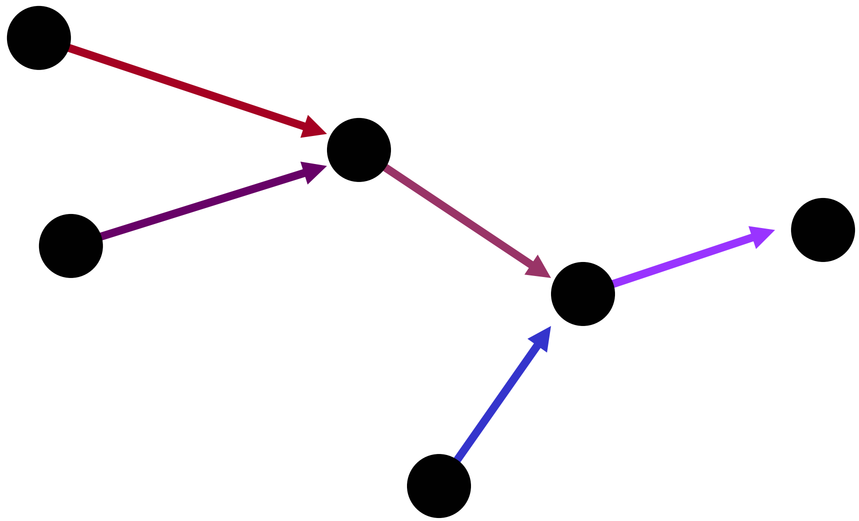
Modeling Data-Centric Routing in Wireless Sensor Networks



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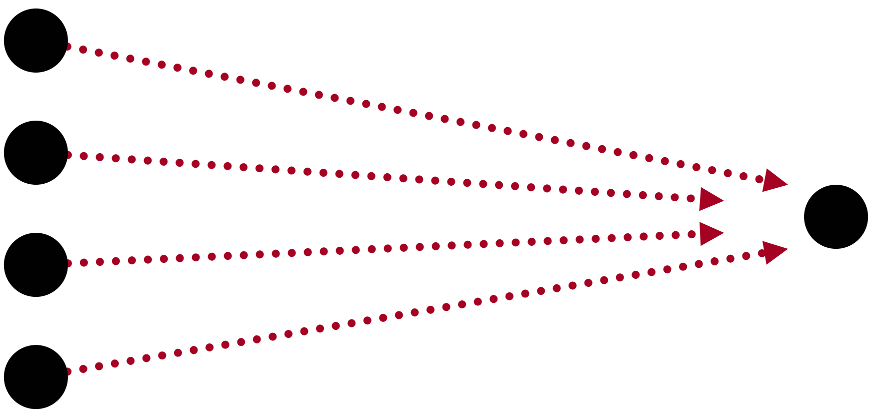
CS 428

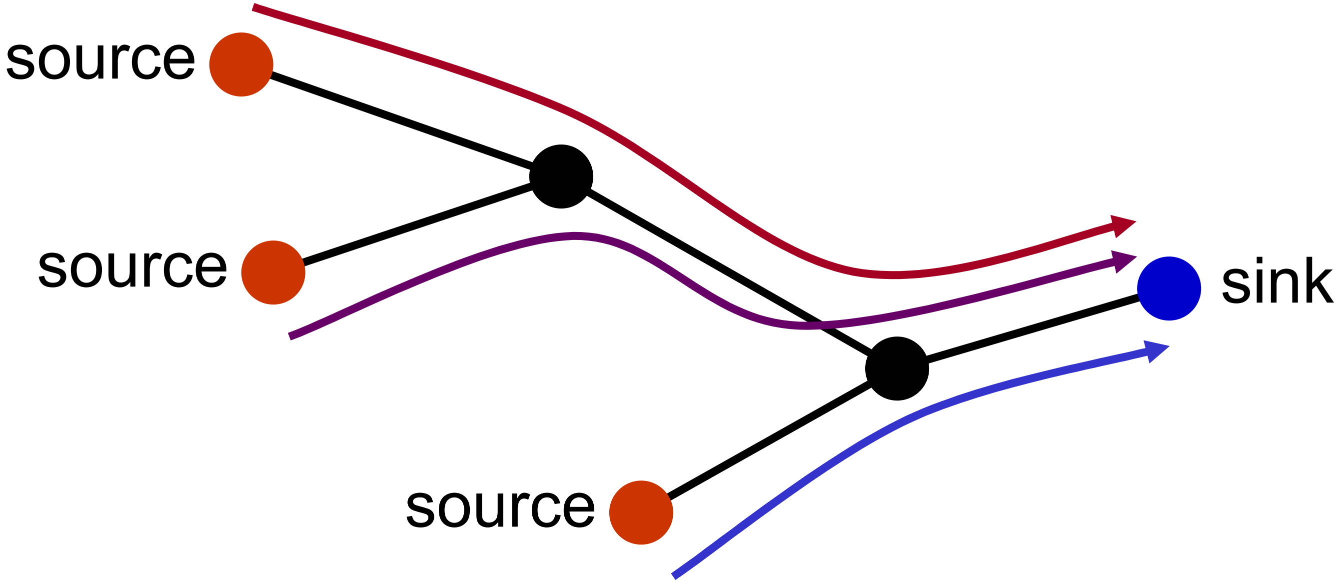
Two important characteristics of wireless sensor networks:

- Limited (and often irreplaceable) energy per node
- Many-to-one flows of ***highly correlated*** data



We need energy-efficient schemes for this situation…

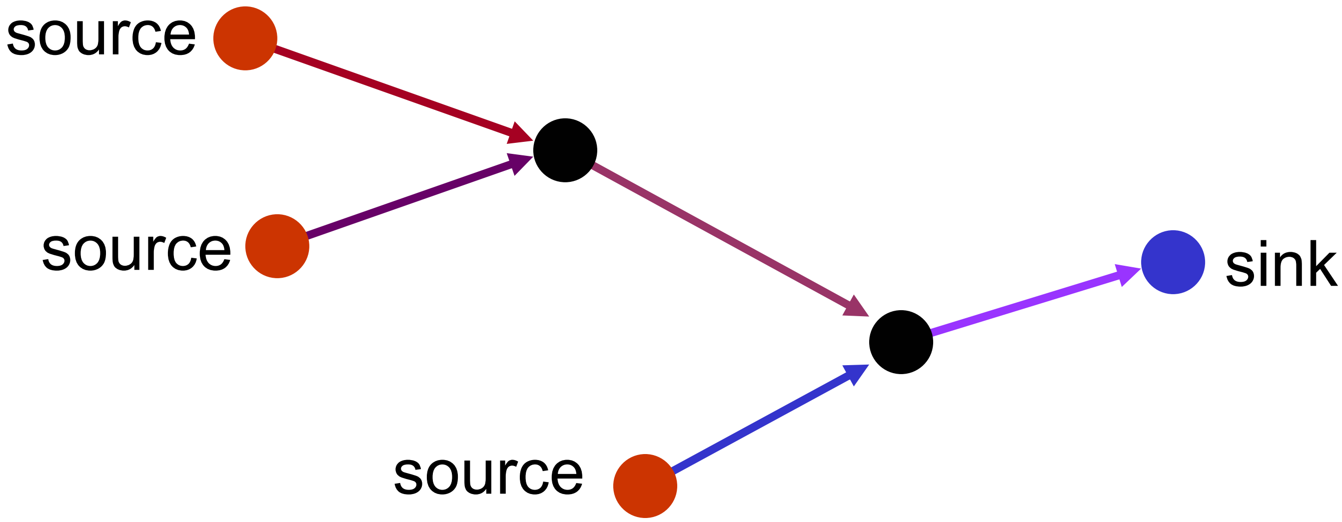
Address-Centric (AC) Routing



Each source ***independently*** sends its data to the sink.

Total number of transmissions : 3 + 3 + 2 = 8.

Data-Centric (DC) Routing

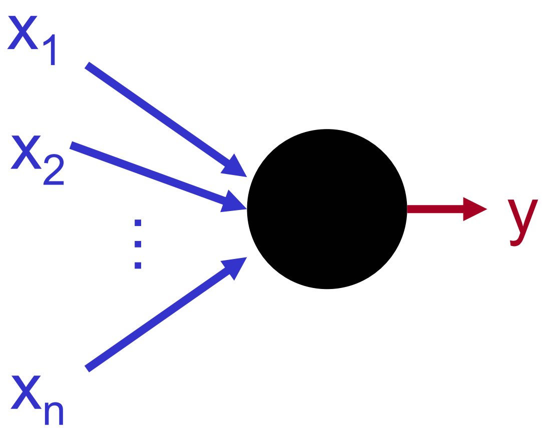


We form a ***data aggregation tree***. At every node, we ***wait*** until all its children have sent their data and then ***aggregate*** their data to send to the parent.

Total number of transmissions : 5 (vs. 8 for AC)

Goal of paper: Analyze effect of DC routing vs. AC routing.

Question 1 : How do we do data aggregation?



$y = f(x_1, x_2, \ldots, x_n)$

We assume that y uses no more bits than $(x_1, x_2, \ldots, x_n)$, and preferably less.

Some simple examples :

- $f(x_1, x_2, \ldots, x_n)$ = largest k elements of $\{x_1, x_2, \ldots, x_n\}$
- $f(x_1, x_2, \ldots, x_n) = (x_1 + x_2 + \ldots + x_n)/n$
- $f(x_1, x_2, \ldots, x_n) = a_1x_1 + a_2x_2 + \ldots + a_nx_n$

Question 2 : How do we find a good data aggregation tree?

Definition of the data aggregation tree:

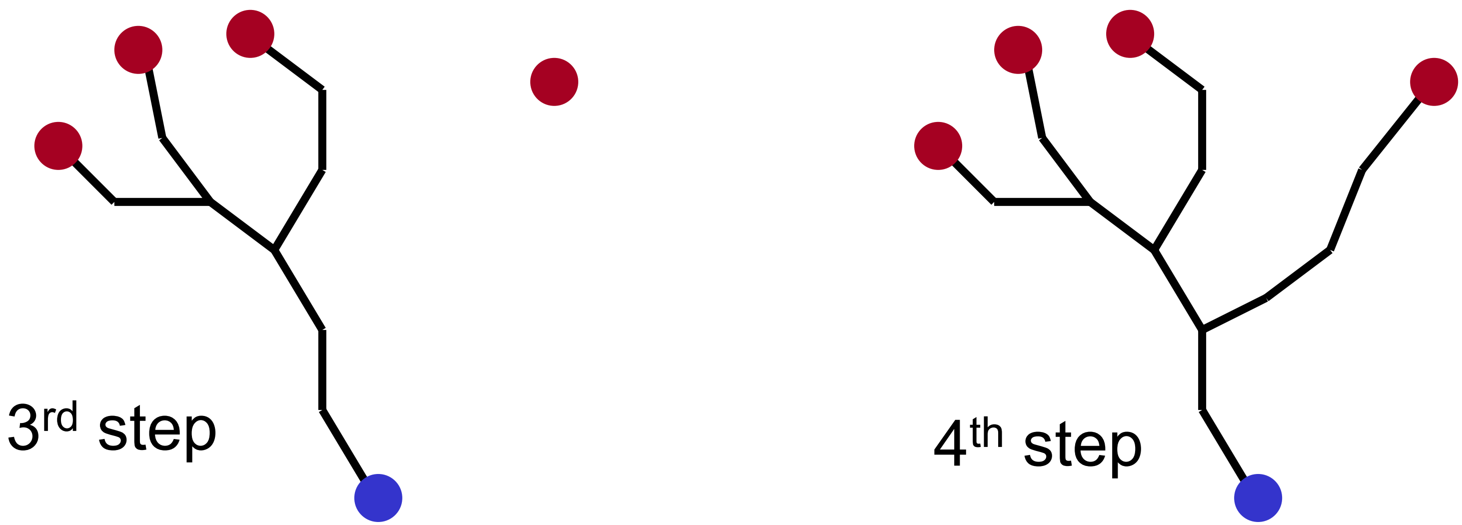
- There is a directed path from each of the sources to the sink.
- Each node in the tree (except the sink) makes only one transmission. Thus there is exactly one directed edge leaving each node.

Number of transmissions = Number of edges in tree

Thus finding the best data aggregation tree solves…

The minimum Steiner tree problem : Given a graph (V, E) and a subset of vertices S, find the minimum connected subgraph that contains S. (***NP-hard***)

A good heuristic: Greedy Incremental Tree (GIT)

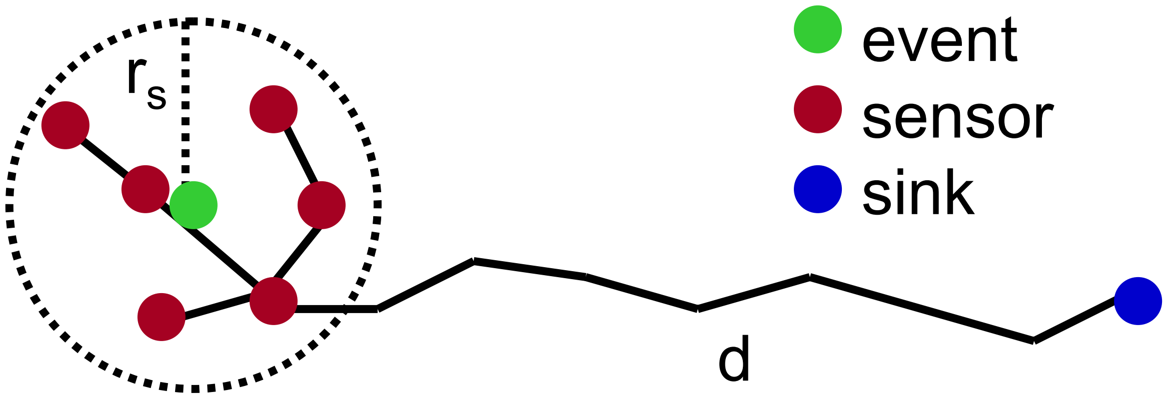


Fact : At most 2 times suboptimal, in general.

Important special case : Suppose the subgraph defined by the subset of sources S is ***connected***. Let d be the shortest distance from the one of the sources to the sink. Then the GIT is ***optimal***, with size d + |S| – 1.

Proof : Incremental cost of first node is d, incremental cost of additional nodes is 1. Clearly best we can do…

The Event Radius (ER) Model



- The event is modeled as a ***single point***.
- All nodes within a sensing range r_s of the event are considered the set of sensors S.
- If the communication radius r_c is large enough (as it often is), then sensors form a connected subgraph. Thus the GIT is optimal.

Intuitive result : If r_s and r_c are fixed, but d $\rightarrow \infty$, then the ratio of the AC cost to DC cost approaches |S|.

Experimental Results (energy costs)

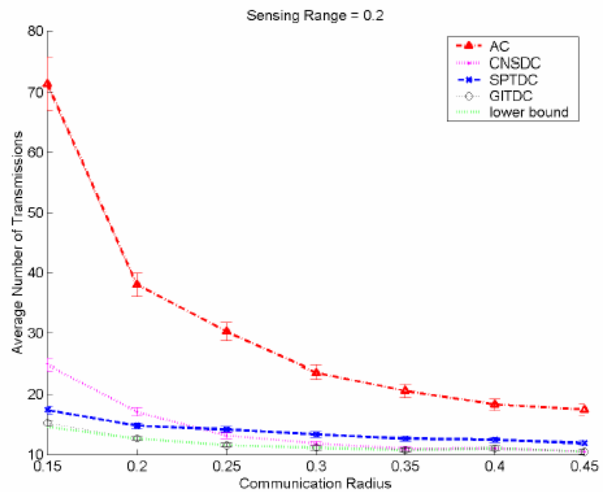


Fig. 5. Comparison of energy costs versus communication radius in event-radius model

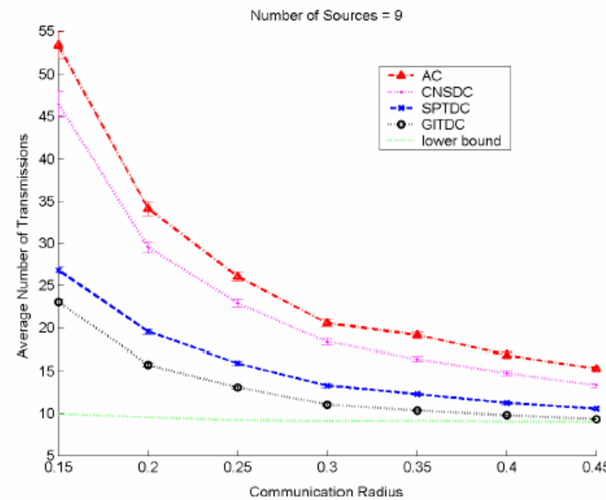


Fig. 8. Comparison of energy costs versus communication radius in random-sources model

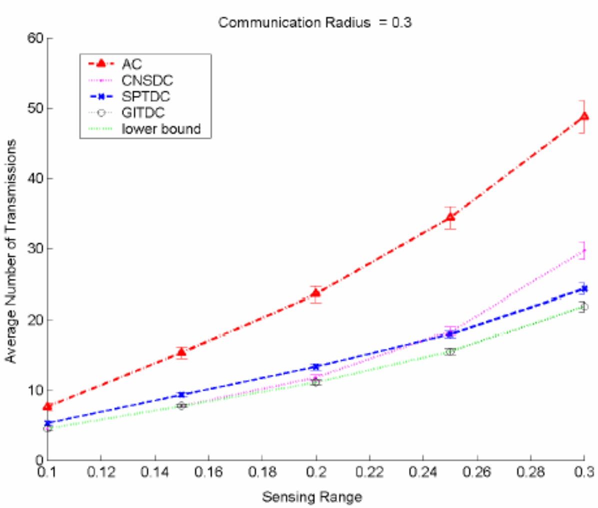


Fig. 6. Comparison of energy costs versus sensing range in event-radius model

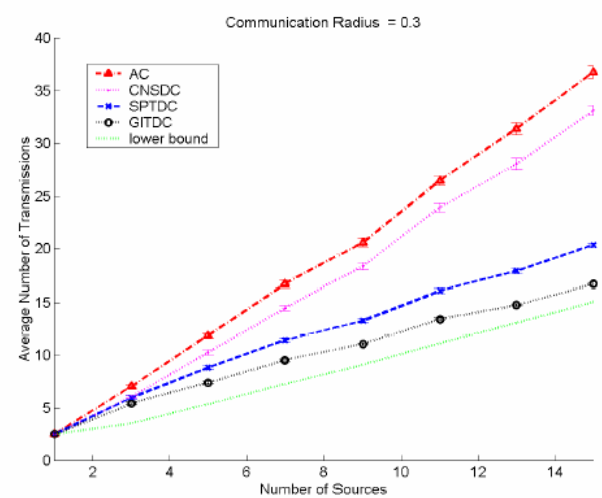


Fig. 9. Comparison of energy costs versus number of sources in random-sources model

Increased delay in DC routing

- For DC routing, each node has to wait for all its children to transmit before its transmits its aggregated data. It follows that we must wait for data from the ***farthest source***.
- For AC routing, we get data as soon as arrives from the ***closest source***.

Thus the increase in delay is approximately proportional to :

(distance between farthest source and sink) – (distance between closest source and sink)

Experimental Results (Delay)

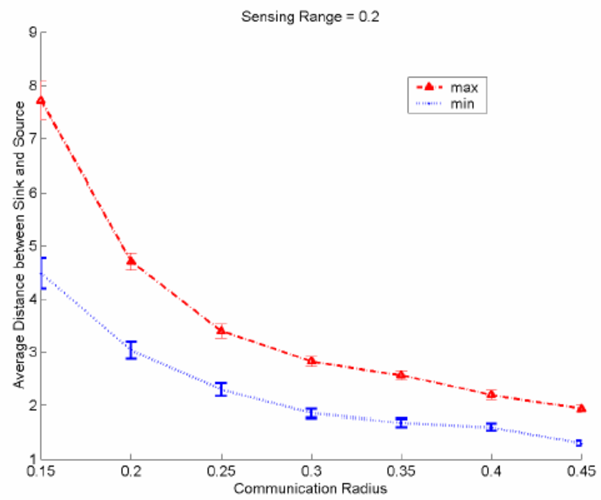


Fig. 10. Distance of sink to nearest and farthest source versus communication radius in event-radius model

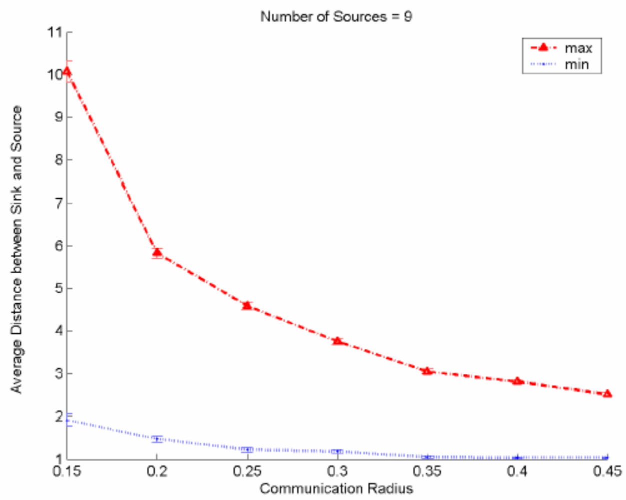


Fig. 12. Distance of sink to nearest and farthest source versus communication radius in random-sources model

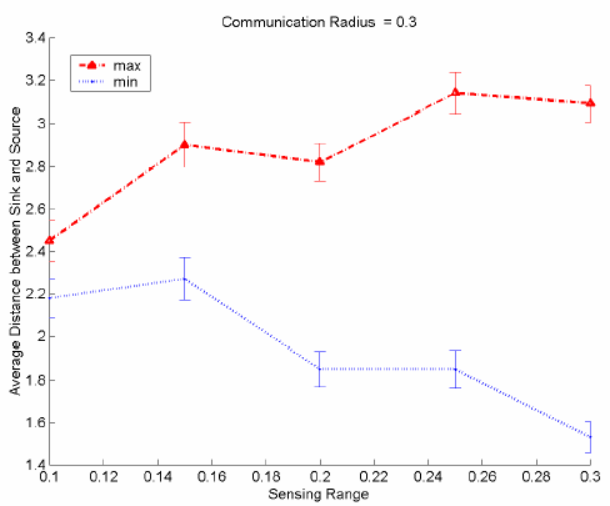


Fig. 11. Distance of sink to nearest and farthest source versus sensing range in event-radius model

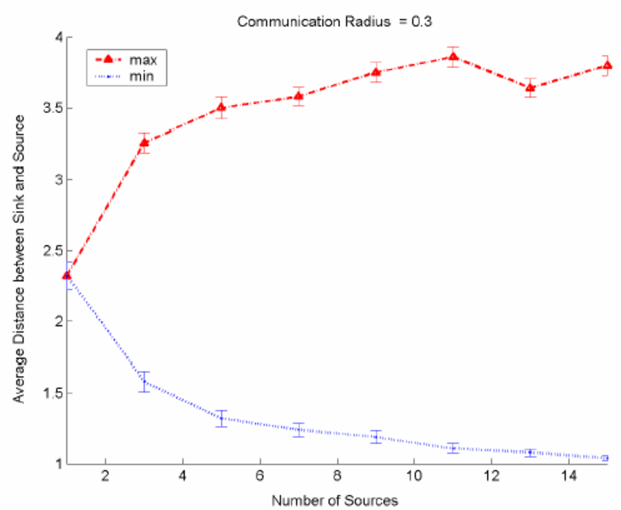


Fig. 13. Distance of sink to nearest and farthest source versus number of sources in random-sources model

Increased robustness in DC routing

- Incremental cost of an extra sensor in AC routing is the cost of the entire route (can be high if distance to sink is high).
- Incremental cost of an extra sensor in DC routing is at most the distance between it and the current data aggregation tree (often low or 1).

DC routing allows for more sensors, which can be used to increase the robustness of the system.

Conclusions

For sensor networks, DC routing results in :

- Dramatically better energy efficiency than AC routing.

- More delay due to data aggregation.

- More robustness, since it is easier to add more sensors.