Power-Saving Protocols for IEEE 802.11-Based Multi-Hop Ad Hoc Networks

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Outline

- Introduction
- Preliminaries
- Power-saving Protocols for MANET
- Communication Protocols for Power-Saving Hosts
- Simulation Experiments

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Introduction (1/2)

- Solutions addressing the power-saving
  - Transmission Power Control
  - Power-Aware Routing
  - Low-Power Mode
- This paper studies the power-saving for IEEE 802.11-based MANETs
  - Low-Power Mode

Introduction (2/2)

- Two major challenges
  - clock synchronization
  - neighbor discovery
- methodology
  - propose three asynchronous power management protocols
  - twofold
    - more beacon
    - To detect each other in finite time
Preliminaries (1/2)

- Power-Saving Modes in IEEE 802.11

[Diagram showing power-saving modes in IEEE 802.11]

Preliminaries (2/2)

- When applied to a multi-hop ad hoc network, three problems may arise.
- Problem Statement
  - Clock Synchronization
  - Neighbor Discovery
  - Network Partitioning
Power-saving Protocols for MANET(1)

- Several guidelines
  - More beacons:
    - To prevent the inaccurate-neighbor problem
  - Overlapping Awake Intervals:
    - Owing to not count on clock synchronization
  - Wake-up Prediction:
    - If a host hears another PS host's beacon, it can derive its wake-up pattern

Power-saving Protocols for MANET(2)

- beacon interval
  - active window
    - To turn on the receiver to listen
  - beacon window
    - For the PS host to send its beacon
  - MTIM window
    - To serve the similar purpose as ATIM window
Power-saving Protocols for MANET(3)

- Notations
  - BI: length of a beacon interval
  - AW: length of an active window
  - BW: length of a beacon window
  - MW: length of an MTIM window
- In the beacon window (resp., MTIM window)
  - To send beacons (resp., MTIM frames) following the DCF access procedure

Power-saving Protocols for MANET(4)

- Protocol 1: Dominating-Awake-Interval
  - basic idea
    - To impose a PS host to stay awake sufficiently long \( \Rightarrow AW \geq BL/2 + BW \)
    - To guarantee any PS host’s beacon window to overlap with any neighboring PS host’s active window
    - The sequence of beacon intervals are alternatively labeled as odd and even intervals
      - To guarantee any two PS hosts could hear each other’s beacon
Power-saving Protocols for MANET(5)

Fig. 3. Structures of odd and even intervals in the Dominating-Awake-Interval protocol.

Power-saving Protocols for MANET(6)

Fig. 4. An example where host B will always miss A’s beacons.
Power-saving Protocols for MANET(7)

- Theorem 1: The Dominating-Awake-Interval protocol guarantees that when $AW > BI/2 + BW$, a PS host’s entire beacon window always overlaps with any neighboring PS host’s active window in every other beacon interval, no matter how much time their clocks drift away.

Power-saving Protocols for MANET(8)

- Protocol 2: Periodically-Fully-Awake-Interval
  - two types of beacon interval:
    - To reduce the active time
    - low-power intervals
      - the length of the AW is reduced to the minimum
    - fully-awake intervals
      - the length of the AW is extended to the maximum
      - only appear periodically
Power-saving Protocols for MANET(9)

- The structures of these beacon intervals
  - low-power intervals
    - \( AW = BW + MW \)
    - send out its beacons
  - fully-awake intervals
    - \( AW = BI \)
    - To discover its neighborhood

By collecting other hosts’ beacons, the host can predict when its neighboring hosts will wake up.

KP: Fig. 5. An example of the Periodically-Fully-Awake-Interval protocol with fully-awake intervals arrive every \( T = 3 \) beacon intervals.

Power-saving Protocols for MANET(10)

- Theorem 2: The Periodically-Fully-Awake-Interval protocol guarantees that a PS host’s beacon windows overlap with any neighbor’s fully-awake intervals in every \( T \) beacon intervals, no matter how much time their clocks drift away.
Power-saving Protocols for MANET(11)

- Comparison with the previous Dominating-Awake-Interval protocol
  - save more power as long as $T > 2$
  - the response time to get aware of a newly appearing host
    - $T$ beacon intervals
  - be appropriate for slowly mobile environments

Power-saving Protocols for MANET(12)

- Protocol 3: Quorum-Based
  - conception
    - nonempty intersection
    - adopt the concept of quorum to design PS hosts' wakeup patterns
    - To guarantee a PS host's beacons can always be heard by others' active windows
Power-saving Protocols for MANET (13)

- Methodology
  - quorum intervals
    - On the $n \times n$ array, a host can arbitrarily pick one column and one row of entries
    - $AW = BI$
  - non-quorum intervals.
    - The remaining $n^2 - 2n + 1$ intervals
    - $AW = MW$

Power-saving Protocols for MANET (14)

- Methodology (cont.)
  - observation
    - be perfectly time-synchronized
    - at least two intersecting beacon intervals

Fig. 6. Examples of the Quorum-Based Protocol (a) intersections of two PS hosts' quorum intervals, (b) host A's quorum intervals, and (c) host B's quorum intervals.
Power-saving Protocols for MANET(15)

- Theorem 3: The Quorum-Based protocol guarantees that a PS host always has at least two entire beacon windows that are fully covered by another PS host’s active windows in every $n^2$ beacon intervals.
Communication Protocols for Power-Saving Hosts(1)

- How a host sends packets to a neighboring PS host?
  - beacon packet has to carry the clock value of the sending host
  - To predict when the PS host will wake up, i.e. the latter’s MTIM windows

<table>
<thead>
<tr>
<th>Protocol</th>
<th>MTIM window’s timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominated-Awake</td>
<td>[(2m + 1) \times BW, (2m + 1) \times BI + BW + MW] (odd int.)</td>
</tr>
<tr>
<td></td>
<td>[2m \times BI + BI/2 - MW, 2m \times BI + BI/2] (even int.)</td>
</tr>
<tr>
<td>Periodically-Fully-Awake</td>
<td>[m \times BI + BW, m \times BI + BW + MW]</td>
</tr>
<tr>
<td>Quorum-Based</td>
<td>[m \times BI + BW, m \times BI + BW + MW] (quorum int.)</td>
</tr>
<tr>
<td></td>
<td>[m \times BI, m \times BI + MW] (non-quorum int.)</td>
</tr>
</tbody>
</table>

Communication Protocols for Power-Saving Hosts(2)

- Unicast

Unicast scenario:
- Beacon interval
  - Beacon frame
  - MTIM frame
  - ACK (after SIFS)
  - Rx in PS state
  - stay awake in the remaining of BI
Communication Protocols for Power-Saving Hosts (3)

- Broadcast
  - Steps (sender):
    - checks the arrival time of the MTIM windows of all its neighbors
    - picks the host, say Y, whose first MTIM window arrives earliest
    - picks those neighbors whose MTIM windows have overlapping with Y's first MTIM window
    - notify them in one MTIM frame
  - The process is repeated until all its neighbors have been notified
  - On receiving a MTIM carrying a broadcast indication, should remain awake until a broadcast packet is received (unreliable assumption)

Simulation Experiments (1)

- Impact of Beacon Interval Length

Fig. 7. Neighbor discovery time vs. beacon interval length. (traffic load = 10 packets, "on" probability = 80%)
Simulation Experiments (2)

Fig. 8. Power consumption for unicast vs. beacon interval length. (traffic load = 10 packets/sec, “on” probability = 80%)

Fig. 9. Power consumption for broadcast vs. beacon interval length. (traffic load = 10 packets/sec, “on” probability = 80%)
Simulation Experiments(3)

- Impact of Mobility

Fig. 10. Power efficiency for unicast vs. “on” probability. (traffic load = 10 packets/sec, beacon interval = 300 ms)

Simulation Experiments(4)

Fig. 11. Power efficiency for broadcast vs. “on” probability. (traffic load = 10 packets/sec, beacon interval = 300 ms)
Simulation Experiments (5)

Impact of Traffic Load

![Graph showing power consumption vs. traffic load for different traffic load levels.]

Fig. 12. Power consumption for unicast vs. traffic load. ("on" probability = 80%, beacon interval = 300 ms)

Simulation Experiments (6)

![Graph showing power consumption vs. traffic load for different traffic load levels.]

Fig. 13. Power consumption for broadcast vs. traffic load. ("on" probability = 80%, beacon interval = 300 ms)
Simulation Experiments(7)

Fig. 14. Power efficiency for unicast vs. traffic load. ("on" probability = 80%, beacon interval = 300 ms)

Simulation Experiments(8)

Fig. 15. Power efficiency for broadcast vs. traffic load. ("on" probability = 80%, beacon interval = 300 ms)
Conclusion

- addressed the power management problem in a MANET
- characterization
  - unpredictable mobility
  - multi-hop communication
  - no clock synchronization