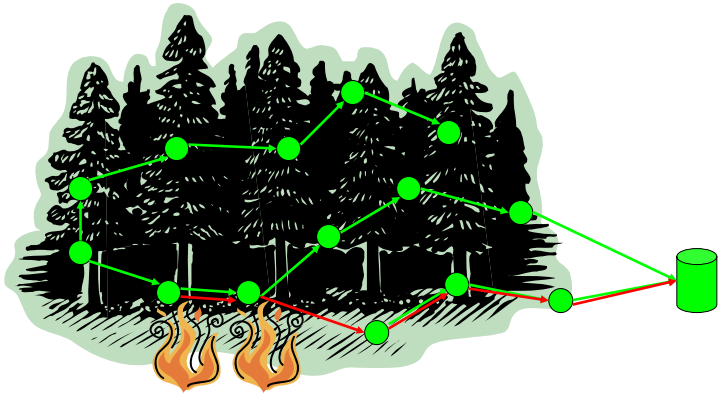
Real-time Communications over Wireless Sensor Networks

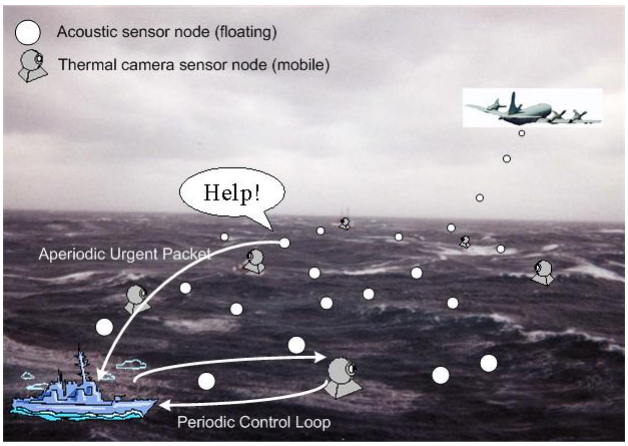
Instructor: Chang-Gun Lee

Forest Monitoring Sensor Networks



- Periodic monitoring of forest
- Fast delivery of emergency event

Rescue Supporting Sensor Networks

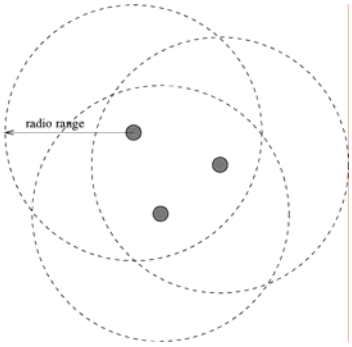


Periodic messages →message delivery meeting deadlines
Aperiodic messages →message delivery ASAP

Wireless Sensor Networks

- Delivering sensory data to the sink in time is important
- Most existing wireless protocols make the underlying assumption that the network traffic is intrinsically random and work in a contention-based way
  - No-deterministic guarantee of message delivery

CSMA/CA MAC Protocol (802.11)



Problems
1. Random arbitration: collisions → waste of channel
2. No overload prevention: Miss all deadlines

Can Real-Time Techniques solve the problems?

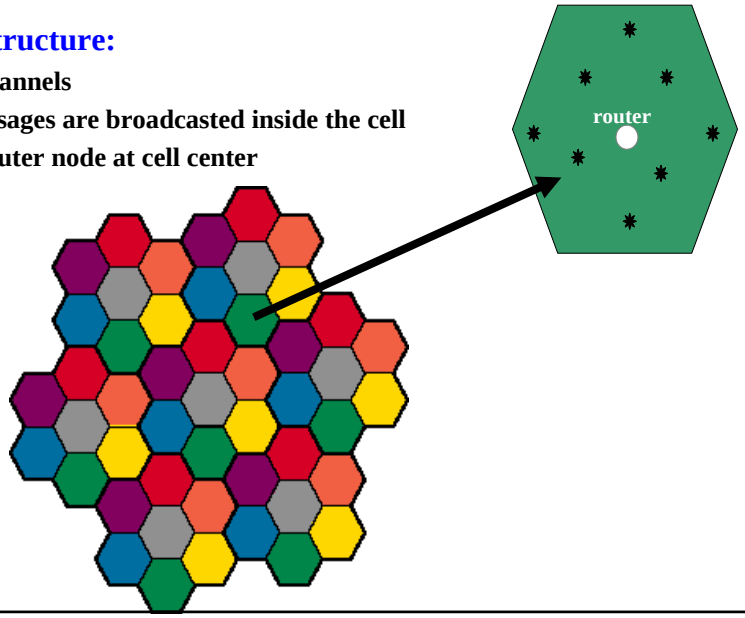
I-EDF

- Motivation: Can we leverage on the "Periodic" nature of sensor messages?
  - Collision-free deterministic MAC protocol
- Ideas
  - Cellular Architecture
  - Implicit EDF for collision free scheduling
  - Frame reclaiming of unused reserved slots for serving Aperiodic messages ASAP

Network Architecture

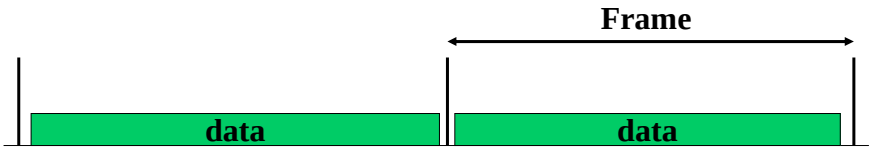
Cell structure:

- **7 channels**
- **messages are broadcasted inside the cell**
- **a router node at cell center**



Intra-cell broadcast

- Medium Access for intra-cell communication
- Time is divided into synchronized frames



- Inside each cell, nodes use *implicit contention*:
  - Periodic nature of sensor data streams, once initialized, allows for EDF scheduling via implicit contention
  - no contention phase, no conflicts, no backoff

Implicit prioritized medium access using EDF

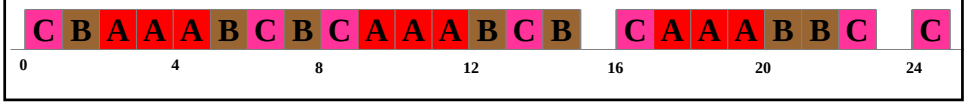
- Distributed scheduling
- The EDF scheduler is replicated to each cell node

node	message size (frames)	period (frames)
A	3	8
B	1	6
	1	8
C	1	4

This table is stored in each node of one cell

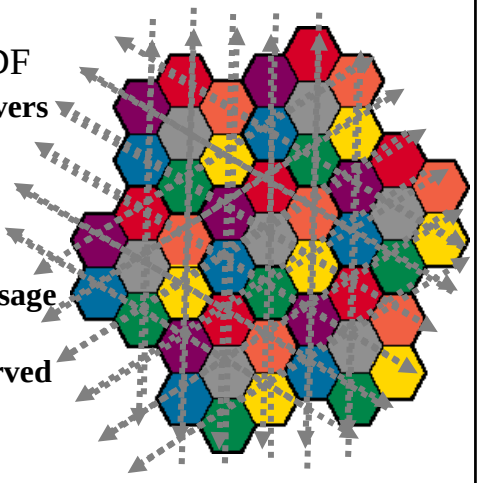
$$\sum_i \frac{MsgSize_i}{period_i} = \frac{3}{8} + \frac{1}{6} + \frac{1}{8} + \frac{1}{4} \leq 1$$

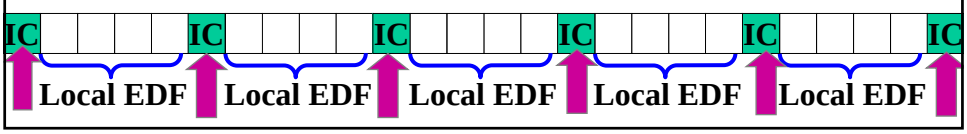
Message set is schedulable!



Mechanism for inter-cell communication

- Inter-cell communication mechanism uses TDM+EDF
  - **routers have two transceivers (used at the same time on different channels)**
  - **sender uses its own cell frequency**
  - **each router sends the message with earliest deadline**
  - **Inter-cell frames are reserved**
  - **blocking term in local schedulability analysis**



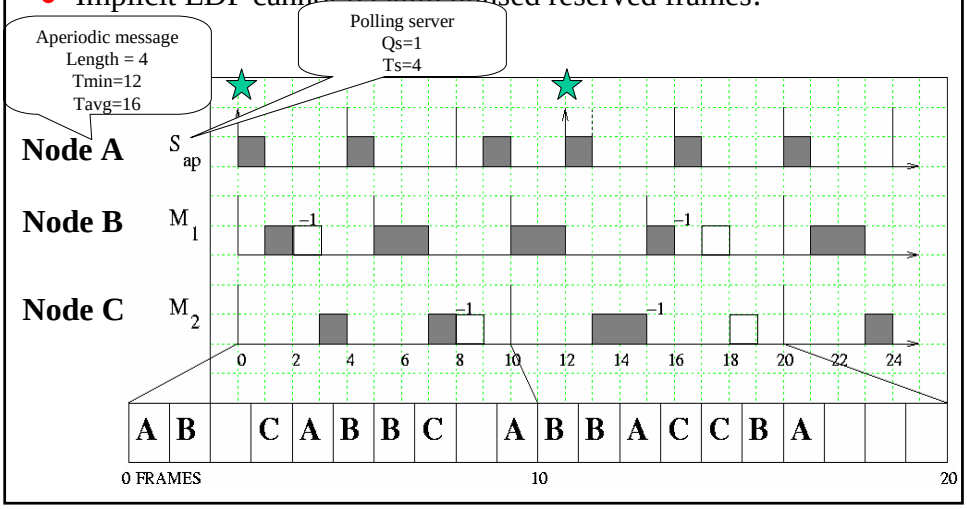


How to send aperidic messages?

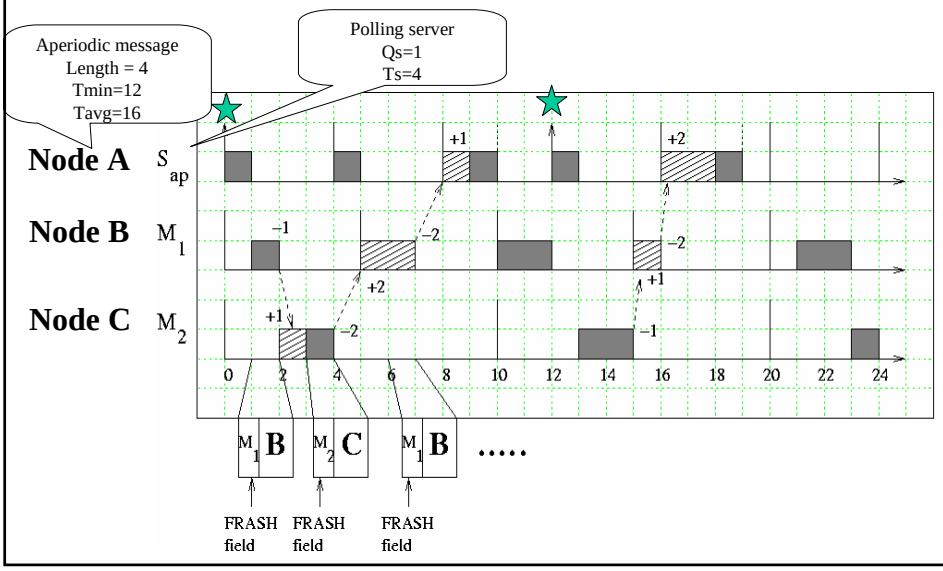
- Use an aperiodic server
  - **Polling server**
  - **CUS (Constant utilization server)**
  - **TBS (Total bandwidth server)**
  - **CBS (Constant bandwidth server)**

Problems with implicit EDF

- **<u>Implicit EDF drawback</u>** ➔ if a message finishes earlier, the unused reserved frames are wasted
- Implicit EDF cannot reclaim unused reserved frames!

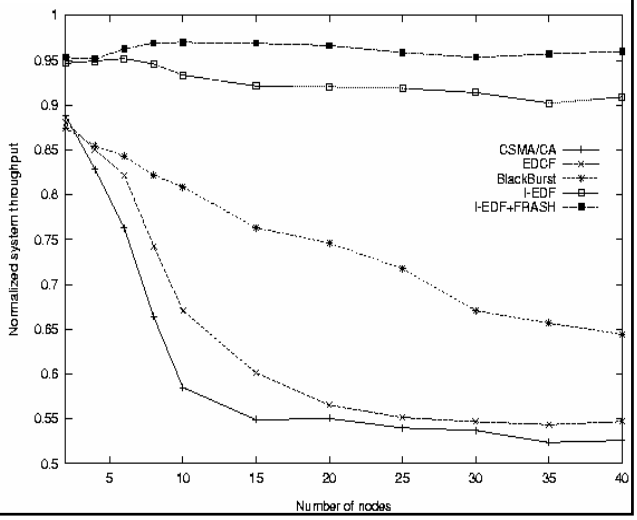


FRASH (FRAme Sharing) Algorithm



Experimental results

- A set of experiments was run in the ns-2 network simulator: IEDF and IEDF+FRASH schemes have been compared with Black-Burst, Enhanced DCF and CSMA/CA.

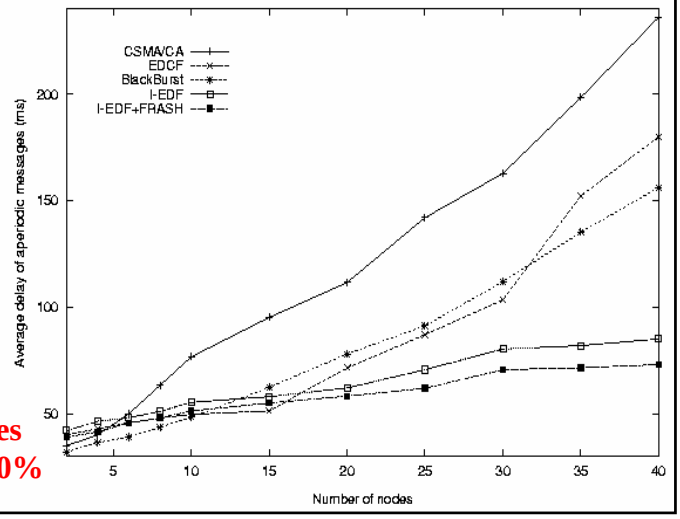


Normalized system throughput with offered load = 90%

Experimental results

- Implicit EDF (I-EDF) and I-EDF with FRASH provide higher system throughput and lower latency under heavy load condition and in dense networks.

Avg. delay of aperiodic messages with offered load = 90%

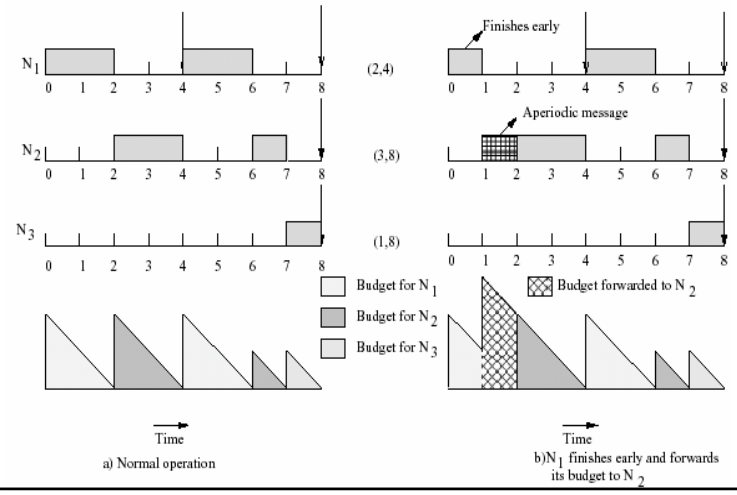


Problem of I-EDF?

- All nodes need to be synchronized!
- Distributed Synchronization is an expensive job
- Any idea?
  - Build I-EDF schedule
  - But, chained triggering of the next execution (not by time-triggering)
  - → RI-EDF (Robust Implicit EDF)

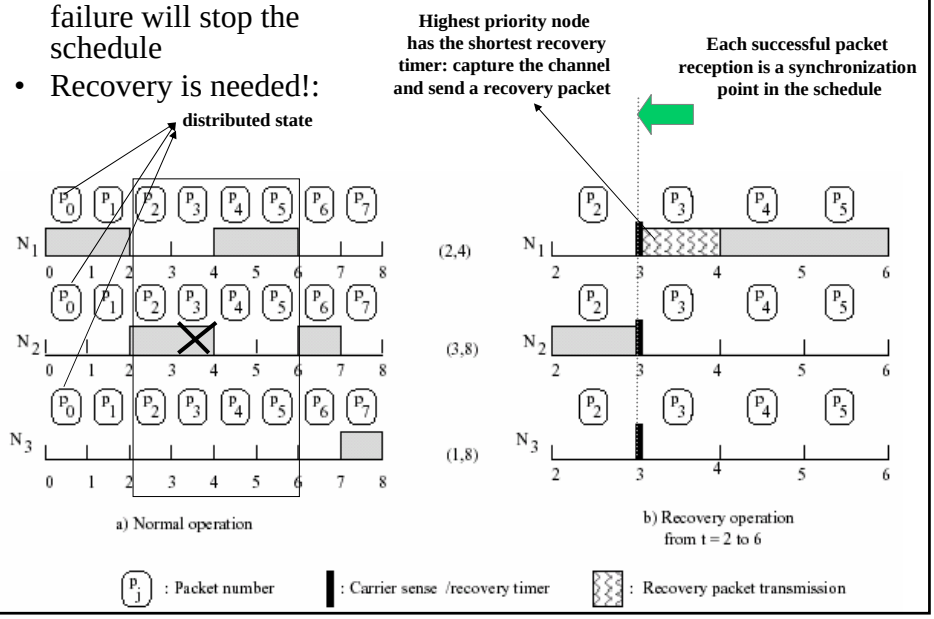
How RI-EDF works?

- Due to the lack of clock synchronization, each node is triggered by the reception of previous message.
- If a message completes earlier than the reserved budget, the left-over budget is forwarded



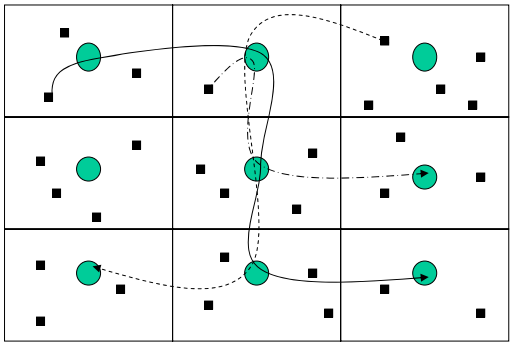
Any problem?

- Packet loss or node failure will stop the schedule
- Recovery is needed!:



Any further problem?

- End-to-end deadline guarantee?
- We have to solve a combined problem of scheduling and routing



Summary

- Wireless sensor networks introduce new challenges not addressed by classical ad hoc networks literature
- A scheduling based MAC protocol has been introduced to guarantee bounded message delay
- **Key Finding**
  - Similarity of job scheduling on CPU and packet scheduling on wireless shared medium
  - So, we can reuse real-time job scheduling techniques
- References
  - Marco Caccamo, L. Zhang, L. Sha, and G. Buttazzo, An Implicit Prioritized Access Protocol for Wireless Sensor Networks, RTSS 2002
  - T. L. Crenshaw, A. Tirumala, S. Hoke, and M. Caccamo, A Robust Implicit Access Protocol for Real-Time Wireless Collaboration, Euromicro Conference on Real-Time Systems, 2005