Energy Saving in Intermittent Receiver-driven Multi-Hop Wireless Sensor Networks

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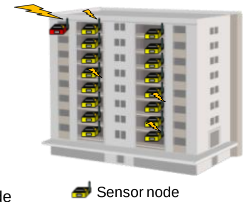
Outline

- Background of our research
  - Intermittent Receiver-driven Data Transmission (IRDT) scheme
  - Control packet collisions in IRDT
- Our goal
- Performance evaluation by computer simulation
- Conclusion and future work

Smart Meter System

- Electricity and gas meters
  - Sensor nodes measure the amount of used energy
  - Sink node(s) collects these data
- Features
  - Wireless communication
  - Low data generation rate
  - Limited battery on each sensor node

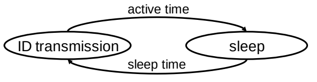


Sensor node
Sink node

Energy saving is necessary for long term operation

Intermittent Operation for Energy Saving

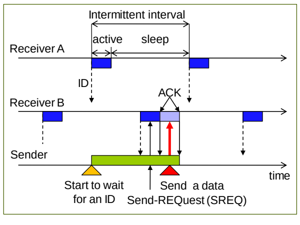
- Intermittent operation of sensor node
  - Alternating 'active' / 'sleep' states repeatedly at the *intermittent interval*
    - Communicating in 'active' state
    - Saving energy consumption with 'sleep' state
- Intermittent Receiver-driven Data Transmission (IRDT)[9]



  - Receivers start communication by sending an ID in active state
  - Senders can choose an appropriate receiver by waiting for an ID
  - We are proposing this technique to IEEE 802.15 Task Group 4
  - Control packet collision degrades IRDT's performance

[9] D. Kominami, M. Sugano, M. Murata, T. Hatauchi, and Y. Fukuyama, "Performance evaluation of intermittent receiver-driven data transmission on wireless sensor networks," in *Proceedings of the 6th International Symposium on Wireless Communication Systems (ISWCS'09), pp.* 141–145, Sep 2009.

Basic IRDT Operation and Control Packet Collisions

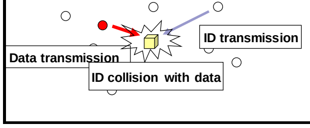


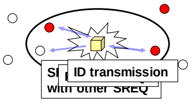
- Receiver
  - Transmits ID periodically

ID collides with other packets

- Sender
  - Waits for an ID from an appropriate receiver and returns an SREQ packet

SREQs collide with each other





Our Goal

- Solve control packet collisions in IRDT
  - ID and SREQ packet collisions degrade IRDT's performance
    - Packet collection ratio
    - Delay time
    - Energy consumption
- Propose two approaches to avoid control packet collisions
  - The collision probability changes
    - according to the *intermittent interval*

⇨ Analytical derivation of the intermittent interval to minimize the control packet collision probability

    - according to the *packet reception rate*

⇨ Using data aggregation in IRDT to decrease the packet reception rate

Formulation of the Probability of Control Packet Collisions

Assumptions:
- All sensor nodes generate data packets according to Poisson process with intensity λ
- All nodes have the same intermittent interval (denoted by T)
- All nodes use minimum hop routing algorithm

- ID-collision probability:

$$P_{ID} = \frac{T_r H(R)}{T}$$

T: Intermittent interval
T_r: SREQ and data reception time
H: Average number of hidden nodes

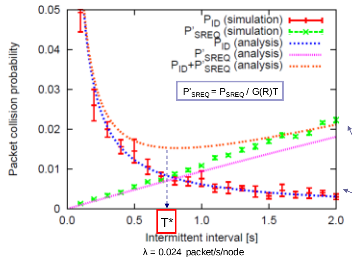
  - Periodical ID transmission causes this collision
    - Short intermittent interval increases ID-collision probability
    - Independent of the data reception rate
- SREQ-collision probability:

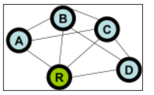
$$P_{SREQ} = 1 - \sum_{k=0}^{|N_b(R)|} C(R,k) e^{-(|N_b(R)|-k)G_b(R)T} (1 - e^{-G_b(R)T})^k$$

$|N_b|$: The number of child nodes
G: Average data reception rate
G_b: G / $|N_b|$
$C(*, k)$: The number of the combination of the k hidden nodes

  - Congestion of data packet causes this collision
    - Long intermittent interval decrease the number of processable data packets per unit time, which increases SREQ collision
    - High data reception rate increases SREQ-collision probability

Derivation of the Proper Intermittent Interval (T*)

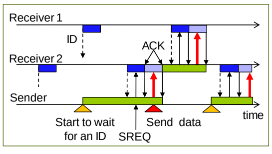




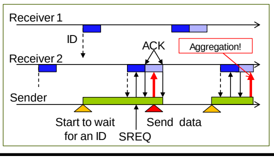
Network model:
Node A, B, C, and D send data packets to the sink node R

- Proper intermittent interval minimizes the sum of P_{ID} and P'_{SREQ}
  - Both P_{ID} and P'_{SREQ} are collision probabilities per one data transmission
  - All nodes use approximate value of T^* obtained by iterative calculation

Data Aggregation for Avoiding Control Packet Collisions



Use data aggregation



- Continuing ID transmission after receiving a data packet
  - Sending the aggregated data packet
    - after a certain time period
    - after a certain number of packets are aggregated
  - Aggregation is assumed to increase the size of the data packet linearly
- Decreasing SREQ collision because of:
  - the decrease of average data reception rate
  - priority use of aggregation between two same hop nodes from the sink node
- Increasing of ID collision with data packet because of:
  - the increase of data reception time

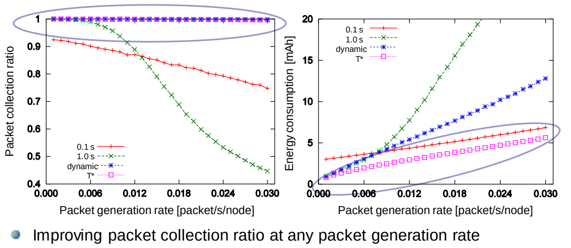
Simulation Model

- Network model
  - 49 sensor nodes and 1 sink node are deployed over 400-m-square
- Assumptions
  - No failure and energy depletion of nodes
  - The collided packets are always both discarded
  - All nodes have information of network topology for minimum hop routing
- Variables
  - Packet generation rate (0.001 ～ 0.030 packet/s/node)
  - Intermittent interval (0.1 s, 1.0 s, Dynamic [9], T^*)
- Parameters

Simulation time	6 [hour]
Communication range	100 [m]
Communication rate	100 [kbps]
Waiting current	25 [mA]
Sending current	20 [mA]
Sleeping current	0 [mA]
ID packet size	40 [byte]
Data packet size	128 [byte]
Other packet size	26 [byte]

Simulation Results of Packet Collection Ratio and Average Energy Consumption

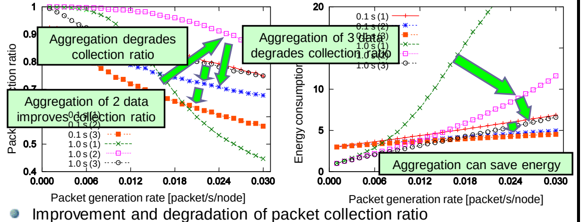
The Impact of the Proper Intermittent Interval -*T**-



- Improving packet collection ratio at any packet generation rate
  - 'Dynamic' and T* can attain almost 100% collection ratio
- Saving more energy compared with 'dynamic'
  - 10% reduction when packet generation rate is 0.001
  - 44% reduction when packet generation rate is 0.030

Simulation Results of Packet Collection Ratio and Average Energy Consumption

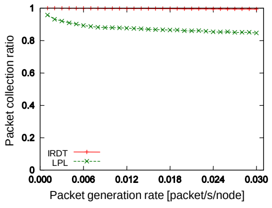
The Impact of Data Aggregation

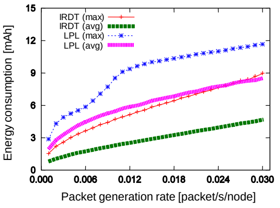


- Improvement and degradation of packet collection ratio
  - Data aggregation is advantageous with long intermittent interval
- Saving more energy
  - The more node aggregates data, the more energy consumption is reduced
    - The suppressing effect becomes smaller as more aggregation is done
    - Aggregation with short intermittent interval is less effective because of ID collision

Simulation Results of Packet Collection Ratio and Average Energy Consumption

The Impact of the Combination of T* and Aggregation





- IRDT can attain higher collection ratio than LPL
- IRDT can reduce more energy than LPL
  - 33% reduction of the average energy consumption
  - 38% reduction of the maximum energy consumption

Conclusion and Future Work

- Proposing the improvement method for IRDT based on control packet collisions and clarifying its effectiveness
  - Analytical derivation of *T** which minimizes the control packet collision probabilities
  - Introduction of data aggregation in IRDT for reduction of the data packet reception rate
- Future work
  - Load balancing
  - Evaluating robustness at the various situations
    - Energy depletion, node failure, link failure

Thank you!