Ripple Flooding in Wireless Sensor Networks

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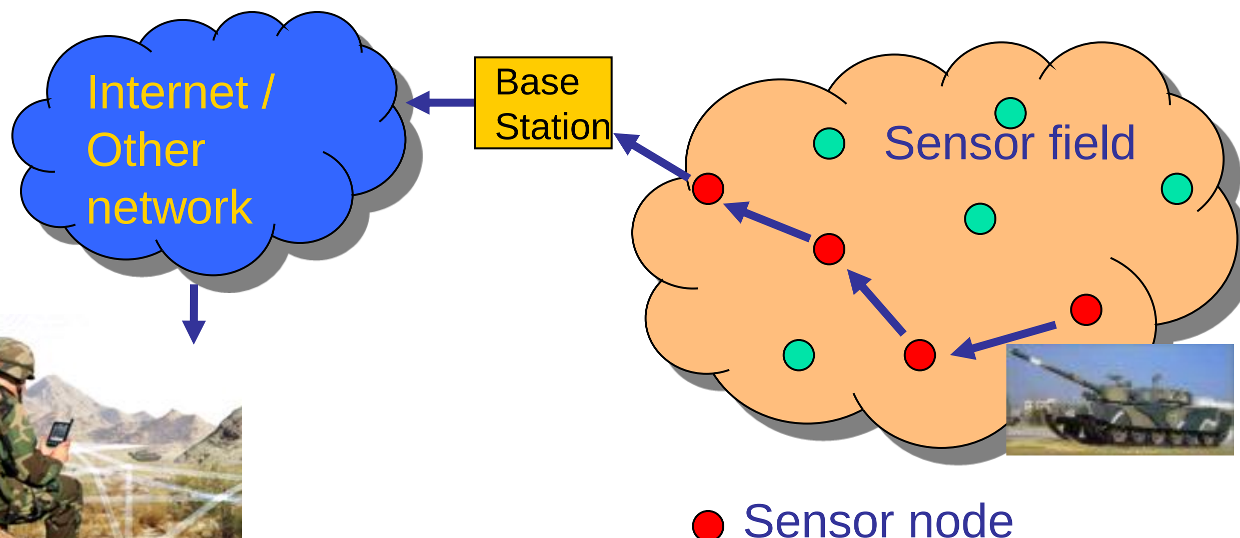
INTRODUCTION

Wireless Sensor Networks

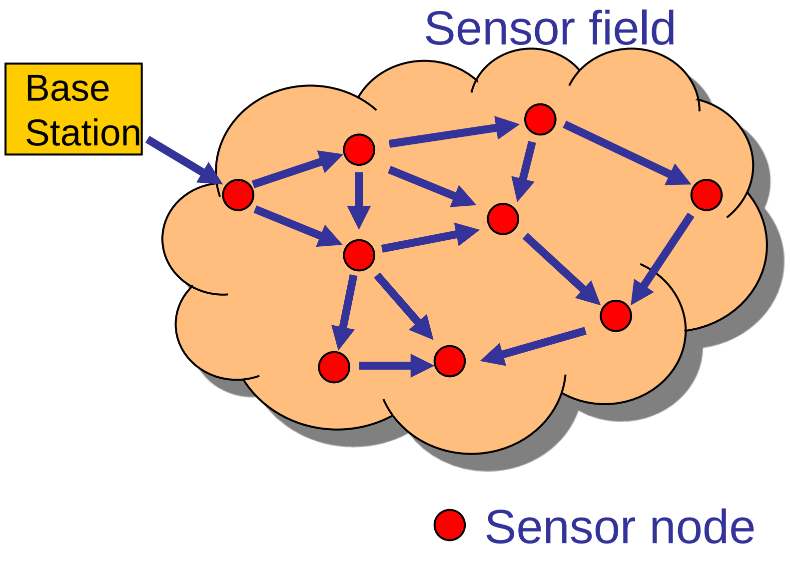
- Networks of large number of distributed sensor nodes that
  - organize themselves into a multi-hop wireless network
  - can cooperate to perform a common task, e.g., estimate moving direction & speed of an event
- Each node normally battery operated has at least one sensor, an embedded processor, and a low-power transceiver



INTRODUCTION

Broadcast & Flooding

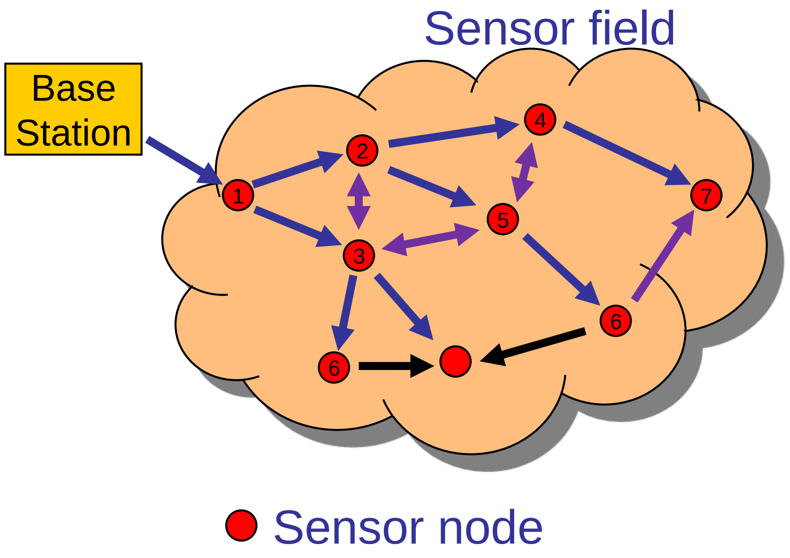
- Broadcast: Sending a message to other nodes
  - A BS may need to disseminate many important messages, such as routing-related information, time information, security key renewal, and queries, to all sensor nodes in a WSN
- Flooding is a common approach to broadcast these messages
  - Flooding is a fundamental operation in WSNs



INTRODUCTION

Broadcast Storm Problem

- Most works in WSNs, like routing protocols and time synchronization, take flooding as a straightforward and direct solution, i.e., simple (blind) flooding
  - A node rebroadcasts the message on receiving a broadcast message for the first time
- Broadcast storm problem
  - Excessive redundancy (Purple)
  - Contention
  - Collision (Black)



RELATED WORKS

- The existing flooding schemes can be categorized into two class based on the information each node keeps:

Class	No need of neighbor information with a unique strategy	1-hop/2-hop neighbor information
Schemes	Probabilistic-based*, counter based, distance-based, location-based, cluster-based scheme	Edge-forwarding, Flooding with self-pruning, Connected dominating set, etc.
Pros	Simple, no need redundant information	Good performance in reliability
Cons	• Difficult in setting the right threshold value in various network situations • Performance in reliability is not good	• Difficult in selection of subset of neighbors for forwarding the flooding messages • Need extra overhead to keep neighbor's information • Most schemes require precise neighbor's location information

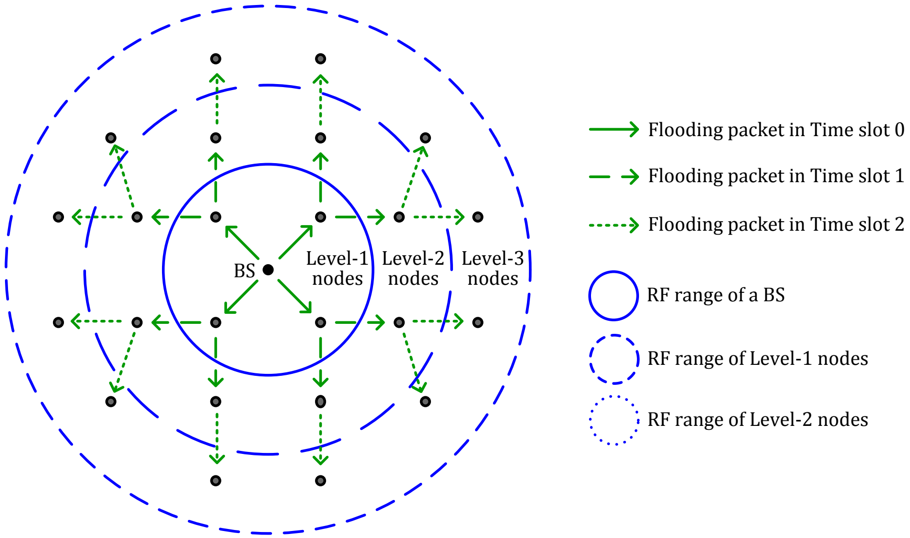
* When a node receives a flooding message for the first time, it will rebroadcast the message with *P*

- Cross-layer approach (MAC+Network) to schedule the receiver's packet rebroadcast on the CSMA/CA MAC layer
  - It uses priority based on the distance, which is measured by RSSI from the sender, to reduce the collision possibility (access-deferring scheme at MAC layer) and broadcast redundancy with 1-hop neighborhood information

MOTIVATION (1/2)

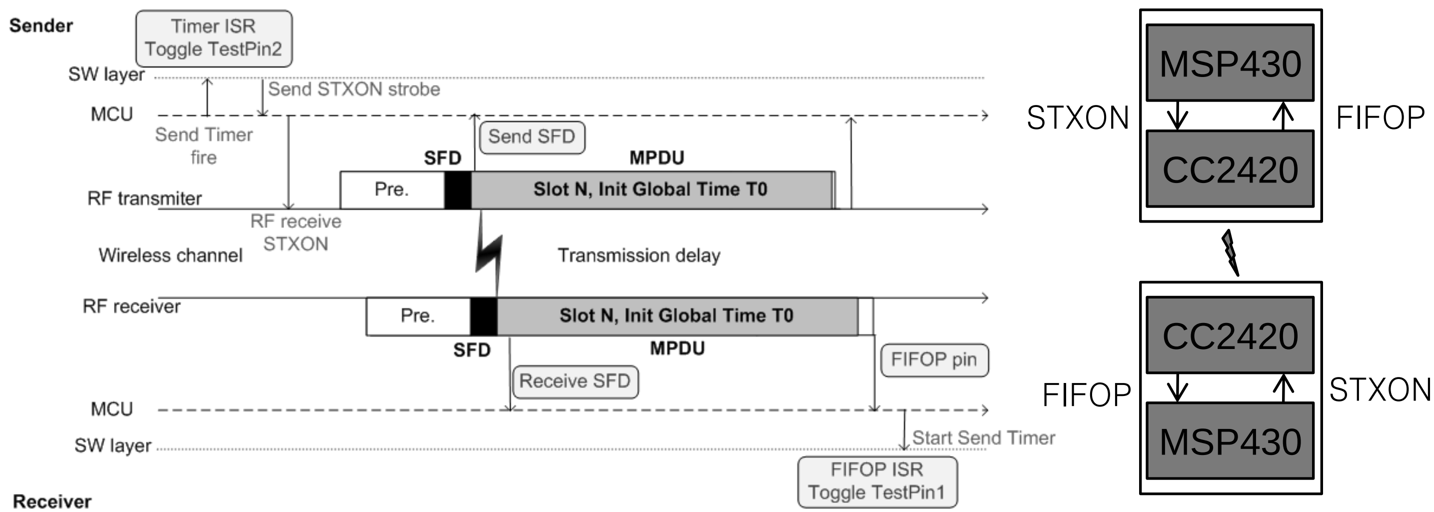
- **Goal of our scheme**
  - To minimize convergence time in flooding with good reliability performance and without using any overhead (1-hop/2-hop information)

- **Key assumption: Sending multiple packets at the same time**
  - Redundancy, contention, and collision are mitigated: If the packets are same and the senders in the same level are timely coordinated on their packet sending



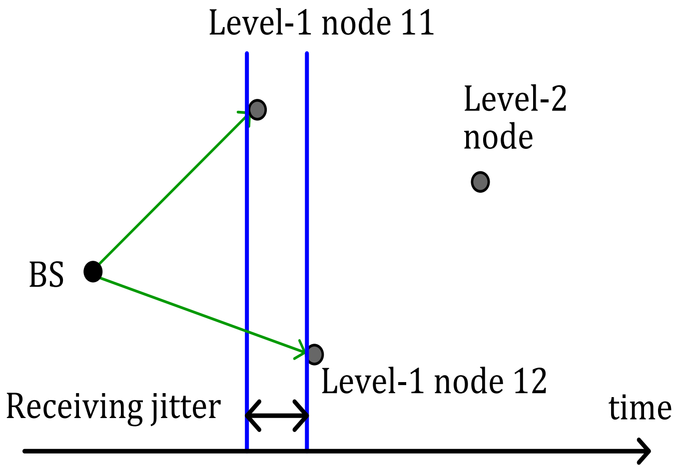
MOTIVATION (2/2)

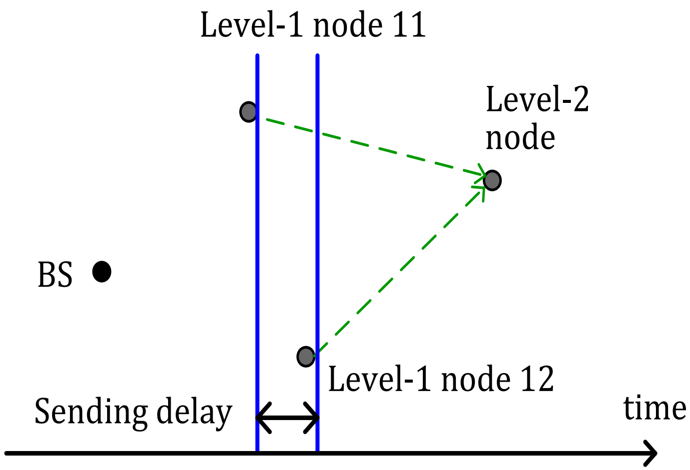
- **Key assumption: Sending multiple packets at the same time**
  - By using the state-of-the-art MAC layer time-stamping scheme (FTSP), we can schedule all the receivers of a flooding message to broadcast at the same time
  - By synchronizing the receivers of a flooding message at a FIFOP pin, the message will be rebroadcasted after a predefined time interval by all the receivers.



FEASIBILITY ANALYSIS WITH REAL NODES (1/2)

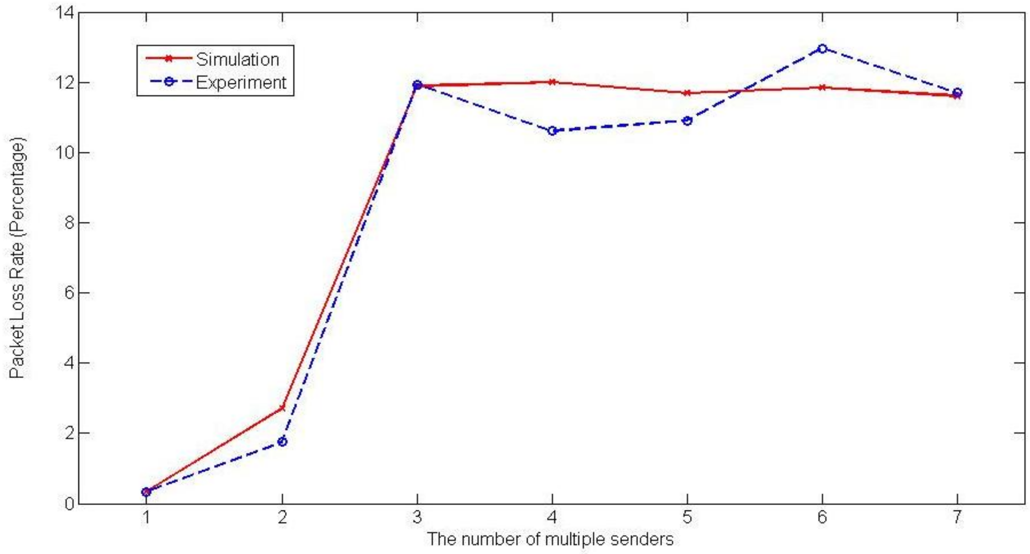
- The purpose of the experiment: To figure out the characteristics of the random delays in senders and receivers
  - A BS sends a broadcast packet periodically and two level-1 nodes receive the broadcast packet at the same time → receiving jitter
  - After a predefined time interval, two senders send the same packet at the same time based on their timer and a level-2 node will receive the same packet → Sending delay jitter





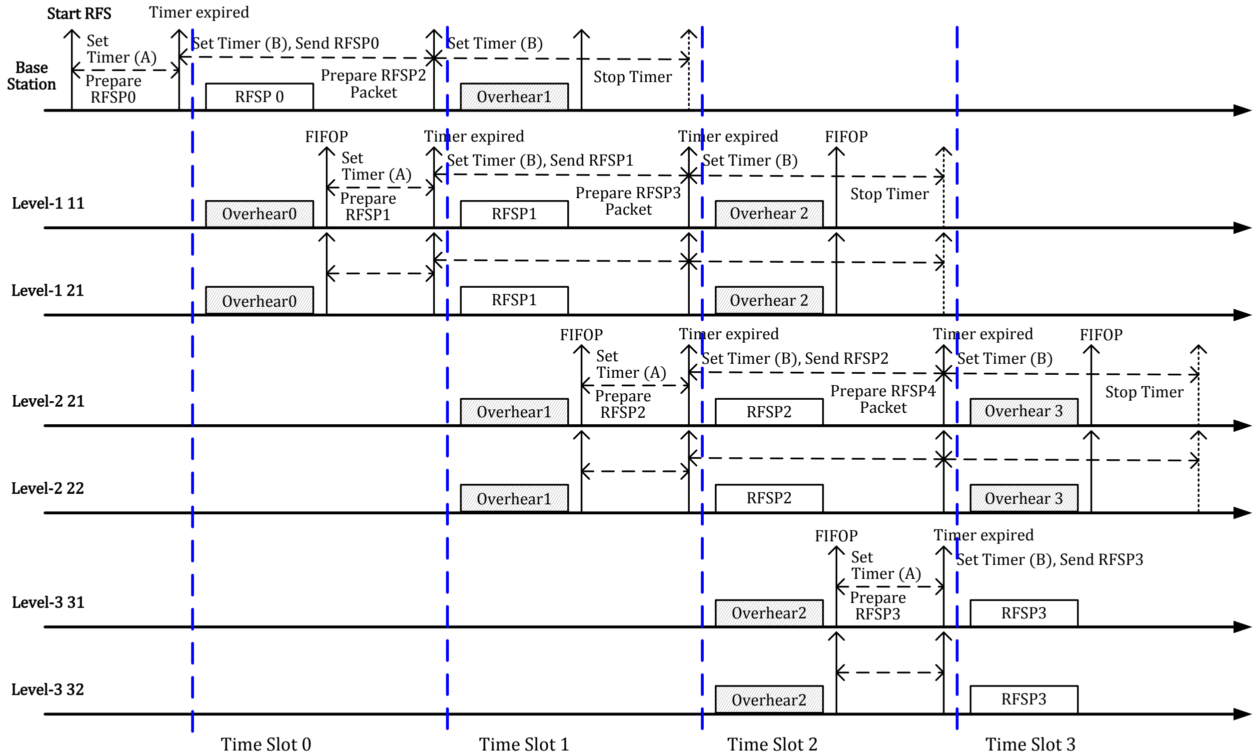
FEASIBILITY ANALYSIS WITH REAL NODES (2/2)

- With the test, we found out that
  - 2 level-1 nodes receive the broadcast packet from the BS with average 120ns receiving jitter and send out the broadcast packet with average 120ns and maximum 350ns delay
  - If we increase the number of level-1 nodes, three or more level-1 nodes send out the broadcast packet with maximum 700ns delay jitter
  - The number of senders is varied from 1 to 7 and we measure Packet Loss Rate for 600 times. The result is shown in the figure below as a dash line and simulation result with power delay profile is also shown as a solid line. → the PLR is bounded by 13% regardless of the number of senders.



RIPPLE FLOODING SCHEME (1/3)

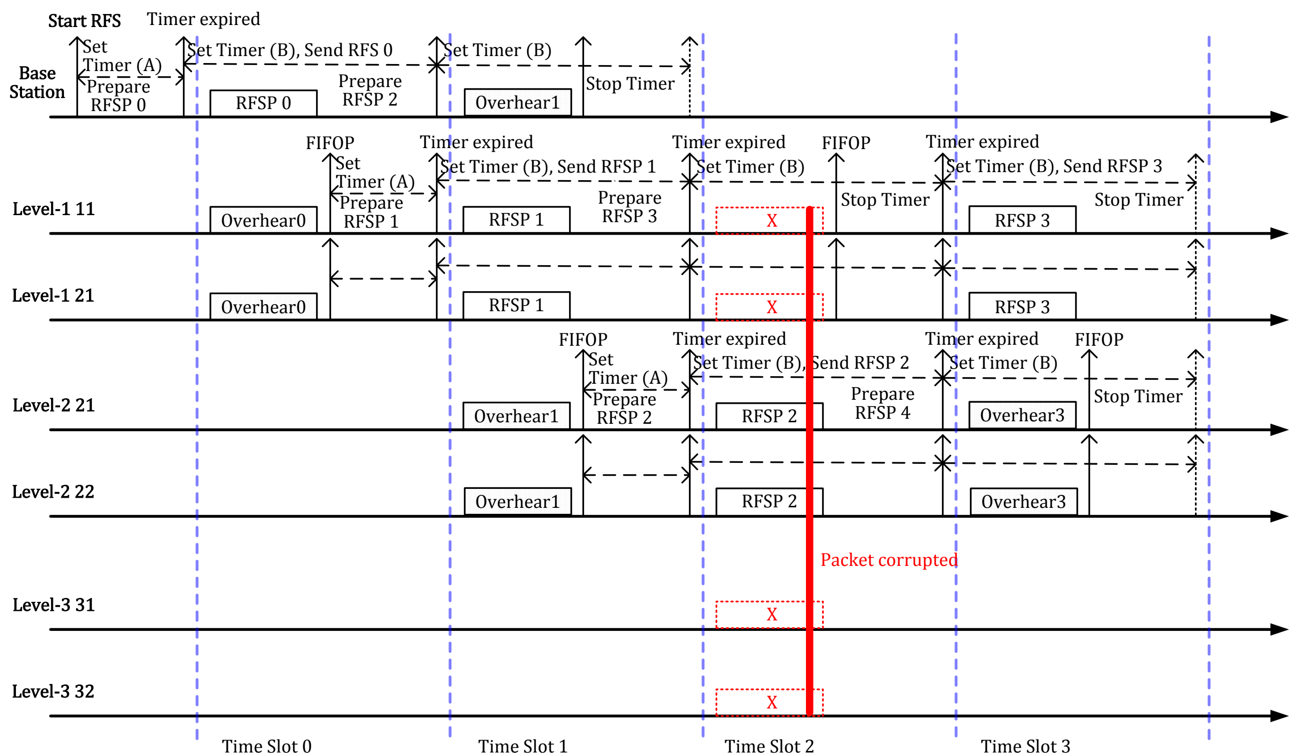
- Basic operation:
  - When a node receives a RFS packet, it rebroadcast the packet after a predefined time interval *A* using its own timer.
  - After rebroadcasting, the node waits for an implicit ACK from lower layer nodes.
  - If the node receives an implicit ACK by overhearing, it stops RFS. If not, it rebroadcast the packet for maximum retry times



* Time slot n, which has a time interval *B*, is a time interval that level-n nodes rebroadcast the packet they received at *A* time interval ago.

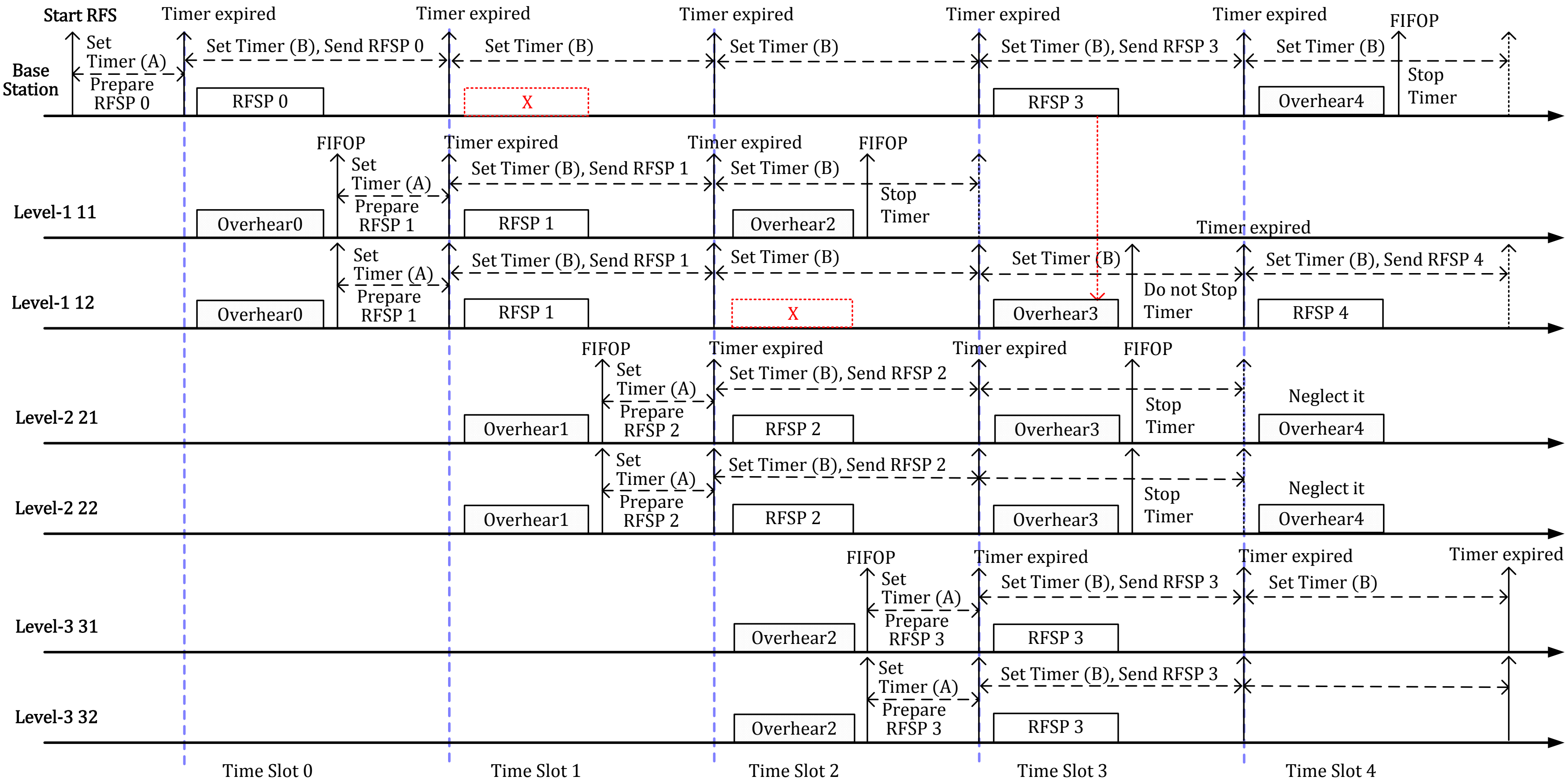
RIPPLE FLOODING SCHEME (2/3)

- Delayed retransmission: waits for 2 more slots to retransmit
  - The level-2 nodes retransmit the RFS packet at time slot 2, but what if the packet is corrupted by unknown reason. In this case, the level-2 nodes cannot receive an implicit ACK packet from the level-3 nodes but can receive a retransmission from only level-1 nodes at time slot 3.
  - Since the level-2 nodes have no way to discriminate between an implicit ACK packet from the level-3 nodes and a retransmission from level-1 nodes, the level-2 nodes may stop RFS.



RIPPLE FLOODING SCHEME (3/3)

- Ripple flooding scheme with delayed retransmission: Synchronizing rebroadcasting & PLR reduction with multiple changes of receiving



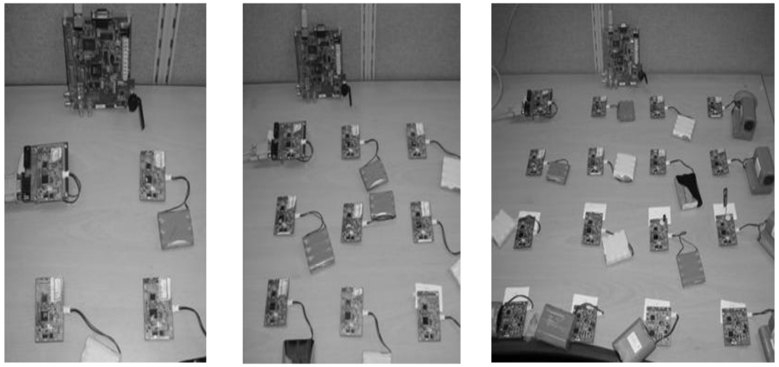
ENVIRONMENT OF EXPERIMENT

- **Environment**
  - We have implemented the RFS and simple flooding, on the sensor with the MSP430 microcontroller and the CC2420 transceiver to evaluate the major performance metrics including the convergence time and the reliability.
  - The convergence time is the average time interval from the time the broadcast was initiated to the time the last node finishing its rebroadcasting.
    - The convergence time is measured with a packet sniffer by recording time from the beginning (a BS sends out the first flooding packet) to the finishing (the last node sends the rebroadcast packet).
  - The reliability is the ratio of the number of nodes that receive the BS' transmission to the total number of nodes in the network.
- **Scenario**
  - After sending 100 RFS packets, the BS increases Tx power and sends a special command to require nodes' receiving status. After receiving the command, all nodes report to the BS the number of different flooding packets they have received.
  - To form a multi-hop topology, the RF output power control and RSSI filtering are used. The RSSI filtering is to receive the packet only exceeding a certain RSSI threshold, e.g. -70 dBm.

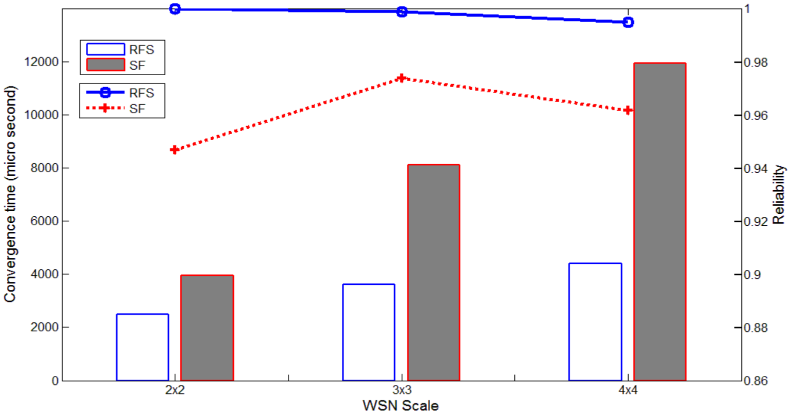
RESULT OF EXPERIMENT (1/2)

Effect on WSN Scale

- **RFS is faster than simple flooding in convergence time.**
  - The convergence time difference between RFS and simple flooding becomes proportionally bigger as the network scale increases
  - The increase rate for RFS is about 1 ms and increase rate for simple flooding is about 4ms. → RFS is 4 times faster than simple flooding under similar test topology.
- **The reliability of RFS is on average 3% better than the reliability of simple flooding.**



Test topology (2x2, 3x3, 4x4 grid)

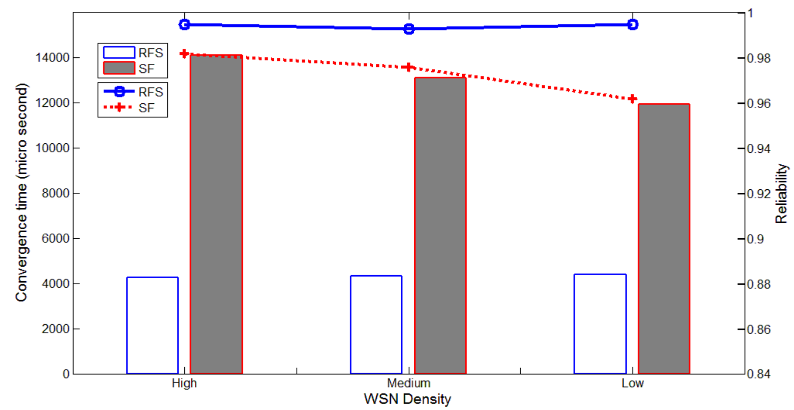


RESULT OF EXPERIMENT (2/2)

Effect on WSN Densities

- **In 4x4 grid topology, we changed the distance between nodes.**
- **In this test, we want to see whether the number of multiple senders affect performance of RFS.**

Test topology (High, Medium, Low)



CONCLUSION

- **The Ripple flooding scheme for WSN improves the convergence time of the packet flooding without sacrificing the reliability and energy efficiency on the WSN by using a synchronized packet rebroadcasting instead of avoiding collision with clear channel assessment and random back-off.**
  - The theoretical analysis of the delay spread on a receiver shows that the upper bound of PLR of the multiple senders is about 13%. Taking the result of theoretical analysis into consideration, the RFS adopts overhearing and delayed retransmission method.

- **We implement the RFS and simple flooding on the sensor node with the MSP430 microcontroller and the CC2420 transceiver.**
  - The experimental result shows that the convergence time of RFS is 3.5 times faster than the CSMA MAC based flooding in the dense network environments.
  - The reliability is 3% better on average.

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Q&A

Thank You !