Cooperation decreases energy consumption in 802.11 networks

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Cooperative MAC

- **IEEE 802.11 MAC overview**
  - CSMA/CA
  - Long term channel access fairness inherent in MAC design: In the long term, all nodes in the network will get equal number of access opportunities.
  - Performance anomaly: Low data rate nodes (say 1 Mbps) will occupy the channel for longer duration for the same size frame leading to reduced overall network throughput.
- **Cooperative MAC**
  - Our solution: Reduce the channel access time of low data rate node by assisting its transmission. i.e. two hop forwarding.

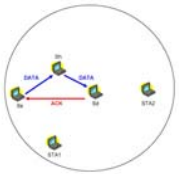

Fig 1: Cooperative MAC

Energy model

- **WLAN card in three different modes**
  - Transmit: When data bits are being transmitted on to the channel (Power = P_T watts)
  - Receive: When data bits are being received and processed from the channel (Power = P_R watts)
  - Idle: When the card is idle – no transmission or reception of bits (Power = P_I watts)
- **WLAN card operation**
  - In receive mode when sensing the channel
  - When receiving a frame destined to other nodes: in receive mode until destination address is processed and then switch to idle mode to save power
- **Analysis**
  - Assumption: Saturated network
  - Let the time duration for which the WLAN card is in transmit, receive and idle mode be T_T, T_R and T_I respectively.
  - Energy expense = $P_T * T_T + P_R * T_R + P_I * T_I$ Values used: P_T = 2.05 watts, P_R = 0.95 watts and P_I = 0.85 watts

Result: Network energy

- **Sum of energy expense for all nodes in the network**
  - Since transmit power is higher compared to receive or idle power the total energy expenditure of the network for a given traffic reduces due to cooperation.

Table 1: Bits-per-joule for 802.11b network

Packet Length	W/o forw(x 10^4)b	With forw(x 10^4)b
1024 bytes	7.6576	16.937
768 bytes	7.4604	15.961
512 bytes	7.0948	14.311
256 bytes	6.1855	10.925

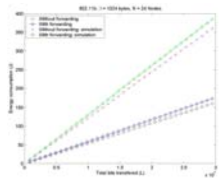

Fig 2: Energy expense for the network

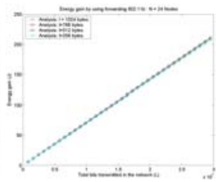

Fig 3: Energy gain due to forwarding

What about the Forwarding node?

- **Question**
  - What happens to the energy expense for the forwarding node?
- **Assumption**
  - Only one high data rate node participating in forwarding
- **Answer**
  - We demonstrate energy saving for the forwarding node due to its cooperation.
- **Cooperation regions**
  - For a given high data rate node (Forw. Node in Fig.4), only the low data rate nodes within the 11 Mbps and 5.5 Mbps range of the Forw. node can be assisted.

Fig 4: Area of cooperation for forw. node

Forwarding node energy analysis

- **Forwarding node operation**
  - Wake-up from sleep mode (OFF) for frame transmission.
  - Assist low data rate node to reduce the channel busy time.
  - Transmit own bits when channel access becomes available according to 802.11 MAC.
  - Switch back to OFF state when done with own bits.

Energy Efficiency Analysis

Fig 5: Example: Forwarding node states

Result: Forwarding node energy

- **Analysis**
  - Calculate time forwarding node will spend in each state: Transmit, Receive and Idle for both forwarding and non-forwarding cases.
- **Savings**
  - Forwarding node saves on idle time
  - Forwarding node spends additional energy to receive and transmit data for low data rate node

Table II: Bits-per-joule for high data rate forwarding nodes

11 Mbps node	W/o forw(x 10^4)b	With forw(x 10^4)b
Analysis	8.2845	8.8939
Simulation	7.8552	8.7389
5.5 Mbps node	W/o forw(x 10^4)b	With forw(x 10^4)b
Analysis	8.1544	8.2206
Simulation	7.7032	8.4592

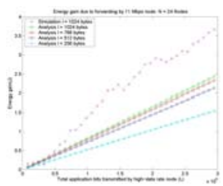

Fig 6: Energy expense for a 11 Mbps forwarding node

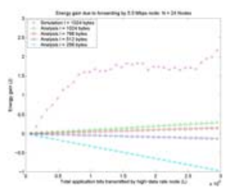

Fig 7: Energy expense for a 5.5 Mbps forwarding node

Generalization of the power requirements

Problem

- Different wireless cards have different power requirements for transmit, receive and idle modes.
- Under what constraints on these powers can energy savings for forwarding node maintained?

- **Analysis**
  - Define relationship between the three power requirements as given below.
  - **Let**

$$P_R = \beta P_I,$$

$$P_T = \alpha P_I.$$

  - **Condition for maintaining energy savings**

$$T_{inc}(X)\alpha + R_{inc}(X)\beta \le I_{dec}(X).$$

  - where T_{inc} is the increase in the transmission time, R_{inc} is the increase in the receive time and I_{dec} is the decrease in the idle time.

Result: Power requirements

- **Energy saving area**
  - The area below the lines in Fig. 8 is the operating area for a 11 Mbps node.
  - The area below the lines in Fig. 9 is the operating area for a 5.5 Mbps node.
  - As long as the point coordinate (α, β) for a given P_R, P_I and P_T fall below the lines in the figures Fig.8 and Fig.9, the corresponding high data rate node will save energy by participating in forwarding.

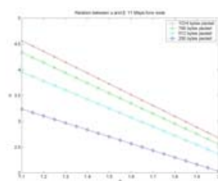

Fig 8: Optimal power area for 11 Mbps node

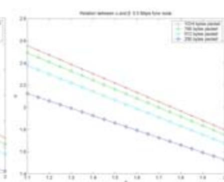

Fig 9: Optimal power ratio for 5.5 Mbps node