An Implicit Prioritized Access Protocol for Wireless Sensor Networks

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Outline

- Real-time scheduling overview
- EDF Scheduling
- MAC using Implicit EDF
- Implicit EDF with FRASH
- Experimental evaluation

Real-time systems 101

- Time-bound on execution of tasks
- Hard real-time
  - Guaranteed response time
  - Need **proof** that the time constraints are met
  - Aircraft safety controls, Missile systems
- Soft real-time
  - Execution may not be guaranteed
  - Statistical distribution of response time acceptable
  - Online transaction systems, telephone switches, electronic games
- Periodic vs Aperiodic tasks

Real Time Scheduling Overview

- "Scheduling Algorithms for Multiprogramming in a Hard-Real-Time Environment", Journal of the ACM,1973 C.L. Liu & J.W. Layland
- Controlling access to a shared resource
  - CPU, I/O resources, network resources
- Scheduling Disciplines
  - Earliest Deadline First
  - Rate Monotonic Scheduling
  - Maximum Urgency First
  - Minimum Laxity First

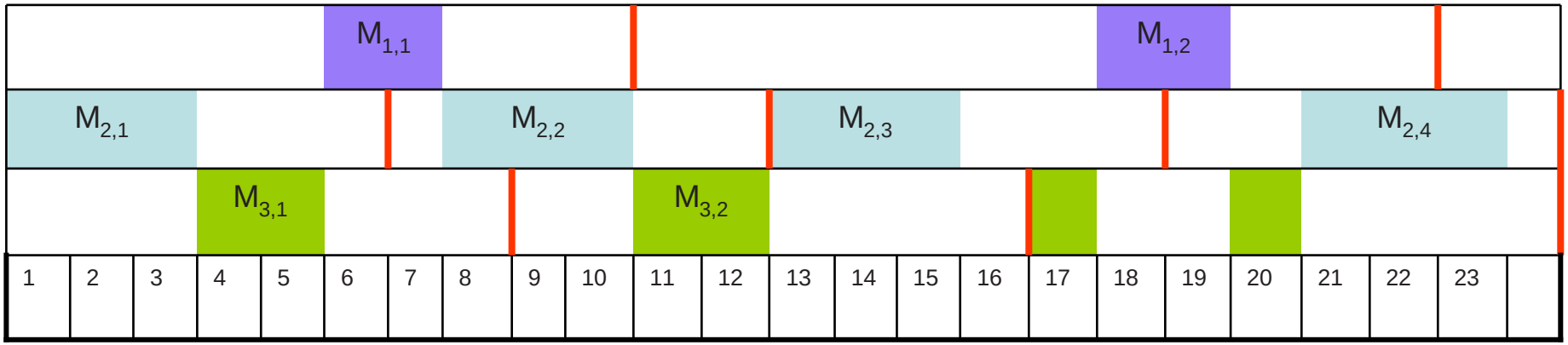
Terminology & Notations

- Task (M_i)
  - Executable entity
- Job ($M_{i,j}$)
  - Instance of a task
- Release time
  - Time at which a task becomes ready to run and a job is released
- Period (T_i)
  - Time between releases of two instances of the same task
- Deadline ($D_{i,j}$)
  - Relative time at which a job should complete execution
- Execution Time / Run Time (m_i)
  - time taken to complete execution without interruption
- Frame
  - Discrete unit of time

EDF Scheduling

Job with earliest deadline chosen for execution

M_i	T_i	m_i
M_1	5	2
M_2	6	3
M_3	8	2



Aperiodic task scheduling

- Wrap aperiodic tasks as periodic tasks
- Polling Server
  - Periodic server which does polling for aperiodic events
  - At the beginning of each period, the budget is recharged at its maximum value, capacity Q_s
  - Budget is consumed during job execution
  - When the server becomes active and there are no pending jobs, deactivates itself until next period
  - New job will wait until next activation
  - When the server becomes active and there are pending jobs, they are served until budget = 0.

Schedulability

- Schedule feasible if and only if
  - $(m_1/T_1) + (m_2/T_2) + \ldots + (m_n/T_n) \leq 1$
    [Liu and Layland]
  - Utilization <= 100%
- With aperiodic tasks
  - Polling server considered a periodic task
  - Need to consider the capacity of the polling server also – Q_s/T_s

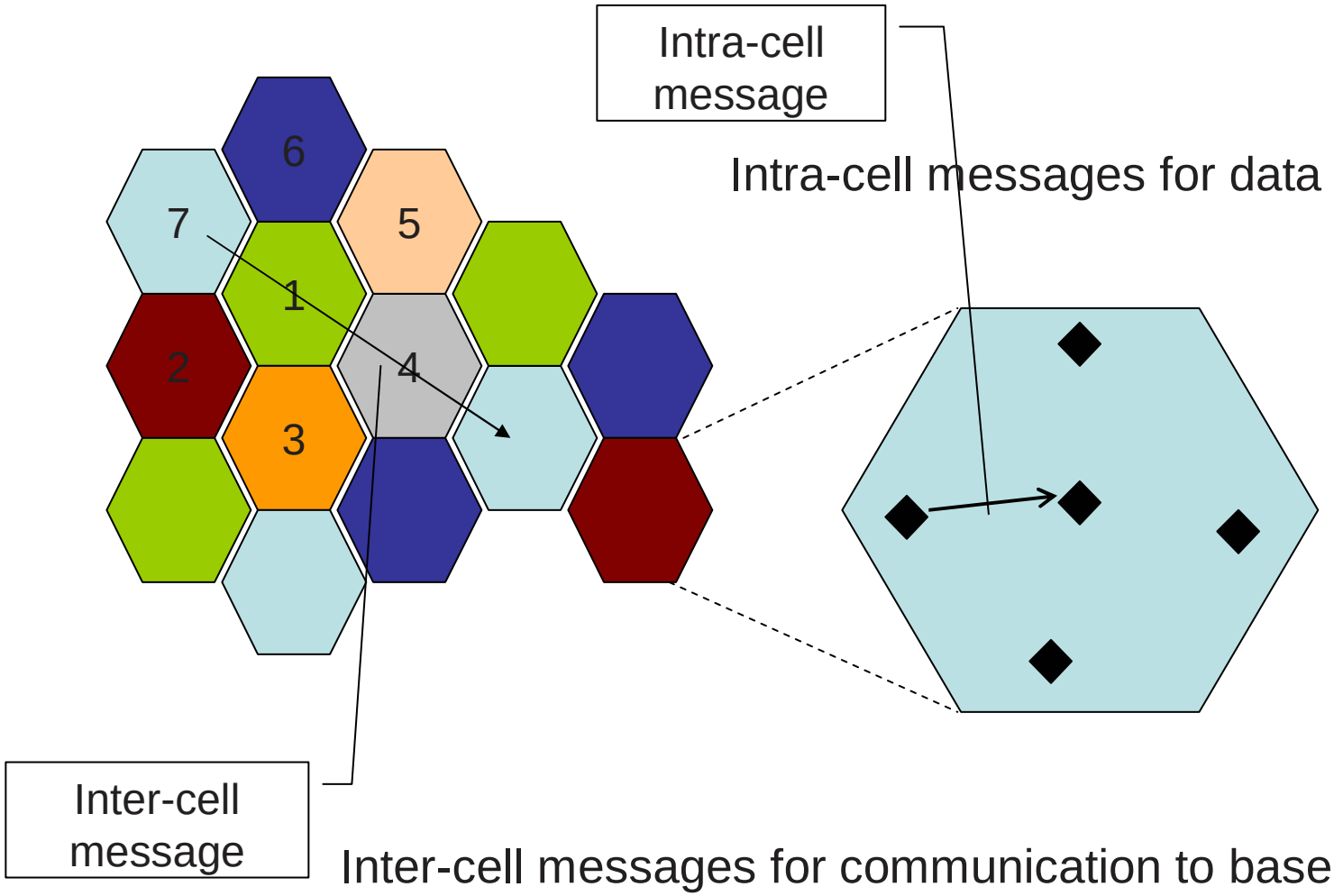
MAC in sensor networks

- Contention for the shared wireless channel
- RTS/CTS variations
- CSMA/CA
- MACA
- MACAW

Assumptions

- Sensor networks
  - have mainly periodic traffic
  - use wireless multi-hop communication
  - are topologically static and tracks moving targets

Cellular Network architecture



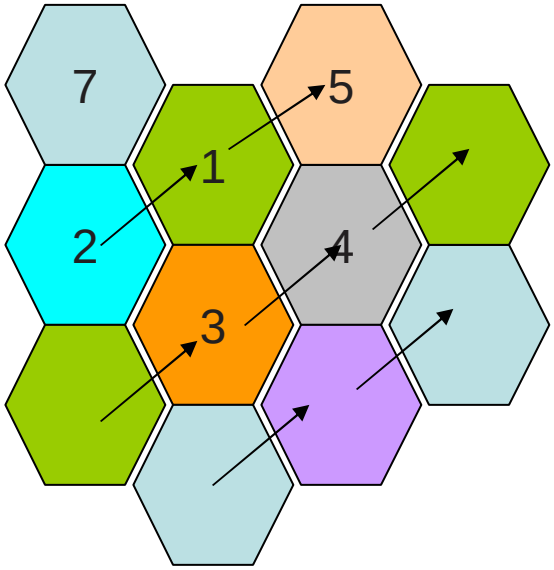
MAC using EDF

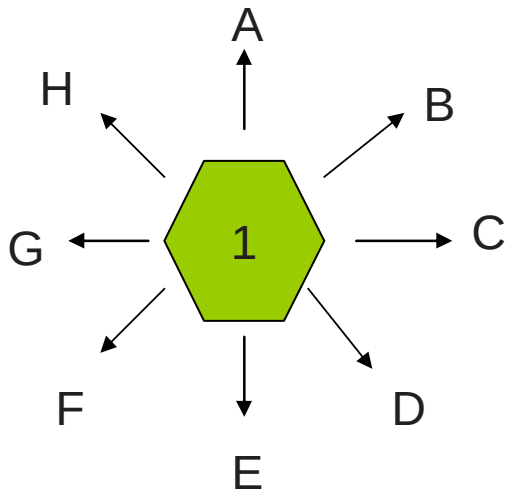
- Intra-cell messages scheduled based on EDF
- Replicate EDF schedule of message transmissions at each node
- Message selection at every node based on message deadline
- Implicit contention resolution
- Frame sharing by aperiodic tasks
- Periodic transmission of inter-cell messages

Message Ordering

- Total ordering of messages within a node
  - Based on deadline
  - Ties resolved using rank of sender node
  - same sender, same deadline messages resolved based on message rank

Inter-cell messages

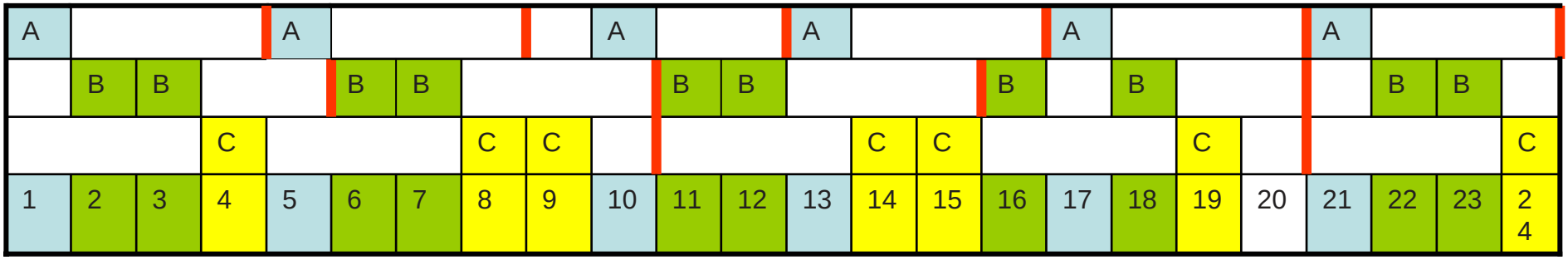




A	intra-cell	B	intra-cell	C	intra-cell	D	intra-cell

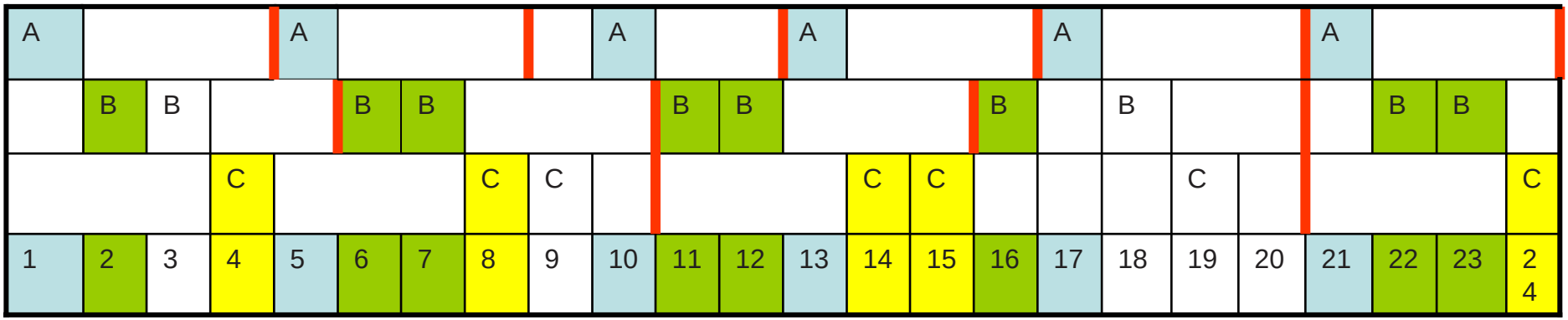
I-EDF - Example

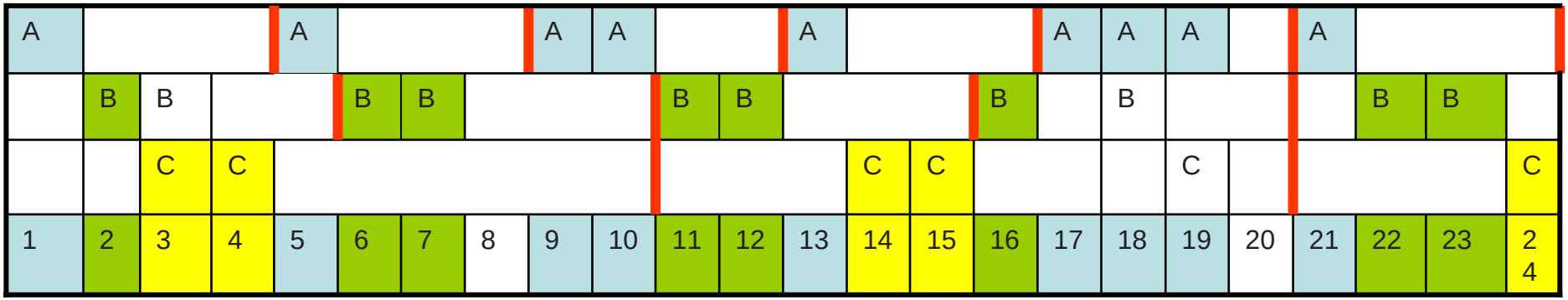
M_i	T_i	m_i	N_i
M_{ap}	4	1	A
M_2	5	2	B
10	10	3	C



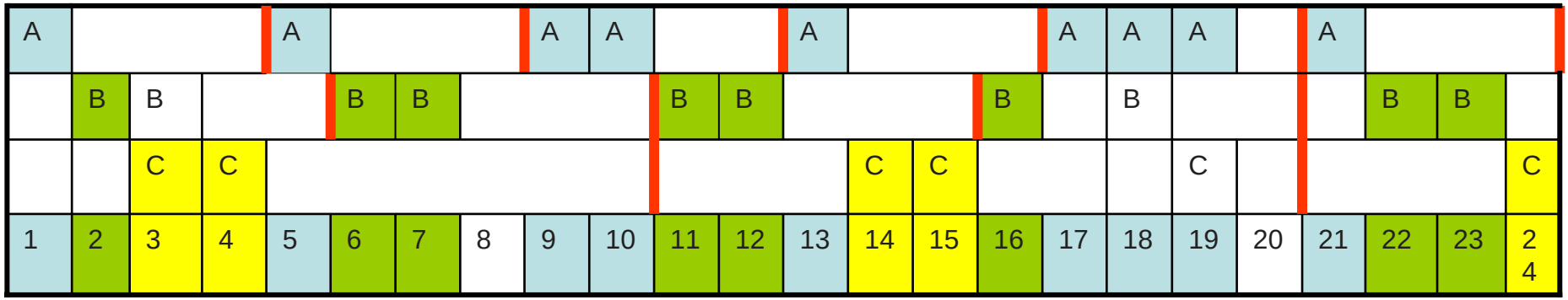
I-EDF with FRASH

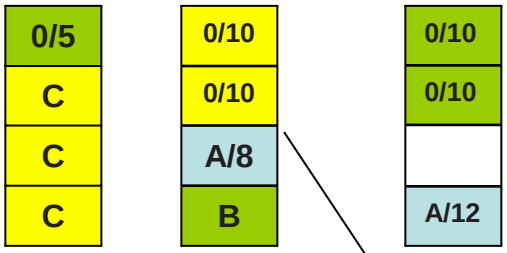
Frames released pre-maturely





Free frames usage

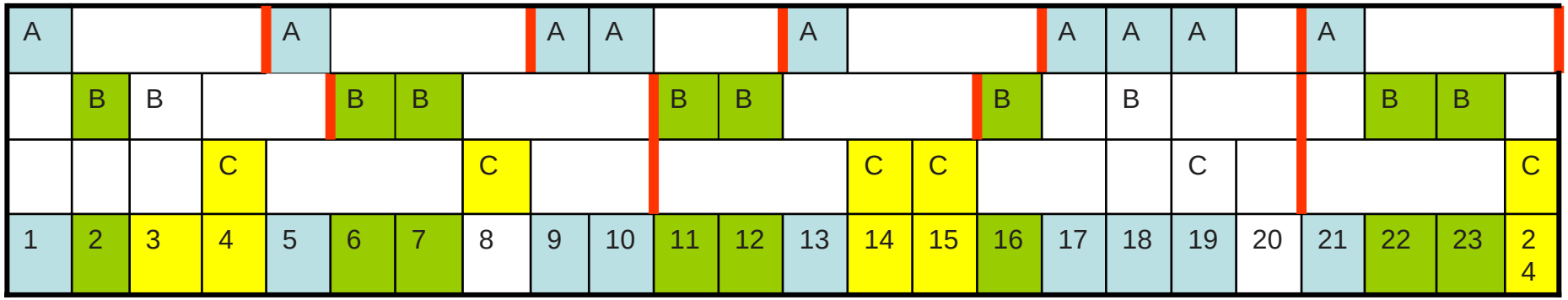


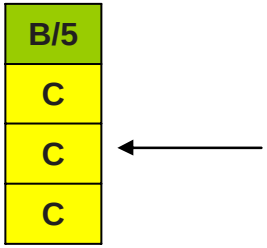


A won't be be able to use the null frames because of its earlier deadline

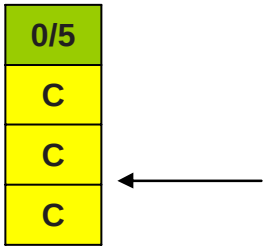
Packet loss

C does not get transmission by B during frame #2





Ready queue at C at the end of frame #2



Ready queue at A and B at the end of frame #2

Theoretical validation

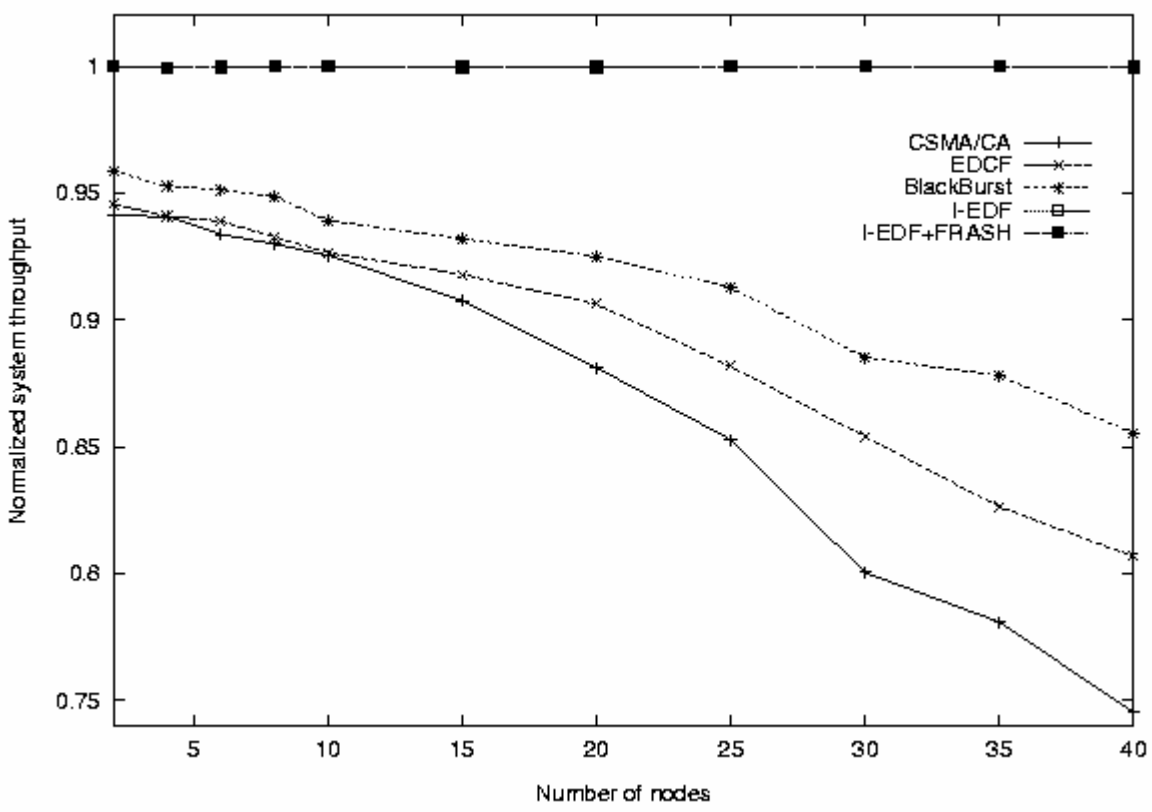
- Schedulability condition

$$\sum_{i=1}^{n} \frac{m_i}{T_i} + \sum_{j=1}^{s} \frac{Q_j}{T_j} \leq 1$$

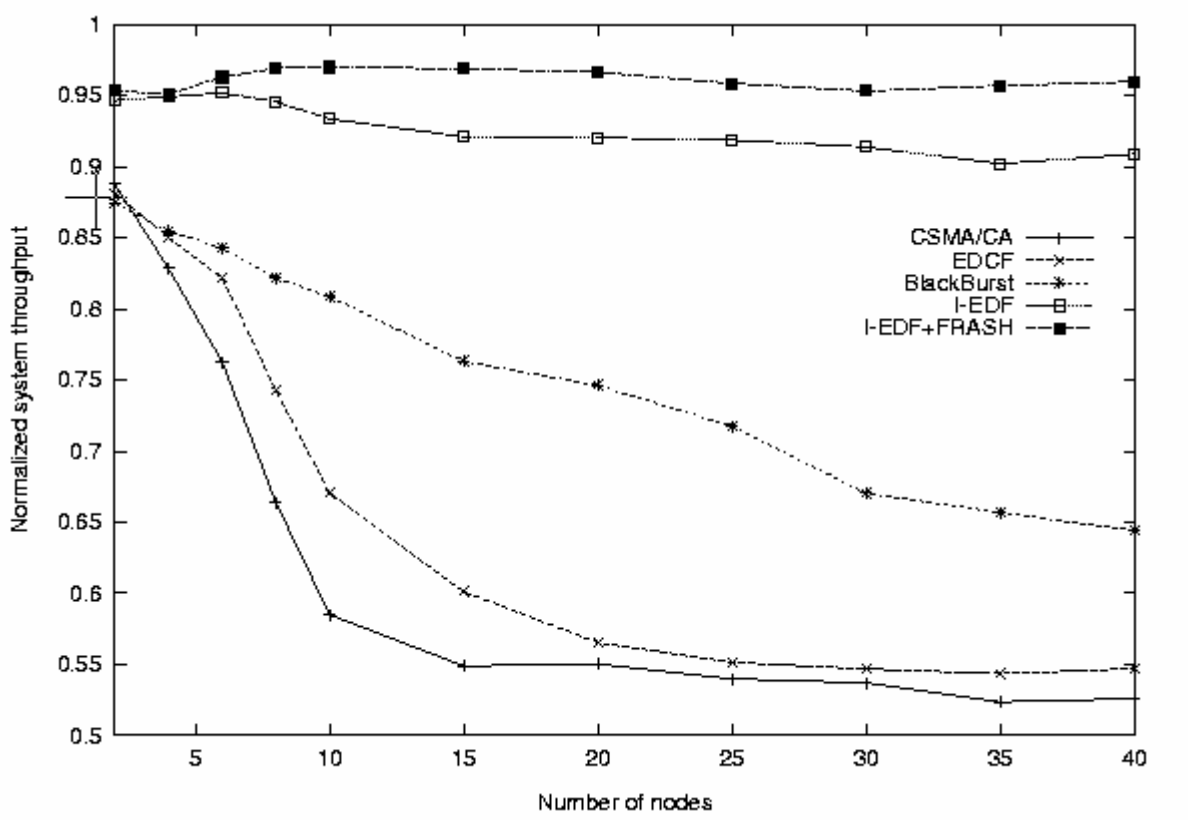
n – Number of periodic messages
s – Number of aperiodic servers
Q_j – Capacity of jth aperiodic server

Experimental Setup

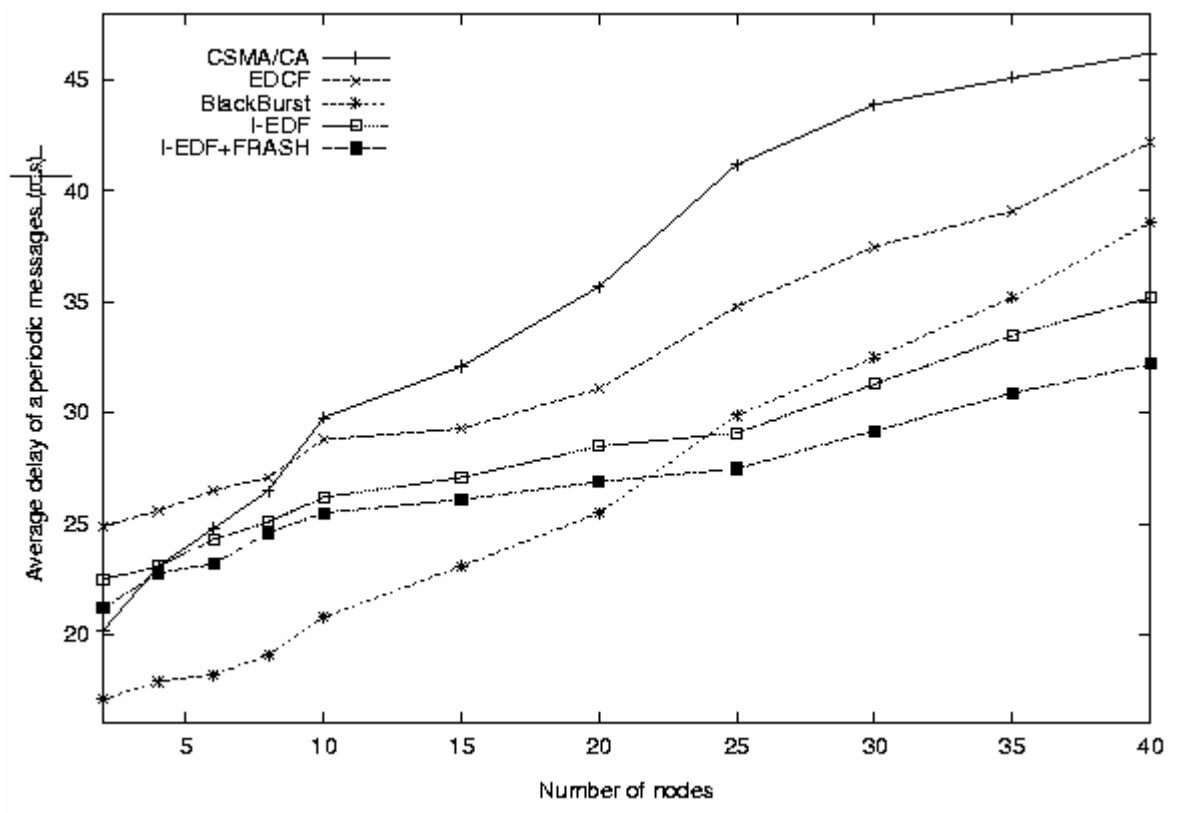
- ns-2 simulator extended with I-EDF and I-EDF with FRASH
- Wireless channel assumed to be ideal – no packet loss due to distortion, noise, etc
- Static nodes in a 200m x 200m area
- Periodic traffic using VBR messages
- Polling server used to handle aperiodic messages
- Metrics:
  - System throughput
  - Average response time for aperiodic messages



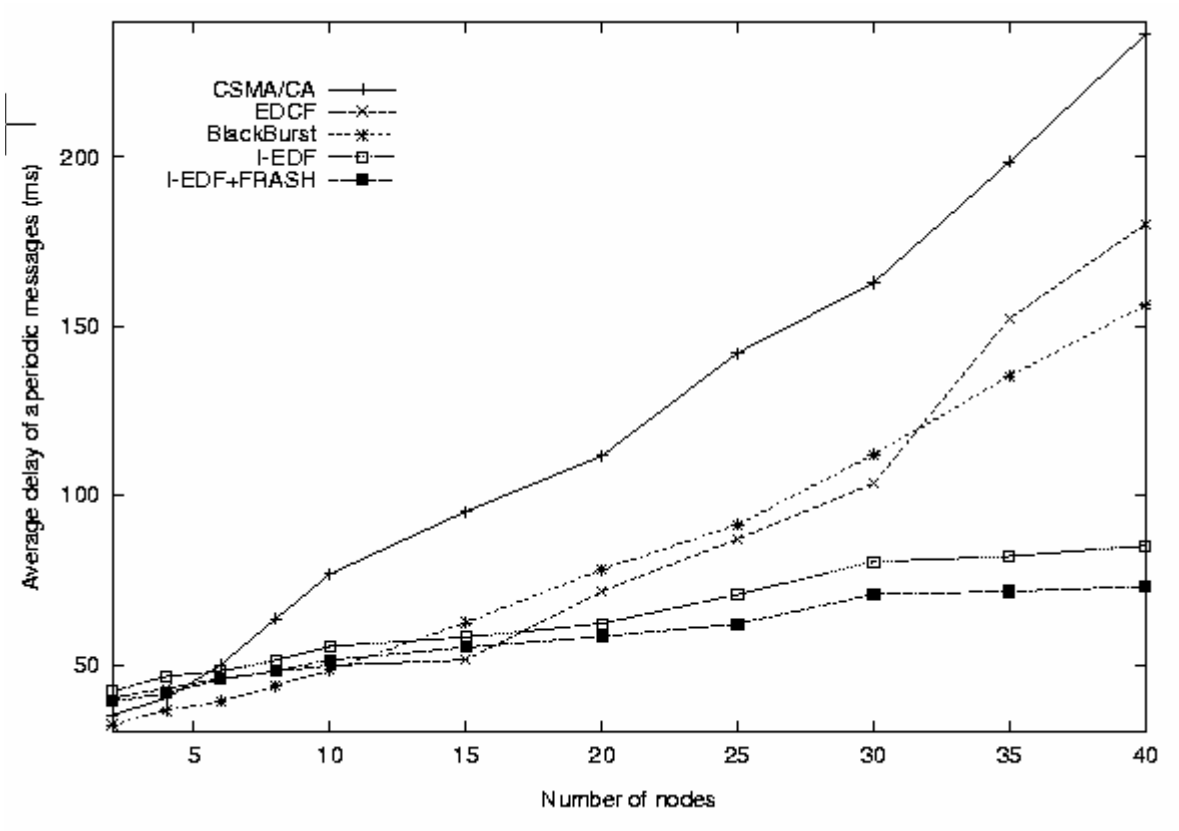
Normalized system throughput with offered load = 65%



Normalized system throughput with offered load = 90%



Avg. delay of aperiodic messages with offered load = 65%



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

Comparision

MACA	MACAW	I-EDF
		No control packets