MMAC: A Mobility-Adaptive, collision-Free MAC Protocol for Wireless Sensor Networks

Muneeb Ali
Computer Science Department,
LUMS

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Introduction

- Wireless Sensor Networks have emerged as one of the first real applications of Ubiquitous Computing
- Energy-Efficiency has been considered as the single most important design challenge in Sensor Networks
- Recent work on Medium Access Control (MAC) protocol for Sensor Networks focused on energy-efficiency instead of fairness, delay, and bandwidth utilization.
- Mobility poses unique challenges to MAC protocol design

Mobility in Sensor Networks

We define mobility in sensor networks as:

1. Weak Mobility: Topology changes, Node joins, and Node failures.
2. Strong Mobility: Concurrent Node joins and failures, and physical mobility - either because of mobility in the medium (e.g. water or air) or by means of special motion hardware

MMAC handles both strong and weak mobility.

Related Work

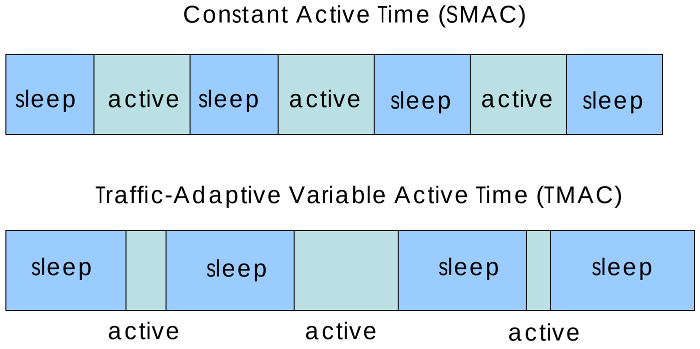
•The most widely used MAC protocol for Sensor Networks is SMAC.

•SMAC introduced a low-duty cycle operation in multi-hop wireless sensor networks, where the nodes spend most of their time in sleep mode to reduce energy consumption

•Papers on TRAMA and TMAC showed that SMAC with fixed sleep and awake periods does not perform well with variable traffic loads.

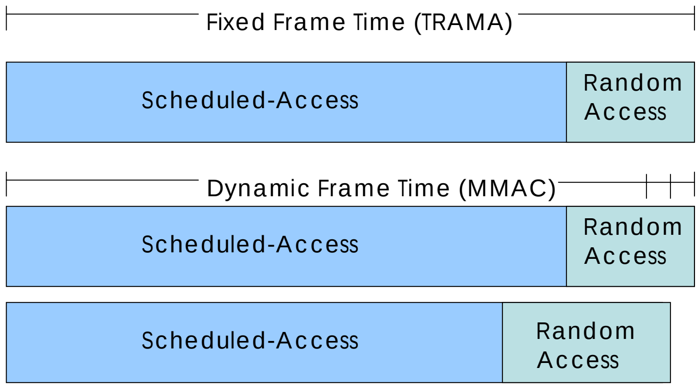
•The frame time in SMAC, TRAMA and TMAC is fixed, and we show that a dynamic frame time, inversely proportional to level of mobility, is required in mobile sensor networks

Contention-based Protocols



Constant active-time (SMAC) vs Traffic-Adaptive dynamic active time (TMAC)

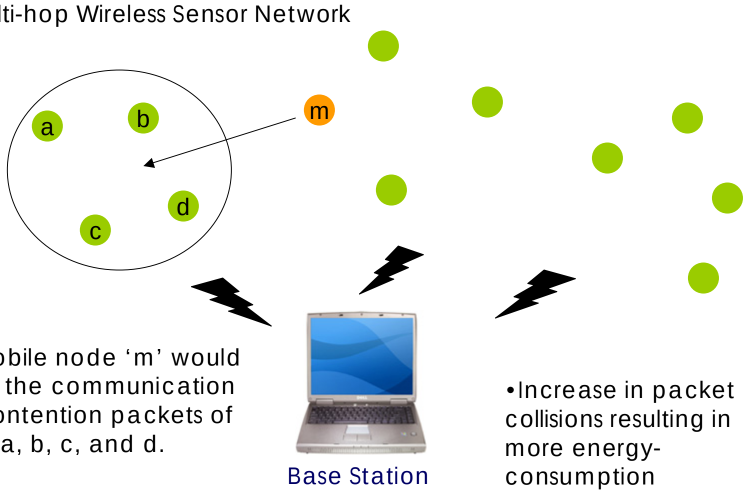
Schedule-based protocols



Fixed Frame Time (TRAMA) vs Dynamic Frame Time (MMAC)

Problem with Contention-based Protocols

A multi-hop Wireless Sensor Network

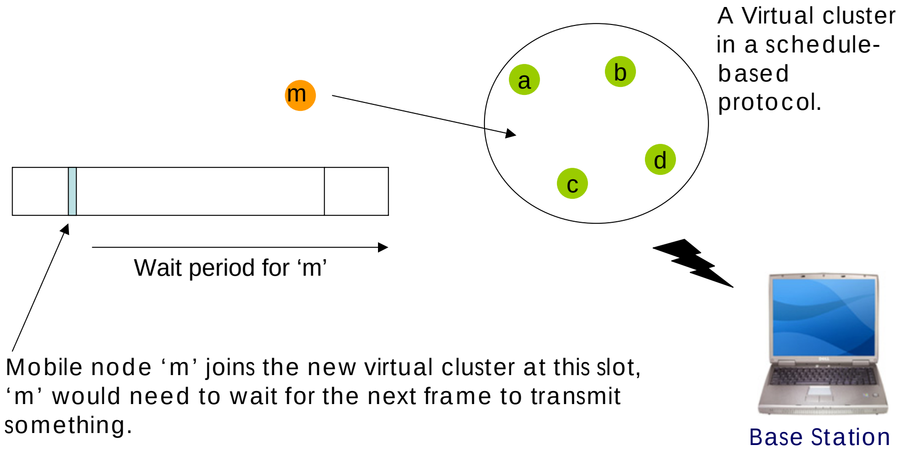


The mobile node ‘m’ would disturb the communication and contention packets of nodes a, b, c, and d.

- Increase in packet collisions resulting in more energy-consumption

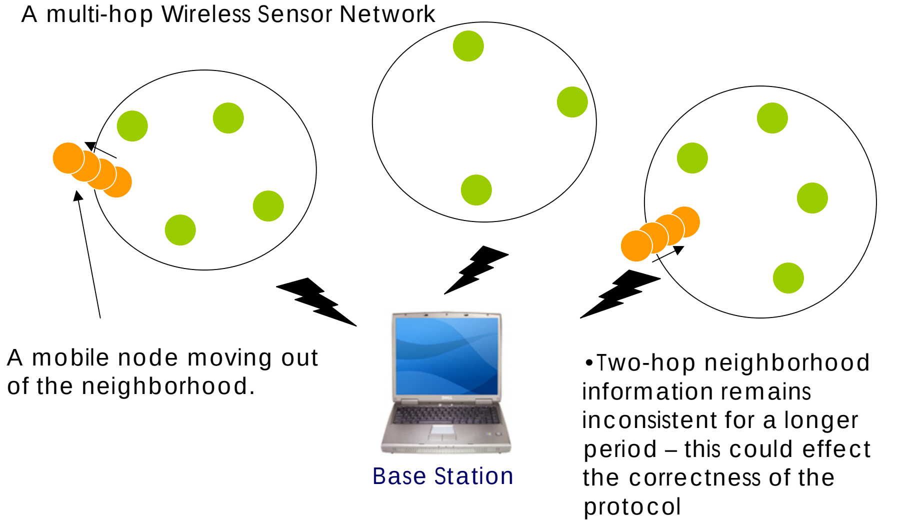
Problem with Schedule-based Protocols

A multi-hop Wireless Sensor Network



Problem with Schedule-based Protocols

A multi-hop Wireless Sensor Network



MMAC Protocol

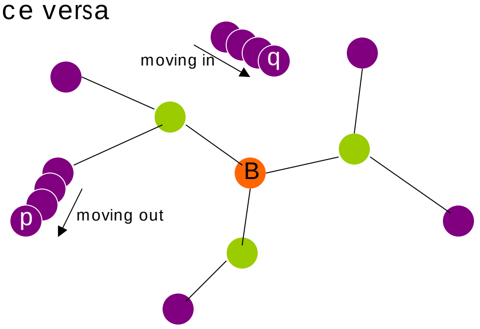
- MMAC introduces a mobility-adaptive frame time that enables the protocol to dynamically adapt to changes in mobility patterns.
- We will only discuss issues related to mobility.
- MMAC uses location information to predict the mobility behavior of sensor nodes. Localization is a well studied problem in Wireless Sensor Networks.
- We use the AR-1 model by Zainab et al. for mobility estimation.

Mobility-Adaptive algorithm

- Basic Idea: If a large number of nodes are expected to enter or leave the two-hop neighborhood of a node *B* – reduce the frame time and vice versa

The nodes which are expected to enter or leave the 2-hop neighborhood during the frame F are NOT included in the schedule

If there are a lot of nodes entering or leaving the 2-hop neighborhood then it is desirable to have frequent “random access time” so that the topology changes could be reflected in the schedule



2-hop neighborhood of a node ‘B’
Node ‘p’ is moving out of the neighborhood
Node ‘q’ is moving into the neighborhood

Mobility-Adaptive algorithm

1. For all nodes in the network locally calculate the 'optimal predicted states' using the AR-1 model.
2. For all nodes in the 2-hop neighborhood of a node 'B' calculate the 'average estimated location'.
3. Using the above information populate the sets "Incoming nodes" (IN) and "Outgoing nodes" (ON) for node 'B'
4. If a node 'A' is a member of either 'IN' or 'ON' do not consider 'A' in the 2-hop neighborhood of 'B'
5. If the number of members in these two sets is greater than a threshold value reduce "frame time"
6. If the number of members in these two sets is less than a threshold value increase "frame time"
7. Adjust the Scheduled-Access time and the Random-Access time according to the new Frame Time.

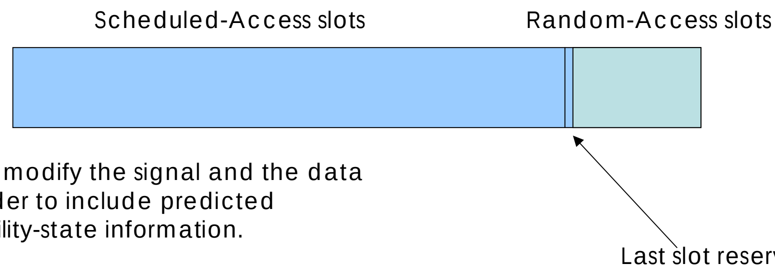
Protocol Issues

We identify the following issues with the generic mobility adaptive algorithm:

1. Mobility Information: Individual nodes can only predict their own future mobility state but in the mobility-adaptive algorithm each node requires future mobility state of ALL current and potential two-hop neighbors

2. Synchronization: Using the mobility-adaptive algorithm, individual nodes could independently calculate frame times different from each other, leading to synchronization problems in the schedule-based protocol.

Mobility Information



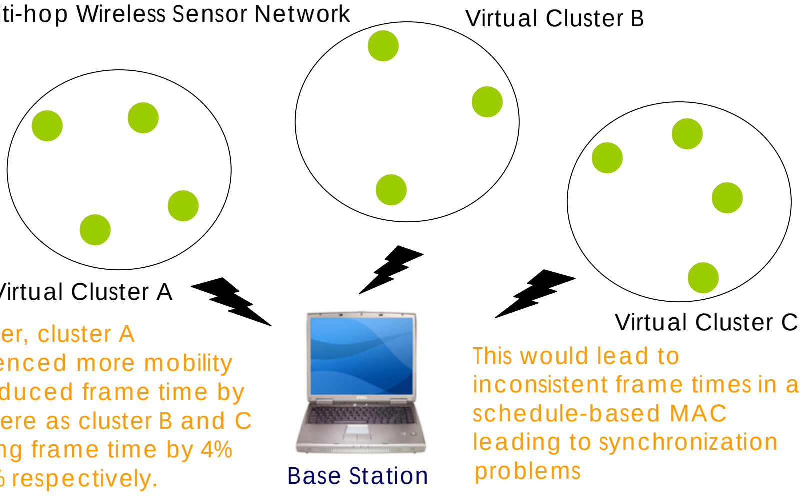
•We modify the signal and the data header to include predicted mobility-state information.

•At the start of each frame each node *A*, independently calculates the expected mean (x,y) of *A* in the next frame.

Last slot reserved for BROADCAST from head node for sending all received mobility-information

Synchronization Problem

A multi-hop Wireless Sensor Network



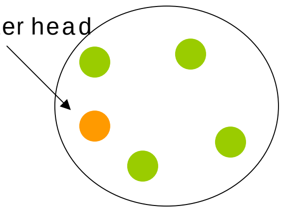
Consider, cluster A experienced more mobility and reduced frame time by 7%, where as cluster B and C reducing frame time by 4% and 3% respectively.

This would lead to inconsistent frame times in a schedule-based MAC leading to synchronization problems

Synchronization

A multi-hop Wireless Sensor Network

Cluster head

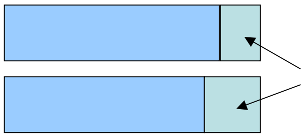


Virtual Cluster A

Base Station

Frame times would ONLY change during a "Global Synchronization Period" (GSP).

A GSP occurs before each LEACH-style round when cluster-heads are re-elected.



Random-access time

Each frame before the next GSP, the frame times in the network remain the same but the random-access-period of each cluster members would increase or decrease reflecting the mobility pattern

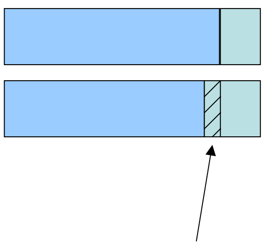
Synchronization

The frame times of all nodes would be the same at any given time in the entire network

If all two-hop neighbors of a node *A* belong to the same cluster then their random access time and scheduled access time would be the same

If a node *E* has two-hop neighbors belonging to more than one virtual cluster, then in the two-hop neighborhood of *E* the frame times would be the same but the scheduled-access and random-access times could be different

Such a node *E* should use the shortest scheduled access time and the shortest random access time out of the different ones in use.



Do NOT transmit anything during this time

Simulation Results

- Simulations performed in NS-2 with 'sensor networks' module by Wendi Heinzelman.
- Simulator uses "First Order Radio Model" for energy calculations:

Etransmit(k,d) = Eelectric * k + Eamplifier * k * d2
Ereceive(k) = Eelectric * k

k = k-bits per packet
d = distance

Comparison Protocol Set

- We performed a comparative study of MMAC with TRAMA, SMAC, and CSMA.
- As CSMA has no energy-saving mechanisms; it is included in the comparison protocol set as a 'worst case' protocol.
- TRAMA embodies schedule-based MAC protocols for sensor networks.
- The well-known SMAC protocol represents contention-based protocols.

Simulation parameters

• Transmission range of nodes = 100 meters

• Nodes are randomly deployed on a 500m x 500m plane

• Traffic is generated at a variable-rate

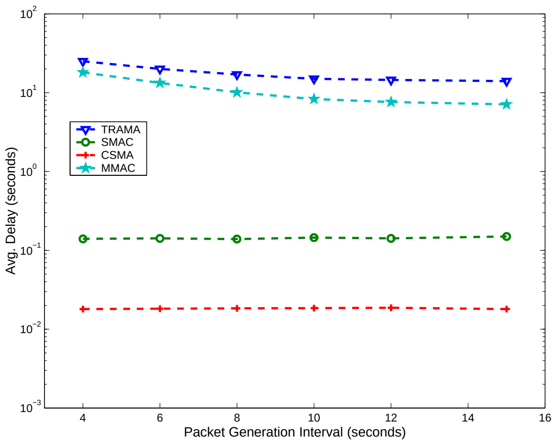
• In order to route a packet, at each hop the node simply forwards the packet to the node closer to the sink

• For SMAC, *SYNC_INTERVAL* = 10sec and *DUTY_CYCLE* is variable as either 10% or 50%

• For TRAMA and MMAC *SCHEDULE_INTERVAL* = 100 transmission slots

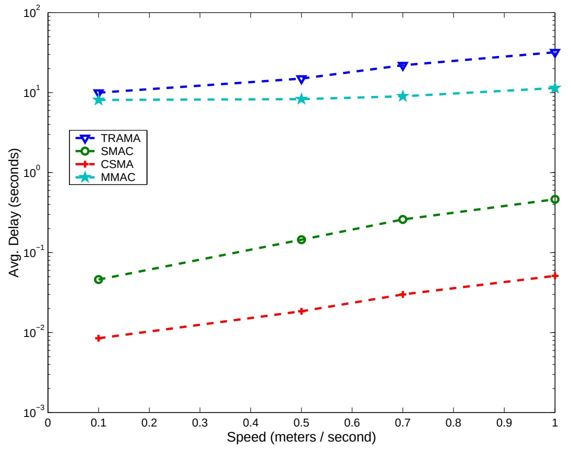
• Random access period is 72 transmission slots and is repeated every 10,000 transmission slots

Average Packet Delay



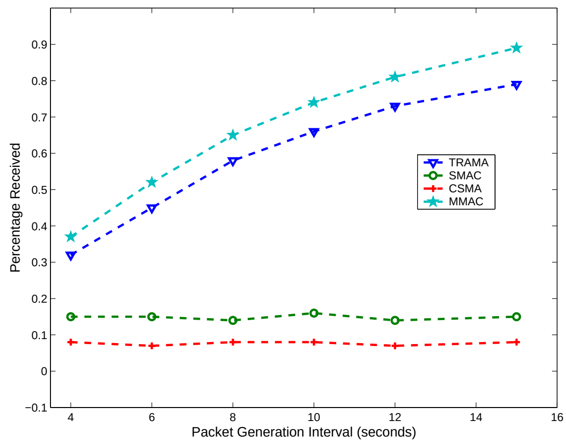
Average Packet Delay (Variable Traffic)

Average Packet Delay



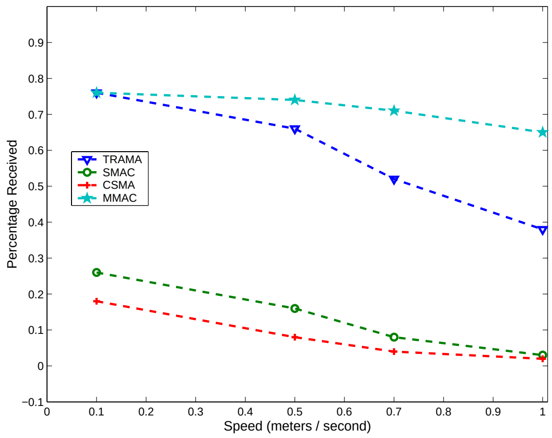
Average Packet Delay (increasing Mobility)

Packets Received



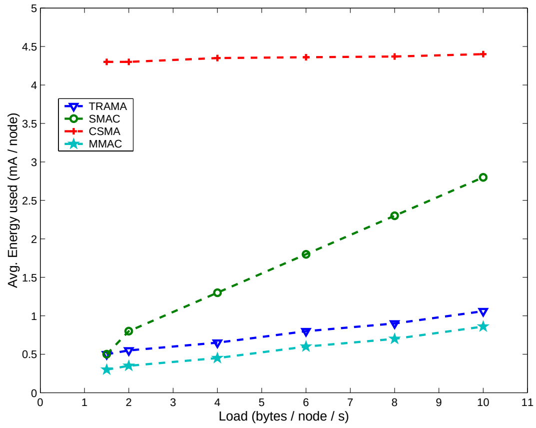
Percentage of Packets Received (Variable Traffic)

Packets Received



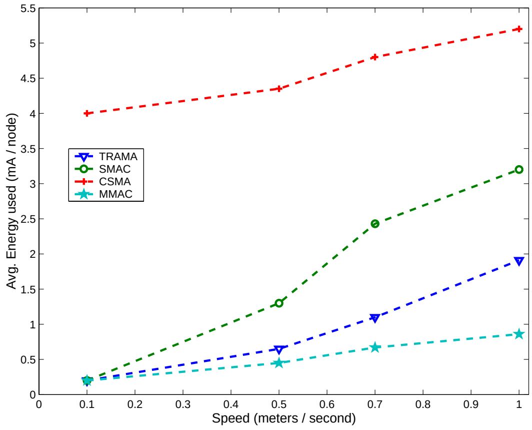
Percentage of Packets Received (increasing Mobility)

Energy consumed



Average Energy consumed per Node (Variable Traffic)

Energy consumed



Average Energy consumed per Node (increasing Mobility)

Conclusion

- Showed how current MAC protocols are not suited for "mobile" sensor networks
- Proposed a new schedule-based MAC protocol – MMAC
- MMAC adapts the frame-time, transmission slots, and random-access-slots according to mobility.
- Simulation results indicate that:
  1. MMAC performs parallel to current MAC protocols when there is little or no mobility
  2. In sensor networks with mobile nodes or high network dynamics, MMAC outperforms existing MAC protocols in terms of energy-efficiency, delay, and packet delivery

Further Information

Muneeb Ali, and Zartash Afzal Uzmi

{muneeb,zartash}@lums.edu.pk

http://suraj.lums.edu.pk/~muneeb

Thank You !