RMAC: A Routing-Enhanced Duty-Cycle MAC Protocol for Wireless Sensor Networks

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Outline

- Introduction
- R-MAC
- Performance Evaluation
- Discussions
- Conclusions

Introduction

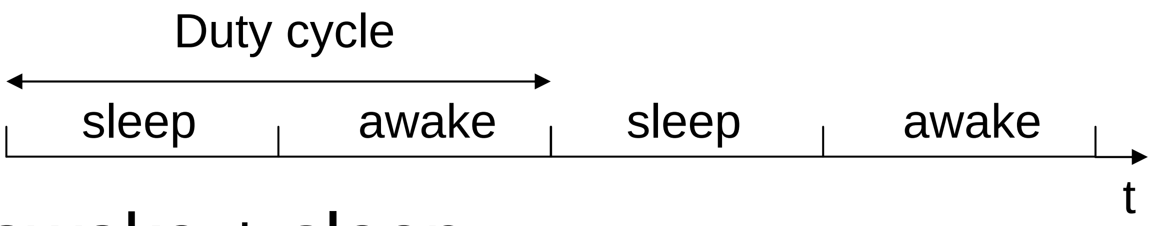
- The network lifetime is based on the average power consumption of sensor nodes.
- Several *sleep scheduling* schemes are proposed to increase longevity of sensor networks.

Transmit > Receive > Idle **>>** Sleep

- Power consumption is reduced by these schemes but delivery latency is increased.

Introduction

- Duty cycle
  - Awake state
  - Sleep state
  - 1 duty cycle = awake + sleep



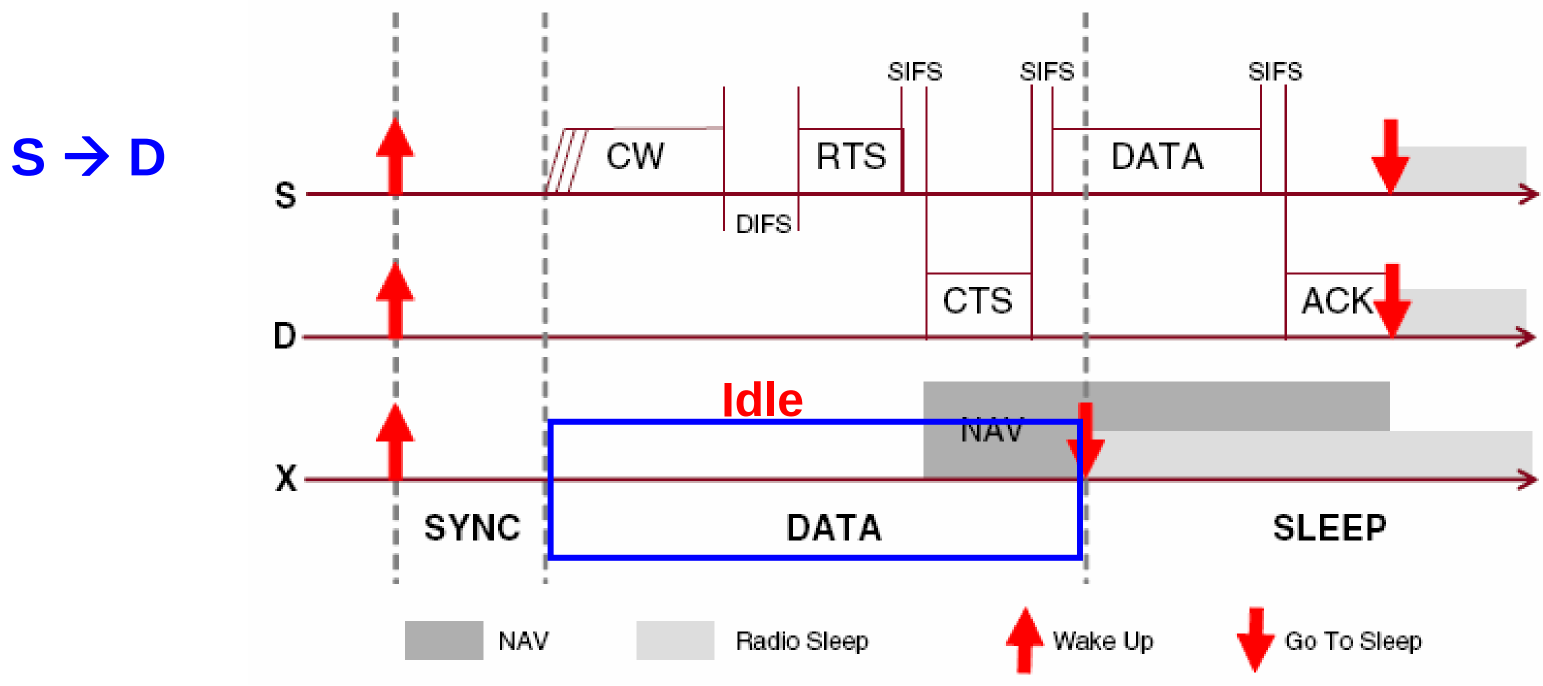
- Design challenges
  - To achieve high throughput
  - Low latency
  - Energy efficiency

Introduction

- Synchronous approaches
  - Pre-scheduled wake-up pattern
  - Ex: S-MAC (2002), T-MAC (2003), D-MAC (2004)
- Asynchronous approaches
  - Independent wake-up pattern
  - Ex: B-MAC (2004), Wise-MAC (2005), X-MAC (2006)
- Hybrid approaches
  - CSMA + TDMA
  - Ex: Z-MAC (2005), Funneling-MAC (2006)

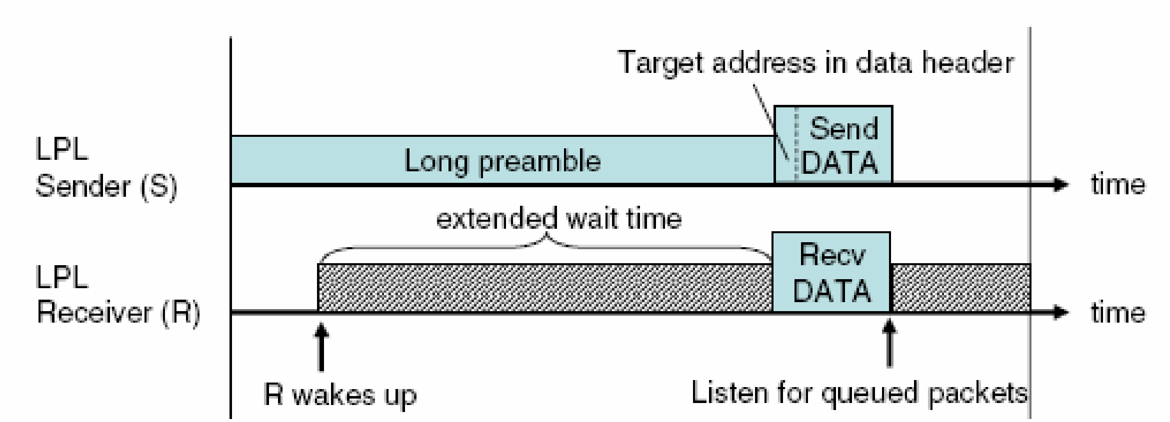
Synchronous Protocol --S-MAC

- Periodically sleeps, wakes up, listens to the channel, and then returns to sleep



Asynchronous Protocol

- No idle listening
- Low power listening (LPL)
  - Preamble sampling
- A sender transmits a ***preamble*** before sending data.
- When the receiver will wake up and detect the preamble, it **stays awake** to receive this data.

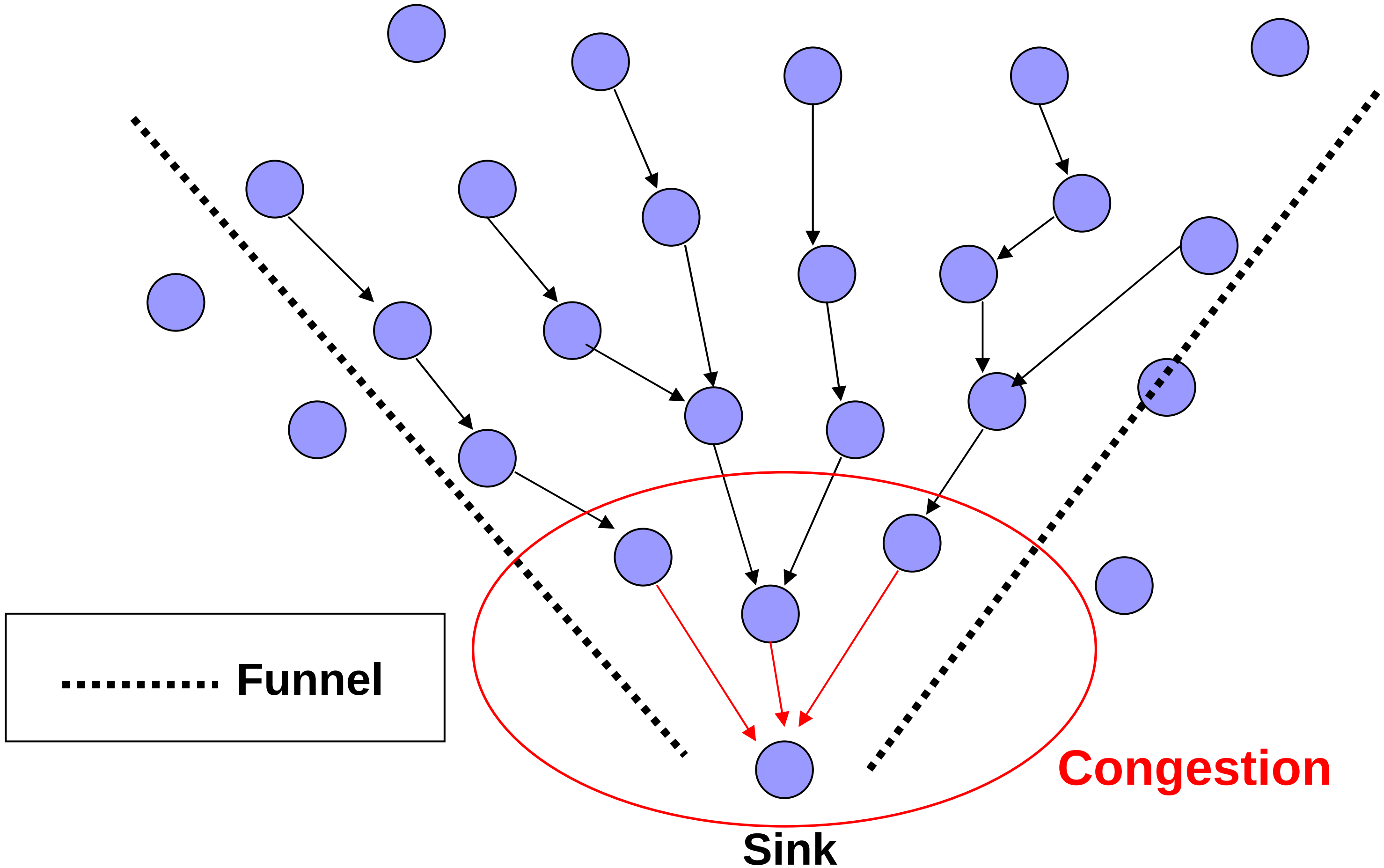


Hybrid Protocol --Z-MAC

- Z-MAC uses CSMA as the baseline MAC scheme, and uses a TDMA schedule to enhance channel utilization under high contention
- Unlike TDMA, a node may transmit during any time slot in Z-MAC

Hybrid Protocol--Funneling-MAC

Funneling effect



Hybrid Protocol --Funneling-MAC

- A hybrid protocol
  - CSMA/CA + localized TDMA
- Sink-oriented
  - The TDMA scheduling is managed by the **sink**
- Localized TDMA
  - TDMA only operates in the funneling region close to the sink, called **intensity region**.

RMAC: A Routing-Enhanced Duty-Cycle MAC Protocol for Wireless Sensor Networks

Motivation

- S-MAC only can forward **one** packet over a single hop in each operational cycle

- Goal:

  To deliver a data packet **multiple** hops in a single operational cycle

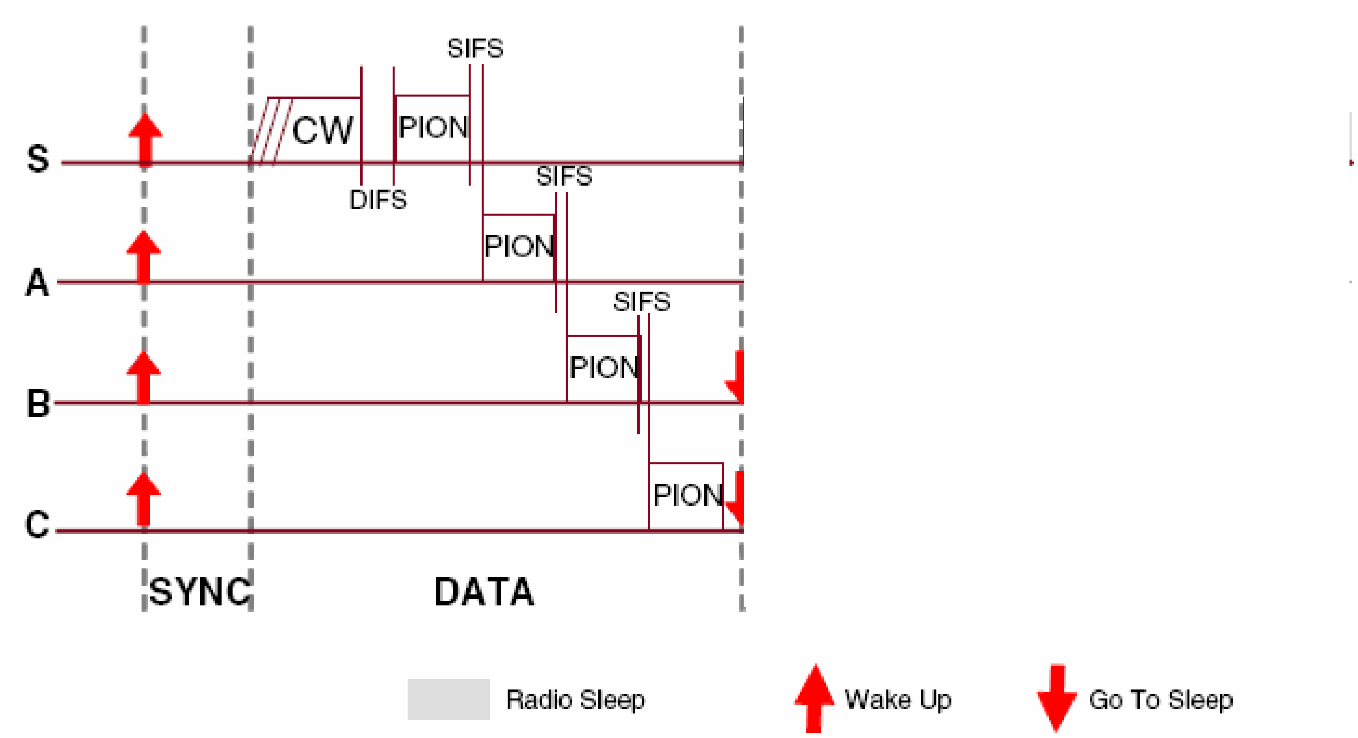
R-MAC --Overview

- R-MAC is a synchronous protocol
- Operational cycle includes three fields:
  - SYNC
  - DATA
  - SLEEP
- R-MAC uses a control packet, *PION*, to arrange the transmission schedule
- The data transmission operates in the *SLEEP* period

Pioneer Control Frame (PION)

- The PION serves as RTS/CTS
- The fields of PION includes
  - Current node ID
  - Next-hop ID
  - Duration of the transmission
  - Previous node ID
  - Des. ID
  - # of hops the PION has traveled

SYNC+DATA Period

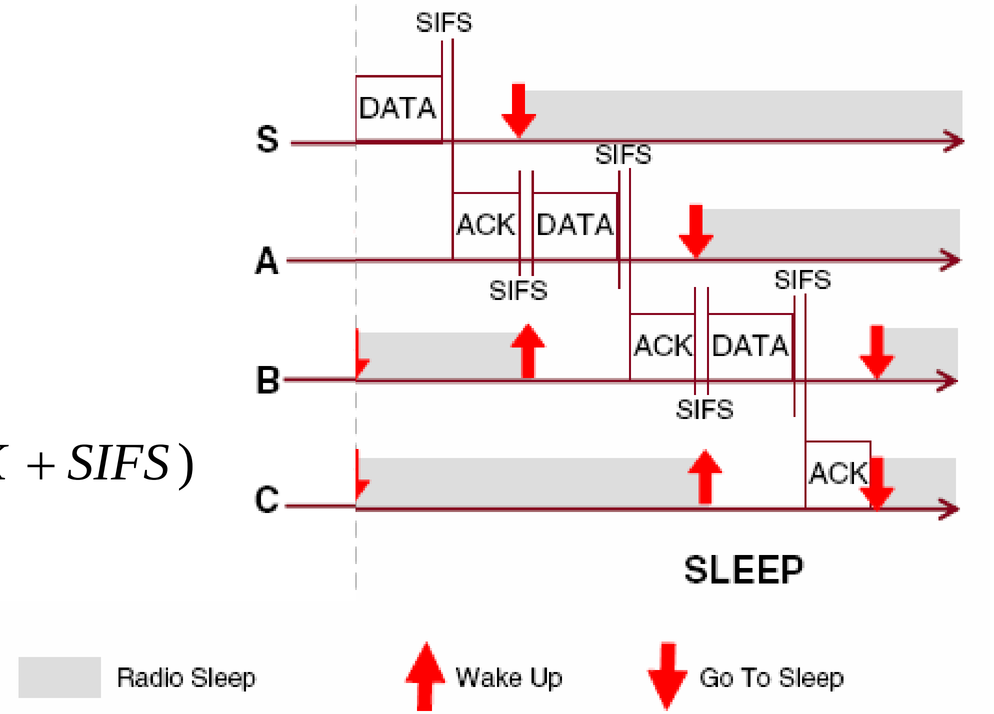


- When node S has data to send, it initiates its request at the start of the DATA period
- Node S will send PION <S, S, A, T_{Dur}, C, 0>

SLEEP Period

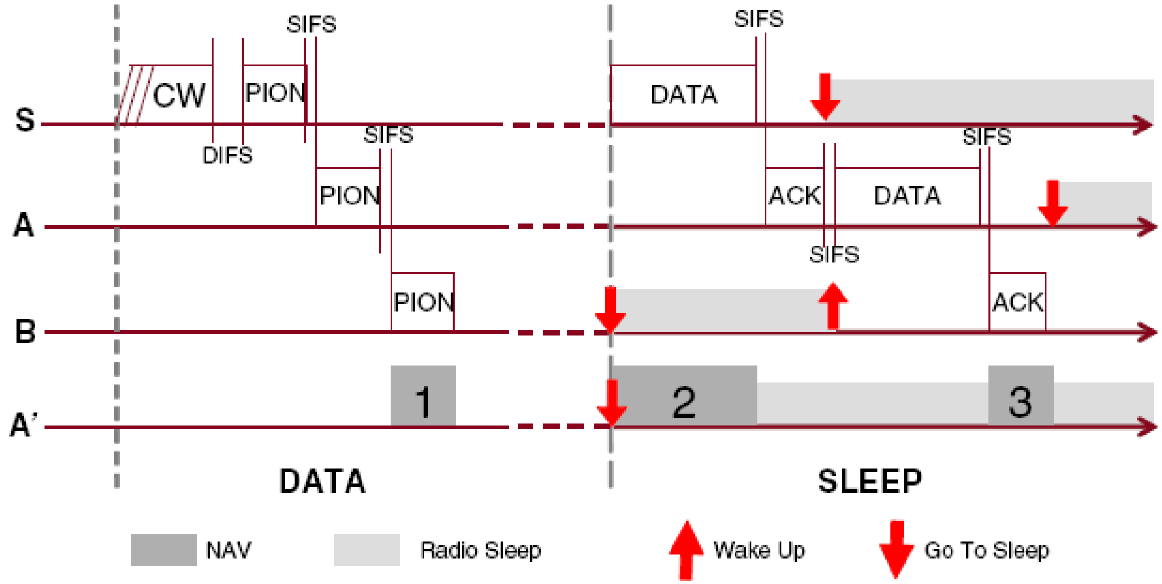
Wakeup time of i_{th} hop node:

$$T_{wakeup}(i) = (i-1)\cdot(durDATA + SIFS + durACK + SIFS)$$



- The data relaying process continues at each hop until the final destination is reached or the data reaches at the node that does not receive the confirmation PION from its next hop node

Setting the NAV



- The NAV in R-MAC records segments of time [start_time, end_time]
- Example: A' is a neighbor of node A
  - Confirmation PION segment (1): [now, now+durPION]
  - Data segment (2): [$t_{datastart}$, $t_{datastart}$ +durDATA]
  - ACK segment (3): [durDATA+durACK+3*SIFS, $t_{ackstart}$+durACK]

Handling data losses

- If PION is lost
  - The upstream node will initiate a new PION in the next DATA period
  - Worse case: the downstream node wakes up and receive nothing
- If data or ACK gets lost
  - The upstream node goes back to sleep and tries again in the next DATA period, starting with a new PION

Simulation Evaluation

TABLE I
NETWORKING PARAMETERS

Bandwidth	20 Kbps	Sleep Power	0.05 W
Rx Power	0.5 W	Carrier Sensing Range	550 m
Tx Range	250 m	Contention window (CW)	64 ms
Tx Power	0.5 W	DIFS	10 ms
Idle Power	0.45 W	SIFS	5 ms

TABLE II
TRANSMISSION DURATION PARAMETERS

	Frame Size (bytes)	Tx Latency (ms)
RTS/CTS	10	11.0
ACK (in S-MAC/RMAC)	10	11.0
PION	14	14.2
DATA (in S-MAC/RMAC)	50	43.0

Traffic load: CBR

Simulation Evaluation

Duty cycle (5%) for both SMAC and RMAC

$$R = \frac{T_{awake}}{T_{cycle}} = \frac{T_{SYNC} + T_{DATA}}{T_{SYNC} + T_{DATA} + T_{SLEEP}}$$

$$T_{DATA}(S\text{-}MAC) = CW + \text{DIFS} + durRTS + \text{SIFS} + durCTS$$

$$T_{DATA}(RMAC) = CW + \text{DIFS} + durPION + \underline{N} \cdot (\text{SIFS} + durPION)$$

CYCLE DURATION PARAMETERS

	T_{SYNC} (ms)	T_{DATA} (ms)	T_{SLEEP} (ms)	T_{cycle} (ms)
S-MAC	55.2	104.0	3025.8	3185.0
RMAC	55.2	168.0	4241.8	4465.0

N = 4

Simulation Models

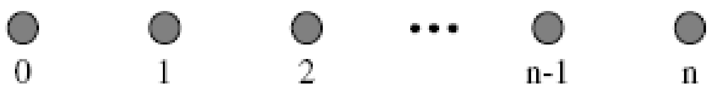


Fig. 5. Chain scenario

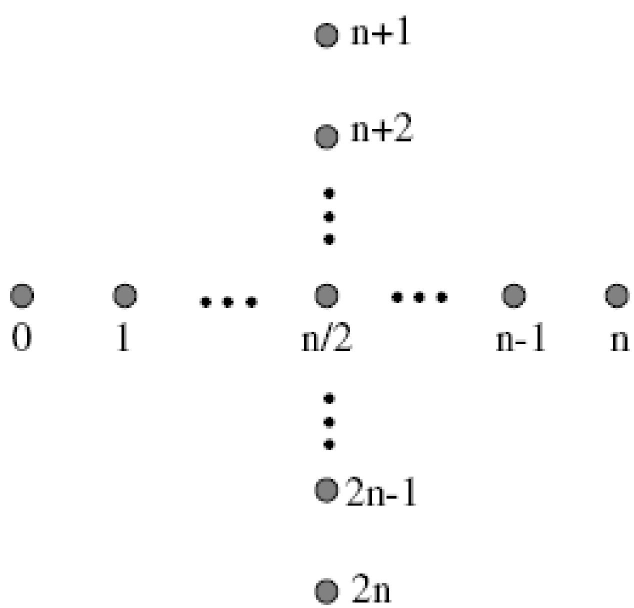


Fig. 6. Cross scenario

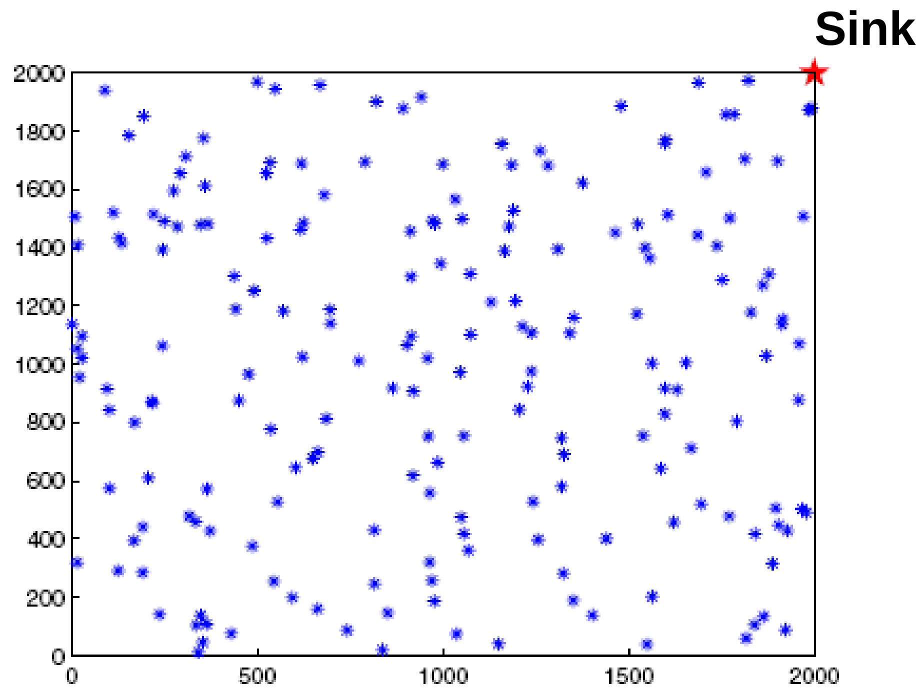
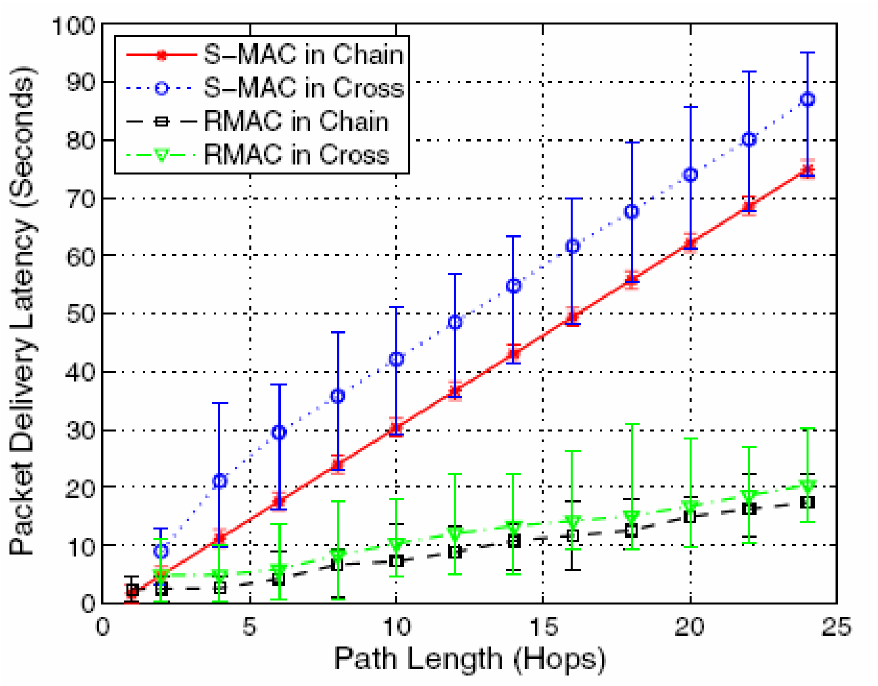


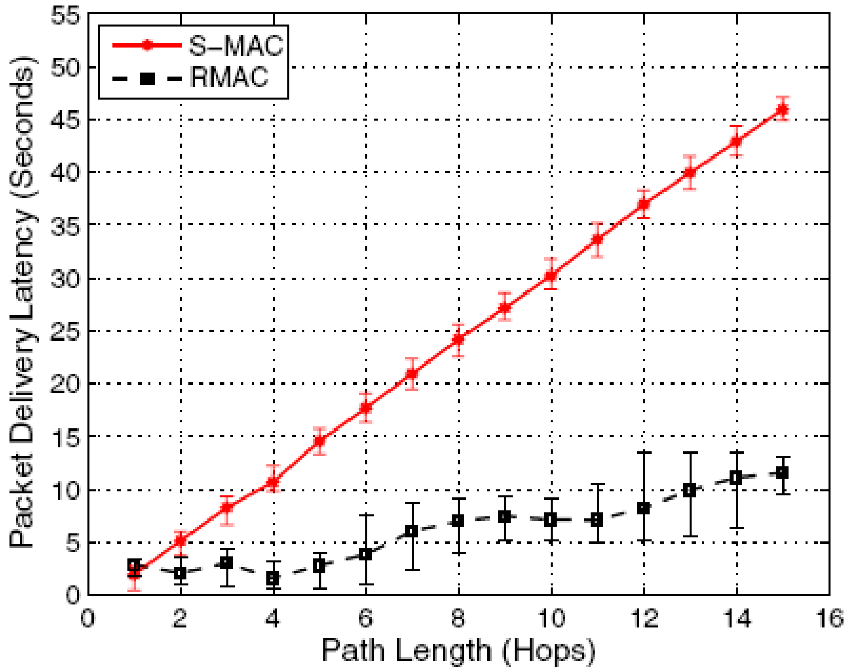
Fig. 7. A realistic 200-node network

Max. path length = 15 hops

Delivery Latency



Chain and Cross Models



Realistic Model

Traffic load: 100 packets at the rate of 1 packet every 50 secs.

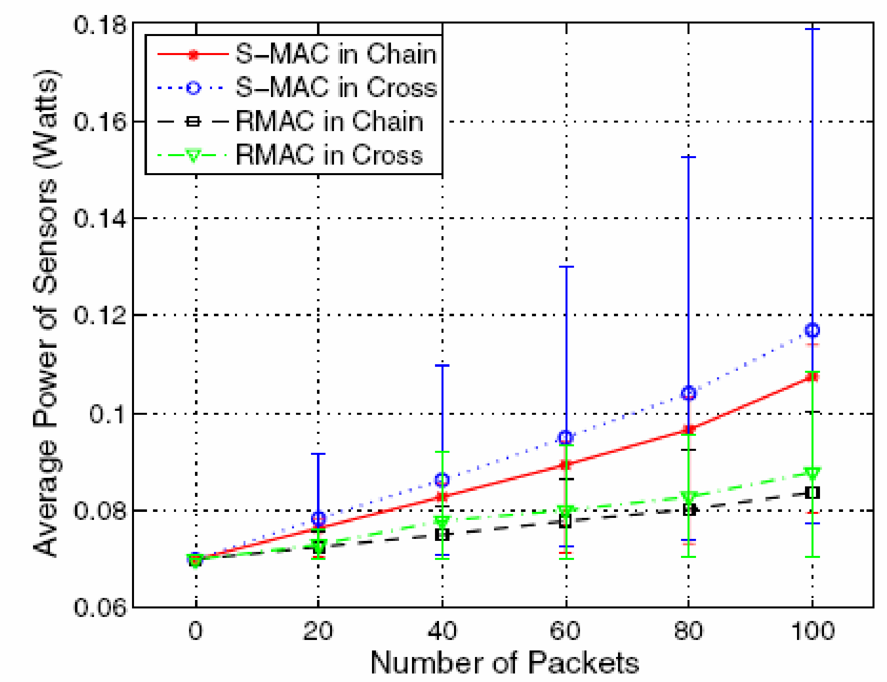
Delivery Latency – 24 hops

TABLE IV
RESULTS OF 24-HOP NETWORKS

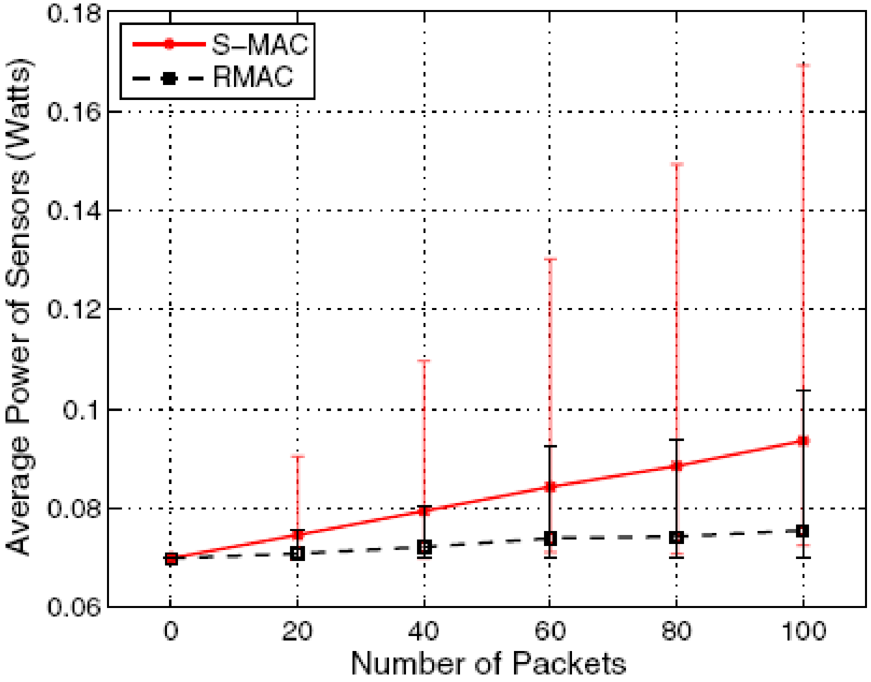
	Scenario	Latency (seconds)	T_{cycle} (seconds)	$\frac{Latency}{T_{cycle}}$ (cycles)	$\frac{PathLength \cdot T_{cycle}}{Latency}$ (hops/cycle)
S-MAC	chain	74.9	3.185	**23.52**	**1.02**
S-MAC	cross	87.0	3.185	**27.32**	**0.88**
RMAC	chain	17.4	4.465	**3.90**	**6.16**
RMAC	cross	20.4	4.465	**4.57**	**5.25**

For chain model
SMAC: <u>1.02</u> hops/cycle < RMAC: <u>6.16</u> hops/cycle

Energy Consumption



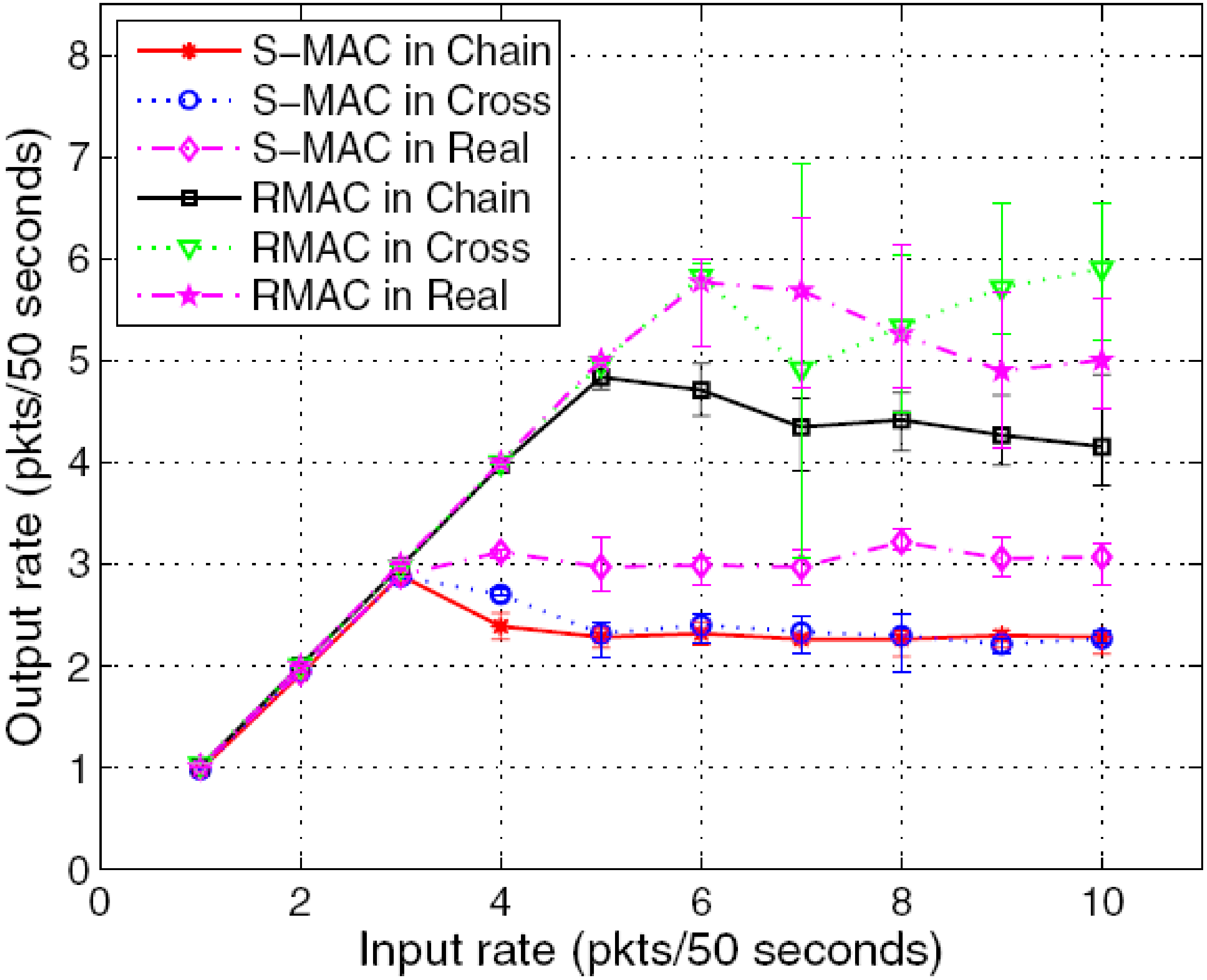
Chain and Cross Models



Realistic Model

Traffic load: 100 packets at the rate of 1 packet every 50 secs.

Throughput

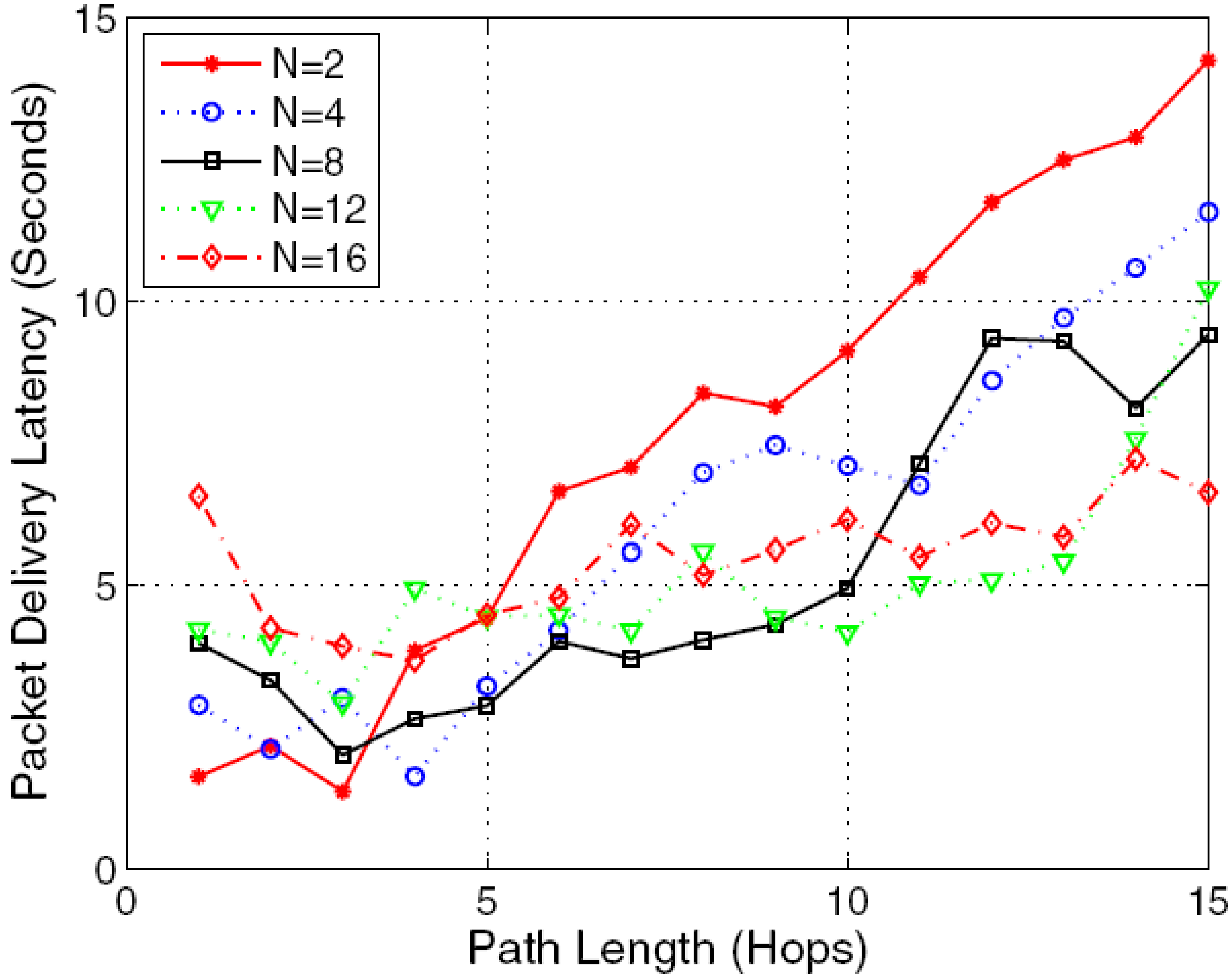


S–MAC in Chain
S–MAC in Cross
S–MAC in Real
RMAC in Chain
RMAC in Cross
RMAC in Real
Output rate (pkts/50 seconds)
Input rate (pkts/50 seconds)
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10

PION Relaying Number (N)

Best choice
N = K

K: hops away from sink node



Conclusions

- RMAC is a duty-cycle MAC protocol that is capable of multi-hop data delivery in a single cycle
- RMAC uses PION packet to setup multi-hop schedule for forwarding data
- RMAC can reduce delivery latency, and improve the power consumption and network throughput