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

Department of Computer Science and Engineering
The Pennsylvania State University
University Park, PA 16802

*Dept. of Electrical and Computer Engineering
Cleveland State University
Cleveland, OH 44115

Sunho Lim, Chansu Yu*, Chita R. Das

{slim, das}@cse.psu.edu
c.yu91@csuohio.edu

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.

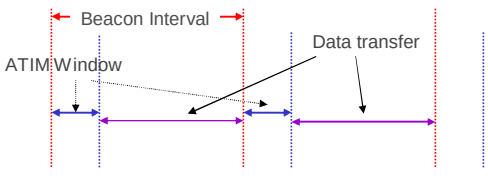
Device	Idle / Listening	Low-Power
Lucent IEEE 802.11 WaveLAN-2	1.15 W	0.045 W
TR 1000, used in Berkeley Motes	13.5 mW	0.015 mW

- 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.

PENNSTATE

Two Power Modes in IEEE 802.11

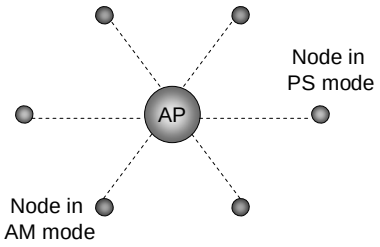
- Active mode (AM).
- Power saving mode (PS):
  - A node periodically wakes up during the packet advertisement period (ATIM window) to see if it has data to receive.
  - When a node receives an advertised packet (ATIM message) that is not destined to itself,
    - It switches to a low-power state during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



PENNSTATE

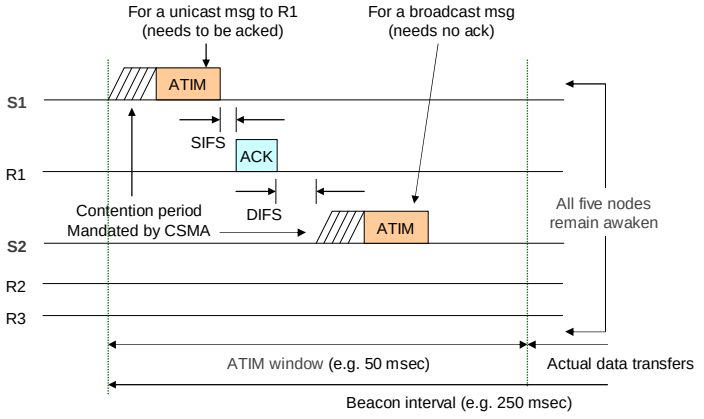
IEEE 802.11 PSM: In Infrastructure Networks

- 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.



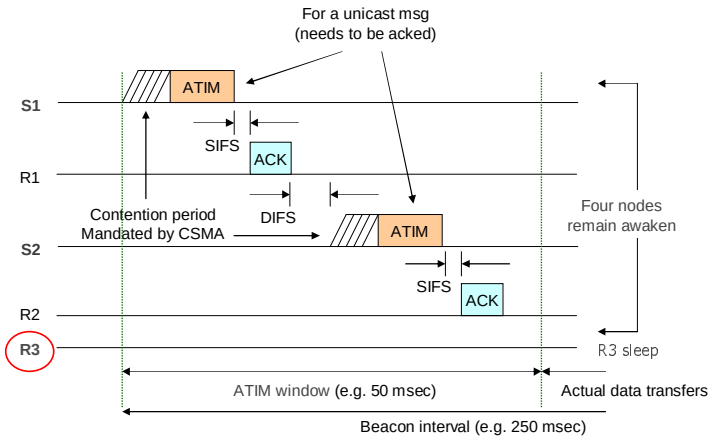
- AP maintains nodes' mode of operation.
- Uses TIM (Traffic Indication Map).
- Requires synchronization (beacons).

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



- One unicast and one broadcast message:
  - All five nodes remain awaken during entire beacon interval.

IEEE 802.11 PSM: In One-hop Ad-hoc Networks (cont.)

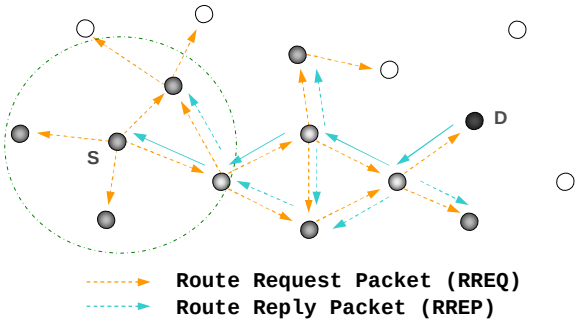


- Two unicast messages:
  - All nodes except R3 should remain awaken during entire beacon interval.

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

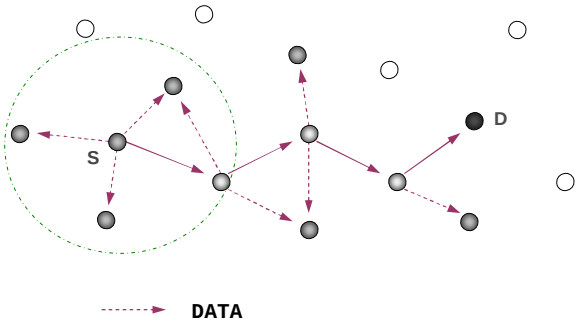
- Multihop routing algorithms complicate the situation (e.g. DSR).
  - DSR improves the routing efficiency via overhearing.
  - Because nodes need to eavesdrop other communications to gather route information.
- DSR with the IEEE 802.11 PSM.
  - With overhearing "enforced".
    - Nodes should not sleep, 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



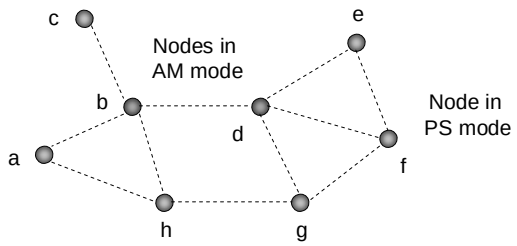
- Route discovery & maintenance.
  - Data transmission in wireless networks is broadcast in nature.
  - Intermediate relaying nodes & other nearby nodes also learn the path to the destination via **overhearing**. But it incurs **high energy cost**.

DSR Protocol: Redundant Overhearing



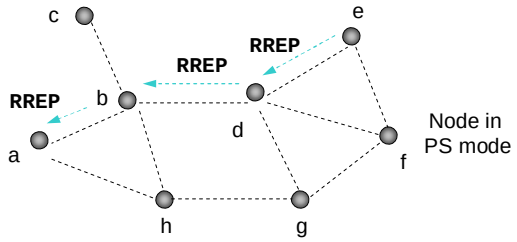
- Sending multiple data packets over the same path.
  - Nearby nodes overhear **redundant path information** and thus, **waste more energy**.

IEEE 802.11 PSM: In Multi-hop Ad-hoc Networks, Span [Mobicom'01]



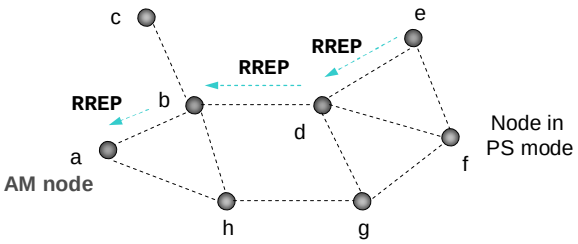
- Construct a routing backbone which consists of AM nodes.
  - Coordinator eligibility rule.
  - Coordinator-ship should change to improve load balance.
- Disadvantages
  - Frequent power mode changes.
  - Less energy savings due to AM nodes, particularly in sparse networks.

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]

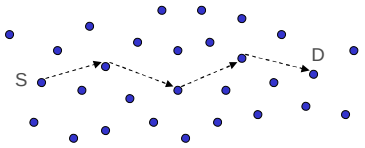


- Event-based mode switching: A node remains in active mode for "some time" (e.g. 2 seconds) if it receives a **RREP** hoping that data packets are delivered shortly.
- Disadvantages
  - Frequent power mode changes.
  - Less energy savings due to AM nodes.
  - Determination of "some time" cannot always be optimal.
  - Easily suffer from communication scenario with many short messages.

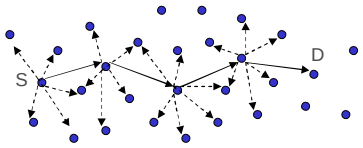
The Proposed Solution: Randomized Communication Mechanism

- 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.

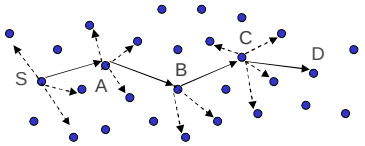
The Proposed Solution: Randomized Communication Mechanism (cont.)



(i) **No overhearing**



(ii) **Unconditional overhearing**



(iii) **Randomized 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.

The Proposed Solution: Randomized Communication Mechanism (cont.)

- 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?

PENNSTATE

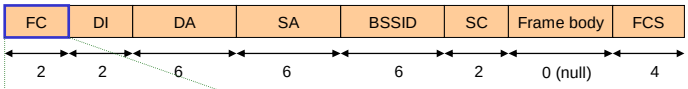
The Rcast Issues (Q1): Which Overhearing Method to Use?

- 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.

PENNSTATE

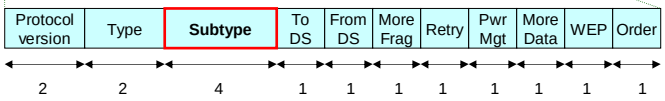
The Rcast Issues (Q2): How to Specify it? - ATIM Frame

- Format of an ATIM frame (length in octets)



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

FC: Frame control (length in bits)



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?

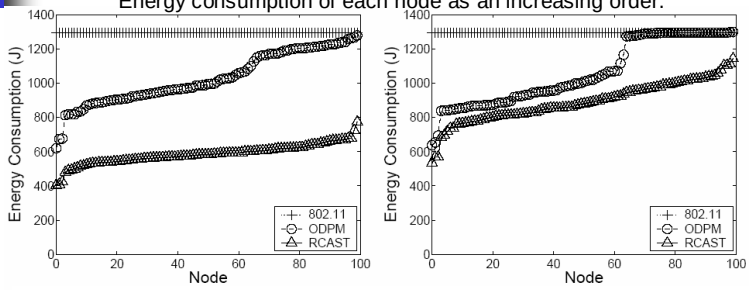
- When a node receives an ATIM frame for a unicast packet,
  - Check destination address (DA) and subtype ID.
  - If the node is the intended destination, it remains awaken
  - If the node is not the destination, but the sender wants unconditional overhearing (ID = 1111_2), it remains awaken.
  - If the node is not the destination, but the sender wants randomized overhearing (ID = 1101_2).
    - 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 / 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

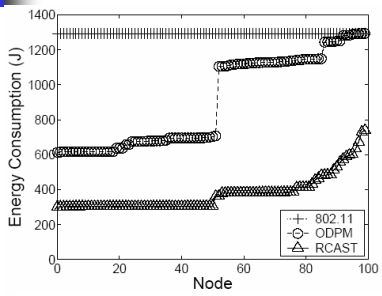
Energy consumption of each node as an increasing order.



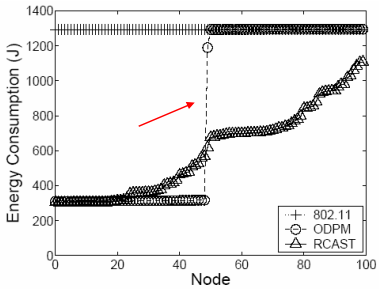
$I_{pkt} = 2.5, T_{pause} = 60$ $I_{pkt} = 0.5, T_{pause} = 60$

- 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).

Performance Evaluation: Energy Consumption (Static)



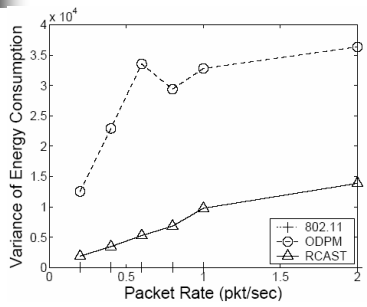
I_{pkt} = 2.5, No mobility



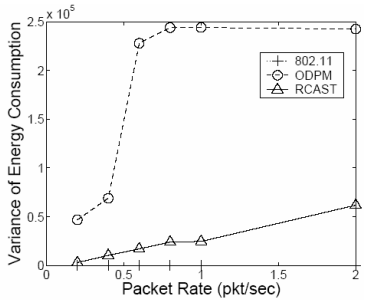
I_{pkt} = 0.5, No mobility

- 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



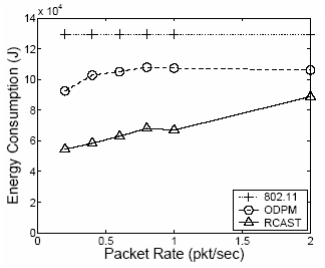
T_{pause} = 60



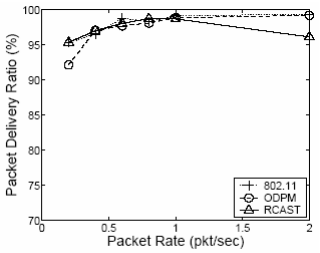
T_{pause} = 1125

- 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.

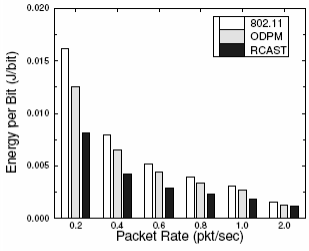
Performance Evaluation: Energy Consumption, PDR, & EPB



EC: T_{pause} = 60



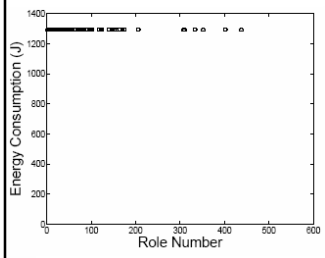
PDR: T_{pause} = 60



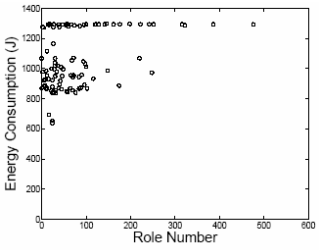
EPB: T_{pause} = 60

- 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.

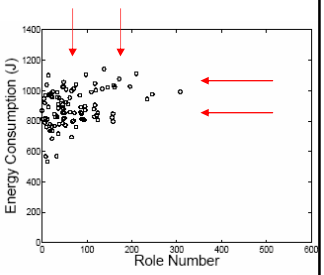
Performance Evaluation: Role Number Vs. Energy Consumption



802.11: R_{pkt} = 2



ODPM: R_{pkt} = 2



Rcast: R_{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 !!