Distributed Utility Optimization in Mission-Oriented WSN

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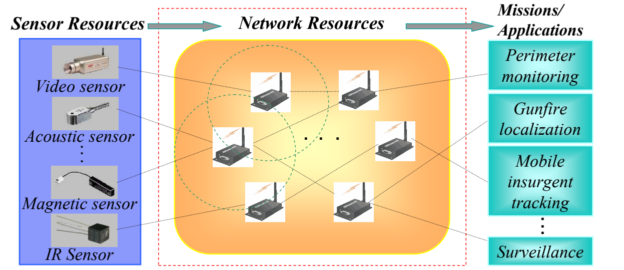
"How to share the network resources (wireless bandwidth) to maximize the effectiveness of sensor-enabled applications (missions)?"

- WSN environments with significant bandwidth constraints

- Heterogeneous missions utilizing multiple types of sensors.



Challenges

Mission-oriented Sensor Networks

Mission utilizes multiple sensors

- Different sensors have different relative importance
- Importance of one sensor changes dynamically based on data quality from other sensors.

Sensor contributes to multiple missions

- Multicast flows
- Different missions need different amount of data from the same sensor.

Mission-oriented **Wireless** Sensor Networks

Wireless medium

- Channel capacity is not fixed
- Exploit broadcast capabilities at the link layer
- Contention among transmissions can change

Dynamic environment

- Missions come and go at different times
- Topology changes frequently (node mobility, wireless link variability, sensor activation

Mission-oriented **Military** Wireless Sensor Networks

High priority missions

- High priority missions have different resource requirements
- Need for differentiated or prioritized congestion control

Broad Approach

Network Utility Maximization (NUM)

A Distributed, Utility-Based Formulation of Resource Sharing

- *Each mission has a "utility": $U_m(x_1, x_2, \ldots, x_s)$*
  - *A measure of how "happy" the mission is*
  - *A function of source rates from all its sensors*
- *Allocate WSN resources (network interface bandwidth of nodes) to maximize cumulative utility.*
- *Congestion control is formulated as a utility maximization problem*

Our Objective:

"Rate/Congestion Control for Network Utility Maximization"

Our Analysis Framework

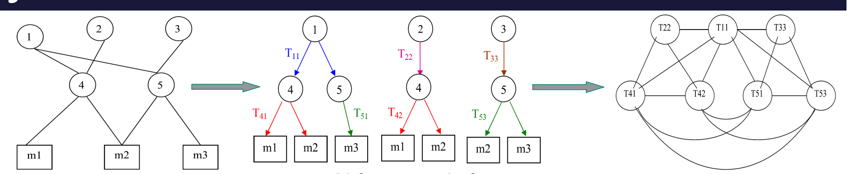
$$SENSOR\ (U, L):$$

$$\text{maximize} \sum_{m \in M} U_m(X_m)$$

$$\text{subject to}: \quad \sum_{\forall (k,s) \in l} \frac{x_s}{c_{k,s}} \le 1$$

$$\text{for each maximal clique } l \in L$$

- *Airtime constraint over "transmission-specific" cliques*
- *Cliques => "contention region"*
- *No two transmissions in a clique can occur simultaneously*

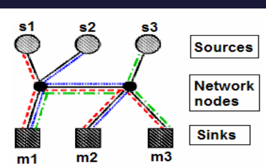


Connectivity graph

Multicast trees (with broadcast transmissions)

Conflict graph

WSN-NUM Protocol



- *Price-based, iterative scheme*
- *Solve two independent sub-problems*
- *Network nodes:*
  - *Aim to maximize "revenue"*
  - *Compute Clique cost: degree of congestion in the clique*
  - *Flow cost = sum of costs of all cliques along the flow*
- *Mission (sink):*
  - *Aims to maximize its utility minus the cost*
  - *Sends path cost to each source*
  - *Sends 'willingness to pay' for each source*
- *Sensor (source):*
  - *Adjusts rate to drive gradient to zero:*

$$NETWORK(L; w):$$

$$\text{maximize} \sum_{s \in S} \sum_{m \in M} w_{ms} \log(x_s);$$

$$\text{subject to} \sum_{\forall (k,s)} \frac{x_s}{c_{k,s}} \le 1, \text{ for each clique } l \in L,$$

$$\text{over } x_s \ge 0.$$

$$\mu_l(t) = \left(\sum_{\forall (k,s) \in l} \frac{x_s(t)}{c_{k,s}} - 1 + \varepsilon \right)^+ \Big/ \varepsilon^2$$

$$SINK_m(U_m; \lambda_m):$$

$$\text{maximize } U_m\left(\frac{\overline{w}_m}{\overline{\lambda}_m}\right) - \sum_{s \in set(m)} w_{ms}$$

$$\text{over } x_s \ge 0.$$

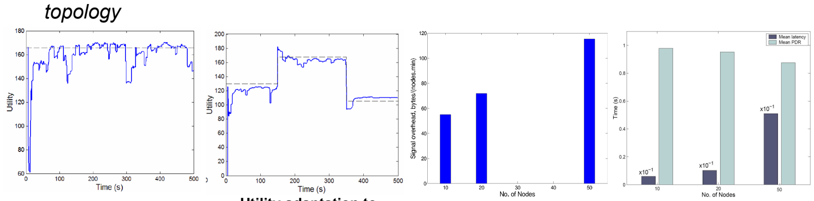
$$w_{ms} = \lambda_{ms} * x_s : \text{"willingness to pay"}$$

$$w_{ms} = x_s(t) \frac{\partial U_m}{\partial x_s}$$

$$\frac{d}{dt} x_s(t) = \kappa \left(\sum_{m \in Miss(s)} w_{ms}(t) - x_s(t) * \left(\sum_{\forall l \in flow(s)} \mu_l(t) * \sum_{\forall (k,s) \in l} \frac{1}{c_{k,s}} \right) \right)$$

Protocol-level Simulation

We simulated this protocol on 802.11b based network and studied network utility, delays, losses, overheads. Results show that our framework can provide (i) very good resource sharing and (ii) fast adaptation to changes in missions or sensor topology



Utility of a 50-node network | **Utility adaptation to Network dynamics** | **Signaling overhead** | **Loss and latency in network**

Future Work and Publications

Future work includes:

- Extension of utility functions to consider alternative additional metrics (latency, loss) or non-concave behavior

- Joint optimization of rates with wireless interface transmission power, since transmission power is a scarce resource that directly affects link bandwidth and contention regions.

S.Eswaran, A. Misra, T. LaPorta, "Distributed Utility Optimization in Mission-oriented Wireless Sensor Networks", submitted to Infocom 2008.

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