Rcast: A Randomized Communication Scheme for Improving Energy Efficiency in MANETs

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Outline

- Motivation
- Related Work
  - IEEE 802.11 Power Saving Mechanism (PSM) in Infrastructure, One-hop Ad-hoc, and Multi-hop Ad-hoc Networks
  - Dynamic Source Routing (DSR): Overhearing Perspective
- The Proposed Solution
  - Rcast Mechanism
  - Performance Evaluation
- Conclusions & Future Works
Motivation

- One of the most critical issues in MANETs is energy conservation.
- Exploiting low-power state is the key to maximize the energy efficiency.

<table>
<thead>
<tr>
<th>Device</th>
<th>Idle / Listening</th>
<th>Low-Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lucent IEEE 802.11 WaveLAN-2</td>
<td>1.15 W</td>
<td>0.045 W</td>
</tr>
<tr>
<td>TR 1000, used in Berkeley Motes</td>
<td>13.5 mW</td>
<td>0.015 mW</td>
</tr>
</tbody>
</table>

- IEEE 802.11 PSM (Power Saving Mechanism) cannot be both energy-efficient & routing performance-efficient in multihop networks.
  - e.g., DSR heavily relies on overhearing.
  - Heart of this problem is semantic discrepancy: A node transmits a unicast packet, but it wishes that all its neighbours overhear it.

Two Power Modes in IEEE 802.11

- Active mode (AM).
- Power saving mode (PS):
  - A node periodically wakes up during the packet advertisement period (ATIM window) to see if it has data to receive.
  - When a node receives an advertised packet (ATIM message) that is not destined to itself,
    - It switches to a low-power state during the data transmission and thus, saves energy.
IEEE 802.11 PSM: 
In Infrastructure Networks

- AP can transmit data frames to an AM node at any time.
- For PS nodes,
  - AP buffers data frames.
  - AP announces buffered traffic at a predetermined time.
  - AP transmits the data frames.

Node in AM mode

Node in PS mode

AP maintaining nodes' mode of operation.

Uses TIM (Traffic Indication Map).

Requires synchronization (beacons).

IEEE 802.11 PSM:
In One-hop Ad-hoc Networks

For a unicast msg to R1 (needs to be acked)
For a broadcast msg (needs no ack)

SIFS

DIFS

ATIM

ATIM

SIFS

DIFS

ATIM window (e.g. 50 msec)

Beacon interval (e.g. 250 msec)

One unicast and one broadcast message:
- All five nodes remain awake during entire beacon interval.
IEEE 802.11 PSM: In One-hop Ad-hoc Networks (cont.)

- Two unicast messages:
  - All nodes except R3 should remain awake during entire beacon interval.

IEEE 802.11 PSM: In Multi-hop Ad-hoc Networks

- Multihop routing algorithms complicate the situation (e.g. DSR).
  - DSR improves the routing efficiency via overhearing.
  - Because nodes need to eavesdrop other communications to gather route information.

- DSR with the IEEE 802.11 PSM.
  - With overhearing "enforced".
    - Nodes should not sleep, but receive all the routing and data packets transmitted in their vicinity.
    - Routing performance is O.K., but energy consumption is large.
  - Without overhearing
    - Network performance degrades significantly.
DSR Protocol: Overhearing Perspective

- Route discovery & maintenance.
  - Data transmission in wireless networks is broadcast in nature.
  - Intermediate relaying nodes & other nearby nodes also learn the path to the destination via overhearing. But it incurs high energy cost.

DSR Protocol: Redundant Overhearing

- Sending multiple data packets over the same path.
  - Nearby nodes overhear redundant path information and thus, waste more energy.
IEEE 802.11 PSM:
In Multi-hop Ad-hoc Networks, Span [Mobicom’01]

- Construct a routing backbone which consists of AM nodes.
  - Coordinator eligibility rule.
  - Coordinator-ship should change to improve load balance.
- Disadvantages
  - Frequent power mode changes.
  - Less energy savings due to AM nodes, particularly in sparse networks.

IEEE 802.11 PSM:
In Multi-hop Ad-hoc Networks, ODPM [Infocom’03]

- Event-based mode switching: A node remains in active mode for “some time” (e.g. 2 seconds) if it receives a RREP hoping that data packets are delivered shortly.
IEEE 802.11 PSM: In Multi-hop Ad-hoc Networks, ODPM [Infocom’03]

- Event-based mode switching: A node remains in active mode for “some time” (e.g. 2 seconds) if it receives a RREP hoping that data packets are delivered shortly.

- Disadvantages:
  - Frequent power mode changes.
  - Less energy savings due to AM nodes.
  - Determination of “some time” cannot always be optimal.
  - Easily suffer from communication scenario with many short messages.

The Proposed Solution: Randomized Communication Mechanism

- Propose a message overhearing mechanism: RandomCast or Rcast.
  - Every node operates in PS mode.
  - Sender: A sender can specify the desired level of overhearing when it advertises a packet.
    - No overhearing
    - Unconditional overhearing
    - Randomized overhearing
  - Receiver: Upon receiving a packet advertisement during an ATIM window, a node makes its decision whether or not to overhear based on the specified overhearing levels.
The Proposed Solution: Randomized Communication Mechanism (cont.)

(i) No overhearing

(ii) Unconditional overhearing

- In the randomized overhearing:
  - Some of the neighbors overhear, but others do not.
  - Those who determine not to overhear switch to the low-power state during the transmission period.

(iii) Randomized overhearing

Key idea of Rcast:

- **Temporal locality:**
  - Overheard route information will probably be overheard again in the near future.

- **Spatial locality:**
  - Even though a node misses particular route information, it is highly probable that one of its neighbours overhears.
  - Neighbour nodes can offer the information when the node asks for it.
The Rcast Design and Implementation Issues

- When a node has a unicast packet to send,
  - Q1: Which overhearing method to choose?
  - Q2: How to specify its decision?

- When a node receives an ATIM frame for a unicast packet that is not destined to it but requires randomized overhearing,
  - Q3: How to determine whether to overhear or not?

The Rcast Issues (Q1):
Which Overhearing Method to Use?

- DSR employs three control packets:
  - **RREQ** (broadcast), **RREP** (unicast), and **RERR** (unicast)
  - In addition, **DATA** (unicast)
- We use the overhearing mechanism for these unicast packets.
  - Randomized overhearing for **RREP/DATA** packets
  - Unconditional overhearing for **RERR** packet
- Can a broadcast packet, **RREQ**, be Rcasted?
  - e.g. In dense networks, it would avoid redundant rebroadcasts of the same packet.
  - However, the overhearing decision must be made conservatively to make sure that the packet is propagated correctly until it reaches the final destination.
The Rcast Issues (Q2):
How to Specify it? - ATIM Frame

Format of an ATIM frame (length in octets)

<table>
<thead>
<tr>
<th>Protocol version</th>
<th>Type</th>
<th>Subtype</th>
<th>To DS</th>
<th>From DS</th>
<th>More Frag</th>
<th>Retry</th>
<th>Per Mgt</th>
<th>More Data</th>
<th>WEP</th>
<th>Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

- DI: Duration/Connection ID
- DA, SA, BSSID: Addresses of destination, source, and IBSS
- SC: Sequence control
- Frame body: Null for ATIM frame
- FCS: Frame check sequence

Type: 00 for management frame such as ATIM frame
Subtype: 1001 for ATIM frame (No overhearing)
Original ATIM frame subtype:
1111 for ATIM frame (Unconditional overhearing)
1101 for ATIM frame (Randomized overhearing)

The Rcast Issues (Q3):
How to Determine it?

- When a node receives an ATIM frame for a unicast packet,
  - Check destination address (DA) and subtype ID.
  - If the node is the intended destination, it remains awaken.
  - If the node is not the destination, but the sender wants unconditional overhearing (ID = 1111), it remains awaken.
  - If the node is not the destination, but the sender wants randomized overhearing (ID = 1101),
    - It decides to remain awaken and overhear with probability \( P_R \).
    - For this, each node maintains a probability \( P_R \).
      - Simply use the number of neighbors \( P_R = 1 / \text{number of neighbors} \).
      - Can be extended to consider mobility, and remaining battery energy.
Performance Evaluation

- Simulation testbed.
  - NS-2 simulator with the CMU wireless extension.
  - 100 nodes located in an area of 1500 x 300 m^2, 2 Mbps data rate.
  - 20 CBR sources generate 0.2~2 256-byte data packets every sec.
  - Random waypoint mobility model.

- Performance comparisons.
  - Unmodified IEEE 802.11 (without PSM).
    - Unconditional overhearing only.
  - On Demand Power Management (ODPM).
    - e.g. Source and destination nodes remain in AM for 2 seconds, if it receives RREP packet.
  - RandomCast Mechanism (Rcast).

Performance Evaluation: Energy Consumption

![Energy consumption graph]

- 802.11: consumes the maximum energy.
- ODPM: source and destination nodes continue to be awaken, including intermediate nodes between them.
- Inter-packet interval is smaller than the predefined timeout values (2.0 sec).

\[ I_{\text{pkt}} = 2.5, \quad T_{\text{pause}} = 60 \]

\[ I_{\text{pkt}} = 0.5, \quad T_{\text{pause}} = 60 \]
Performance Evaluation: Energy Consumption (Static)

Performance gap between ODPM and Rcast is clearer in static scenario (min. 299 J, max 1293 J).
- ODPM: More nodes spend the maximum amount of energy (when inter-packet interval is smaller than the predefined timeout values, 2.0 sec). Nodes spend energy while idling (when inter-packet interval is larger than the timeout value).

Performance Evaluation: Variance of Energy Consumption

- 802.11: shows no variance.
- All the nodes consume the same maximum amount of energy.
- ODPM: acceptable in mobile and low-traffic scenarios.
- Rcast: more promising in every possible scenario, especially under low mobility or high traffic scenario.
Performance Evaluation:
Energy Consumption, PDR, & EPB

EC: $T_{\text{pause}} = 60$

PDR: $T_{\text{pause}} = 60$

EPB: $T_{\text{pause}} = 60$

- In Energy Per Bit (EPB),
  - 802.11: suffers even though it shows the best PDR, because of its high energy cost.
  - Rcast: requires as much as 75% less energy than ODPM.

Performance Evaluation:
Role Number Vs. Energy Consumption

802.11: $R_{\text{pkt}} = 2$
ODPM: $R_{\text{pkt}} = 2$
Rcast: $R_{\text{pkt}} = 2$

- Energy unbalance is mainly caused by non-uniformity in packet forwarding responsibility.
- Role number: measurement of the influence, or utility of a specific node when forwarding packets in a network.
Conclusions & Future Works

- Integrated the IEEE 802.11 PSM and DSR, and improve energy performance in MANETs.
  - Propose a message overhearing mechanism, Rcast.
  - Less overhearing without a significant impact on network performance.
  - Adaptive energy-efficient communication in MANETs.

- For future work,
  - Investigate the effect of other factors for making the overhearing decision.
    - E.g., mobility and remaining battery energy.
  - Explore the use of Rcast for broadcast messages, and incorporate with other routing protocols.

Thank You!!