802.11 Power Saving Issues

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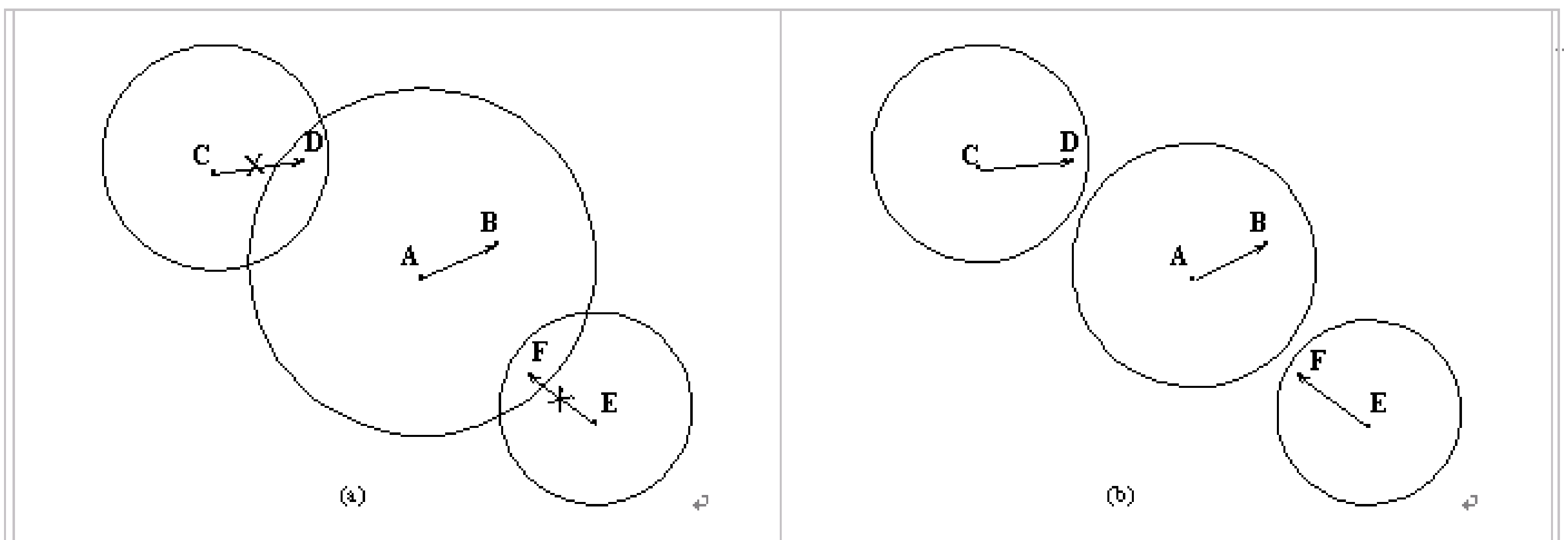
Power-Related Issues

Backgrounds

- Battery is a limited resource in any portable device.
  - becoming a very hot topic is wireless communication
- Power-related issues:
  - PHY: transmission power control
  - MAC: power mode management
  - Network Layer: power-aware routing

Transmission Power Control

- tuning transmission energy for higher channel reuse
- example:
  - A is sending to B (based on IEEE 802.11)
  - Can (C, D) and (E, F) join?



Power Mode Management

- doze mode vs. active mode
- example:
  - A is sending to B (based on 802.11)
  - Does C need to stay awake?

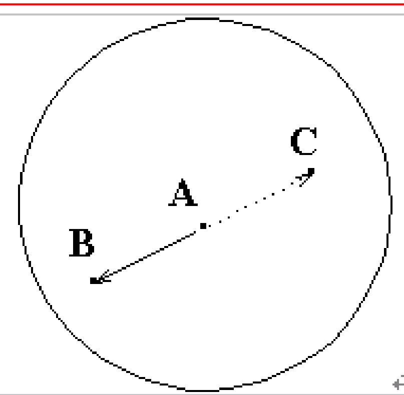
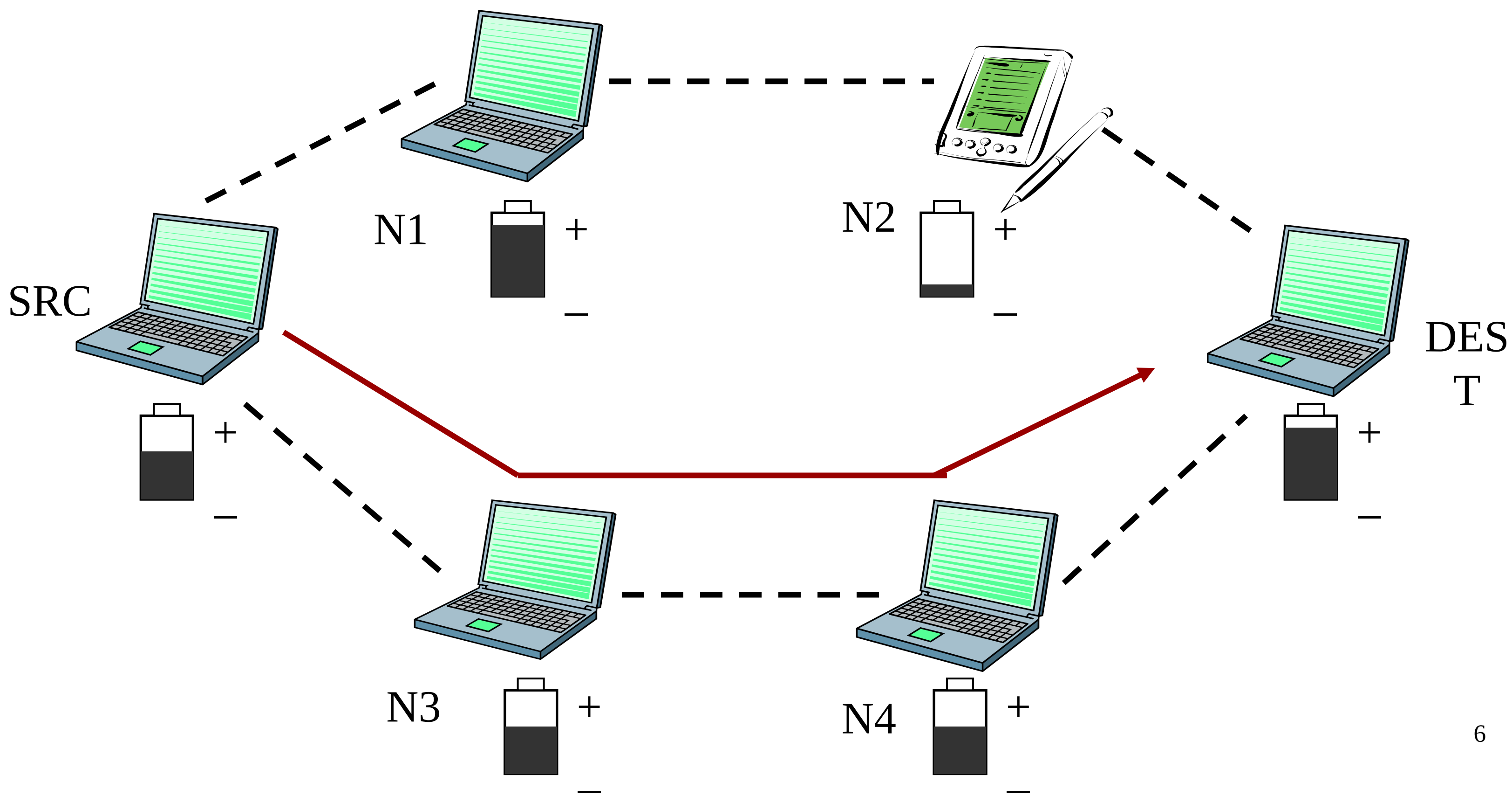


Figure 2 A scenario which shows that host A is sending to host B and host C can turn off its receiver since no receiving activity is possible for it for a while.

Power-Aware Routing

- routing in an ad hoc network with energy-saving in mind
- Example: in an ad hoc network



Power Mode Management in IEEE 802.11

Power Consumption

- IEEE 802.11 power model
  - transmit: 1400 mW
  - receive: 1000 mW
  - idle: 830 mW
  - sleep: 130 mW

	Doze mode	Receive mode	Transmit mode
Lucent ORiNOCO WLAN PC Card	0.05 Watt	0.9 Watt	1.4 Watt

Table 1 Doze/receive/transmit powers of Lucent ORiNOCO Wireless LAN PC Card (data from http://www.agere.com, dated September 13, 2000).

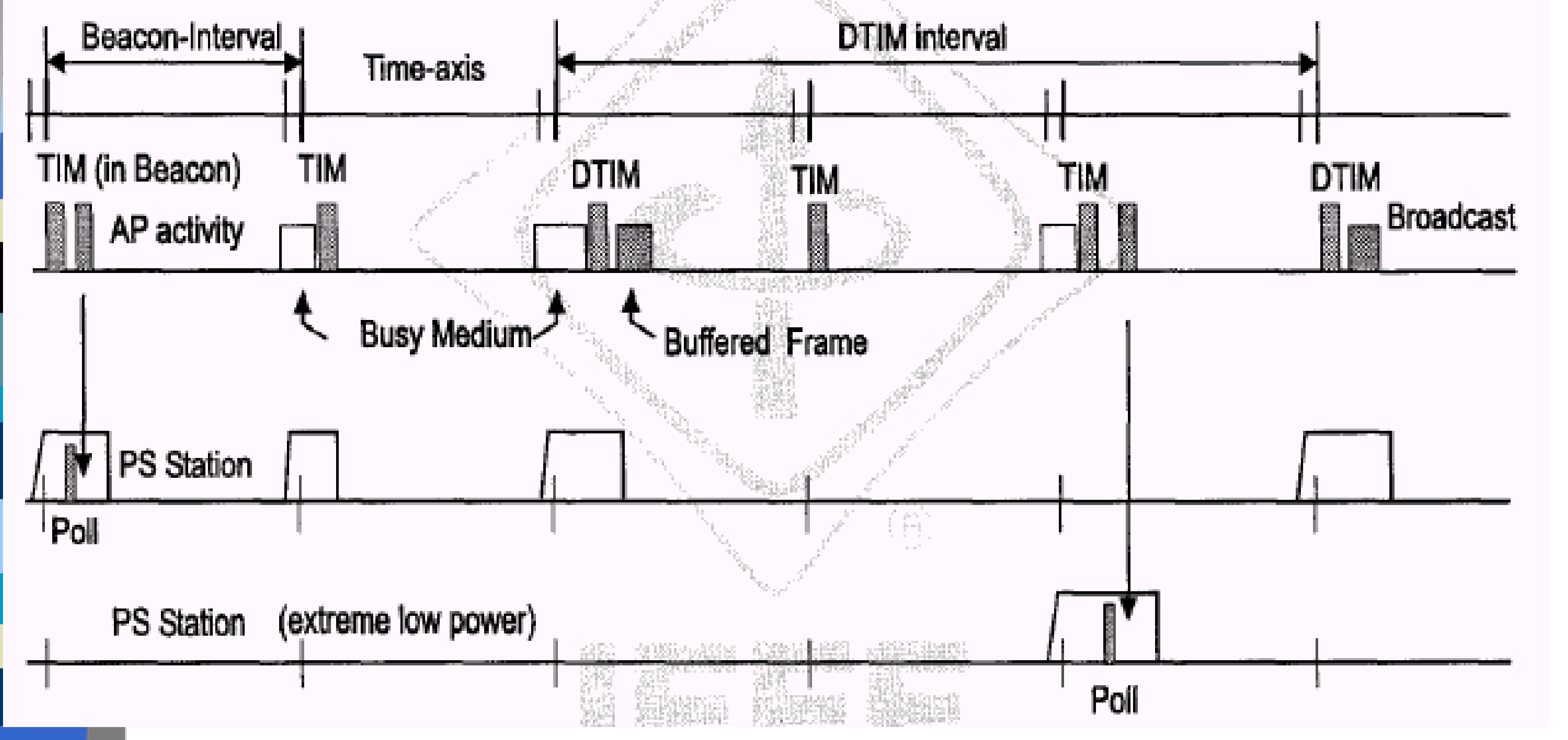
Problem Definition

- Power modes in IEEE 802.11
  - PS and ACTIVE

- Problem Spectrum:
  - infrastructure
  - ad hoc network (MANET)
    - single-hop
    - multi-hop ad hoc networks

Infrastructure Mode

- two power modes: active and power-saving (PS)

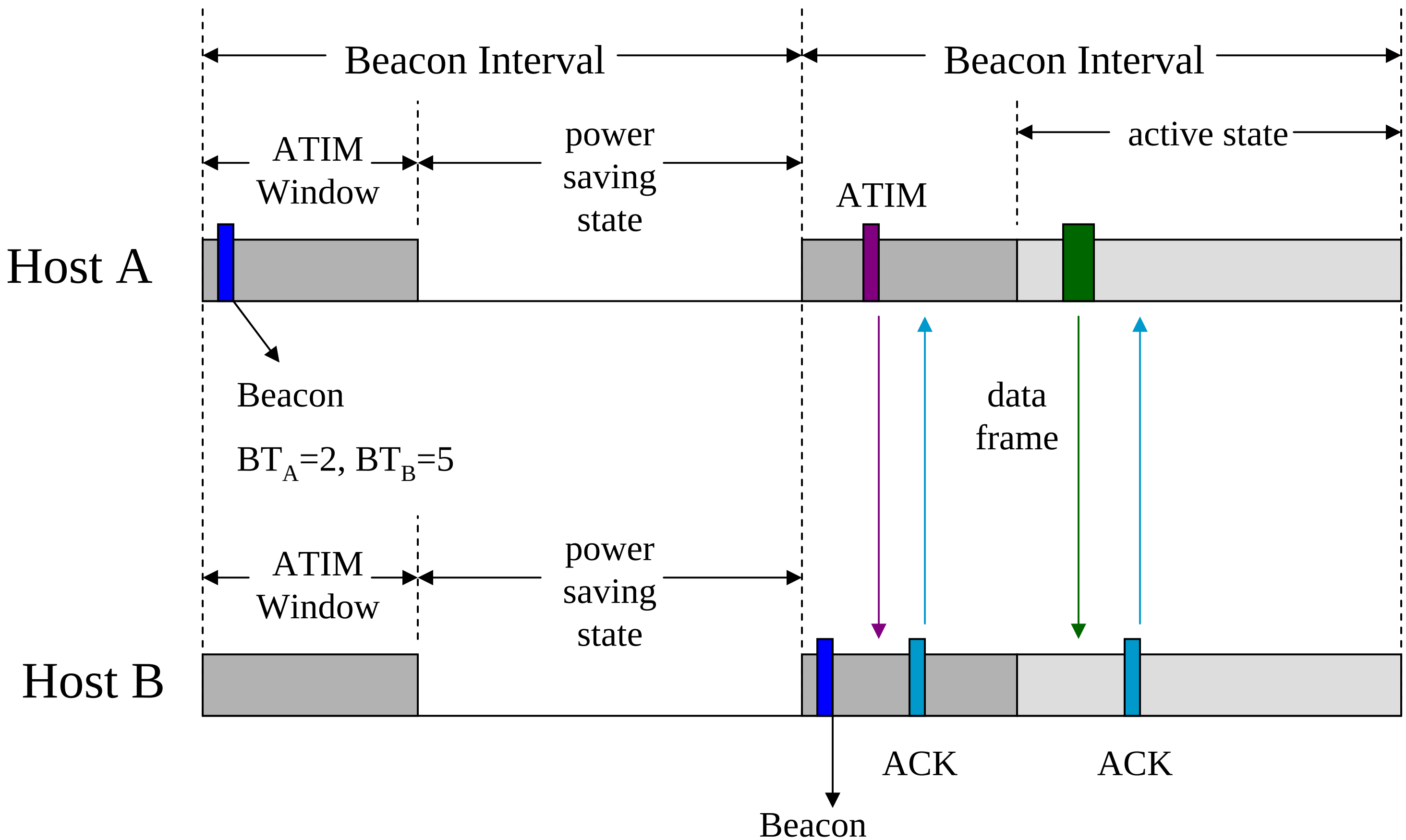


Details

- AP monitors modes of mobile hosts.
  - A host always notifies AP its mode.
- Periodically, AP transmits beacons.
  - A PS host only listens to beacons to check possible coming packets.
  - signaled by traffic indication map (TIM)

Ad Hoc Mode (Single-Hop)

- PS hosts also wake up periodically.
  - interval = ATIM (Ad hoc) window



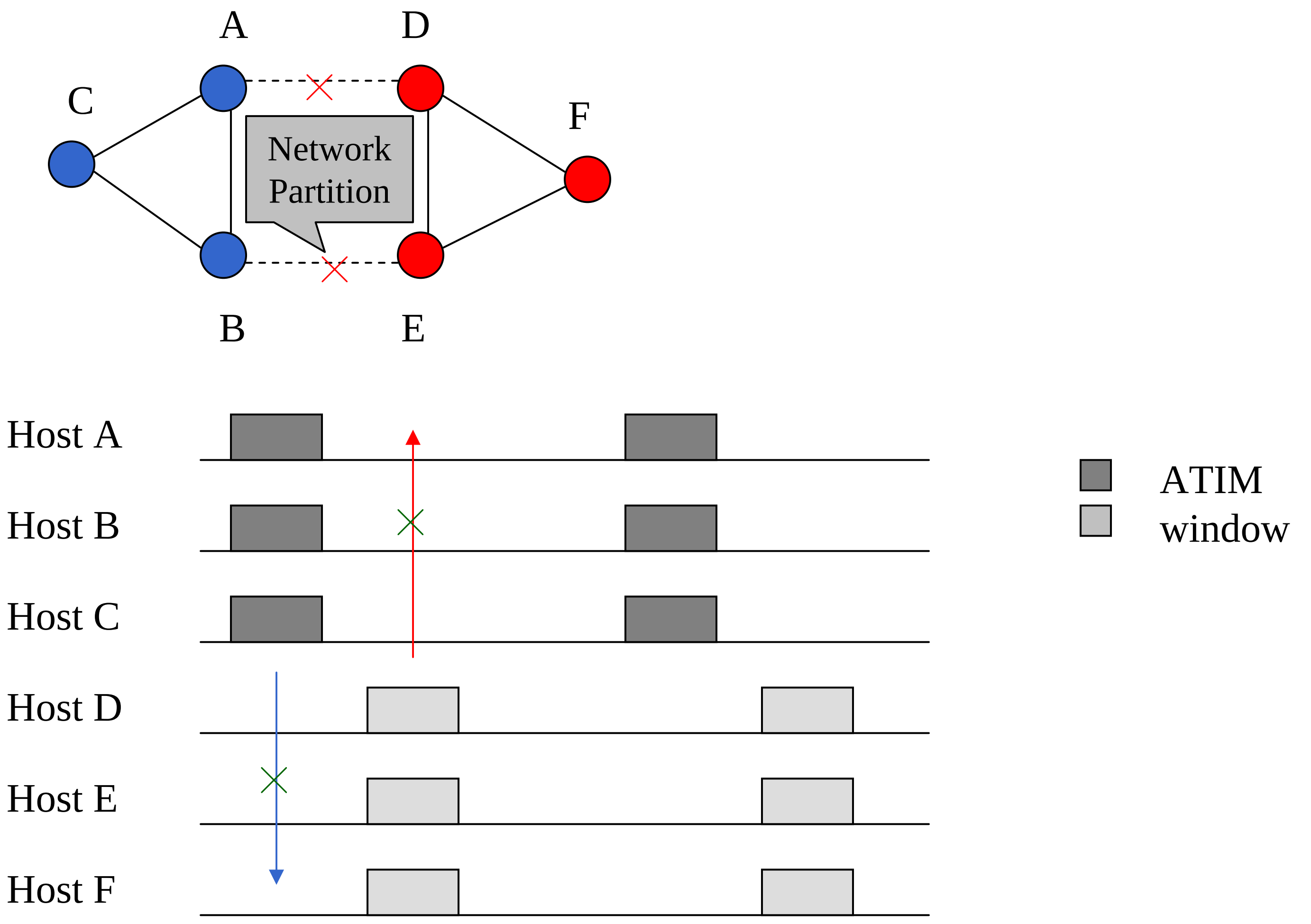
Details

- In each ATIM window
  - every host contends to send a beacon
    - for clock synchronization
    - inhibiting (one beacon in each interval)
  - contends to send ATIM to wake up PS hosts with buffered packets
  - after the ATIM window, contend to send data frames by CSMA/CA

Problems with Multi-Hop MANET

- Clock Synchronization:
  - a difficult job due to communication delays and mobility
- Neighbor Discovery:
  - by inhibiting other's beacons, hosts may not be aware of others' existence
- Network Partitioning:
  - with unsynchronized ATIM windows, hosts with different wakeup times may become partitioned networks

Network-Partitioning Example



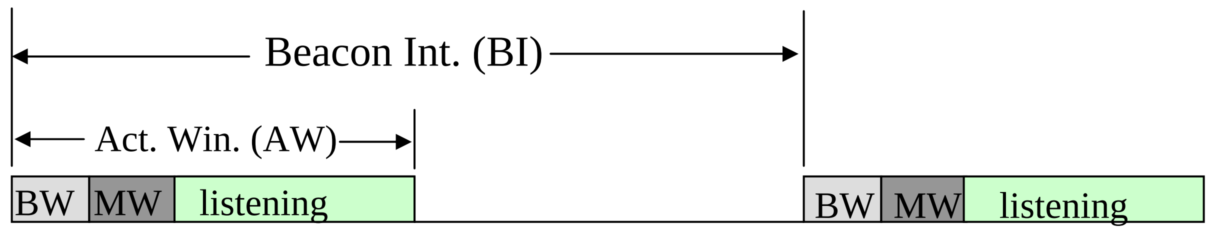
What Do We Need?

- PS protocols for multi-hop ad hoc networks
  - Fully distributed
  - No need of clock synchronization (i.e., asynchronous PS)
  - Always able to go to sleep mode, if desired

Features of Our Design

- Guaranteed Overlapping Awake Intervals:
  - two PS hosts' wake-up patterns always overlap
  - no matter how much time their clocks drift
- Wake-up Prediction:
  - with beacons, derive other PS host's wake-up pattern based on their time difference

Structure of a Beacon Interval



- BI: beacon interval (to send beacons)
- AW: active window
  - BW: beacon window
  - MW: MTIM window (for receiving MTIM)
  - listening period: to monitor the environment

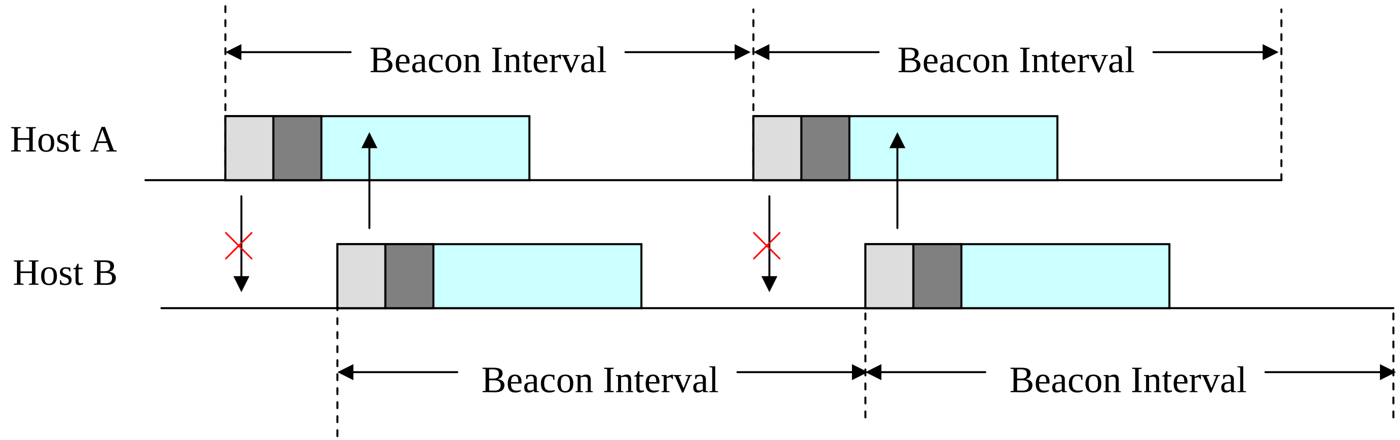
Three Protocols

- Based on the above structure, we propose three protocols
  - Dominating-Awake-Interval
  - Periodical-Fully-Awake-Interval
  - Quorum-Based

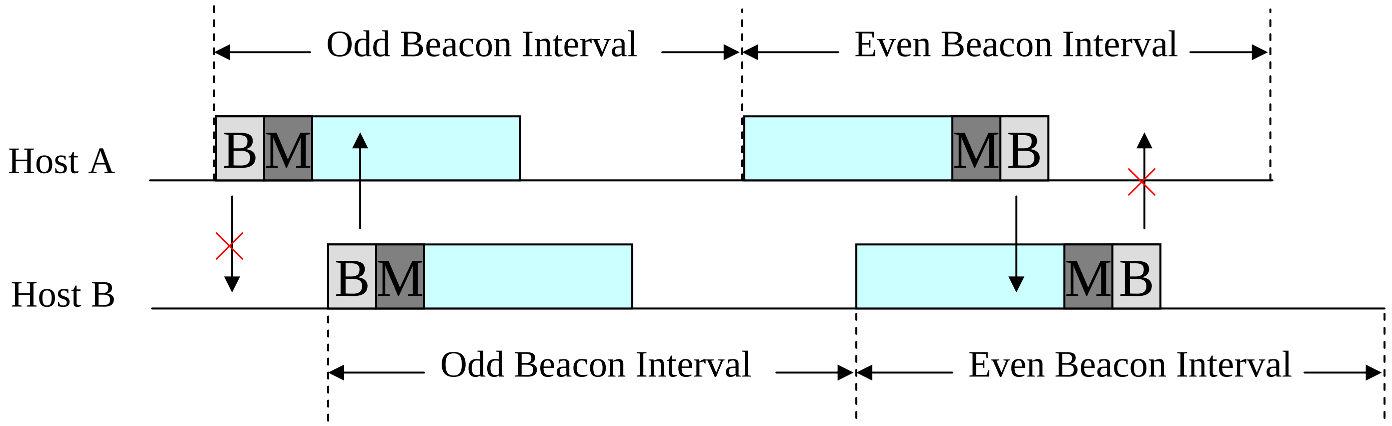
P1: Dominating-Awake-Interval

- intuition: impose a PS host to stay awake sufficiently long
- "dominating-awake" property

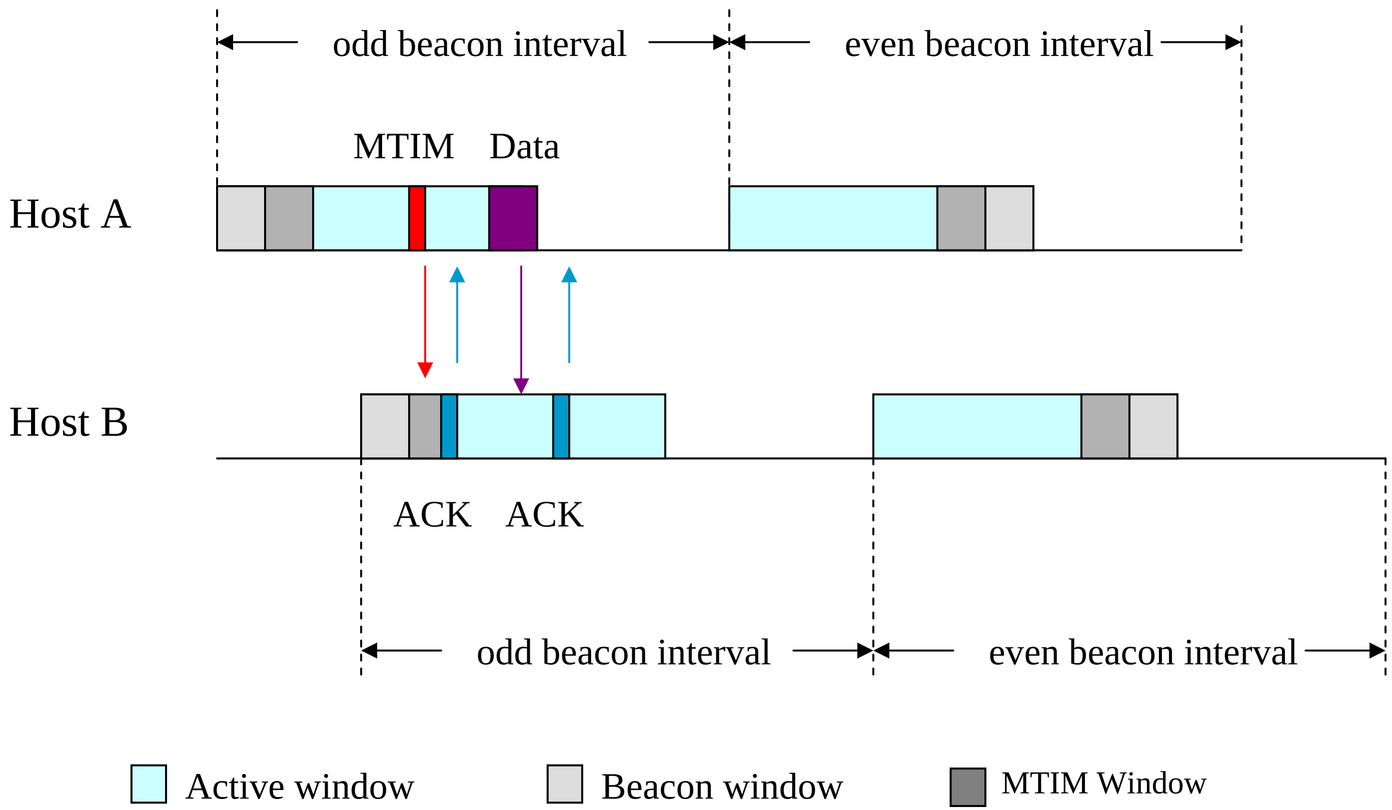
$$AW \geq BI/2 + BW$$



- Problem:
  - only dectectable in ONE direction
- Adjustment:
  - odd beacon interval:
    - Active Window = BW + MW + listening
  - even beacon interval:
    - Active Window = listening + MW + BW



Unicast Example



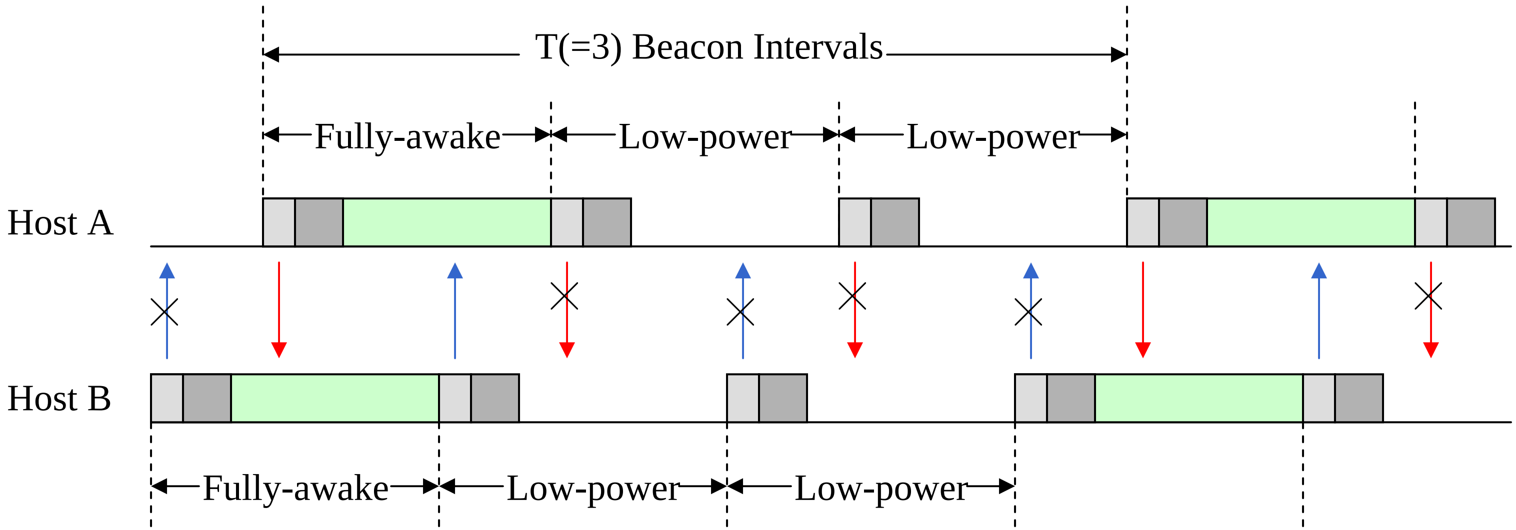
Characteristics

- dominating awake
  - wake-up ratio < 1/2
- sensibility
  - A PS host can receive a neighbor's beacon once every two beacon intervals.
  - suitable for highly mobile environment

P2: Periodical-Fully-Awake-Interval

- Basic Idea:
  - In every T intervals, stay awake in one full interval.
  - wake-up ratio ≅ 1/T
    - compared to 1/2 of protocol 1
- Two types of beacon intervals:
  - Low-power interval
  - Fully-awake interval (in every T intervals)

Example (T = 3)



T: Interval between the fully awake periods

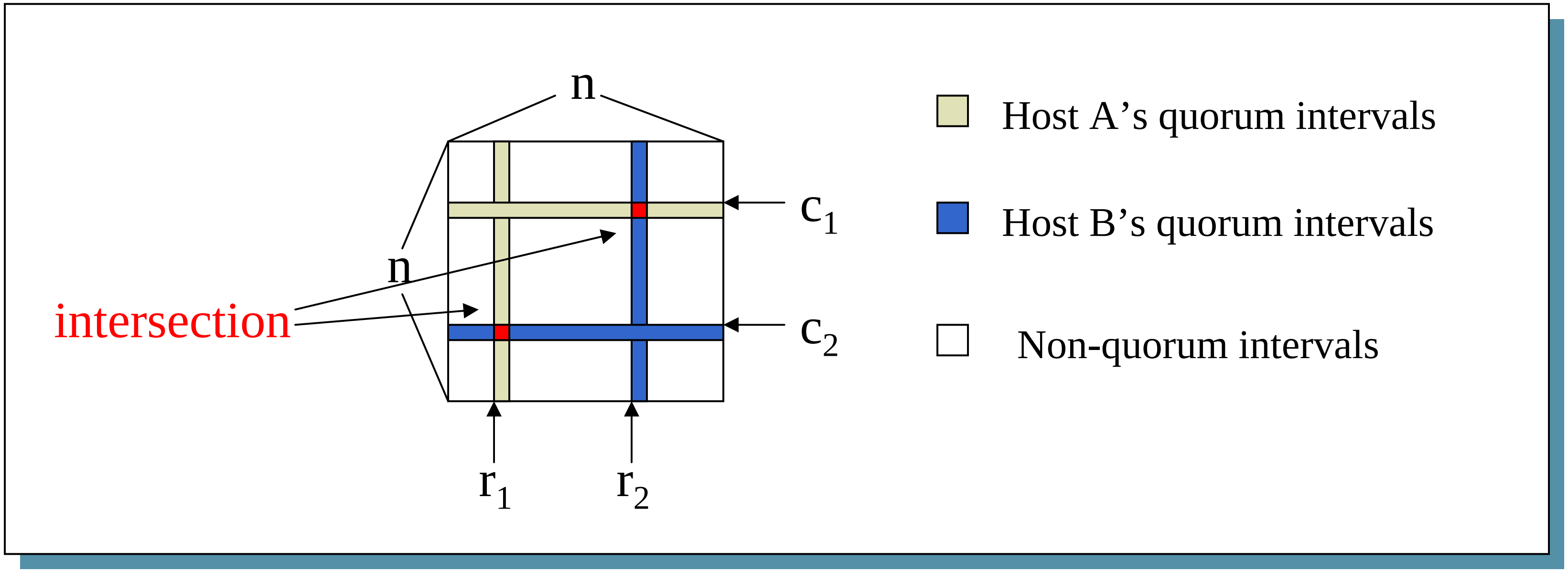
A PS host can receive its neighbor's beacon frame in every T = 3 beacon intervals

Definitions of Intervals

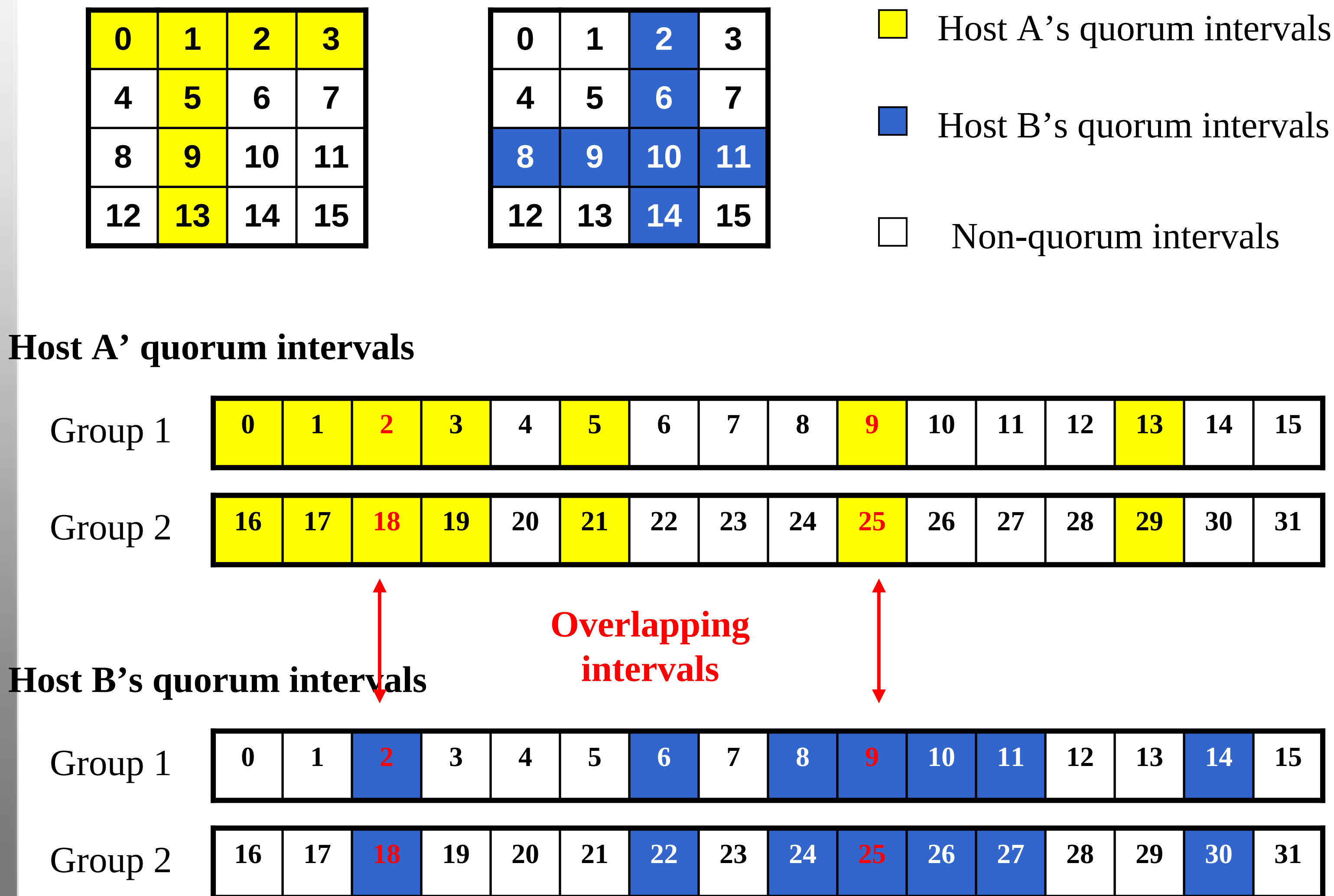
- Low-power interval:
  - active window + doze window
  - AW = BW + MW
    - i.e., listening period = 0
- Fully-awake interval:
  - no doze window
    - i.e., AW = BI
  - very energy-consuming, so only appears once every T beacon intervals

P3: Quorum-Based

- Quorum Sets:
  - Two quorum sets always have nonempty intersection.
  - (used here to guarantee detectability)
- A matrix example:



Example (2D matrix quorum)



Overlapping Property

- Overlap no matter how clocks drift

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

Host A’s quorum intervals

Host B’s quorum intervals

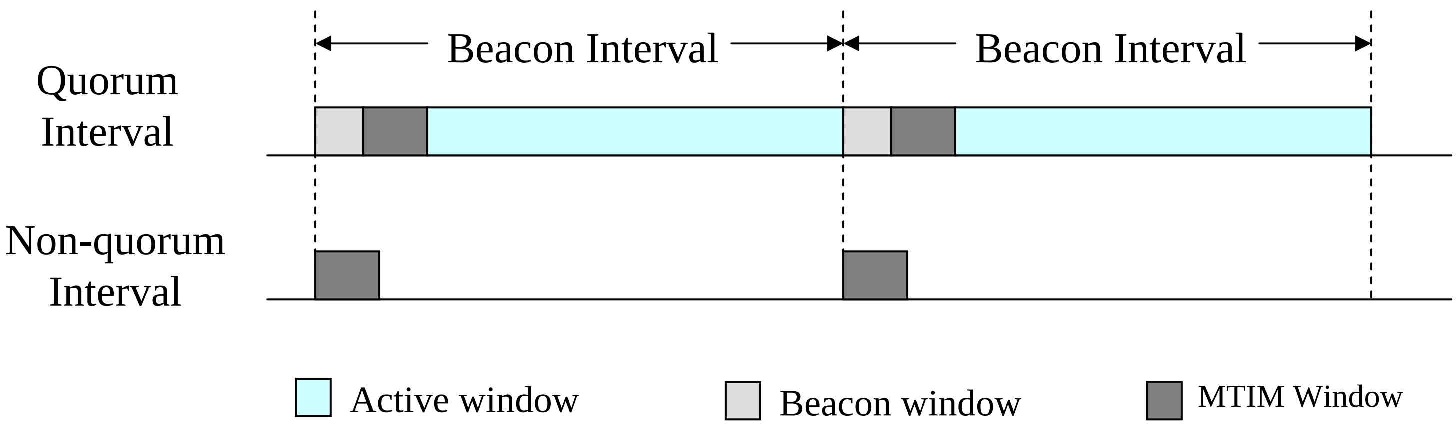
- demo ...

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Quorum and Non-quorum Intervals

- Quorum interval:
  - AW = BI (i.e., fully awake)
- Non-quorum interval:
  - no beacon, only MTIM window
  - AW < BI
  - BW = 0, AW = MW



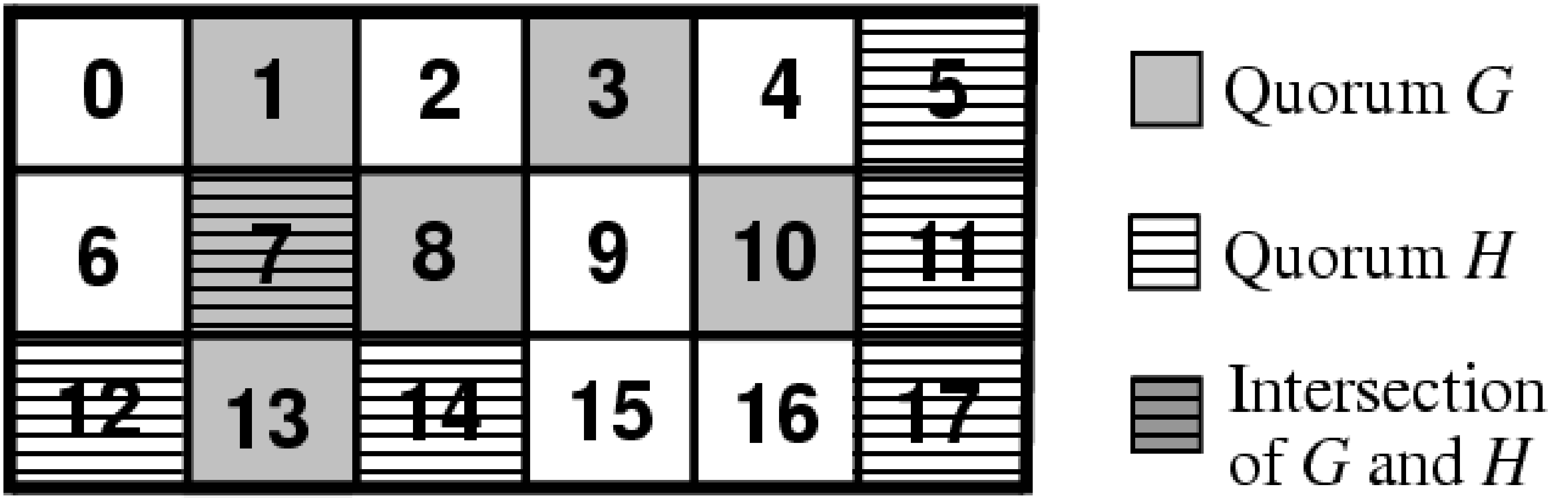
Optimal Quorum Size

- Optimal quorum size:
  k, where $k(k-1)+1=n$ and $k-1$ is a prime power ($K \approx \sqrt{n}$)

Optimal Quorum Systems

- Near optimal quorum systems
  - Grid quorum system
  - Torus quorum system
  - Cyclic (difference set) quorum system
- Optimal quorum system
  - FPP quorum system

Torus quorum system

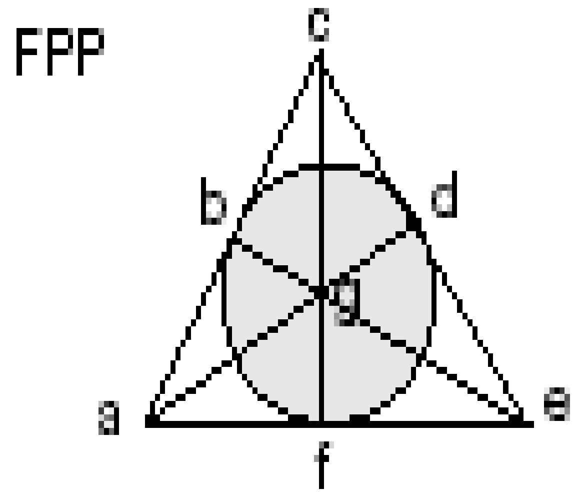


Cyclic (difference set) quorum system

- Def: A subset D={d1,…,dk} of Zn is called a difference set if for every e≠0 (mod n), there exist elements di and dj∈D such that di-dj=e.
- {0,1,2,4} is a difference set under Z8
- { {0, 1, 2, 4}, {1, 2, 3, 5}, {2, 3, 4, 6}, {3, 4, 5, 7},
  {4, 5, 6, 0}, {5, 6, 7, 1}, {6, 7, 0, 2}, {7, 0, 1, 3} } is a cyclic (difference set) quorum system

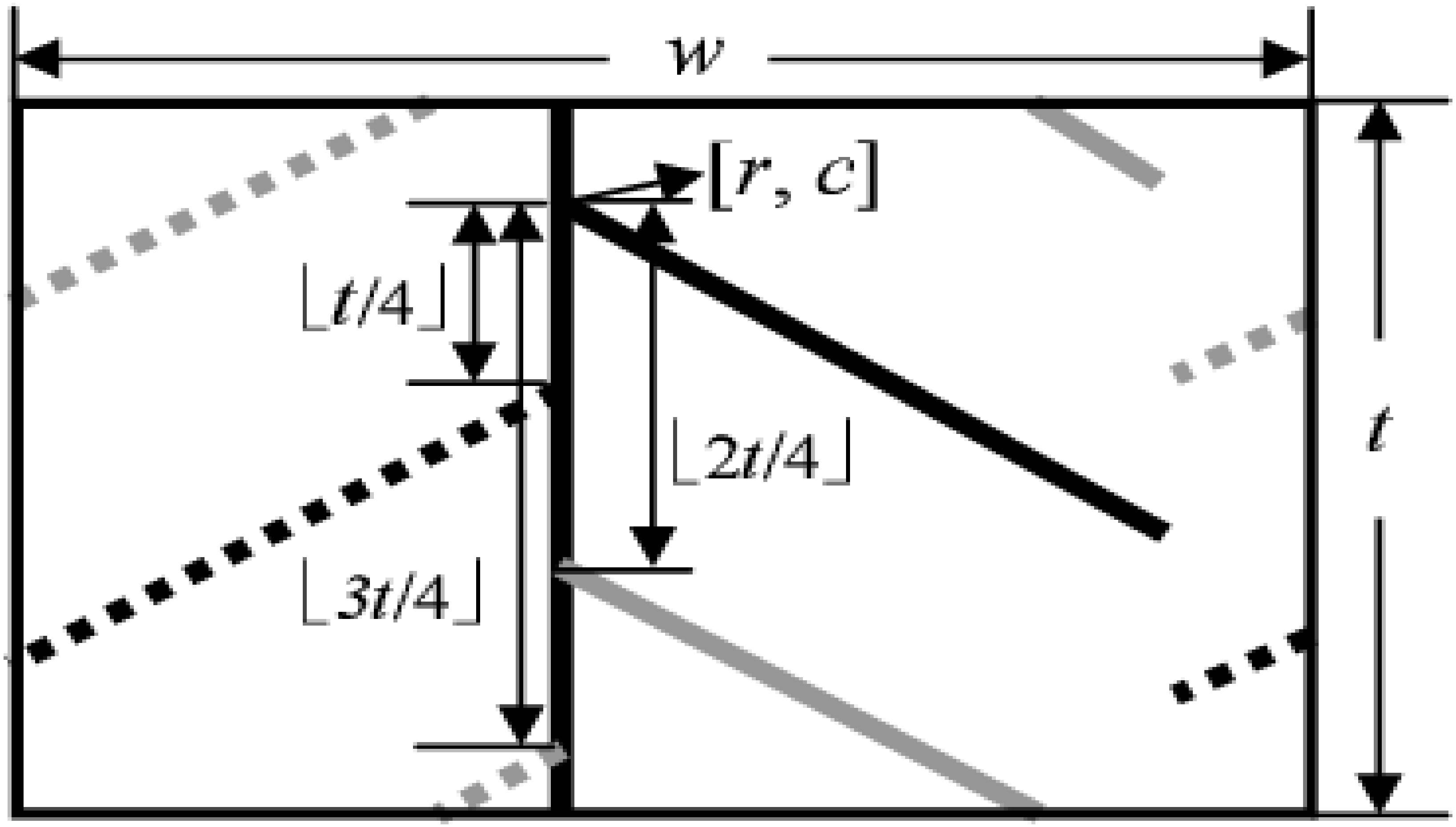
FPP quorum system

- FPP:
  Finite Projective Plan
- Proposed by
  Maekawa in 1985



- For solving distributed mutual exclusion
- Constructed with a hypergraph
- Also a Singer difference set quorum system

E-Torus quorum system



Summary

Protocol	Numbers of beacons	Active ratio	Neighbor sensitivity
Dominating	1	1/2+BW/BI	BI
Periodical	1	1/T	T*BI/2
Quorum	$(2n-1)/n^2$	$(2n-1)/n^2$	$(n^2/4)$ * BI

BI: length of a beacon interval

AW: length of an active window

BW: length of a beacon window

MW: length of an MTIM window

T: interval between the fully awake periods

n: length of the square

Summary

- Identify the problems of PS mode in IEEE 802.11 in multi-hop ad hoc networks.
  - clock drifting, network-partitioning
- Propose several PS protocols
- Connecting this problem to quorum issue in distributed systems.

Multicast group 睡眠週期同步機制

Host1	0	1	2	3	0	1	2	3
Host2	0	1	2	3	0	1	2	3

Multicast group 睡眠週期同步機制

- Multicast group 睡眠週期同步機制
  - CRT (中國餘式定理)
    - Let $p1, p2, \ldots, pm$ be m positive integers which are pairwise relatively prime, i.e. $\gcd(pi, pj)=1$ for $1 \le i < j \le m$.
    - Let $N = p1 \times p2 \times \ldots \times pm$ and let $r1, r2, \ldots, rm$ be m integers, where $ri < pi, \forall 1 \le i \le m$. Then, there exists a solution I solving the system of simultaneous congruences $I \equiv r1 \pmod{p1} \equiv r2 \pmod{p2} \equiv \ldots \equiv rm \pmod{pm}$.

Multicast group 睡眠週期同步機制

- Multicast group 睡眠週期同步機制
  - CRT (中國餘式定理)

CRT-MAC

R1	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	p1=5, r1=0
R2		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	p2=3, r2=1
R3									**0**	**1**	**2**	p3=2, r3=8

10=2p1+r1=3p2+r2=1p3+r3

Multicast group 睡眠週期同步機制

- Multicast group 睡眠週期同步機制

R1	0	1	2	3	4	5	6	7	8
R2		0	1	2	3	4	5	6	7
R3									0

Busy waiting approach

R1	0	1	2	3	4	5	6	7	8	9	10
R2		0	1	2	3	4	5	6	7	8	9
R3									0	1	2

CRT-MAC