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

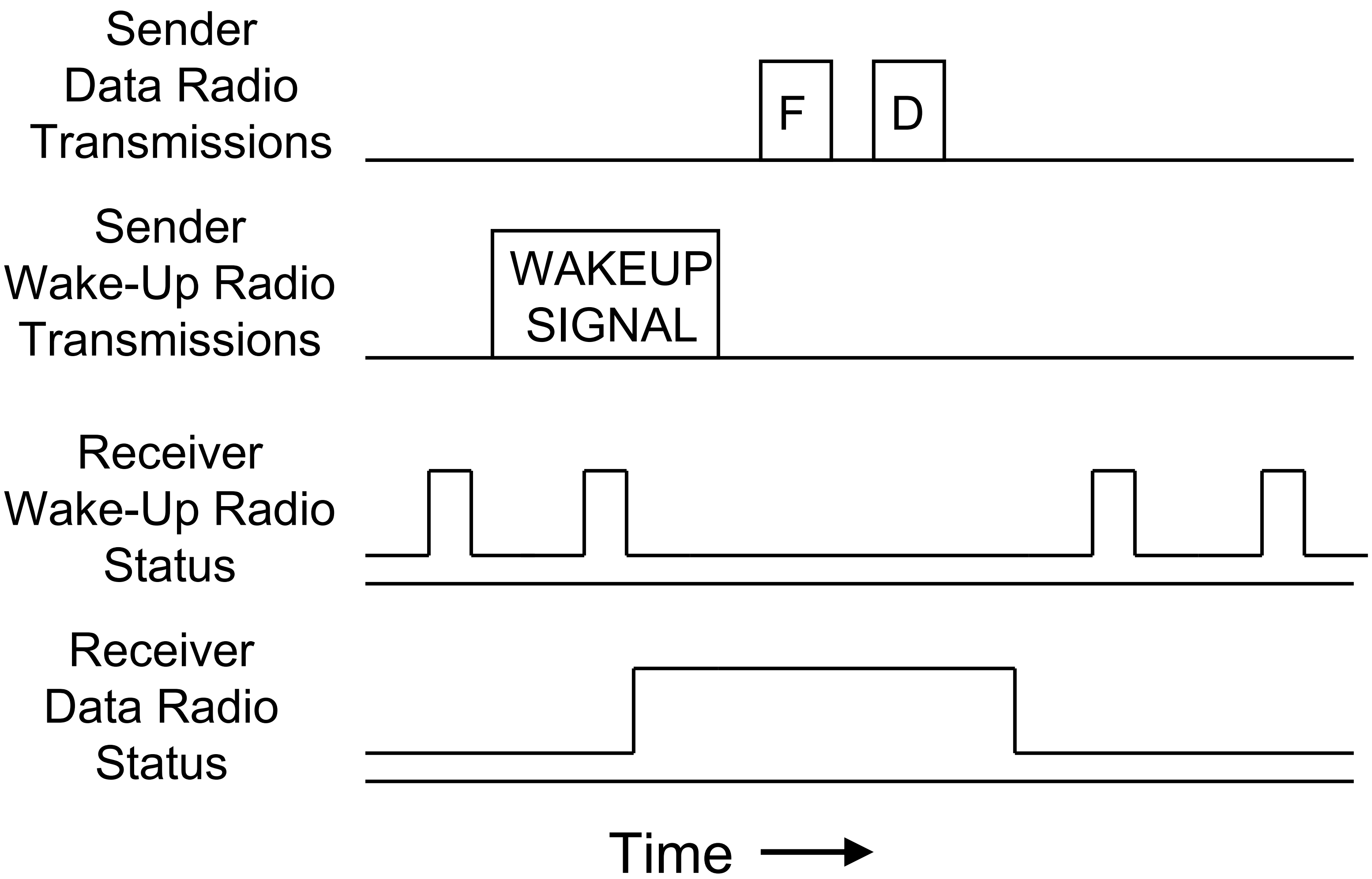
Out-Of-Band Protocol

- 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)



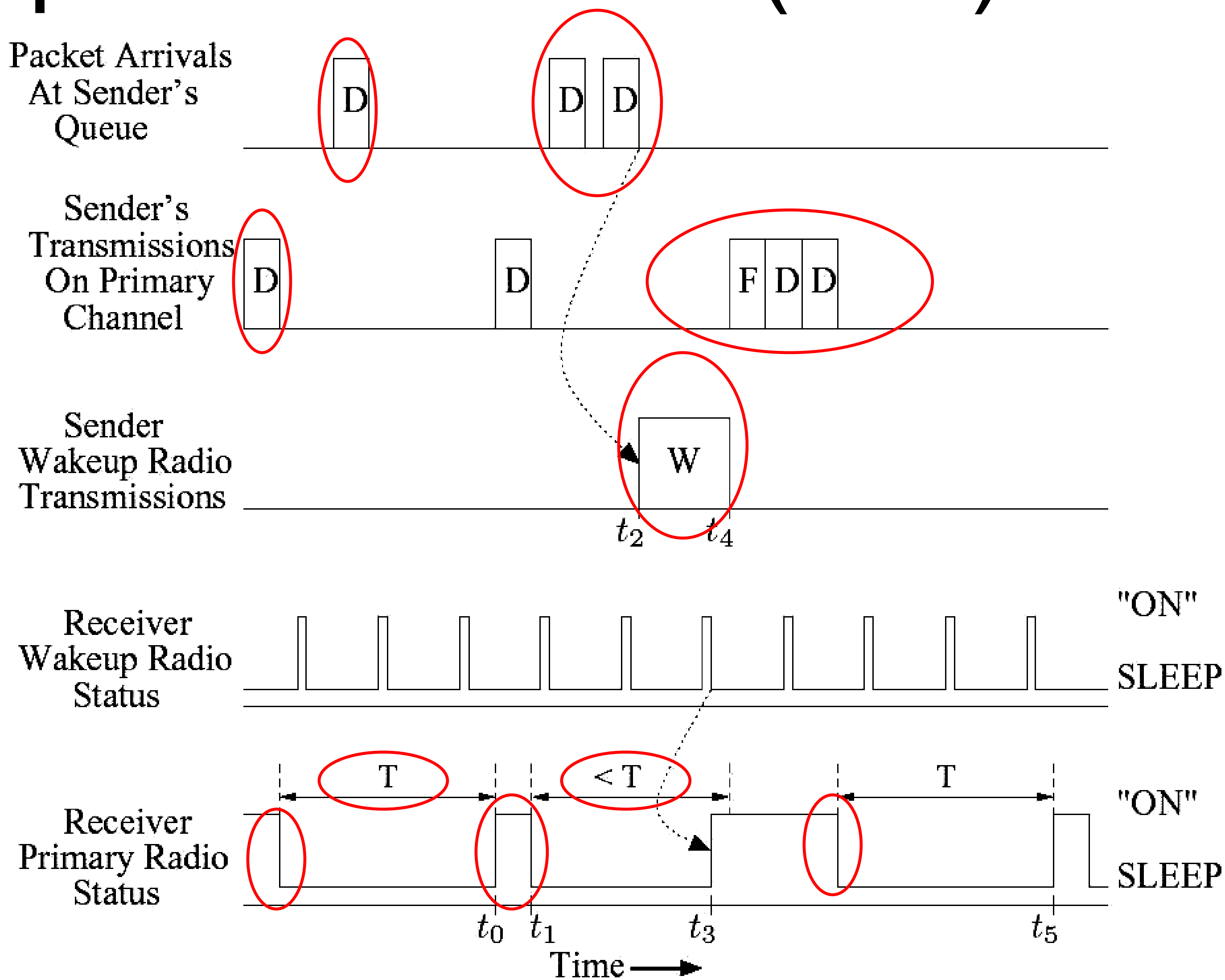
Adding Synchronous Wake-Ups

- 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

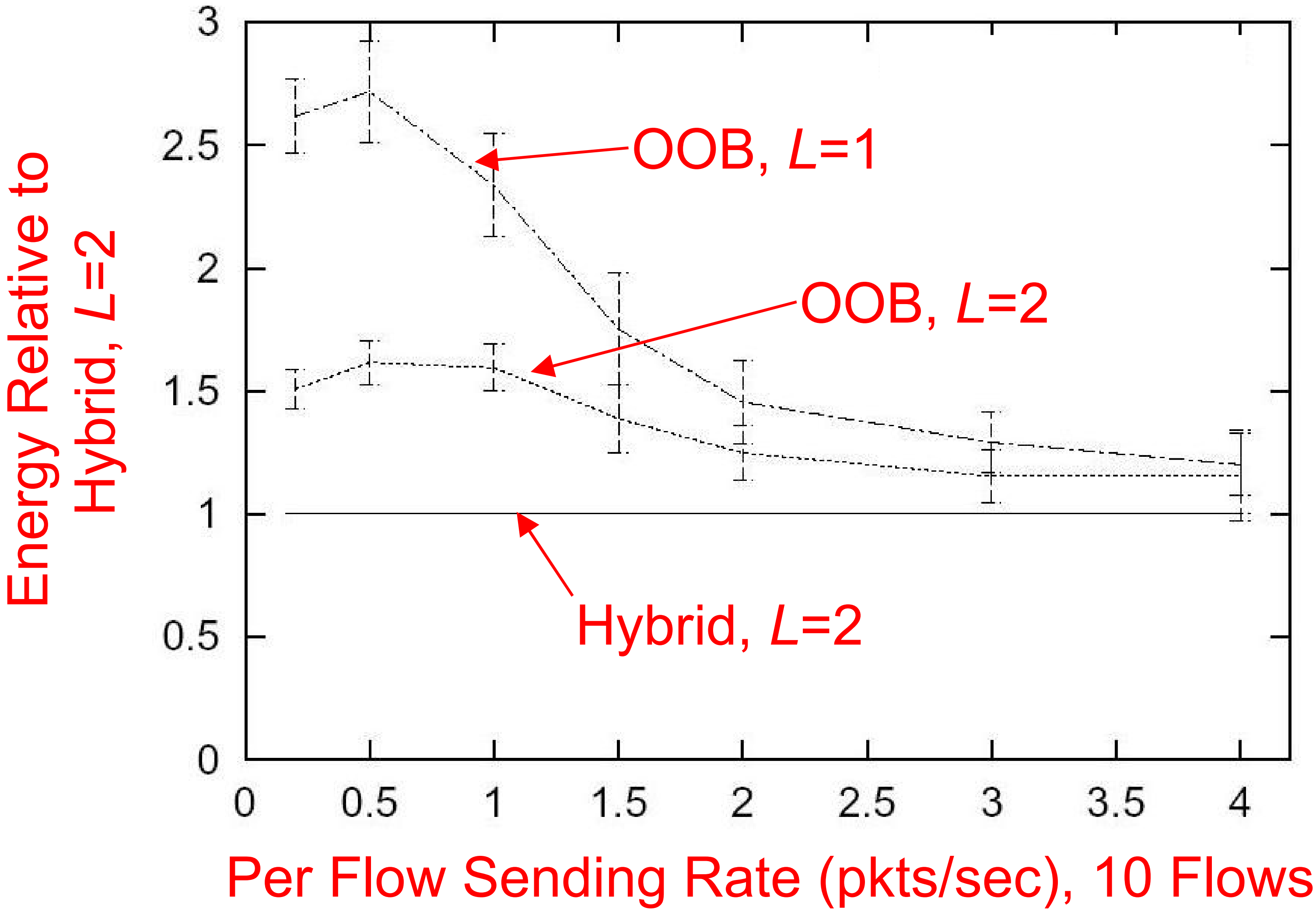
Tradeoff in Choosing *T*

- 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



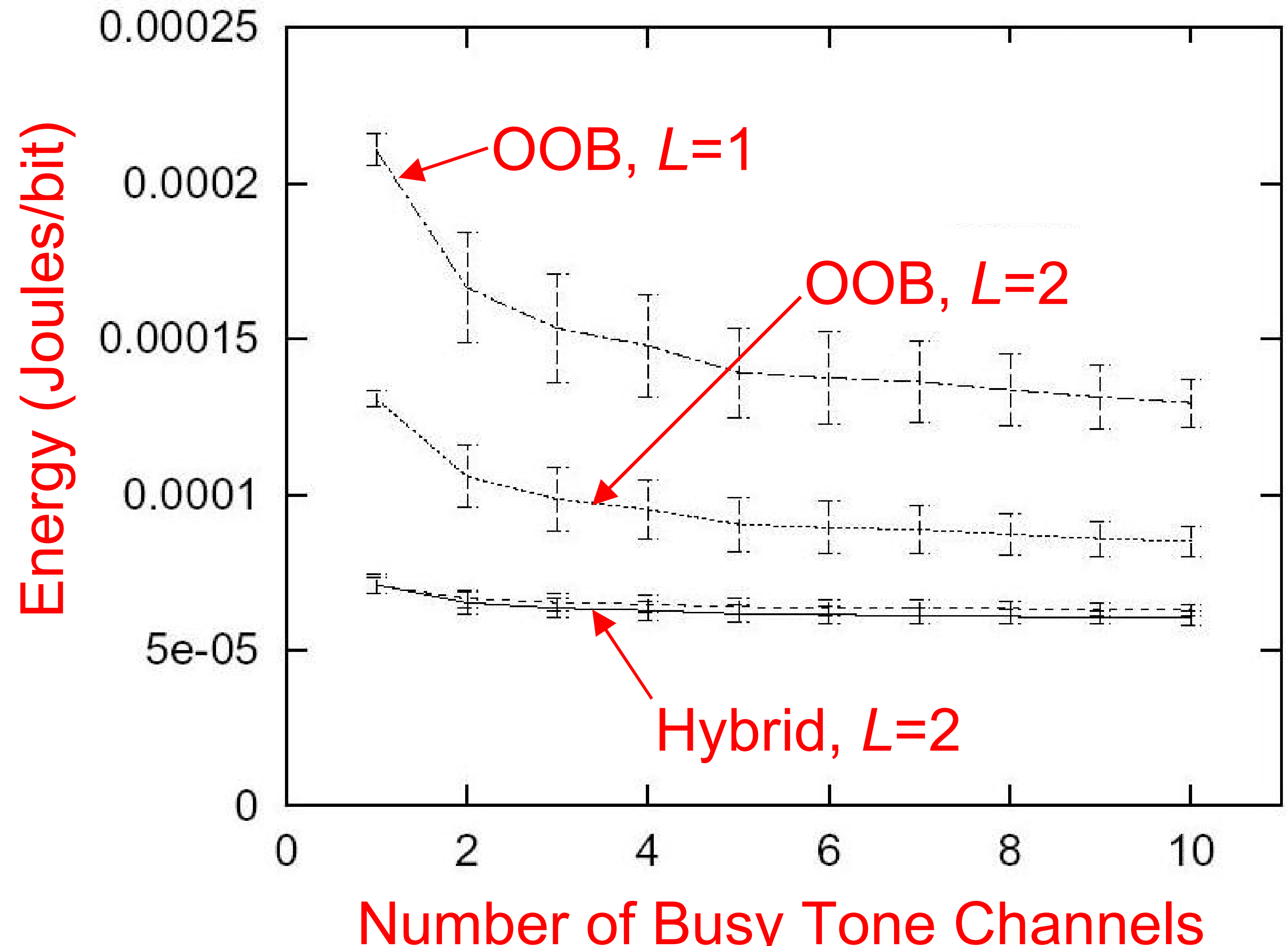
Talk Overview

- 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

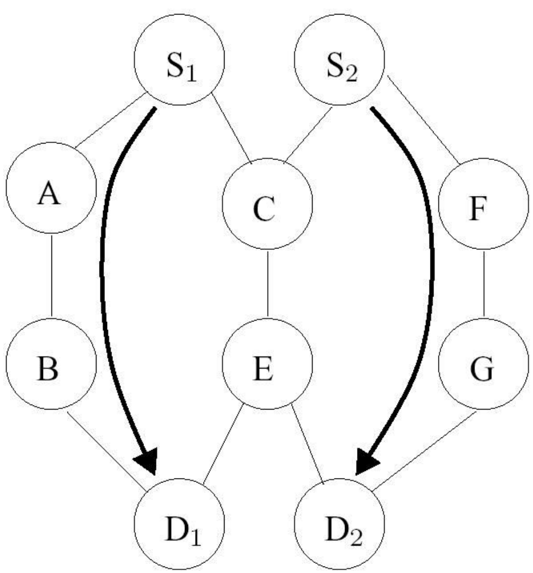
- Network layer info can lead to better power save decisions
  - For flow from **A** to **C**, a protocol can consider **A**→**B**→**C**, rather than **A**→**B** and **B**→**C** independently
- Many areas of computer science use multi-level design as a trade-off for different metrics
  - For example,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

Multi-Level Power Save

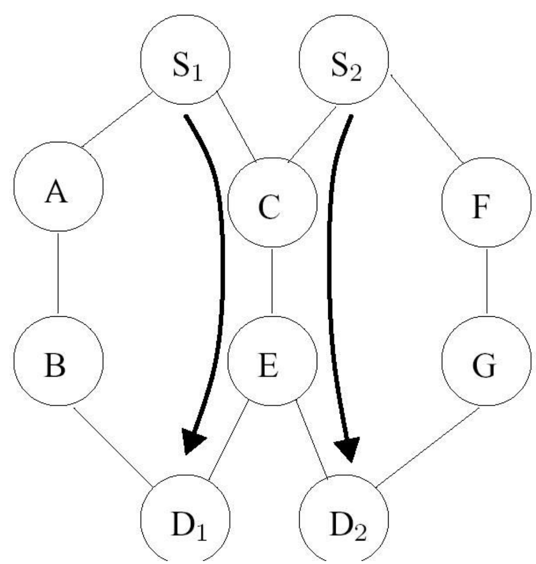
- Applying this idea to power save, the chosen routing paths can use different power save protocols based on the traffic being forwarded
- Each protocol increases the energy consumption of the path while decreasing the latency
- Previous work has demonstrated limited cases of this idea, but no work has 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