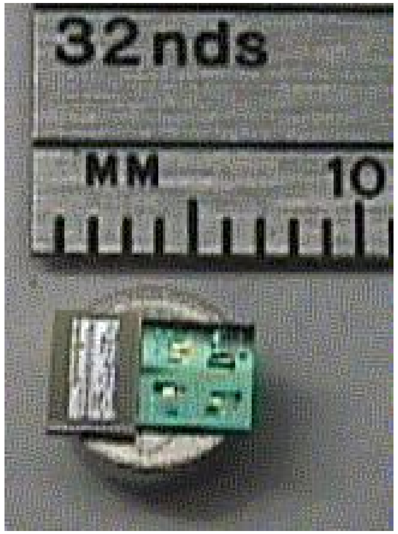
MAC and Broadcast

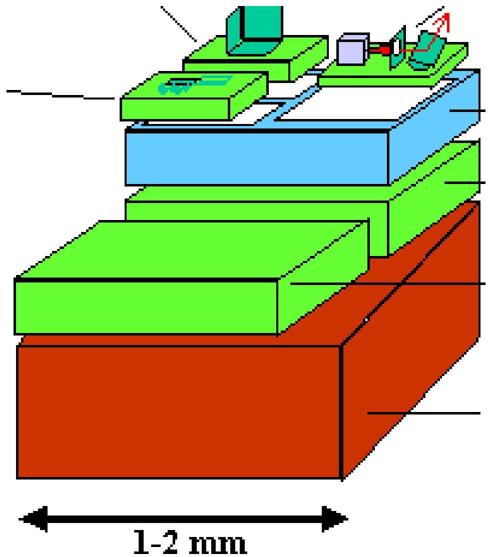
Introduction

- What are sensor networks?
- “Challenge of the century”
- **New paradigm** for distributed computing

What are they?

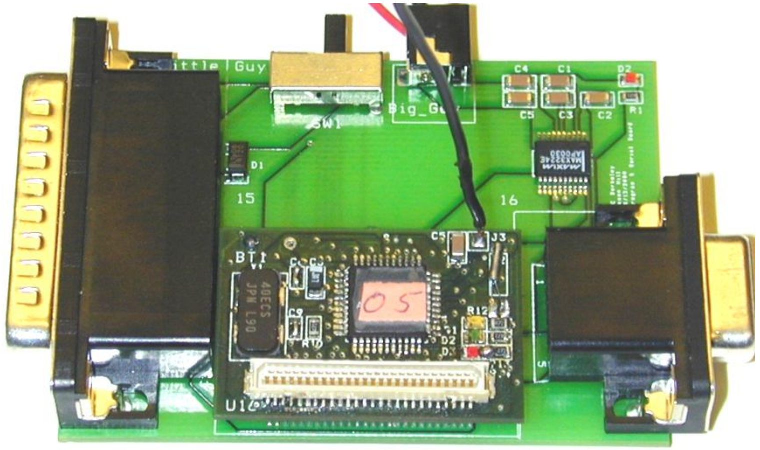
- Smart sensor = Micro-sensors + on-board processing + low-power wireless interfaces
  - All feasible at very small scale
- Berkeley Smart Dust

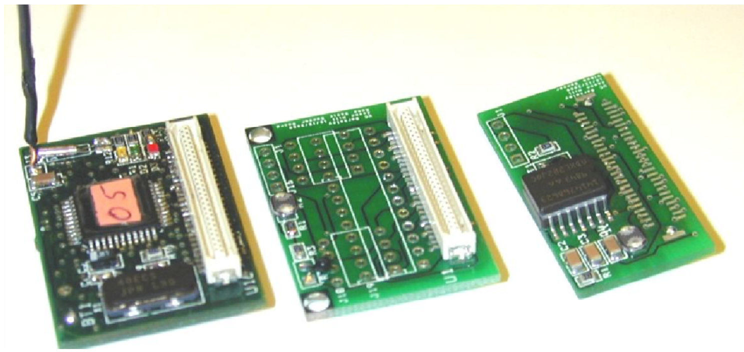




Mica Mote

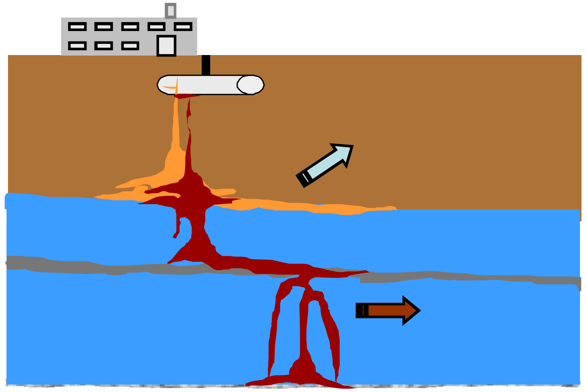
- Two Board Sandwich
  - CPU/Radio board
  - Sensor Board
- Size
  - Mote: 1×1 in
  - Pocket PC: 5.2×3.1 in
- CPU
  - Mote: 4 MHz, 8 bit
  - Pocket PC: 133 MHz, 32 bit
- Memory
  - Mote: 4KB SRAM
  - Pocket PC: 32 MB RAM
- Radio
  - Mote: 50 kbps
  - Bluetooth: 433.8 kbps; Wireless LAN: 10 Mbps





Applications

Seismic Structure response

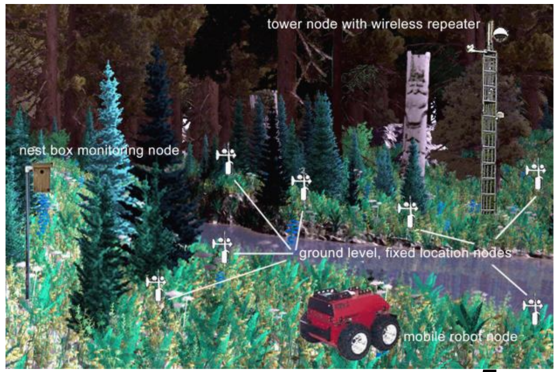


Contaminant Transport

- Smart sensors **massively distributed** in environments for sensing and control
- Enable **spatially and temporally dense** environmental monitoring
- **Embedded Networked Sensing will reveal previously unobservable phenomena**

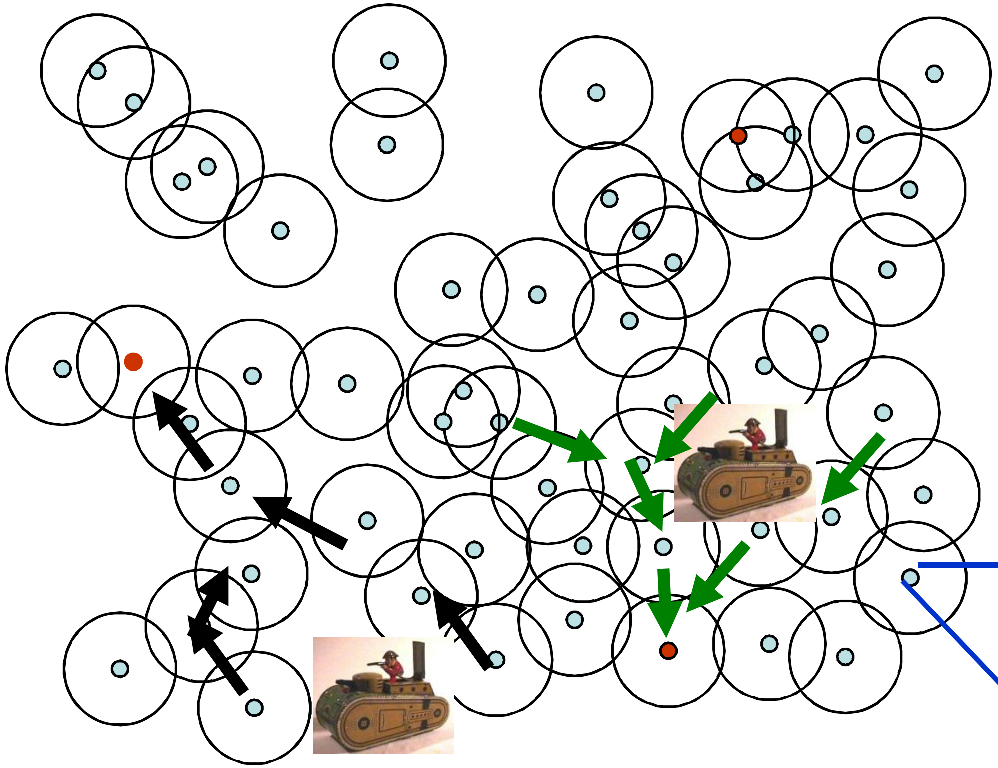
Marine Microorganisms

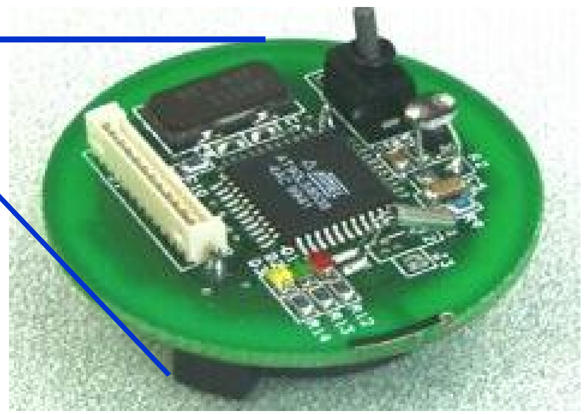
Ecosystems, Biocomplexity



Modified from Deborah Estrin, SIGMETRICS keynote, http://lecs.cs.ucla.edu/~estrin/talks/Sigmetrics-June02.ppt

Acoustic Tracking





Berkeley mote

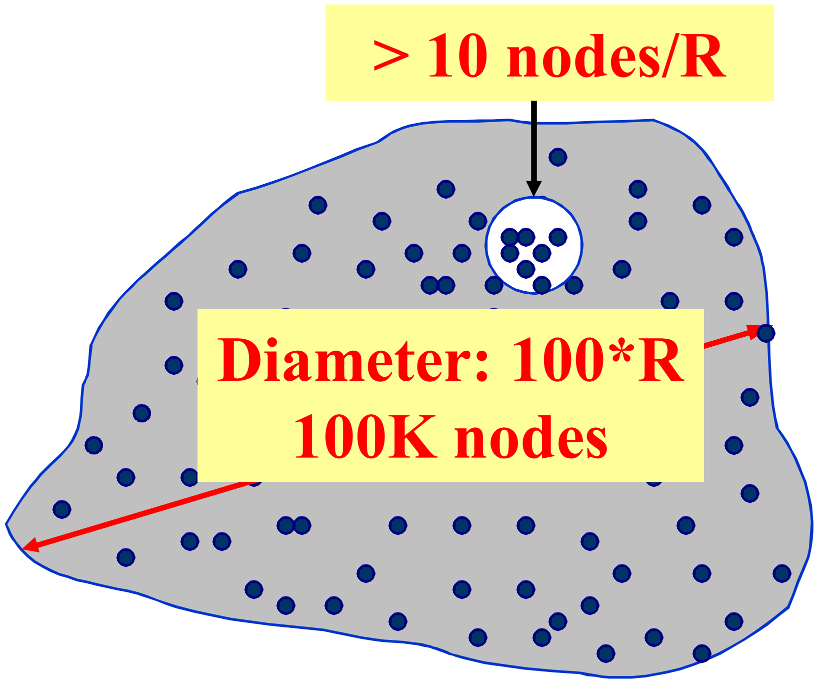
Modified from Lui Sha et. al.,,MURI presentation

Large Scale

- Number of nodes
- Diameter of networks
- Density

Radio radius R ≈ 30 m

Surveillance over 9 km^2 →

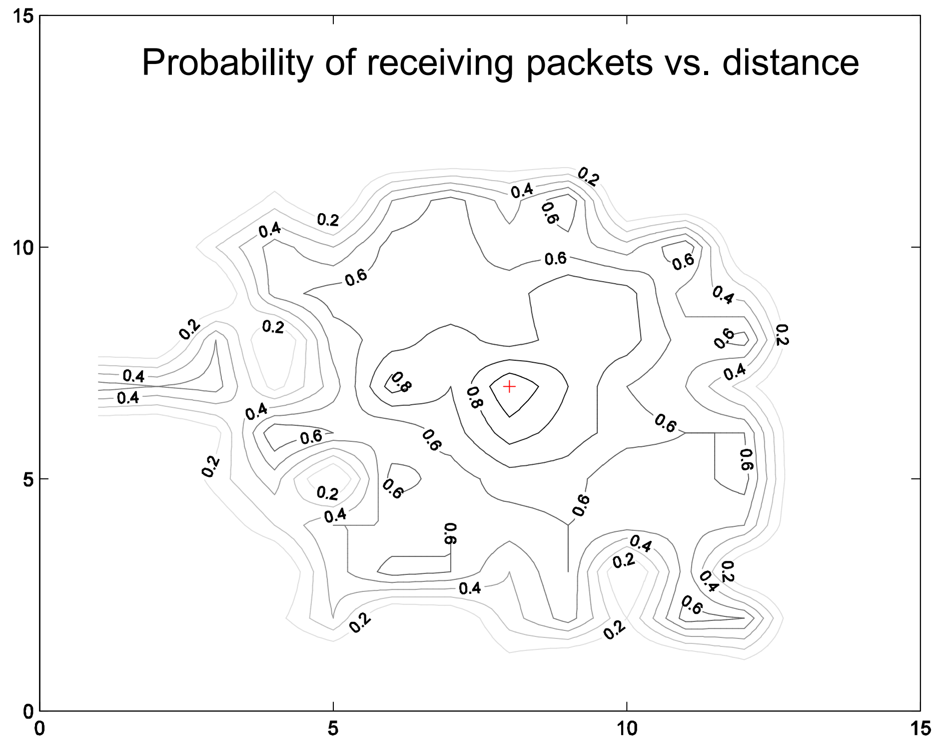


Severe Resource Constraints

- Bandwidth, CPU, memory, and storage
- **Energy**
  - Batteries, solar cells
  - Long life time
    - Bird habitat monitoring: 9 months
    - Bridges: years
- **Need power management!**

Unpredictability

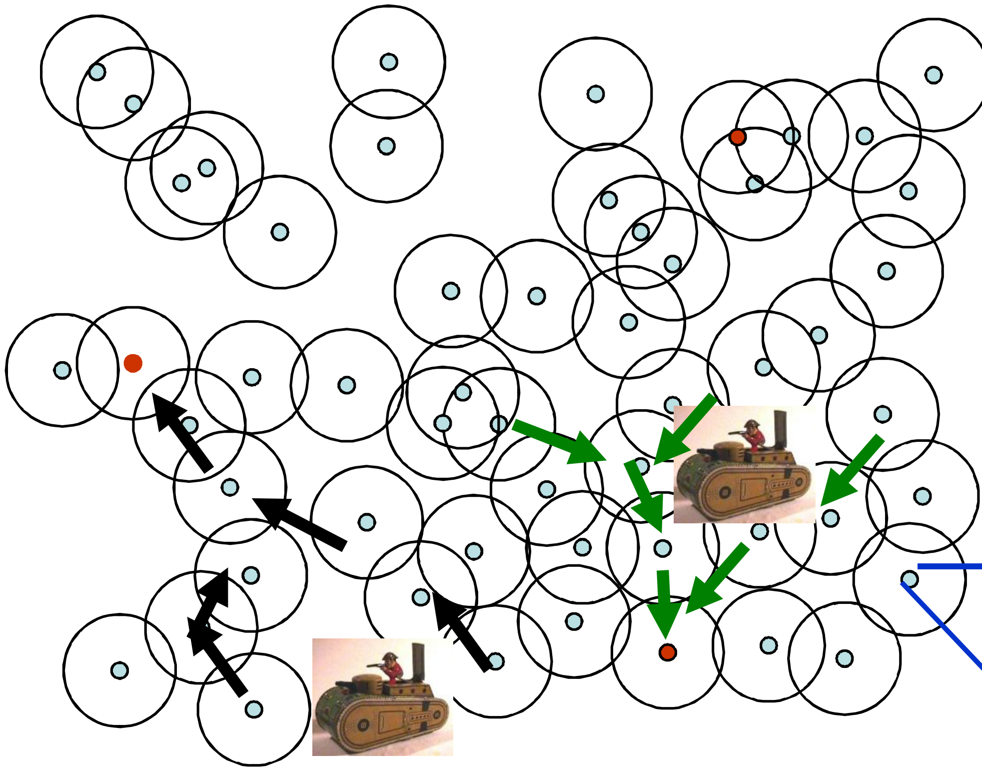
- Wireless
  - Environmental noises
  - Terrain
  - High fault rates
  - Unknown and changing topologies



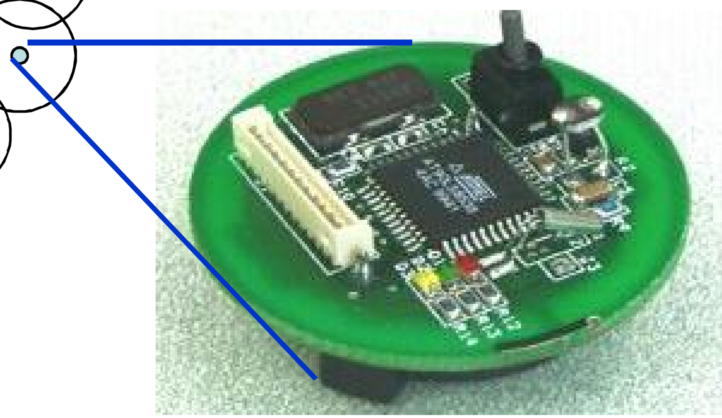
169 motes, 13x13 grid, 2 ft spacing, open area, RFM radio, simple CSMA

Deborah Estrin, SIGMETRICS keynote, http://lecs.cs.ucla.edu/~estrin/talks/Sigmetrics-June02.ppt

Real-Time Requirements



Timing constraints: locate/report targets within 30 sec



Berkeley mote

Security

- Physically exposed to potential hackers
- Wireless communication
- Resource-constrained

Sensor network is the

“challenge of the century”!

Data-Centric Communication

- Maximize **information** about physical events
  - NOT raw data throughput (as in traditional networks)
  - High redundancy in raw data
  - **In-network data aggregation** instead of sending everything to base stations

Decentralized Control

- Self-adaptation to handle unpredictabilities
  - Routing: avoid hot spots
  - Power management: optimal topology and lifetime
  - data caching/placement
  - Fault-tolerance
- Scalability: cannot depend on global information
- **Decentralized control**
  - Only depend on neighborhood information
  - Need to guarantee aggregate stability!

RI-MAC

目的

- 最小化sender与receiver的交互时间
- 降低占用信道的时间
- 降低占空比
- 适用低流量与高流量场景

X-MAC

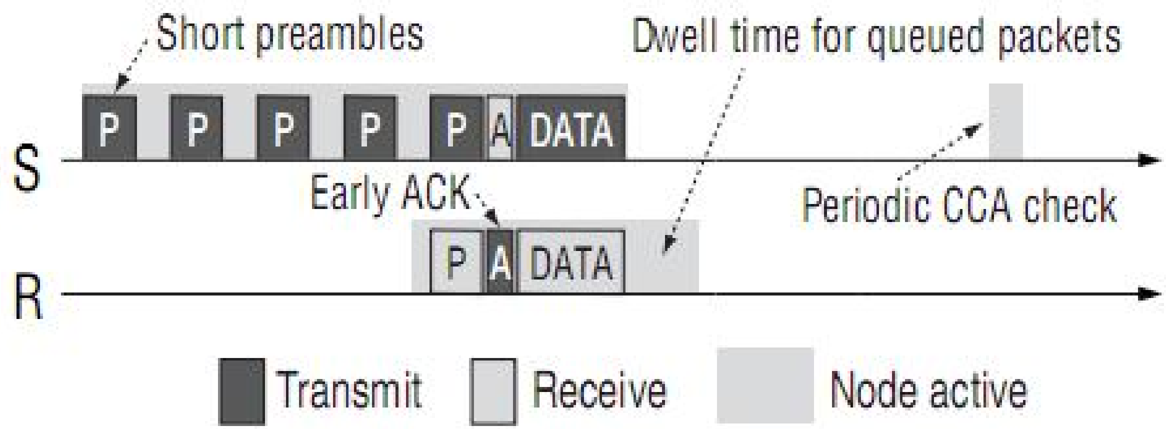


Figure 1: Operation of X-MAC, including the *strobed preamble* and *early acknowledgment*. During a scheduled wakeup time, a node does a CCA (clear channel assessment) check that is longer than the gap between two short preambles.

X-MAC+UPMA in TinyOS

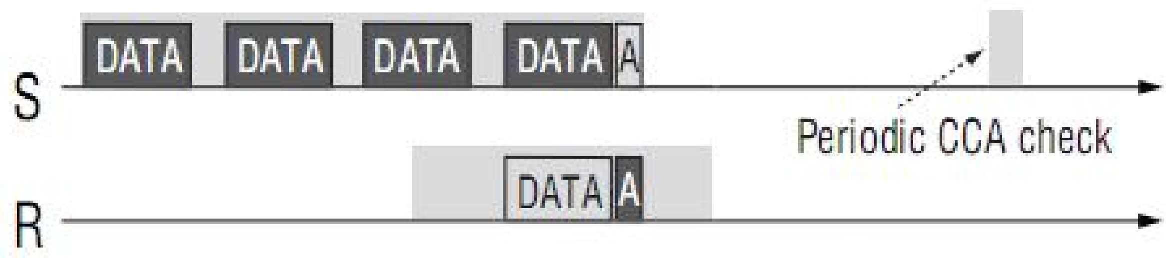


Figure 2: The variation of X-MAC implemented in the UPMA package in TinyOS. The strobed preamble is replaced by a chain of DATA frame transmissions.

RI-MAC

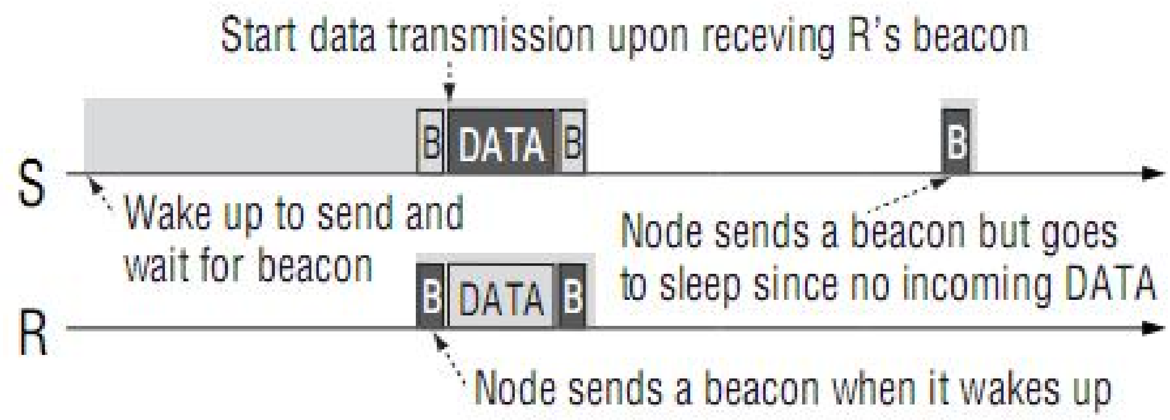


Figure 3: Overview of RI-MAC. Each node periodically wakes up and broadcasts a beacon. When node *S* wants to send a DATA frame to node *R*, it stays active silently and starts DATA transmission upon receiving a beacon from *R*. Node *S* later wakes up but goes to sleep after transmitting a beacon frame since there is no incoming DATA frame.

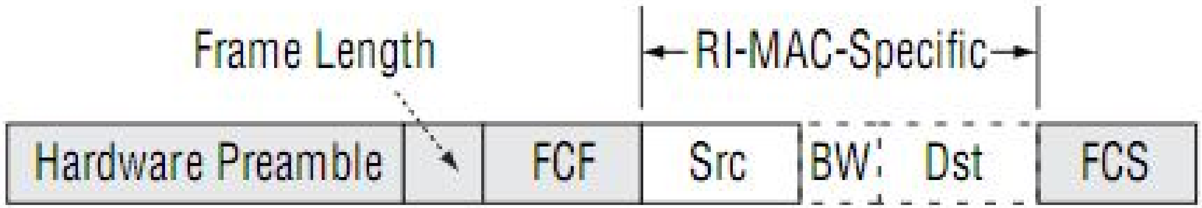


Figure 4: The format of an RI-MAC beacon frame for an IEEE 802.15.4 radio. Dashed rectangles indicate optional fields. The Frame Length, Frame Control Field (FCF), and Frame Check Sequence (FCS) are fields from IEEE 802.15.4 standard.

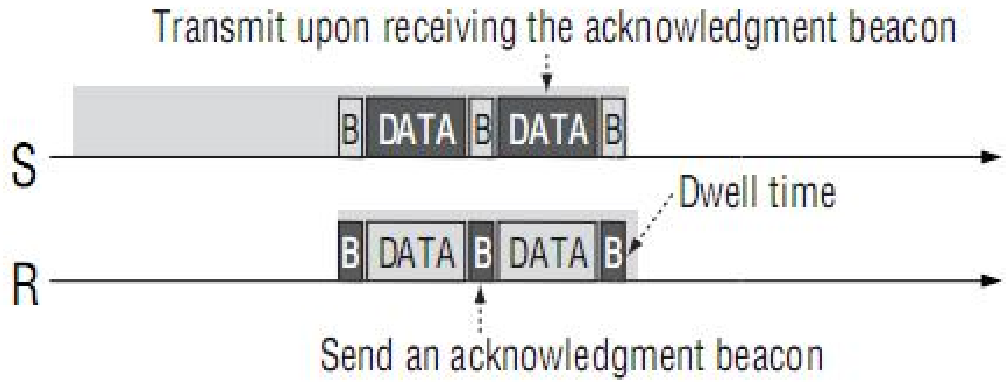


Figure 5: The dual roles of a beacon in RI-MAC. A beacon serves both as an acknowledgment to previously received DATA and as a request for the initiation of the next DATA transmission to this node.

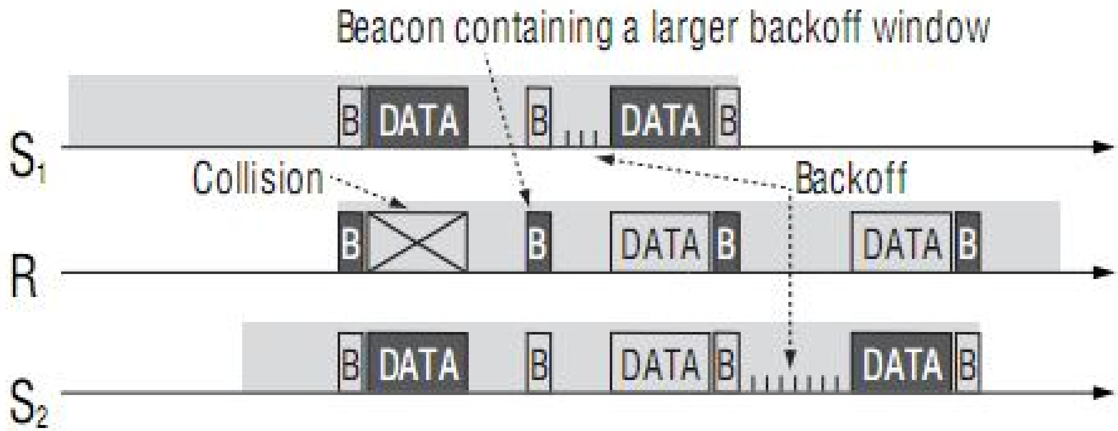


Figure 6: DATA frame transmission from contending senders in RI-MAC. For the first beacon, the receiver *R* requests senders (here, S_1 and S_2) to start transmitting DATA immediately upon receiving the beacon. If a collision is detected, *R* sends another beacon with increased BW value to request that senders do a backoff before their next transmission attempt.

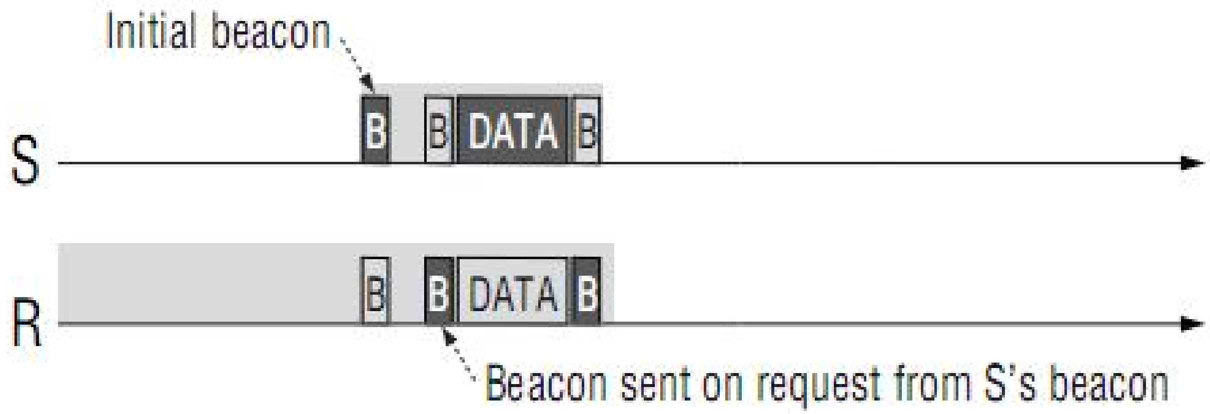


Figure 7: RI-MAC *beacon-on-request*. When node *S* wakes up for transmitting a pending DATA frame, it sends a beacon with the Dst field set to the destination of the pending DATA. If the destination node *R* is already active, *R* in response transmits a beacon to enable *S* to begin DATA transmission immediately.

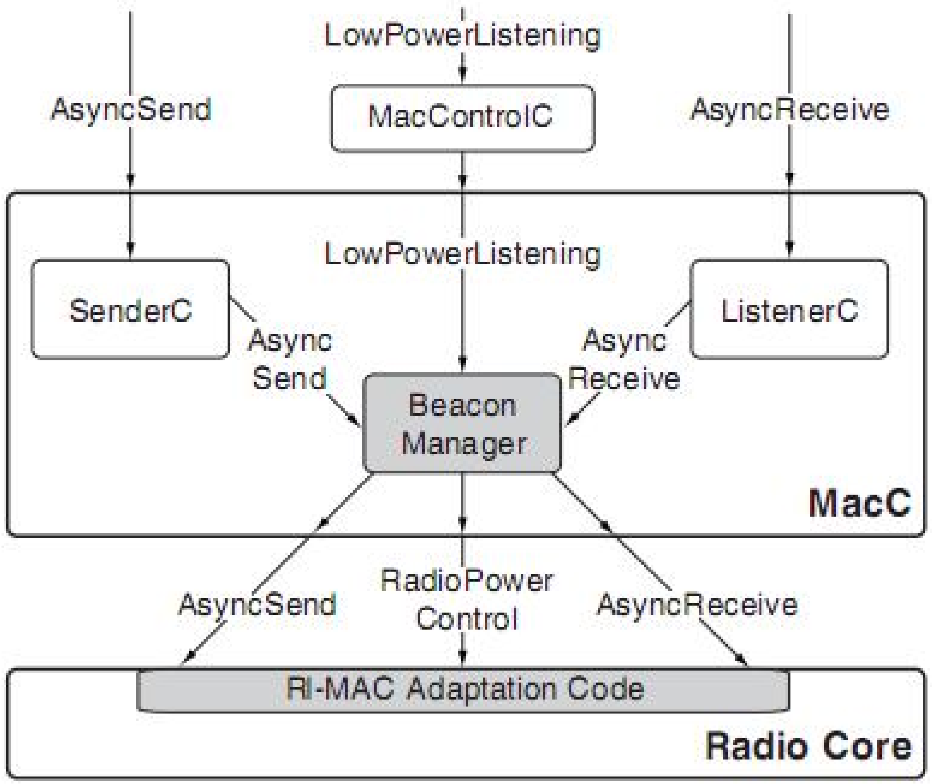
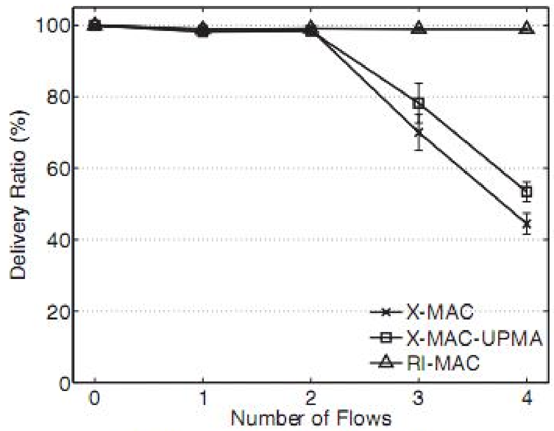
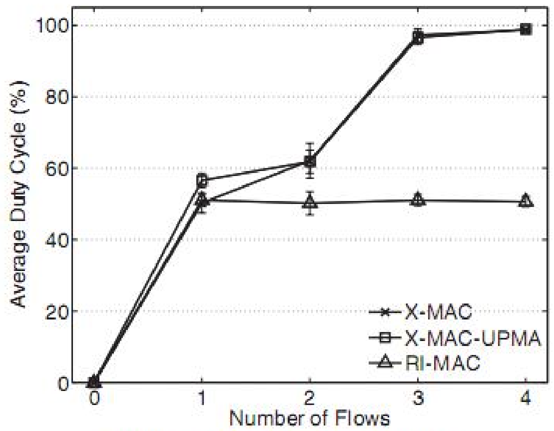


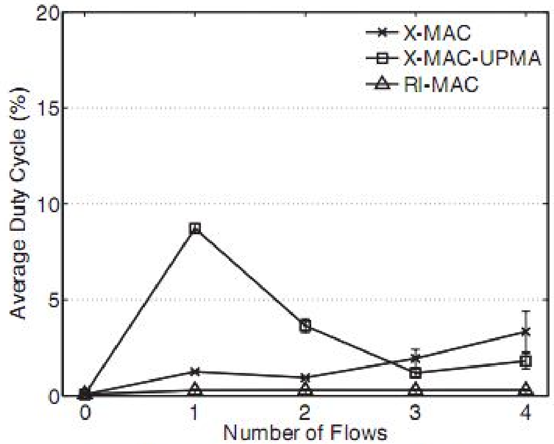
Figure 8: Composition of RI-MAC within the UPMA framework in TinyOS.



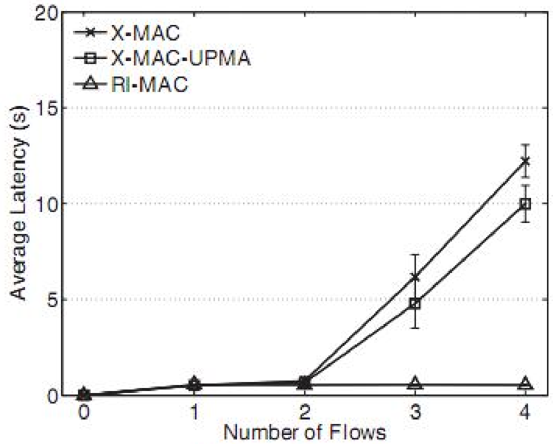
(a) Average Packet Delivery Ratio



(b) Average Duty Cycle of Senders



(c) Average Duty Cycle of Receivers



(d) Average Latency

PW-MAC

PW-MAC

- 解决异步网络中的重传问题
- Sender预测receiver的醒来时间
- 提出策略消除预测误差的影响

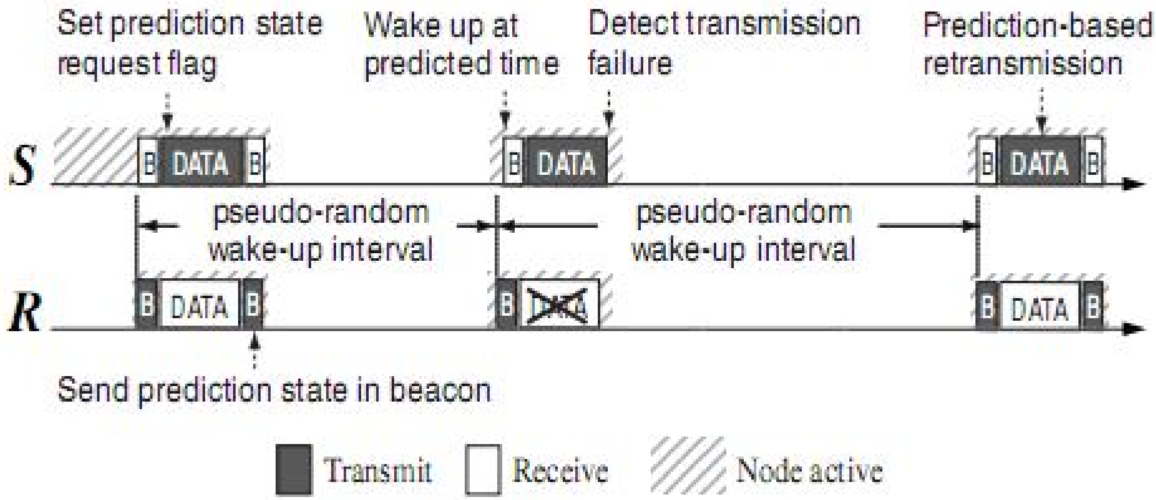


Fig. 1. A sender S in PW-MAC requests the prediction state of a receiver R and wakes up right before R does, after learning the prediction state of R. The prediction-based retransmission mechanism of PW-MAC enables S to detect the transmission failure and efficiently do packet retransmissions.

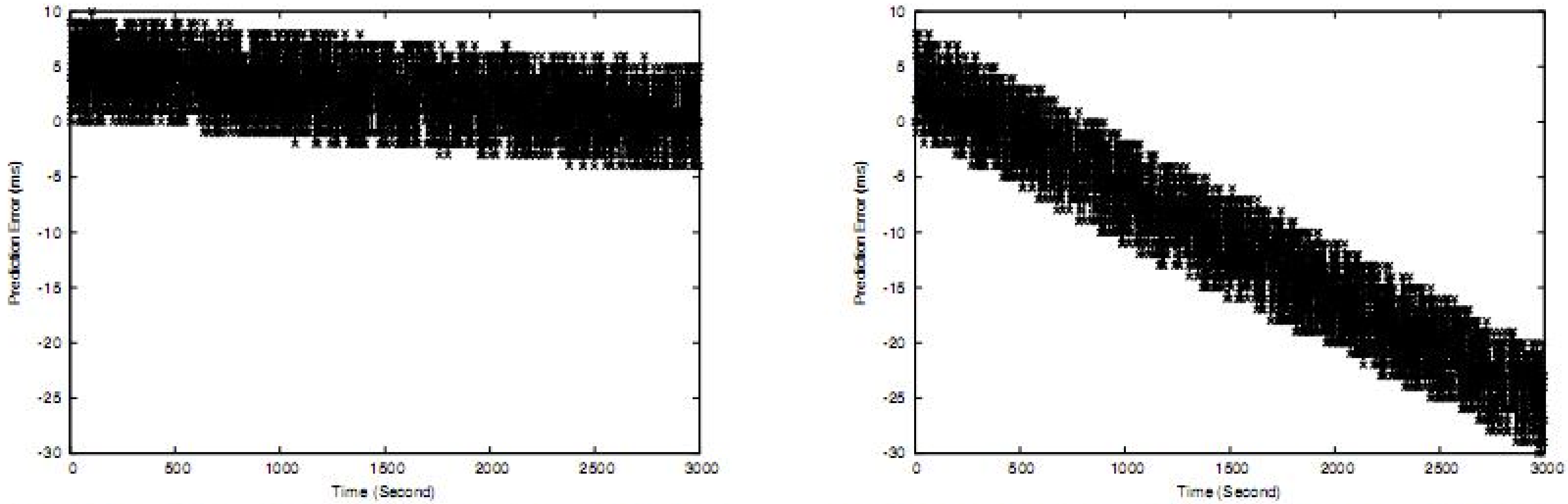
linear congruential generator (LCG)

$$X_{n+1} = (aX_n + c) \bmod m$$

Here, $m > 0$ is the *modulus*, a $(0 < a < m)$ is the *multiplier*, c $(0 \leq c < m)$ is the *increment*, and X_n $(0 \leq X_n < m)$ is the current *seed*. Each X_{n+1} generated can be used as a pseudo-random number and becomes the new seed.

The *prediction state* of R learned by S comprises the parameters and current seed of the pseudo-random number generator of R (6 bytes in total), as well as the current time difference between S and R (4 bytes); a sender thus needs only 10 bytes of memory to store the prediction state of a receiver.

相同配置的两对节点



(a) Factors such as variable operating system and hardware latency dominate the prediction error, as clock drift between these two motes is very small.

(b) Clock drift is much more significant between these two motes, dominating other factors such as variable operating system and hardware latency.

Fig. 2. The prediction error between two different, arbitrarily chosen pairs of MICAz motes over time.

These results demonstrate that clock drift may not always be the dominating factor causing prediction error.

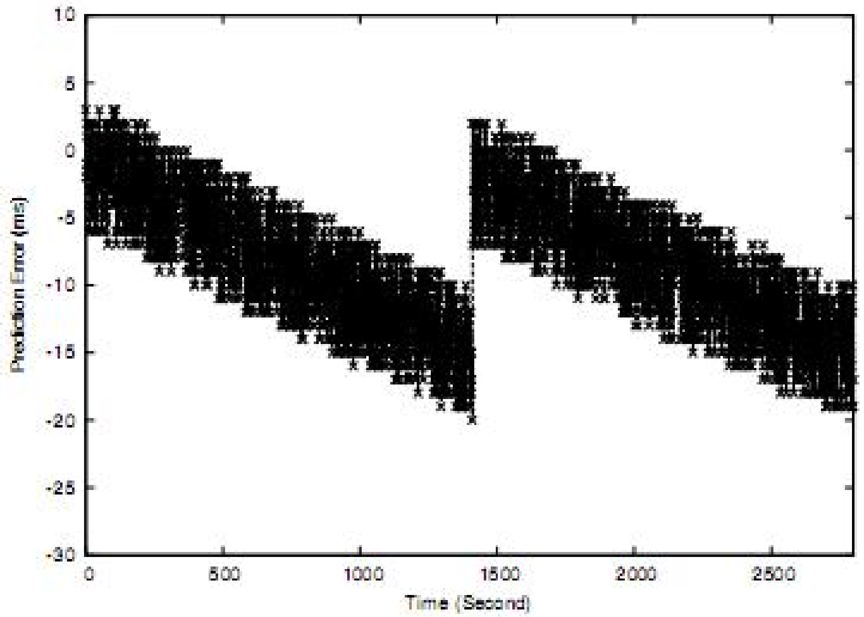


Fig. 3. The development of prediction error with on-demand correction. The correction threshold is configured as 20 ms, which is the same as the sender wakeup advance time. The same pair of MICAz motes as used in Figure 2(b) were used in this experiment.

当误差过大时进行更新

ADB

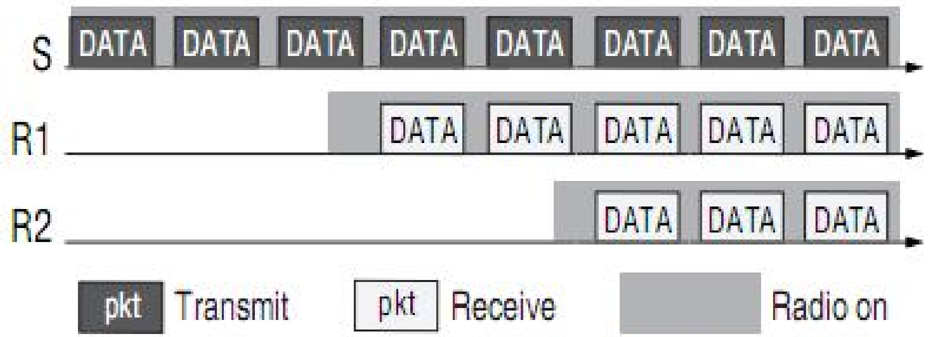


Figure 1. Broadcast support in X-MAC-UPMA [8,18]. A transmitter *S* repeatedly transmits copies of a broadcast DATA packet over a duty-cycle interval, during which each neighbor (nodes *R1* and *R2*) wakes up at least once and thus has an opportunity to receive the packet.

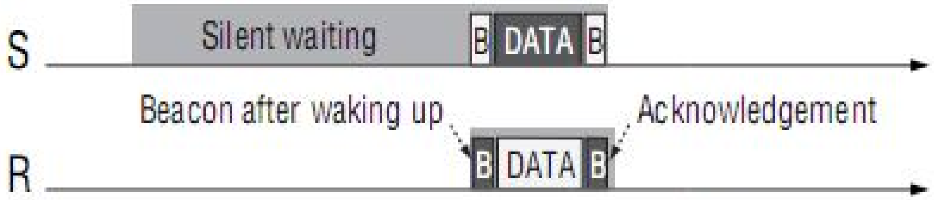


Figure 2. Unicast support in RI-MAC [17]. Each node wakes up on an independent schedule, with each wakeup interval varying randomly between $0.5 \times T$ and $1.5 \times T$, for a nominal duty-cycle period of T. A node transmits a *base beacon* when it wakes up, allowing a waiting sender to transmit a DATA packet to it. Upon receiving a DATA packet, the node transmits an *acknowledgment beacon* (ACK), confirming receipt and allowing other senders to also transmit a DATA packet to it, if needed. RI-MAC's collision resolution mechanisms are not shown here.

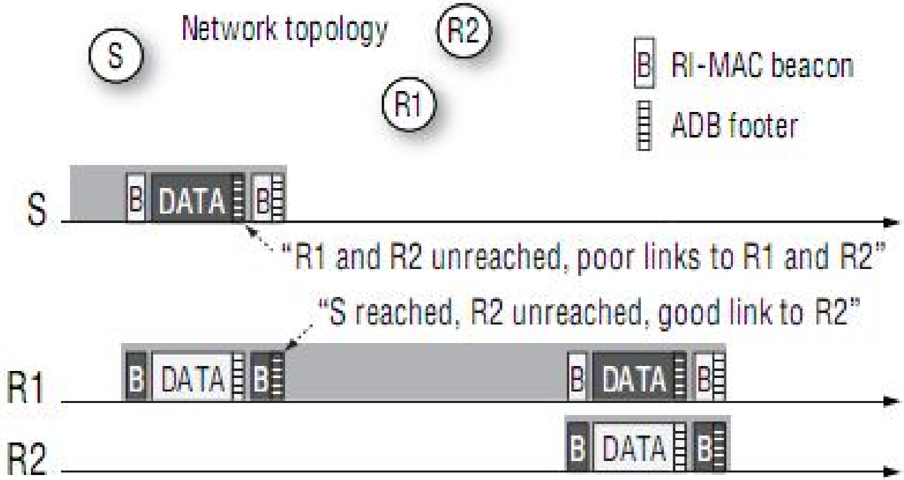


Figure 3. Overview of ADB. Node *S* broadcasts a DATA frame to node *R1* and *R2* via unicast transmission. The footer in DATA and ACK beacons helps *S* and *R1* to decide which node will deliver the DATA to *R2* and helps *R2* to learn that both *S* and *R1* have received the DATA.

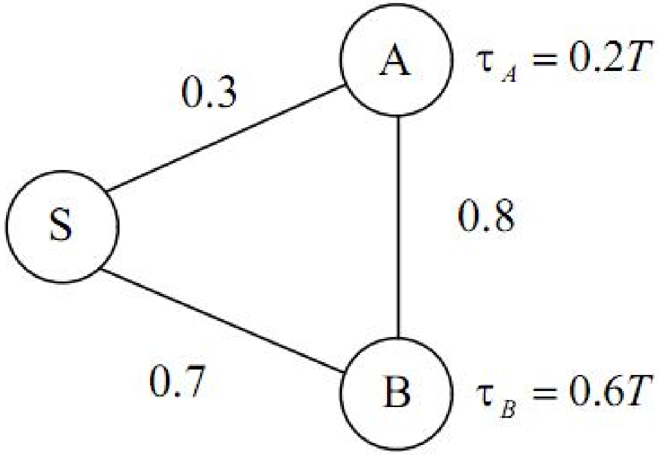


Fig. 1. An example with three nodes.

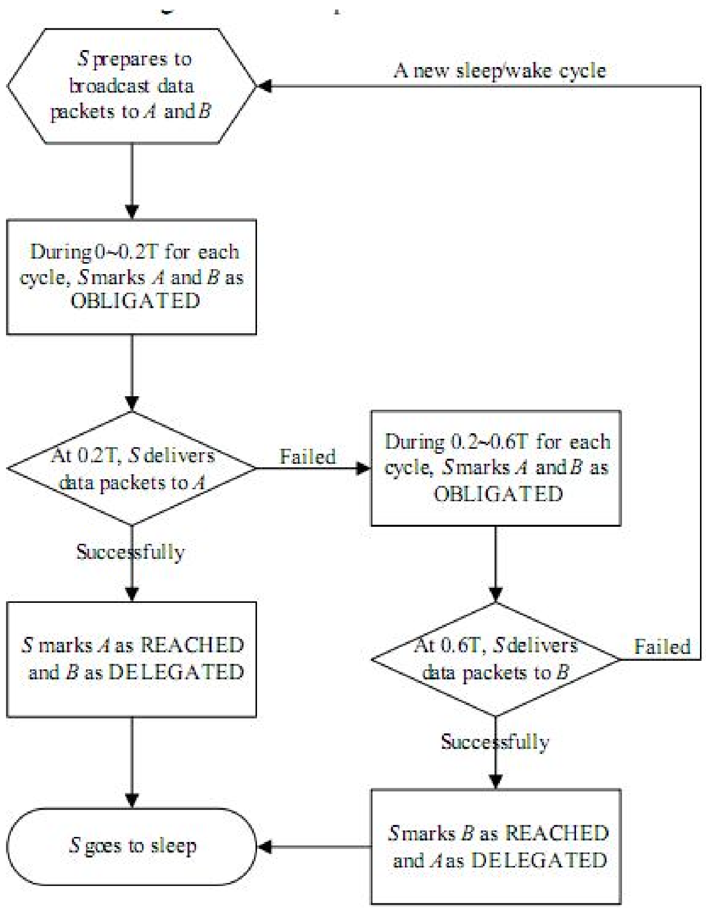


Fig. 2. The operations for node S at different scenarios.

EMBA

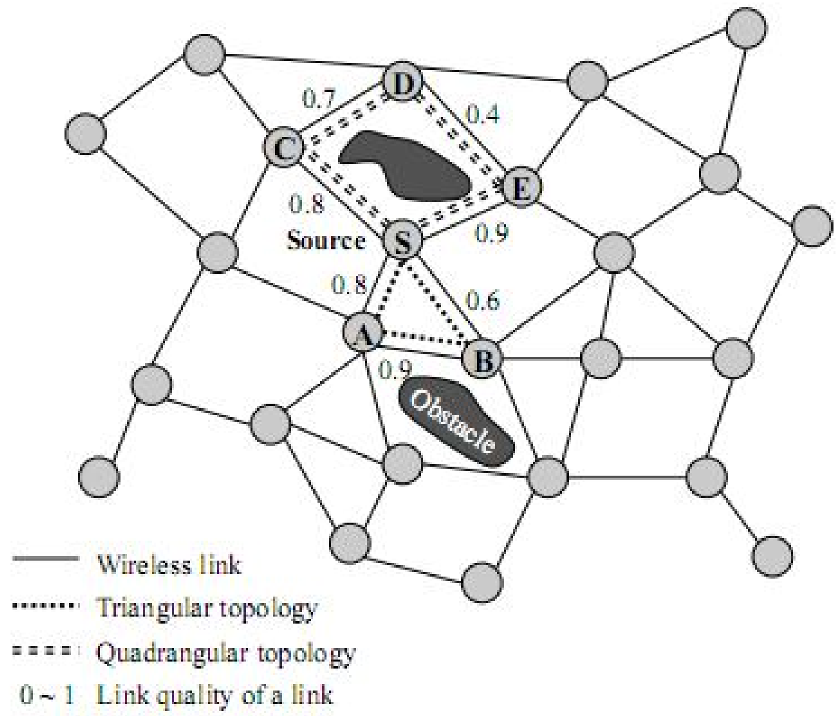


Fig. 1. A WSN which is composed of heterogeneous local topologies such as triangles, quadrangles, and so on.

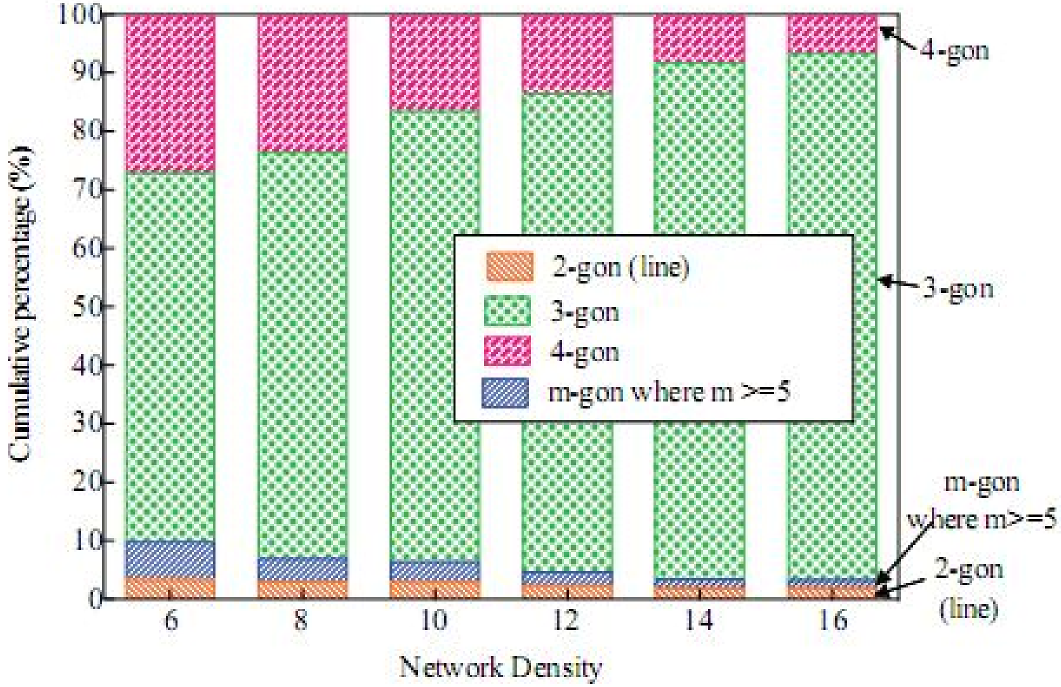
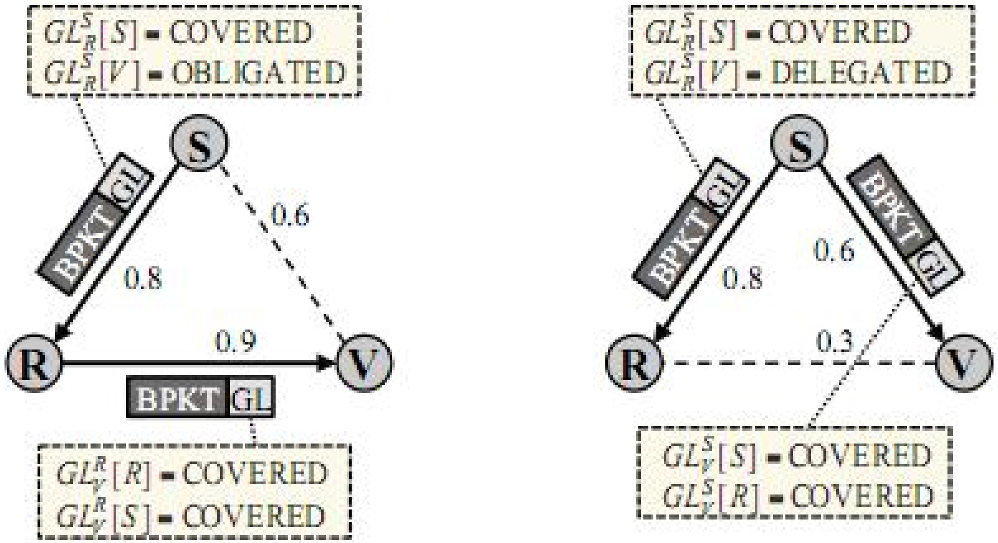
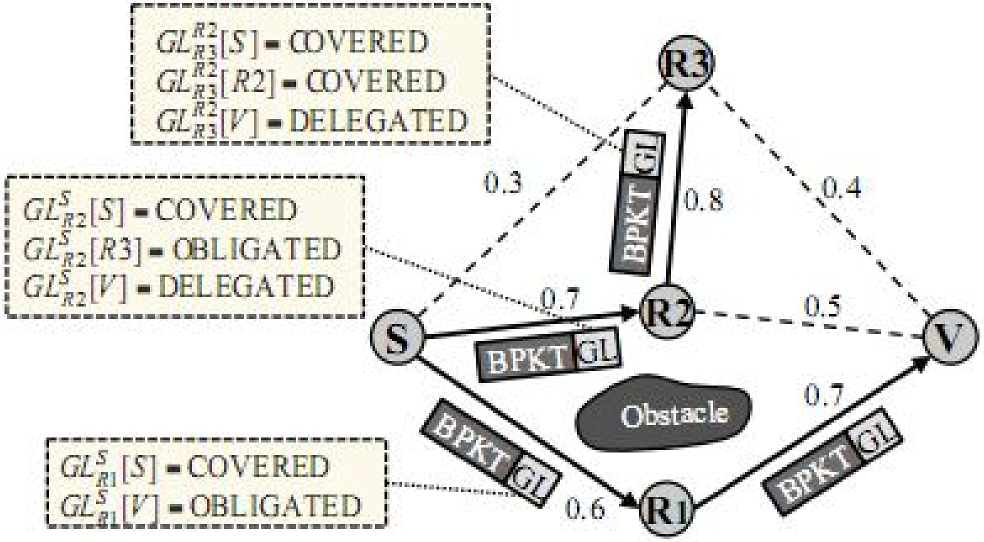


Fig. 2. Cumulative percentage of frequency of each n-gon.



(a) Operation of the forwarder's guidance in a triangular topology. Forwarder S sends a broadcast message with GL to a receiver R. If the link from R to V is better than that from S to V, forwarder S gives OBLIGATED guidance to R so that V will be covered by R. Otherwise, forwarder S gives DELEGATED guidance to R and attempts covering of node V for itself.

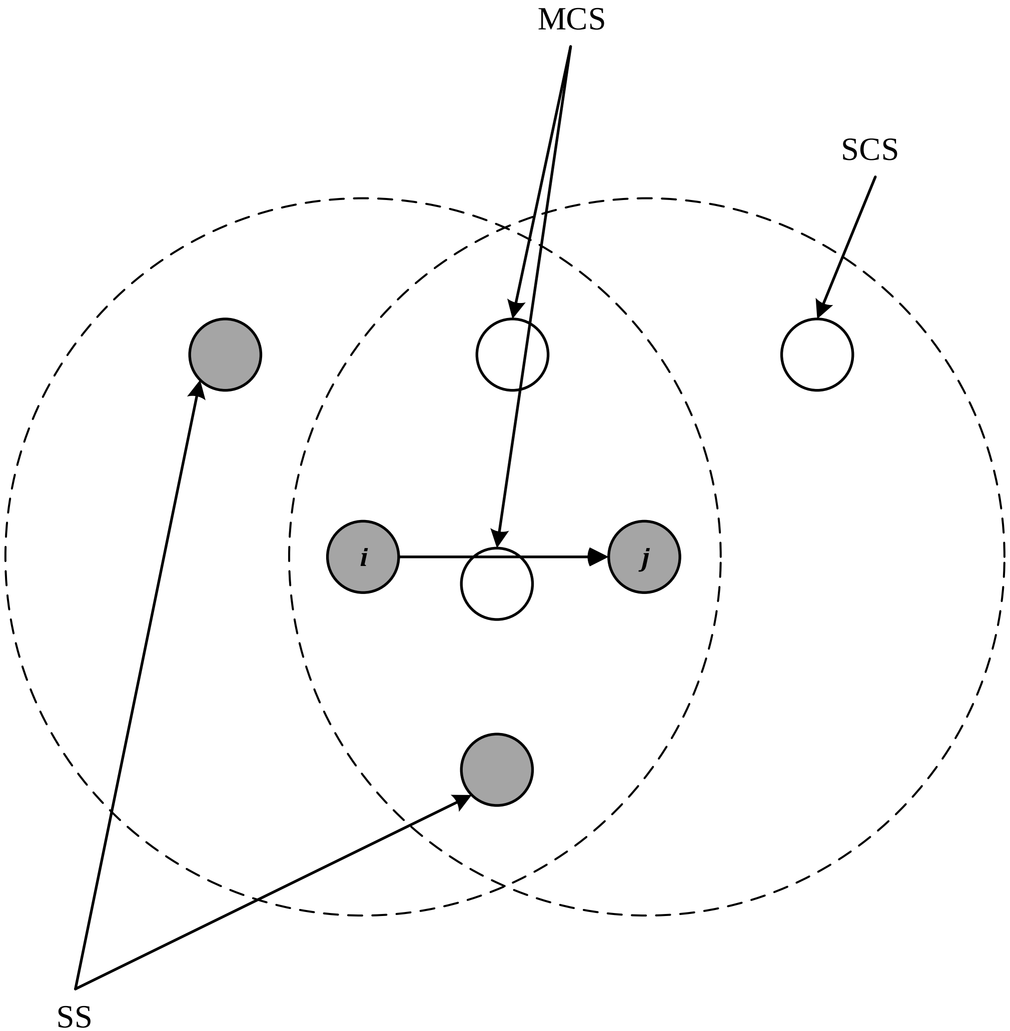


(b) Operation of the forwarder's guidance in a complex topology including a quadrangle formed by four nodes: *S*, *R1*, *R2*, and *V*. Forwarder *S* sends the broadcast message only to nodes *R1* and *R2*. Covering of node *R3* is delegated to node *R2* because the link quality from *R2* to *R3* is better than that from *S* to *R3*. Although nodes *R1*, *R2*, and *R3* can communicate with node *V*, *R1* only attempts to cover *V*. It helps to avoid not only redundant transmissions to *V* but also collisions at *V*.

CEB

Coverage Efficiency-based Broadcast

集合分类



the sender set (*SS*)
the single covered set (*SCS*)
the multiple covered set (*MCS*).

$$Inf_i = \frac{|\, SCS_i \,|}{|\, Neighbor_i \,|}.$$

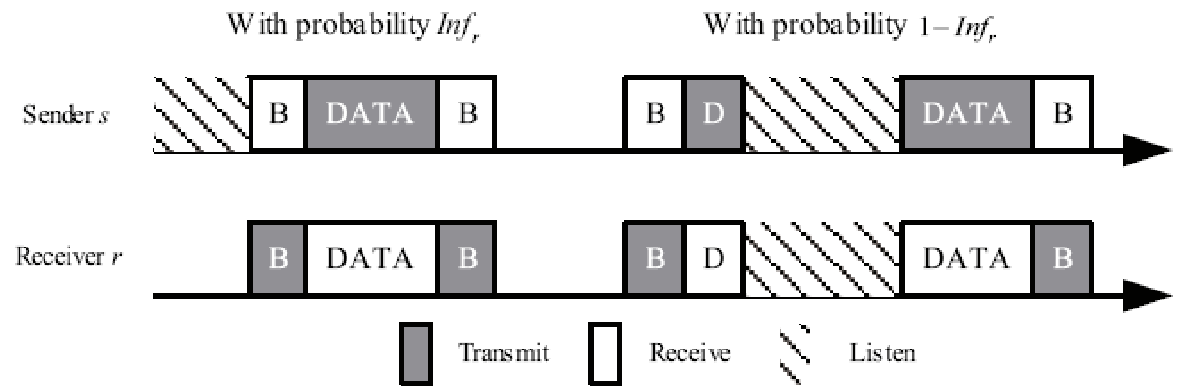


Fig. 1: Transmission for neighbor nodes in *MCS*.

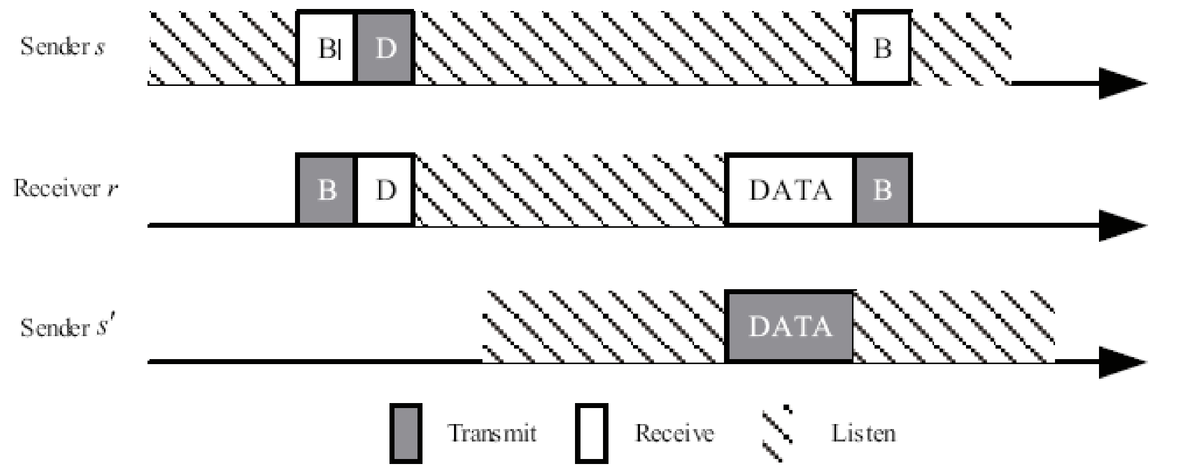


Fig. 2: Scenario with multiple senders.

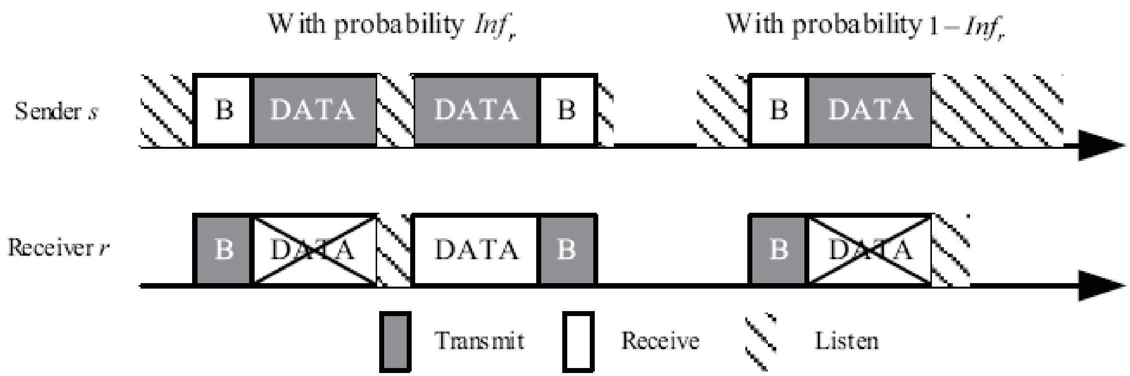


Fig. 3: Transmission for neighbor nodes in *SCS*.

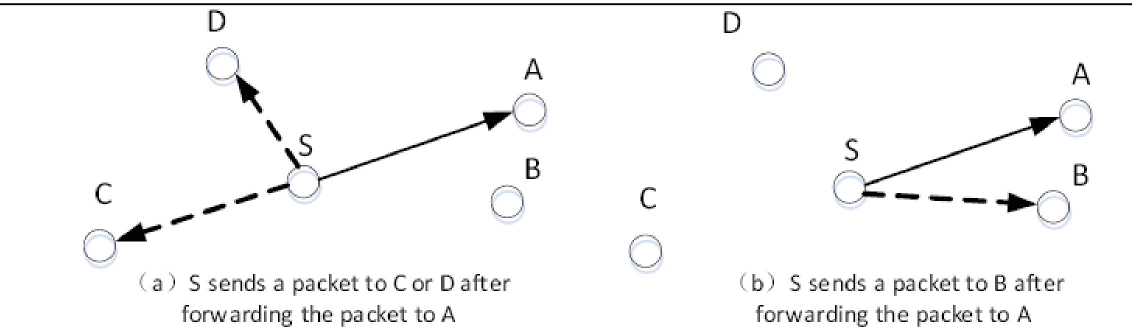


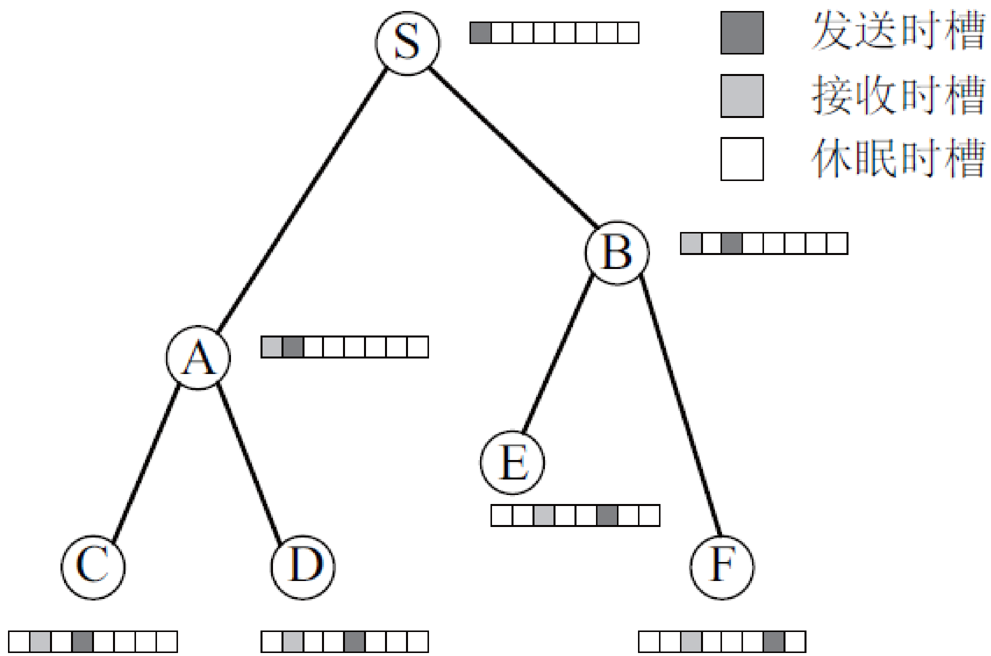
Fig. 4: Example of coverage efficiency, (a) is better than (b).

Nodes in *SCS* are more helpful in accelerating the broadcast process.

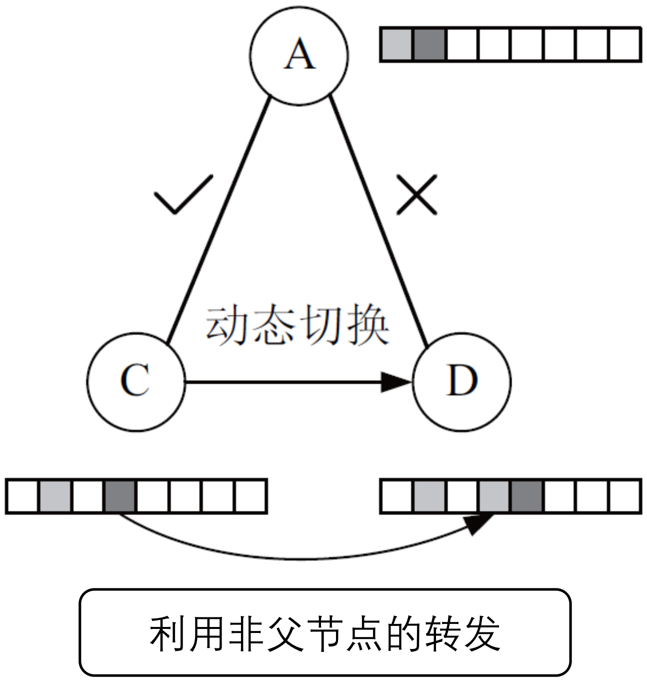
FNCSST

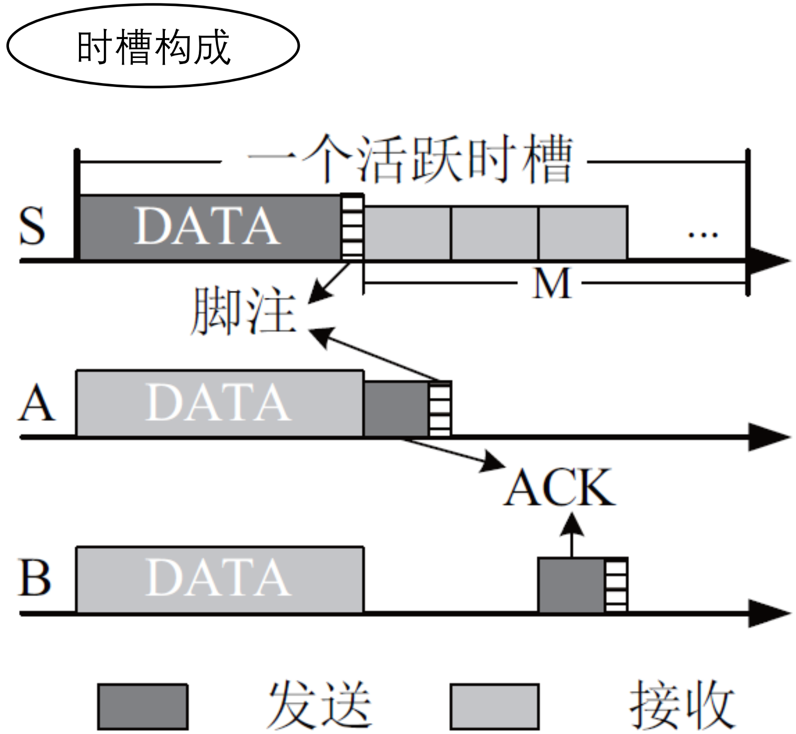
基于网络编码与调度生成树的广播

基于调度的广播树

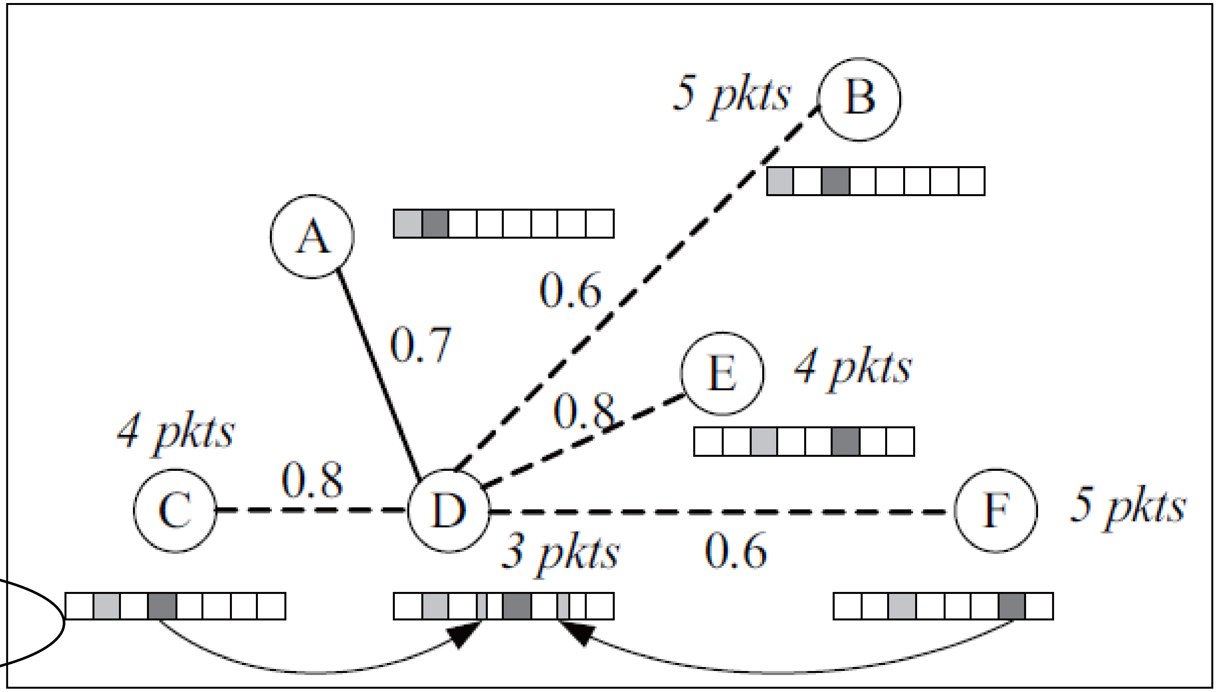


动态切换过程


A
动态切换
C
D
利用非父节点的转发


时槽构成
一个活跃时槽
S
DATA
...
M
脚注
A
DATA
ACK
B
DATA
发送
接收

期望包数增长 eRI



限制集合大小为2

链路最优{C,E}

$$RI_{CE} = p_{CD} \cdot q_{ED} \cdot 1 + q_{CD} \cdot p_{ED} \cdot 1 + p_{CD} \cdot p_{ED} \cdot 1 = 0.96$$

包数最大{B,F}

$$RI_{BF} = p_{BD} \cdot q_{FD} \cdot 1 + q_{BD} \cdot p_{FD} \cdot 1 + p_{BD} \cdot p_{FD} \cdot 2 = 1.2$$

☆ {B,C}

$$RI_{BC} = p_{BD} \cdot q_{CD} \cdot 1 + q_{BD} \cdot p_{CD} \cdot 1 + p_{BD} \cdot p_{CD} \cdot 2 = 1.4$$

综合包数与链路质量

集合优化算法

扩充性质

集合中加入新的发送节点，总能增加eRI

替换性质

使用链路质量更优、包数更多的发送节点替换，总能增加eRI

算法目标

从N个包数更多的邻居中选出M个节点，最大化eRI

最优子结构

$$S_M^* = \underset{S \in \{X_1^{(M)}, X_2^{(M)}, \cdots, X_z^{(M)}\}}{arg\ max} eRI_S \qquad X_i^{(m)} = \underset{S \in \{Y_{i,1}^{(m)} \cup Y_{i,2}^{(m)} \cup \cdots \cup Y_{i,tt_i}^{(m)}\}}{arg\ max} eRI_S$$

$$Y_{i,j}^{(m)} = \{n_{l_i,tt_i} + \cdots + n_{l_i,tt_i-j+1} + X_{i-k}^{m-j} | k = 1, \cdots, i-1\}$$

时间复杂度

$O(K^3M^2)$

K为定值，批次大小