Multi-user Data Sharing System in Radar Sensor Networks

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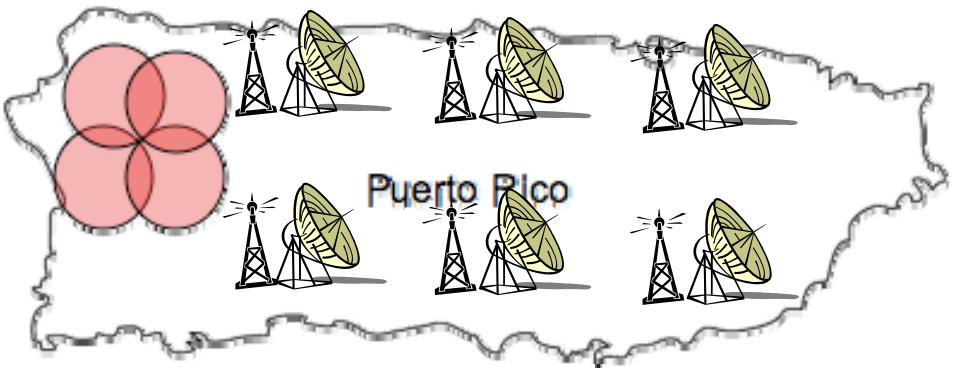
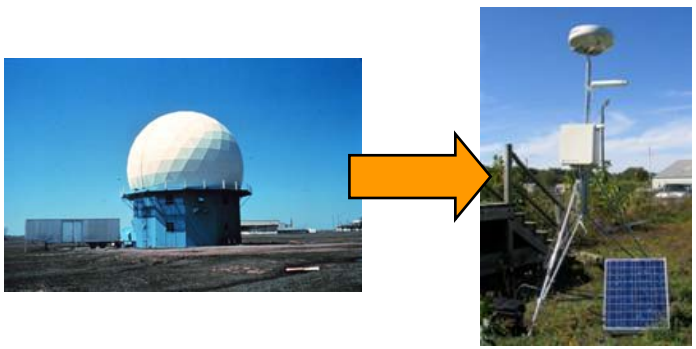
Emerging Rich Sensor Networks



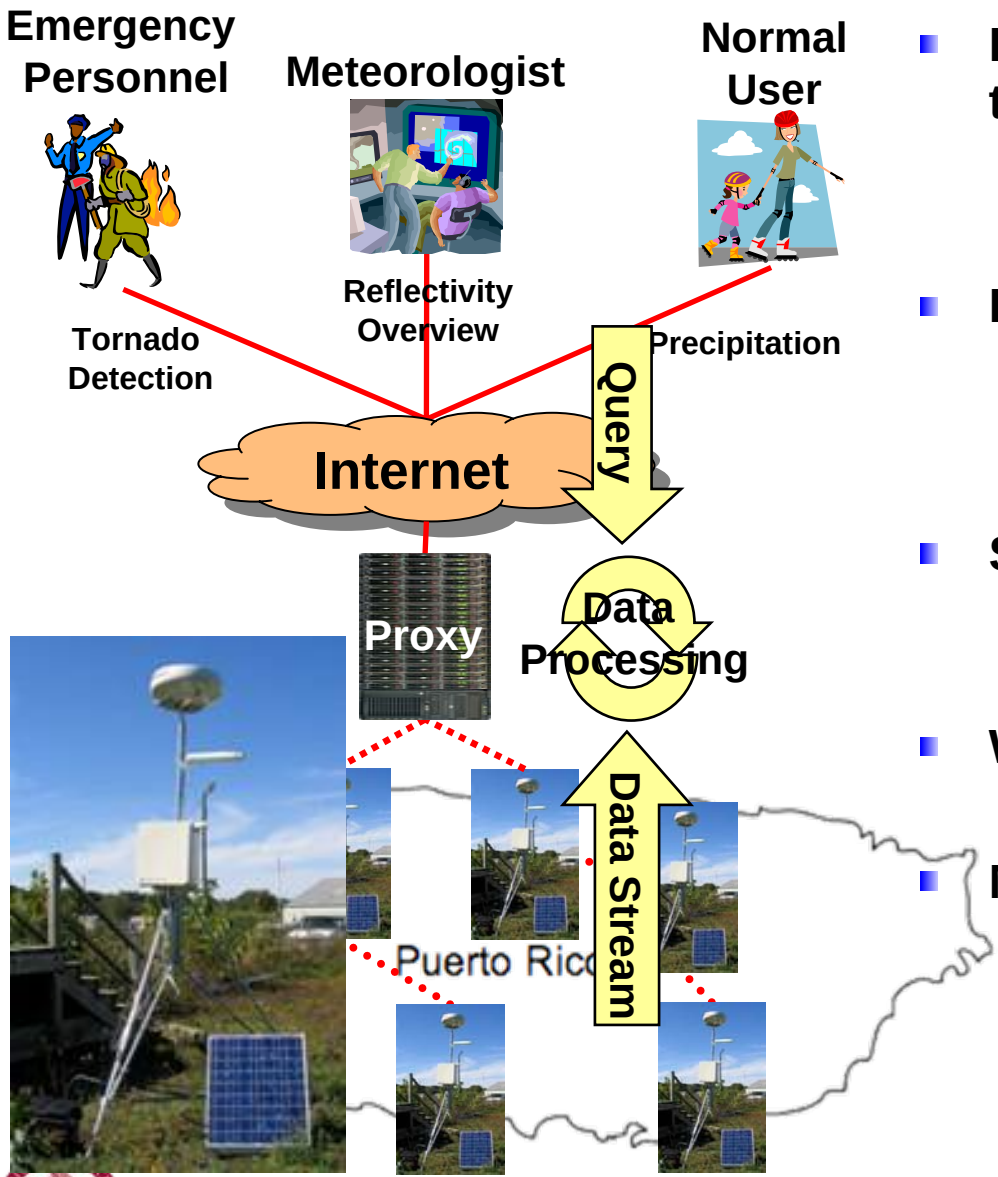
Radar Sensor Network

Camera Sensor Network



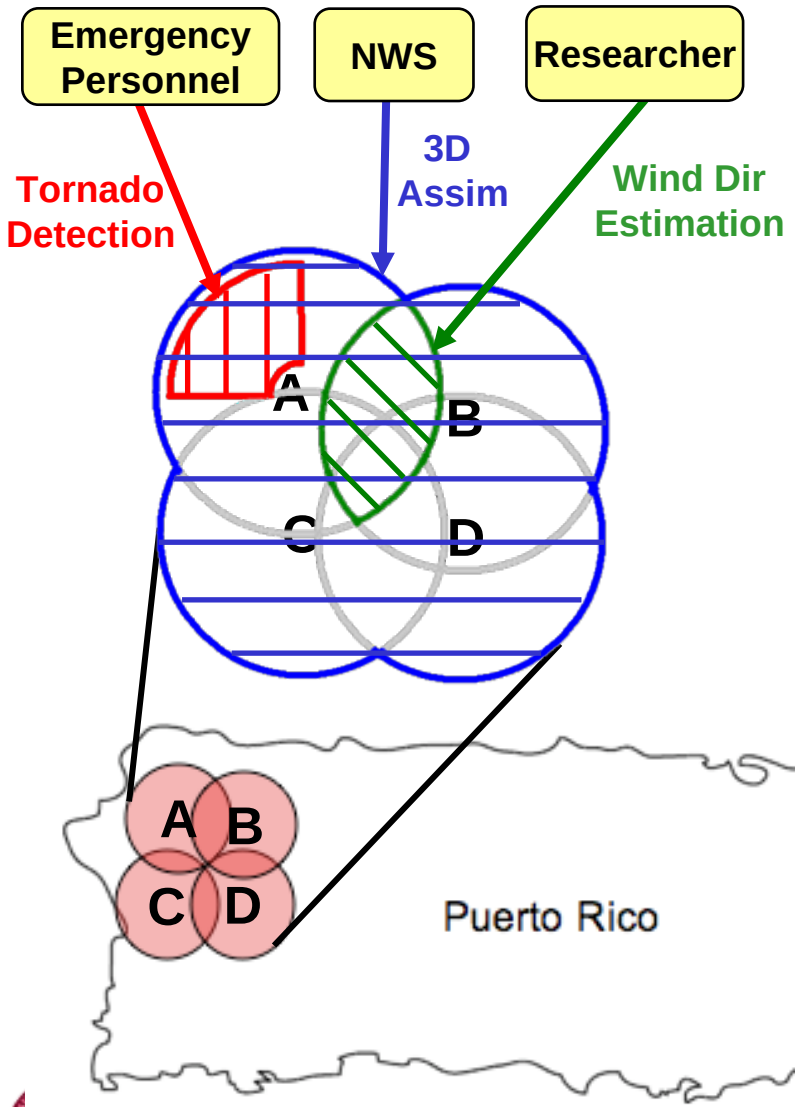
- **Richer energy**
  - **Tethered power**
- **High data rate**
  - **Many MB/second**
- **Diverse users/applications needs**
  - **E.g. First responders, Commuters, Insurance, for traffic monitoring**

CASA Radar Sensor Networks



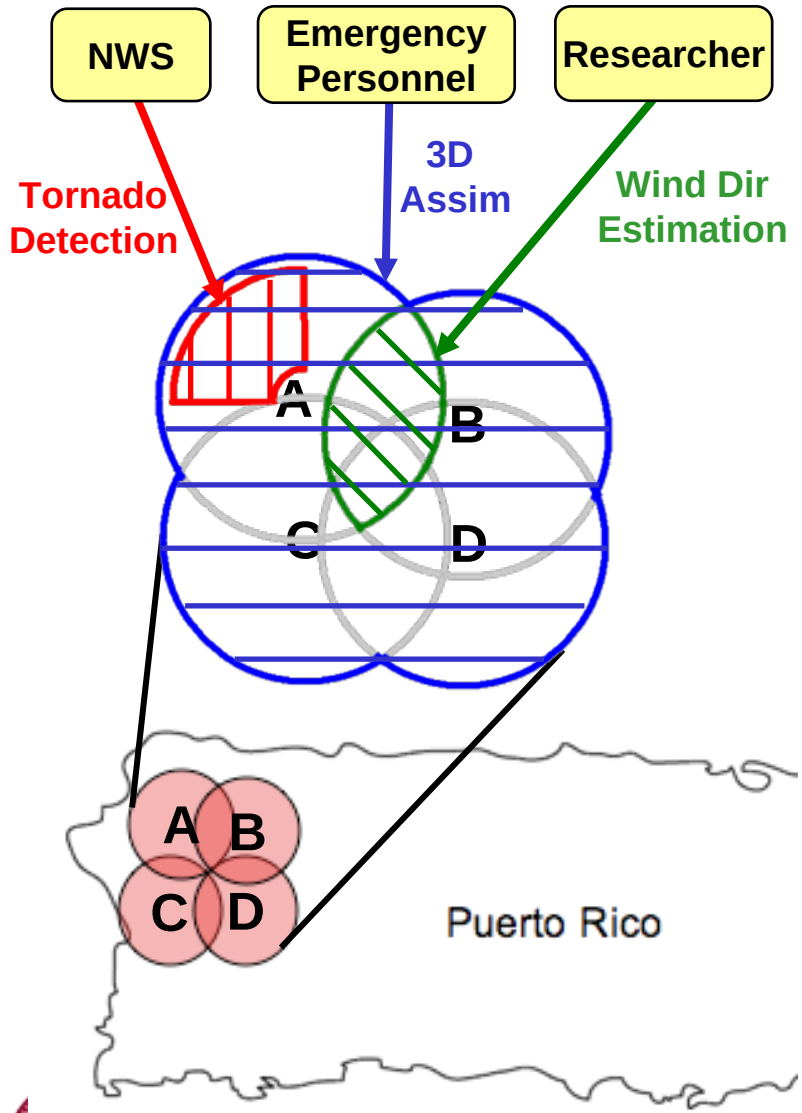
- **Densely monitoring the lower troposphere**
  - **Tornado, storm, flood, …**
- **High rate sensor streams**
  - **300MB per radar scan every 30 seconds**
- **Stream-based system**
  - **Data processing is done on proxy**
- **Wide-area wireless mesh network**
- **Multiple, diverse user needs**
  - **Emergency personnel, meteorologist, other…**

Challenges in Multi-user WSNs



- **Limited network resources**
  - **Bandwidth << Data needs**
- **Diverse end user query needs**
  - **Diverse data quality metrics**
    - **Tornado: location error.**
    - **Wind direction: direction error**
  - **Different spatial areas of interest**
    - **Wind direction: overlapping area between radars**
  - **Different data fidelity needs**
    - **Tornado detection > 3D assimilation**
  - **Different priorities and deadlines**
    - **Priority:NWS > Em. Mgr**
    - **Deadline: Em. Mgr < NWS**

Problem Statement



- How to design next generation wireless radar sensor networks to:
  - **Jointly optimize** for different data quality metrics and different priorities and deadlines of different users
  - **Share bandwidth** and data across different users
  - **Adapt gracefully** to bandwidth dynamics
  - **Prioritize** important data during critical weather events.

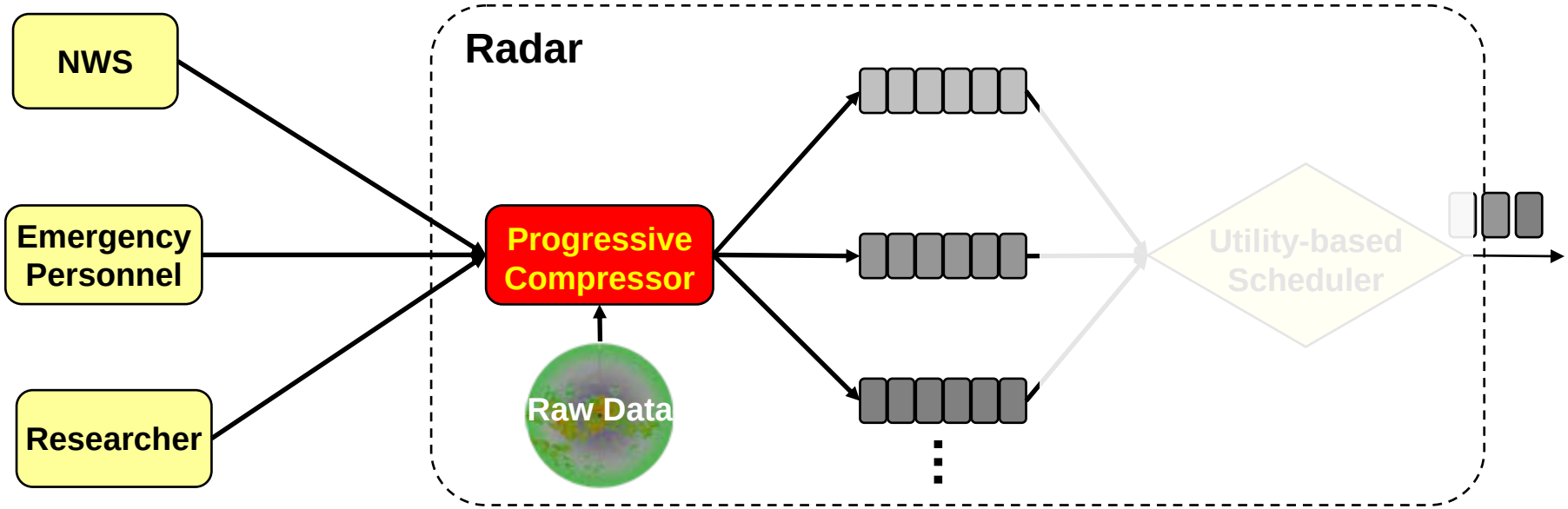
Key Ideas in Multi-User Data Sharing

- **Utility-driven transmission scheduling** to prioritize data transmission and maximize overall utility
- **Progressive compression** to minimize bandwidth usage and adapt to bandwidth fluctuation
- **Global transmission control** to prioritize data transmission among radars

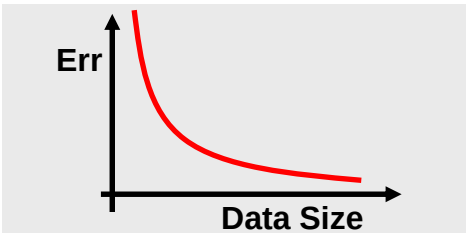
Outline

- Motivation
- Key Ideas
- Progressive Compression
- Utility-driven Transmission Scheduling
- Global Transmission Control
- Evaluation
- Summary

Progressive Compressor

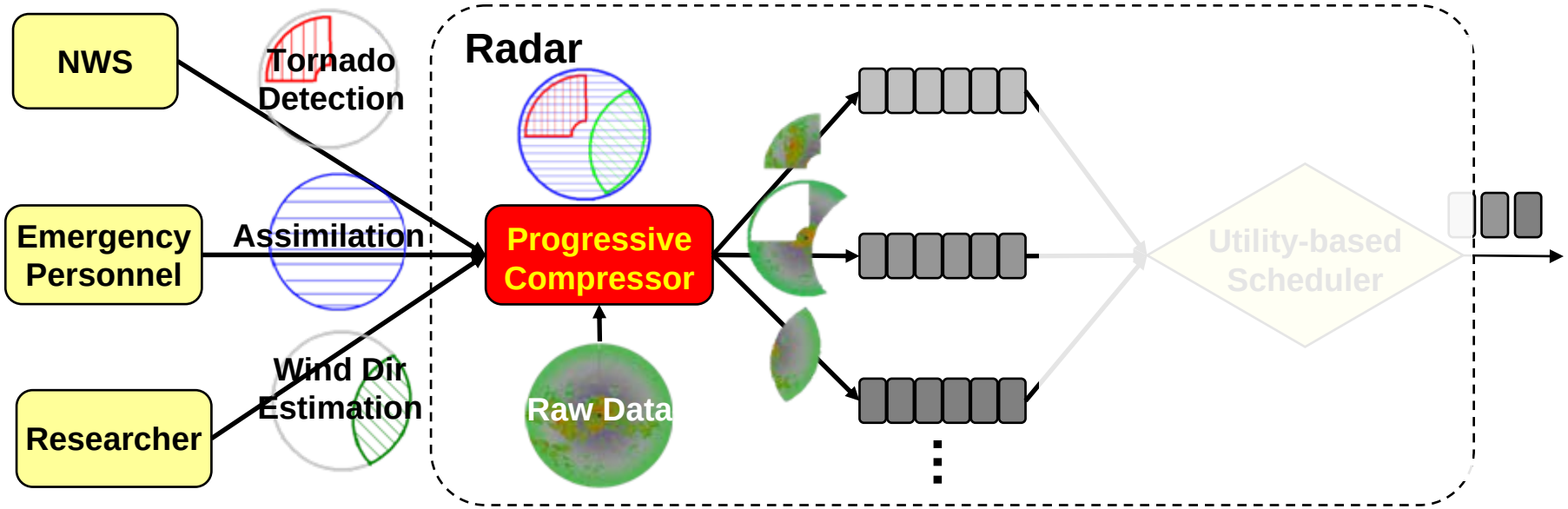


- SPIHT algorithm [*set partition in hierarchical trees*]
  - Wavelet-based encoder, preserves important features of interest for meteorologist
  - Adapts to bandwidth fluctuation
  - Most important data is transmitted first



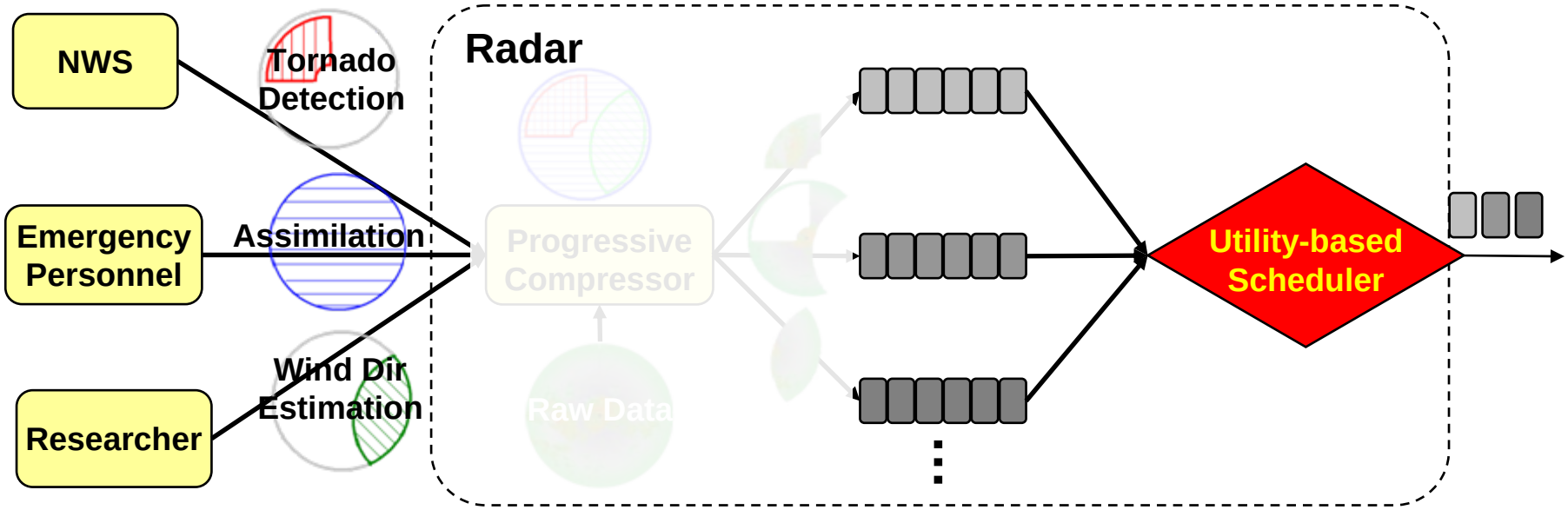
Decode error of SPIHT

Progressive Compressor



- **Operation of Progressive compressor:**
  - **Split scan into spatial regions, each with a set of queries associated with it.**
  - **Generate a separate stream for each spatial region.**

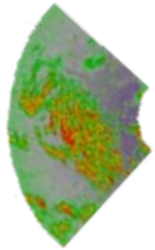
Utility-based Scheduler



- Utility-based Scheduler
  - Decides which packet offers greatest improvement to overall utility
- Key questions
  - How to determine utility of packet to a query?
  - How to aggregate utilities across diverse queries?
  - How to schedule packets based on their utilities?

Utility of a Packet to a Query

- What does scheduler have
  - Marginal Data MSE
- What does scheduler need
  - Marginal query quality
- How to map data MSE to query quality
  - Train a mapping function a priori using sample data sets



Distance between detected tornado and the actual one

$$E_{tornado} = \begin{cases} |I_{raw} - I_{dec}|\frac{d}{300} & d \le 300\text{meter} \\ I_{dec} & \text{false positive} \\ I_{raw} & \text{false negative} \end{cases}$$

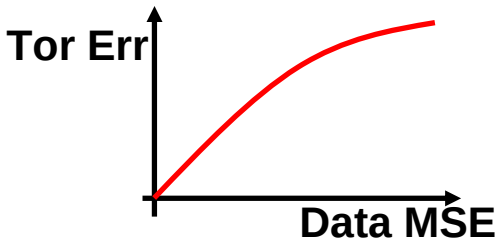
Intensity of actual tornado

Intensity of detected tornado

Application level

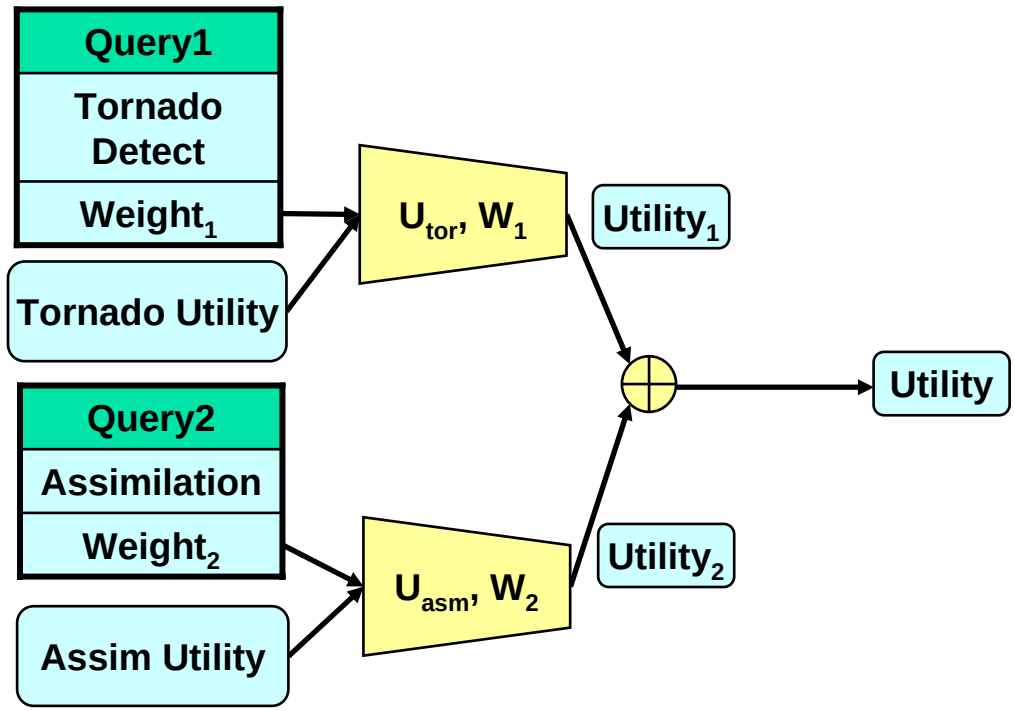
Training

Networking level



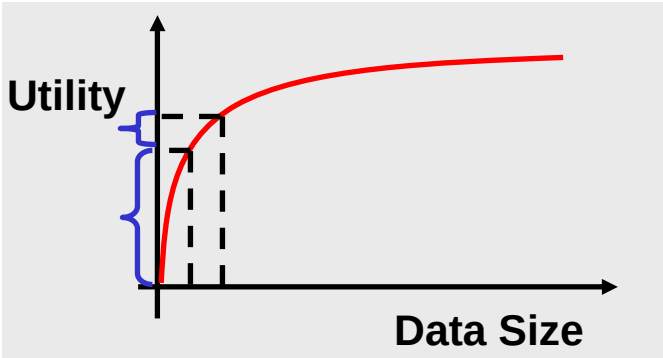
Aggregate Utility across Diverse Queries

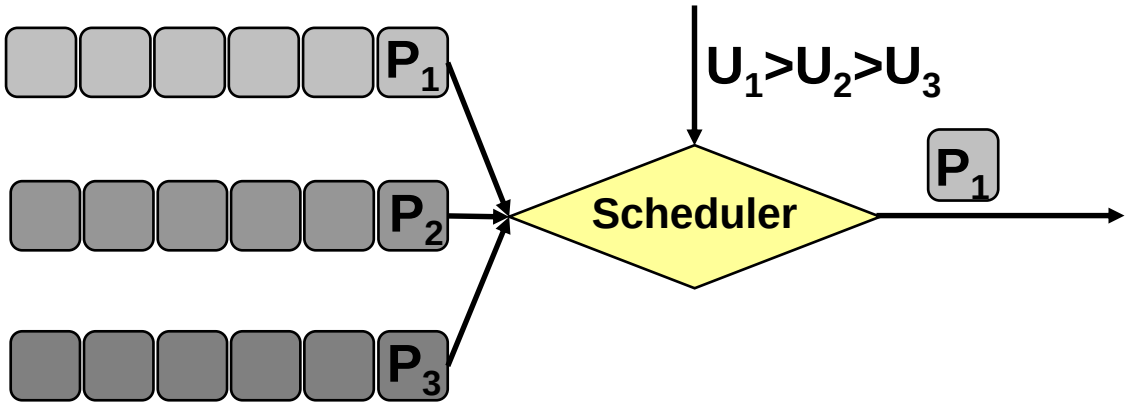
- **Aggregated utility is a weighted combination of utilities for each query**
  - $Weight_{query}=f(query\_priority, query\_deadline)$
  - $Util_{Agg}=sum(Weight_{query}*Util_{query})$



Schedule Packets based on Utility

- **Schedules packet with the highest utility**
- **Optimal if utility function as a function of data size is concave**





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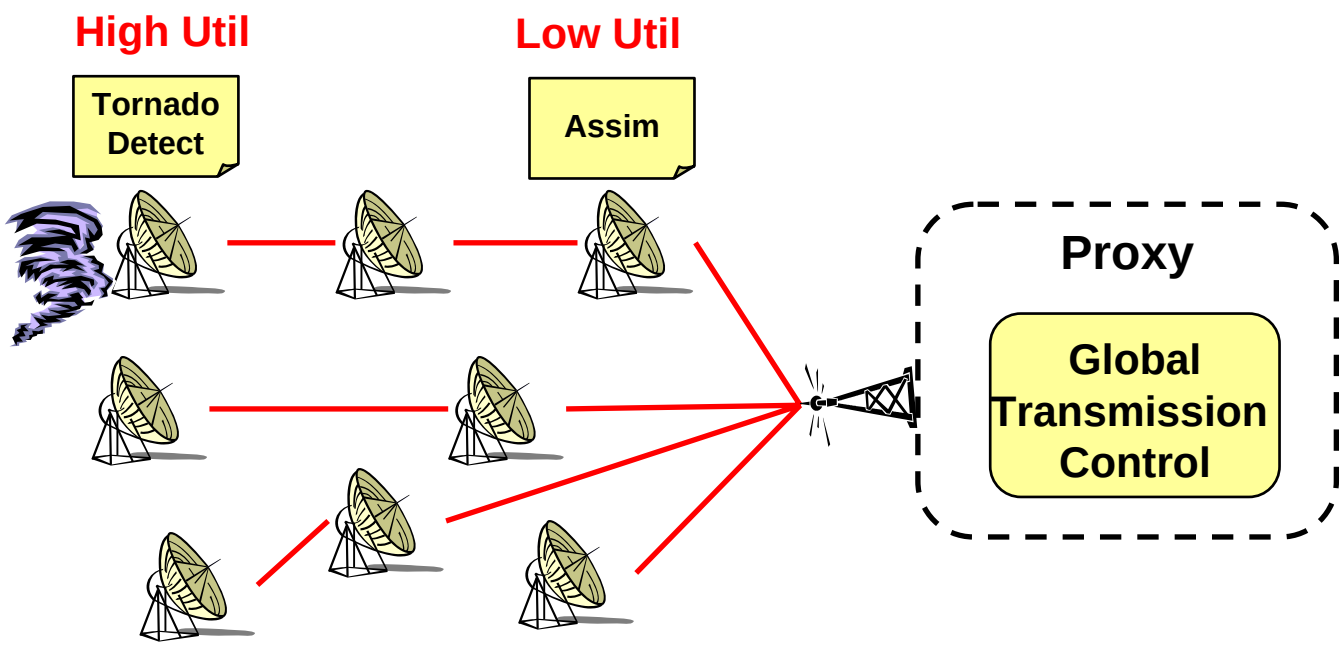
- **Global Transmission Control**
- **Evaluation**
- **Summary**

Global Transmission Control

- **Problem:**
  - **Radar with critical data may not get sufficient bandwidth**
- **Solution:**
  - **Proxy pauses streams that are achieving low/no utility gain**



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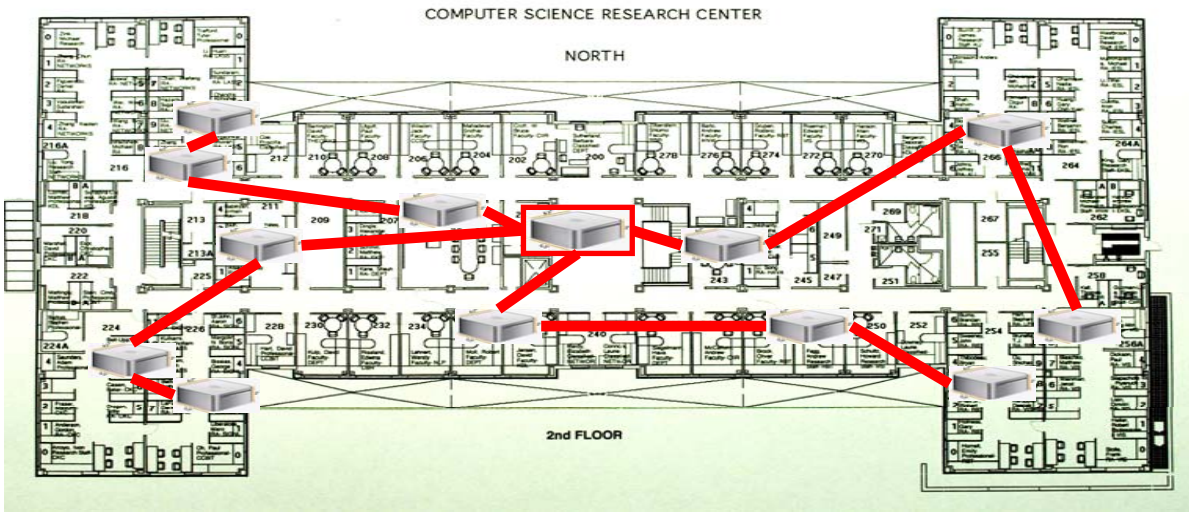
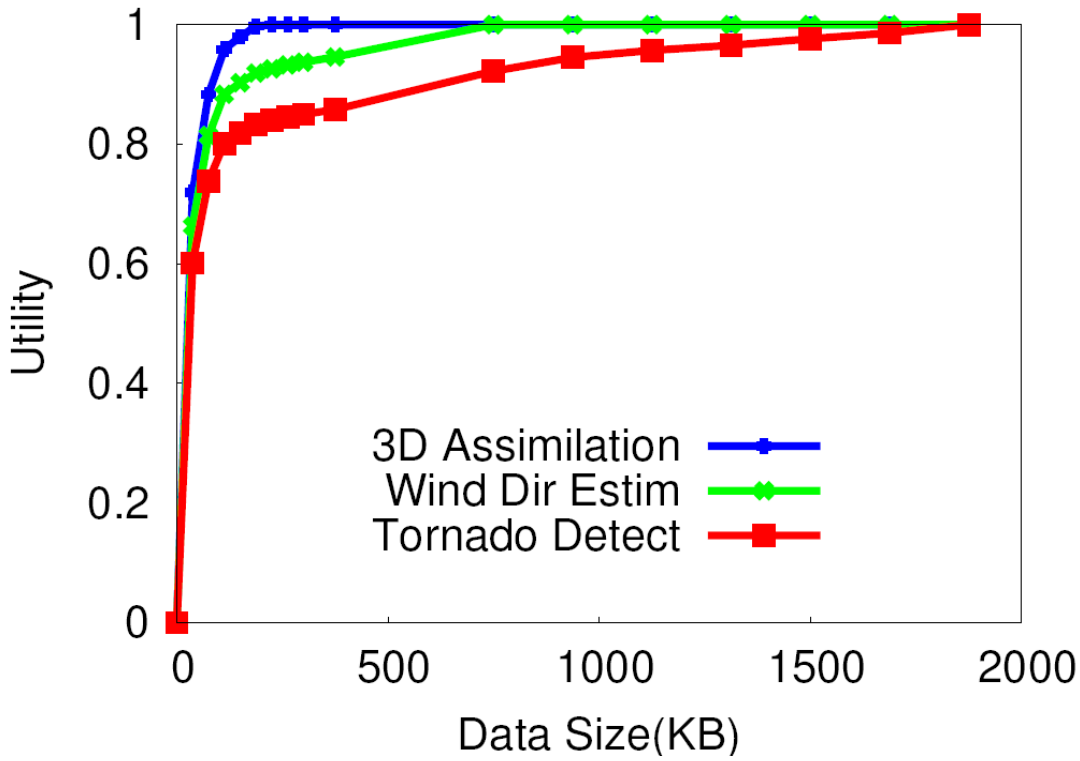
Evaluation



- Testbed
  - 13 MacMini as adhoc mesh nodes
  - 3-hop topology
- Data Sets
  - Real data traces from Oklahoma radar testbed
  - Simulated data by ARPS(Advanced Regional Prediction of Storms)
- Query Pattern
  - Tornado Detection, 3D assimilation and Wind Direction assimilation queries arrive in a round robin manner. Deadlines are chosen from a Poisson distribution with mean at 30 seconds.

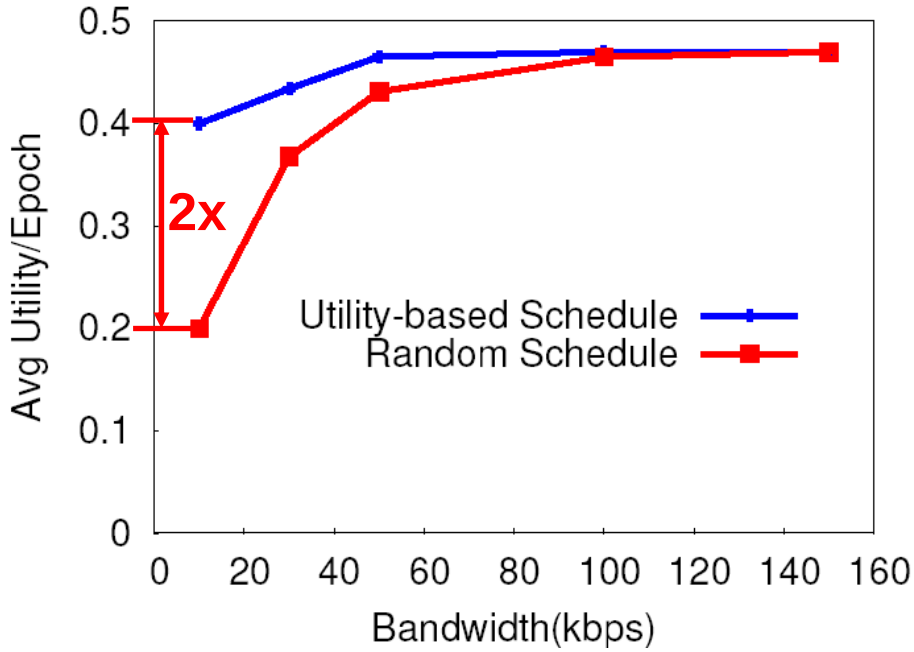
Determining the Utility Function



Tornado detection needs more accurate data than 3D assimilation.

Performance of Utility-driven Scheduler

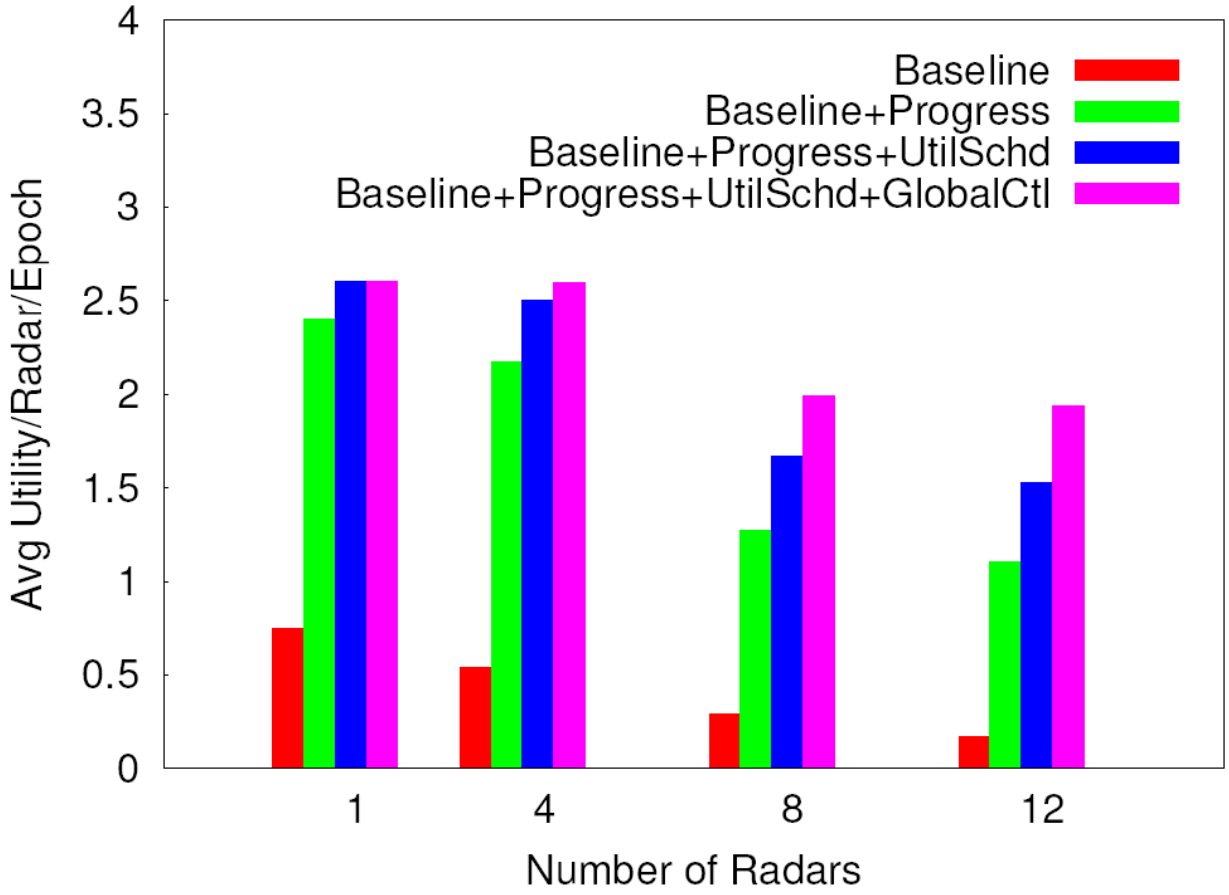
- **Compare utility-driven scheduler to random scheduler**



The utility-based scheduler achieves 2 times higher utility than the random scheduler

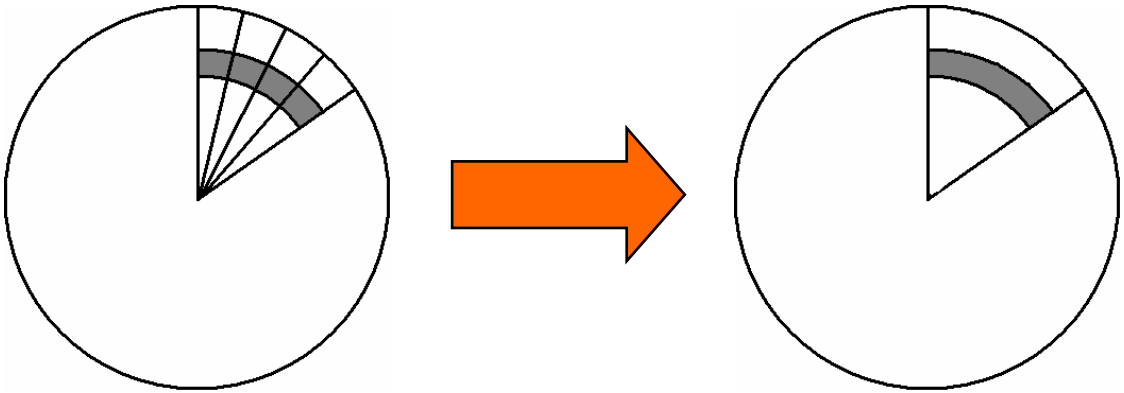
Scalability

- **Demonstrates that our system as a whole scales well with network size**



Scalability

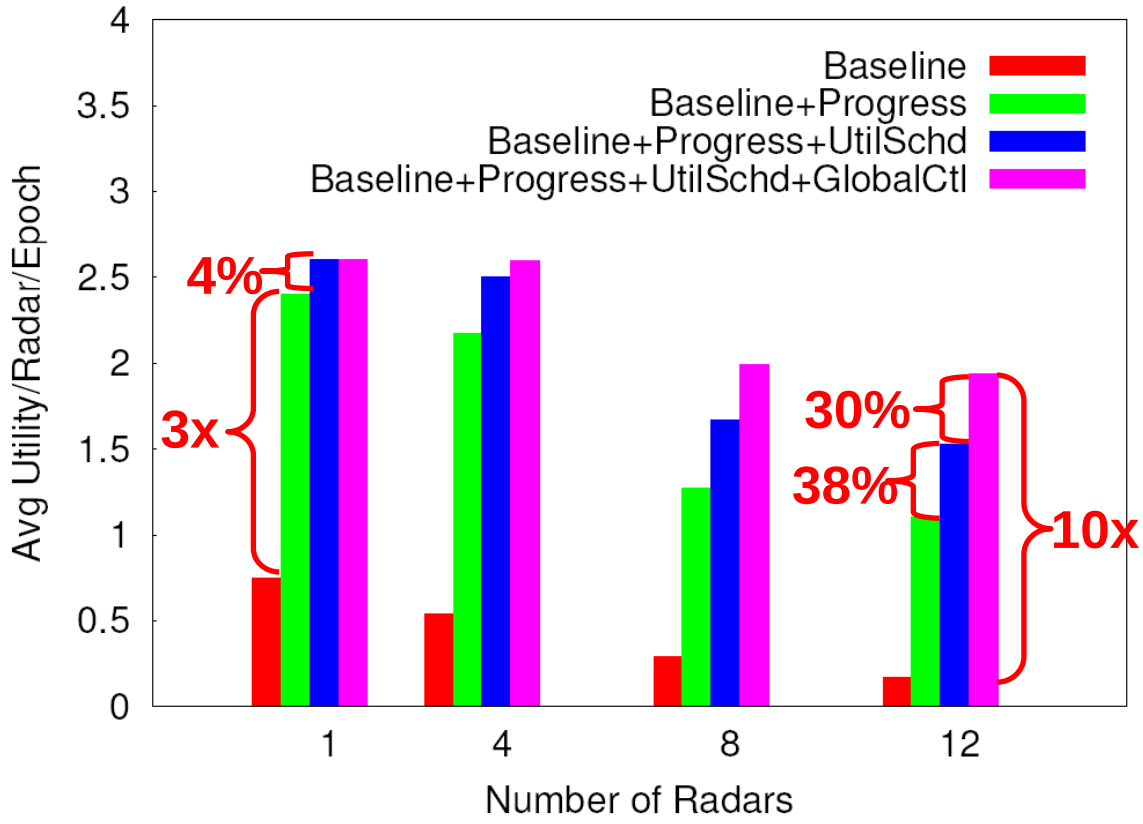
- **Baseline System**
  - **Averaging compression**



  - **Bandwidth estimation**
    - **Estimate bandwidth for next epoch (30 secs) based on history of bandwidth from previous epochs.**
    - **Conservative estimate to ensure that compressed scan can be transmitted in the 30 seconds.**

Scalability

- **Demonstrates that our system as a whole scales well with network size**



Our system achieves more than 10 times higher utility than the baseline system

Related Work

- **Multi-query optimization in sensor network**
  - **SQL Queries and simple aggregates: Trigoni, et. al [DCOSS 2005]**
  - **We have more complex data processing requirements.**

- **Utility-driven network design in sensor networks and Internet**
  - **SORA [NSDI05], Kelly et al [JORS98]**
  - **Does not address application-level data quality metrics and data sharing between users**

- **Global transmission control**
  - **Conflict Graph – Jain et al [Wireless Network 05], Rate control – Rangwala et al [Sigcomm06]**
  - **We use application level utility of data to control transmissions.**

- **Radar sensor networks**
  - **Schedules radar scanning strategy to satisfy end-user needs Zink et al [EESR05].**

Summary

- Illustrates new challenges in next-gen radar sensor networks
- Design and implementation of a multi-user data sharing system that:
  - Gracefully degrades utility under bandwidth fluctuations by using progressive compression
  - Utility-driven packet scheduling based on end-user data quality metrics, priorities, and deadlines.
  - Globally prioritizes data transmission across radars.
- Results show one order of magnitude improvement in application utility over existing radar data transmission system.

The End

Questions?