Wireless Sensor Networks

Wake-up Receivers

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Sensor Networks

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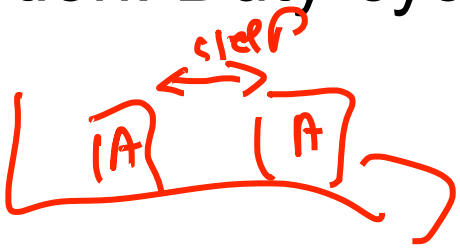
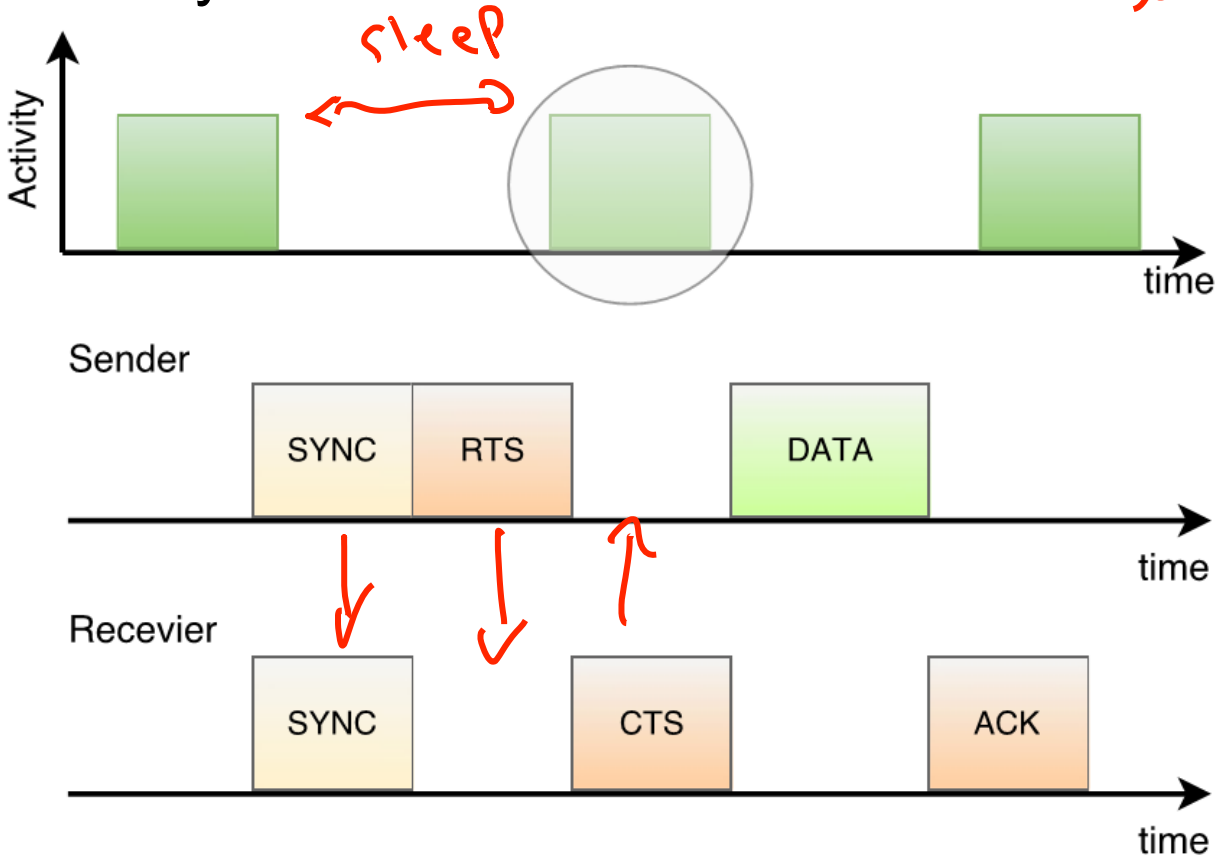
- Energy is the main concern for WSN
- Potential energy waste sources:
  - Idle Listening
  - Overhearing
  - Retransmission
  - Overmitting
- Reduce power consumption: Duty-cycling



MAC Protocols

- Medium Access
  - Pure-synchronous

Rendevous Wake-up Scheme

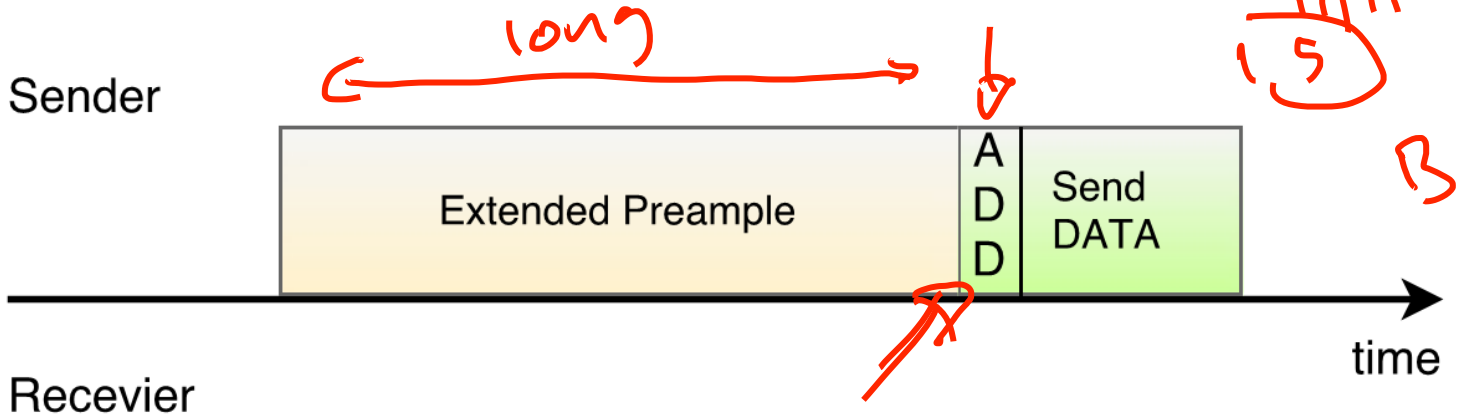


S-MAC

T-MAC

MAC Protocols

- Medium Access
  - Pseudo-asynchronous



MAC Protocols

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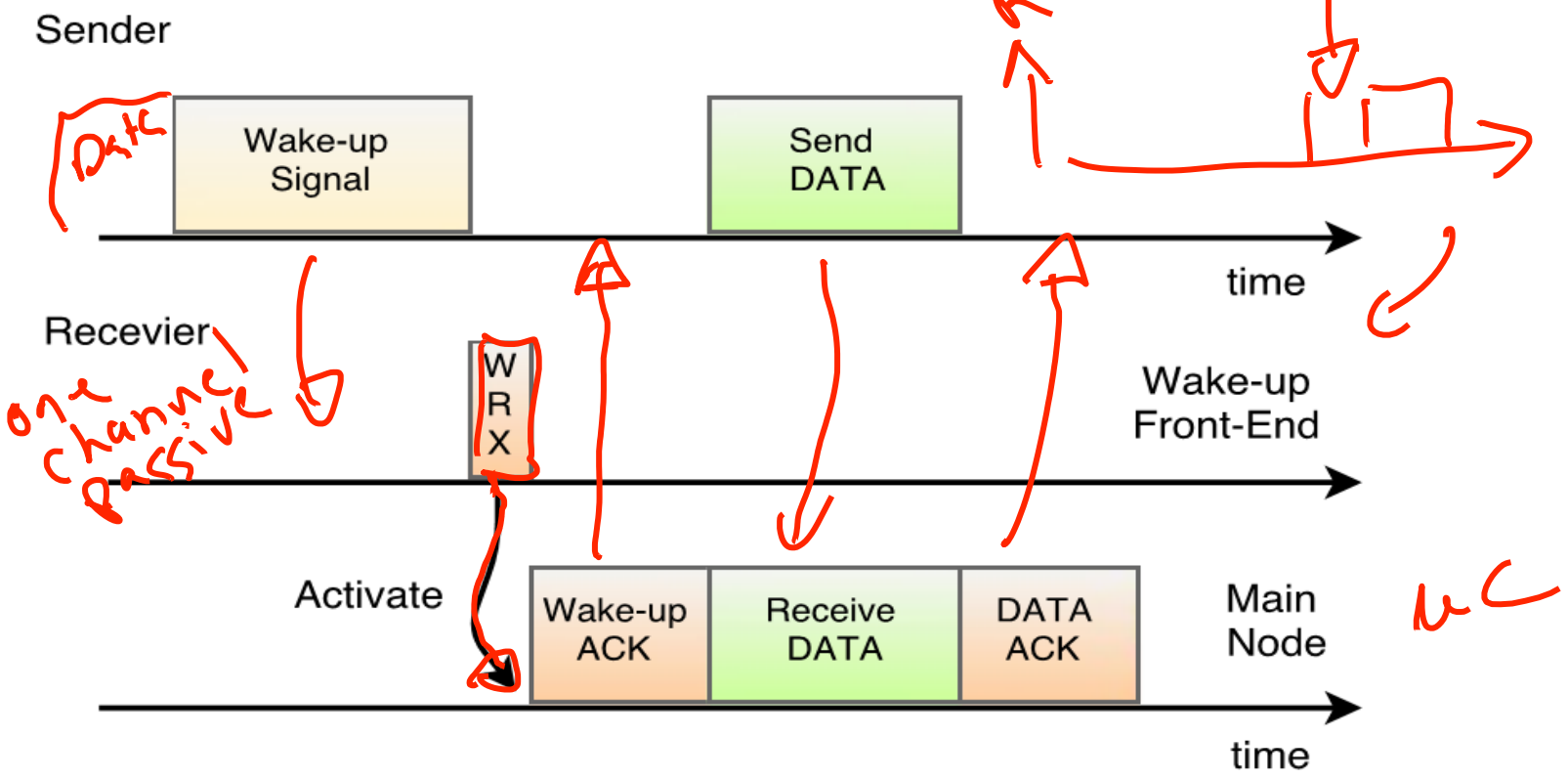
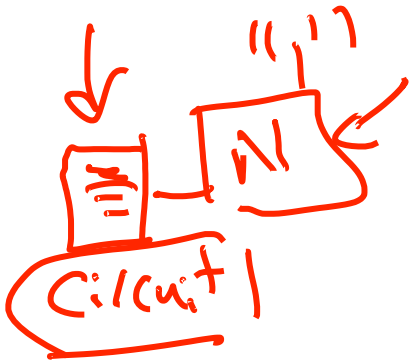
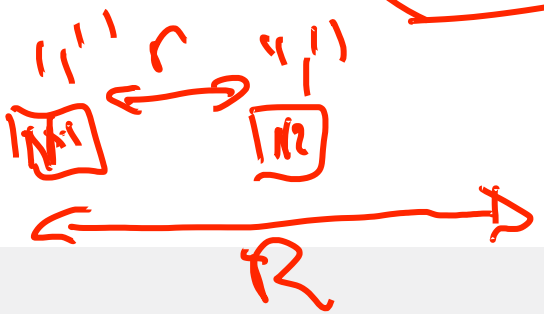


Wake-up on Demand Radio

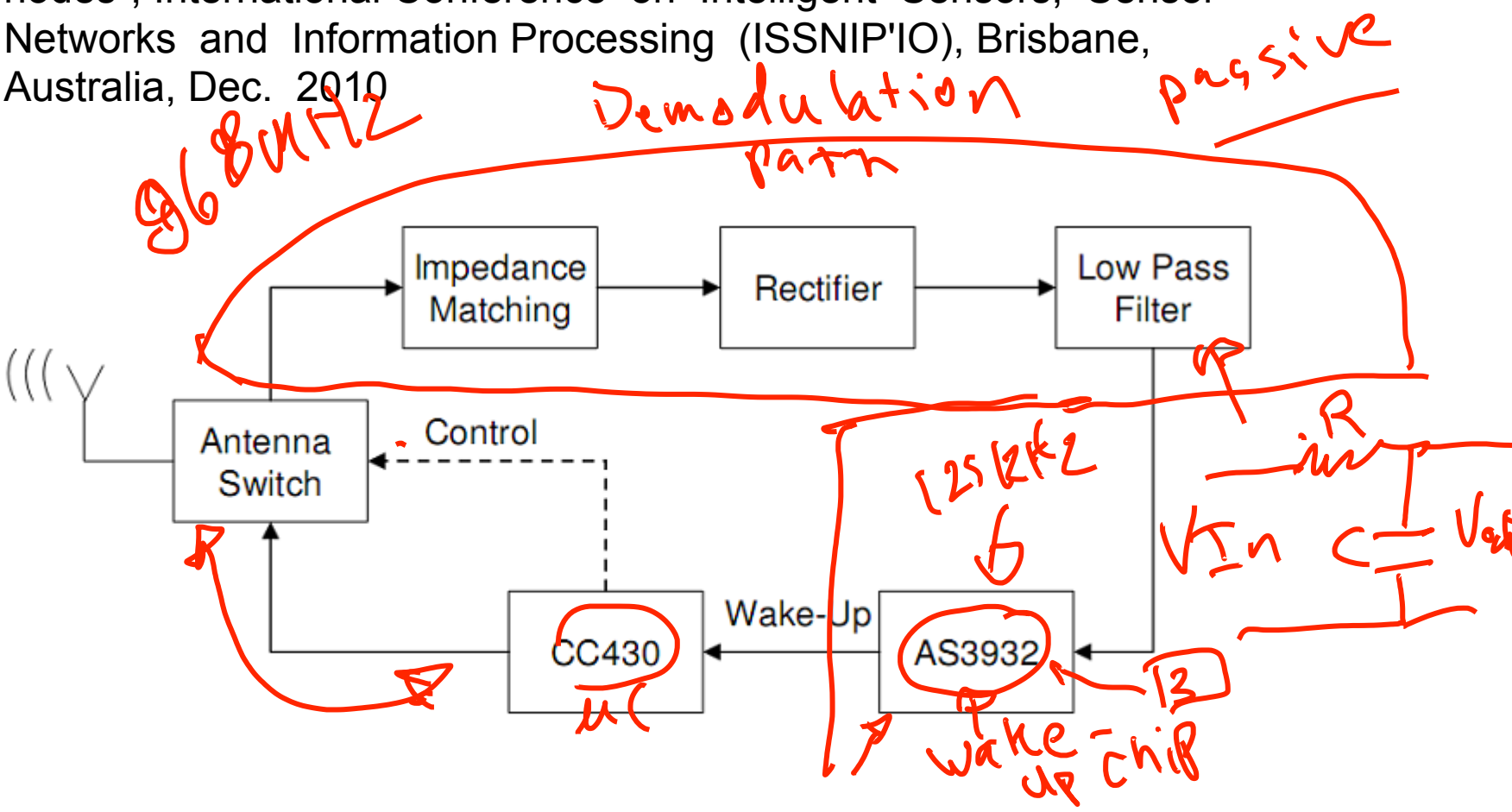
- Communication occurs only when required
- Benefits:
  - Nodes always in a sleep phase
  - Avoid the energy waste sources
  - Ultra low power energy consumption
- Challenges:
  - Hardware cost and Complexity
  - Wake-up signals energy
  - Wake-up distance
  - Network topology





Wake-up Receiver Design

- Gamm et. al., “Low power wake-up receiver for wireless sensor nodes”, International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP'IO), Brisbane, Australia, Dec. 2010



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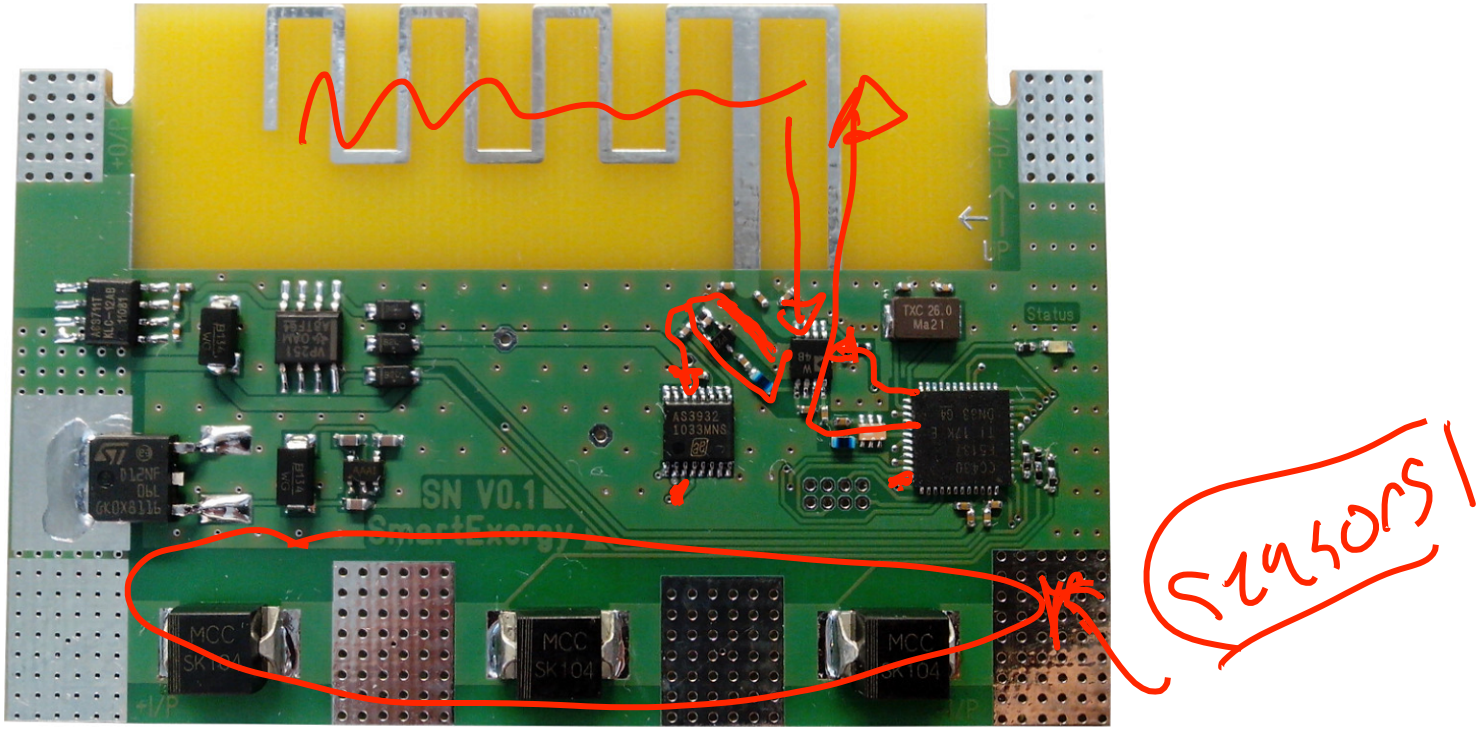
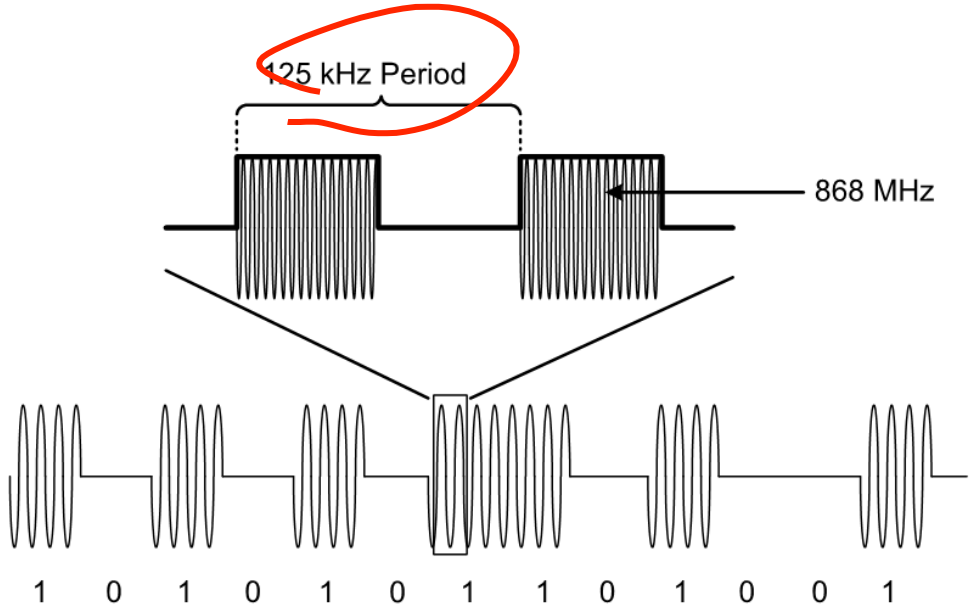


Wake-up Receiver Design

- Gamm's Design:
  - Operating frequency 868 MHz
  - ASK Modulation
    - Wake-up chip operates on 125 KHz
    - Transform 868 MHz to 125 KHz
  - Power consumption < 8.2 µW
  - Receiver sensitivity -53 dBm
  - Wake-up distance up to 100 m

Wake-up Receiver Design

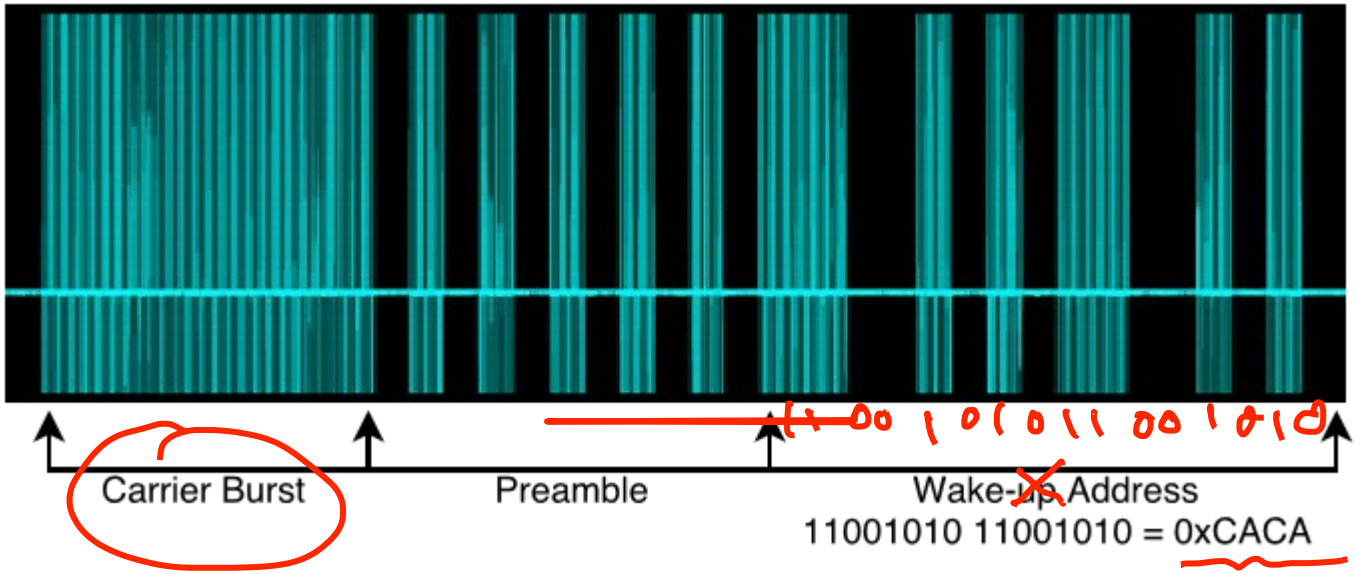
- Wake-up Signal Construction:
  - Switch the transceiver on/off (ASK)
  - Generate 125 KHz periods
  - Data rate affects the signal length and distance



Radio Transc.
on/off
OOK ASK
18 - 150
kHz

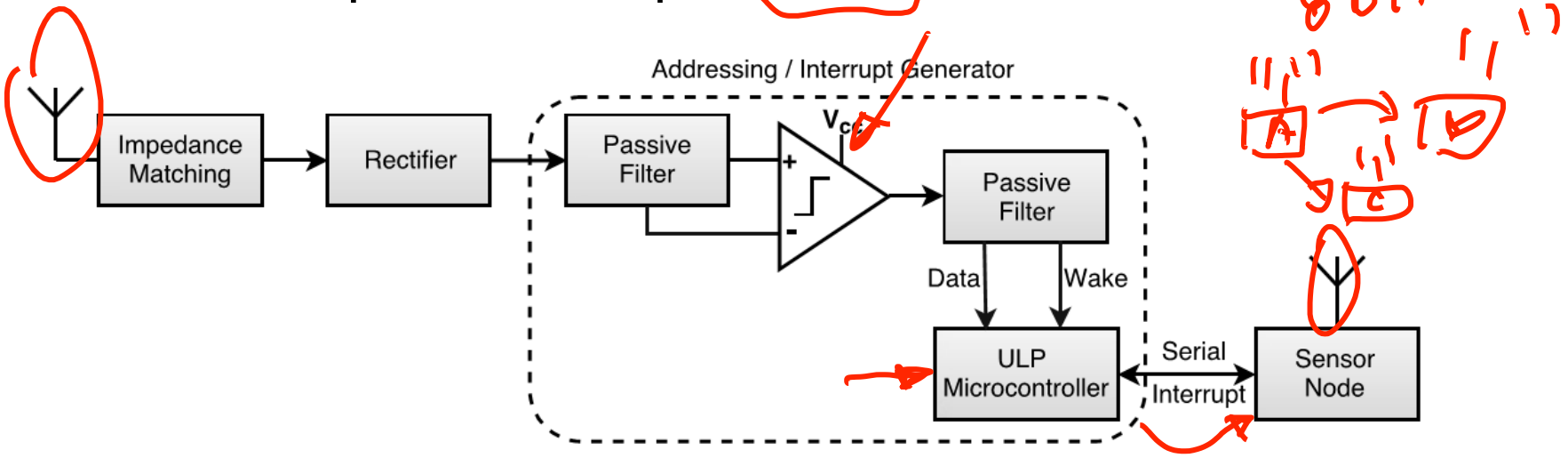
Wake-up Receiver Design

- Wake-up Signal Construction:
  - Carrier Burst to stabilize the Wake-up chip
  - Preamble
  - Wake-up Address



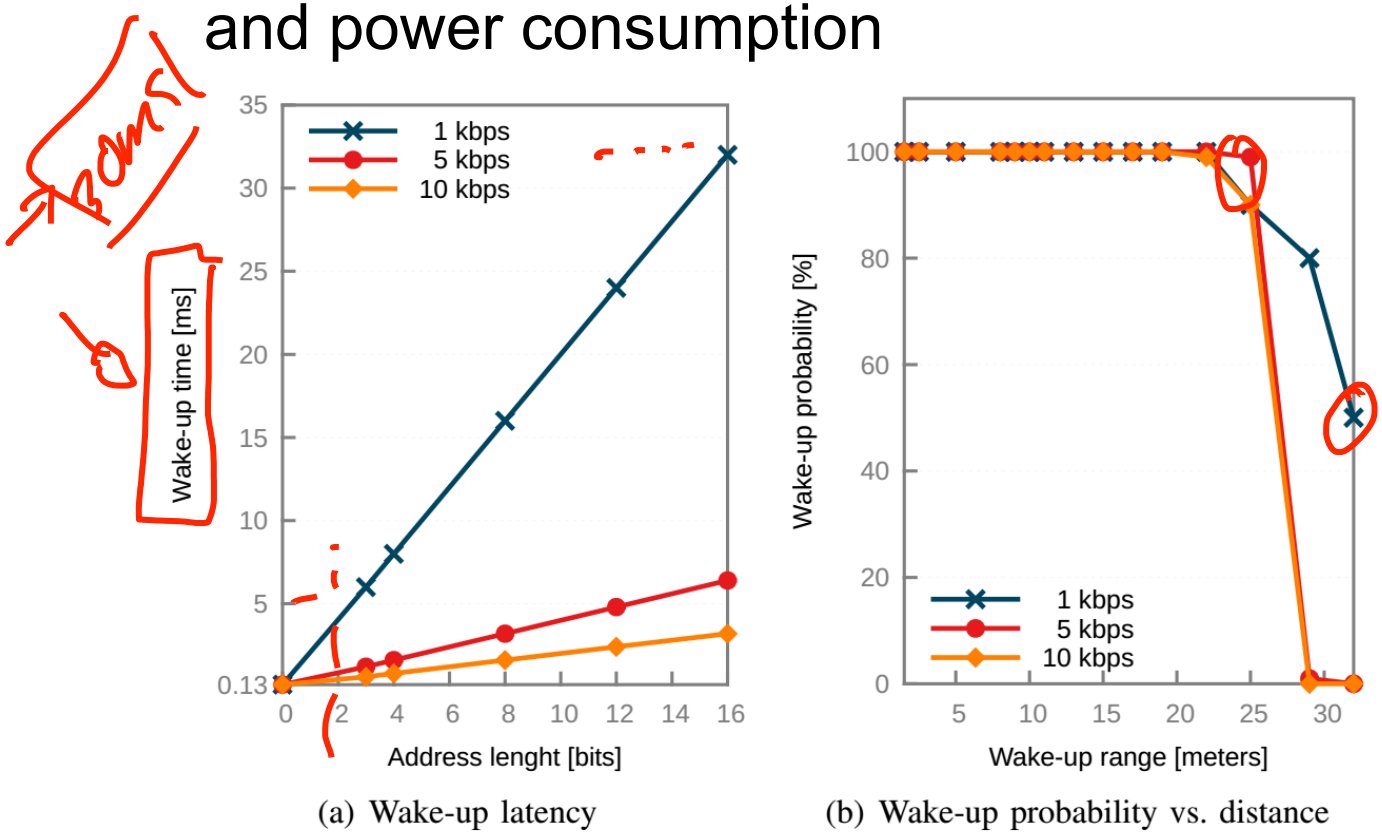
Wake-up Receiver Design

- D. Spenza, M. Magno, S. Basagni, L. Benini, M. Paoli, and C. Petrioli, "Beyond duty cycling: Wake-up radio with selective awakenings for long-lived wireless sensing systems," in *Computer Communications (INFOCOM), 2015 IEEE Conference on*, April 2015, pp. 522–530.
  - Power consumption 1.3 µW
  - Receiver sensitivity -55 dBm
  - Wake-up distance up to 31 m



Wake-up Receiver Design

- Spenza/Magno Design:
  - Data rate: Trade-off between coverage distance and power consumption

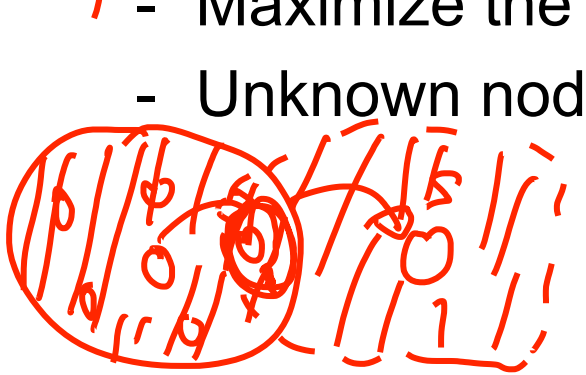


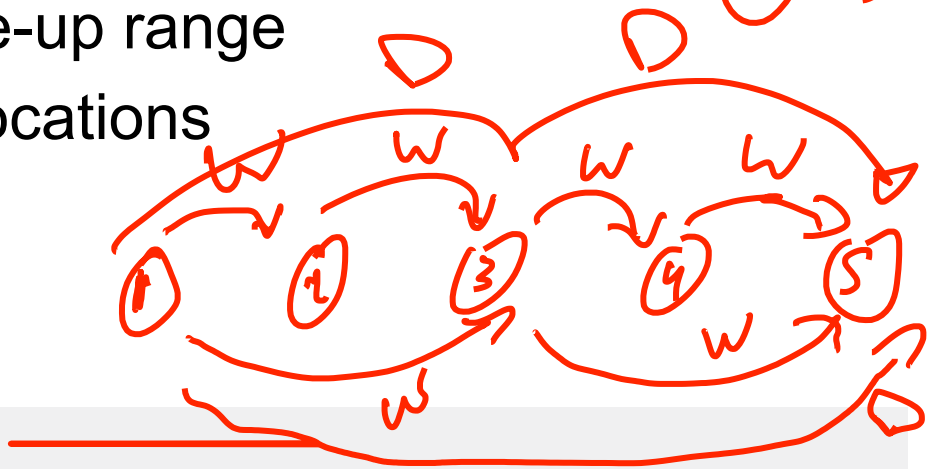
(a) Wake-up latency

(b) Wake-up probability vs. distance

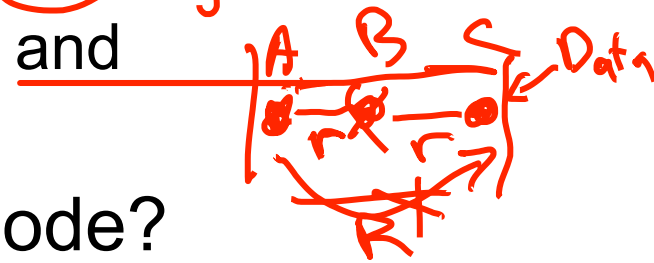
Wake-up Receiver Algorithms

- Motivation to design new protocols:
  - New protocols to adequate the new hardware
  - Wake-up receivers Problems
    - Short wake-up ranges
    - Higher wake-up signal energy compared to data messages
  - Minimize the wake-up signal transmission
  - Maximize the wake-up range
  - Unknown nodes' locations





Wake-up Receiver Algorithms

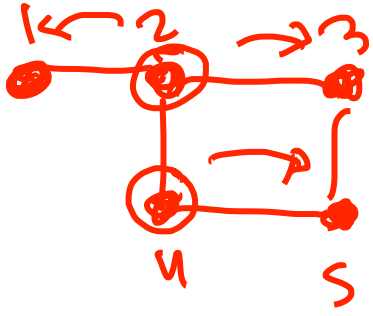


- Requirement:
  - Nodes' density guarantee coverage and connectivity of Wake-up graphs
- How can we reach every single node?
  - Establish a Minimum Connected Dominating Set
  - The wake-up problem is an Online-variant of the MCDS

offline Information in advance

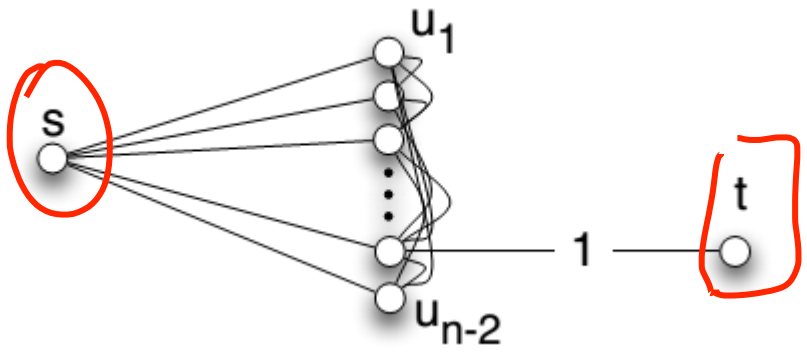
online - Information becomes Nodes are woken-up

{2, 4}



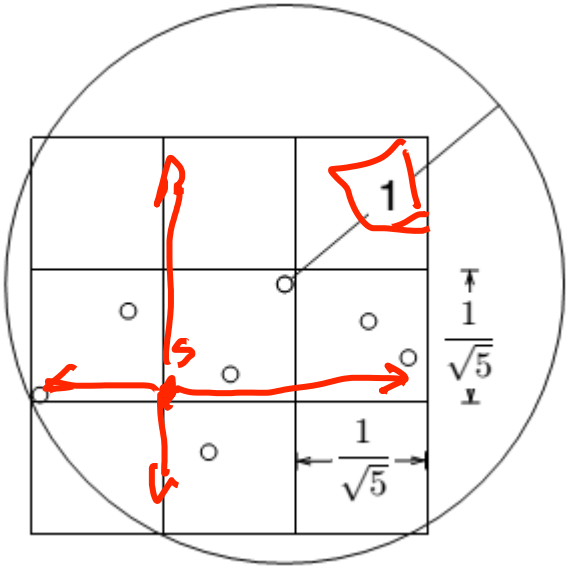
Wake-up Receiver Algorithms

- A. Bannoura, C. Ortolf, L. Reindl, C. Schindelhauer, "The wake up dominating set problem", Theoretical Computer Science, Volume 608, Part 2, Pages 120-134, 10 December 2015.
- Computing MCDS-UDG is NP-Complete [Lichtenstein, 1982]
  - All deterministic algorithms for MCDS-UDG has a competitive ratio at least $n/2 - 1/2$



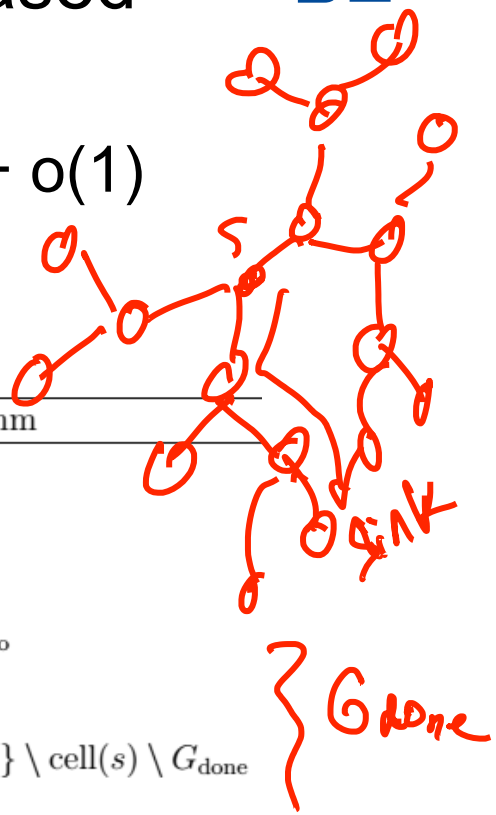
Wake-up Receiver Algorithms

- A straight-forward solution is a grid based algorithm
  - Achieves a constant competitive ratio 5 + o(1)
  - Flooding on the grid



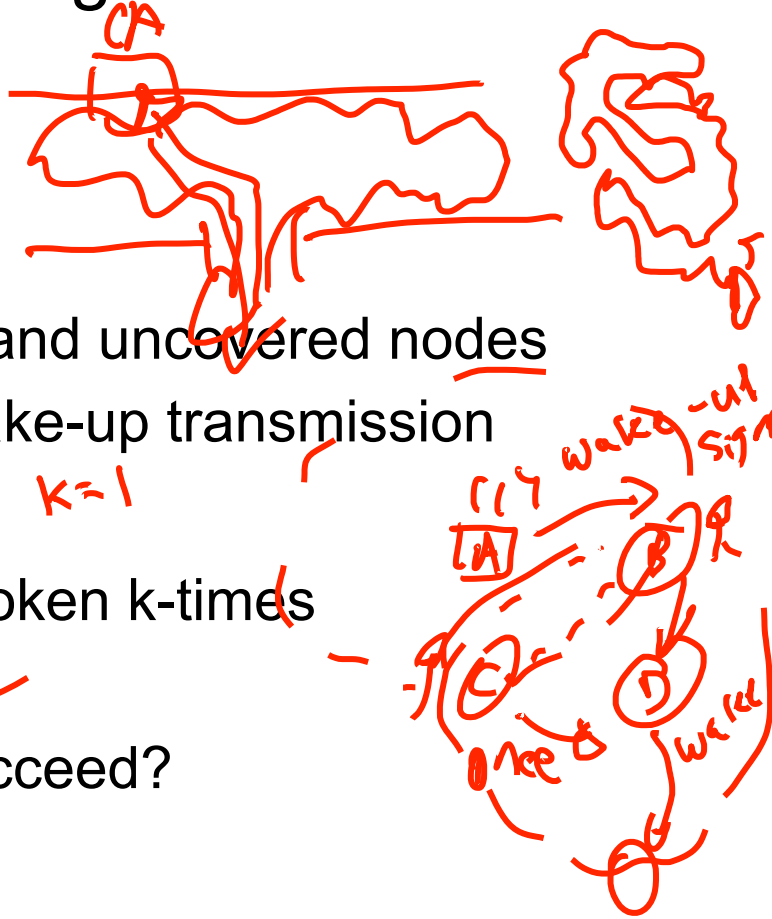
Algorithm 1: Grid based wake-up algorithm

Send wake up from s
$G_{\text{done}} \leftarrow \{\text{cell}(s)\}$
$G_{\text{to-do}} \leftarrow \{\text{cell}(u) \ : \ \{u, s\} \in E\} \setminus \{\text{cell}(s)\}$
while $G_{\text{to-do}} \neq \emptyset$ **do**
  Pick a node w such that $\text{cell}(w) \in G_{\text{to-do}}$
  Send wake up from w
  $G_{\text{done}} \leftarrow G_{\text{done}} \cup \{\text{cell}(w)\}$
  $G_{\text{to-do}} \leftarrow G_{\text{to-do}} \cup \{\text{cell}(u) \ : \ \{u, w\} \in E\} \setminus \text{cell}(s) \setminus G_{\text{done}}$
end



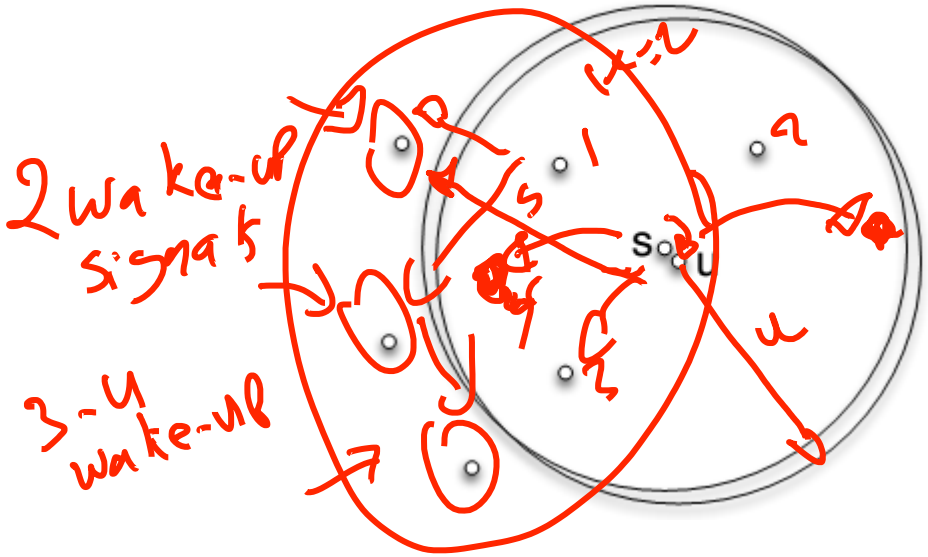
Wake-up Receiver Algorithms

- A position oblivious wake-up algorithm
  - Flooding
  - Random Walk
  - Epidemic approach
    - Distinguish between covered and uncovered nodes
    - Use simple counter to stop wake-up transmission
  - Random *k*-covered wake-up
    - Nodes either transmit or be woken k-times
    - Computes CDS with $O(\log n)$
    - Does the algorithm always succeed?



Wake-up Receiver Algorithms

- Counter example when k = 1



once or covered twice
{1, 2, 3}

k = 2
once and covered twice

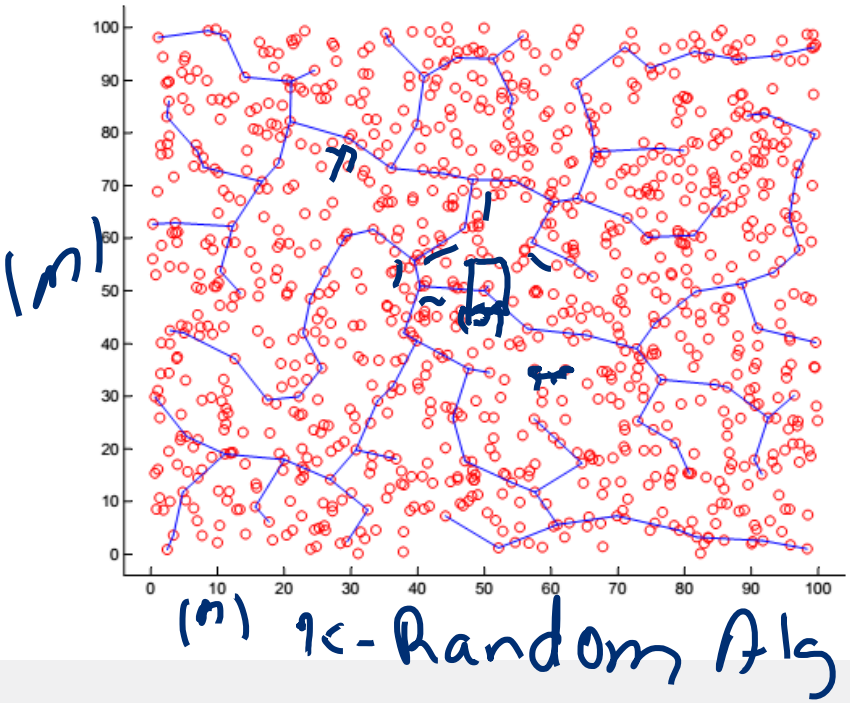
- Greedy k-cover algorithm
  - Measure signal strength to estimate the distance
  - Maximize the wake-up distance

small packets

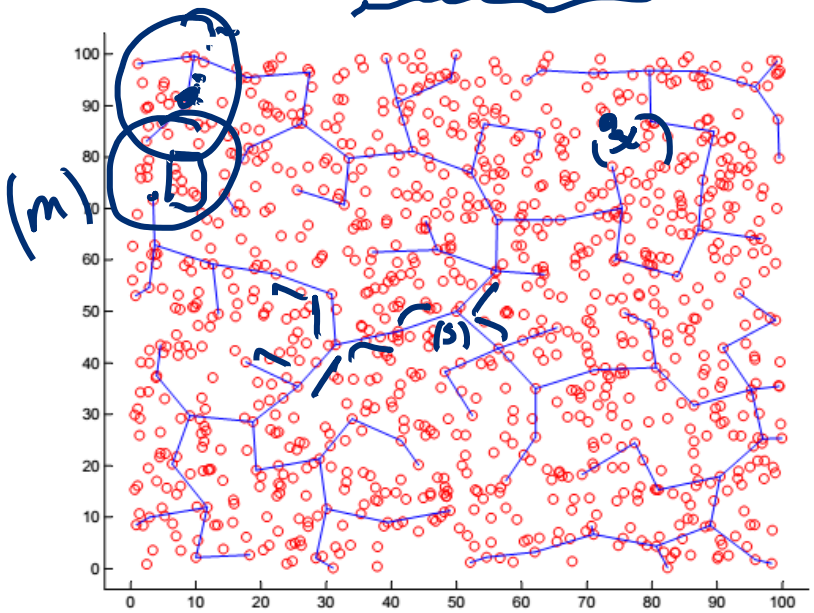
No guarantee you cover All nodes

Wake-up Receiver Algorithms

- Simulation
  - Randomly deployed varying number of nodes
  - Area of square length 100 meters
  - Wake up communication range of 10 meters



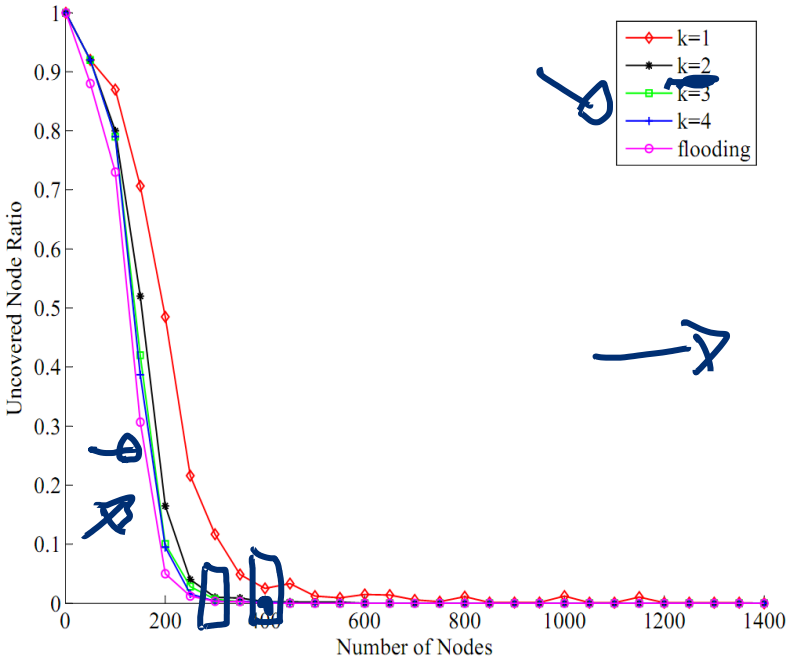
(m) k-Random Alg.

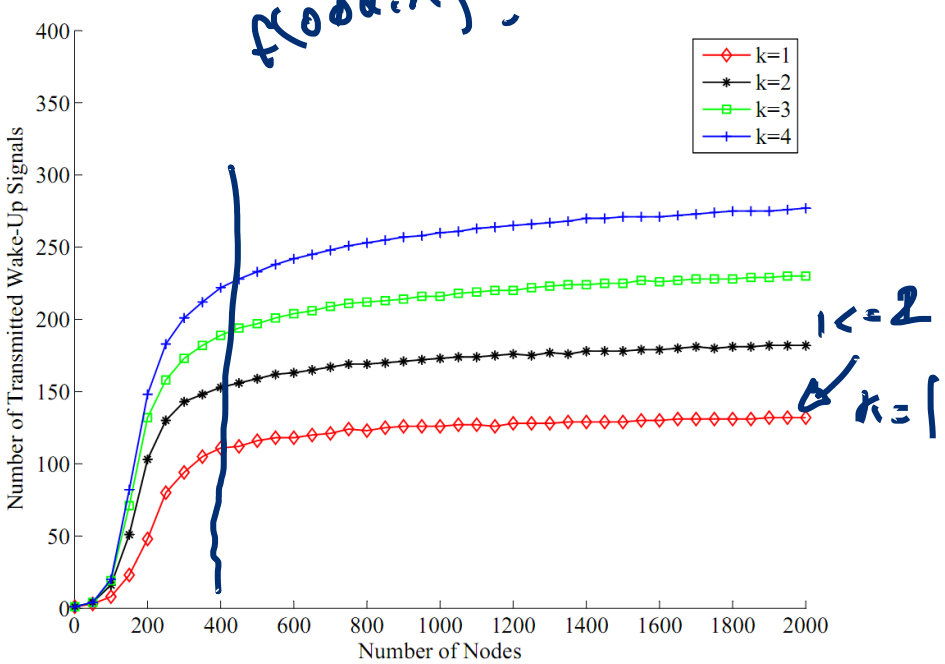


(m) k-greedy Alg.

Wake-up Receiver Algorithms

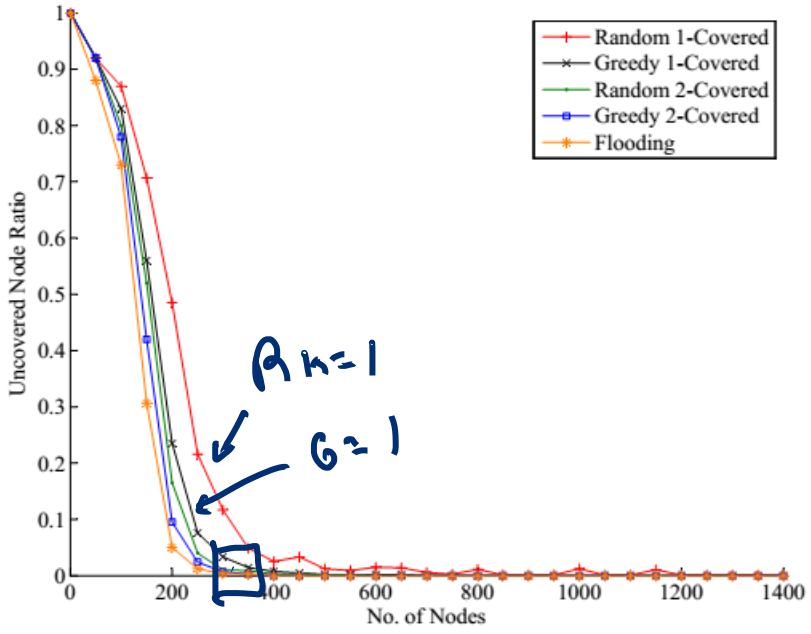
- Measure algorithms' quality:
  - Coverage: ratio of the uncovered nodes
  - Complexity: number of transmitted wake up



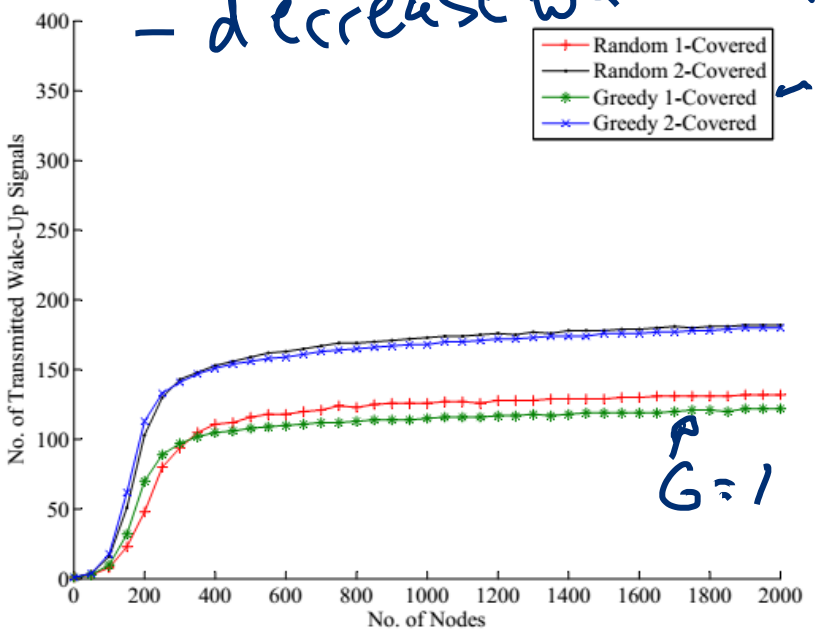


Wake-up Receiver Algorithms

- Greedy 1-coverage delivers a good combination of message complexity and coverage

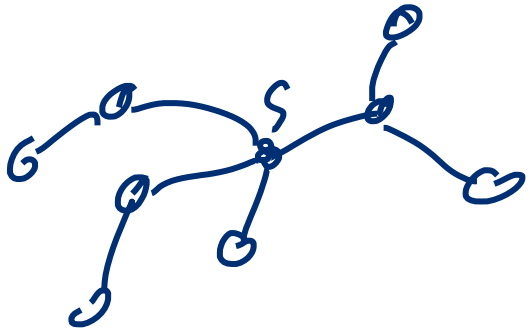


increase wake-up range
– decrease wake-up signals



Wake-up Receiver Algorithms

- Expensive to construct trees from scratch
- Hybrid algorithms to combine:
  - Duty cycle
  - Wake-up receivers



- A. Bannoura, L. Reindl, C. Schindelhauer, "Convergecast Algorithms for Wake-up Transceivers", *SensorNets 2016: 5th International Conference on Sensor Networks*, Rome, Italy, February 19-21, 2016.