An Energy Efficient MAC in Wireless Sensor Networks to Provide Delay Guarantee

Anirudha Sahoo
and
Prashant Baronia

Department of Computer Science and Engineering
IIT Bombay, Powai, Mumbai, India.

Outline

- Introduction
- MAC protocols
- S-MAC – Salient Features
- RTMAC (Real Time MAC)
- Simulation Results
- Conclusion and Future Work

Introduction

- WSN is an emerging technology with more and more applications embracing it
  - Environmental monitoring, earthquake detection etc.
- For sending sensed data, a sensor node has to gain access to the medium
  - Thus MAC protocol plays an important role in WSN
  - If application is a realtime application, then the underlying MAC has to provide real time support
- In this paper, we propose a MAC for WSN which provide real time delay guarantee

MAC Protocols in WSN

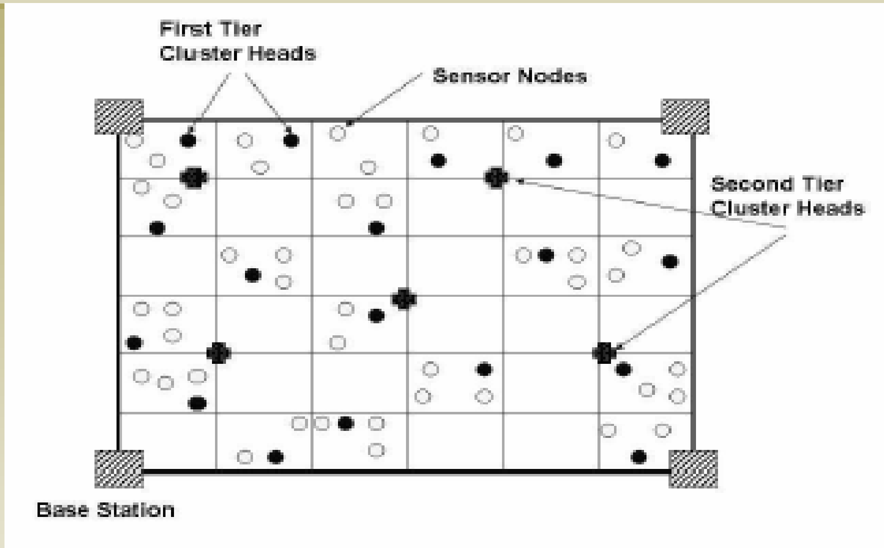
- MAC protocols in WSN can be broadly classified into two types
  - TDMA Based MAC
    - Time is divided into slots
    - Each node knows when to transmit
    - Schedule is predetermined
    - Synchronization problems
  - Contention Based MAC
    - Carrier sensing & collision avoidance
    - Probabilistic Delay guarantee
    - Multiple access with collision avoidance
    - e.g. IEEE 802.11

S-MAC

- Periodic Listen and Sleep
  - Each node goes into periodic sleep (power save mode in IEEE 802.11)
  - To reduce control overhead and latency neighboring nodes are synchronized
- Collision Avoidance
  - Similar to IEEE 802.11
- Overhearing Avoidance
  - Go to sleep if your neighbor is in transmit or receive stage.
- Message Passing:
  - Divides long messages into small fragments and keep the channel to transmit all the segments back to back. Uses one RTS/CTS for the entire message.

Real Time MAC (RTMAC)

Topology



- The sensed area is divided into grids.
- Each grid forms a cluster with a cluster head.
- These cluster heads in turn form a cluster with a cluster head of their own.
- Presently we focus on the single grid of the network.
- Better performance is achieved in uniformly distributed sensor nods with cluster head in the middle

Assumptions

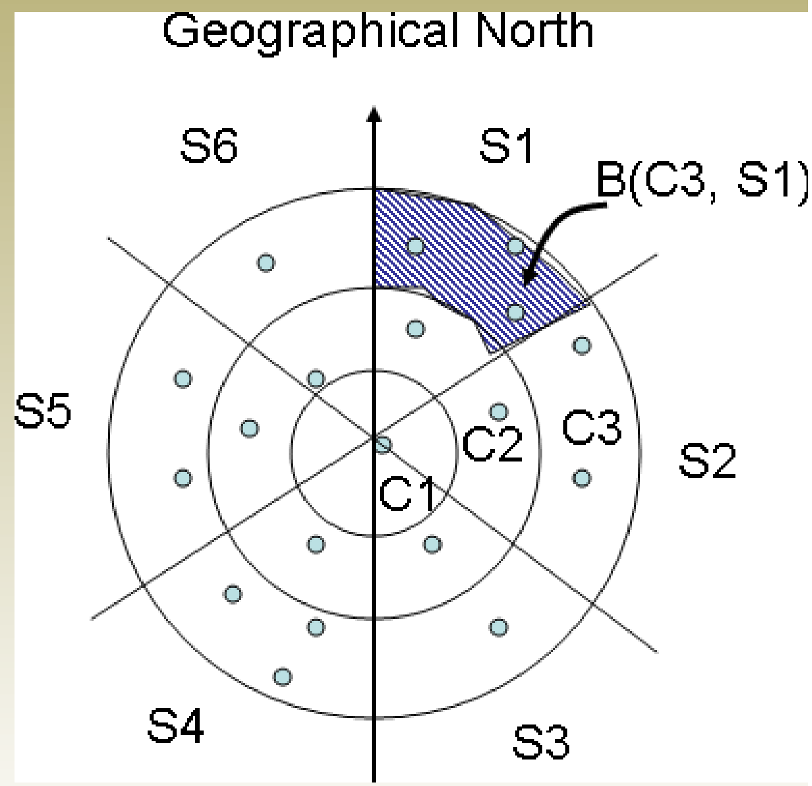
- Sensor nodes and cluster head are stationary
- All nodes in the network are homogeneous
- The transmission range and interference range of sensor nodes are same
- Each node has a unique id in the network
- Event rate is slow enough to neglect queuing delay
- Separate channel for control packets and data packets.
- Propagation delay is negligible
- Clocks of sensor nodes are synchronized by using out-of-band time synchronization sources
- Network carries constant size small packets

Control Plane

- Hop Count Calculation Algorithm
  - All Nodes broadcast *HELLO* beacon which carries node id and a counter initialized to 1
  - Intermediate nodes increment the counter and retransmit the beacon
  - Each node transmits a beacon for a particular node only once
  - When cluster head receives the beacon it sends *ACK* with same value of node id and counter as the beacon
  - Intermediate nodes just retransmit the *ACK* message
  - Beacons containing its node id is accepted by the node and the counter value is set as the hop count from cluster head
  - Node may receive multiple beacons addressed to itself. It takes the one with minimum counter value
  - Node times out if it does not receive *ACK* and retransmits the *HELLO* beacon
  - Process continues till all the nodes have a hop count and all the *HELLO* and *ACK* packets die down in the network

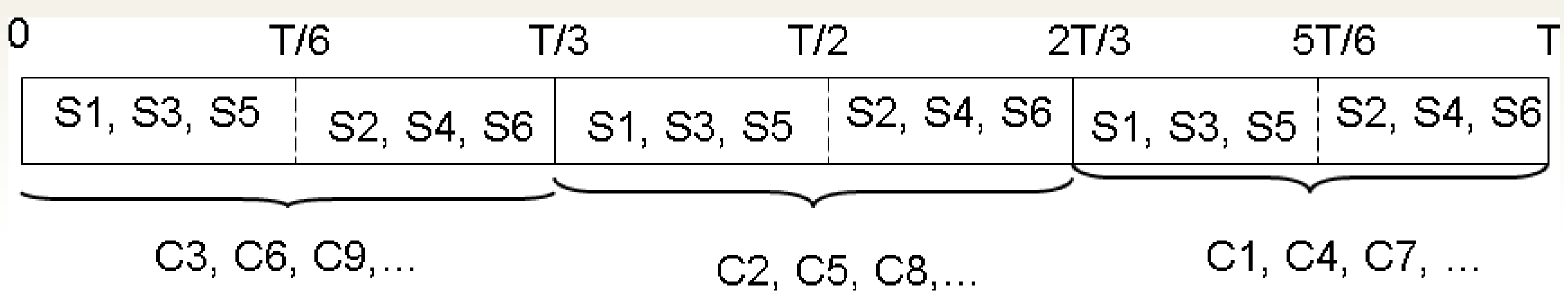
Slot Assignment

- Nodes can now be seen as arranged in virtual circle with circles, sectors and blocks
- Slots are distributed depending upon the distance from the cluster head
  - Nodes in circle C1 and C4 can communicate simultaneously
  - Nodes in same circle but in Sector S1, S3 and S5 can communicate simultaneously
- Block (C_3, S_1) and (C_3, S_3) can have same time slot
- The angle of a sector $\theta = 60^0$
- Cluster head uses HELLO beacon method to know the number of nodes in a block



Slot Assignment

- The super frame T is divided into 3 slots
  - Slot [2T/3-T] given to circle C1, [T/3-2T/3] to circle C2 and slot [0-T/3] to circle C3
- The blocks in a ring are divided into two non-interfering sets
  - Each set is assigned half of the above timeslot, e.g., [0,T/6] is assigned to S1, S3 and S5 and [T/6, T/3] is assigned to S2, S4 and S6.
- C_1 and C_2 are special cases
- Node level slots are allocated by the cluster head from the block level slot of size T/6.



Notations Used for Delay Analysis

- T_r : Transmission time of a packet
- t_{node} : size of a node level time slot
- N : total number of nodes in the cluster
- N_1 : number of nodes in C1
- N_2 : number of nodes in C2
- H : hop count of a sensor node
- M : maximum number of nodes allowed in a block
- D : is the worst case delay of an event, happening H hops away from the cluster head, to reach the cluster head.

Delay Analysis

- In the worst cas, the delay in the outermost circle where the event happens is $T + T_r$
- In subsequent transmission from one circle to the other, the packet experiences a delay of $T/3 + T_r$
- C_1 and C_2 are exceptions and the delay in them is $N_1 * t_{node}$ and $N_2 * t_{node}$ respectively
- Delay is given by the equation below

$$D = \begin{cases} T + T_r + (H-3)(\frac{T}{3} + T_r) + \\ \quad N_2 \cdot t_{node} + T_r + N_1 \cdot t_{node} + T_r & for H \geq 3 \\ T + T_r + N_1 \cdot t_{node} + T_r & for H = 2 \\ T + T_r & for H = 1 \end{cases}$$

Delay Analysis (cont'd)

- Improving Delay
  - If the angle of a sector θ is kept constant the blocks in the rings further away will have large area.
  - M will be large $\rightarrow$ T will be large $\rightarrow$ D will be large
  - Thus as we move further away from the center we can decrease the value of θ and thus the value of M and improve delay
- Energy Efficiency
  - Nodes should be awake only when it is their slot to send data or their neighbors slot to send data
    - Hence when nodes in circle C4 are transmitting nodes in circle C2 can sleep
    - Similarly nodes in circle C3 can sleep during slot of circle C2
  - At any time 1/3rd of the network sleeps thus saving energy

SIMULATION

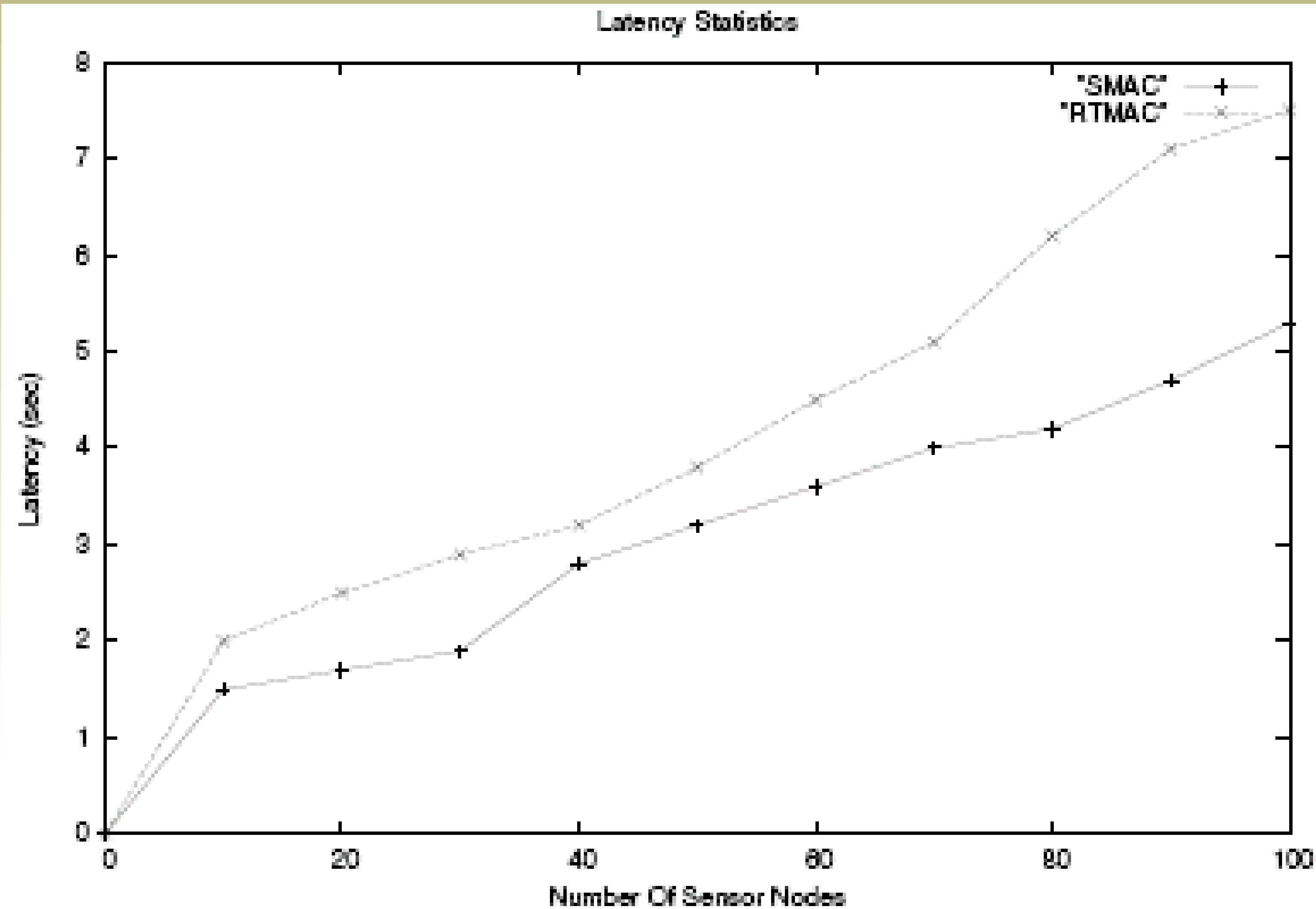
Simulation Setup

- used ns2 simulator
- Nodes uniformly distributed in an area of 500x500 m^2 with the cluster head at the center.
- 3 rings
- Each node has a transmission range of 100m
- Each phenomenon/event is carried in a packet of size 48 bytes.

Latency Measurement

- Latency *vs* Network Size
- RTMAC has higher latency than S-MAC
- But S-MAC cannot gauarntee that each and every packet will meet their deadline
- Small difference in amount of delay
- Hence RTMAC is more suitable for applications which require each and every packet to meet their deadline at the cost of some delay increase.

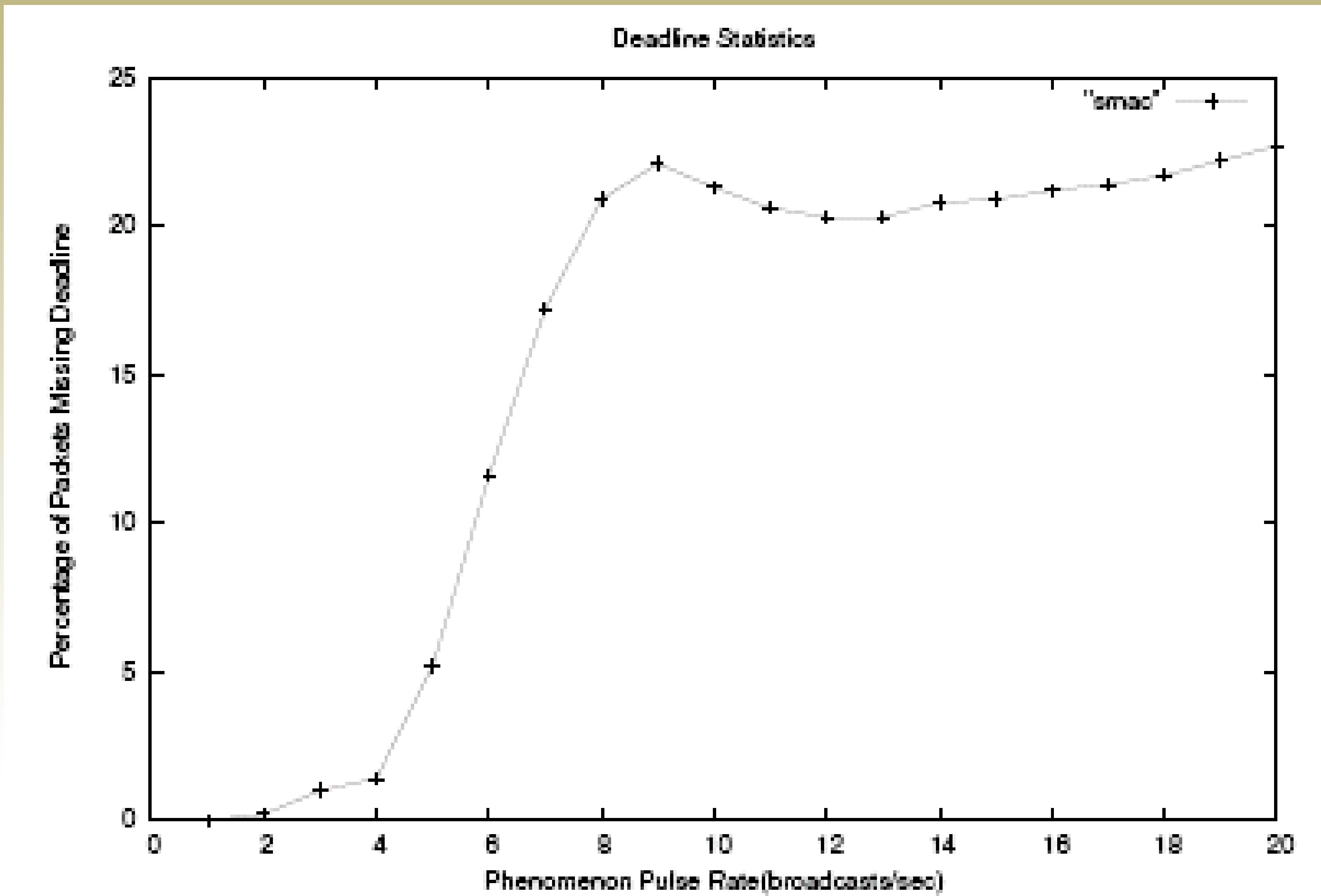
Latency Measurement



Deadline Compliance

- Phenomenon rate *vs* %of S-Mac packets missing deadline.
- Deadline was normalized against maximum delay of a packet in RTMAC
- Thus RTMAC has *zero* packet loss
- When the event generation rate increases more and more packets miss deadlines
- Thus S-MAC is not desirable for applications which require hard delay guarantee

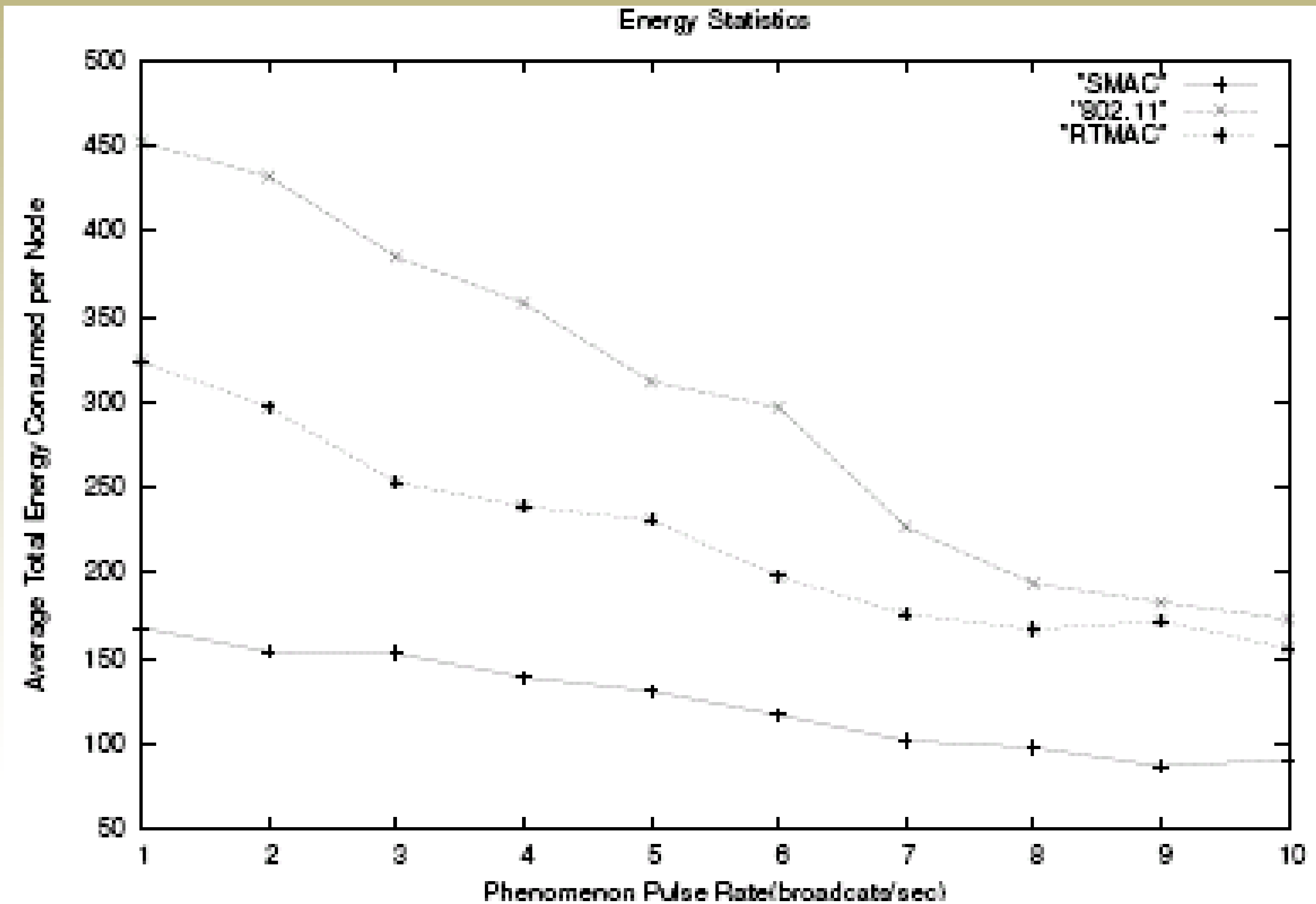
Deadline Compliance



Energy Efficiency

- Average energy consumed on each node vs phenomenon rate
- The sensor node was assumed to spend *1.0, 2.0, 0.001* and *4.0* units of energy for transmission reception, sleeping and idle listening.
- Idle listening causes 802.11 to consume far more energy than S-MAC and RTMAC in case of low traffic
- In heavy traffic S-MAC is better due to message passing and overhearing avoidance

Energy Efficiency



Conclusion

- New collision free TDMA based protocol
- Distributed algorithm for the slot distribution.
- Slot reutilization techniques to reduce the message latency.
- Energy efficient algorithm.
- Deterministic delay guarantee.
- Implemented the support for RTMAC in NS2 (Network Simulator).
- Simulation results show promising results

Future Work

- Fully distributed algorithm for slot assignment.
- Scalability issues.
- Increase the energy efficiency of the protocol

References

[1] I. Akyildiz, W.Su, and Y. Sankarsubramaniam, “A survey on sensor networks," IEEE Communications Magazine, August 2004.

[2] I. Demirkol and C. Ersoy, “Mac protocols for wireless sensor networks: a survey,"
2003.

[3] S. Kulkarni and M. Arumuga, “Tdma services for sensor networks," International
Conference on Distributed Computing Systems Workshops, 2004.

[4] A. Woo and D. Culler, “A transmission control scheme for medium access in sensor
networks," Seventh Annual International Conference on Mobile Computing and Networking, 2001.

[5] P. Boon, “Real-time communication and coordination in wireless embedded sensor
networks," Operating System Methods for Real-Time Applications, 2004.

[6] W. Ye and J. Heidemann, “Medium access control in wireless sensor networks,“ USC/ISI Technical Report, 2003.

[7] J. Heidemann and D. Estrin, “Medium access control with coordinated adaptive sleeping
for wireless sensor networks," IEEE Transactions on Networks, vol. 12, no. 3, 2004.

[8] B. Krishnamachari, D. Estrin, and S. Wicker, “The impact of data aggregation in
wireless sensor networks," 2003.

References

[9] “http://webs.cs.berkeley.edu,"

[10] A. El-Hoiydi, “Spatial tdma and csma with preamble sampling for low power adhoc networks," Seventh International Symposium on Computers and Communications, July 2002.

[11] T. Dam and K. Langendeon, “An adaptive energy-ecient mac protocol for wireless

sensor networks," The First ACM Conference on Embedded Networked Sensor Systems, 2003.

[12] P. Lin, C. Qiao, and X. Wang, “Medium access control with a dynamic duty cycle for sensor networks," IEEE Wireless Communications and Networking Conference, vol. 3, 2004.

[13] “The network simulator ns-2," http://www.isi.edu/nsnam/ns/.

[14] I. Downard, “Simulating sensor network in ns-2," Naval Research Laboratory.

Thank You

Questions??