Distributed Load Shedding with Minimum Energy

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Introduction

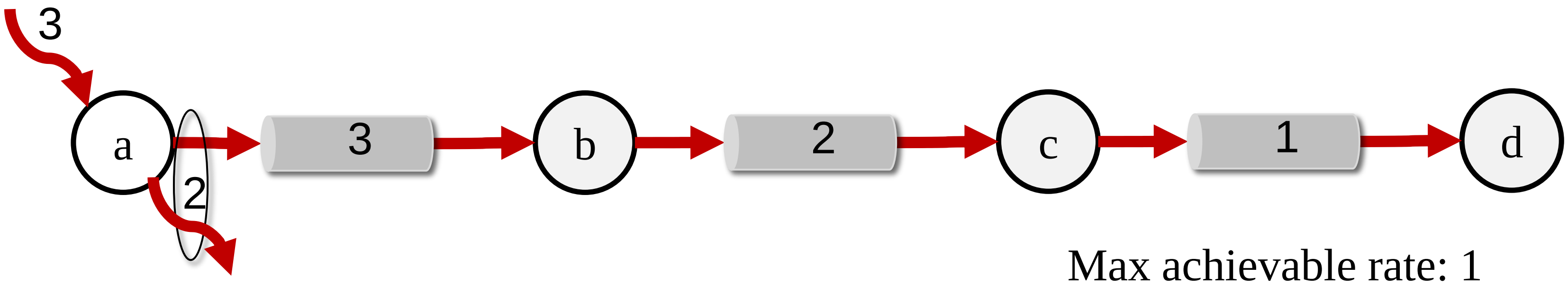
- Problem: Congestion control at every **source** is complex.
  - Sources may not be trusted
  - Network variability

- Solution: **In-network** congestion control without source cooperation.
  - Simplified decision process in a large network
  - No specified nodes responsible for congestion control

In this talk:
Resolve congestion **inside the network** without burdening source
- Sources inject packets
- The network adapts by shedding packets
- Packets are dropped as earlier as possible – energy efficiency

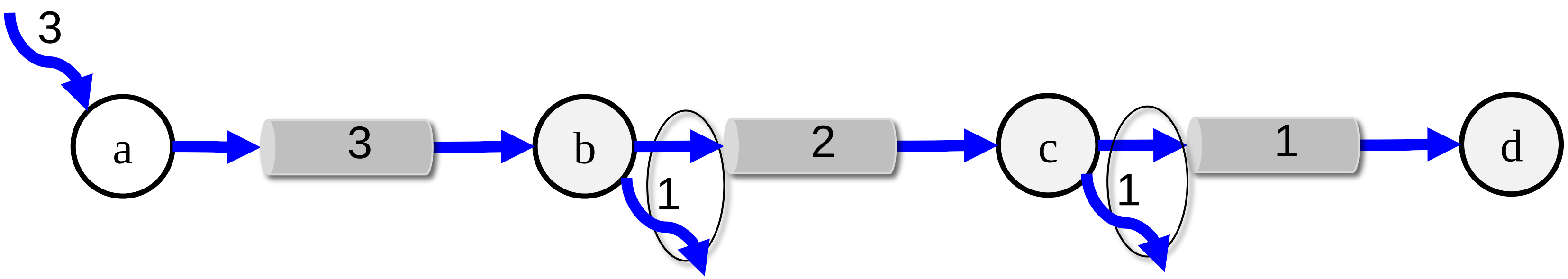
Congestion Control

- Source-based load shedding



Max achievable rate: 1
Shedding rate: 2@a

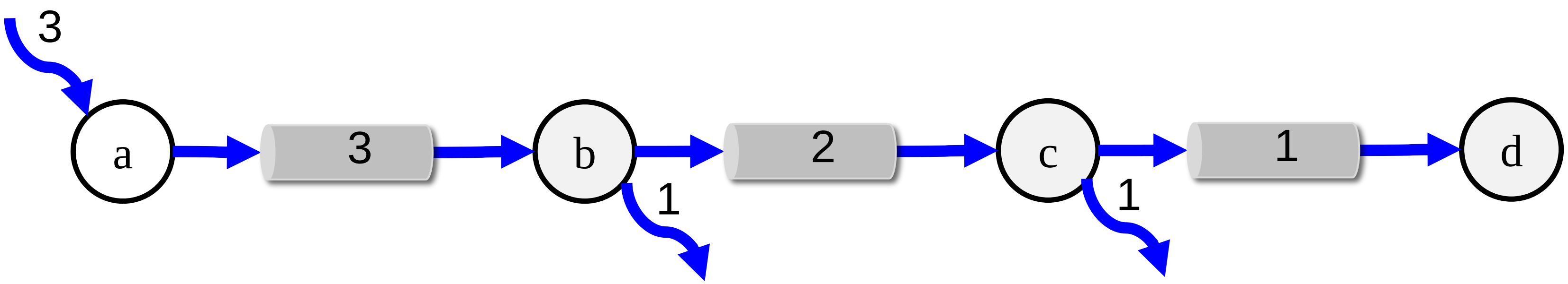
- Distributed load shedding



Max achievable rate: 1
Shedding rate: 1@b, 1@c

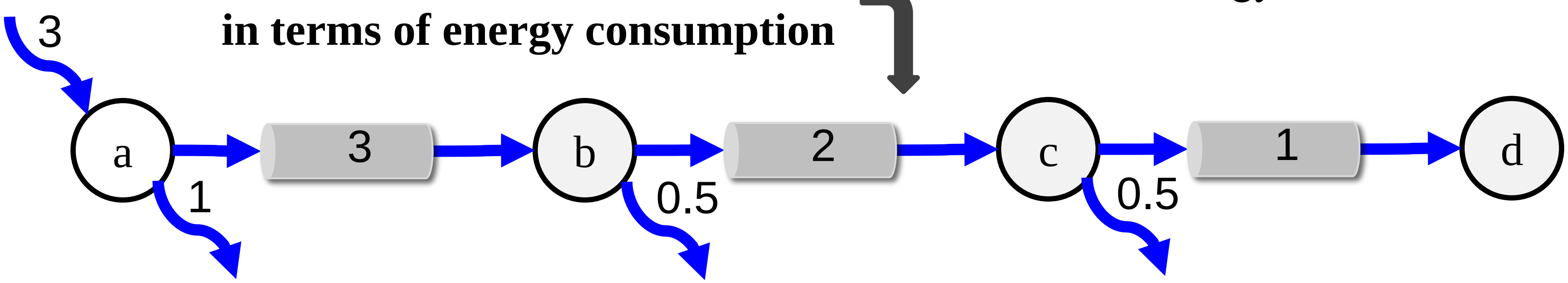
Distributed Load Shedding (DLS)

- **Source injects** the whole load to the network
- **Threshold-based** load shedding at all nodes
- All nodes use **the same threshold**



Shedding rate: 1@b, 1@c
Wasted TX energy: 1· 1 + 2 · 1 = **3**

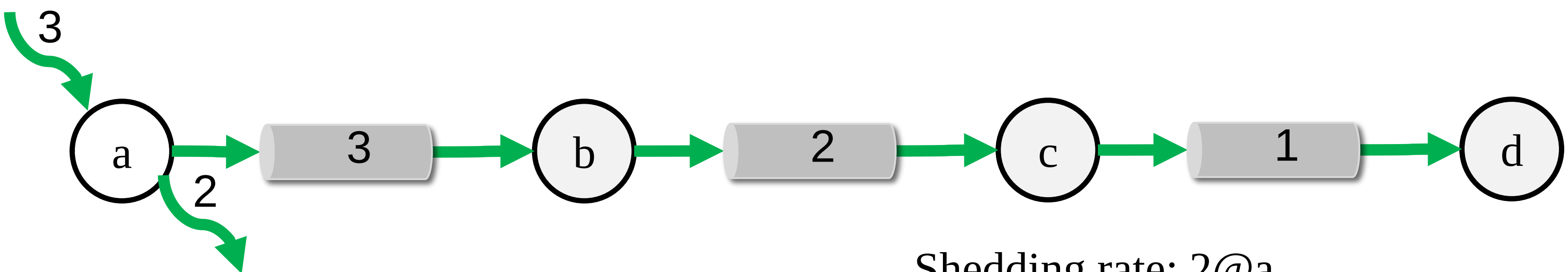
or even better
in terms of energy consumption



Shedding rate: 1@a, 0.5@b, 0.5@c
Wasted TX energy: 1· 0.5 + 2 · 0.5 = **1.5**

Energy-efficient Distributed Load Shedding (E-DLS)

- **E-DLS:** Thresholds increase as the node gets closer to the destination

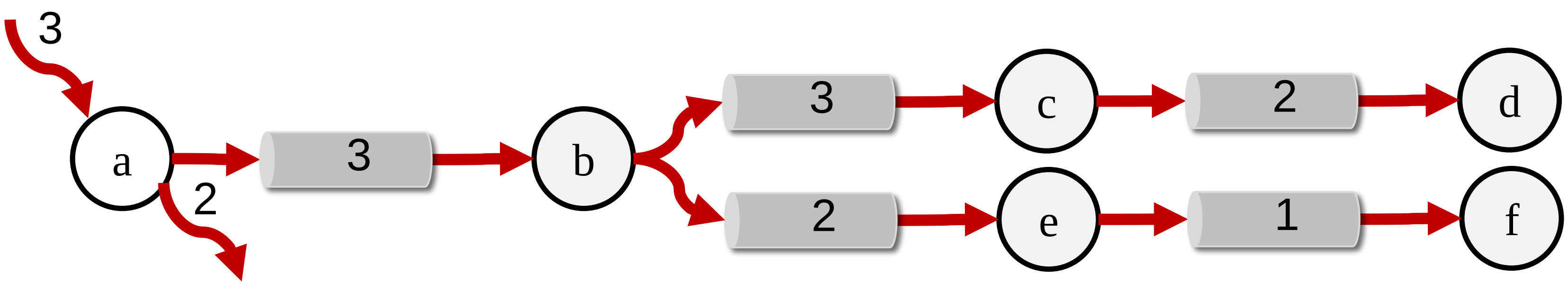


Shedding rate: 2@a
Wasted TX energy: **0**

- Simple ***distributed load shedding***
- Optimal throughput performance
- Minimum wasted TX energy as ***source-based load shedding***

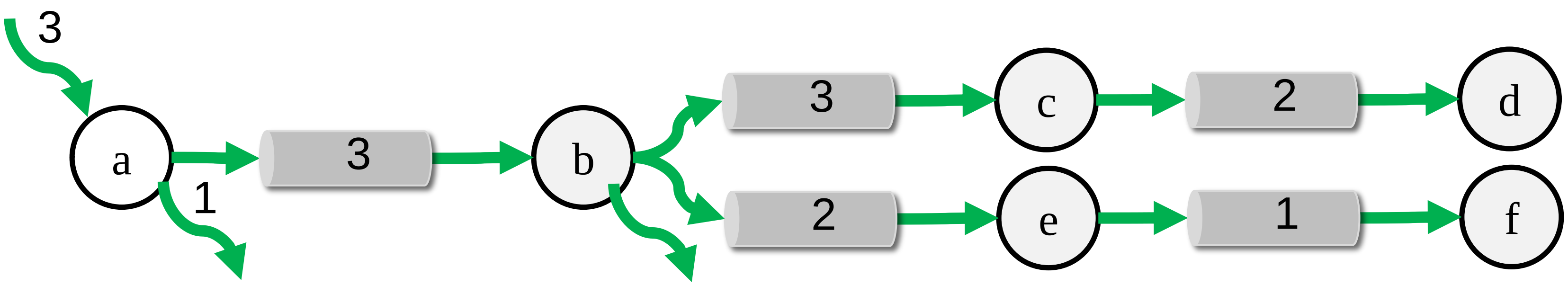
multicast E-DLS

- **Source-based load shedding**



Max achievable rates: 1@d, 1@f

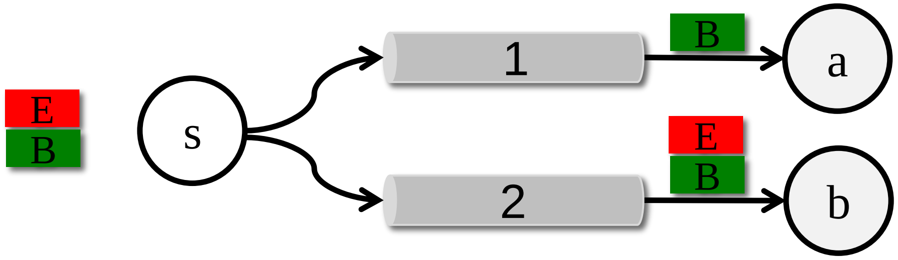
- **multicast E-DLS**



1 for link (b,e)

Max achievable rates: **2@d**, 1@f

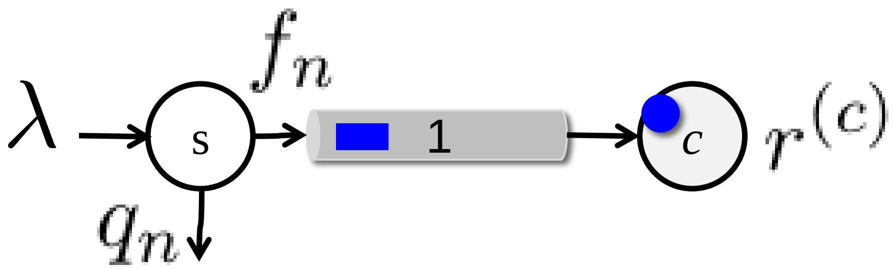
Multirate multicast



- Same stream at **different rate** per receiver
- Layered video coding
  - Basic layer packets: necessary for decoding at lowest quality
  - Enhanced layer packets: improve quality

Formulation of NUM

Throughput maximization : $\max_{\boldsymbol{f},\boldsymbol{q}} \sum_c r^{(c)}$

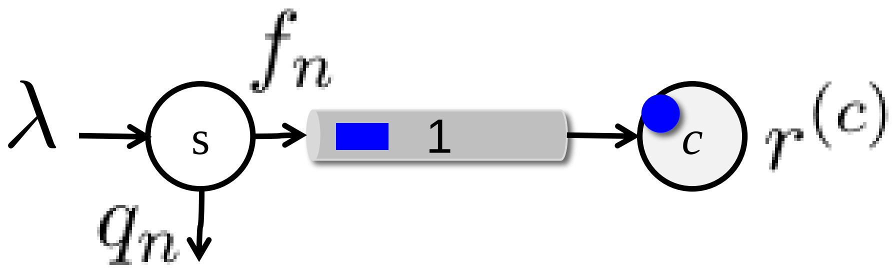


$$r^{(c)} = \lambda - q_n$$

Equivalent to **minimization of shedding rates**

that is (for one session c) : $\min_{\boldsymbol{f},\boldsymbol{q}} \sum_n q_n$

NUM for energy-efficiency



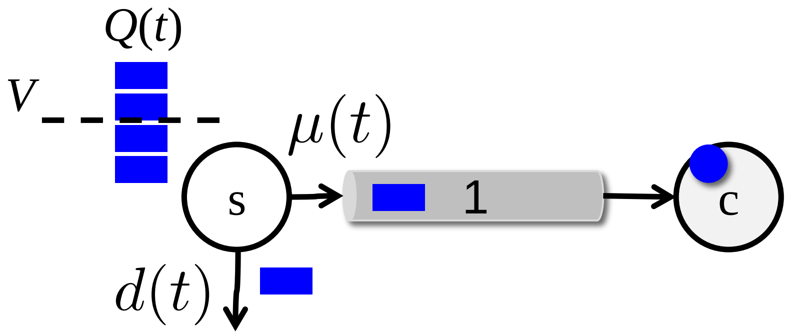
Transmissions minimization : $\min_{\boldsymbol{f},\boldsymbol{q}} \sum_n f_n$

Equivalent to **maximization of weighted shedding rates** :

$$\max_{\boldsymbol{f},\boldsymbol{q}} \sum_n h_n q_n$$

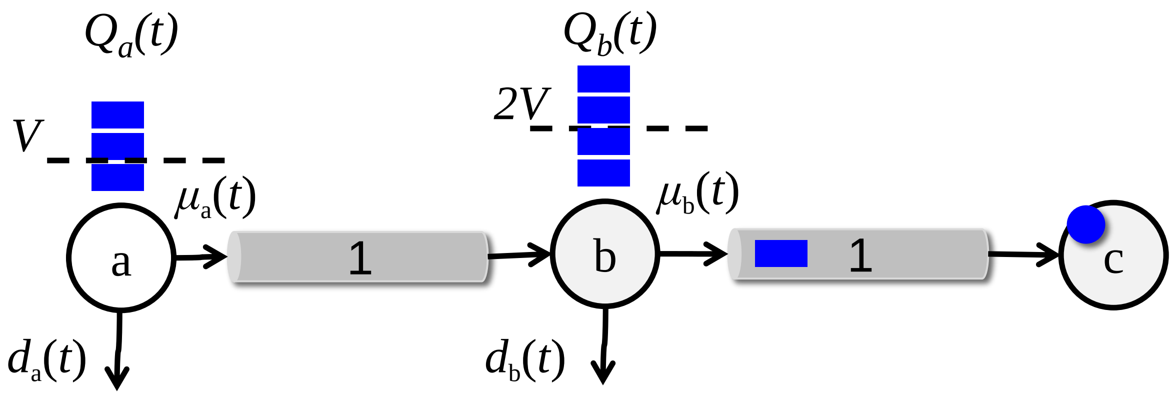
subject to : $\min_{\boldsymbol{f},\boldsymbol{q}} \sum_n q_n$

Real-time control: shedding



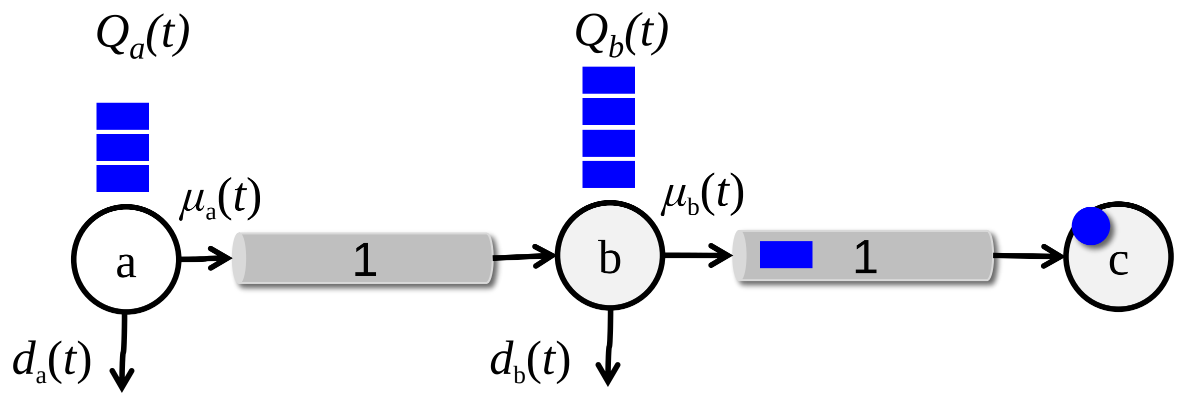
- At every slot
  - Choose $d(t)$ to drop packets
  - Choose $\mu(t)$ to route packets
- **Threshold-based shedding**: If $Q(t) > V$ drop d_{max} packets, else zero

Proposed energy-efficient shedding



- Threshold **increases** as hop count to the destination **reduces**
- **Threshold at each node:** $(K - h_n)\,V$

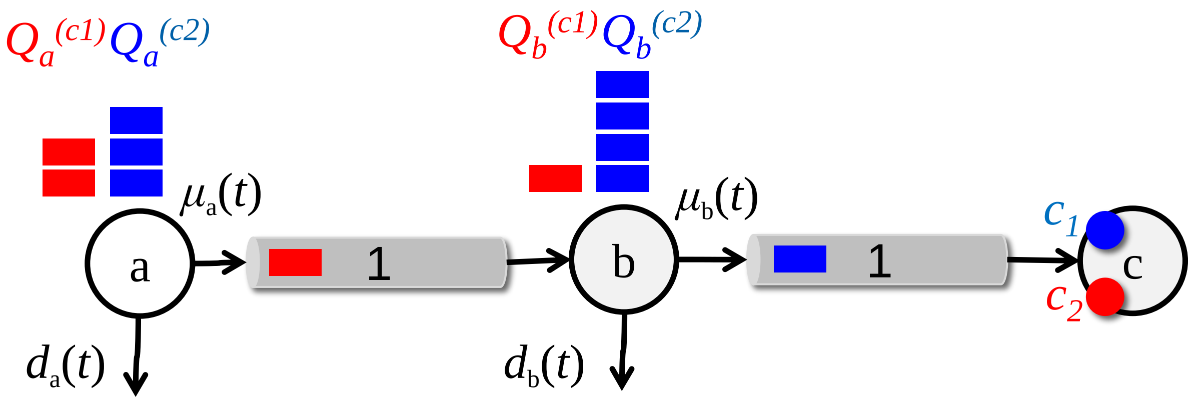
Real-time control: Proposed routing (path)



- **Backpressure routing**: Transmit at capacity if $Q_a(t) > Q_b(t)$ (positive differential backlog)

Backpressure+threshold-based shedding = maximum throughput for this unicast session

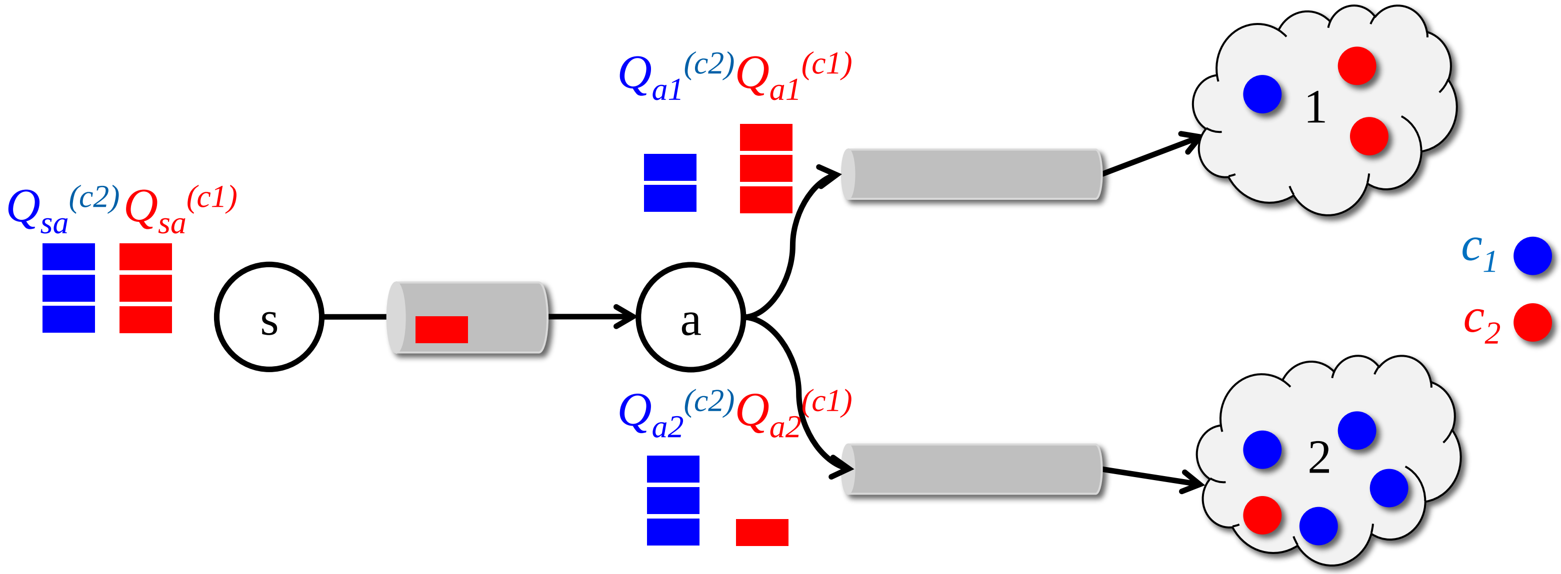
Proposed routing (multiple sessions)



- **Backpressure weight**: $Q_a^{(c_1)} - Q_b^{(c_1)}$ or $Q_a^{(c_2)} - Q_b^{(c_2)}$
  - Transmit the session with the maximum weight

Max sum throughput for multiple unicast

Proposed multicast routing (tree)



- Backpressure weight: $Q_l^{(c)}(t) - \sum_{l':p(l')=l} Q_{l'}^{(c)}(t)$

link (s,a) $\begin{cases} Q_{sa}^{(c_2)} - Q_{a1}^{(c_2)} - Q_{a2}^{(c_2)} \\ Q_{sa}^{(c_1)} - Q_{a1}^{(c_1)} - Q_{a2}^{(c_1)} \end{cases}$

- Transmit the session with the maximum weight

Max sum throughput for multirate multicast

Summary of contributions

- Formulate NUM using **shedding rates** focusing on energy efficiency.

- In-network optimal congestion control policy for **unicast** & **multirate multicast**:
  - Threshold-based shedding
  - Backpressure routing
  - Gradually increased thresholds

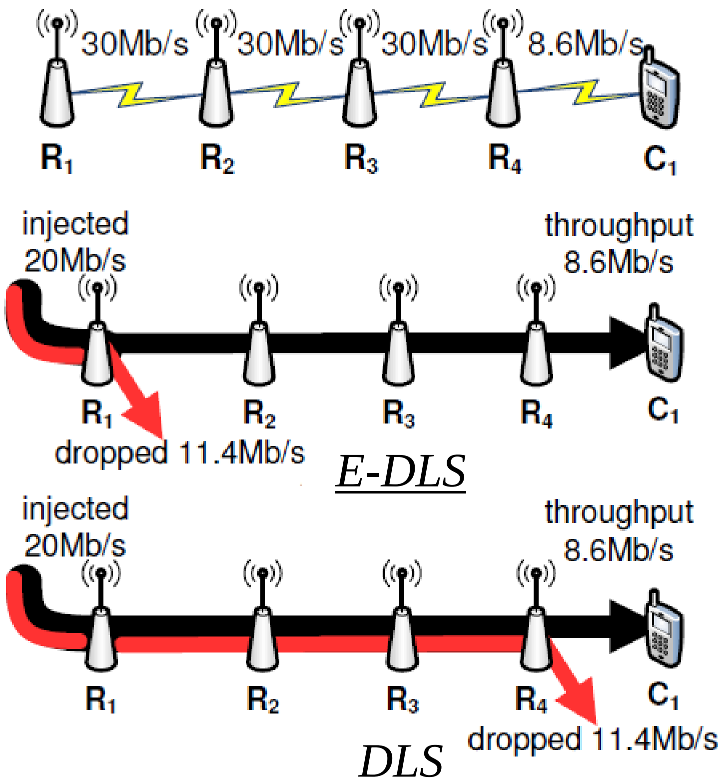
(Threshold-based shedding and Backpressure routing → Maximum throughput; all three → Energy Efficient)

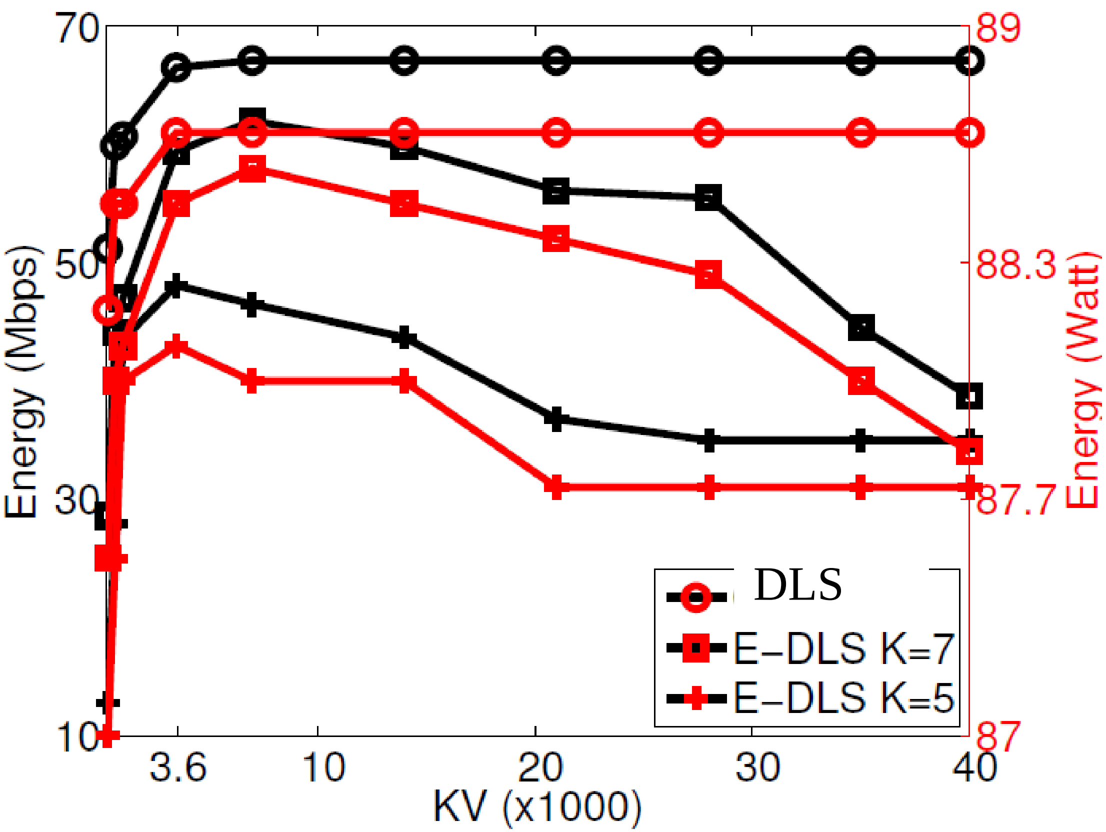
Testbed experimentation

- Testbed experimentation
  - NITOS testbed (Volos, Greece)
  - Click Modular Router

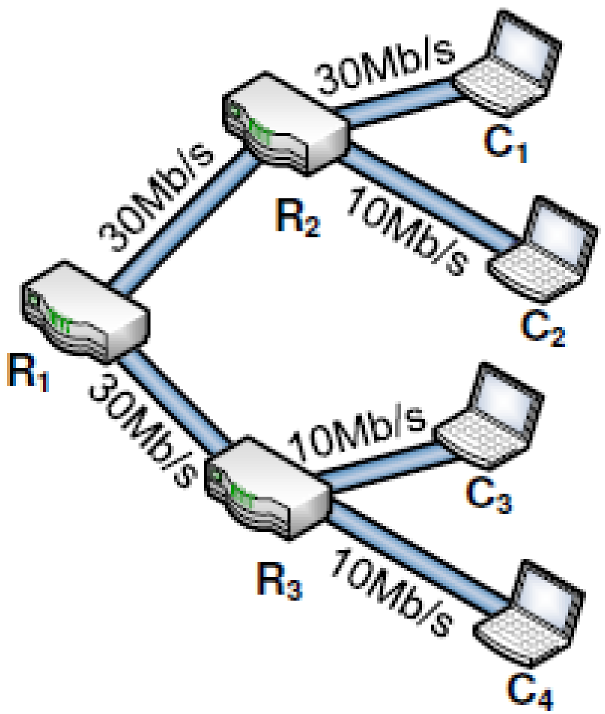
- Implementation of the policy
  - Exchange backlog information
  - Virtual slot mechanism
- Results
  - Full throughput ✔
  - Minimum energy consumption ✔
  - Negligible messaging overhead ✔

Throughput/Energy on 4-hop path

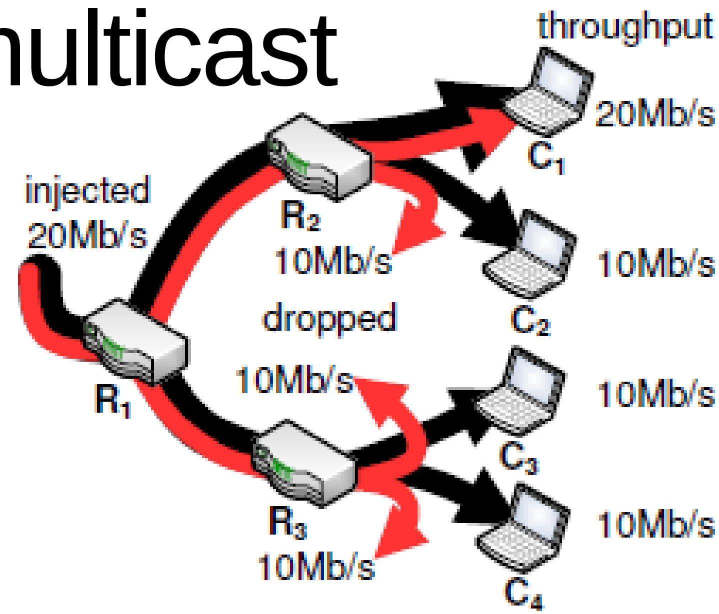




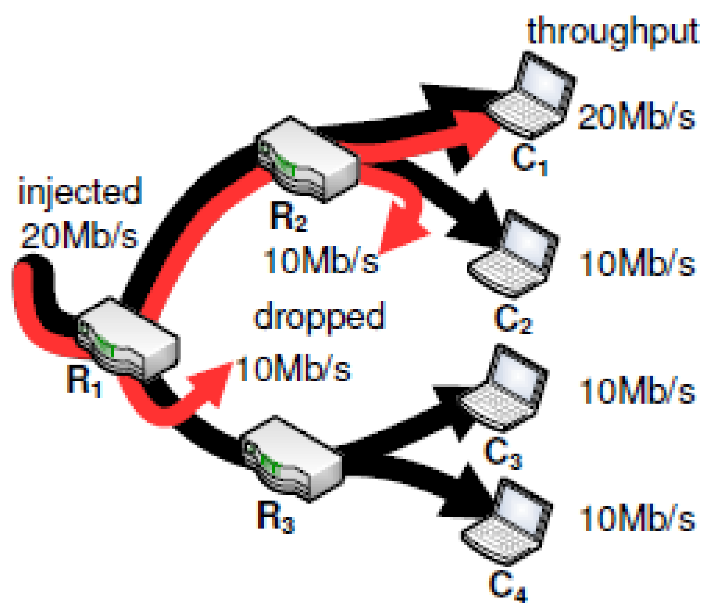
Throughput/Energy on multicast



DLS



E-DLS



Conclusions

- Proposed an energy-efficient distributed congestion control scheme
  - Support for unicast sessions and proof of optimality
  - Extension for multirate multicast
  - Validation of both schemes with testbed experimentation

- Future work:
  - Proof of the optimality of the extension for multirate multicast

Thank you!

Questions?

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Previous solutions

- Primal-Dual algorithms: **[Kar02], [Deb04]**
  - Messaging between sources and receivers
- Backpressure-based: **[Neely05]**, **[Bui08]**
  - Sources decide how many packets to inject
- Backpressure-based and Distributed: **[Li12, Paschos14]**
  - Adaptation inside the network