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Generic Routing Metric and Policies for WSNs

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Overview

- Motivation
- Related Work
- Limitations of Existing Metrics
- Our Model
  - The GEM-metric
  - Routing Policies
- Evaluation
  - GEM-metric without Policies
  - GEM-metric with Policies
- Conclusions and Future Work

Motivation

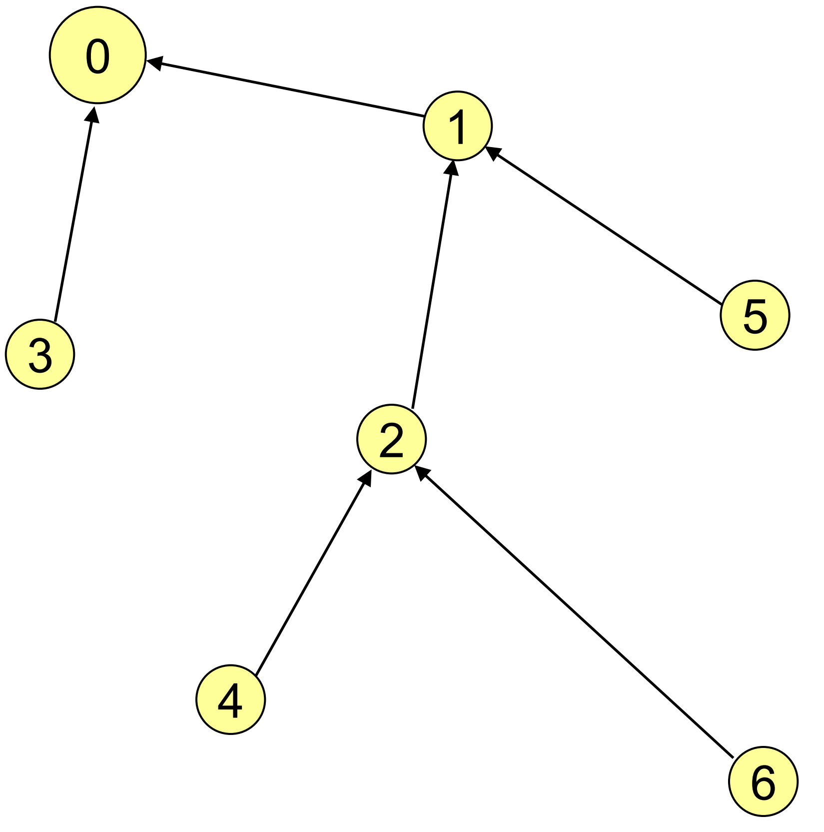
→ Monitoring scenarios are one of the biggest WSN application groups

→ Self-organization into a sensor network

→ Energy-awareness is a crucial factor

→ There is a need to include energy consumption as an optimization parameter

- Three concepts of energy-aware multihop routing:
  - QoS (Transport reliability)
  - Energy consumption
  - Application requirements



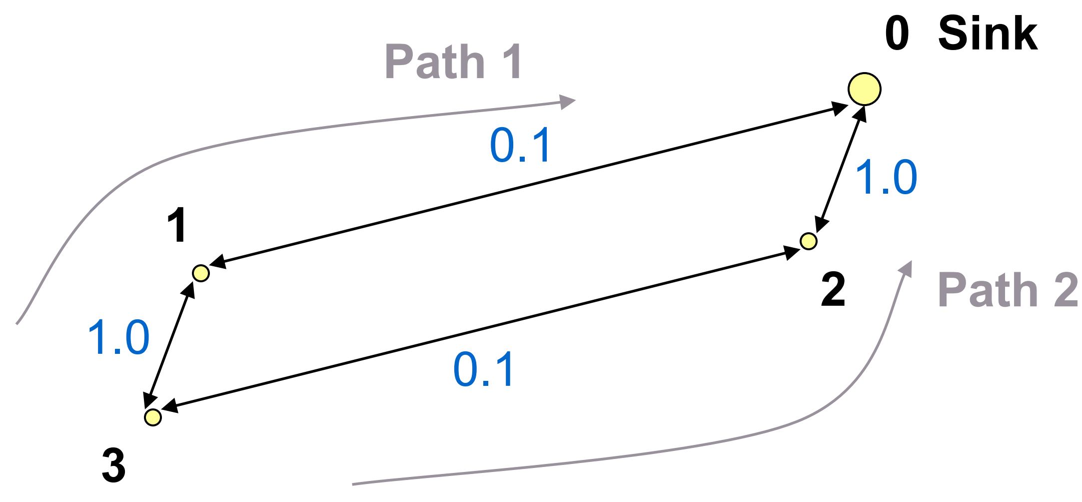
Problem: What is the best many-to-one routing tree for a given application?

Routing metric defines the routing tree configuration

Related Work

- Parameters Management
  - Transmission Power Level (**TPL**) [D. Son et al., M. Kubisch et al.]
  - Maximum Number of Retransmissions (**ReXmit**) [O. Gnawali et al.]
- Energy Consumption Modeling [R. Shah et al.]
- Routing Metrics
  - Shortest Path First (**SPF**) [D. De Couto et al.]
  - Success Rate (**SR**) [O. Gnawali et al.]
  - Expected Transmission Count (**ETX**) [D. De Couto et al.]

Limitations of Existing Metrics



- Shortest Path First (**SPF**)
- Success Rate (**SR**)

$$\prod_{i \in Path} p_i \rightarrow \max$$

- Expected Transmission Count (**ETX**)

$$\sum_{i \in Path} \frac{1}{p_i} \rightarrow \min$$

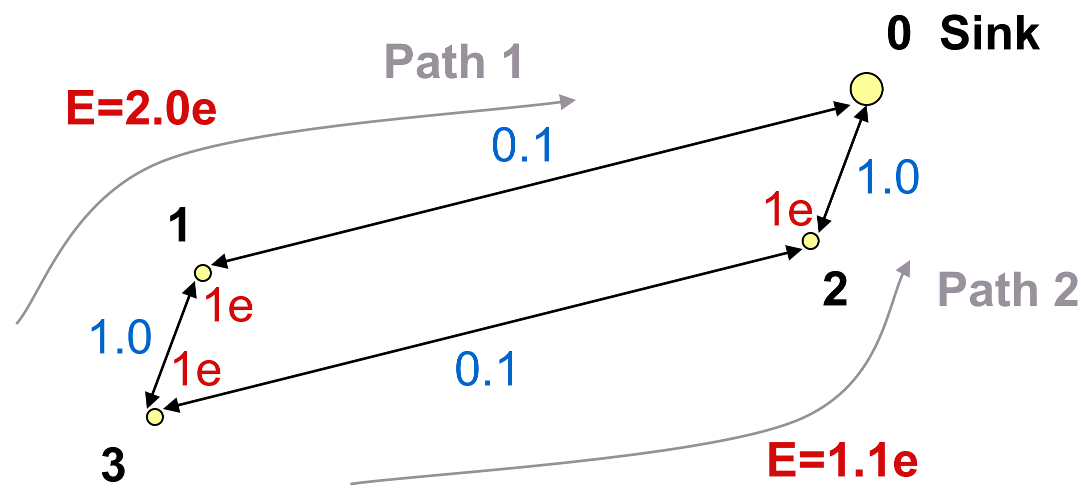
SPF = 2

SR = 1.0×0.1 **= 0.1**

ETX = $\frac{1}{1.0} + \frac{1}{0.1}$ **= 11**

Path 1 = Path 2

Limitations of Existing Metrics



e – energy unit

Path 1 ≠ Path 2

Energy consumption of a path is dependent of the traffic direction

in contrast to the packet reception rate

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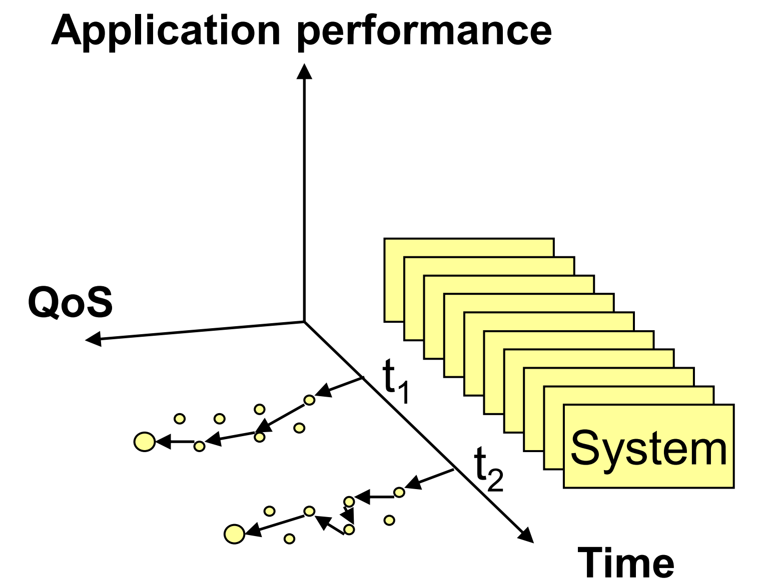
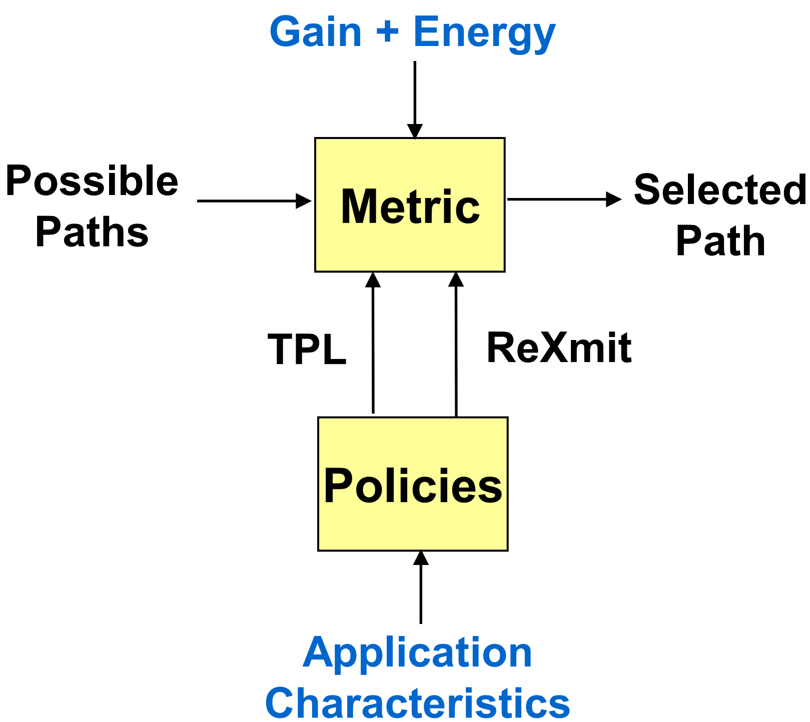
Our Model: Assumptions

Observation:

- Transport reliability is determined independently at any point in time
- Energy resource depends on the history of previous system performance





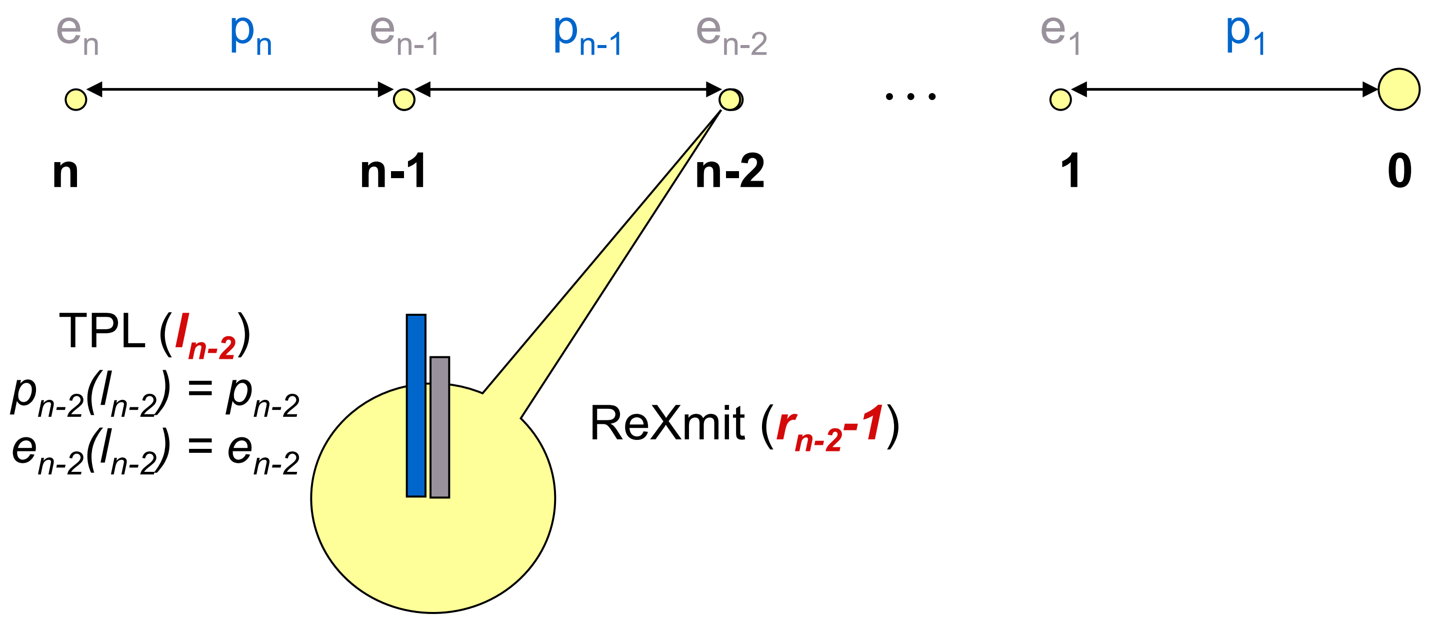
Assumptions and Parameterization:

- Two independent parameters allow to tune the direction of optimization:
  - Transmission power level (**TPL**)
  - Number of retransmissions (**ReXmit**)
- These parameters are time-dependent

Our Model: Terminology

p_i – probability of packet reception after one send operation

e_i – number of energy units consumed for one send operation



$a_i = \sum_{k=1}^{r_i} p_i (1 - p_i)^{k-1}$ - probability of packet reception over a link

$e_i b_i = e_i \left(\sum_{k=1}^{r_i} k p_i (1 - p_i)^{k-1} + r_i (1 - p_i)^{r_i} \right)$ - amount of energy consumed by one link

Our Model: General Case

- No retransmissions ($r_i = 1$)

SR

$$E(Gain_{path})_{r_i=1} = p_n(p_{n-1}(\ldots p_2(p_1)\ldots))$$

$$E(Energy_{path})_{r_i=1} = e_n + p_n(e_{n-1} + p_{n-1}(\ldots + p_2(e_1)\ldots))$$

- Limited number of retransmissions ($r_i = x_i << \infty$)

$$a_i = \sum_{k=1}^{x_i} p_i(1-p_i)^{k-1}$$

$$b_i = \sum_{k=1}^{x_i} kp_i(1-p_i)^{k-1} + x_i(1-p_i)^{x_i}$$

$$E(Gain_{path})_{r_i=x_i} = \prod_{i=1}^{n} a_i$$

$$E(Energy_{path})_{r_i=x_i} = b_n e_n + a_n(b_{n-1}e_{n-1} + a_{n-1}(\ldots + a_2(e_1)\ldots))$$

- Unlimited number of retransmissions ($r_i = \infty$)

$$a_i = 1$$

$$b_i = \frac{1}{p_i}$$

$$E(Gain_{path})_{r_i=\infty} = 1$$

$$E(Energy_{path})_{r_i=\infty} = \sum_{i=1}^{n} \frac{e_i}{p_i}$$

ETX

Routing Metric: GEM-metric

$$\text{GEM-metric} = \frac{E(Gain)_{r_i}}{E(Energy)_{r_i}} \rightarrow \max$$

- **G**ain per **E**nergy **M**aximization metric
- **Routing Path:**
  - Chooses best throughput path and takes energy into account
  - Aware of both parameters (TPL and ReXmit)
  - Considers that ReXmit is always limited
  - ETX is an asymptotic function, for ReXmit approaching infinity
  - Inverse of $E(Gain)_{r_i}$ shows the expected number of transmissions to be performed over the path in order to achieve guaranteed delivery
  - No global knowledge needed

Routing Policies

Energy-Aware Policies: Aimed at optimizing path characteristics based on the application requirements to the routing module

Policy examples [from the literature]:

- Neighborhood Control
  - Decrease TPL if the number of neighbors exceeds a predefined value and vice versa
  - ➢ Adaptation to dense and sparse scenarios
- Lifetime Control
  - Adjusts TPL or/and ReXmit based on application performance history
  - ➢ Adaptation to long running monitoring scenarios
- Link Quality Based (**LQB**)
  - Increase TPL if the link quality to the parent node is lower than some value and tries decrease TPL if the link quality is 100%.
  - ➢ Adaptation to scenarios which require stable good quality links and are still energy constrained

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Evaluation

Testbed:

- 10 Tmote Sky sensor nodes
- Office environment
- Each experiment: 100 seconds, repeated 5 times

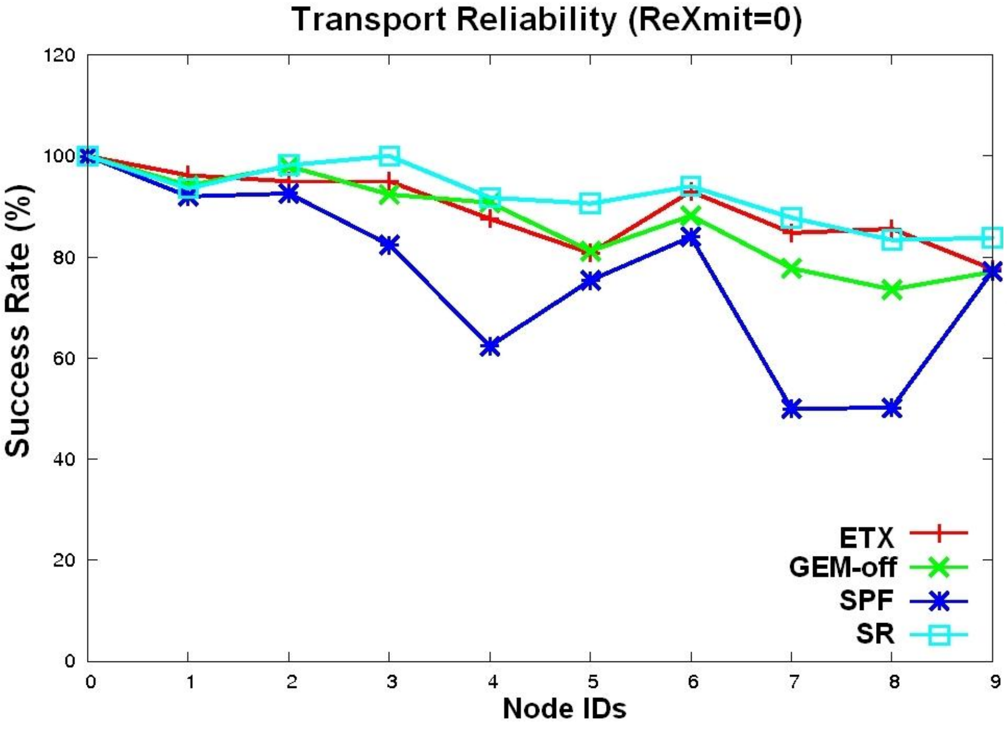
Routing Settings:

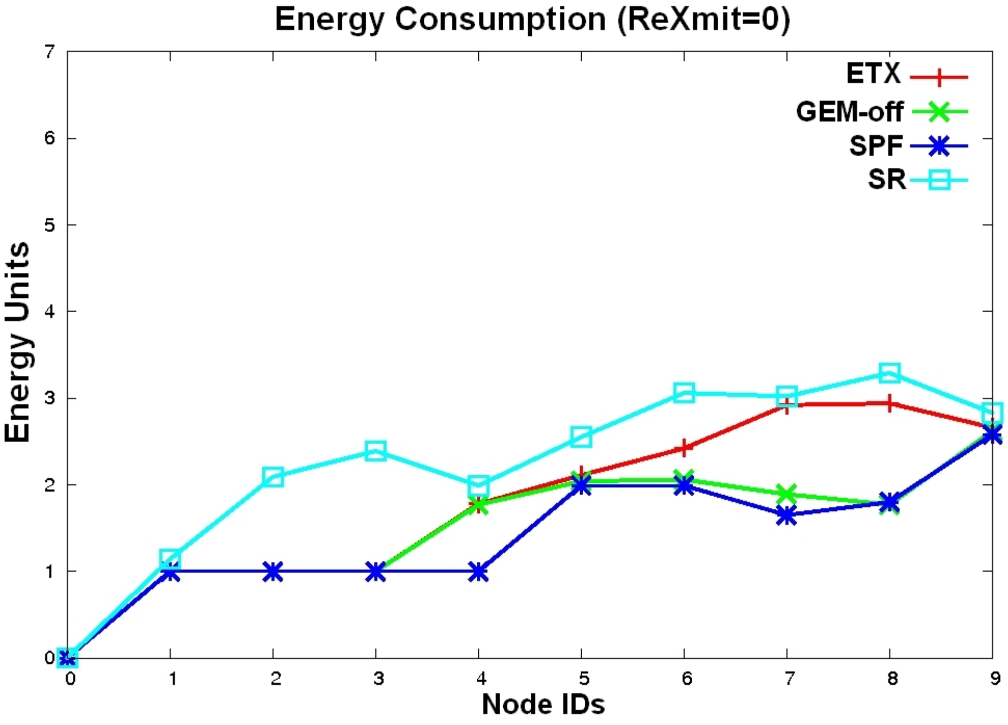
- Link quality estimator: moving average with a window size of 10
- Initially: TPL=2

Evaluation Scenarios:

- GEM-metric without policies (**GEM-off**) compared to SPF, SR, ETX
- GEM-metric with LQB policy (**GEM-lqb**) compared to GEM-off

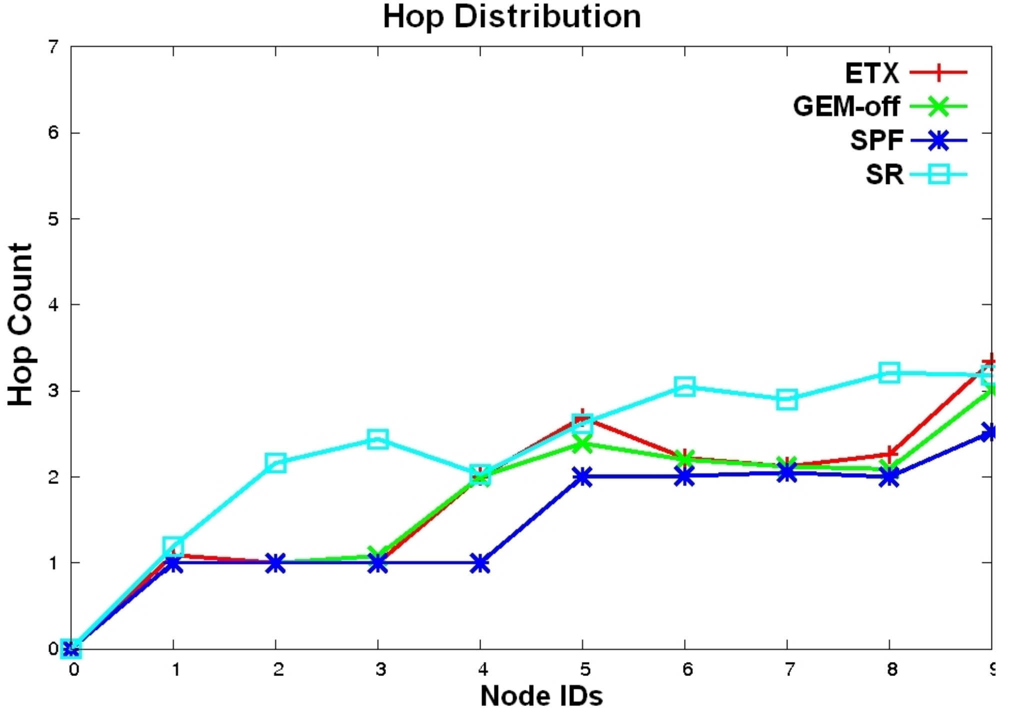
Evaluation GEM-off

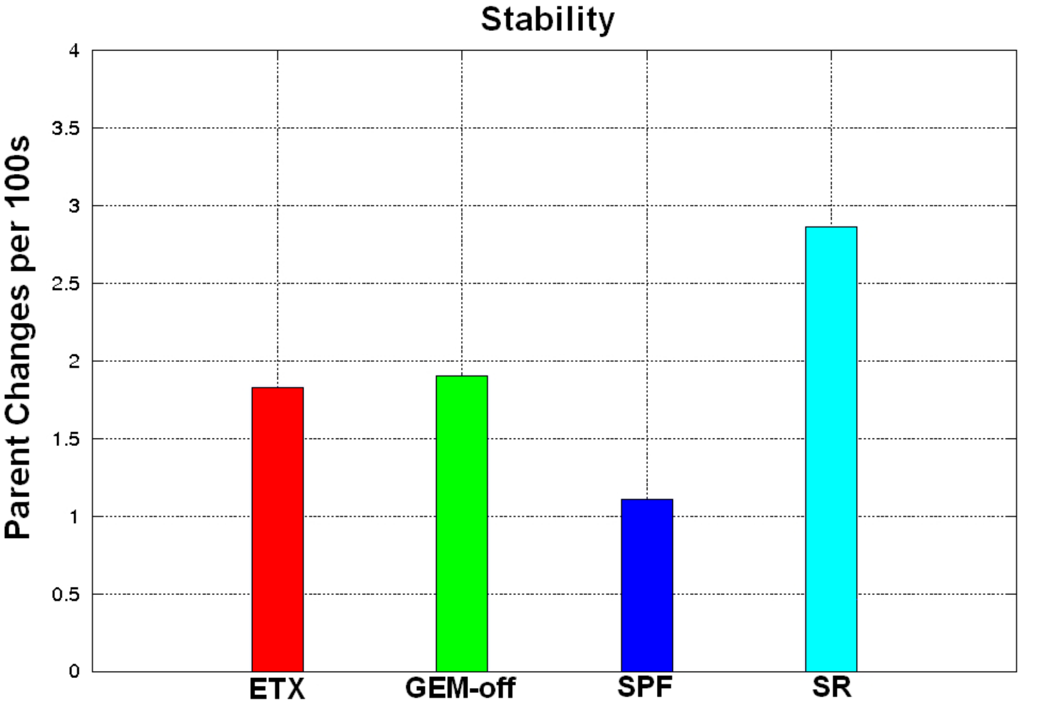




- End-to-end packet success rate
  - GEM-metric shows nearly the same behavior as ETX
- Energy Consumption
  - GEM-metric provides considerable gains in energy because the number of retransmissions is always limited to a certain finite value

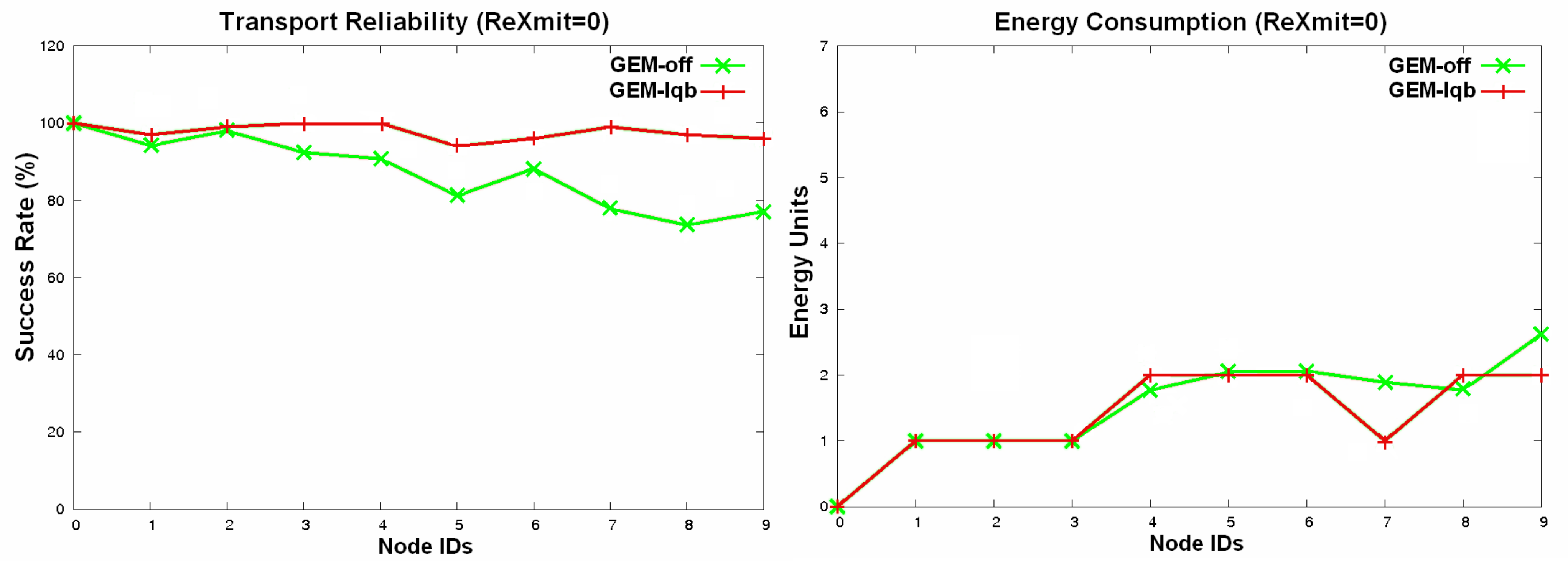
Evaluation GEM-off cont.





- Hop Distribution
  - ETX and GEM show the same performance
- Route Stability
  - SR and SPF are extreme cases

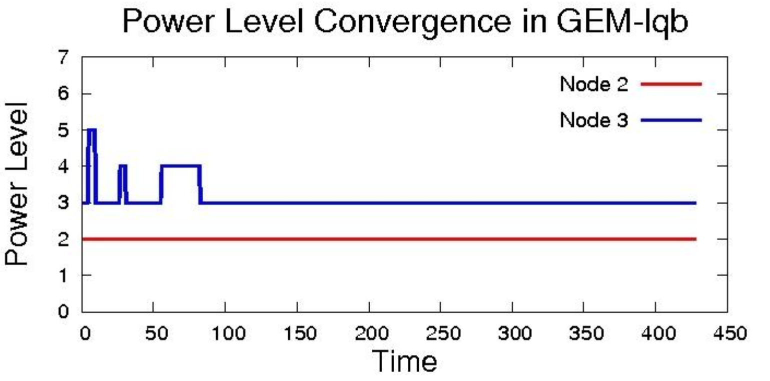
Evaluation GEM-lqb

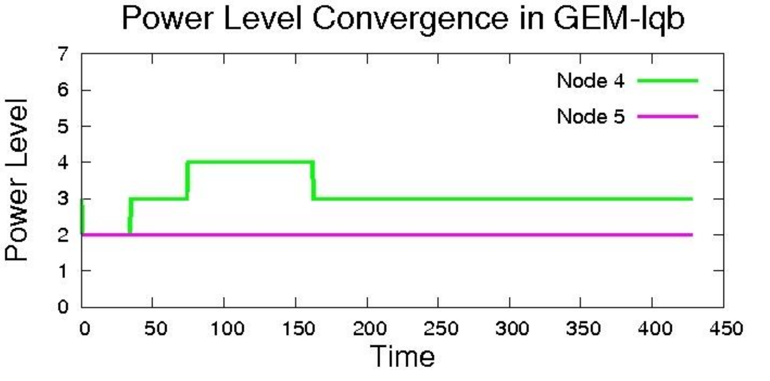


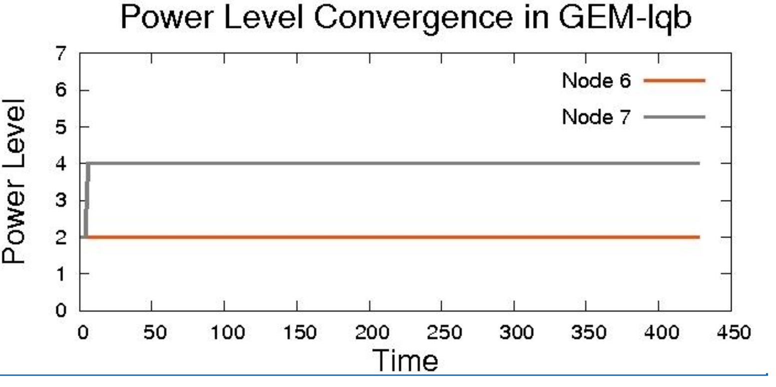
- End-to-end packet success rate
  - LQB policy makes the links to be of a better quality
- Energy Consumption
  - Increase of TPL by some nodes allows to reach the nodes closer to the sink
  - Increase of TPL makes send operation up to 10% more expensive only!

Evaluation GEM-lqb cont.

- Hop Distribution
  - Small changes in TPL decrease the depth of the routing tree
- Route Stability
  - LQB make links be more stable
- Route Maintenance Overhead
  - LQB is based on local information only
- Policy Convergence
  - No changes in TPL after 160s of run
  - In general, convergence of policies not guaranteed
  - Further research needed







Conclusions and Future Work

- The Model
  - Includes other metrics as special cases
- The GEM-metric
  - Based on the model
  - Parameterized
  - Takes energy into account
- Routing Policies
  - Reflect the goal of the application
  - Influence the direction of optimization
- **Future Work**
  - Classification of policies and the extent of their influence on GEM-metric
  - Policy characteristics: convergence, applicability, etc.
  - Integration in existing protocols (routing, aggregation, …)

Thank You for Attention!

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Are there any questions?