Multi-Channel Wireless Networks

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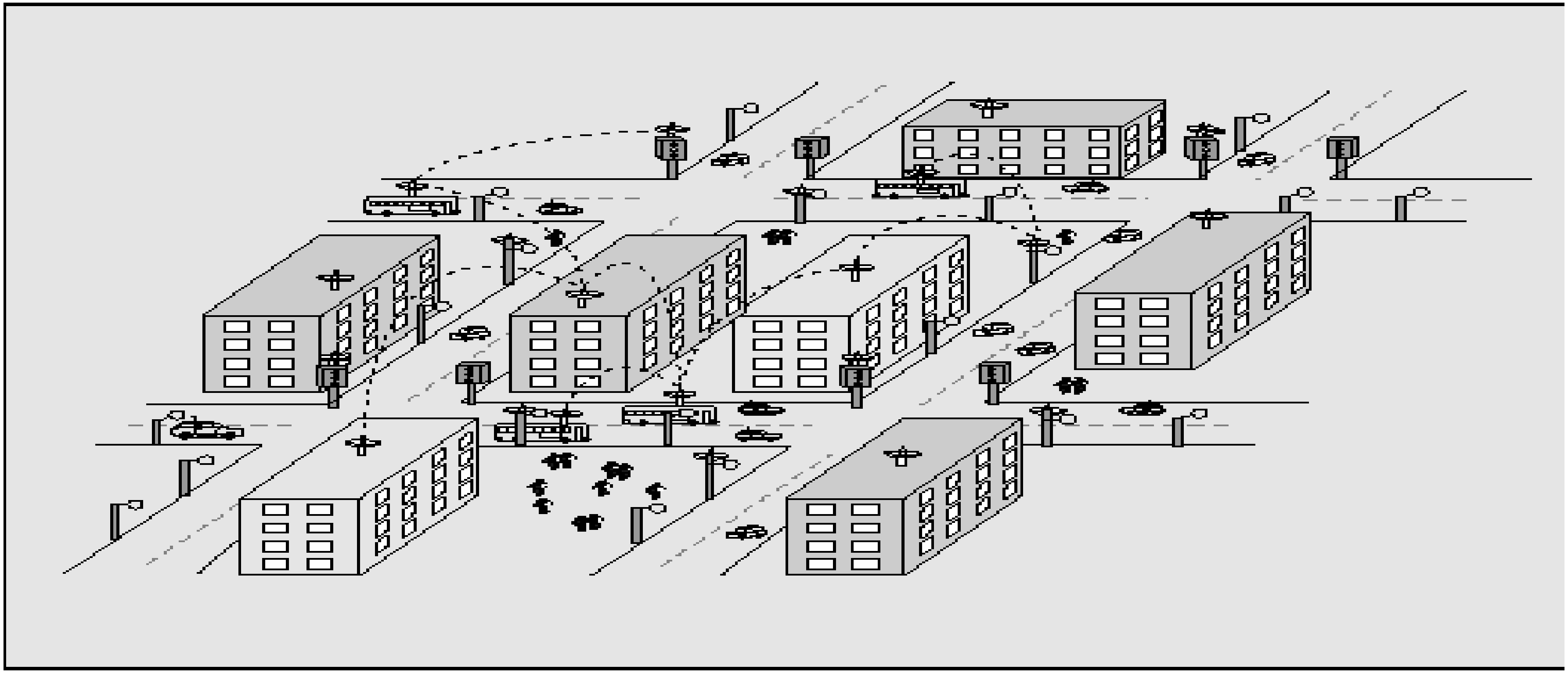
Outline and Papers

- Wireless Mesh Networks
- Motivation: Increasing Throughput
- Important Issues in Multi-channel Wireless Networks
- Kernel Level changes needed to support multiple channels
- Abstraction Layer proposed
- Protocols for single interface: M-MAC

- Papers
  - **Multi-channel Mesh Networks: Challenges and Protocols**
    Pradeep Kyasanur, Jungmin So, Chandrakanth Chereddi, Nitin H. Vaidya (UIUC)
    IEEE Wireless Communications, 13(2), April 2006.
  - **Multi-channel MAC for Ad Hoc Networks: Handling Multi-Channel Hidden Terminals using a Single Transceiver**
    Jungmin So, Nitin Vaidya (UIUC)
    ACM Mobihoc 2004
  - **Mesh Networks: Commodity Multi-hop Ad Hoc Networks**
    Raffaele Bruno, Marco Conti, and Enrico Gregori (National Research Council)
    IEEE Communications 2005 Volume 43 Issue 3

Wireless Mesh Networks



•Wireless mesh networks are built on a mix of fixed and mobile nodes interconnected via wireless links to form multi-hop adhoc networks.

Wireless Mesh Networks

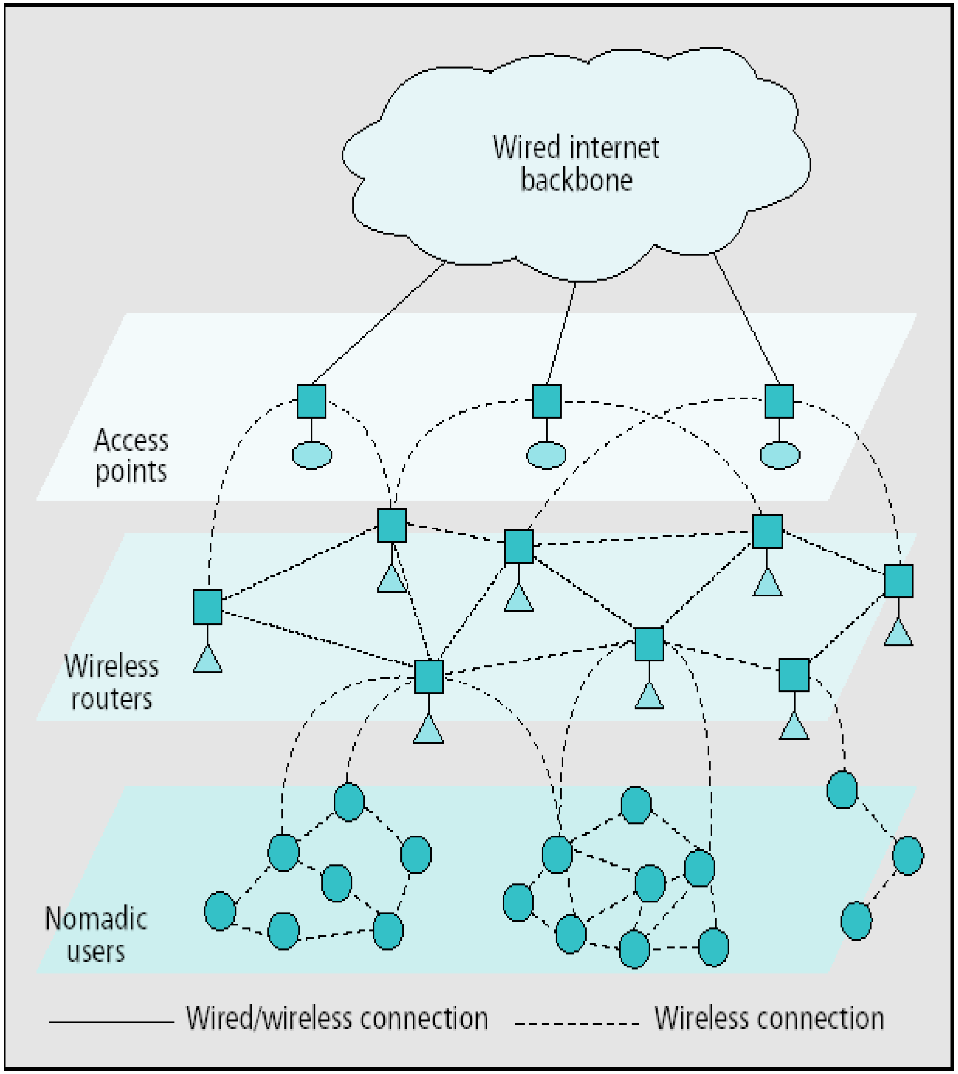


Figure 2. *A three-tier architecture for wireless mesh networks.*

- Wireless mesh networks (WMNs) are dynamically self-organized and self-configured, with the nodes in the network automatically establishing an ad hoc network and maintaining the mesh connectivity [Akilydiz et al.]
- Key difference between Ad Hoc Networks: Hierarchy and Scalability
- Open standards implementing Mesh technologies include IEEE 802.11s, IEEE 802.16a, IEEE 802.20 (Mobile Broadband)

Motivation : Increasing Throughput

- Mesh-networking architecture may spur the growth of video-sharing among community members
- So, an important challenge in multi-hop wireless mesh networks is to provide as much bandwidth as possible.
- **Multiple wireless channels** can increase the throughput as at least two pair of nodes are communicating at the same time.

Multiple Channels Example

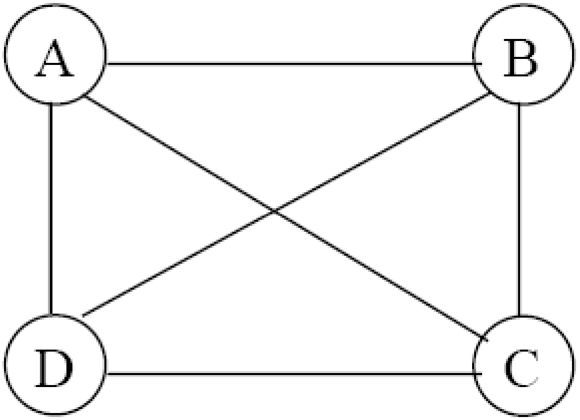


Fig. 2. Example scenario: Each node has one interface and two channels are available.

- All nodes fixed on common channel
    - One channel unused
- A,B fixed on channel 1 and C and D are fixed on channel 2
    - No connectivity between A,B and C,D
- Allow channels to switch frequently and schedule sender and receiver to be on common channel at the same time

Distributing load across all channels

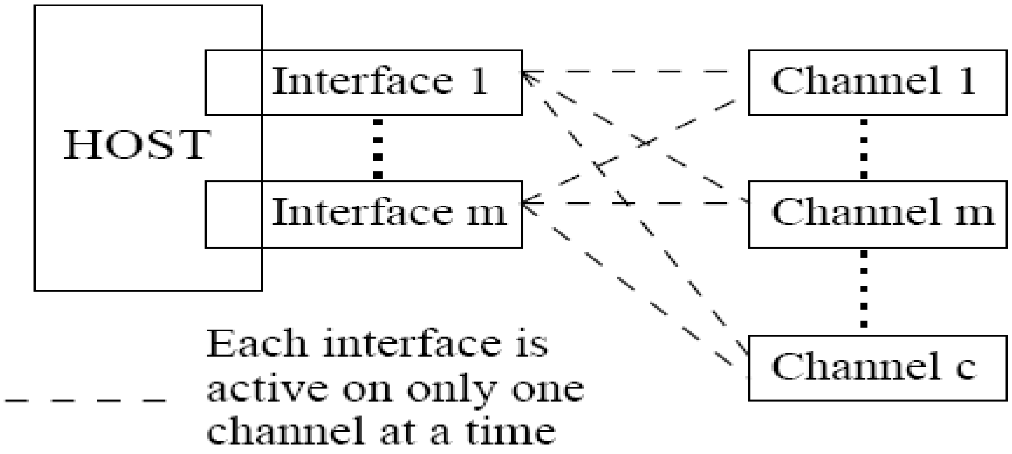


Fig. 1. Channel and interface model.

- **m interfaces, c channels and c > m**

Distribute Load across all channels

- Approach1: Keep the m interfaces fixed on m channels
  - low utilization
- Approach 2:Keep the m interfaces fixed on non-disjoint m channels
  - Simple implementation, but network connectivity is affected
- Approach 3: Frequently switch the interfaces of a node among different channels
  - Flexible but sender and receiver has to coordinate
- Approach 4: Hybrid
  - Keep some interface fixed and switch on some other interface.

Channel Coordination

- **Problems due to multi-channel**
  - **Repeated failures in communication usually implies node down**
  - **But in multi-channel, the receiver may not be listening on the channel used by the sender**
- **Sender and Receiver has to be coordinated, so both use the same channel at the same time**
- **Channel Coordination: Different Approaches**
  - **1] Rendezvous on common channel (MMAC)**
  - **2] Well-known switching sequence so sender can predict receiver channel at any time.**
    - **Both require tight-clock synchronization.**
  - **3] Fix one interface on a common channel and use that for negotiating (DCA)**
  - **4] Fix one interface on a common channel, but different for different nodes (HMCP)**

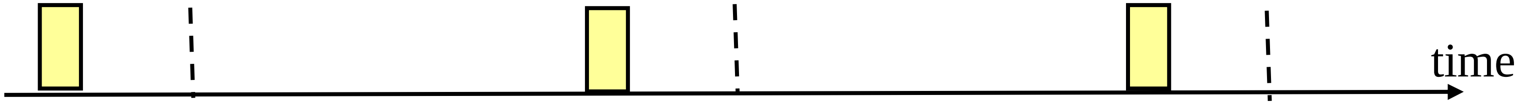
Support Broadcast

- Local broadcast: A packet sent by one node is received by all neighbors
- Many network applications use this functionality
  - Routing protocols use this to efficiently disseminate information
- Techniques for achieving local broadcast in multi-channel network:
  - If there is a periodic rendezvous, broadcast can be sent during that period
    - Increases delay
  - If different nodes use different fixed channels, then a packet has to be transmitted on all channels
    - High cost
- Depending on frequency of broadcast, use appropriate channel coordination protocol

MMAC

- **Link-layer multi-channel protocol designed for single interface hardware.**

- **Main idea (Similar to IEEE 802.11 PSM)**
  - **Divide time into fixed-size interval using beacons**
  - **Have small window at the start of the interval to indicate traffic and negotiate channel for use during the interval**



- **Targeted for other multi-channel MAC**

IEEE 802.11 DCF Operation

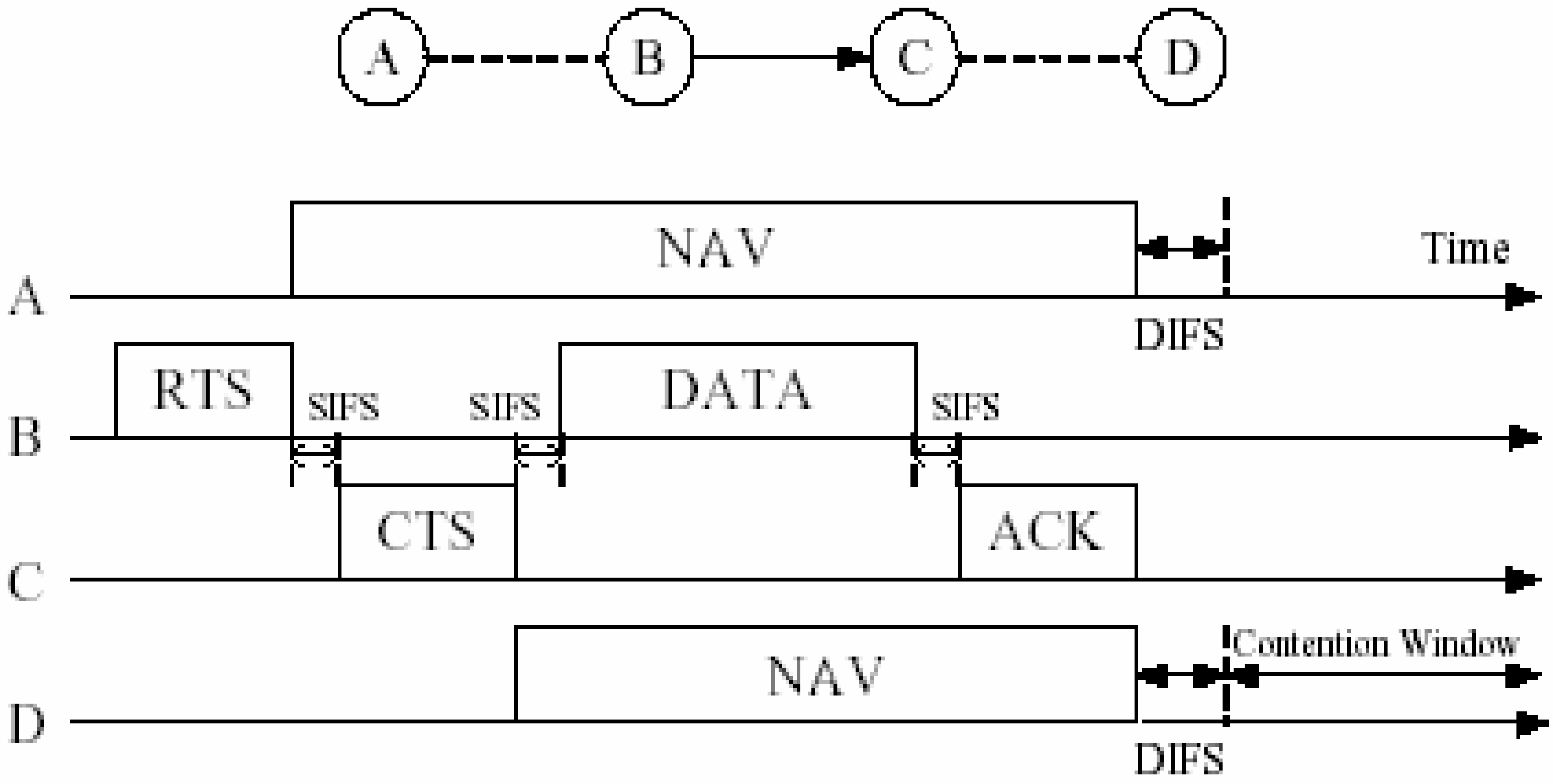
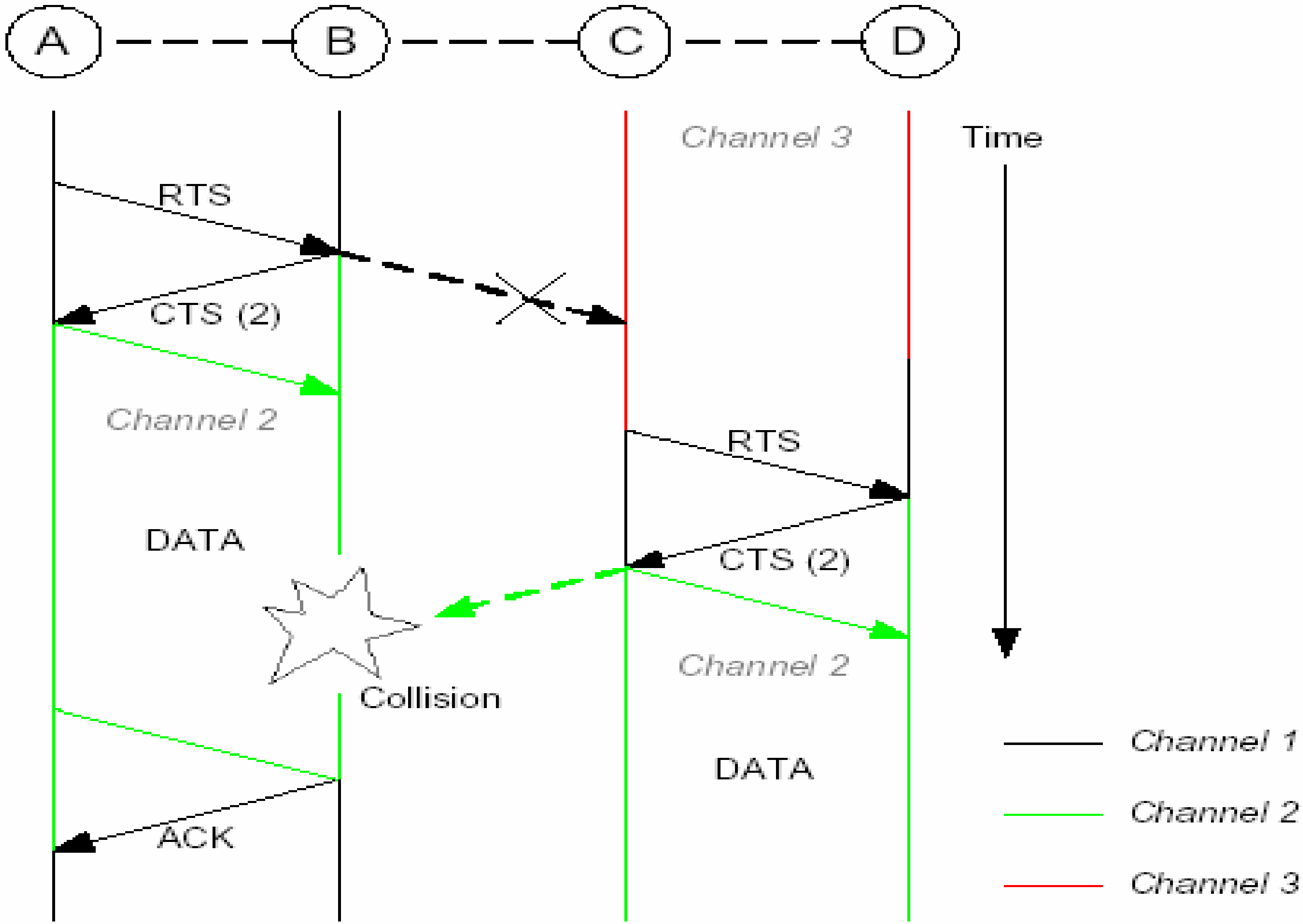


Figure 1: Operation of IEEE 802.11 DCF.

Multi-channel Hidden Terminal Problem



IEEE 802.11 PSM

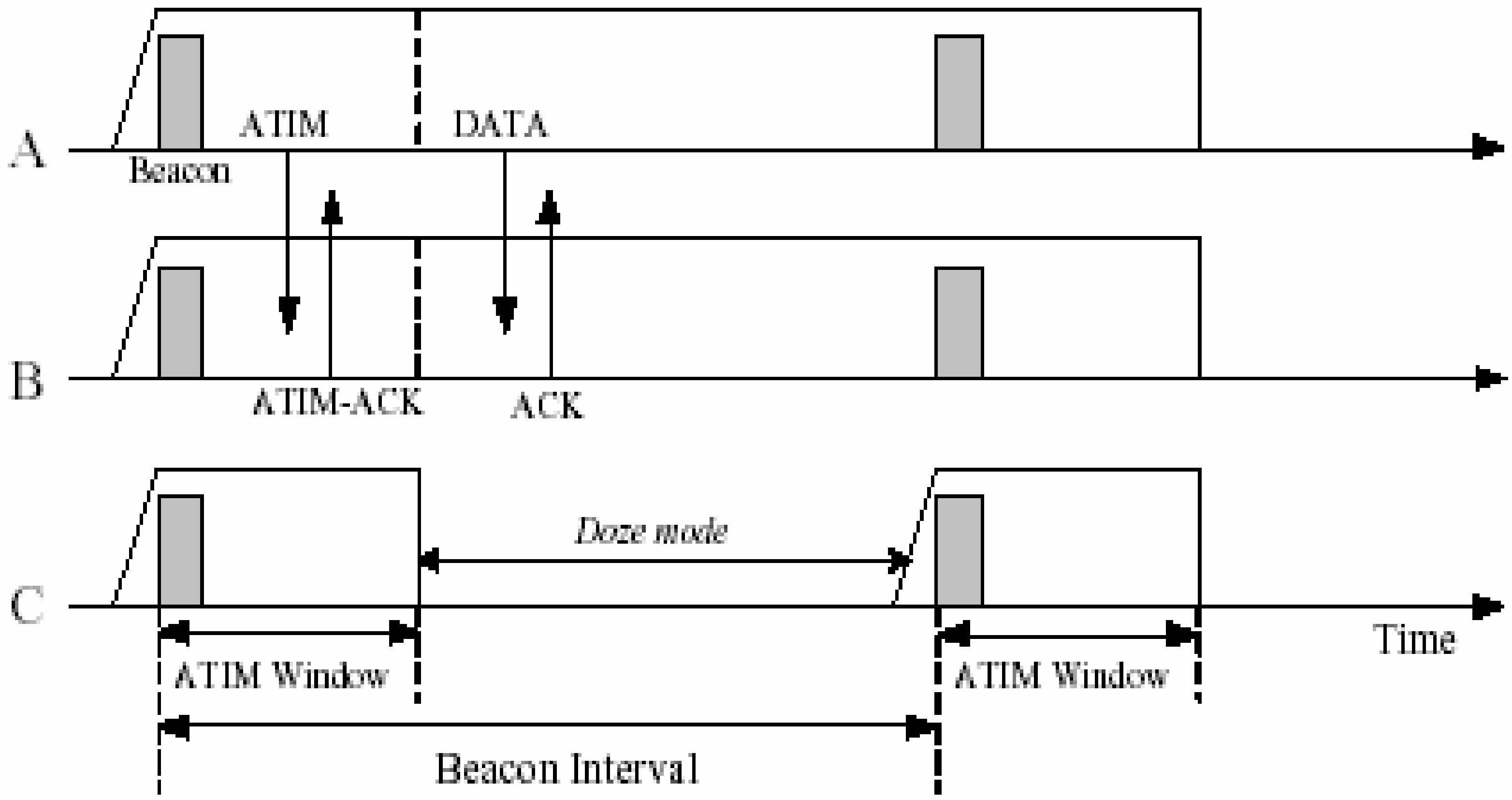


Figure 2: Operation of IEEE 802.11 PSM.

MMAC Assumptions

- N channels are available and they have same bandwidth
- Each host is equipped with a single half-duplex transceiver
- Transceiver is capable of switching channels dynamically (224 micro seconds [IEEE 802.11 WG])
- Nodes are time-synchronized
  - Out-of-band solutions like GPS can be used with no overhead
  - In-band solutions like IEEE 802.11 Timing Synchronization Function
    - Each node sends a beacon after waiting for a random delay and only if it hasn't received a beacon during that time.

M-MAC Operation Continued

Preferable Channel List (PCL)

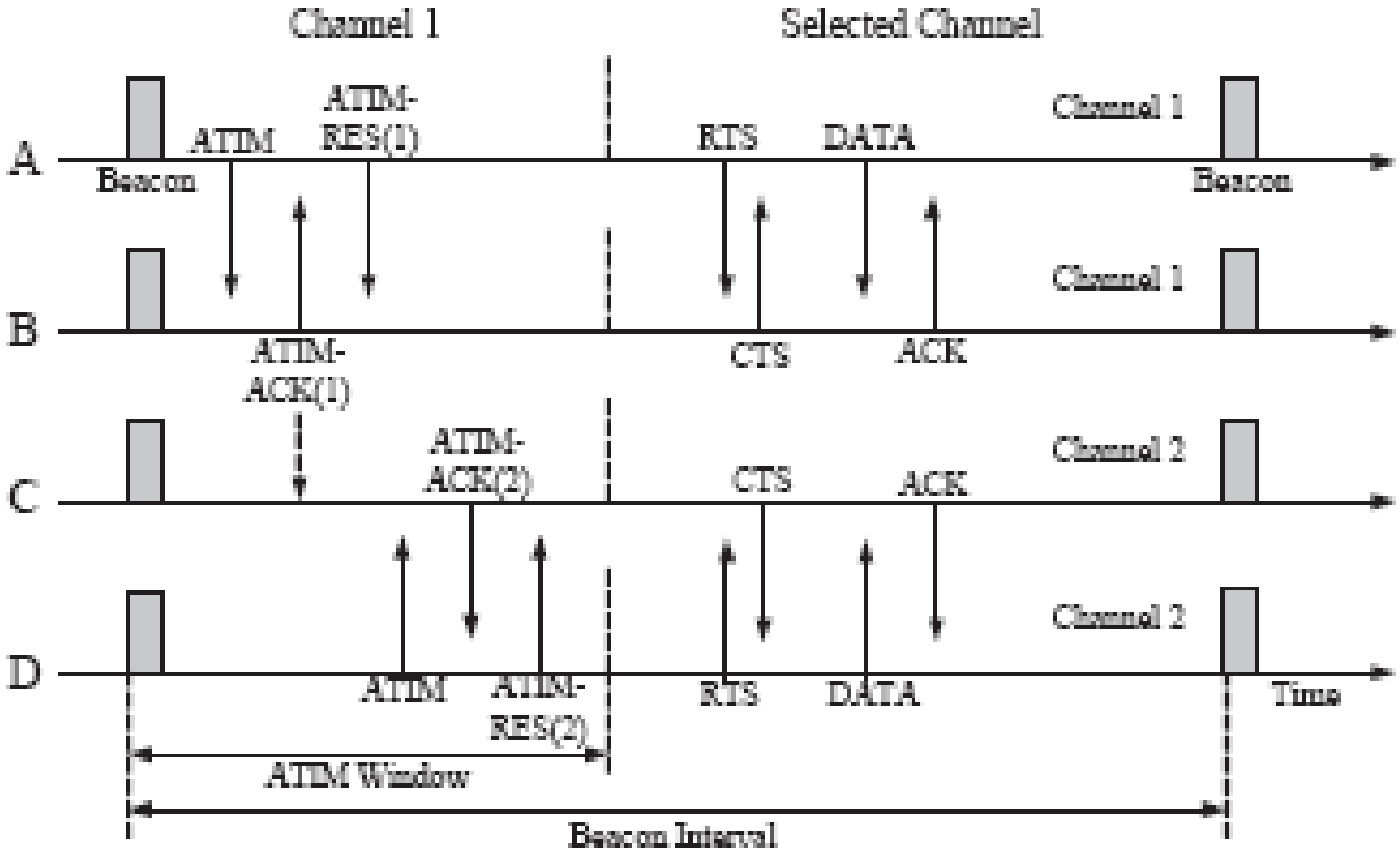
- Each node maintains preferable channel list. Each channel stored in the list can be in any one of the following state:
    - HIGH – Selected already for use in this interval
    - MID – Not yet taken by anyone in the transmission range
    - LOW – Taken by at least one neighbor in the transmission range and a count represents how many neighbors are using the channel

- PCL Maintenance
    - Initialize channels to MID during boot-up and start of every beacon
    - Change channel state to HIGH if both source and destination agree
    - Change channel state to LOW when ATIM-ACK/ATIM-RESV is overheard
    - Increment count when changing to state Low

MMAC Operation Continued

- Channel Negotiation
  - Source sends ATIM with it’s PCL to destination
  - Destination uses its PCL and source’s PCL to decide the channel
  - Destination sends ATIM-ACK with a channel suggestion
  - If Source can select that channel, it sends ATIM-RESV (reservation). Else it doesn’t send ATIM-RESV and no communication with destination in this interval
- Rules for Selecting the Channel
  - Choose the channel with least scheduled traffic
  - Overhear ATIM-ACK/ATIM_RESV packets to select the best channel
  - Algorithm: Choose the first available channel in the order below:
    - HIGH state in B’s PCL, HIGH state in A’s PCL, MID state in both, MID state in at least one and lowest count in LOW state

MMAC Operation



Performance Evaluation of MMAC

- Performance Metrics
  - Avg. throughput over all flows in the network
  - Avg. packet delay over all flows in the network
    - Measured as the duration between the time when Link layer of sender receives a packet to send and the time it reaches the destination
- Compare against 802.11 and Dynamic Channel Assignment (DCA)-based protocols
- Study the effect of ATIM window size and number of channels available on the throughput
- Main Results (NS2 Simulation)
  - MMAC achieves more throughput than DCA in moderate to large single/multi-hop networks.
  - MMAC achieves packet delay comparable to DCA in single/multi-hop networks
  - MMAC can utilize the available number of channels better than DCA

Simulation – NS2

- Each channel has bandwidth 2Mbps
- Beacon Interval 100 ms
- Assumption: 3 channels, packet size 512 bytes and 20 ms beacons
- Each simulation was run 40 times and each data point is average of 30 runs.
- Single-Hop
  - 6, 30, 64 nodes, equal number of sources and destinations
  - One source can have only one destination
- Multi-Hop
  - 100 nodes are placed on 500m x 500m area
  - 40 nodes are randomly chosen to be sources and another, 40 nodes to be destinations
  - A source can have multiple destinations and a destination can have multiple sources

Single Hop Network Results

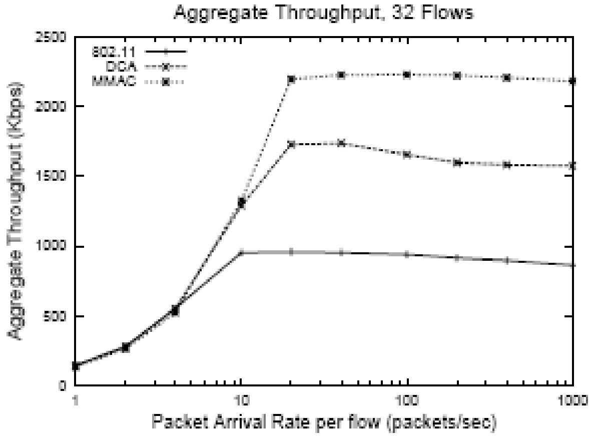
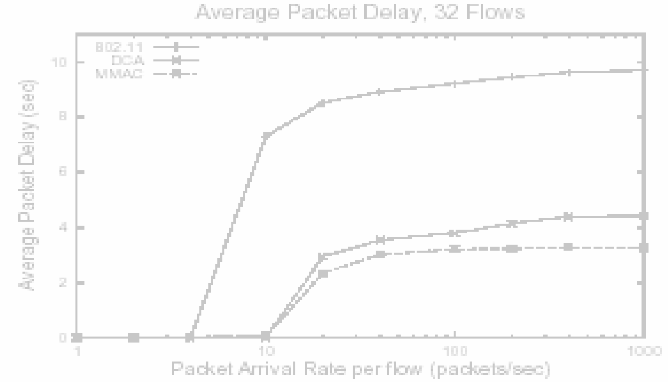


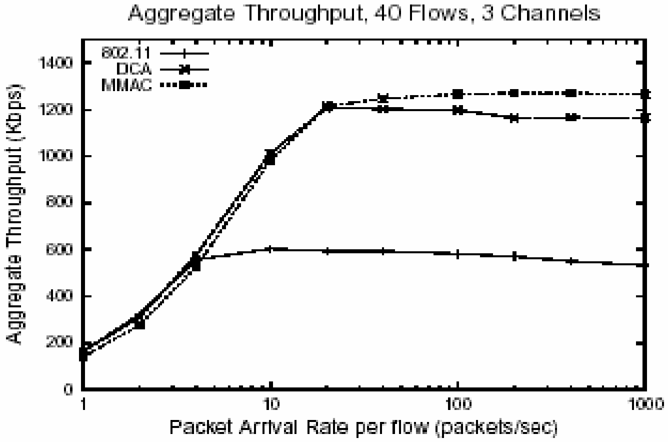
Fig. 4. Aggregate throughput in a scenario with 64 nodes and 32 flows. The number of channels is 3.



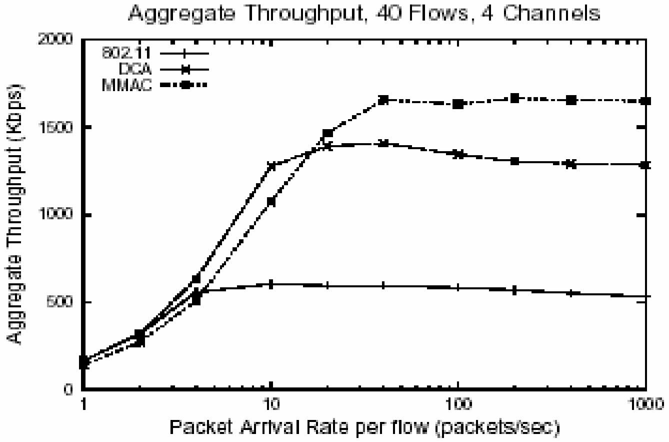
(c) 64 nodes

- **Throughput**
  - MMAC performs significantly better than simple 802.11 in terms of both average throughput and average packet delay
  - MMAC provides 20-30% more throughput than DCA
- **Packet Delay**
  - When # of nodes are small (< 30), MMAC has higher delay than DCA because of ATIM window.
  - When # of nodes grows large (~64), DCA suffer high contention in the control channel

Multi-Hop Network Results



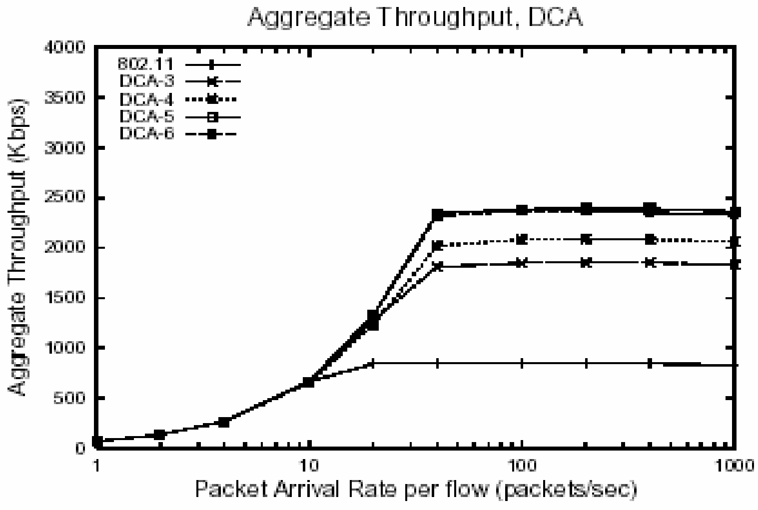
(a) 3 channels



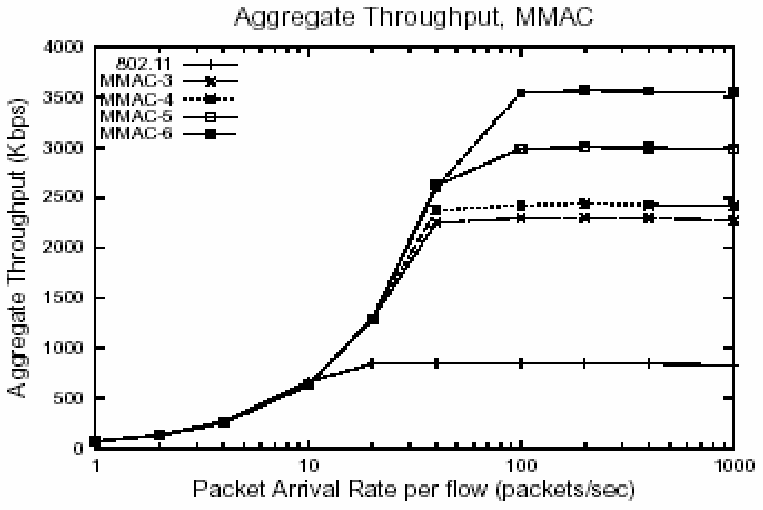
(b) 4 channels

- Not much gain for MMAC when 3 channels are used
  - Because not all three channels are used in all regions
- When increased to 4 channels, DCA performs poorly as the contention increases in the control channel
- Packet delay results are similar to single-hop case

Scaling with number of channels available



(a) DCA

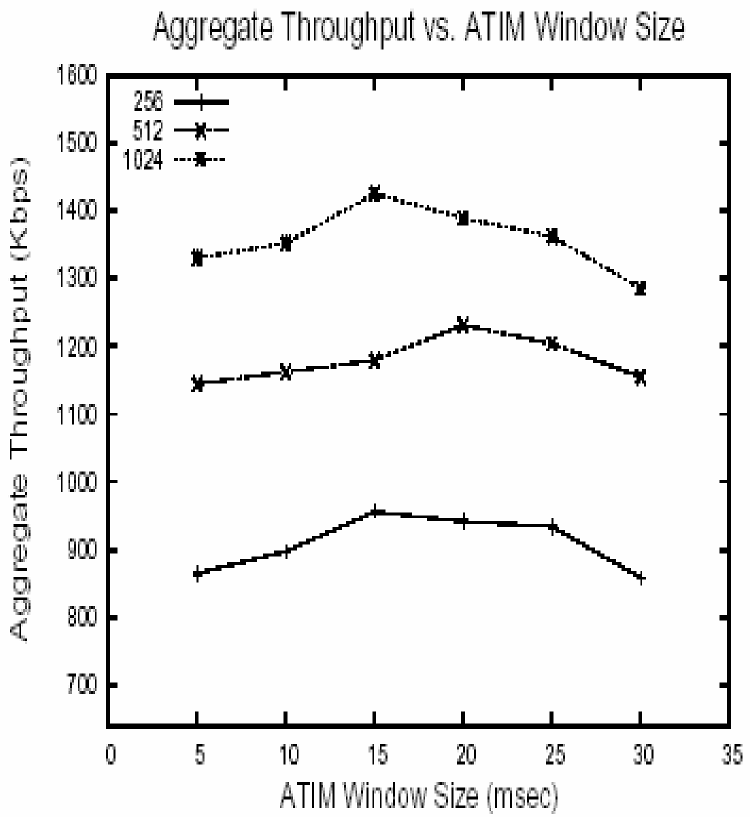


(b) MMAC

- When the number of channels available is increased, MMAC is capable of utilizing it.
- DCA under-utilizes because of contention in the common control channel

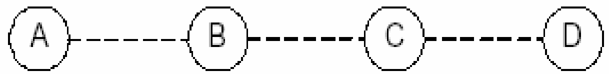
ATIM-Window Size

- ATIM-Window size is indeed a critical parameter.
- If too small/too high, throughput degrades. If too small, some nodes have to stay on default channel. If too high, no benefit is obtained with increased overhead.
- Studied the variation of ATIM-window size with the packet size.
- *Found that ATIM-window size of 15 – 20 % is a good estimate.*
- Assumed CBR traffic. Actually, a study on ATIM-Window size with respect to burst traffic is needed.

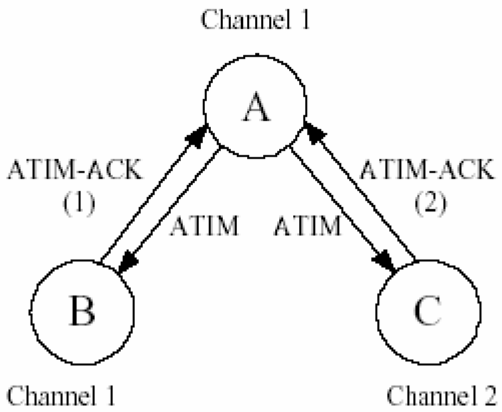


Discussion

- Time Synchronization
  - M-MAC uses IEEE 802.11 PSM synchronization mechanism in simulations
  - May not work in certain multi-hop scenarios
  - Partitioned multi-hop network may not get connected again, if completely out-of-sync [Tseng et al. In Infocom 02]



- One source multiple destination in a beacon interval
  - A can choose only one channel in a beacon interval
  - Queue management , Starvation
  - Throughput is also affected



Implementation Issues

- Specify channels to use for reaching neighbors
  - One-to-one mapping between interfaces and channels is assumed in many system applications
  - For example, kernel routing tables only specify which interface to reach a neighbor.
  - In a multi-channel scenario, channel information should also be included
- Specify channels to use for broadcast
  - Some protocols require a common channel to send all broadcast
  - Others require sending in all channels
- Manage interface Switching
  - Scenario: An interface is busy sending a packet on some channel, say c1 and another packet has to be sent using the same interface but on different channel, say c2
  - Consistently switch between channels
  - Manage buffering of packets that cannot be sent immediately

Abstraction Layer

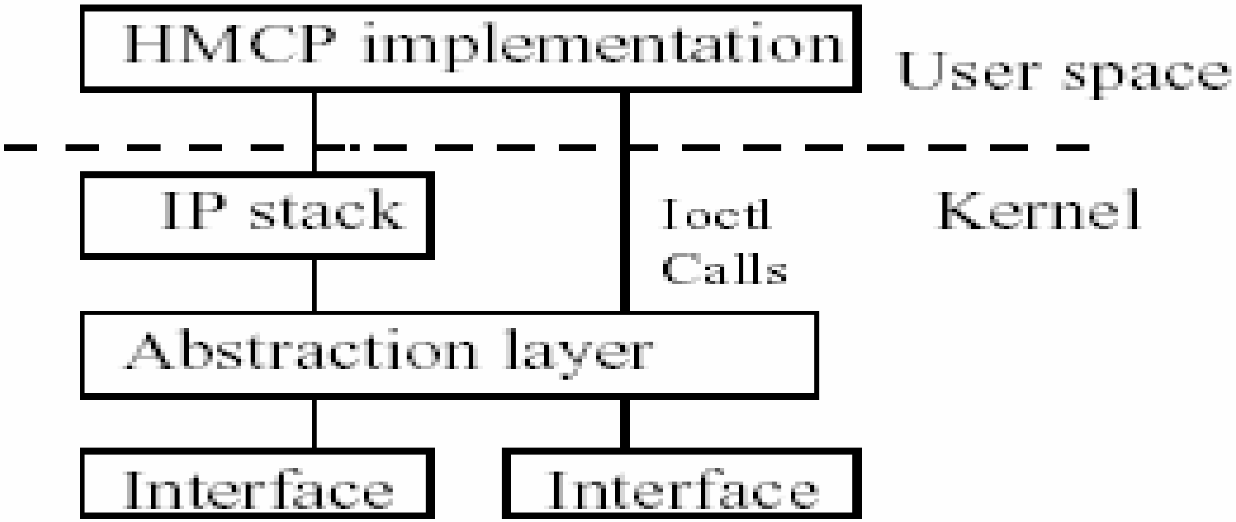
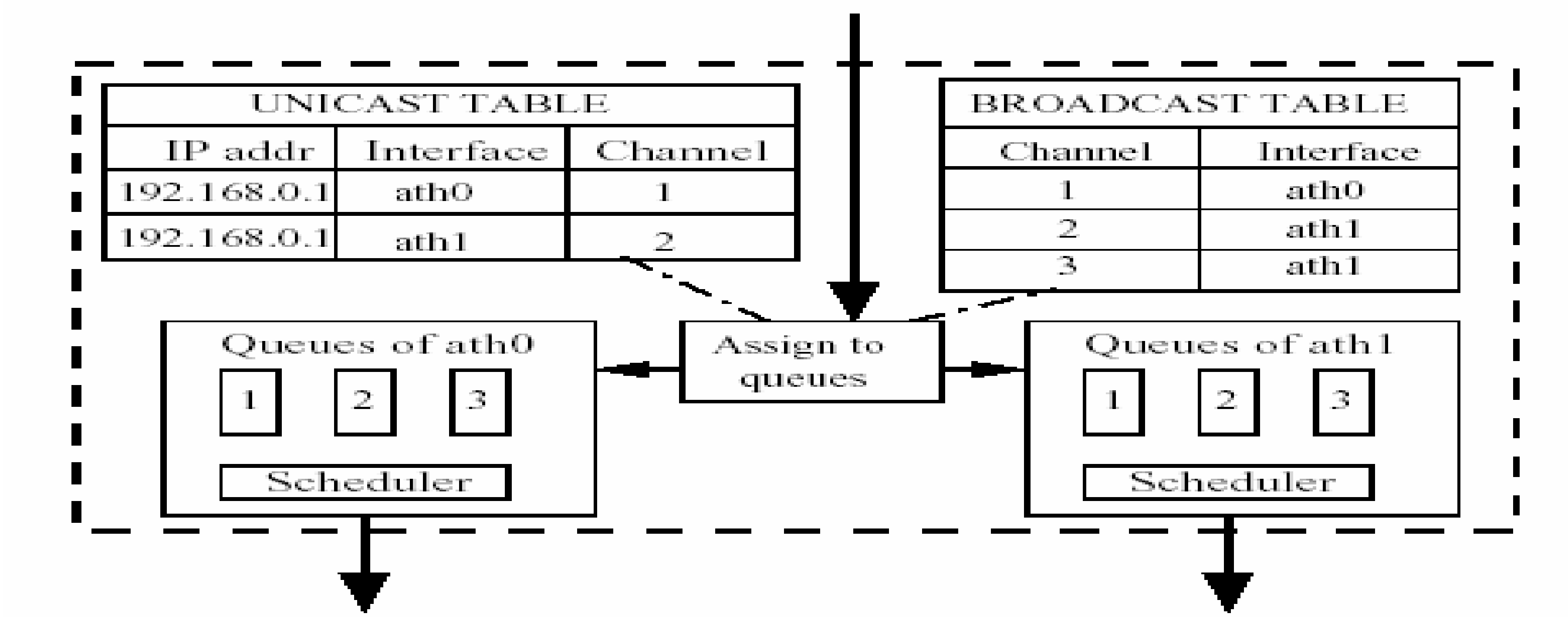


Fig. 8. Implementation of HMCP protocol using abstraction layer support.

- An abstraction layer between network layer and the interface device drivers
- Uses a round-robin Scheduler

Abstraction Layer



- An abstraction layer between network layer and the interface device drivers
- Maintains unicast and broadcast tables that has both interface and channel numbers
- Maintains a separate queue for each interface and each channel
- Uses a round-robin Scheduler

Summary

- Multi-Channel Wireless Networks enhances throughput of the network by utilizing multiple channels.
- But it introduces new issues:
  - Issue 1: Distributed load balancing
  - Issue 2: Channel Coordination
  - Issue 3: Broadcast support
  - Issue 4: Transparent system interface to applications
- A representative protocol for single-interface multiple channel access (MMAC) is discussed in detail
- Main idea of MMAC: Uses rendezvous in time to negotiate channels and balance load

Multi-Channel Wireless Networks

Thank you for your attention

Q & A

Acknowledgements

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- Paper authors for the pictures used in the presentation