Wakeup Scheduling in Wireless Sensor Networks

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Outline

- Introduction
- Network and Traffic Model
- Wakeup Patterns
- Multi-Parent Method
- Evaluation and Comparison
- Conclusions
- Discussions

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.

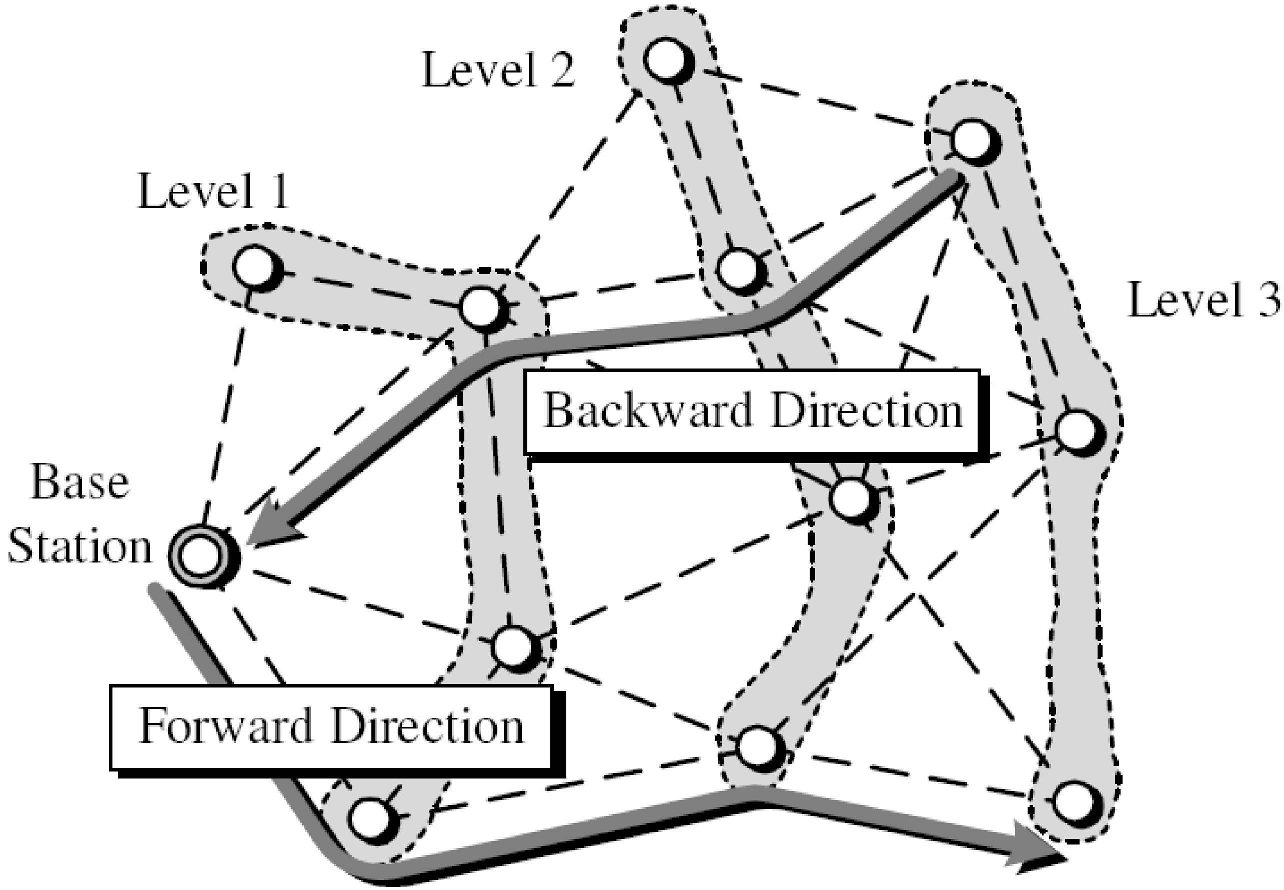
Transmit > Receive > Idle **>>** Sleep

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

Introduction

- Scheduled wakeups
  - Wakeup patterns
- Wakeup on-demand
  - Out-of-band wakeup
  - Two wireless interfaces
    1. Paging or signaling
    2. Data transmission

Network and Traffic Model



Network and Traffic Model

- Channel sniffing and wakeup
  - Based on measuring the received signal strength

For Chipcon CC1100 radio (315, 433, 868 and 915 MHz)

P_{wakeup} = 15uA * 3V * 86400s = 3.9J/day (~ 21Mbits)

- Time synchronization
- Network topology
  - Dense deployment
  - Reliable links

N: number of nodes in the network

L_k: the set of nodes in level k

h: maximum number of levels

$D_{\blacktriangleright}$: forward delay

$D_{\blacktriangleleft}$: backward delay

T: the period of wakeup pattern

Effective wakeup period: $$T_{eff} = \lim_{\tau \to \infty} \frac{\tau}{N_\tau}$$

Effective wakeup rate: $$R_{eff} = \frac{1}{T_{eff}}$$

Power consumption: $$P_{wakeup} = \frac{E_0}{T_{eff}} = R_{eff} E_0$$

Wakeup Patterns

(1)Fixed-power case:

$$P_{wakeup} = 0.5E_0 \Rightarrow T_{eff} = 2s$$

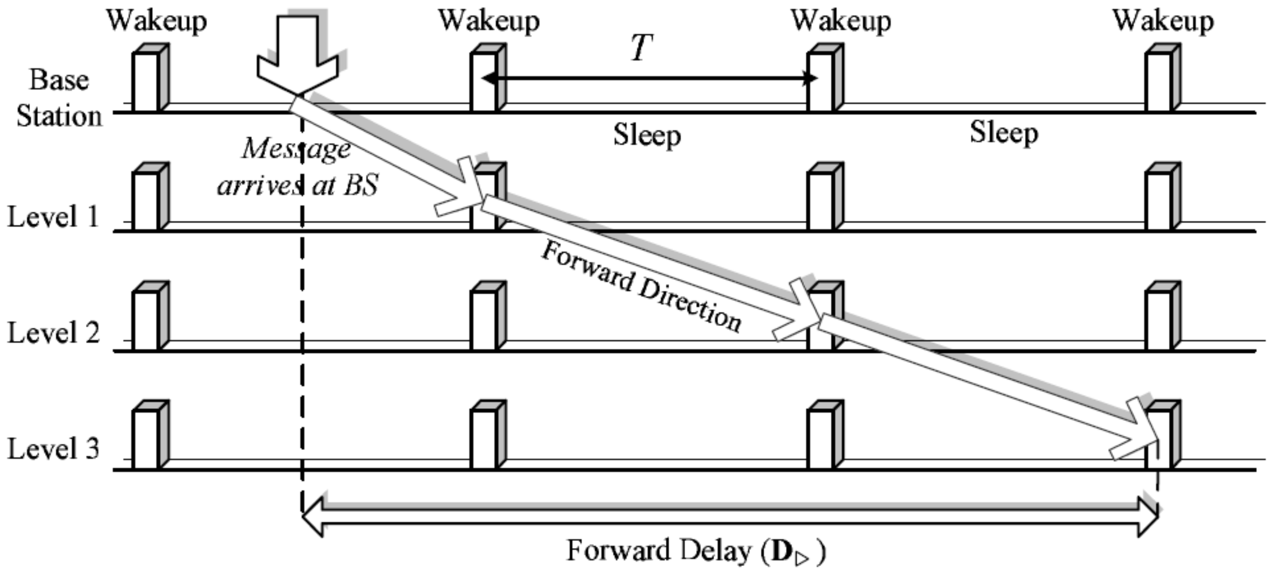
$$E_0 = 3V \times 15\,\mu C = 45\,\mu J / s$$

(2)Fixed-delay case:

$$\max(D_{\triangleright}, D_{\triangleleft}) \leq 1$$

- Full battery capacity: $(2.4 \times 10^8) E_0$
- h= 4 hops

Full Synchronization Pattern --S-MAC



$$\mathbf{D}_{\triangleright}, \mathbf{D}_{\triangleleft} \sim \mathbf{U}\left[\,(h-1)T_{\text{eff}}\ ,\ hT_{\text{eff}}\,\right],$$

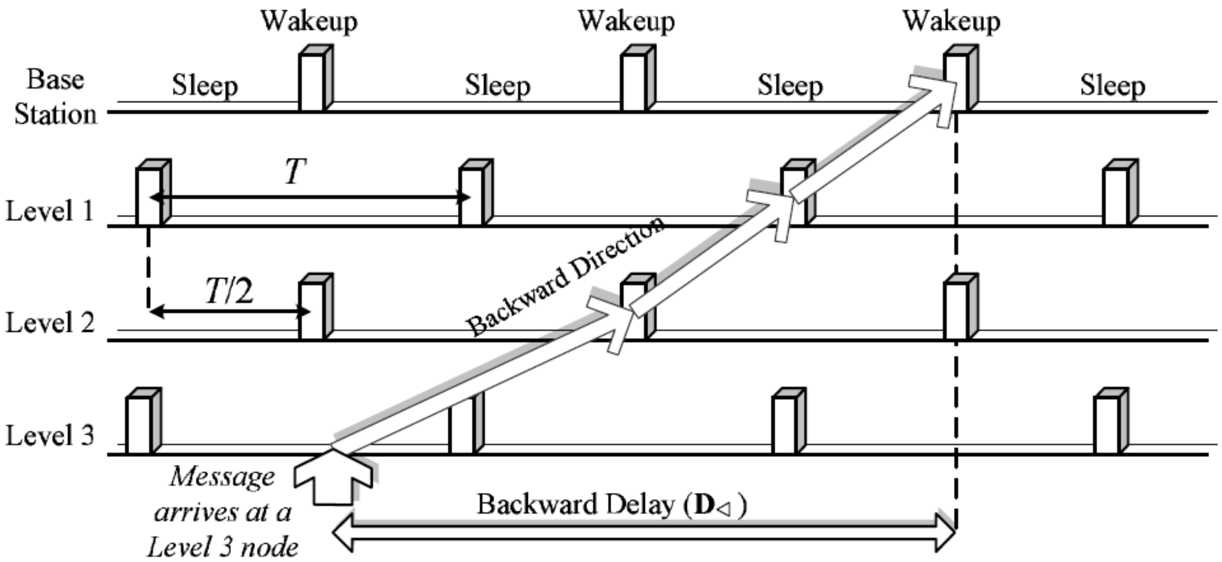
$$\mathbb{E}(\mathbf{D}_{\triangleright}) = (h - \tfrac{1}{2})T_{\text{eff}}.$$

(1) $\mathbf{D}_{\triangleright}, \mathbf{D}_{\triangleleft} \sim \mathbf{U}\,[6,8] \ \Rightarrow \max(\mathbf{D}_{\triangleright}, \mathbf{D}_{\triangleleft}) = 8s$

(2) T_{eff} = 250ms, P_{wakeup} = $4E_0$,Lifetime = 23.1 months

Shifted Even and Odd Pattern

Shift
Even Levels



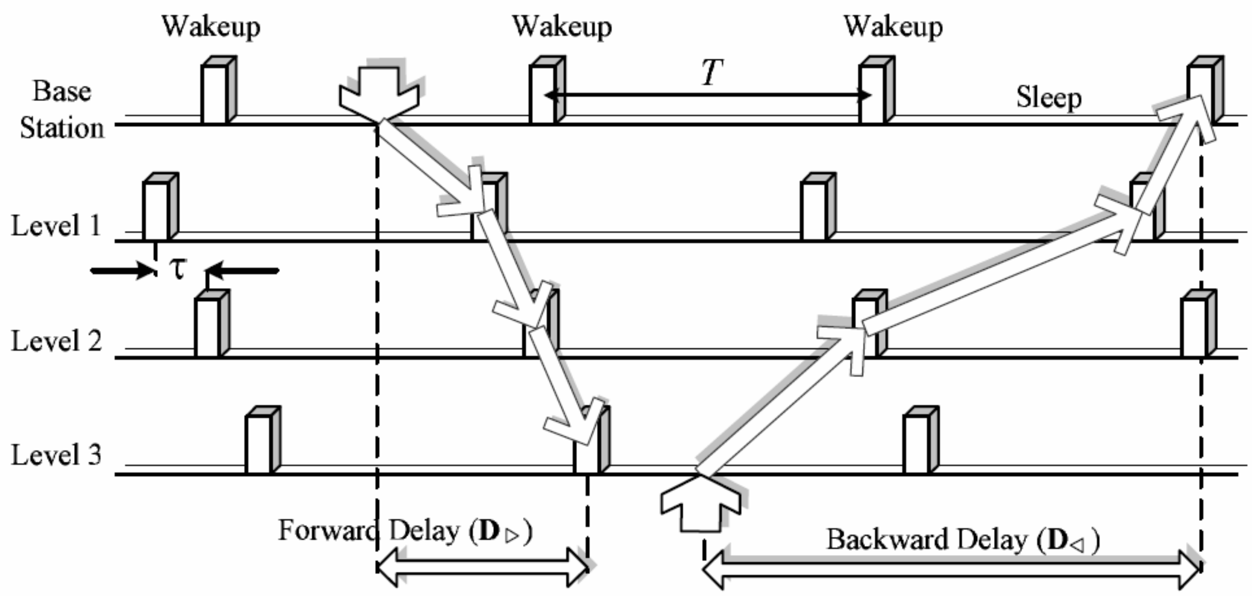
$$\mathbf{D}_{\triangleright}, \mathbf{D}_{\triangleleft} \sim \mathbf{U}[\ (\tfrac{h-1}{2})T_{\text{eff}}\ ,\ (\tfrac{h+1}{2})T_{\text{eff}}\ ]$$

$$\mathbb{E}(\mathbf{D}_{\triangleright}) = \tfrac{h}{2}T_{\text{eff}}.$$

(1) $\mathbf{D}_{\triangleright}, \mathbf{D}_{\triangleleft} \sim \mathbf{U}\,[3, 5] \ \Rightarrow \max(\mathbf{D}_{\triangleright}, \mathbf{D}_{\triangleleft}) = 5s$

(2) T_{eff} = 400ms, P_{wakeup} = 2.5E_0 ,Lifetime = 37 months

Ladder Pattern (Forward) --D-MAC



$$\mathbf{D}_{\triangleright} \sim \mathbf{U}\left[\,(h-1)\tau\;,\;T_{\text{eff}}+(h-1)\tau\,\right]$$

$$\mathbb{E}(\mathbf{D}_{\triangleright}) = \frac{T_{\text{eff}}}{2} + (h-1)\tau.$$

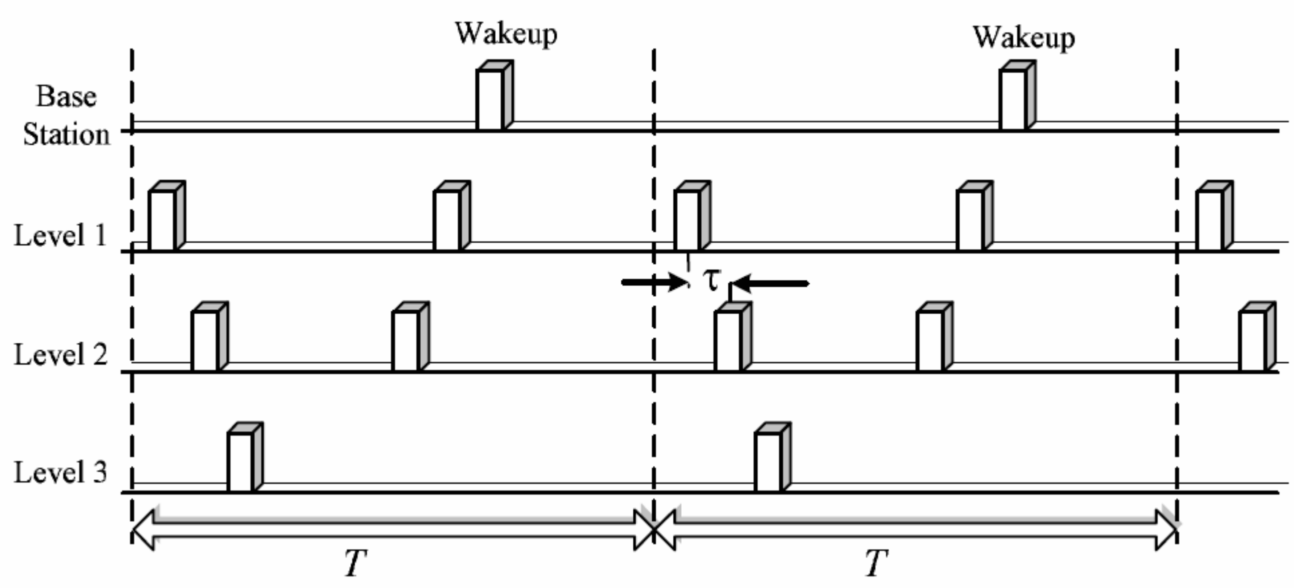
$$\mathbf{D}_{\triangleleft} \sim \mathbf{U}\Big[\;(h-2)(T_{\text{eff}}-\tau)+\tau\;,\;(h-1)T_{\text{eff}}-(h-3)\tau\;\Big]$$

$$\mathbf{D}_{\triangleright} \sim \mathbf{U}\,[0.15, 2.15]\,,\quad \mathbf{D}_{\triangleleft} \sim \mathbf{U}\,[3.95, 5.95]$$

(1) Maximum delay = 5.95s $\tau = 50ms$

(2) T_{eff} = 350ms, P_{wakeup} = 2.86E_0 ,Lifetime = 32.4 months

Two-Ladders Pattern
--Forward + Backward



- Nodes in the middle levels wakeup twice in every period T

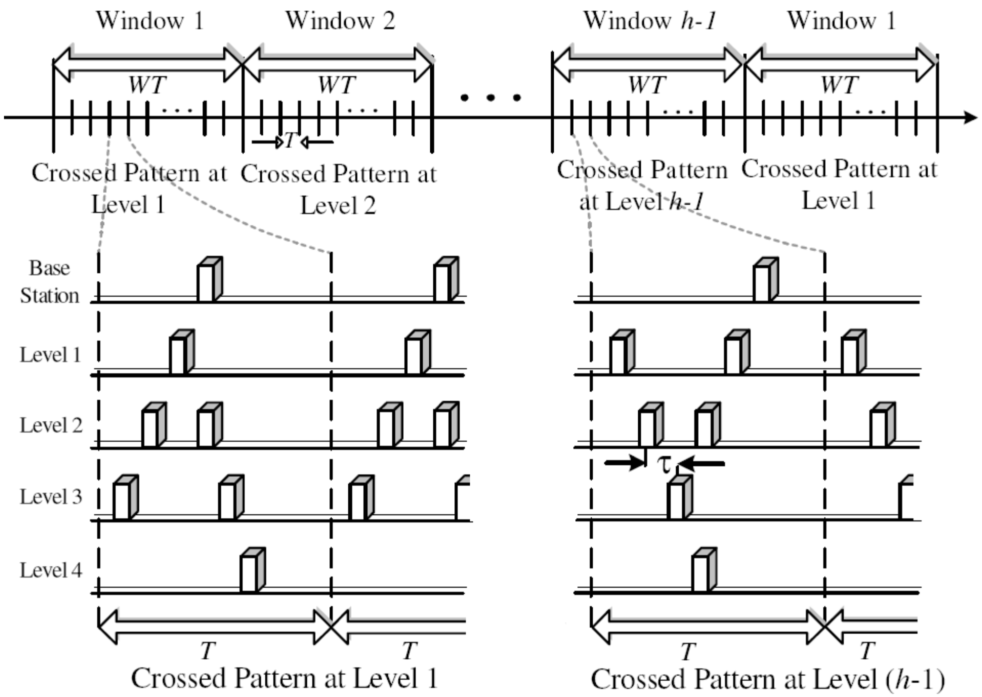
$$\mathbf{D}_{\triangleright}, \mathbf{D}_{\triangleleft} \sim \mathbf{U}\left[(h-1)\tau, \ \ 2T_{\text{eff}} + (h-1)\tau\right]$$

$$\mathbb{E}(\mathbf{D}_{\triangleright}) = T_{\text{eff}} + (h-1)\tau.$$

(1) $\mathbf{D}_{\triangleright}, \mathbf{D}_{\triangleleft} \sim \mathbf{U}\left[0.15, 4.15\right] \ \Rightarrow \max(\mathbf{D}_{\triangleright}, \mathbf{D}_{\triangleleft}) = 4.15s$

(2) T_{eff} = 425ms, P_{wakeup} = 2.35E_0 ,Lifetime = 39.3 months

Crossed-Ladders Pattern



- Cross point can be any of the middle levels
- Full cycle = (h-1)WT

$$T_{eff} = \frac{(h-1)WT}{2W(h-2)+W} = \left(\frac{h-1}{2h-3}\right)T$$

•The forward and backward delays are the same as in ladder pattern

$$\mathbf{D}_{\triangleright}, \mathbf{D}_{\triangleleft} \sim \mathbf{U}\left[(h-1)\tau, \left(\frac{2h-3}{h-1}\right)T_{\text{eff}} + (h-1)\tau\right]$$

$$\mathbb{E}(\mathbf{D}_{\triangleright}) = \left(\frac{2h-3}{2h-2}\right)T_{\text{eff}} + (h-1)\tau.$$

(1) $\mathbf{D}_{\triangleright}, \mathbf{D}_{\triangleleft} \sim \mathbf{U}[0.15, 3.48]$

$\Rightarrow \max(\mathbf{D}_{\triangleright}, \mathbf{D}_{\triangleleft}) = 3.48s$

(2) T_{eff} = 510ms

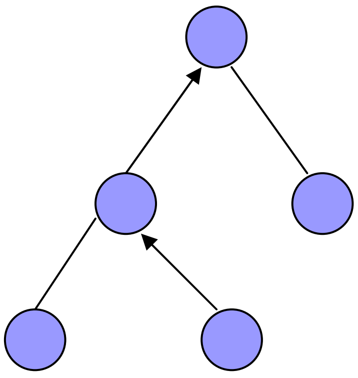
$P_{wakeup} = 1.96E_0$

Lifetime = 47.2 months

Summary

	Max. Delay	T_{eff}	Lifetime
Synchronized	8s	250ms	23.1
Even-Odd Shifted	5s	400ms	37.0
Ladder Froward	5.95s	350ms	32.4
Two-Ladders	4.15s	425ms	39.3
Cross-Ladders	3.48s	510ms	47.2

Multi-Parent Method

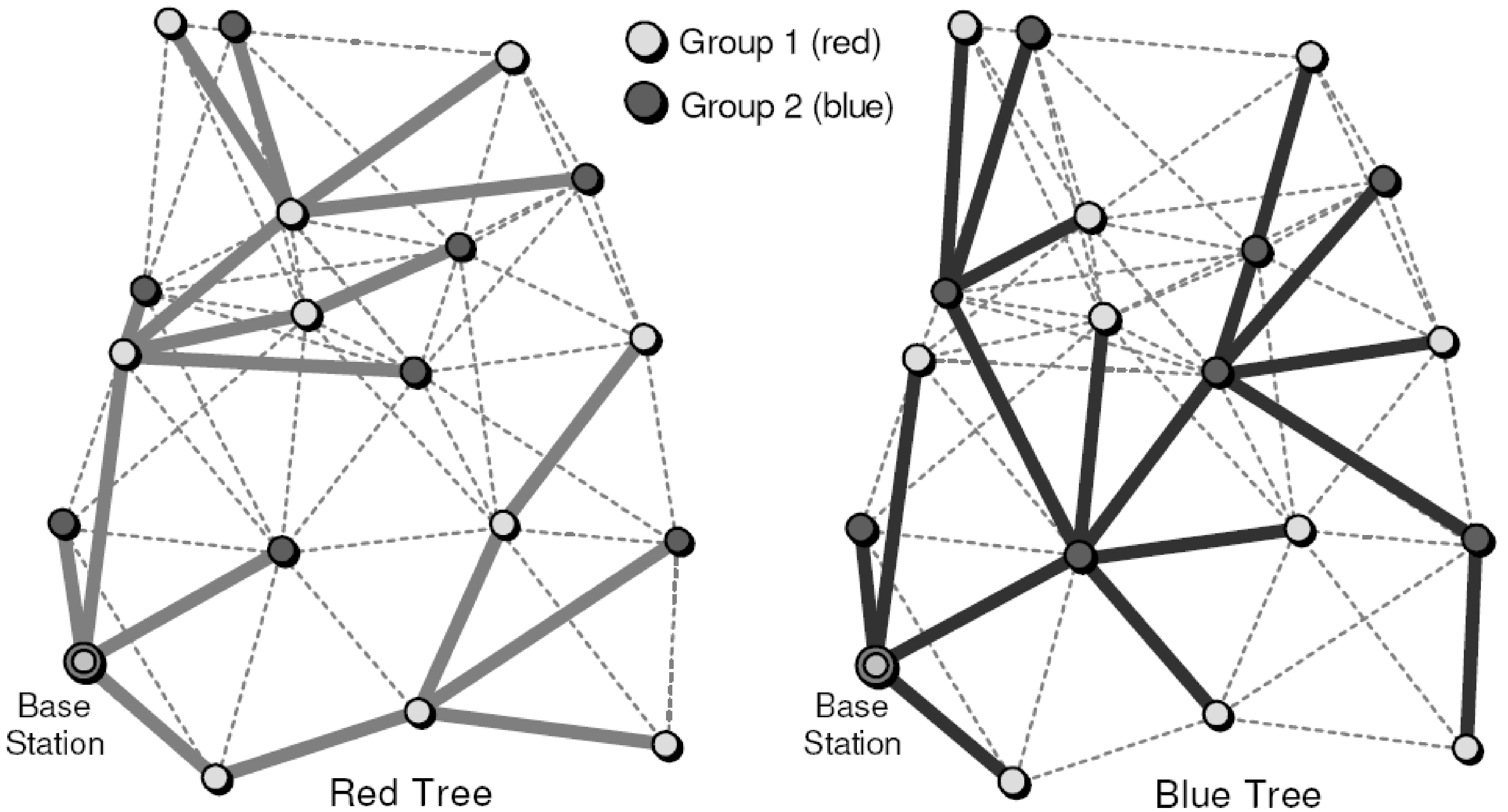


- Original tree topology
  - Single parent
  - Fixed path
  - Same wakeup pattern
- Multi-parent tree topology
  - Multiple parents
  - Multiple paths
  - Different wakeup patterns

Main Assumption

- "We can divide the nodes in the network into multiple disjoint groups such that at least one parent from each group can be assigned to any node in the network."
- Different groups have different wakeup patterns.
- g: the number of groups

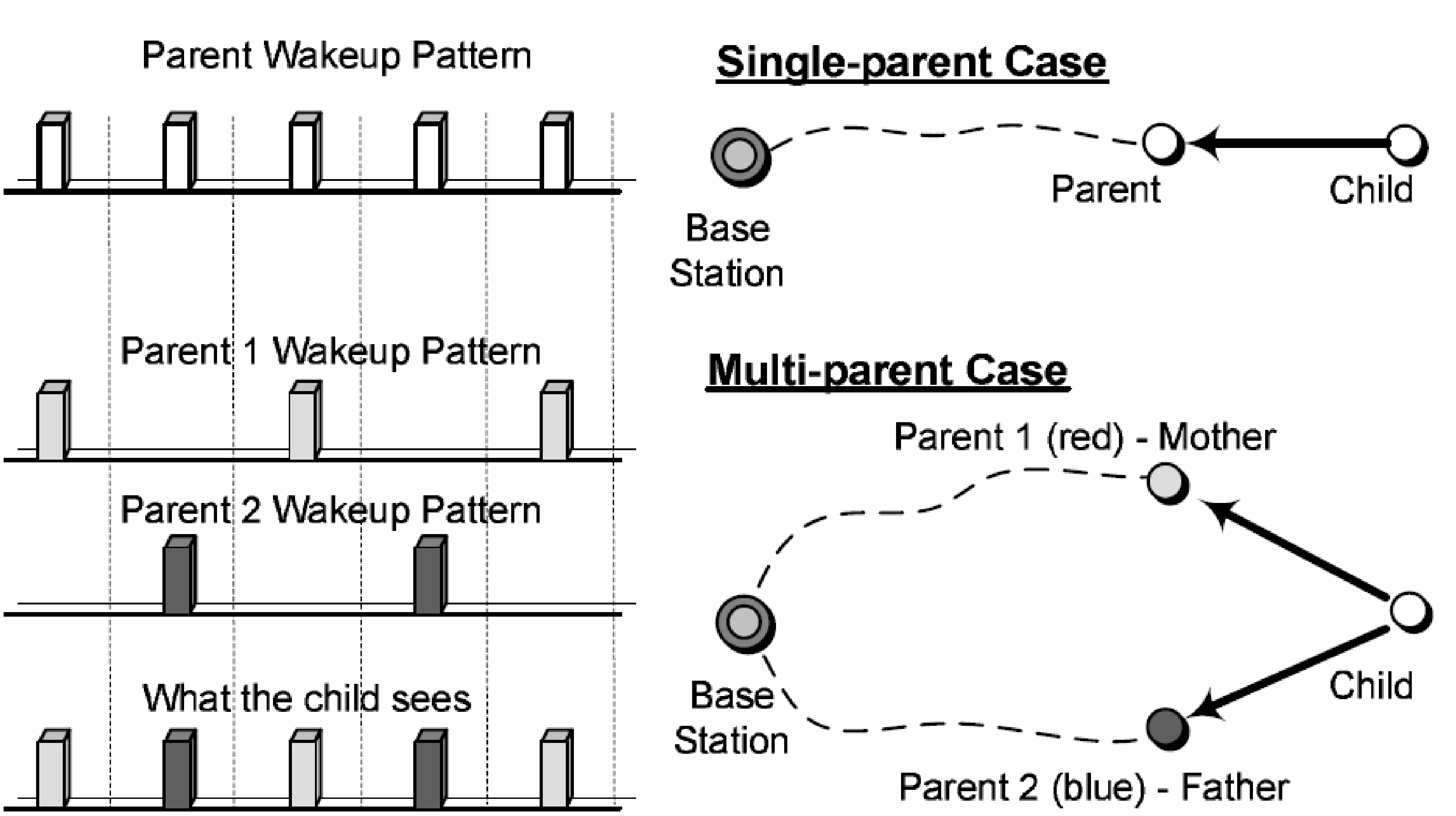
Example – g=2


Group 1 (red)
Group 2 (blue)
Base Station
Red Tree
Base Station
Blue Tree

(red)

(blue)

(red) + (blue)



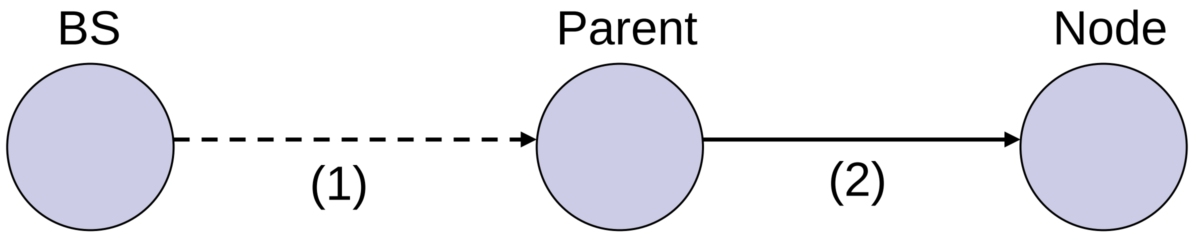
The same as single parent

Backward Delay

- The multi-parent idea can reduce the backward delay but the forward delay is not impacted by this idea.
- The distribution of *backward delay* is the same as in single parent case but the T_{eff} is scaled down by factor g.

$$T_{eff} \Rightarrow (\frac{T_{eff}}{g})$$

Forward Delay



- The delay in (1) is reduced by using different delivery paths

- The multi-parent idea increases the delay in (2)

Combination

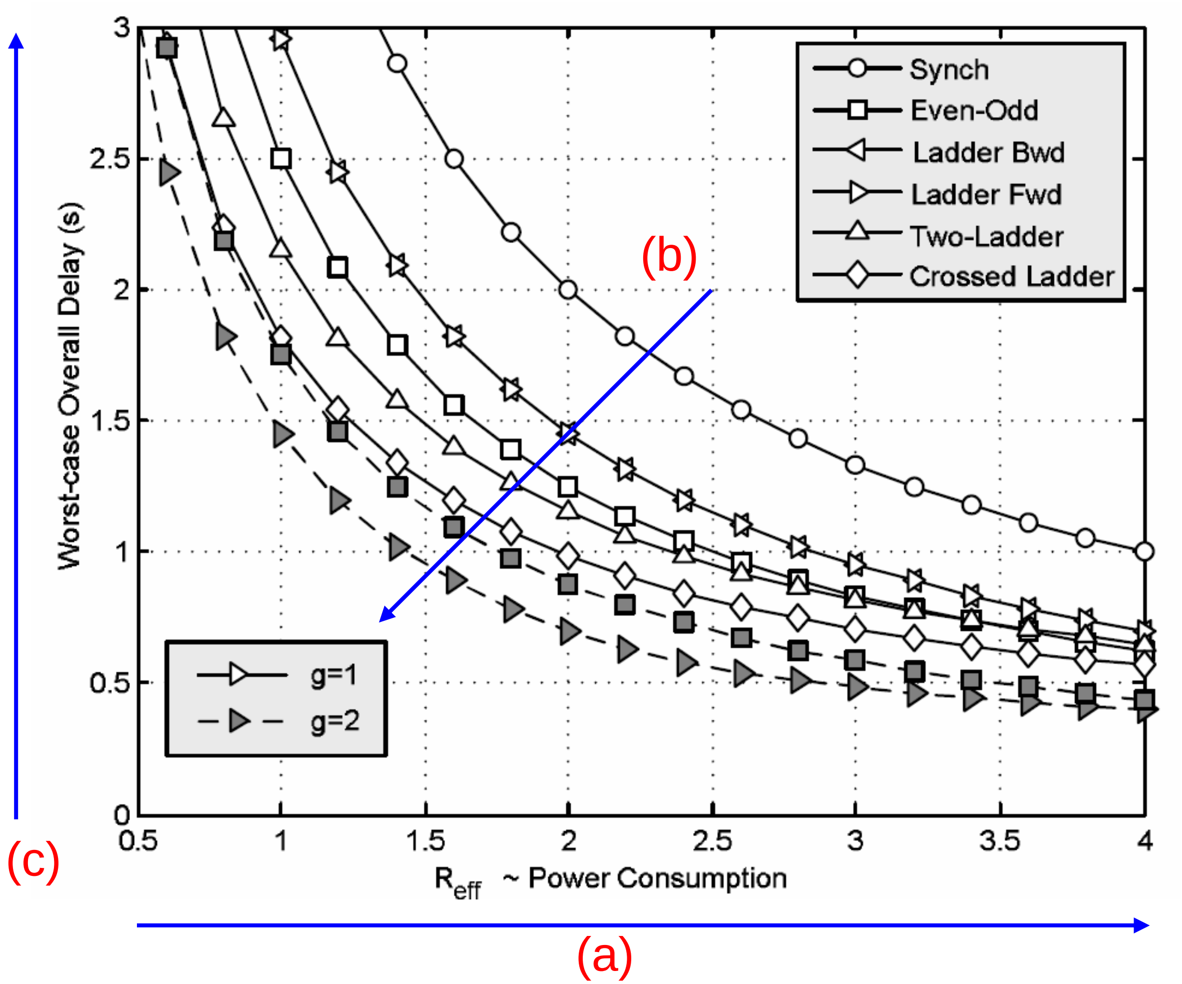
- We can combine multi-parent idea with wakeup patterns to provide the best performance.
- Best combination
  - + Forward ladder pattern

$$\left.\begin{array}{l}\mathbf{D}_{\triangleright} \sim \mathbf{U}\left[0.15, 2.15\right] \\ \mathbf{D}_{\triangleleft} \sim \mathbf{U}\left[1.95, 2.95\right]\end{array}\right\} \Rightarrow \max(\mathbf{D}_{\triangleright}, \mathbf{D}_{\triangleleft}) = 2.95s$$

T_{eff} = 700ms, P_{wakeup} = 1.43E_0 ,Lifetime = 64.8 months

>47.2 in crossed-ladders pattern

Evaluation and Comparison



(a): wakeup rate ↑
delay ↓ , Power ↑

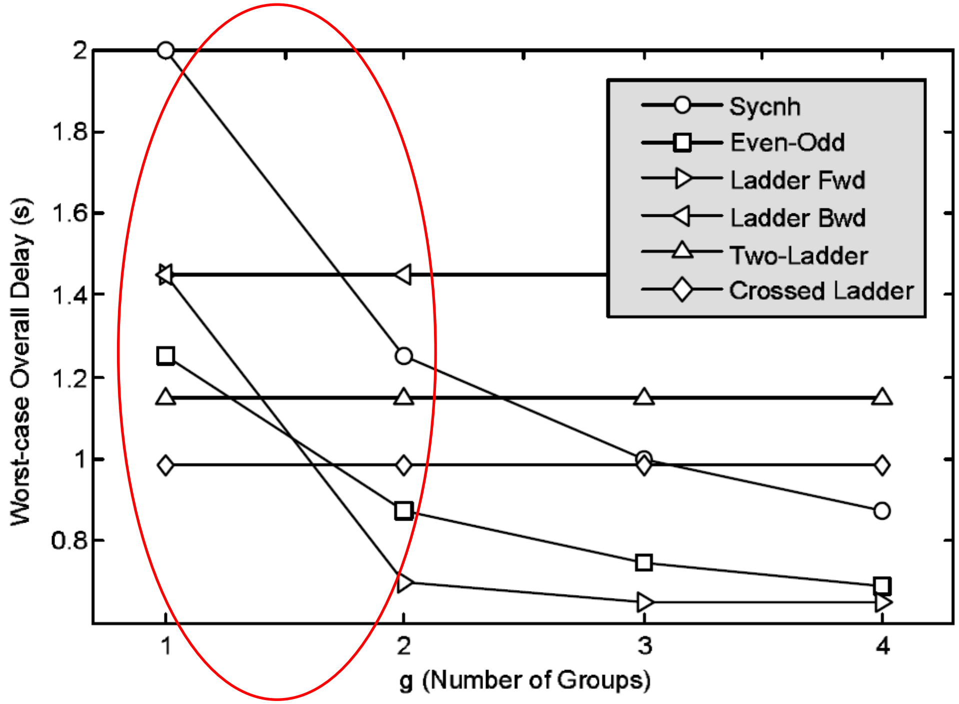
(b): lower curve,
more efficient

(c): for energy-limited system, the selection of good pattern is important

Summary

- g= 1
  - *Crossed-ladder* pattern is the best
    - D=3.48s, T=510ms, lifetime=47.2 months
- g= 2
  - *Forward ladder* pattern is the best
    - D=2.95s, T=700ms, lifetime=64.8 months
- If the system requires a good *backward delay*, backward ladder pattern is the best choice.
  - g = 1, D=2.15s
  - g = 2, D=1.15s

Effect of Number of Groups



- The delay is reduced significantly from g=1 to g=2.
- g=2 is the most practical value

Conclusions

- The authors analyze different wakeup schemes and delay distributions.
- A new wakeup pattern is proposed
  - Crossed-ladders pattern
- A new cross layer idea is proposed
  - Multi-parent method

Discussions

- Delay distribution is not always symmetric
  - Backward delay >= Froward delay
- Application-based wakeup scheme
  - Special purpose wakeup pattern
- Congestion control scheme