TAG: a Tiny AGgregation Service for Ad-Hoc Sensor Networks

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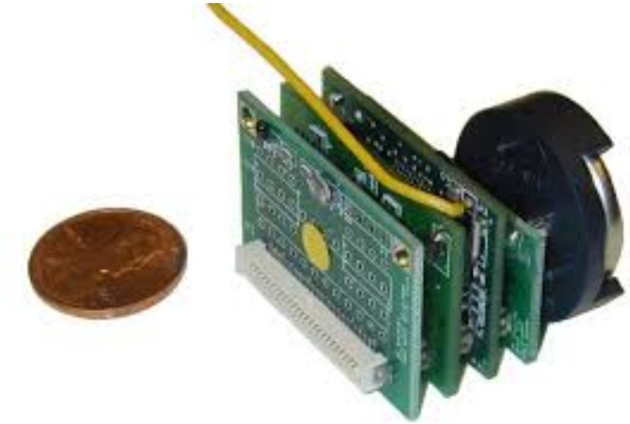
Motivation

Smart Sensors

- Devices that measure real world phenomena (temperature, buildings movement in earthquake)
- Wireless, battery powered, full-fledged computers

Motes

- Smart sensor developed in UC Berkeley
- TinyOS: ease the deployment of motes in ad-hoc networks
- Ad-hoc networks: networks not relying on pre-existing infrastructures(routers, access point)



Motivation

Challenges working with smart sensors:

- Limited power supply while needs long lived deployment & zero maintenance
- Power consumptions dominated by transmitting/receiving messages
- Users have to write low level and error-prune code to collect and aggregate data from the network

Goals:

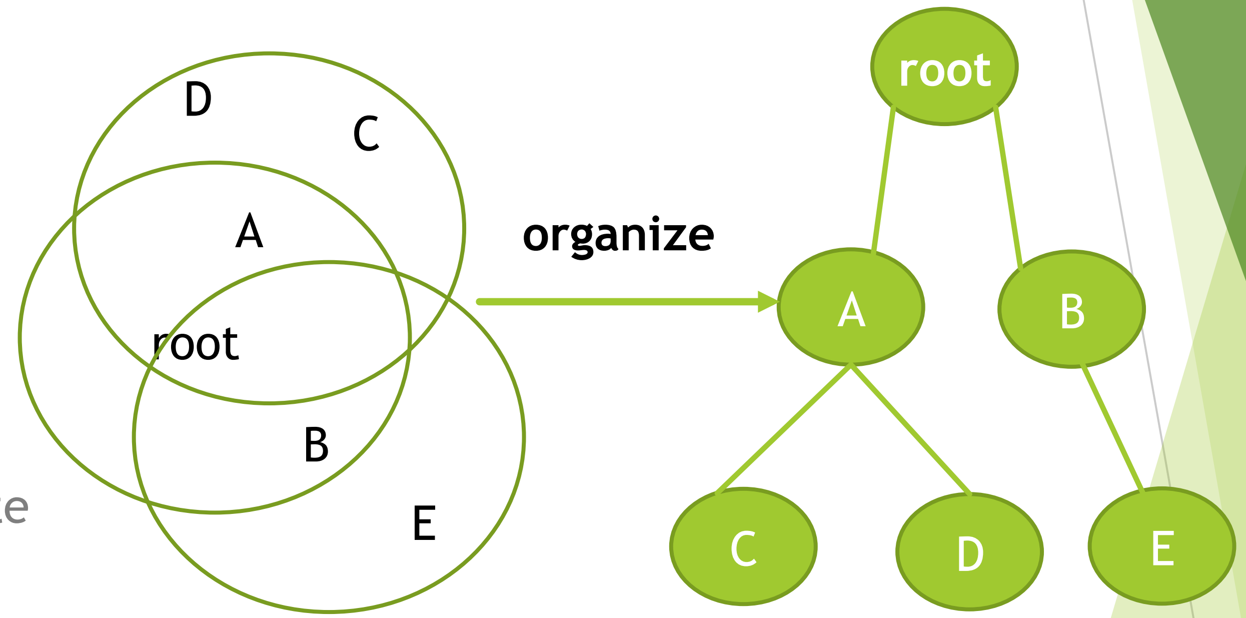
- Have more power-conserving algorithm to reduce radio communication
- Provide a high-level programming abstraction to hide low level details

Tiny AGgregation (TAG)

- Generic aggregation service for *ad hoc* networks of TinyOS motes
- Provides a SQL-like declarative languages for data collection and aggregation
- Intelligent execution of aggregation queries to save time and power
- In network aggregation: calculates aggregation in each node as data flows through it
- Users inject query into a storage-rich basestation(root)

Ad-Hoc Routing Algorithm

- A routing tree is needed for sensor to route data
- A root is assigned with level 0. Root broadcasts message {id,level} to other nodes in its range
- Upon receiving a message, a sensor (without level) will update its level and parent node, and does the broadcast again
- Algorithm ends when all nodes have a level



Query Model and Environment

- SQL-style query syntax
- Example: microphone sensor network for monitoring volume

```
SELECT AVG(volume),room
FROM sensors WHERE floor = 6
GROUP BY room
HAVING AVG(volume) > threshold
EPOCH DURATION 30s
```

Query Model and Environment

- Queries in TAG have the following form:

  SELECT { agg (expr), attrs }

  FROM sensors

  WHERE { selPreds }

  GROUP BY { attrs }

  HAVING { havingPreds }

  EPOCH DURATION *i*

  Supports only aggregates and not arbitrary joins

Query Model and Environment

- The output of a TAG query is a stream of values, rather than a single aggregate value
- Each record consists of one <group id, aggregate value> pair per group
- Each group is time-stamped
- Readings used to calculate an aggregate all belong to the same time-interval epoch
- EPOCH DURATION specifies the amount of time devices wait before sending samples to other devices

Structure of Aggregates

TAG implements aggregates via three functions:

- a merging function ***f***
- an initializer ***i***
- an evaluator ***e***

In general, *f* has the following structure:

$$< z > = f\,(< x >, < y >)$$

Partial-state record resulting from the application of *f* function to $<x>$ and $<y>$.

Partial state records - intermediate state over those values that will be required to compute an aggregate.

Structure of Aggregates

Example: AVERAGE Aggregate

$$f\,(\,\langle S1, C1 \rangle\,,\,\langle S2, C2 \rangle\,) = \langle S1 + S2, C1 + C2 \rangle$$

Merge function for a function, e.g. AVERAGE

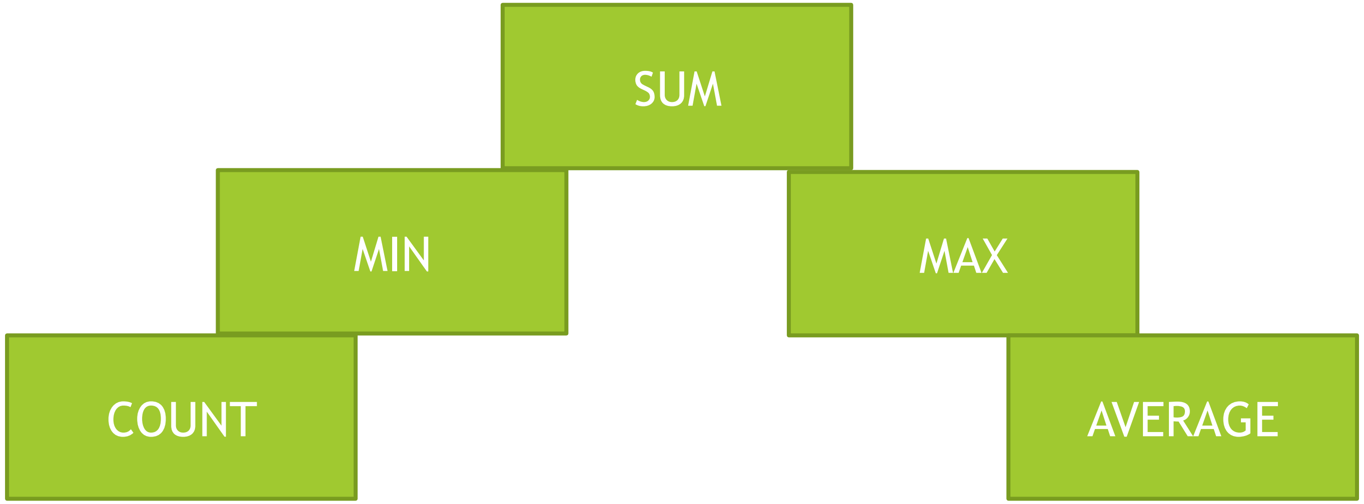
Partial state records

Initializer $i\,(x)$ returns the tuple $\langle x, 1 \rangle$.

For AVERAGE, the evaluator $e\,(\langle S, C \rangle)$ returns S/C.

Aggregate functions

SQL supports the following functions:



Want TAG to support more

Solution : Generic classification of aggregate functions using the proposed dimensions

Aggregate functions

In order to **evaluate the performance of TAG:**

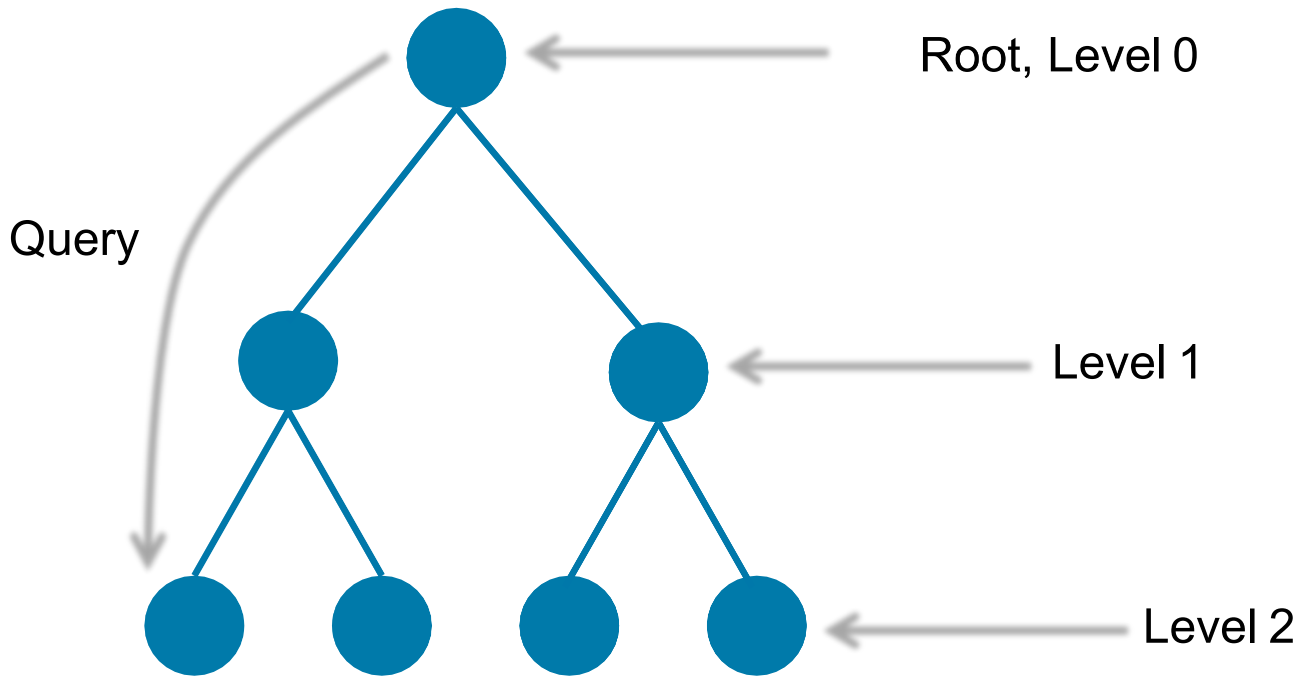
Dimensions proposed:

- **Duplicate sensitive:** It determines if aggregates can be affected by duplicate readings from a single device
- **Exemplary aggregates:** return one or more representative values from the set of all values
- **Summary aggregates:** compute some property over all values
- **Monotonic aggregates :** determines whether some predicates (such as HAVING) can be applied in network
- **Partial state:** relates to the amount of state required for each partial state record which is inversely related to TAG's performance

In-Network Aggregation

Tree-like Topography & Level based Routing

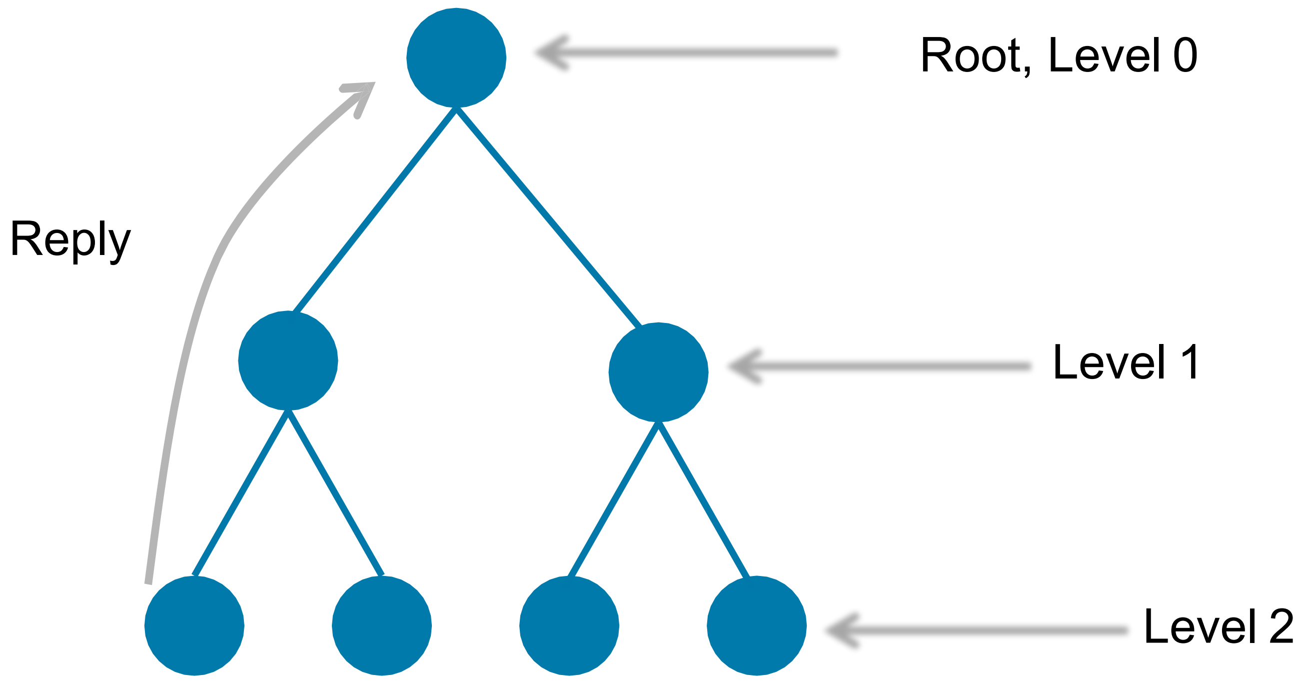
Distribution Phase



In-Network Aggregation

Tree-like Topography & Level based Routing

Collection Phase



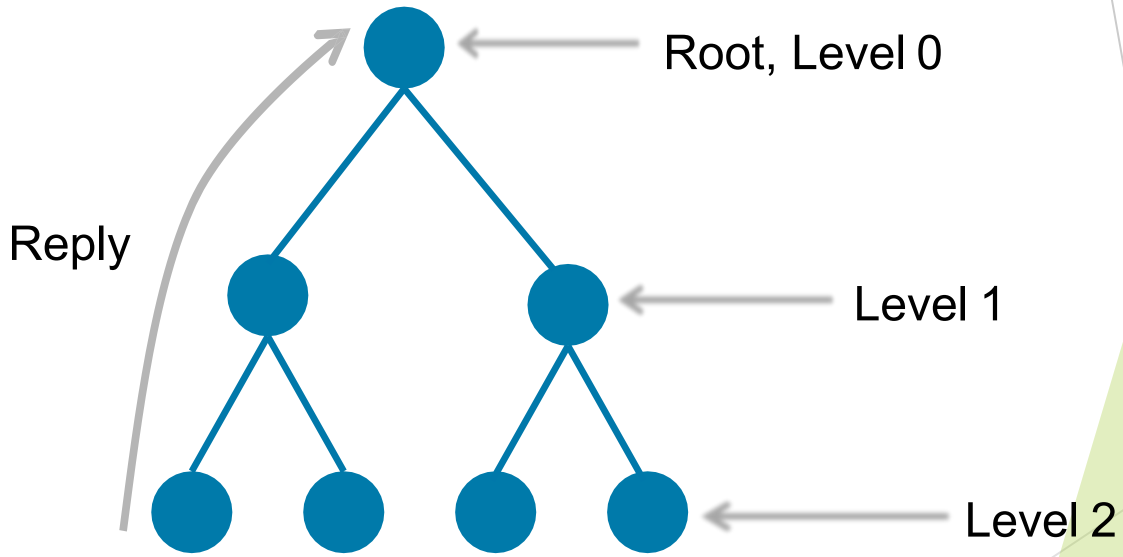
In-Network Aggregation

Tree-like Topography & Level based Routing

Collection Phase

Parents need to wait until they heard from their children before routing aggregate up for the current epoch.

Solution: Subdivide epoch s.t. children are required to delivered their partial state records during a parent-specified time interval

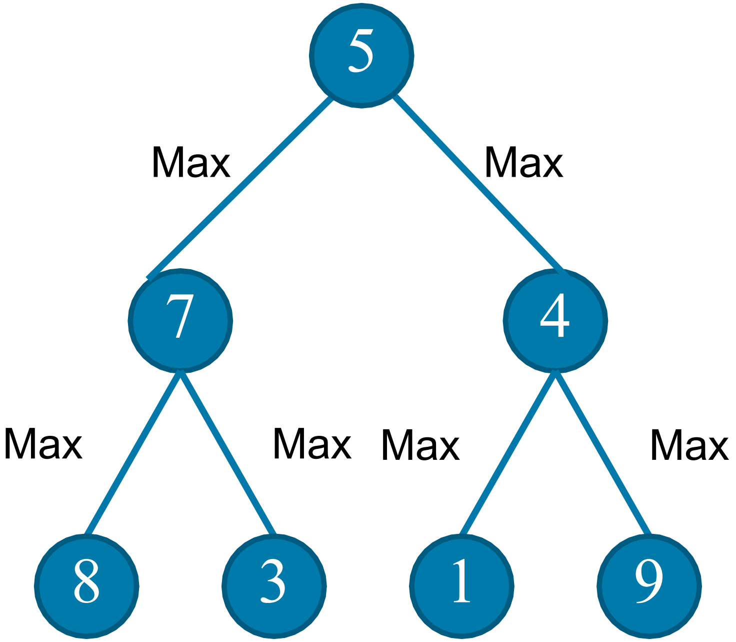


In-Network Aggregation

SELECT MAX(temp) FROM sensors

Without TAG

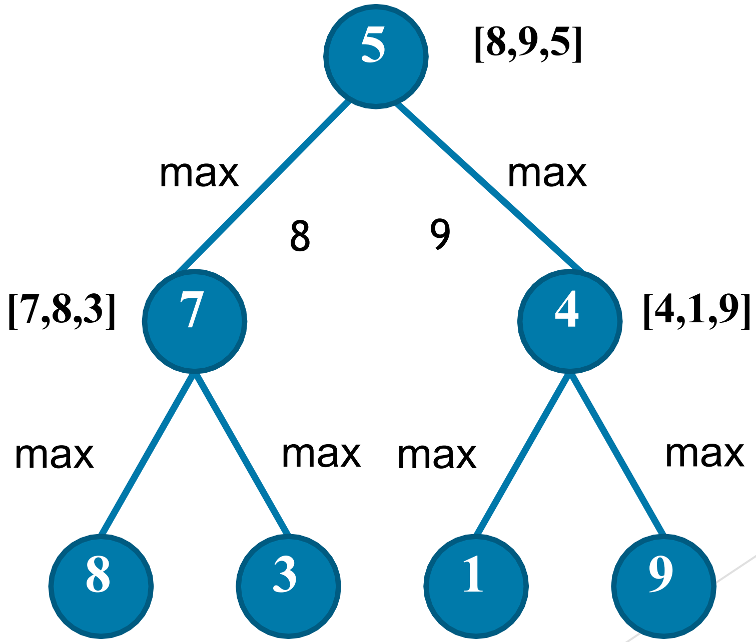
- Total Messages: 14
- Numbers: [5,7,4,8,9,3,1]



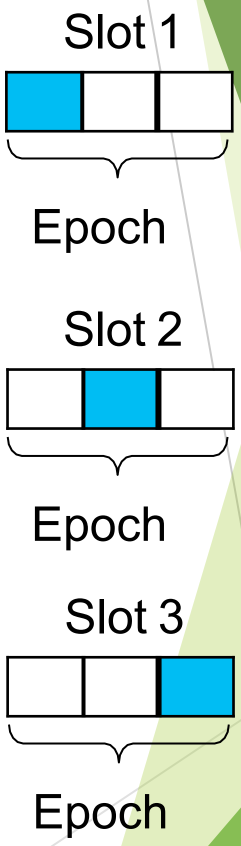
MAX=9

With TAG

Total Messages: 9

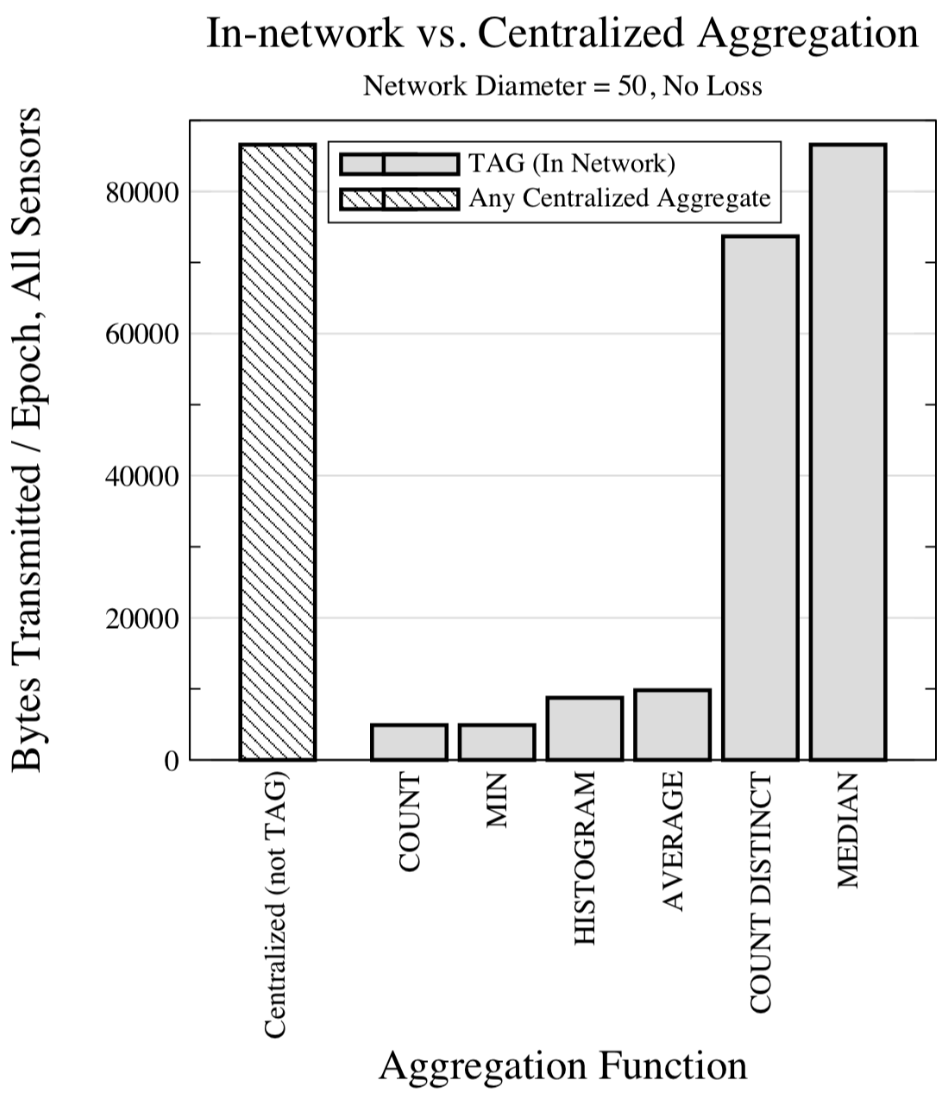


MAX=9



Evaluation

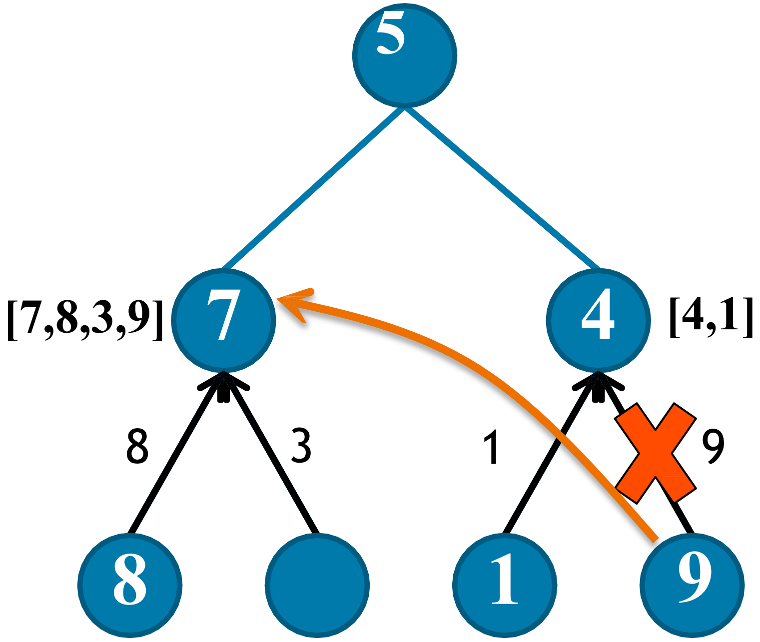
TAG Performance



Optimization

Multiple Parents

- Increased Reliability
  - Duplicate insensitive aggregates
  - Aggregates that can be expressed as a linear combination of parts

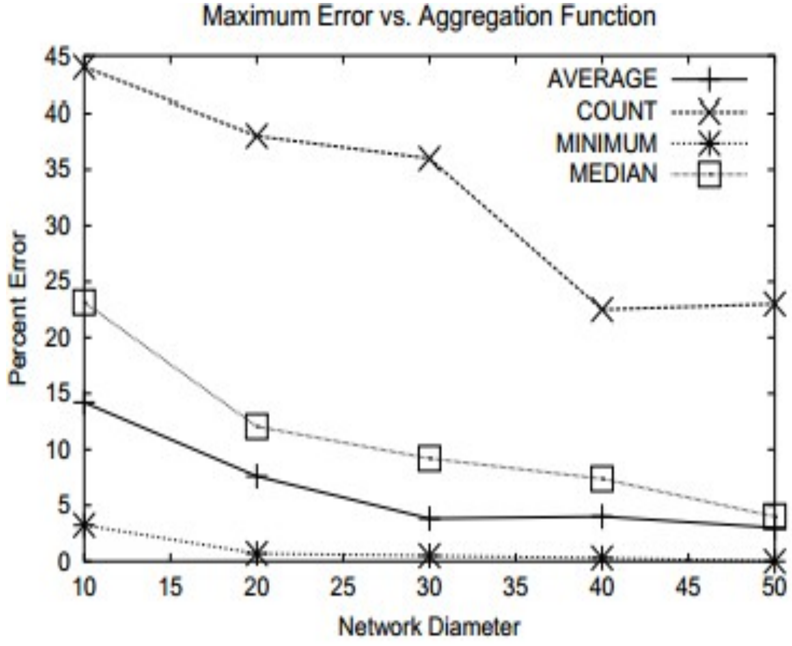


Improving Tolerance to Loss

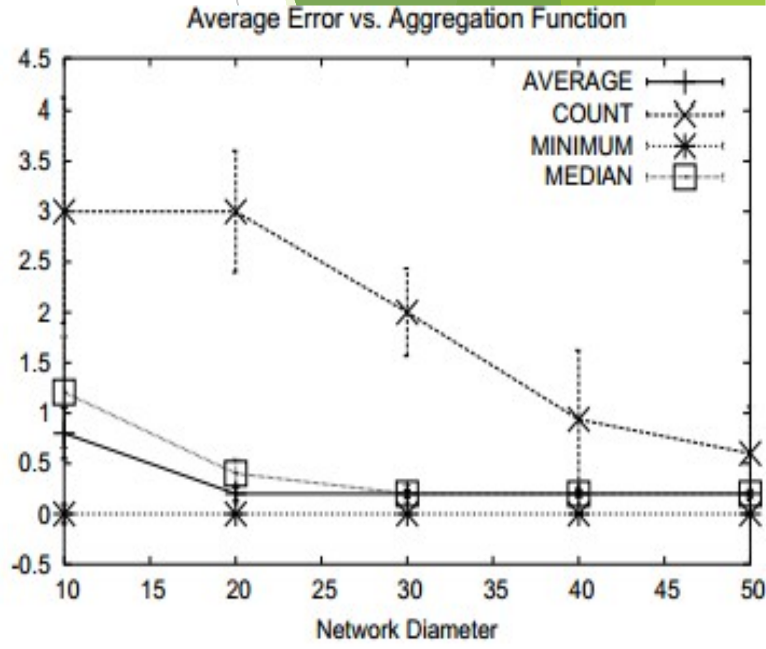
Effect of Loss – Single loss

Monitor quality of links to neighbor

- By tracking the proportion of the packets received from each neighbor
- Assume parent fails if hasn't heard from it for a certain period of time
- Pick a new parent according to the link quality



(a) Maximum Error



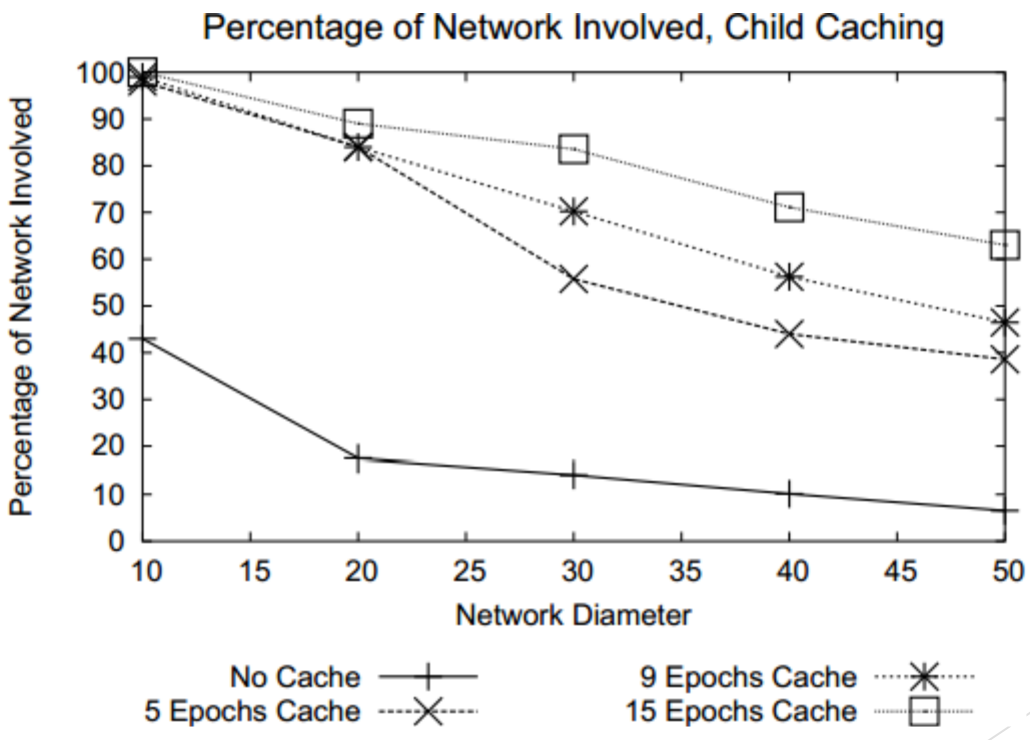
(b) Average Error

Improving Tolerance to Loss

Child Cache

- Increased Availability

  Use old results when new results are not available



Comparison between WABD and TAG

- In the sensor network scenario, the motes have very little compute power — hence the focus is on aggregation where they only evaluate simple functions as opposed to WABD setting
- The aggregation techniques used in TAG are also applicable in WABD.
- They only support aggregates and not arbitrary joins as opposed to WABD.

Conclusion

- In-network aggregation offers an order of magnitude reduction in bandwidth consumption compared to centralized aggregation
- The declarative query enables users to use in-network aggregation with having to write low-level code

Questions?