How about a RR loss?

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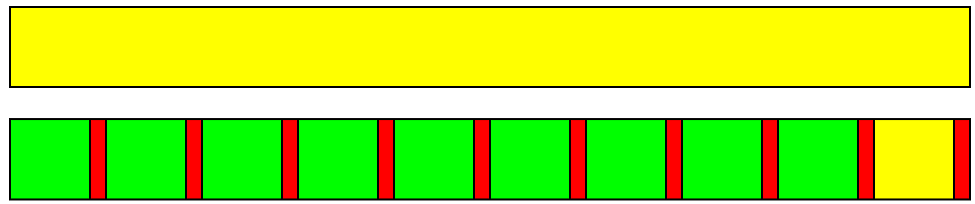
My Approach

- What is desirable?
  - Local time sync
  - Request-based Schedule Update, not periodic
  - Fast convergence
  - Reduce information exchange amount
- Assumptions
  - Symmetric link
  - Topology change slowly relating to packet transmission time
  - Not a dense network, D<=5

Mixer of Contention and TDMA

- Evolving from Current 802.11 MAC
- Basic TDMA frame



•The last slot is always reserved for contention period (CP)

•Other slots could be either CP or RP(Reserved period)

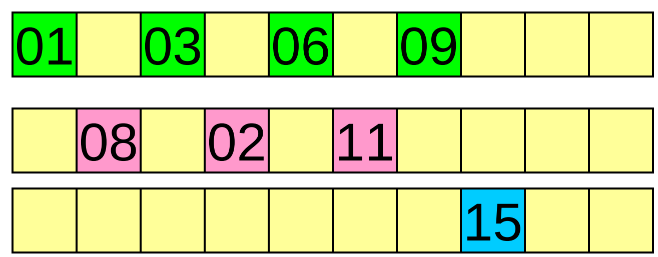
•Guard Time is following each RP

•Each node holds:

•Type I conflict slot table

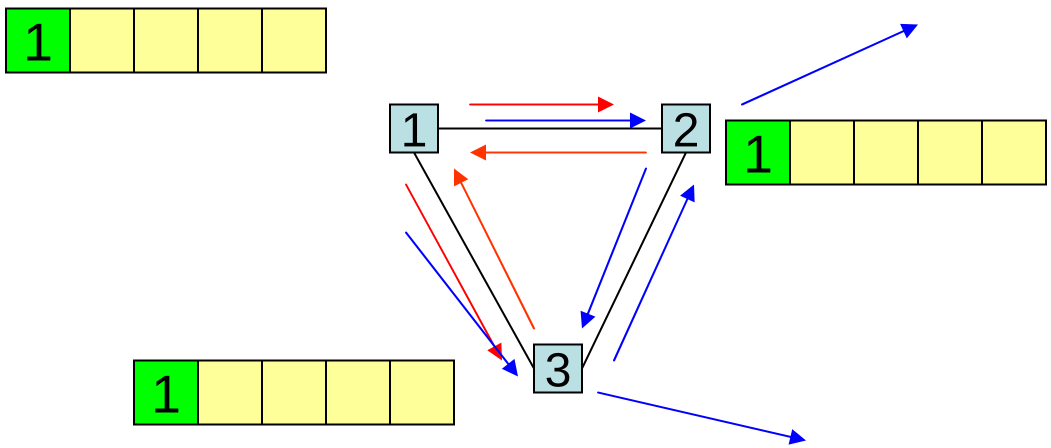
•Type II conflict slot table

•Temporary approval” slot table



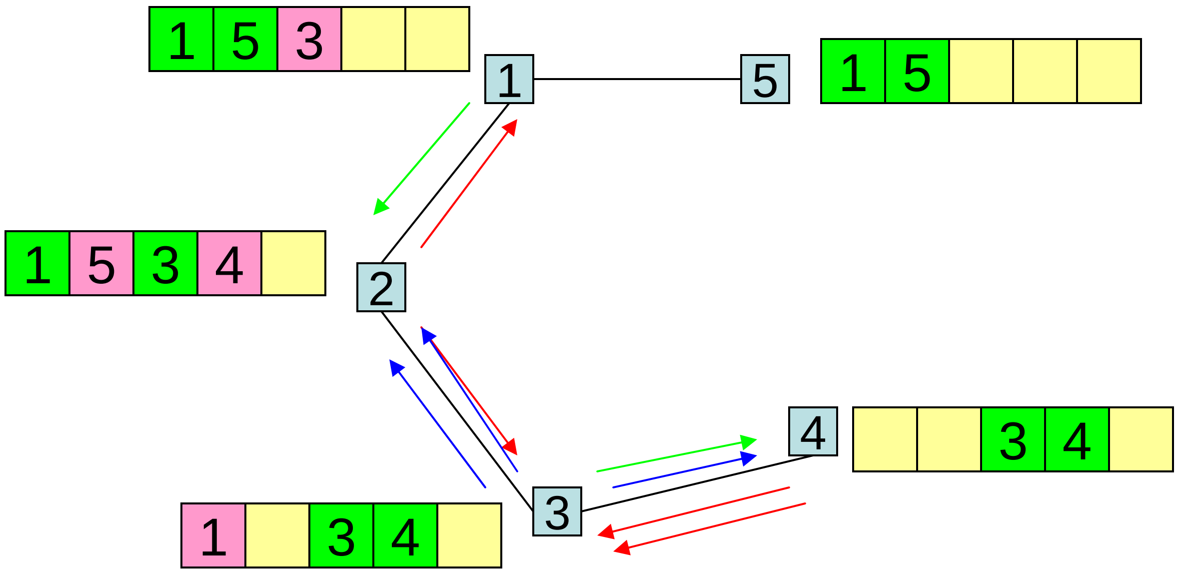
•Only new Type I conflict table is exchanged between neighbors to reduce information change, update stops at 2-hops

Schedule Dynamics (Request-Approve)



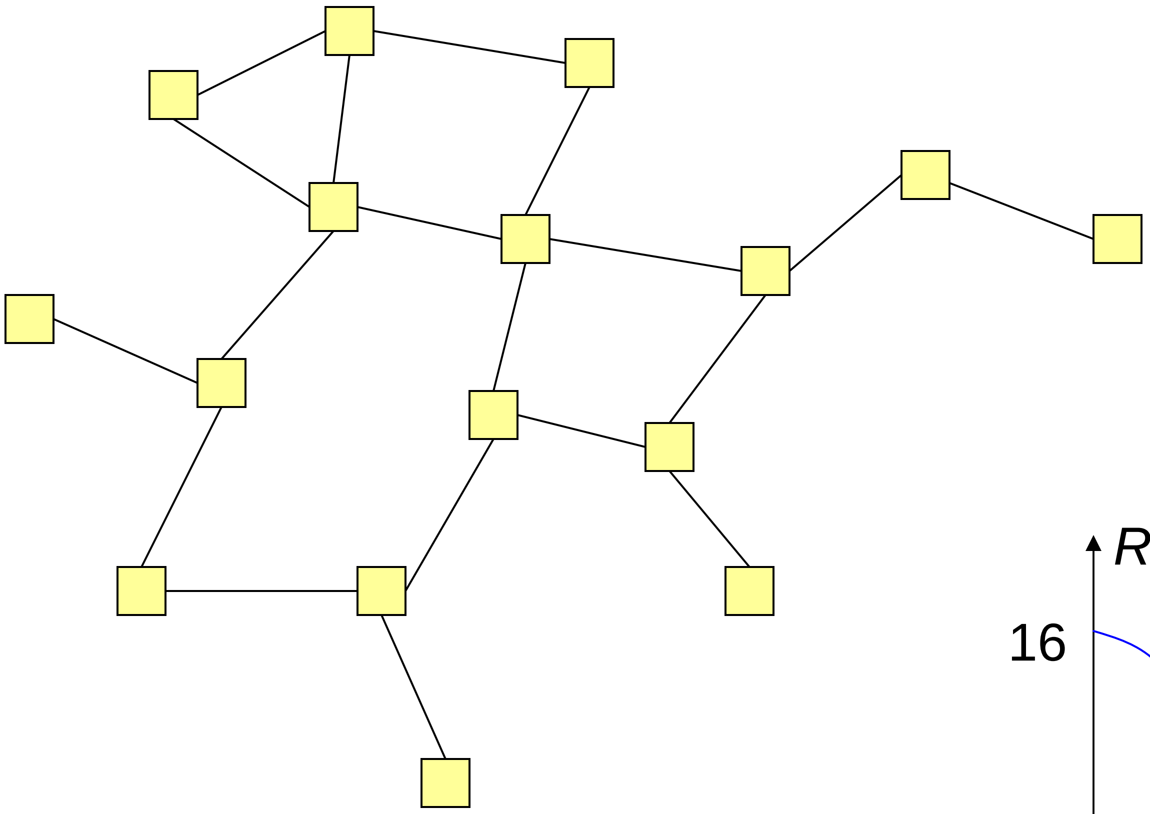
- Initially, Each node has whole frame for contention. Each node discovery neighbors with 2-hops.
- Node 1 Send **SUR** (Schedule Update Request, want to reserve Slot 1
- Node 2,3 check the request, Approve it respectively with **SUA**
- Node 1 declare its successful reservation for slot 1 to 2,3, **SUD**
- Node 2,3 declare their own new schedule to their neighbors respectively, **SUD**

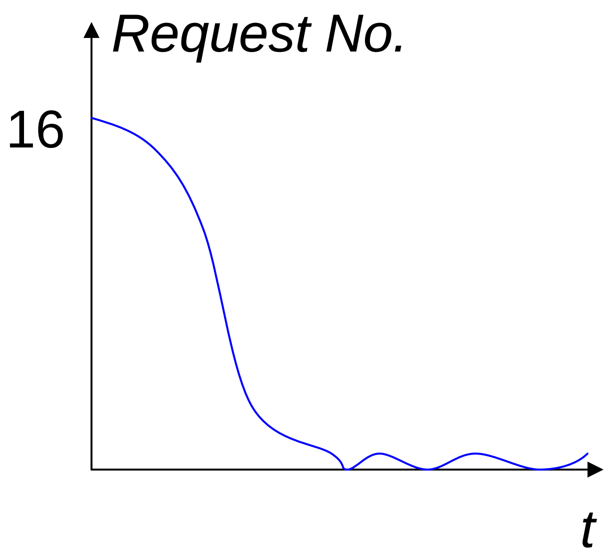
Scenario: request-reject



- Node 2,4 request the use of slot 4
- Node 3 receive 4’s request first, approve it, but reject Node 2’s request, Node 1 approve 2’s request
- Node 4 declare slot 4 with SUD
- Node 3 update and send its own SUD
- Node 2 update its own neighbor record.

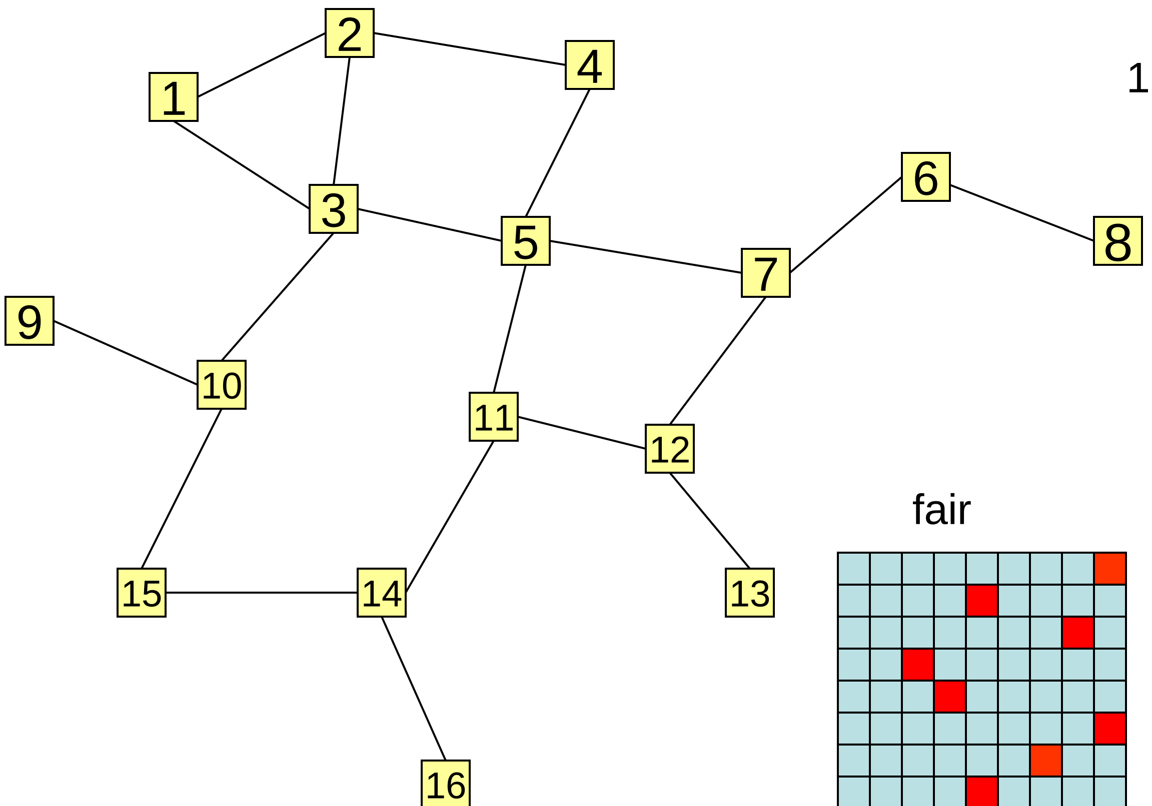
Parallel Computing

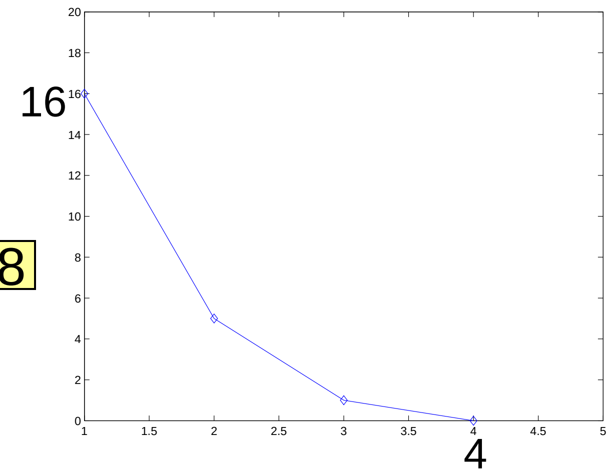


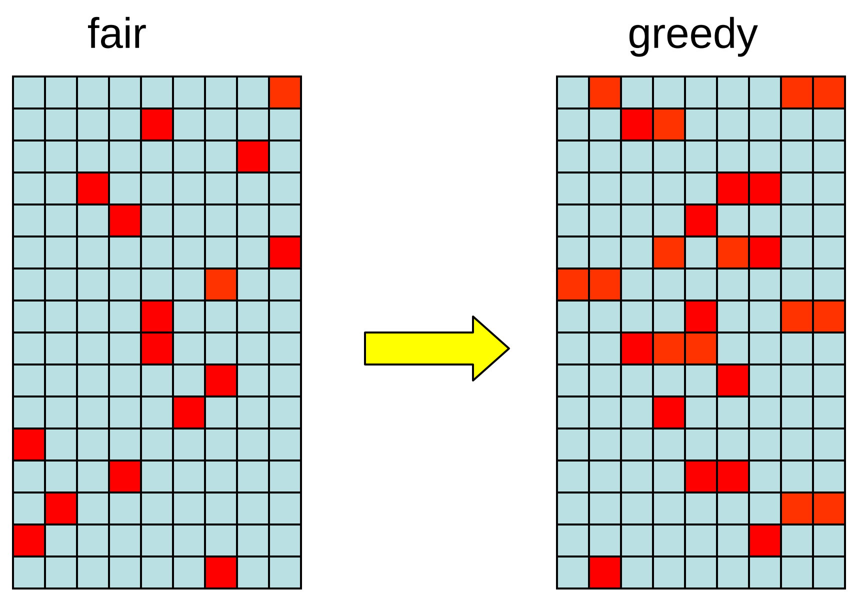


- If we assume every node prefer TDMA

Simulation with MATLab



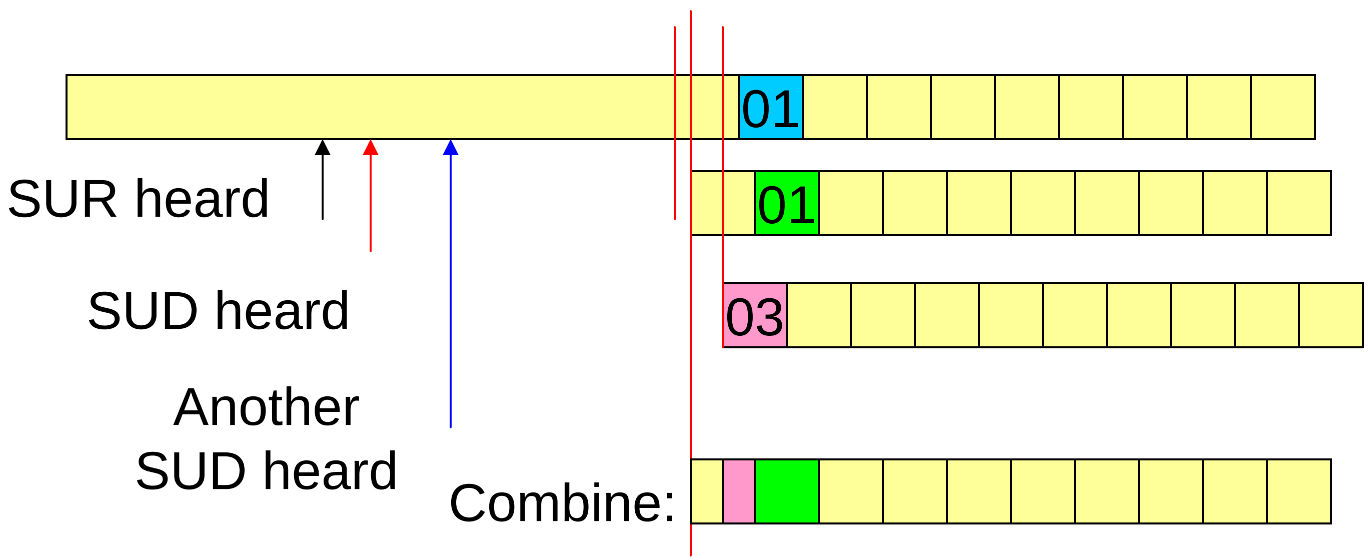




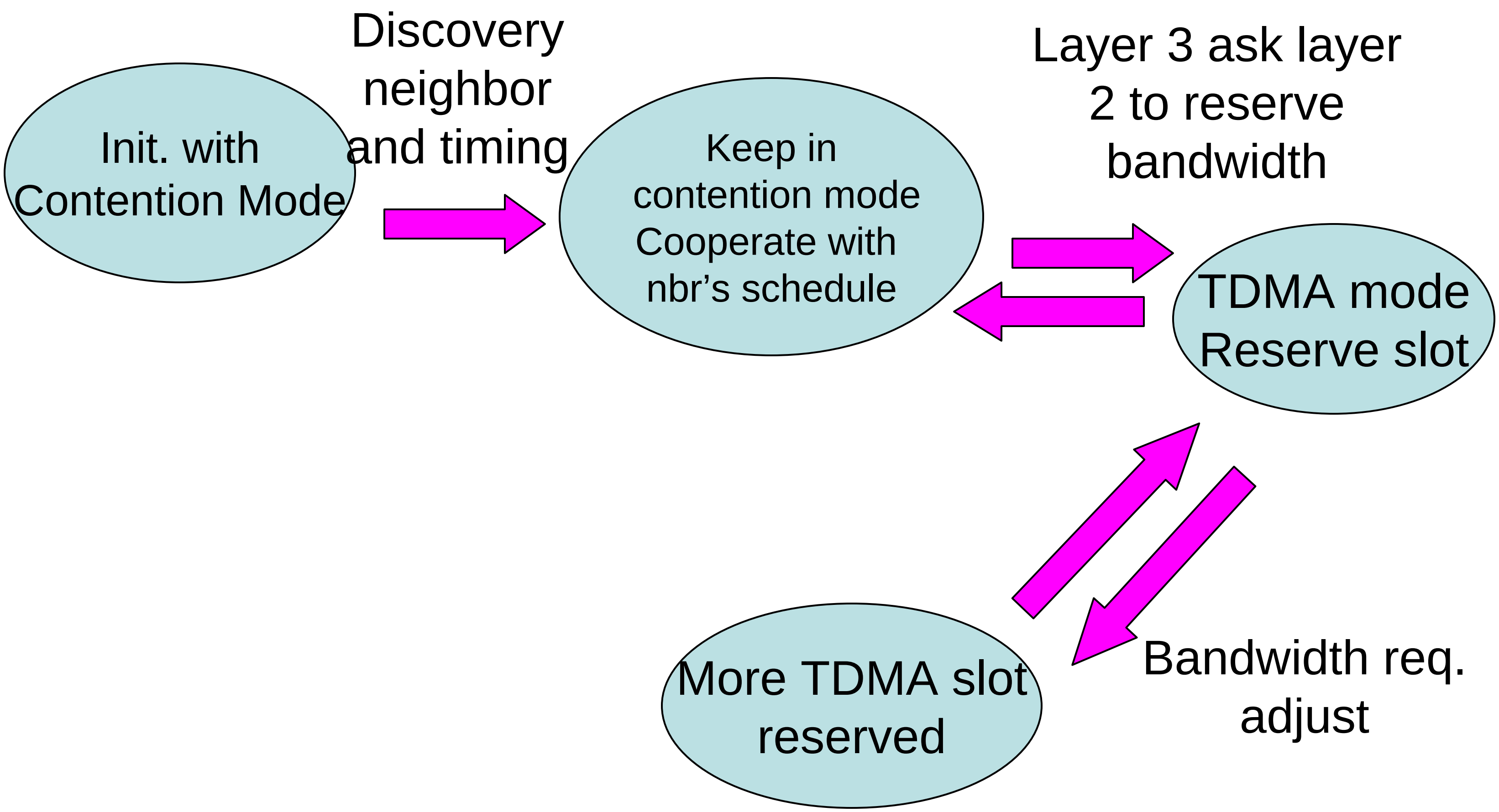
Total reserved TS: 27

Handling Timing Offset

- Local time is requested in SUR, also confirmed in SUD.
- Local time is also broadcast by node with schedule, sending at the beginning of each slot, STB (scheduling & Timing broadcast)
- Each node align its local timing basis when it first hears a SUD message.



Possible State Diagram of Node

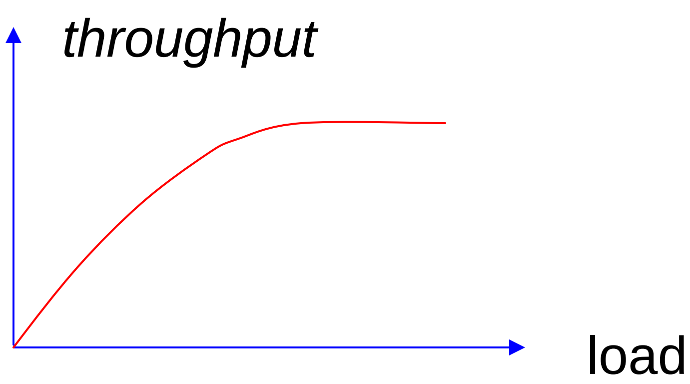


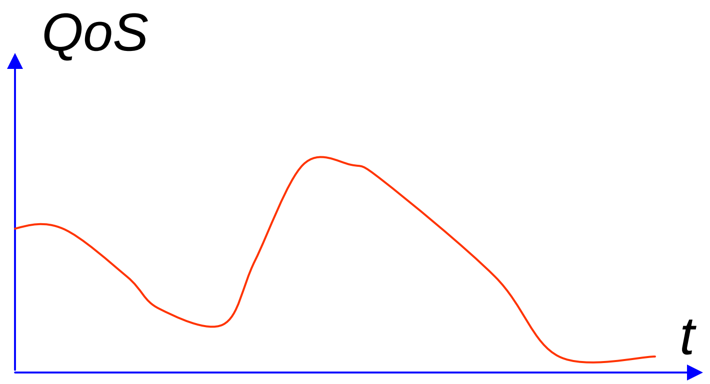
Features

- Use contention-based 802.11 MAC to ensure SUP is responded.
- The network is always working, no halt to wait for new schedule, insensitive to algorithm converge time.
- Preserve last slot for contention, open the door to further SUR.
- Basically, a node holding neighbor (in 2 hops) schedule will not yield an unreasonable request. However, if the info is not update timely, rejection is possible
- Node not only reserve, but also can cancel its schedule with SUR, more adaptive to topology dynamics.

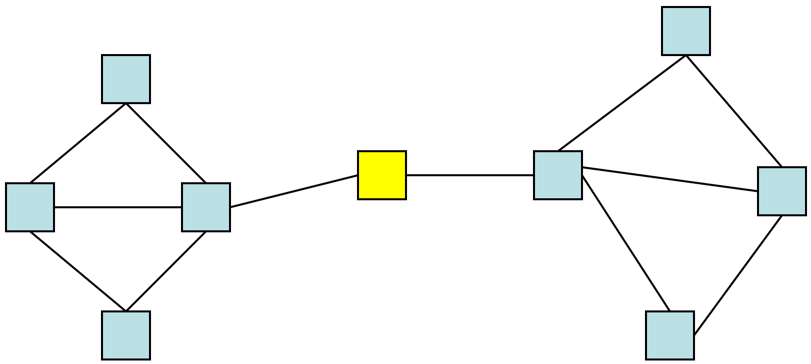
Performance estimate

- Optimal?
  - Loss because lack of global knowledge
  - Timing offset loss
  - Guard time loss depends on the ratio of guard time and slot time.
  - Comparison is only meaningful when static. Dynamic behavior is our focus.
- Robust?
  - Throughput when overloaded?
- Adaptive?
  - Schedule remain in a deadlock because multiple constraints
  - How to Make Schedule flexible without global reset?





Topology Dynamics



- Later-comers are not able to reserve TS unless some node cancel TS, or new topology change. It can only use the CP slot.
- Although self-organizing, need be aware of some critical request.

Hierarchy & Rollback

- *Rollback*:
  - forcing a node to cancel its recent reservation
  - Introducing Special SUR, still raise SUR even this SUR is conflict with current schedule
  - Some arbitrator will decide if it is appropriate to command some node to rollback form current schedule
- *Hierarchy*
  - Everyone created equal ----> Everyone has different weight of (temporary) authority
  - Weight is decided by Connectivity, traffic flow,…node ID, etc.
  - Temporary hierarchy is composed of master-slave relationships
- *Scheme*
  - Special SUR is passed to Master nodes
  - SRC(Schedule Rollback Command) is send to slave nodes
  - Nodes receive SRC send a normal SUR to cancel its last reservation
- Still a distributed algorithm

Challenges & Future work

- Sensitive to time skew and propagation delay.
- Is N to be globally equal?
- Is slot necessary to be equal duration?
- Link Scheduling is more useful than Broadcast Scheduling
- *Integrated with Routing Protocol*
- *A good question: What’s the network behavior if some nodes switch to TDMA? Other nodes feel encouraged or discouraged?*
- *When node degree is not uniform?*

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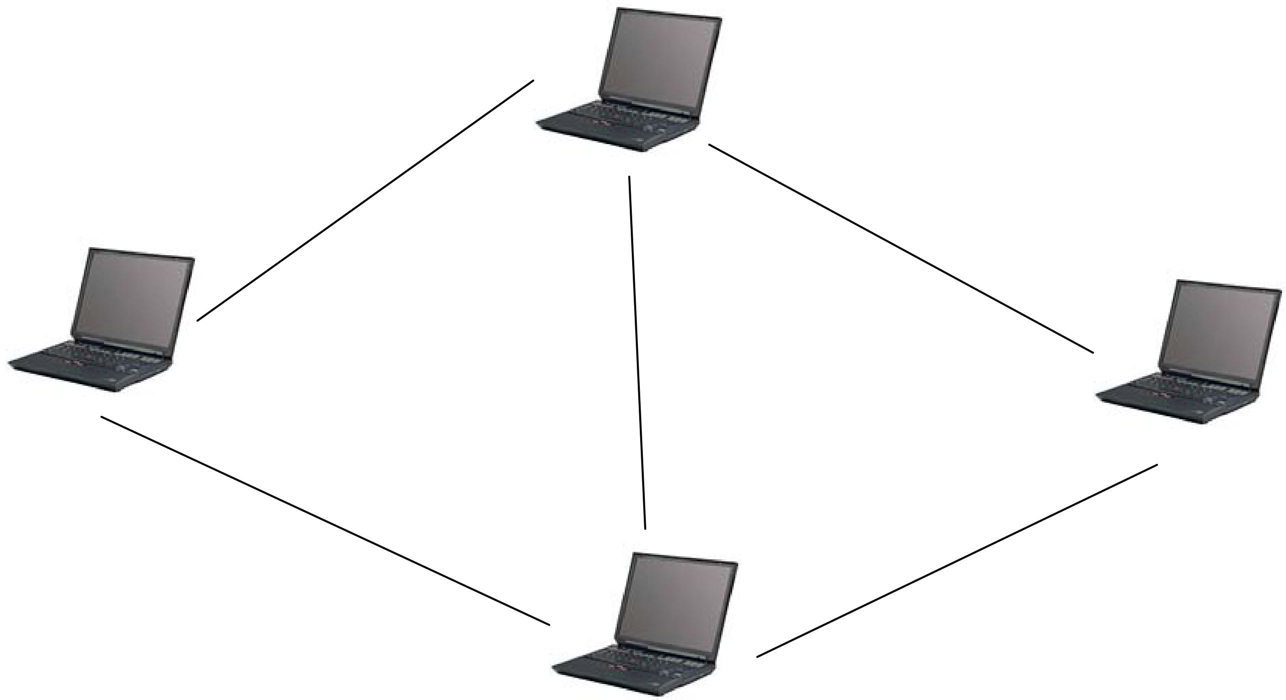
Demonstrate Self-Organizing TDMA

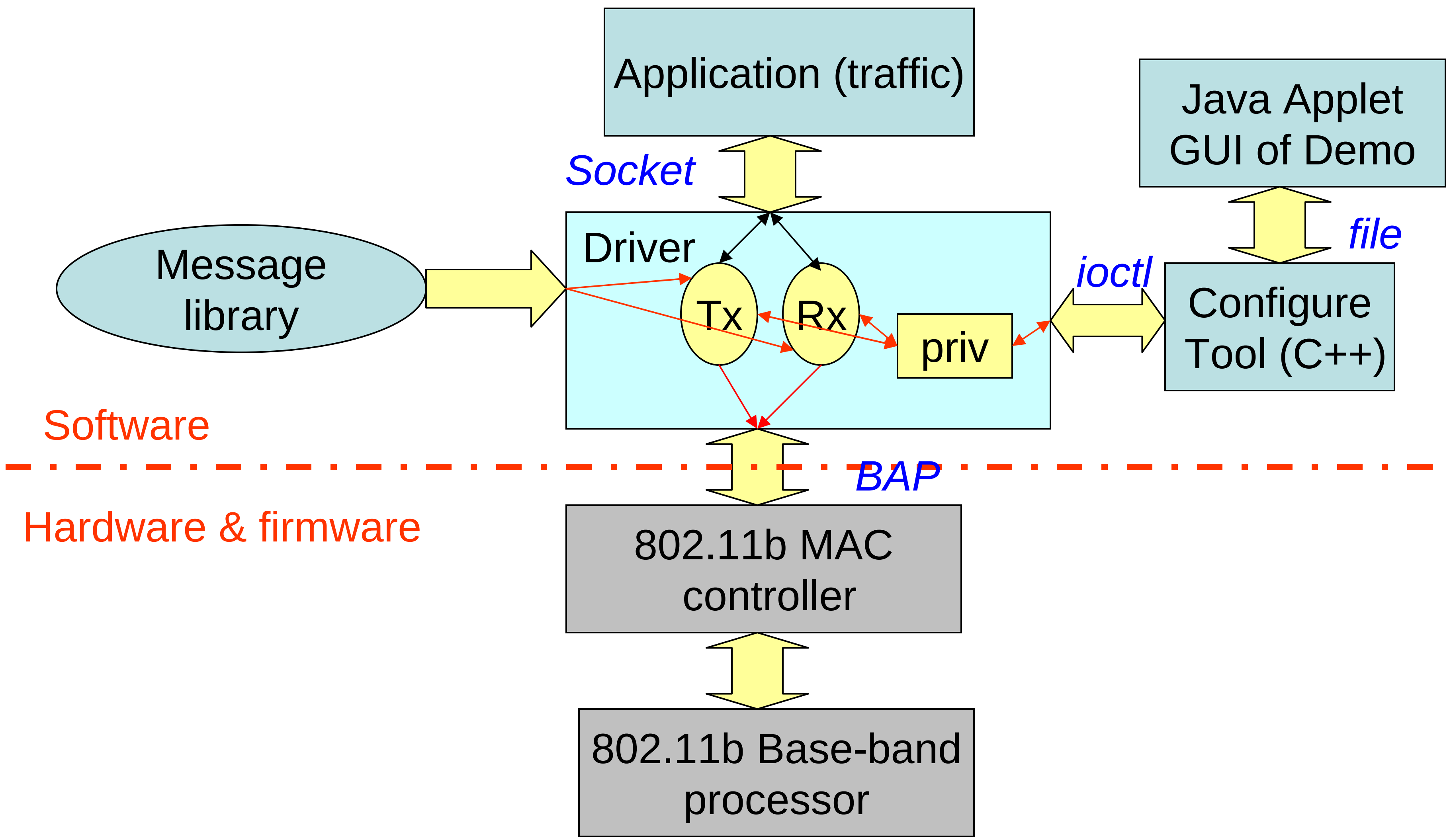


- Application
  - File transfer TCP
  - UPD packet transfer
- Feature
  - Enable TDMA
  - Performance Comp.
  - Adaptive to Node mobility

Choosing Parameters:

- Parameters:
  - TDMA frame: 100ms
  - N = 5, 10
  - Guard time ratio : 10% (1ms)
  - Data rate: 1Mbps
  - 802.11 Driver Modification
  - Adjust power to Radio range ~ 20ft.
  - Node ID: 1,2,3,4
- Timers
  - SUR_Expire timer, how long a SUR should receive response?
  - Timer to periodic exchange HELLO message

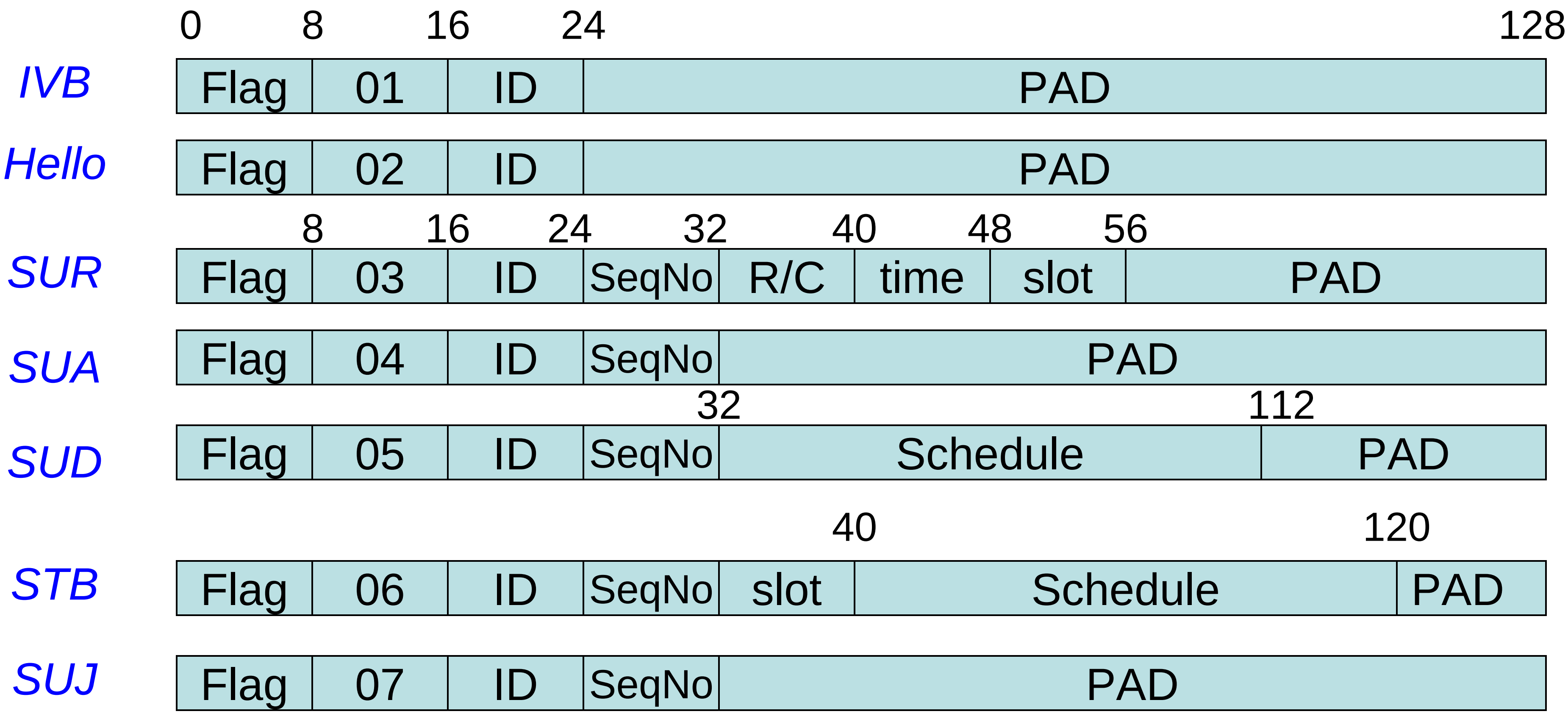
Software Architecture



Define Messages

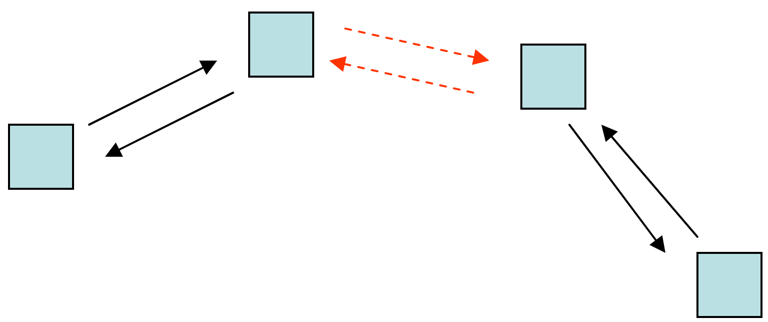
- IVB(Invite broadcast) (for discovery)
- Hello: tell neighbor : I'm (still) here
- SUR (schedule update request)
  - Includes (t, slot no, type), T is preset for all nodes
- SUA (schedule update approve)
- SUJ (schedule update reject)
- SUD (schedule update declare)
- STB (schedule & timing broadcast)
  - Includes (slot no, type I collision schedule)

Message Format



Problem & Consideration

- Considerations
  - Still using DATA+ACK for TDMA



ACK messages : Exposed terminal + Hidden Terminal

Questions?

Welcome Comments!