# CORD: Energy-efficient Reliable Bulk Data Dissemination in Sensor Networks

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# Outline

- Introduction
- Related work
- CORD design
- Protocol evaluation
- Conclusion

# INTRODUCTION

- Reprogramming problem?
  - Updating their software.
- Reliable bulk data dissemination protocol
  1. These protocols is that the data object is propagated from the sink to the rest of the network in a neighborhood by neighborhood fashion.

     Ex : Deluge,MNP,MOAP

# INTRODUCTION

2. In contrast, in the second category of protocols is divided into two distinct phases.
   - First phase : object is reliably propagated from the sink to the core nodes.
   - Second phase :core nodes disseminate the object to their neighboring non-core nodes in parallel.

   Ex : CORD , Sprinker

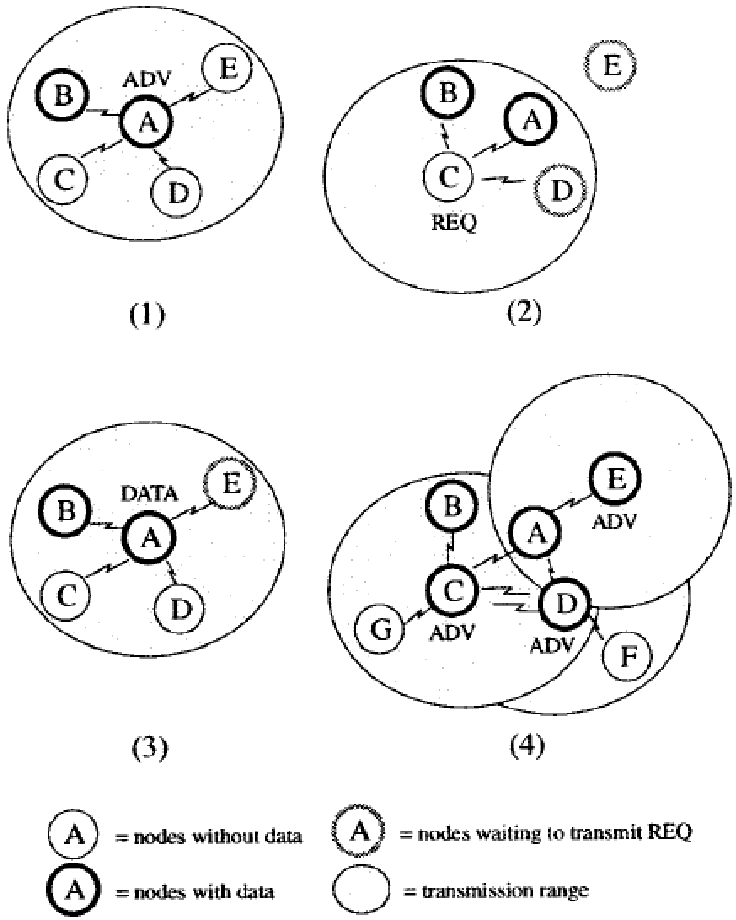
# INTRODUCTION

- CORD (COre based Reliable Dissemination)
  - Construct a core for data dissemination.
  - Core node and non-core node.
  - Two-phase core-based approach.
  - Use coordinated sleep schedule to reduce energy consumption.
- CORD contribution
  - Combine sleep schedule with two-phase approach
  - In experiment ,the energy consumption of CORD is 30-60% of that of Deluge.

# RELATED WORK

- *Data Dissemination in Sensor Networks*
  - The protocols were developed for supporting network reprogramming in multi-hop networks
  - SPIN (Sensor Protocols for Information via Negotiation) for three-phase handshaking
  - Deluge and MNP compare MOAP
  - Deluge compare MNP
- *Connected Dominating Set (CDS)*
  - Subset of nodes in a network are selected as a backbone for routing, or as cluster-heads for data aggregation and forwarding.
  - CORD adapts Cheng's single leader algorithm

# RELATED WORK

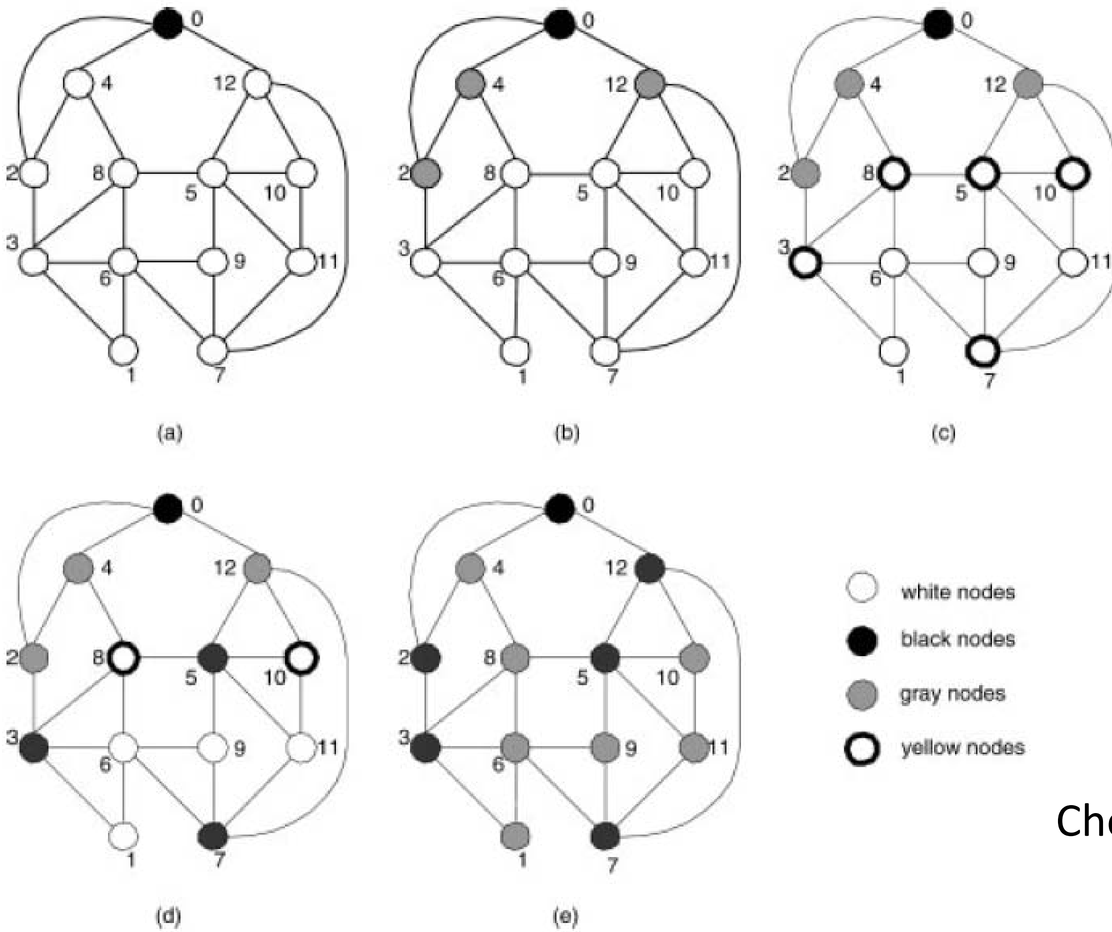



*SPIN-BC: A three-stage handshake protocol for broadcast media*

# CORD DESIGN

- *Core Construction*
  - Cheng’s algorithm
  - Link Quality
    - Two nodes are considered connected only when the link quality between them is above a threshold, $Q_{th}$.
    - Link Quality Indicator (LQI) as a metric of the link quality
  - *Establishing Coordinated Schedules*
    - modified Cheng’s algorithm to integrate core construction with the establishment of coordinated node schedules.

# CORD DESIGN




Cheng's algorithm

# CORD DESIGN

- *Establishing Coordinated Schedules*
  - The sink initiates core construction by starting the schedule and sending a CLAIM message.
  - Nodes  that receive the CLAIM message update their effective degrees.
  - If a node has a good link ,it selects sink as its parent and initiates its own repeating schedule. Then broadcast COMPETE message.
  - Node responds with a SUBSCRIBE message to the competitor.
  - A node that receives SUBSCRIBE messages become a core node, otherwise it becomes a non-core node.

# CORD DESIGN

- *Coordinated Node Sleep Scheduling*
  - In protocols ,we use a pipelined data dissemination approach.
    - nodes that transmit data simultaneously should be at least three hops apart to ensure that transfers of different pages do not interfere with each other.

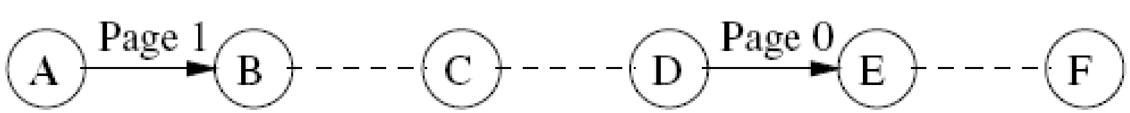



Fig. 1. Pipelined data dissemination

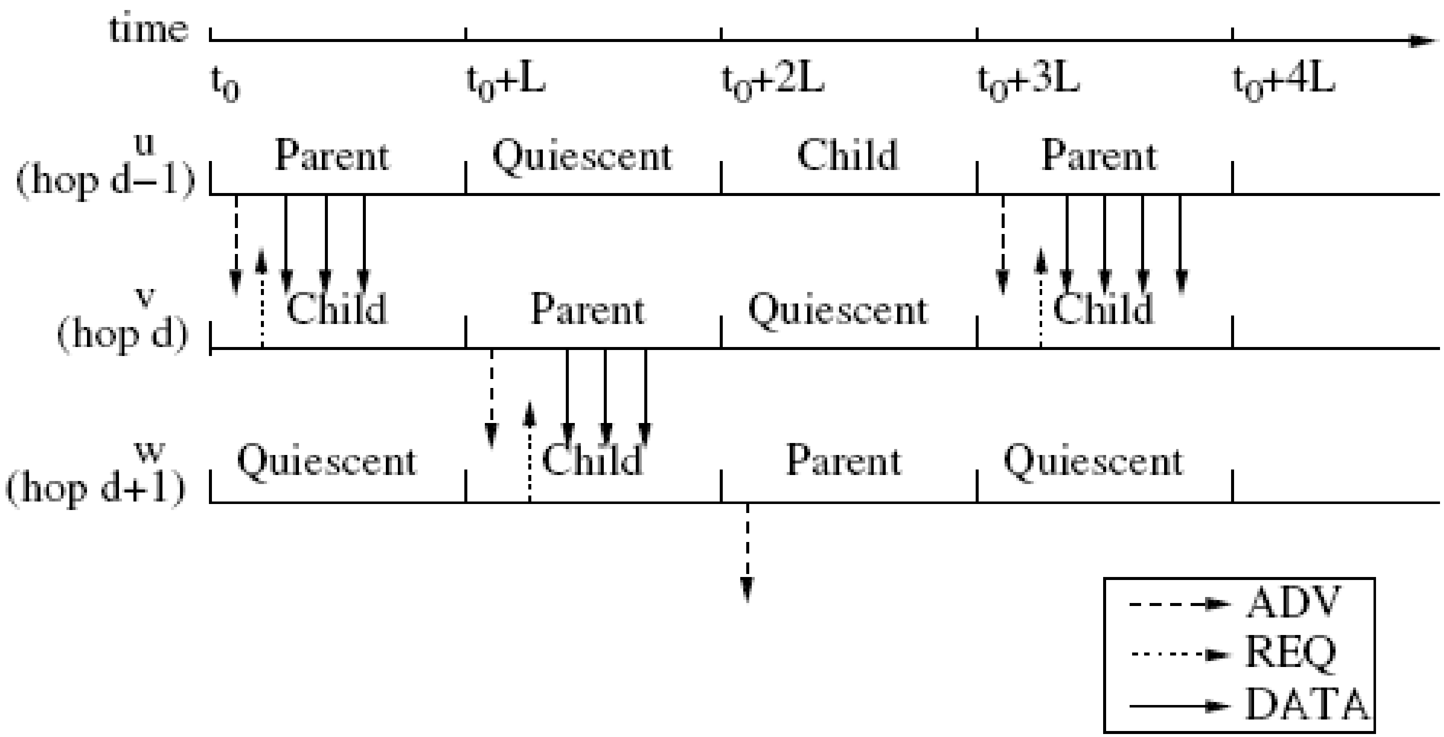
# CORD DESIGN

- *Coordinated Node Sleep Scheduling*
  - We refer to these consecutive slots in a node's schedule
    - P-slot : parent slot
    - C-slot : child slot
    - Q-Slot : quiescent slot
  - Different schedule in different nodes.
    - Core node: C-P-Q schedule
    - Non-core node: C-Q-Q schedule

# CORD DESIGN

- *Coordinated Node Sleep Scheduling*
  - Each node synchronizes the boundaries of its time slots with its parent in the core at the time of core construction.
  - A node's C-slot coincides with the P-slot of its parent in the core.
  - The sink marks its first slot as a P-slot . Nodes that receive advertisements or data from their parents assign the current slot to be a C-slot.

# CORD DESIGN


time
t0
t0+L
t0+2L
t0+3L
t0+4L
u
(hop d–1)
Parent
Quiescent
Child
Parent
v
(hop d)
Child
Parent
Quiescent
Child
w
(hop d+1)
Quiescent
Child
Parent
Quiescent
ADV
REQ
DATA

# CORD DESIGN

- *Two-phase Data Dissemination*
  - In the first phase:
    - pages of the object are propagated through the core in a pipelined fashion.
    - The non-core nodes passively participate by listening to communications between core nodes.
  - In the second phase:
    - non-core nodes make requests to their local core nodes for missing data packets

# PROTOCOL EVALUATION

- CORD using the nesC programming language on the TinyOS platform.
- *Evaluation Metrics & Methodology*
  - Use table I to compare the energy consumption.

| | |
|---|---|
| CPU current in active state | 1.8mA |
| CPU current in sleep state | 5.1uA |
| Radio current in receive state | 23mA |
| Radio current in transmit state | 21mA |
| Radio current in sleep state | 1uA |
| External EEPROM current in write state | 20mA |
| External EEPROM current in read state | 4mA |
| External EEPROM current in sleep state | 2uA |

TABLE I
TELOSB CURRENT SPECIFICATION

# PROTOCOL EVALUATION

- *Testbed Description and Results*
  - Indoor
  - Outdoor

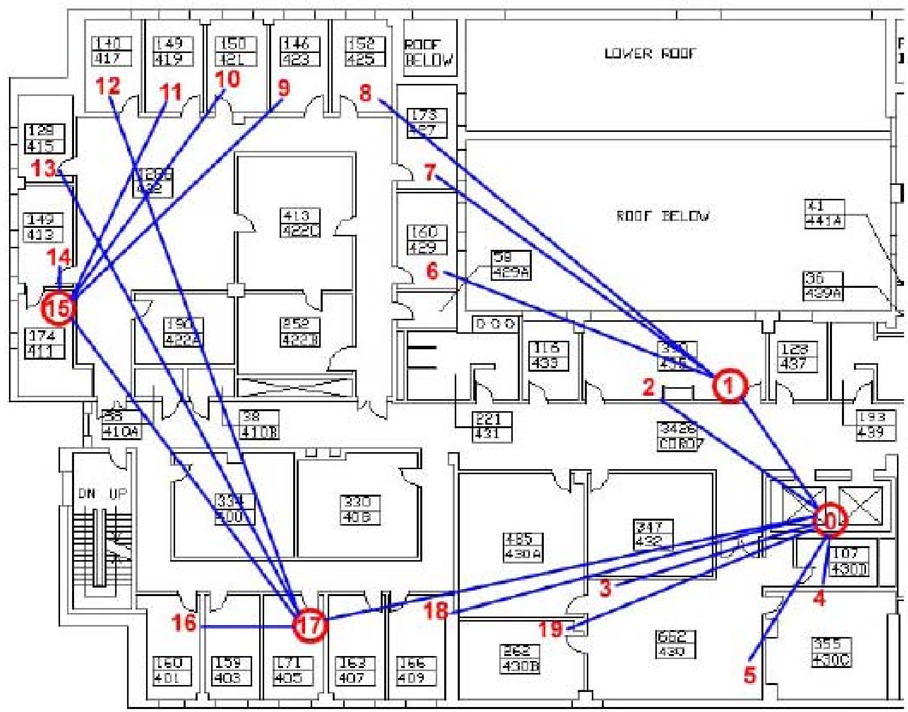


Fig. 3. Indoor TelosB network testbed including the core structure from one experiment (nodes in circles are core nodes)

# PROTOCOL EVALUATION

- *Testbed Description and Results*

| | Latency (sec) | Node Uptime (sec) | Number Packet Transmissions | Node Energy(mAh) |
|---|---|---|---|---|
| CORD | $243 \pm 14.7$ | $76.3 \pm 5.55$ | $261 \pm 32.6$ | 0.52 |
| Deluge | $226 \pm 17.3$ | $226 \pm 17.3$ | $331 \pm 21.5$ | 1.56 |

TABLE II
AVERAGE OBJECT DELIVERY LATENCY AND ENERGY EXPENDITURE PER NODE FOR INDOOR EXPERIMENTS (CONFIDENCE INTERVALS ARE SHOWN WITH 90% CONFIDENCE LEVEL)

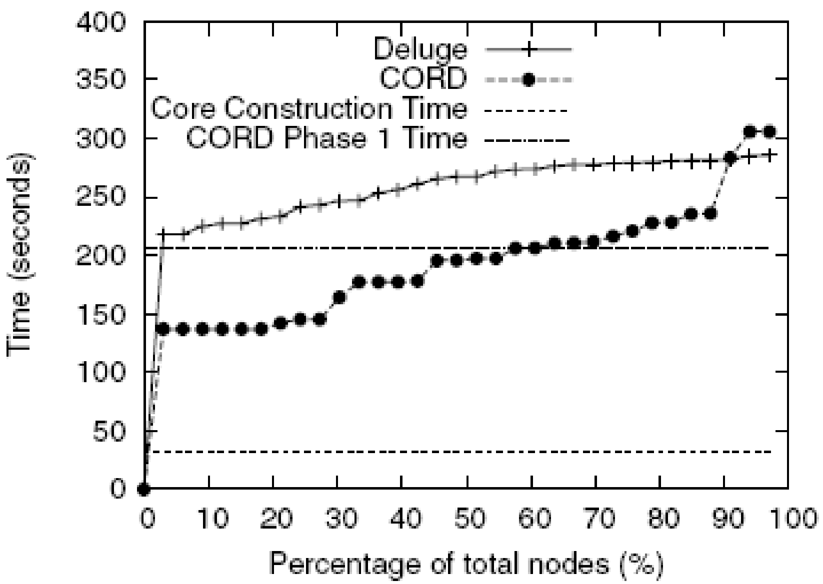
# PROTOCOL EVALUATION

- *Testbed Description and Results*

| | Latency (sec) | Node Uptime (sec) | Number Packet Transmissions | Node Energy(mAh) |
|---|---|---|---|---|
| CORD | $301 \pm 10.0$ | $95.9 \pm 5.56$ | $398 \pm 78.7$ | 0.66 |
| Deluge | $313 \pm 10.1$ | $313 \pm 10.1$ | $483 \pm 5.91$ | 2.15 |

TABLE III
AVERAGE OBJECT DELIVERY LATENCY AND ENERGY EXPENDITURE PER NODE FOR OUTDOOR EXPERIMENTS (CONFIDENCE INTERVALS ARE SHOWN WITH 90% CONFIDENCE LEVEL)

# PROTOCOL EVALUATION



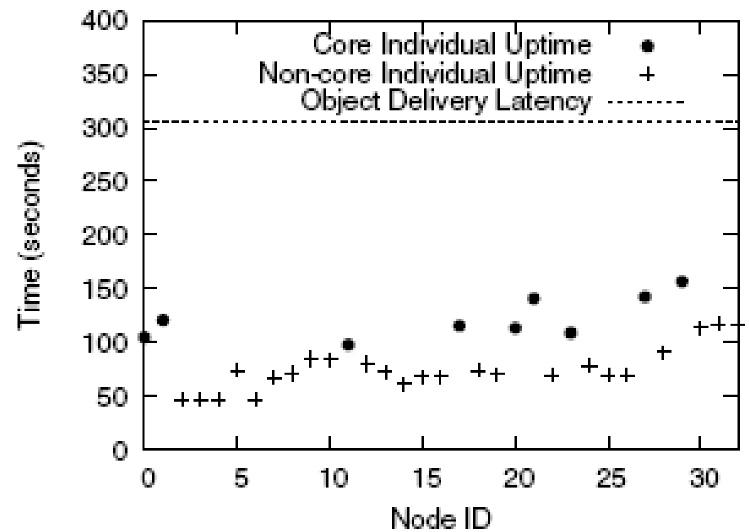




Fig. 8. Individual node uptime for CORD in one experiment on outdoor 3x11 TelosB network

# PROTOCOL EVALUATION

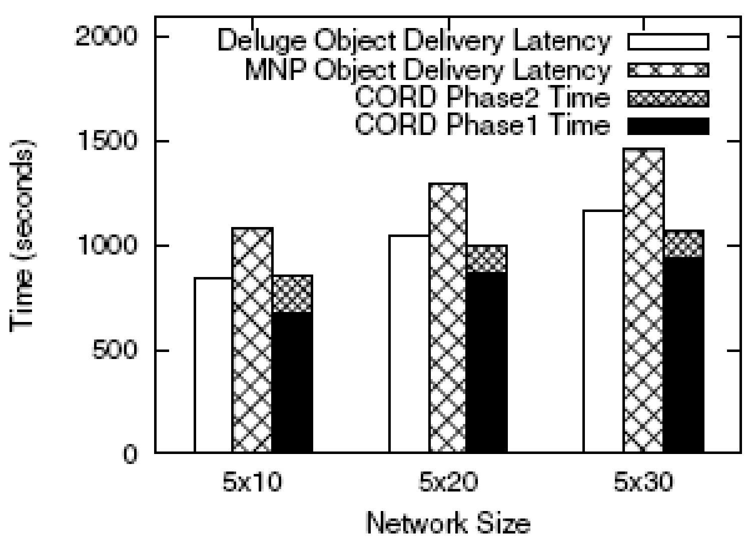
- *Simulation Results*
  - grid network is denoted by *m*n-s*

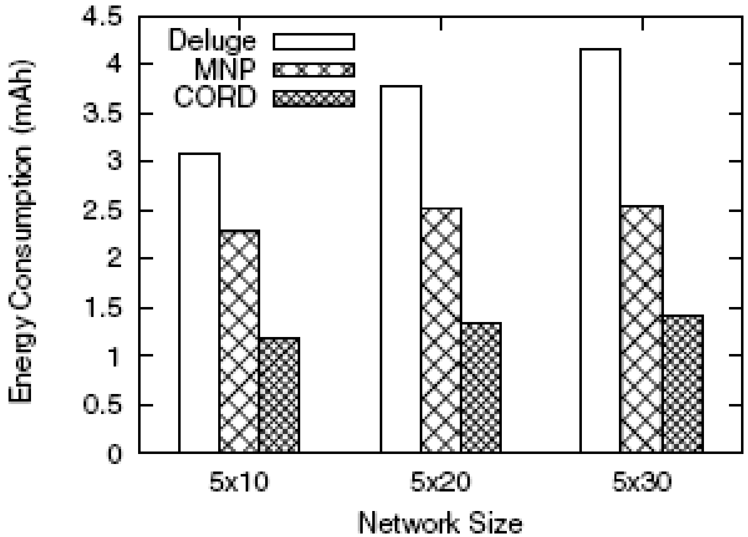
| | |
|---|---|
| Network topology | 5x20 Grid |
| Spacing | 9 meters |
| Transmission power level | medium (0dBm) |
| Object size | 10 pages |
| Page size ($K$) | 128 packets |
| Packet payload size | 23 bytes |
| Slot length ($L$) | 6 seconds |

TABLE IV
DEFAULT PARAMETER SETTINGS FOR THE SIMULATION EXPERIMENTS

# PROTOCOL EVALUATION

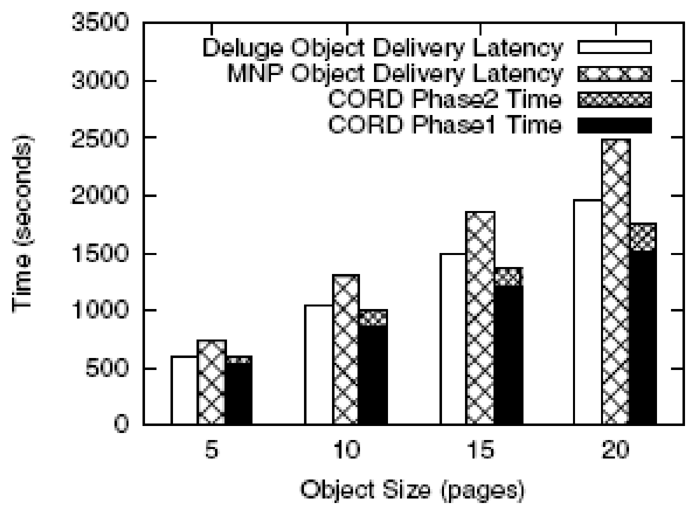
- *Simulation Results*
  - *Effect of Network Size:*



# PROTOCOL EVALUATION

- *Simulation Results*
  - *Effect of Data Object Size*




\- Fig. 15. Latency for various object sizes (5x20-9 network)

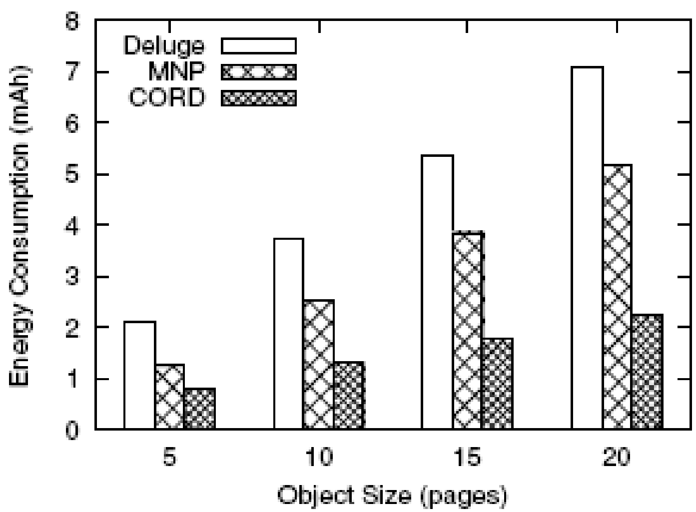



Fig. 16. Energy consumption for various object sizes (5x20-9 network)

# PROTOCOL EVALUATION

- *Simulation Results*
  - *Effect of Network Density*

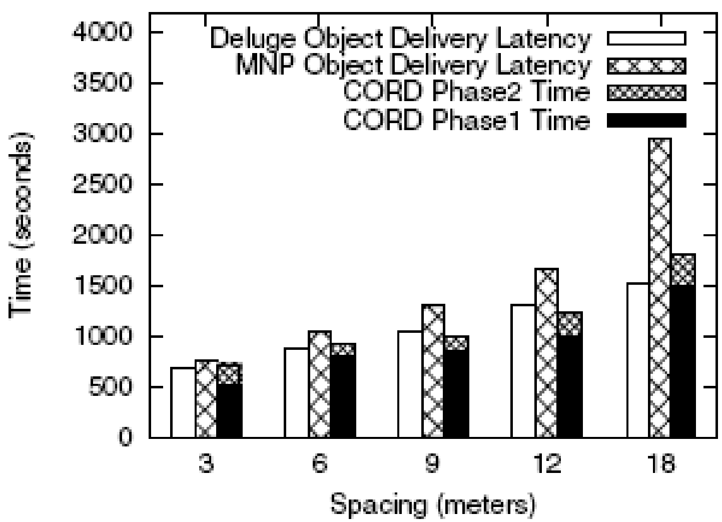



Fig. 17. Latency for various network densities (5x20 network)

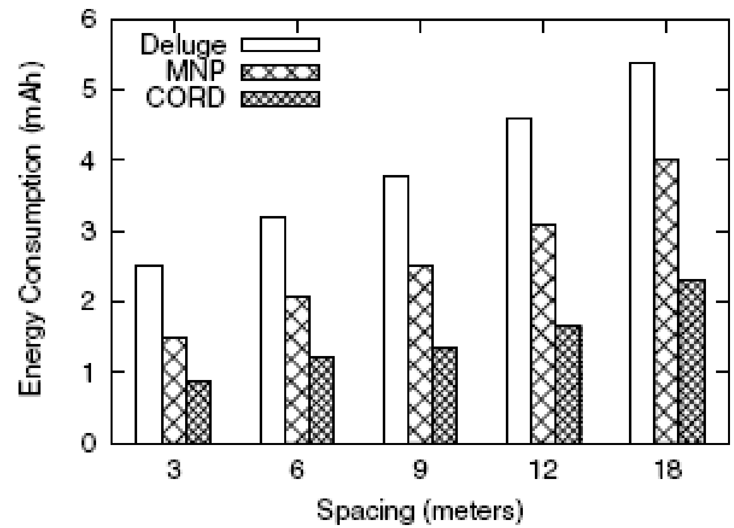



Fig. 18. Energy consumption for various network densities (5x20 network)

# CONCLUSIONS

- CORD differs from previously proposed protocols in its aggressive use of sleep scheduling in conjunction with a two-phase core-based pipelined object propagation approach.
- The energy consumption for large object dissemination in CORD is 30%-60% of that of Deluge.