Battery Efficient Operation of Radio MAC Protocol

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Abstract

Battery efficient operation of scheduled multiaccess protocols for sharing a wireless channel among portable mobile users are described. The proposed techniques for minimizing battery power consumption have broad applicability in frame-based scheduled access schemes under a variety of signaling methods, including but not limited to spread-spectrum radio transmissions. For purposes of exposition, this contribution is presented in the context of the medium access control protocol for radio LANs proposed in [*NAT*91].

Portable or laptop computers that run on battery power constitute a fast-growing segment of the computer industry. An important requirement on a standard medium access control protocol for use in such portable mobile stations is that it place minimal demand on battery power for wireless communication. In this contribution we describe techniques for minimizing the battery power consumed at the wireless link adapters of mobile stations.

Ideally, a mobile station that performs wireless communication should consume power for communication only when it is actively transmitting or actively receiving information. Scheduled access multiaccess protocol can be implemented to effectively conserve battery power by suitable control of the state of transmitter and receiver units at the portable mobile stations. The main idea is to control the mobile station transmitters/receivers to be turned ON only when necessary and turned OFF at the earliest opportunity. For the purpose of exposition, in the remainder of this contribution, we assume the medium access control protocol with a frame structure as described in [*NAT*91]. Battery efficient operation is accomplished by utilizing the control information contained in the AH (Outbound) and BH (Inbound) headers (see Fig. 1). We outline below only those aspects of MAC protocol that relate to battery power conservation.

Period A -

- AH (*Broadcast from Access Point to mobile stations*) - the interval during which the Access Point broadcasts a special message to all the mobile stations that identifies the beginning of Period A. The Access Point controls outbound transmissions to the mobile stations by broadcasting the following control information in Header AH which is received by all mobile stations. The header includes:
  - A list of mobile stations $\{U_1, U_2, \ldots, U_n\}$ that will be receiving data from the Access Point in the current frame and the order in which they will receive packets.
  - Bandwidth allocated to mobile stations in this frame $\{R_1, R_2, \ldots, R_n\}$, where R_i is the number of packets that will be directed to mobile station U_i from the Access Point in the current frame.
- A (*Broadcast from Access Point to mobile stations*) - the interval during which outbound traffic is transmitted. On correct reception of the above broadcast information, a mobile that is not included in Header AH can turn its receiver OFF for a time duration TA (total number of slots allocated to Period A). The adapter of each receiving mobile station can compute exactly when it should be ready to receive packets from the Access Point (add up the slots allocated to all receiving mobile stations that precede it). Each receiving mobile station puts its receiver to *sleep* (by turning its power OFF) after scheduling to *wake* up the receiver (by turning its power ON) at its designated time for receiving data. After a mobile station receives packets directed to it, its receiver is again put to sleep. Thus, when an Access Point broadcasts packets, only the mobile stations that are the intended recipients actually receive them. At the end of Period A, all mobile stations wake up their receivers by turning them ON just in time to receive Header BH corresponding to Period B.

Period B -

- BH (*Broadcast from Access Point to mobile stations*) - the interval during which the Access Point broadcasts a control message to all the mobile stations that includes TB, length of the Period B and the following slot allocation information.
  - A list of mobile stations $\{V_1, V_2, \ldots, V_m\}$ that are allowed to transmit packets to the Access Point in the current frame and the order in which they should transmit.
  - Bandwidth allocated to mobile stations in this frame $\{S_1, S_2, \ldots, S_m\}$, where S_i is the number of packets that the mobile station V_i can transmit in the current frame.

- B (*Contention Free Transfer from Mobile stations to Access Point*) - the interval during which inbound traffic is transmitted. On correct reception of the broadcast Header BH, each mobile station can turn its receiver OFF for duration TB, the length of the Period B. The mobile stations transmit packets to the Access Point according to the allocation information received in Header BH. Each mobile station knows its position in the ordered list. It computes exactly when it should begin transmission (by summing the number of slots allocated to its predecessors in the list). At its designated time, the mobile station can transmit for a fixed period of time whose duration depends on the number of slots allocated to it. If a mobile station fails to receive BH correctly, then it will not make use of any slots that may have been allocated to it in the current frame.

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  | G |AH|      A      |BH|      B        |CH|      C       | G |

  |...|..||||||||||||||..|||||||||||||||||..|||||||||||||||...|

  |   |  | Broadcast   |  | Contention Free|  | Contention   |   |

  |   |  | Access Point|  | Mobiles to     |  | Mobiles to   |   |
  |   |  | to Mobiles  |  | Access Point   |  | Access Point |   |

->| H |  |<--TA------->|  |<------TB------>|  |<---TC------->| H |<-

   AH - Header for Period A (includes receiver slot allocations)
   BH - Header for Period B (includes transmitter slot allocations)
   CH - Header for Period C
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Figure 1. Frame Structure of Medium Access Control Scheme

Period C -

- CH (*Broadcast from Access Point to mobile stations*) - the interval during which the Access Point broadcasts a special message to all the mobile stations, identifying the end of the Period B and the beginning of the Period C. The message also conveys TC, length of the Period C.

- C (*Random Access from Mobile stations to Access Point*) - the interval during which any station may contend for the channel and transmit a message without the consent of the Access Point. In Period C, the mobile stations that do not wish to transmit go to *sleep* (by powering down both their transmitters and receivers) till the end of the current frame. A mobile station that has a packet to transmit follows a contention-based protocol. Assuming Slotted-ALOHA protocol is used, the transmitter is turned ON just for the slot in which the packet is transmitted. A timer is set to *wake* the receiver of the mobile station just in time to receive acknowledgement messages (packet collided or not) and then go to *sleep*.

The methods described above are simple and effective in reducing power consumption in any frame based Scheduled Access Protocol scheme for sharing wireless channels among portable mobile users. Our techniques for battery efficient operation of the protocol rely on implementation of timers that do not consume significant battery power when compared with transmitter, receiver, microprocessor or logic in the wireless adapter cards. The following data taken from manufacturer's manuals indicate that timers can be implemented with relatively low power consumption. The example is representative of what can be saved in a realistic system. As an example, a Microcontroller XXX consumes 385 mW in Normal running mode and 55 mW in Idle mode (i.e., with internal timer and oscillator running).

A Radio Transceiver YYY consumes 325 mW in Transmitter ON mode, 400 mW in Receiver ON mode and 1 mW in Standby mode. When the timer is used, Microcontroller XXX can be put into Idle mode (55 mW) and the Radio Transceiver YYY can be put in Standby mode (1 mW).

Suppose f_t is the fraction of the time a user is actively transmitting (i.e., user is allocated $(TA + TB)\,f_t$ slots in Period B) packets to the Access Point. Suppose f_r is the fraction of the time the user is actively receiving packets addressed to him (i.e., user is allocated $(TA + TB)\,f_r$ slots in Period A). The power consumed using the current method will be (a slightly optimistic estimate):

$$(385 + 325)\,f_t + (385 + 400)\,f_r + (55 + 1)\,(1 - f_t - f_r) \;=\; 710\,f_t + 785\,f_r + 56\,(1 - f_t - f_r)\;\; mW$$

The power consumed without the techniques of this contribution will be:

$$400\,(1 - f_t) \;+\; 325\,f_t + 385 \;=\; (785 - 75\,f_t)\;\; mW$$

If $f_t = 0.01$, $f_r = 0.05$ power consumption with our method will be 98.99 mW. Otherwise the power consumed would have been 784.25 mW. In summary, significant power savings can be realized with the techniques described in this contribution, especially as $f_t \rightarrow 0$, $f_r \rightarrow 0$.

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   |...|..|<------------->|  |<----------->|..|<------------>|..|
          | Access Point |  | Mobiles to  |  | Contention   |  |
          | to Mobiles   |  | Access Point|  | from Mobiles|  |

   | G |AH|       A       |BH|      B      |CH|      C      |FT|
   |...|..|||||||||||||||..||||||||||||||..||||||||||||||  |

   |   |  |R1| R2 |R3|R4 | |              |  |              | |
   |   |  |ON| ON |ON|ON | |              |  |              | |

   RECEIVER ALLOCATIONS R1=3, R2=5, R3=3, R4=4

->| FH|  |<-- TA = 15 ->|  |<--TB = 14-->|  |<---TC------>|  |
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Figure 2. Battery Efficient Receiver Operation.

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   | G |AH|       A       |BH|      B      |CH|      C      |FT|
   |...|..|||||||||||||||..||||||||||||||..||||||||||||||  |

   |  |  |                | |S1 |S2| S3  | |               | |
   |  |  |                | |ON |ON| ON  | |               | |

   TRANSMITTER ALLOCATIONS    S1=4, S2=3, S3=7
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Figure 3. Battery Efficient Transmitter Operation.

References

[NAT91] K. S. Natarajan, C. C. Huang and D. F. Bantz, "Medium Access Control Protocol for Radio LANs," IEEE P802.11/91-74, July 8, 1991.