# Implementation of Utility-based Rate Control Protocol (WSN-NUM)

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**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

***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

$SENSOR(U, L)$:

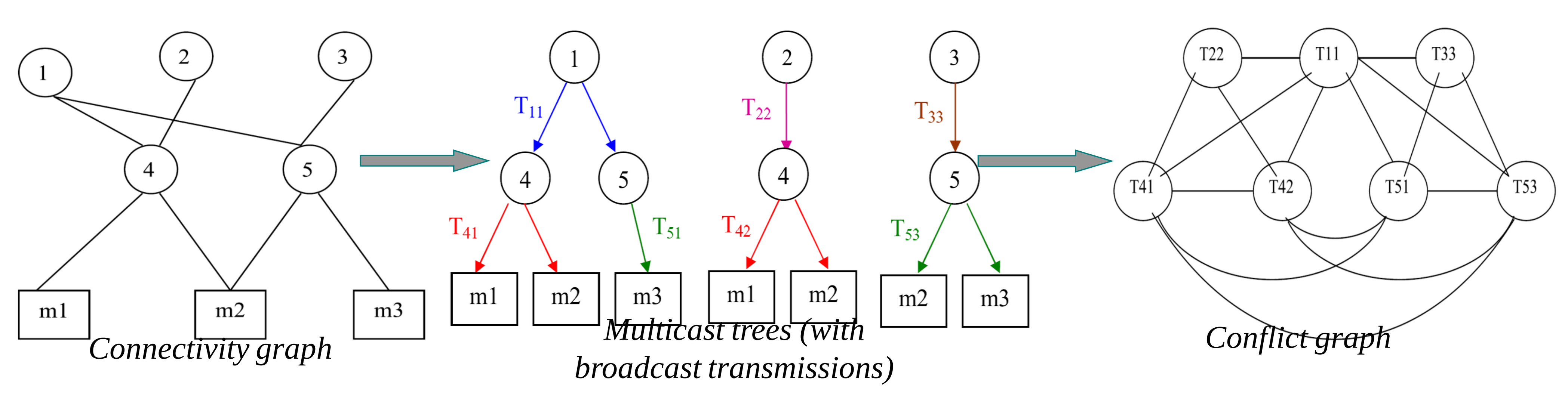
$$\text{maximize} \sum_{m\in M} U_m(X_m)$$

subject to:

$$\sum_{\forall (k,s)\in l} \frac{x_s}{c_{k,s}} \le 1$$

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*




## 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:*

$NETWORK(L; w)$:

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

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

over $x_s \ge 0$.

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

$SINK_m(U_m; \lambda_m)$:

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

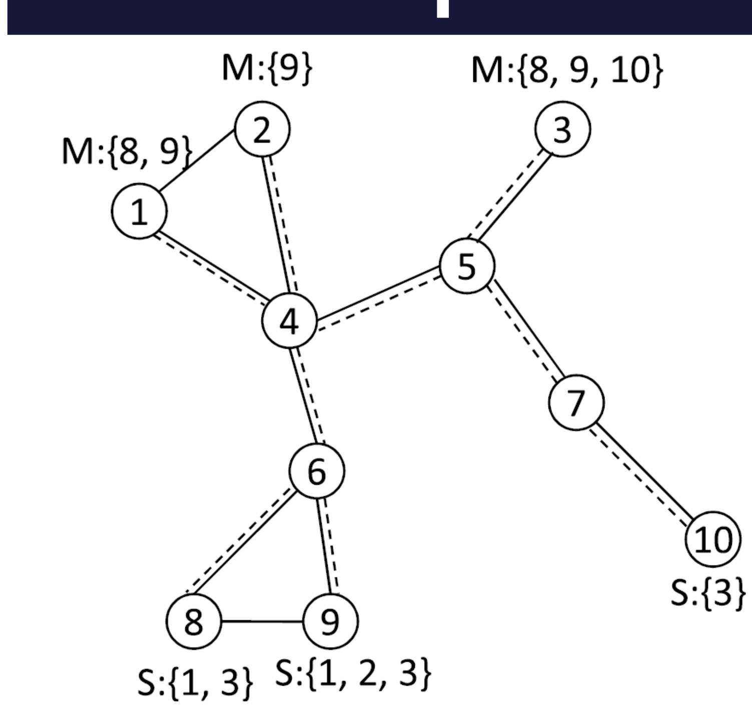
over $x_s \ge 0$.

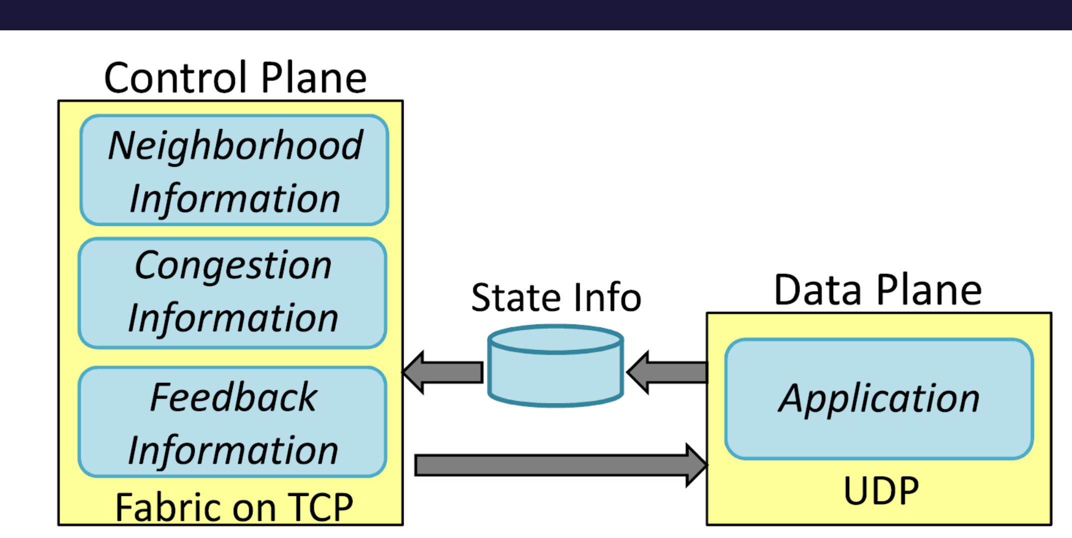
$w_{ms} = \lambda_{ms} * x_s$ : "willingness to pay"

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

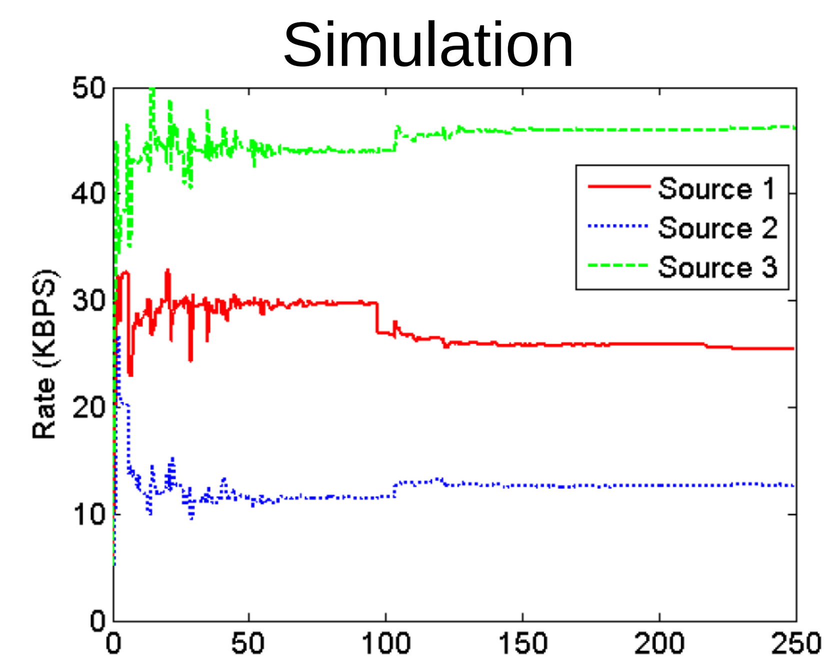
$$\frac{d}{dt}x_s(t) = \kappa\left( \sum_{m\in Miss(s)} w_{ms}(t) - x_s(t) * \left( \sum_{\forall l\in flow(s)} \mu_l(t) * \sum_{\forall (k,s)\in l} \frac{1}{c_{k,s}} \right) \right)$$

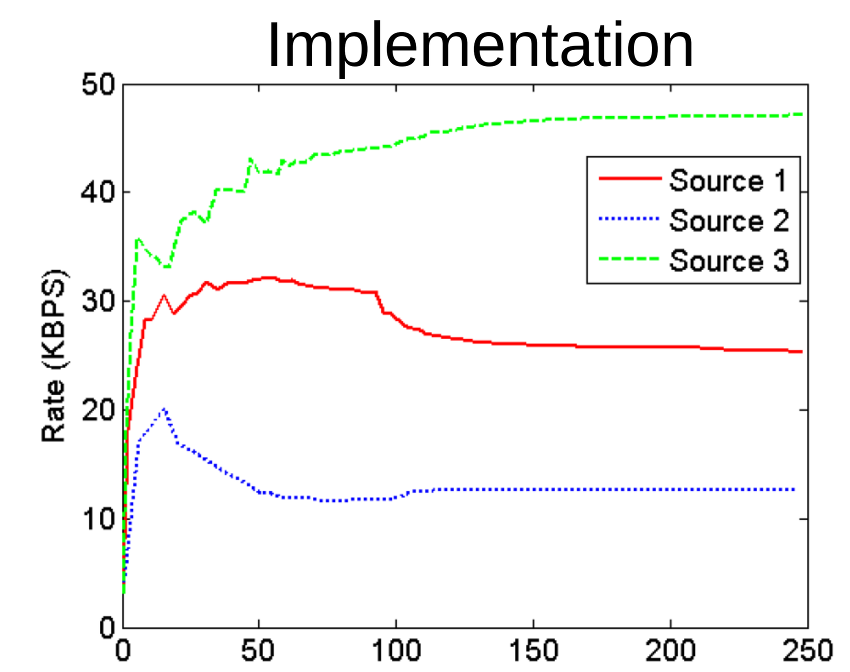
## Implementation Details




## Results




| Parameter | Broadcast | | | Unicast | | |
|---|---|---|---|---|---|---|
| | Optimal | Simulation | Impl. | Optimal | Simulation | Impl. |
| Rate (KBPS) | 33.33<br>16.67<br>50.00 | 25.81<br>13.08<br>46.09 | 25.35<br>11.63<br>46.11 | 23.83<br>11.42<br>41.67 | 19.19<br>9.58<br>35.70 | 18.70<br>9.34<br>34.14 |
| PDR (%) | 0 | 83.30 | 77.70 | 0 | 97.22 | 96.39 |
| Net Rate (KBPS) | 33.33<br>16.67<br>50.00 | 21.50<br>10.90<br>38.39 | 19.70<br>9.03<br>35.82 | 23.83<br>11.416<br>41.67 | 18.65<br>9.31<br>34.7 | 18.01<br>8.99<br>32.88 |
| Utility | 63.01 | 60.92 | 60.34 | 61.41 | 60.17 | 59.90 |

## Conclusion

- Real-time implementation shows correctness and applicability of WSN-NUM
- Using sensor fabric shows compatibility of WSN-NUM with SOA applications
- Many tunable parameters for controlling performance factors such as convergence time and packet loss.

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