TARA: Topology-Aware Resource Adaptation for Congestion Avoidance in Wireless Sensor Networks

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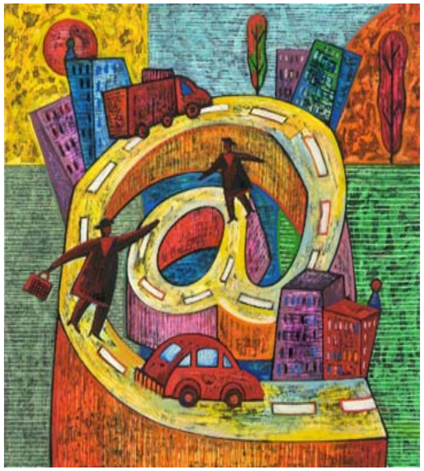

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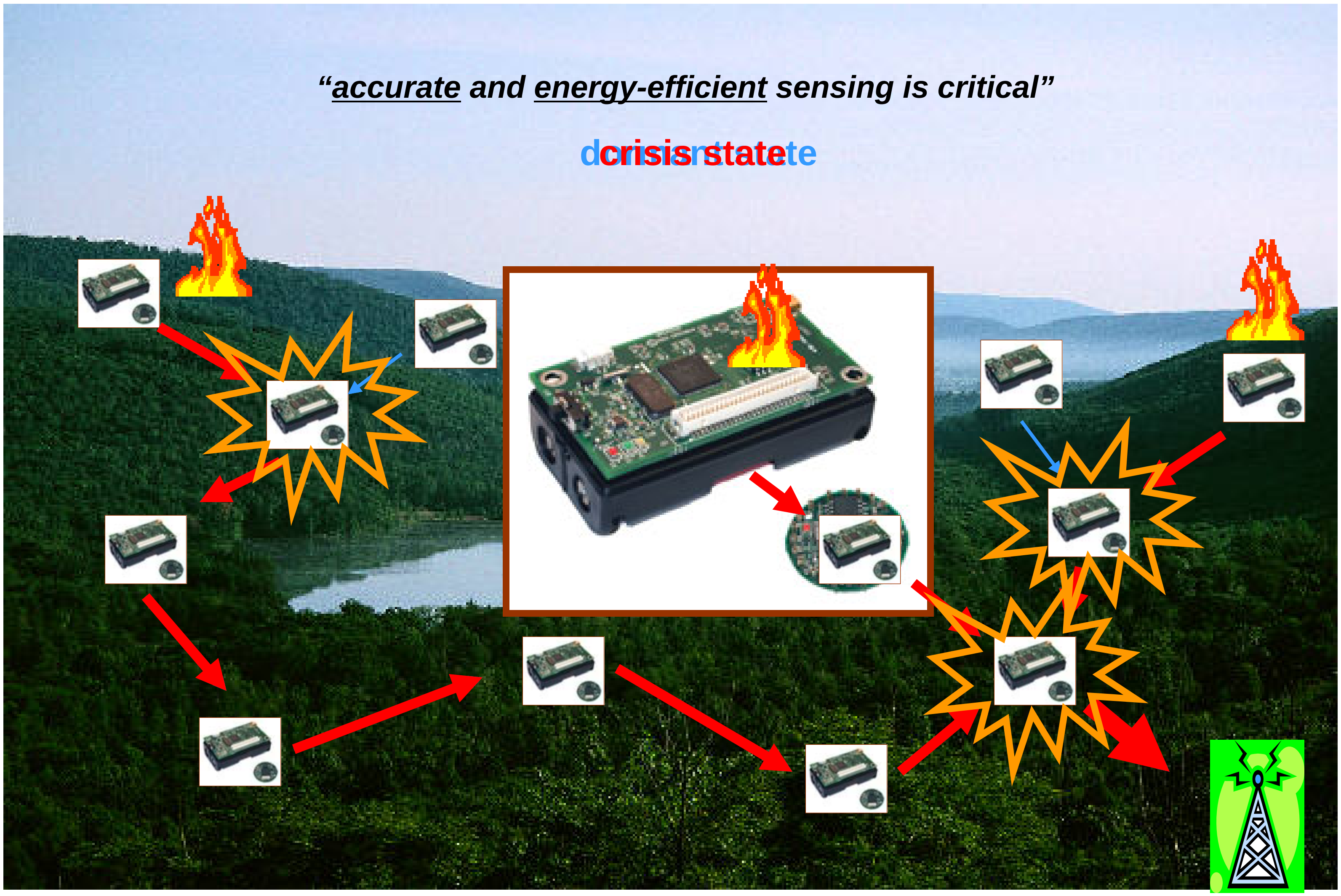
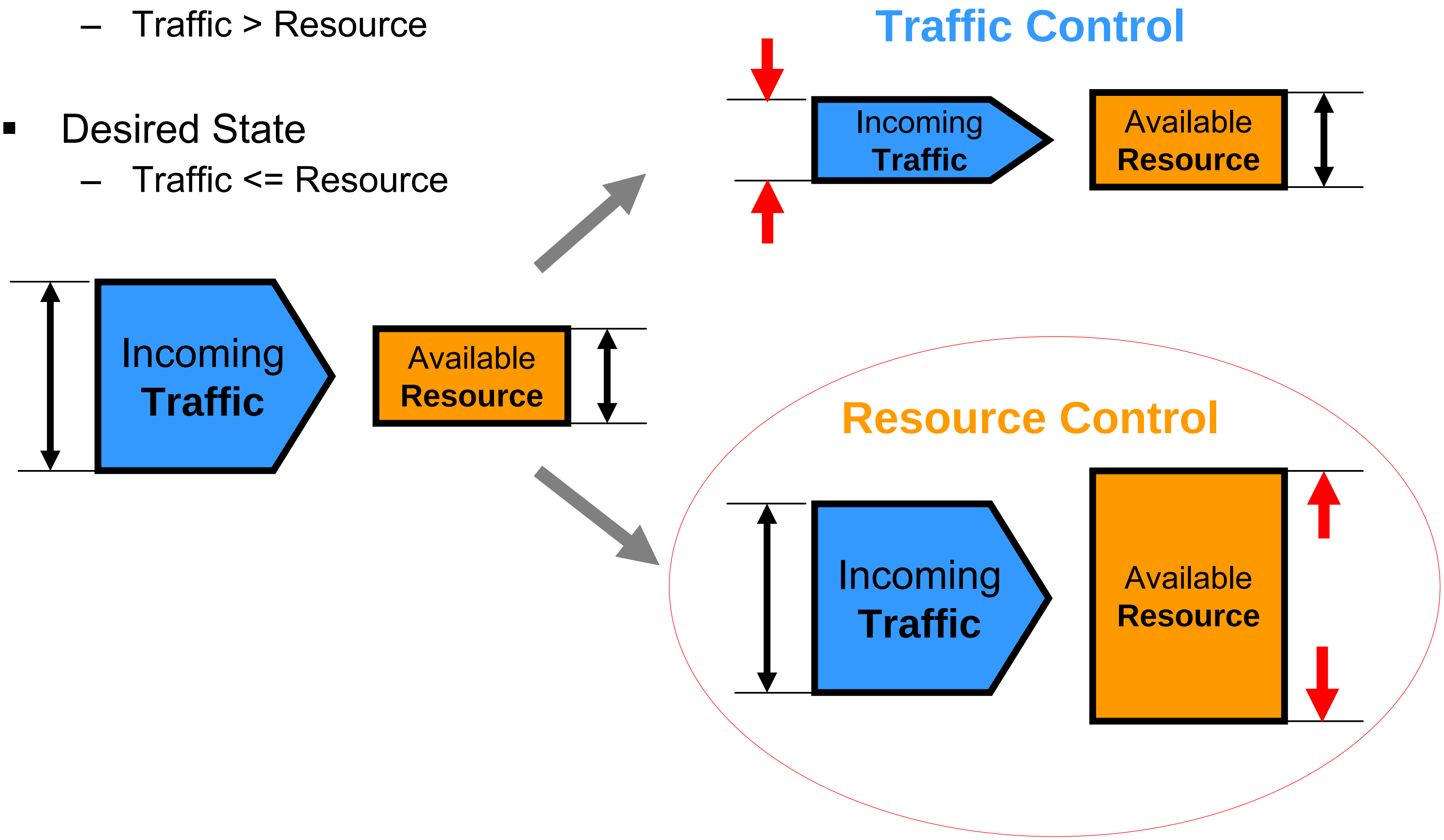
Wireless Sensor Networks



Congestion Controls

- Why congestion ?
  - Traffic > Resource
- Desired State
  - Traffic <= Resource



Why Resource Control ?

- **MUST**
  - Needs to meet application's fidelity requirement
    - data during congestion is of utmost importance (e.g. report of fire).
    - source quenching by traffic control violates fidelity requirement.

- **CAN**
  - Exploit redundancy of resource deployment
    - quick control of elastic resources is viable in sensor networks (e.g. power control, multipath routing).

- **HOW**

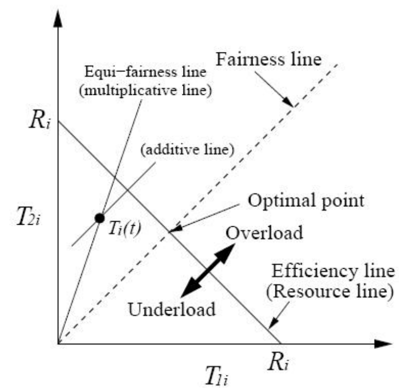
Previous Work

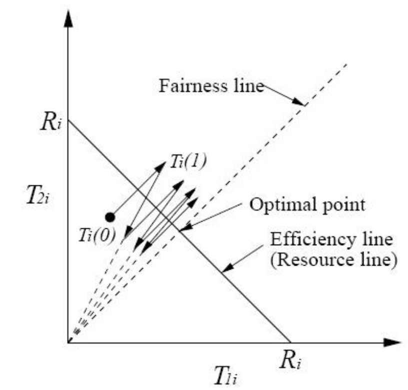
- Traffic Control
  - Fair scheduling
    - EPS (SenSys'04)
  - In-network Aggregation (or Compression)
    - TAG (OSDI'02)
  - Hop-by-hop & end-to-end control
    - CODA (SenSys'03), ESRT (MobiHoc'03), Adaptive Rate Control (MobiCom'01)
    - spatial spreading (Infocom'04)
  - Prioritized MAC
    - Fusion (SenSys'04)

- Resource Control
  - Routing
    - load-aware routing (ICC'01)
    - congestion-adaptive routing (WCNC'05)
  - Power Control
    - JOCP (Infocom'04)

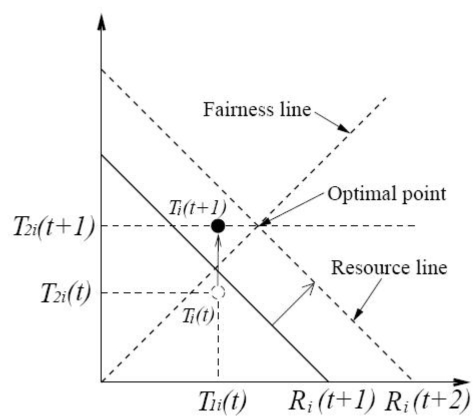
Traffic Control vs Resource Control

- Traffic Control
  - utilization and fairness
  - fixed resource
  - Additive Increase/Multiplicative Decrease (AIMD)
    - $T(t+1) = \begin{cases} T(t)+a & \text{if } T(t) < R \\ mT(t) & \text{if } T(t) > R \end{cases}$
  - decrease operation when congested





- Resource Control
  - fidelity and energy
  - variable resource
  - no fairness
  - increase operation when congested



Goals

- Policy
  - Try to understand the ideal behavior of resource control
- Mechanism
  - Use the understanding to implement a resource control scheme in sensor networks.
- Challenges

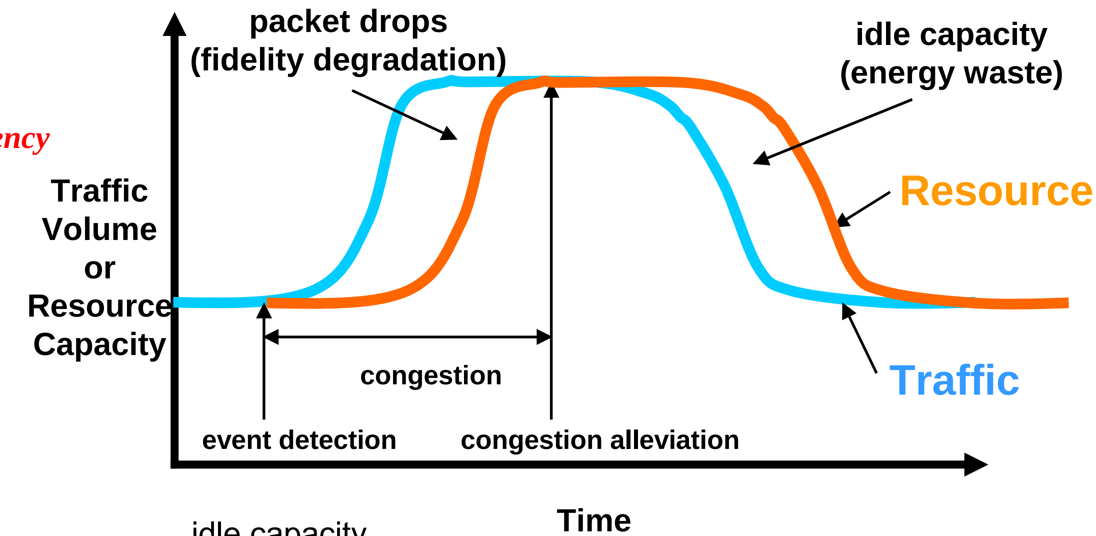
"Traditional traffic control frameworks are not applicable"

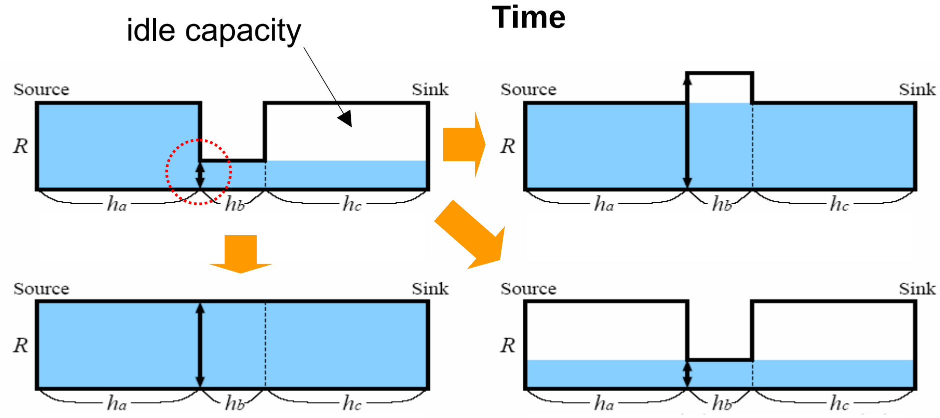
Early Increase/Early Decrease Policy

- Metrics

$$\frac{\textit{Total Energy Consumption}}{\textit{Fidelity}^{obs}} = \textit{Energy Efficiency}$$

- Objective
  - minimize ***Energy Efficiency*** while $\textit{Fidelity}^{obs} > \textit{Fidelity}^{req}$
- Trinary feedback
  - if above upper watermark, R(t+1) = T(t) + α
  - if inside watermarks, R(t+1) = R(t)
  - if below lower watermark, R(t+1) = T(t) + α
- Optimal at end-to-end level

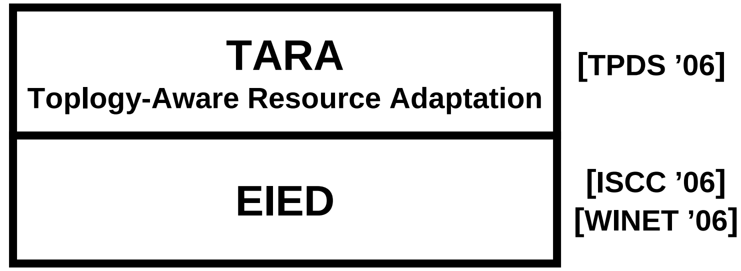


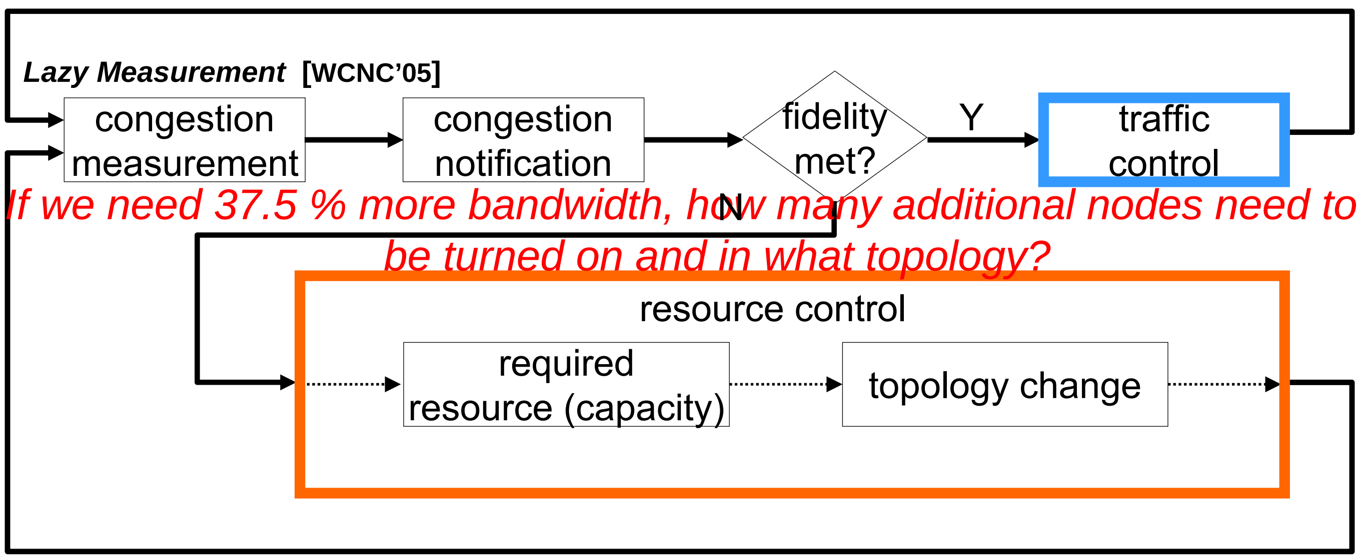


- *R*: available resource
- H_b: bottleneck area

Focus of Research

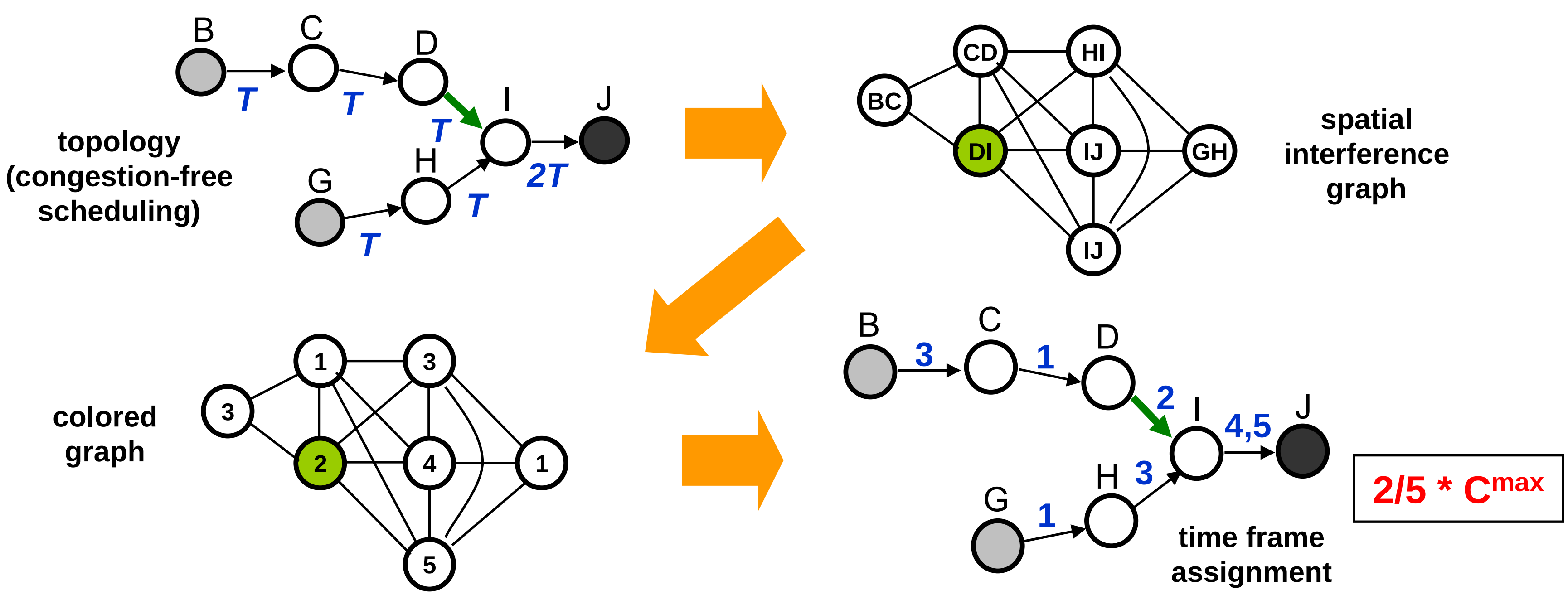
- Policy
  - Early Increase/Early Decrease (EIED)
- Mechanism
  - routing topology change (TARA)





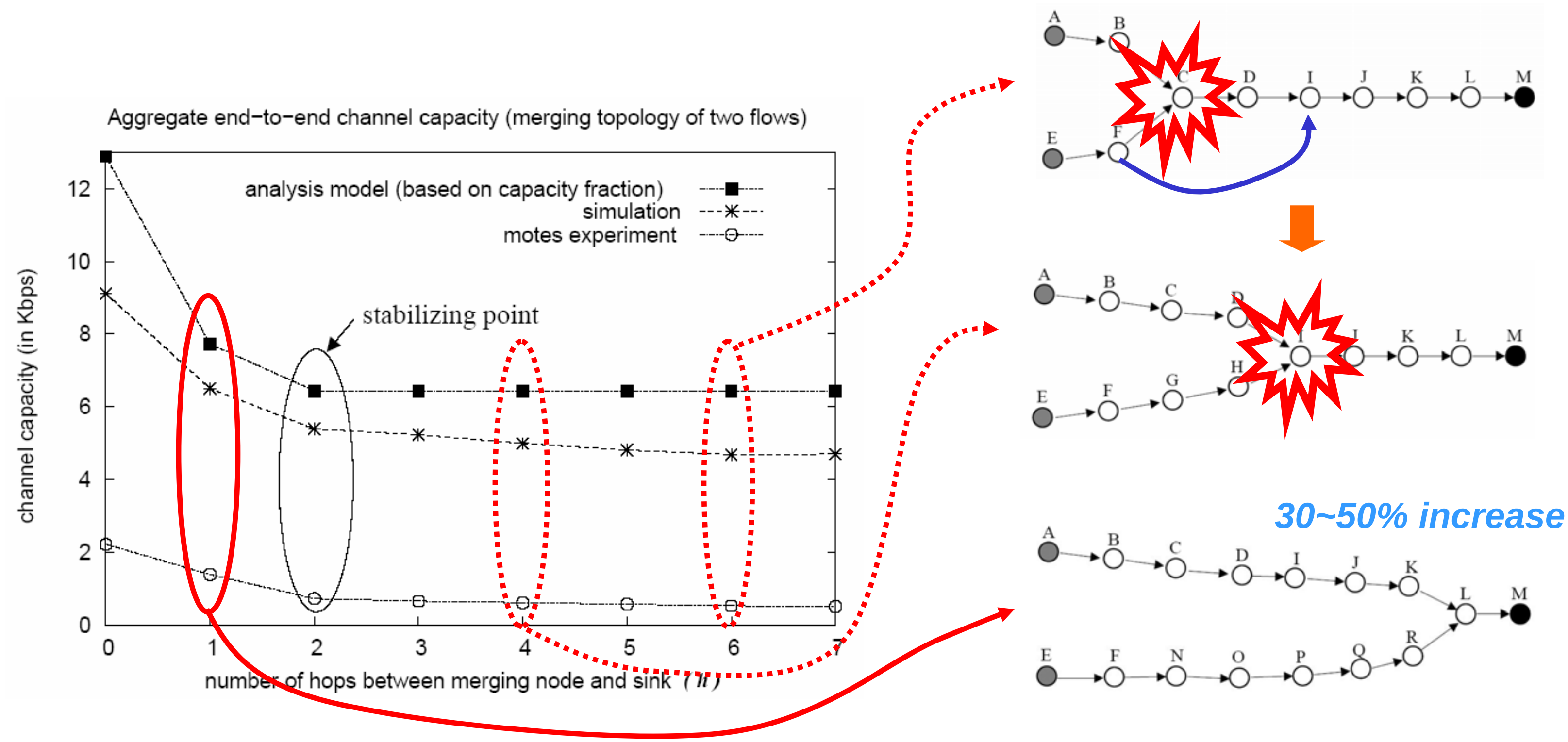
Capacity Analysis Model

- Definition
  - ***T***: one unit of traffic
  - 1 time frame: time interval for a node to transmit one unit of traffic to its immediate neighbor, i.e. one hop.
- Capacity estimation
  - capacity fraction: # of traffic units / required time frames
  - estimated capacity = <u>capacity fraction</u> * maximum one-hop capacity (C^{max})



Capacities of Merging Topologies

- *Capacity analysis model, NS-2 simulation, Berkeley motes experiment*



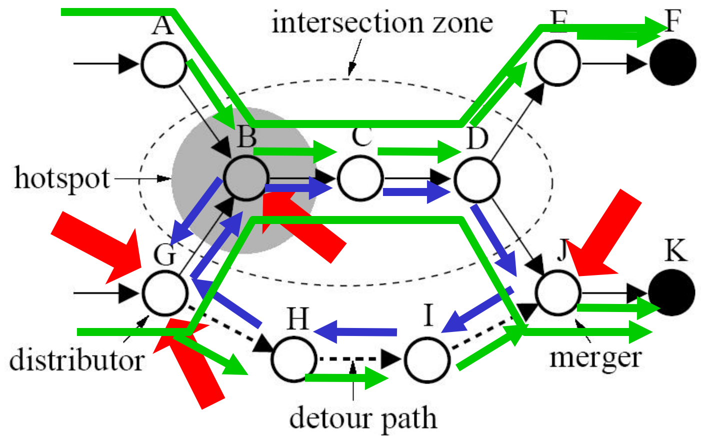
- Lesson: The capacity of a merging topology can be increased by moving the merging point within a small number of hops from the sink.

The real egoistic behavior is to cooperate.

- K. Edwin

Topology-Aware Resource Adaptation (TARA)

- **stream 1: -A-B-C-D-E-F**
- **stream 2: -G-B-C-D-J-K**



control packet

data packet

- stream-based vs. flow-based
  - a stream: all incoming flows destined for the same sink
- hotspot vs. intersection zone
- 5 steps

  - Detecting congestion
  - Finding the distributor
  - Finding the merger
  - Creating the detour path
  - Distributing the incoming traffic

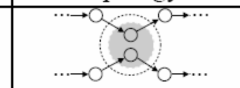
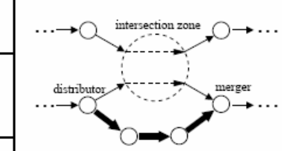
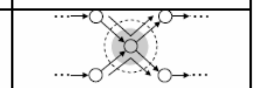
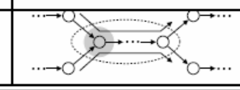
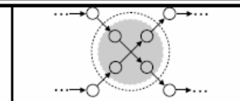
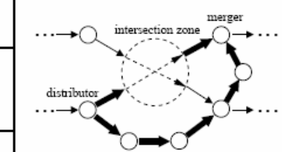
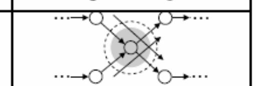
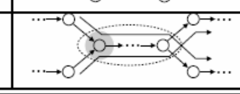
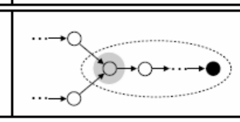
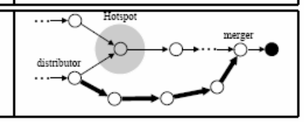
topology awareness

Detour Path Discovery

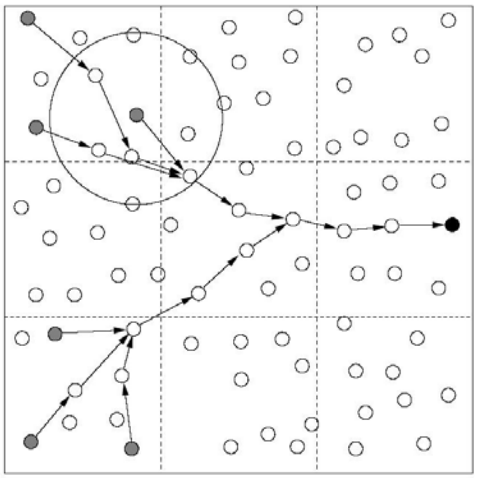
- Goal:
  - To minimize the number of local rebroadcasts
- Reducing rebroadcast
  - local flooding
  - self-pruning by hop count based rebroadcast
- Reliability
  - Random Access Delay (RAD)
  - Unsuccessful reception due to collision with data packets : mostly near the congested nodes
- Prevent parallel resource controlling
  - Overhearing the upstream control message
  - Congestion bit in the packet header

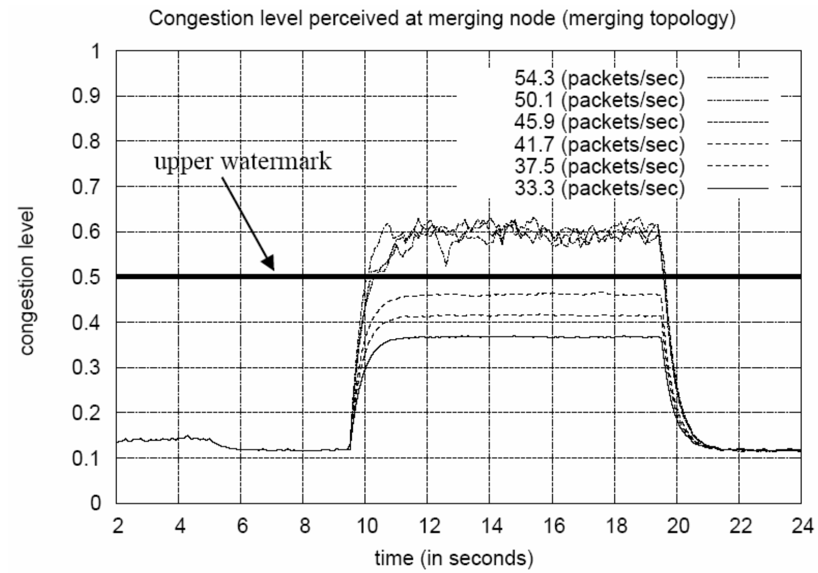
Merger Selection & Traffic Distribution

- Congestion scenarios
  - 3 sharing types
    - no sharing, node sharing, link sharing
  - 4 hotspot building blocks for two dominant streams
  - 3 intersection zones
    - braided, crossing, merging
- Merger selection
  - braided or crossing intersection zones
    - non-congested downstream node
  - merging intersection zone
    - based on distance to sink
- Traffic distribution
  - weighted fair-share scheduling
  - inversely proportional to congestion level
  - $T^{original}/T^{detour} = C^{detour}/C^{original}$

	Cong. type	Congestion topology	Traffic distribution
Braided	1		
	2		
	3		
Crossing	4		
	5		
	6		
Merging	7		

Simulation Environment





sensor field

81 nodes in 160x160m

802.11 DCF 2M bps

no RTS/CTS

radio: 30m(T), 50m(I)

traffic model

event duration: 10 sec

peak rates: 33.3~66.9 packets/sec/source

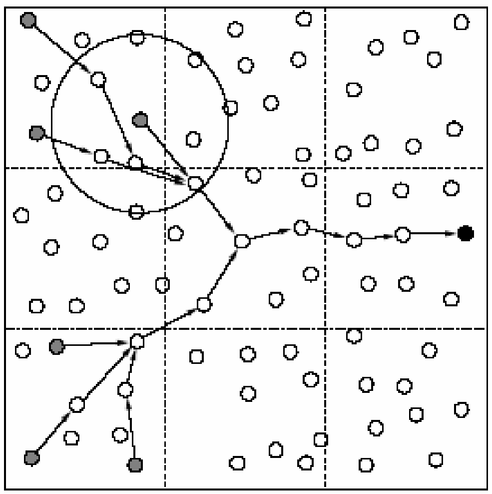
packet size: 100 bytes

energy consumption: 13.5(I),13.5(R),24.75mW(T)

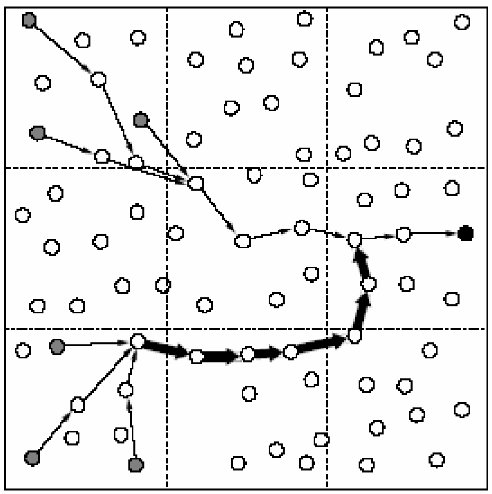
Simulation Strategies

- Strategies
  - no congestion control
    - a baseline scenario
  - traffic control
    - back-pressure message to the upstream nodes.
  - topology-unaware resource control
    - chooses the first downstream node with a low congestion level as a merger to form the detour path.
    - blindly routes all the packets to the detour path.
  - TARA
  - ideal resource control
    - optimal offline resource control algorithm.
    - finds an optimal topology.
    - cannot be implemented in a real system.

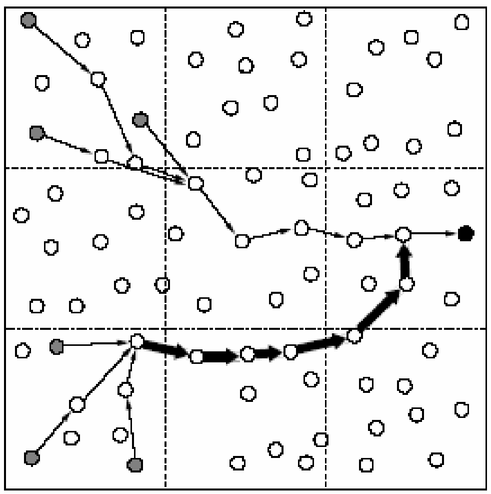
Congestion Control Scenarios



no congestion control
traffic control

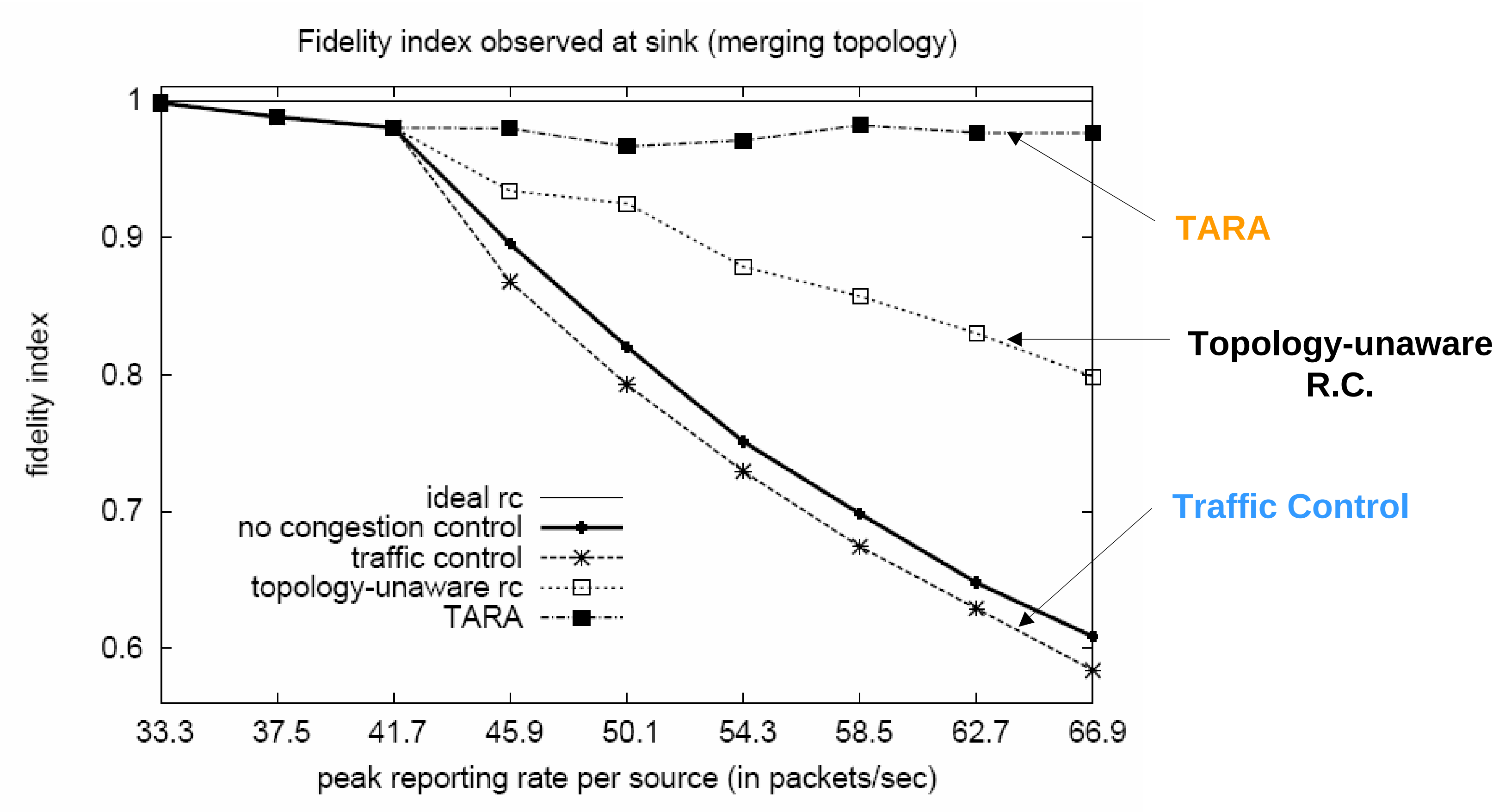


topology-unaware rc

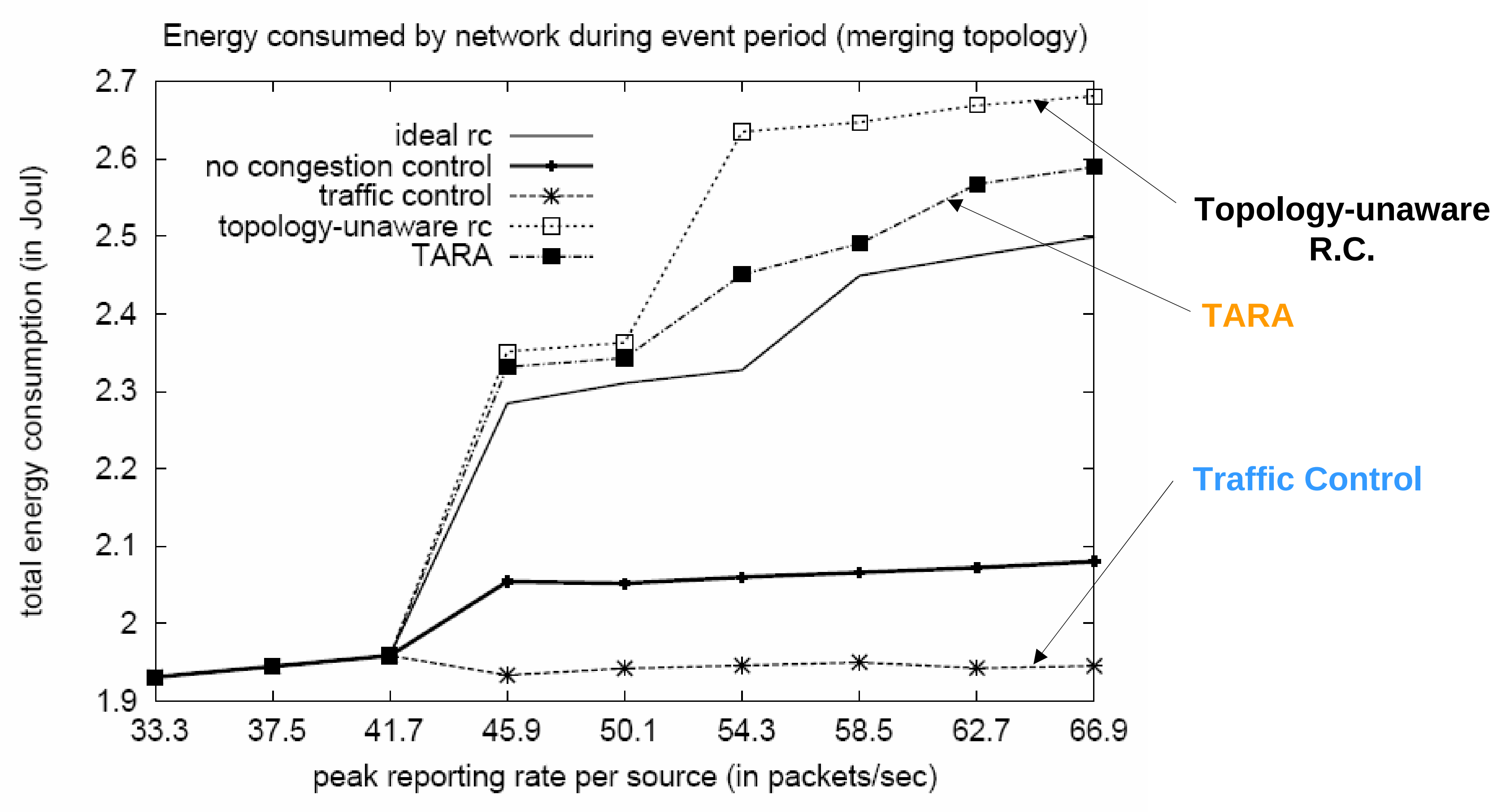


ideal rc
TARA

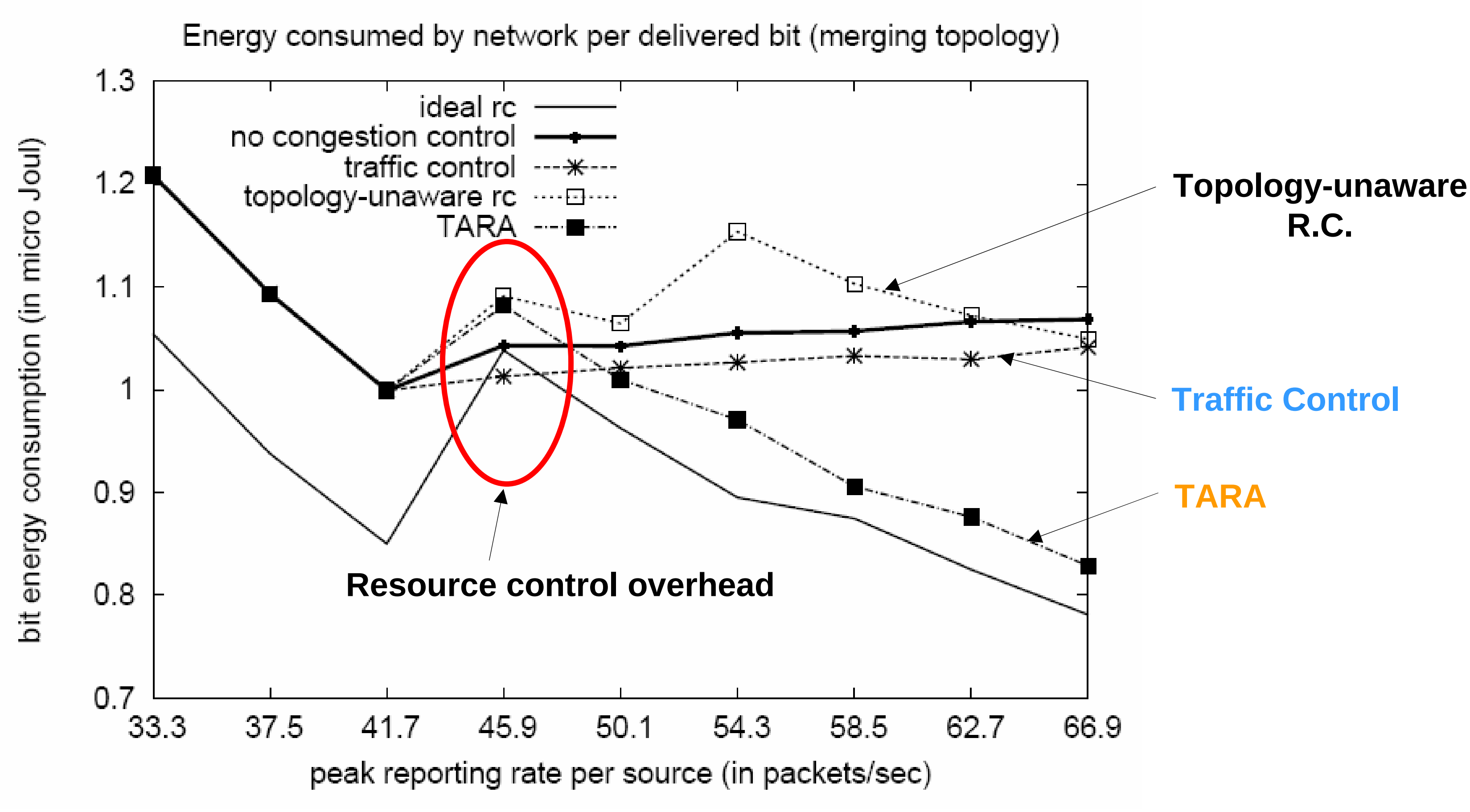
Fidelity Index



Total Energy Consumption



Bit Energy Consumption



Conclusion

- A new approach to control congestion in sensor networks based on resource control.
- Fidelity-met, energy-efficient, and distributed.
- The data delivery and energy conservation of TARA is very close to the ideal case.

Future Work

- Unified congestion control framework
  - Traffic control + Resource control
  - Resource control using various resource control means (e.g. power)

- Coping with transient congestion.

- Quick decision about resource availability.

Thank you !

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Project Home:
http://paul.rutgers.edu/~jwkang/research/tara.html

- As of May 2006, I am looking for a full-time research position.
  Please, feel free to contact me for any questions.