Performance Evaluation of Inter-cluster Multi-hop Communication on Large-scale Sensor Networks

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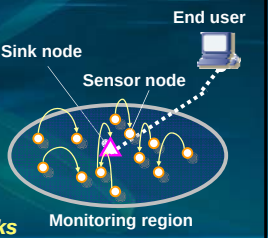
Outline

- Introduction
- Our objective
- Performance evaluation of multi-hop communication between clusters with ideal transmission schedule
- Effect of interference on the network performance
- Conclusion

Sensor Networks

- Network composed of sensor nodes linked by a wireless medium
  - Each sensor node:
    - senses surrounding environment
    - sends data to a sink node
- Various applications
  - Security
  - Disaster prediction
  - Environmental monitoring

Large-scale sensor networks

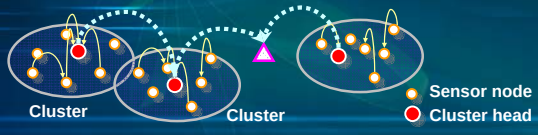


Strategy on large-scale sensor networks

Scalability
Robustness
Energy efficiency → ***Clustering***
e.g., LEACH [2], HEED [3]

Short communication range → ***Multi-hop communication***

Multi-hop communication between clusters is preferable

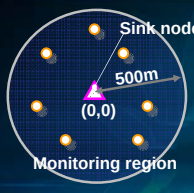


Problem and our goals

- Further evaluations from a broad perspective are required
  - Distribution of power consumption
    - Residual power around the sink node determines the lifetime of the network
  - Data collection time
    - Applications requiring swift data gathering
  - Effect of interference
    - Considerable amount of interference can be occurred

Our goal:
- **Performance evaluation of multi-hop communication between clusters**
- **Confirmation of its effectiveness**

Network model



- Sensor nodes are placed randomly
- Data fusion is not applied
- Nodes are synchronized with each other and with fixed-length time-slots.
- Two channels are used for
  1. inter-cluster communication
  2. intra-cluster communication

· # of sensor nodes : 500

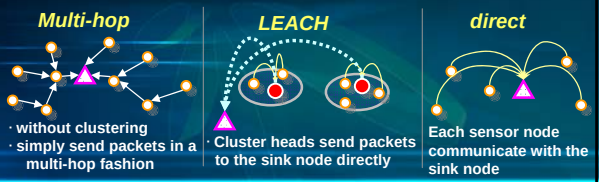
Power consumed for each action

***k* bits, *d* m**

$$\begin{cases} Tx(k,d) = E_{elec}k + \varepsilon_{amp}kd^2 \\ Rx(k) = E_{elec}k \end{cases}$$

Object for Comparison

- As methods of multi-hop communication between clusters, we use:
  - LEACH + multi-hop
  - HEED + multi-hop
- Objects for comparison



· without clustering
· simply send packets in a multi-hop fashion

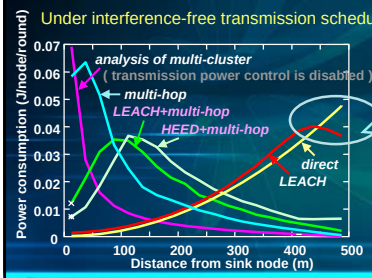
· Cluster heads send packets to the sink node directly

Each sensor node communicate with the sink node

Evaluation of power consumption

- In terms of the highest per-region power consumption, multi-hop communication between clusters cuts power consumption in comparison to simple multi-hop by about 60%.

Under interference-free transmission schedule

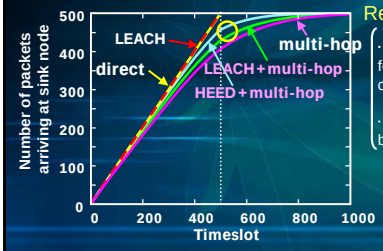


In vast monitoring region, multi-hop communication is necessary.

The larger the monitoring region is, the higher power is consumed in transmission to the sink node

Data collection time

- *LEACH* and *direct* take a minimum time and are optimal.
- The data collection time with clusters decreases in comparison with the case without clusters



Reason:

· We use different two channels for intra-cluster and inter-cluster communication

· The number of transmission can be kept low with clustering

How much interference deteriorates performance?

We construct interference-free ideal transmission schedule and evaluate performance using it

This is improbable scenario
- Enormous amount of information has to be exchanged
- This exchange consumes great deal of power and time

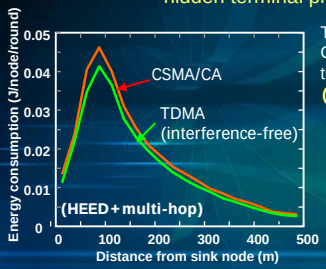
⇒ Frequent interference is unavoidable

- We compare TDMA based on the ideal schedule (as described before) and CSMA/CA (IEEE 802.15.4)
  - Clarify the increase of power consumption and data collection time

The increase of power consumption

- Interference cannot be avoided completely when using CSMA/CA

"hidden terminal problem"



The power consumption of CSMA/CA is not much worse than that of interference-free TDMA **(power consumed to gather same amount of data increase only by 12%)**

CSMA/CA works well for avoiding retransmission

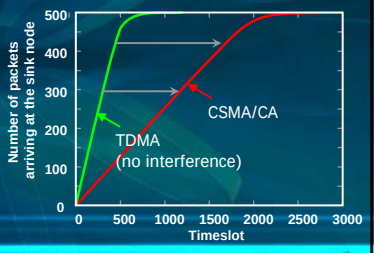
Degradation of data collection time

- Data collection time is 3.7 times longer in CSMA/CA
  - Many sensor nodes are densely deployed
  - Channels are often busy with the transmissions of other nodes

Most backoffs are performed to avoid interference

⇓

Trade-off between power consumption and data collection time

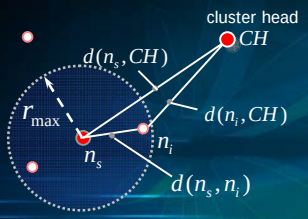


Conclusion

- Focused the fundamental characteristics of multi-hop communication in a large-scale clustered sensor network
  - Distribution of power consumption
    - Multi-hop communication between clusters is preferable for data collection in large-scale sensor networks
  - Data collection time
    - Multi-hop communication between clusters reduce data collection time compared with simple multi-hop communication
- Clarified how much performance degradation occurs due to interference
  - Allowing interference, takes 3.7 times longer to gather equal amounts of data, and that it suppresses the increase of power consumption only 12% in comparison with interference-free TDMA.

- Thank you

Routing

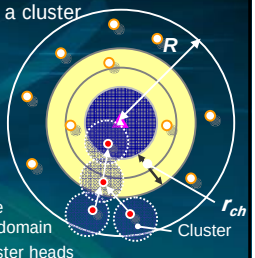


Procedure for selecting relay node within a cluster

(For simplicity, Only the distance to the next hop is used as a selection criterion in choosing a relay node)

Analysis of power consumption (idea)

1. Analysis of power consumed inside a cluster
   - Assuming the clusters form circle
2. Derivation for relay load of cluster head
   - Taking focus on annular domain of width r_{ch} *1 (yellow colored region)
     - cluster heads in the domain receive all the data generated outside the domain
     - Probability of relaying between cluster heads in this domain is very small



*1 r_{ch} : communication ranges of cluster-heads

Analysis of power consumption (result)

The simulation results and those of the analysis are in good agreement.

(For simplicity, we assume transmission distances of sensor nodes are constant.)