# Power Save Mechanisms for Multi-Hop Wireless Networks

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# Problem Statement

- Techniques apply to general, low mobility wireless ad hoc networks
  - For concreteness, we focus on sensor networks
- Sensor networks have limited energy and need to save power as much as possible
- How can we use information about traffic in the network to:
  - Determine when nodes should wake up
  - Choose routes to address the energy-latency trade-off

# Motivation

- Sleep mode power consumption is much less than idle power consumption
- Using information about traffic in the network, we can make better decisions about how frequently to wake up and which routes to use

| Radio State | Power Consumption (mW) |
|---|---|
| Transmit | 81 |
| Receive/Idle | 30 |
| Sleep | 0.003 |

Power Characteristics for a Mica2 Mote Sensor

# Talk Overview

- Combining Synchronous and Out-Of-Band Wake-Up Techniques
  - Schedule future wake-ups between a sender and receiver based on traffic info
- Assigning Multiple Out-Of-Band Channels
  - Efficient assignment based on traffic info
- Multi-Level Power Save
  - Use multiple power save protocols in a network to allow routes with different energy-latency characteristics

# Types of Wake-Up Protocols

- Synchronous
  - When nodes enter sleep mode, they schedule a timer to wake up at a pre-determined time
  - Examples: IEEE 802.11 PSM, S-MAC
- Out-Of-Band (OOB)
  - A sleeping node can be woken at any time via an out-of-band channel
  - Examples: STEM, PicoRadio, Wake on Wireless
- Hybrid
  - Synchronous plus Out-Of-Band

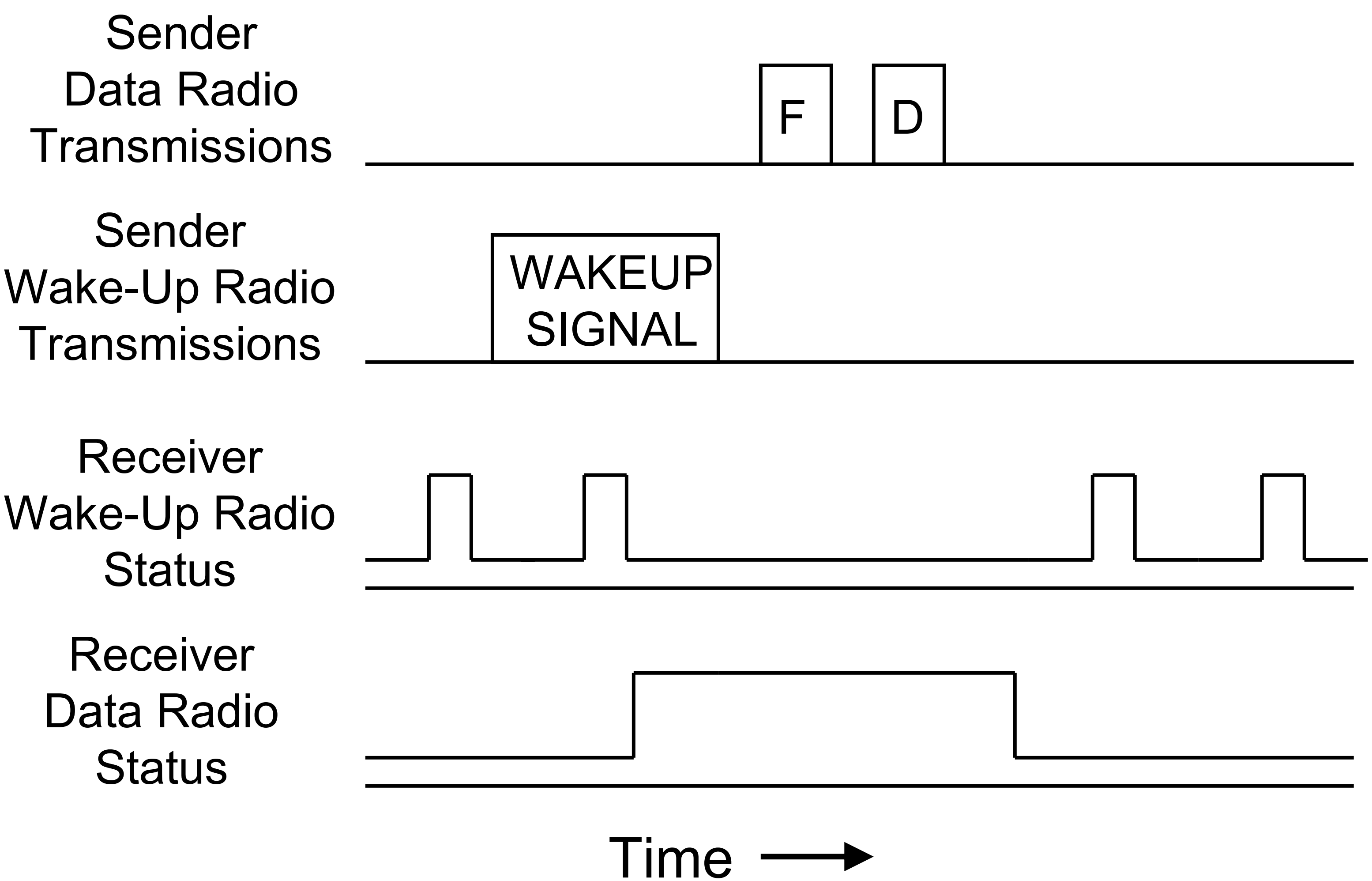
# Out-Of-Band Protocol

- Use a busy tone (BT) channel to wake up neighbors
  - BT is broadcast on the channel for specified duration
  - No information is encoded in the BT
  - Serves as binary signaling mechanism to neighbors
- Advantage
  - Only have to detect energy on channel rather than decode packet
    - Simple hardware
    - Small detection time
  - No need to handle collisions
- Disadvantage
  - BT awakes entire neighborhood

# Out-Of-Band Protocol (STEM)

- Two Radios
  - One for data and one for BT
- Data Sender
  - Transmit BT long enough to wake up all neighbors
  - Send RTS (a.k.a., *FILTER*) packet on data channel indicating which node is the intended receiver
- Other Nodes
  - Periodically carrier sense BT channel, if busy then turn on data radio
  - After RTS is received, return data radio to sleep if you are not the intended receiver; otherwise, remain on to receive data

# Busy Tone Wake-Up (STEM)



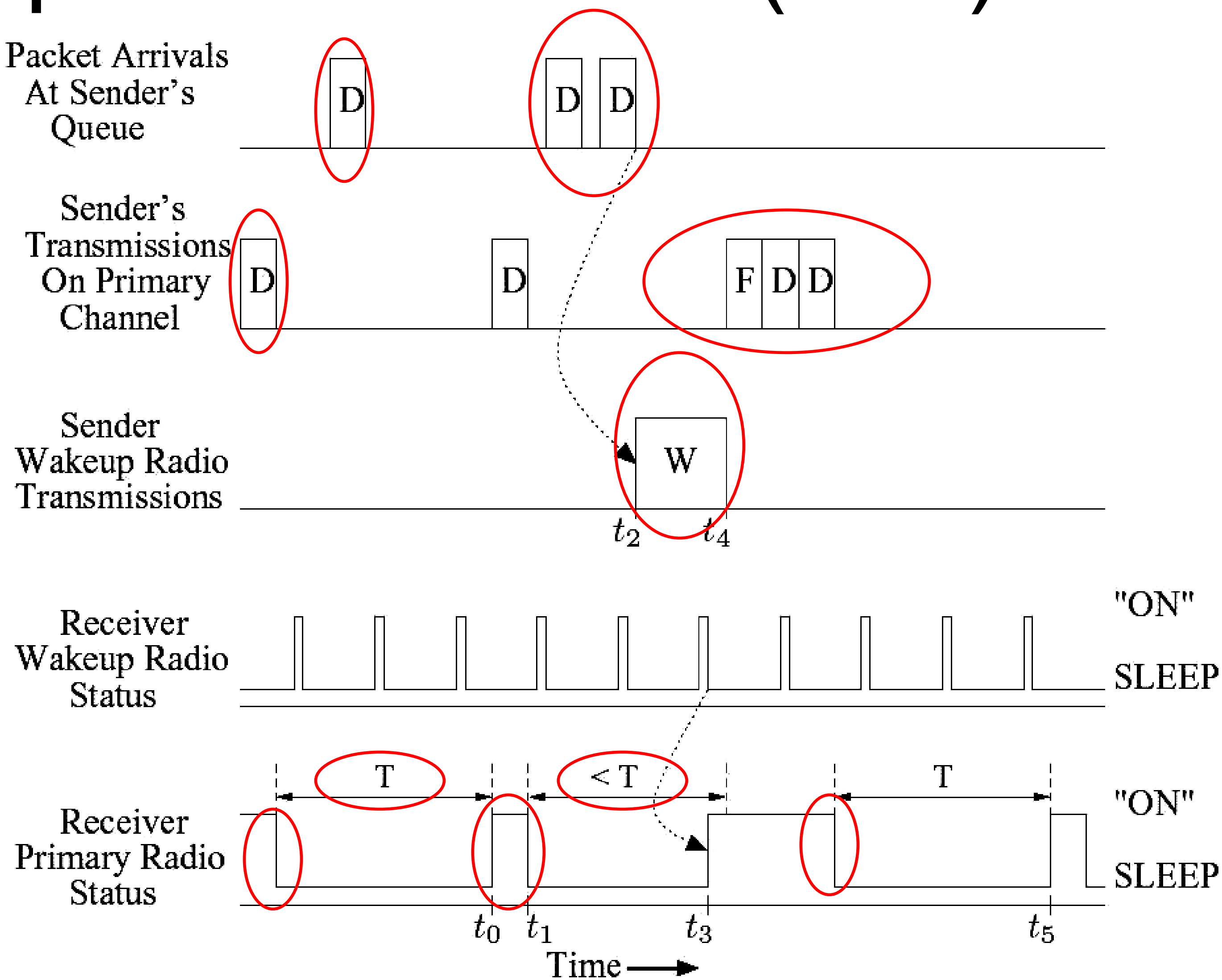
# Adding Synchronous Wake-Ups

- After last packet in the sender's queue is sent:
  - Sender and receiver agree to wake up (i.e., turn on data radio) $T$ seconds in the future
- If sender's queue reaches a threshold ($L$) before the next scheduled synchronous wake-up:
  - A BT wake-up must be done

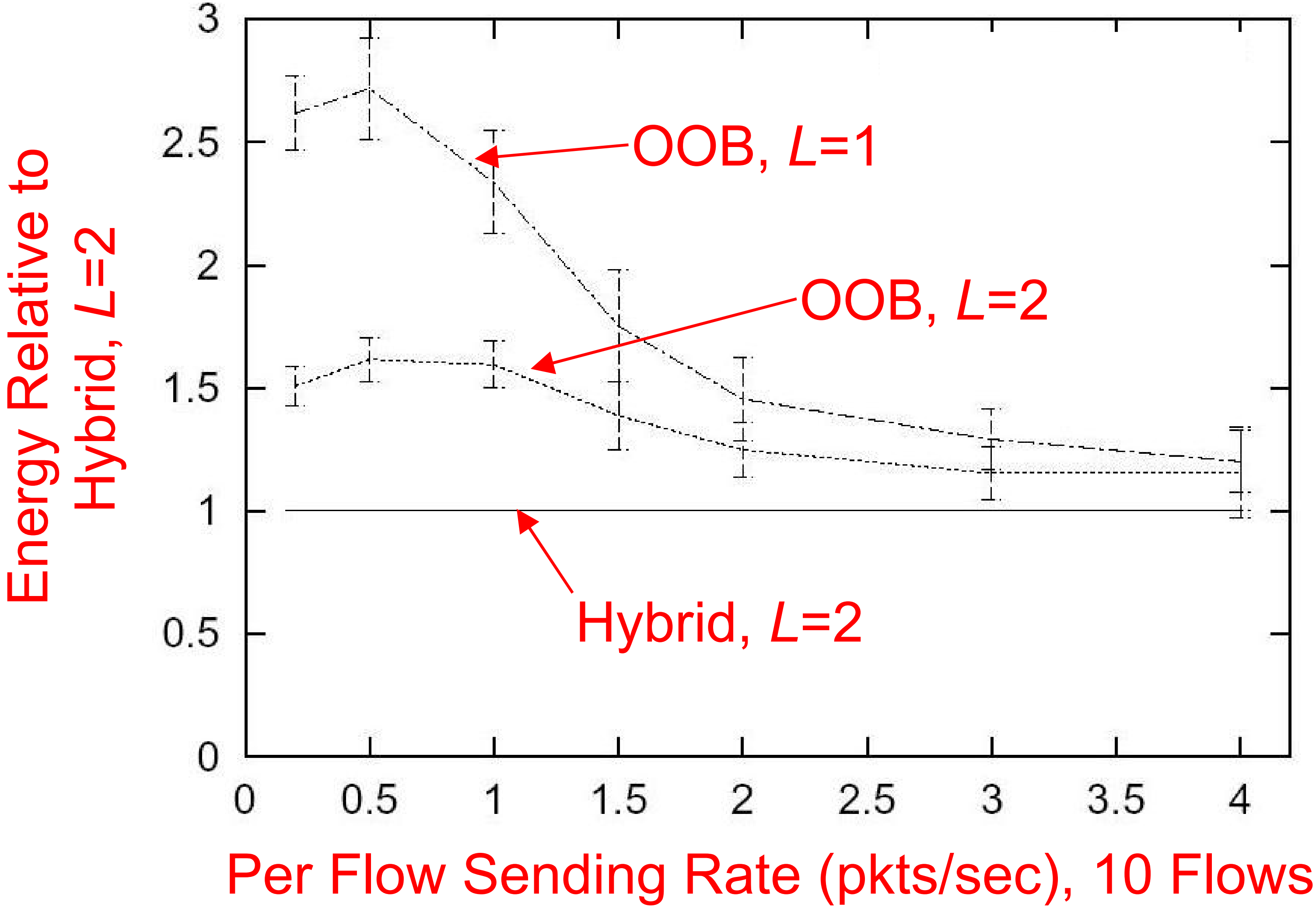
# Tradeoff in Choosing *T*

- Too small
  - Nodes wake up when there are no pending packets
  - Nodes waste energy idly listening to the channel
- Too large
  - BT wake-up is more likely to occur
  - Entire neighborhood must wake up in response to BT

# Proposed Protocol ($L$=2)



# Multi-Hop Energy Consumption



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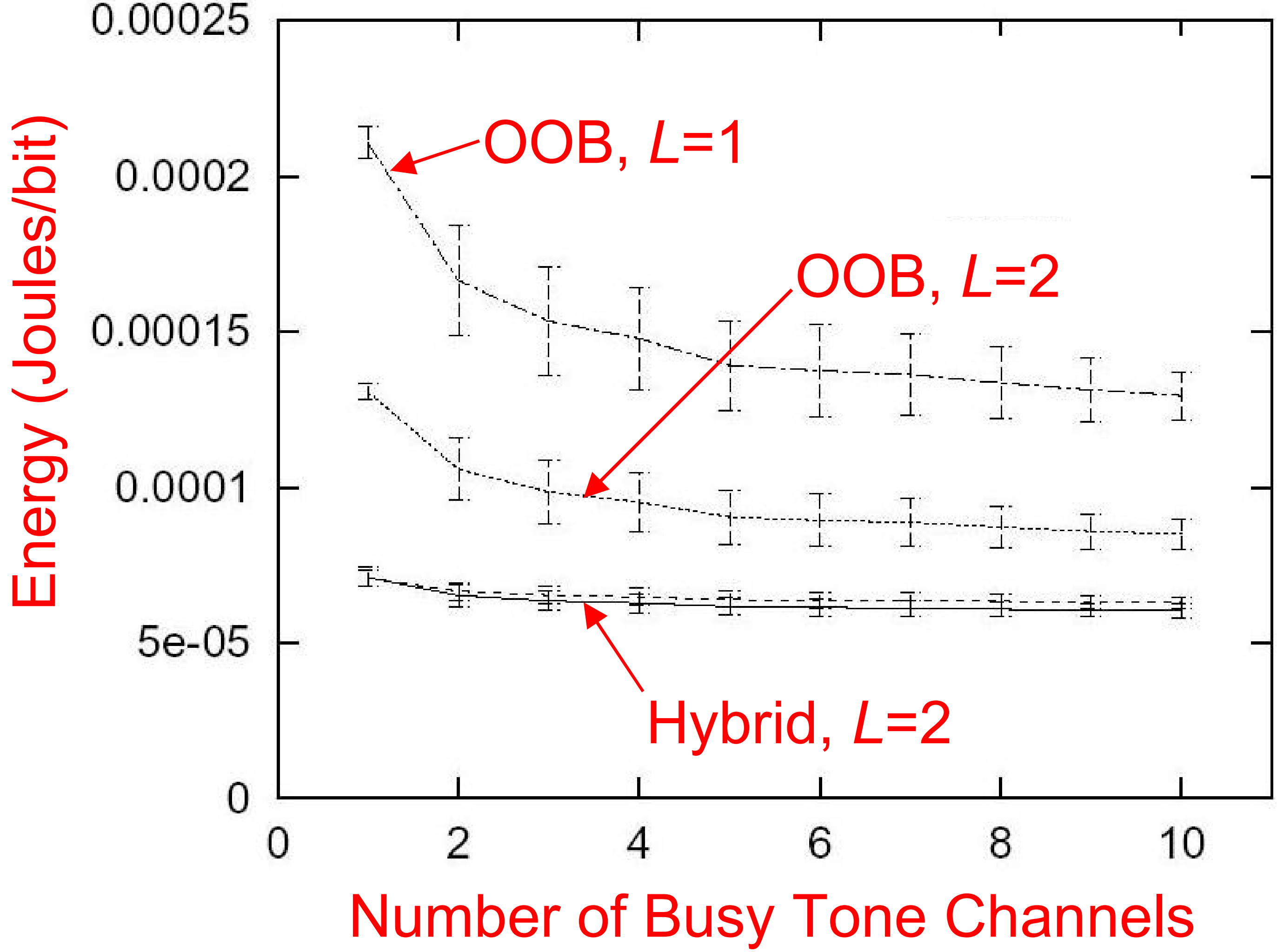
- Combining Synchronous and Out-Of-Band Wake-Up Techniques
- Assigning Multiple Out-Of-Band Channels
- Multi-Level Power Save

# Assigning Multiple BT Sub-Channels

- BT wake-ups are costly
  - Require entire one-hop neighborhood to waste energy idly listening for the RTS
- What if the BT channel is partitioned into multiple sub-channels (e.g., FDMA)?
  - How can sub-channel assignment be done?

# Effects of Adding More BT Channels – Random Assignment



# Optimal Channel Assignment in Single-Hop Network

- Paper gives sub-channel assignment algorithm proven to minimize the total number of BT wake-ups in the network
- Strong assumptions
  - Two BT sub-channels
  - The BT wake-up rate is known in advance
  - Not a distributed algorithm

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# Multi-Level Power Save

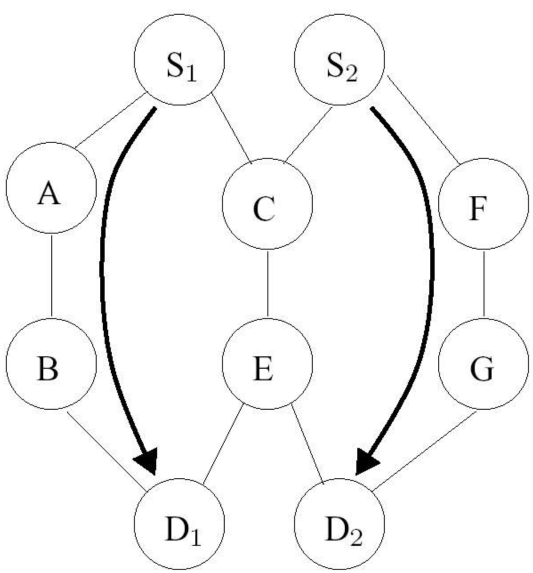
- Network layer info can lead to better power save decisions
  - For flow from **A** to **C**, a protocol can consider **A**→**B**→**C**, rather than **A**→**B** and **B**→**C** independently
- Many areas of computer science use multi-level design as a trade-off for different metrics
  - For example, cache is faster than main memory, but is more expensive and has a smaller capacity

# Multi-Level Power Save

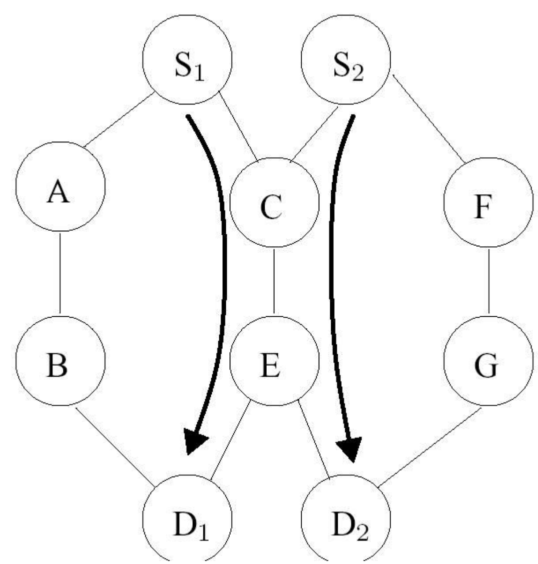
- Applying this idea to power save, the chosen routing paths can use different power save protocols based on the traffic being forwarded
- Each protocol increases the energy consumption of the path while decreasing the latency
- Previous work has demonstrated limited cases of this idea, but no work has fully investigated the idea from this perspective
- Multi-Level Example
  - Multiple versions of 802.11 PSM with different beacon interval lengths

# Multi-Level Power Save Challenges

- Determining which power save protocol neighbors are running to be able to communicate properly
- Deciding how flows choose which protocol is desired by the flow
- Changing routing metrics:




versus



# Conclusion

- Power save is a problem that needs enhancements at individual layers as well as cross-layer interaction
- Combining wake-up techniques (e.g., synchronous and OOB) can save energy
- Partitioning the OOB wake-up channel can help
  - Sub-channel assignment with *K* channels and multi-hop networks is still an open problem
- Multi-Level power save is a useful abstraction to address the energy-latency trade-off
  - Future work will more fully investigate this idea

# Optimal Channel Assignment in Single-Hop Network

- Assume two BT sub-channels and that the BT wake-up rate is known
- Sub-channel assignment algorithm to minimize total BT wake-ups in the network:
  - Sort nodes based on the cumulative rate at which each node will receive BT wake-ups
  - Do a linear (w.r.t. the number of nodes) scan to find the partition point which minimizes the total BT wake-ups
  - *N* nodes with largest BT wake-up rate end up on one channel and the remaining nodes end up on the other channel