QoF: Towards Comprehensive Path Quality Measurement for Wireless Sensor Networks

Jiliang Wang, Yunhao Liu, Mo Li, Wei Dong, Yuan He

香港科技大學 THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Hong Kong University of Science and Technology

NANYANG TECHNOLOGICAL UNIVERSITY

Nanyang Technological University

清華大學 Tsinghua University

Tsinghua University

Outline

- Background
- Motivation
- QoF Design
- Evaluation
- Conclusion

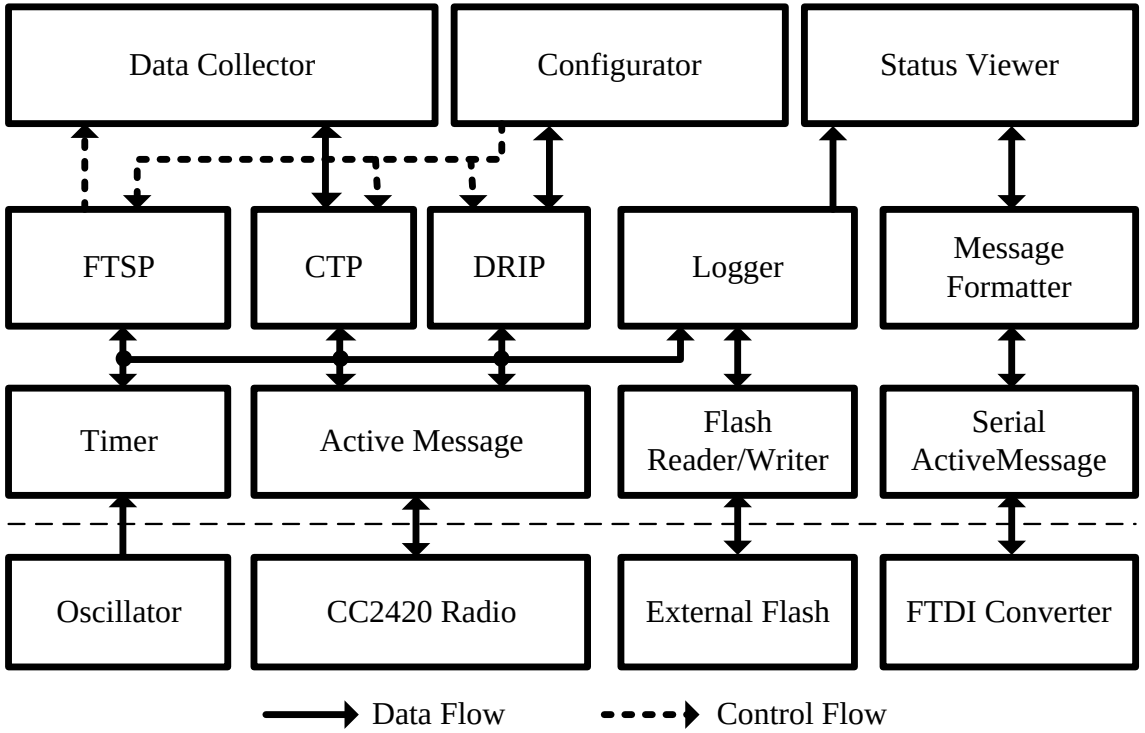
Motivation

- GreenOrbs
  - A large-scale long-term wireless sensor network system in the wild
  - support a variety of forestry applications, such as canopy closure estimates [1], fire risk evaluation, microclimate monitoring, and carbon dioxide measurement.

[1] Lufeng Mo, Yuan He and etc., Canopy Closure Estimates with GreenOrbs: Sustainable Sensing in the Forest. ACM SenSys 2009

Software Architecture

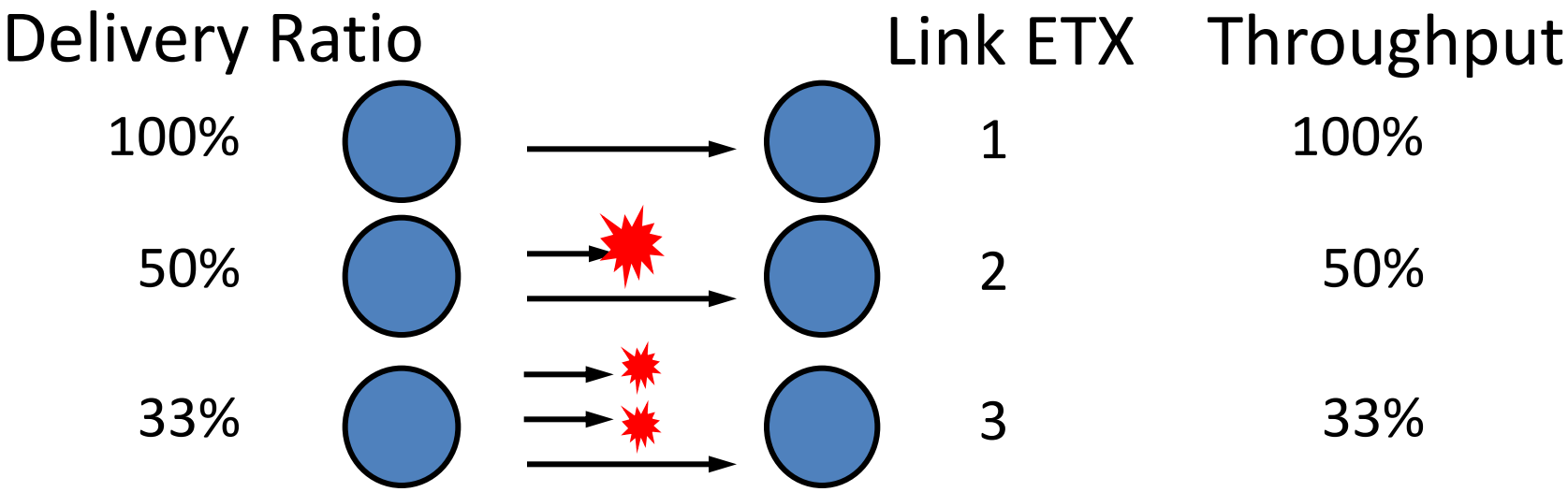
- Software based on TinyOS 2.1.1
  - Low Power Listening
  - Data collection: CTP
  - Parameter dissemination: DRIP



Collection Tree Protocol:CTP

- Minimize total transmissions per packet (ETX[1], 'Expected Transmission Count')

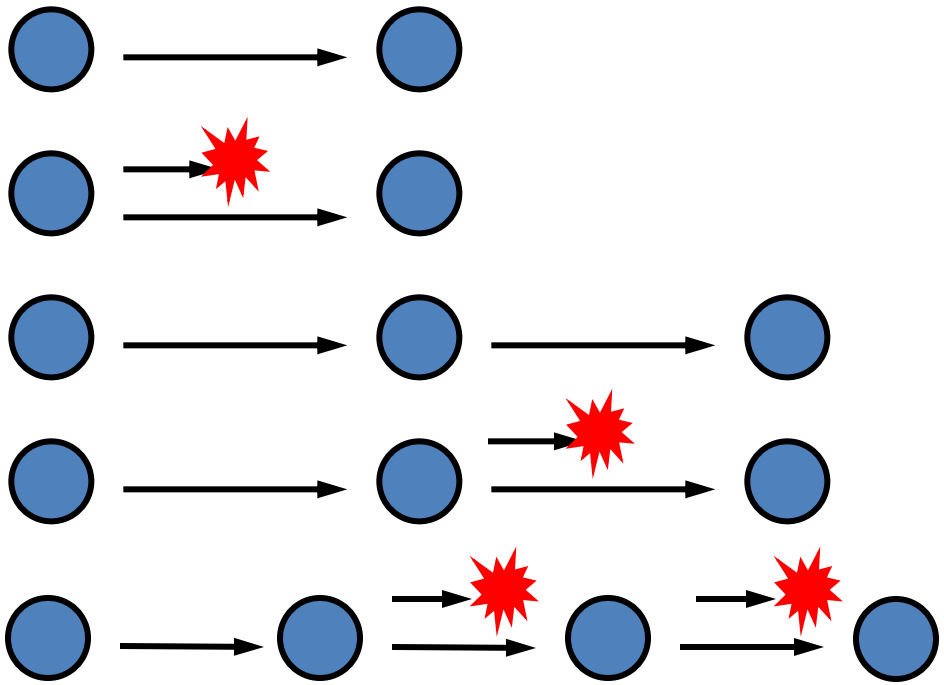
$$\text{Link throughput} \approx 1/\text{Link ETX}$$



[1] Douglas S. J. De Couto, Daniel Aguayo and etc., A HighThroughput Path Metric for MultiHop Wireless Routing. MobiCom 03

Link and Path ETX

Path ETX = Sum of link ETXs



Route ETX	Throughput
1	100%
2	50%
2	50%
3	33%
5	20%

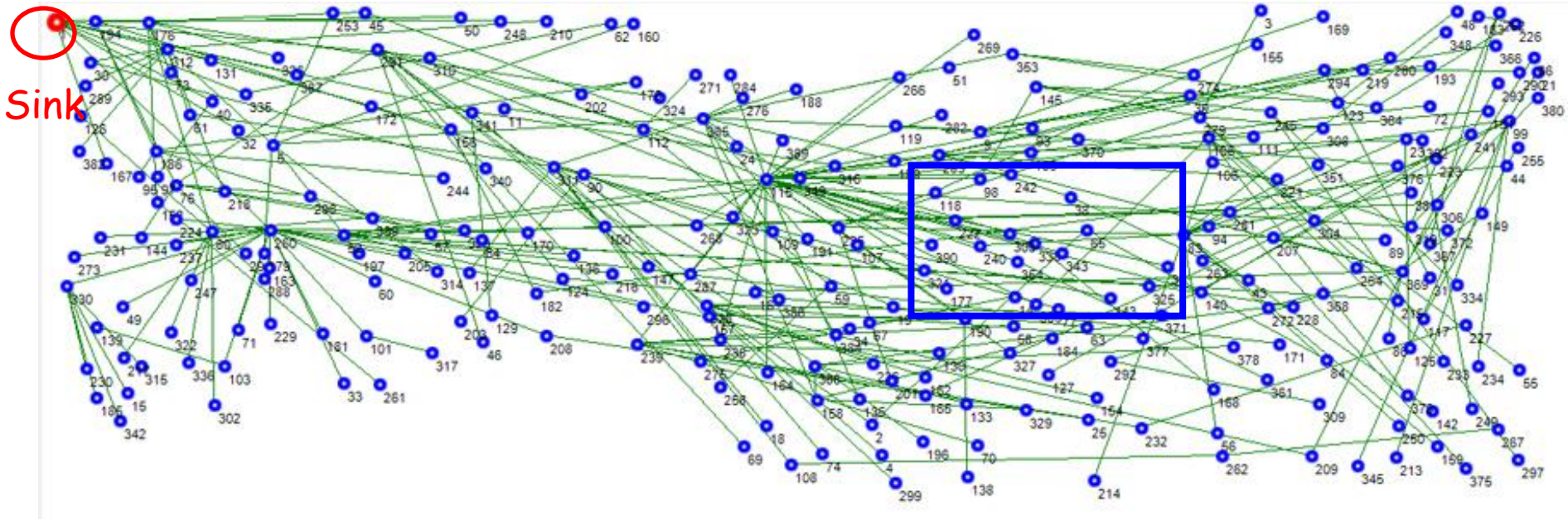
ETX Merits

- ETX predicts throughput for short routes (prefer short routes)
- ETX quantifies packet losses
- ETX quantifies asymmetry

GreenOrbs Topology

- 330-node network topology
- The deployment area is about 40,000 m^2.

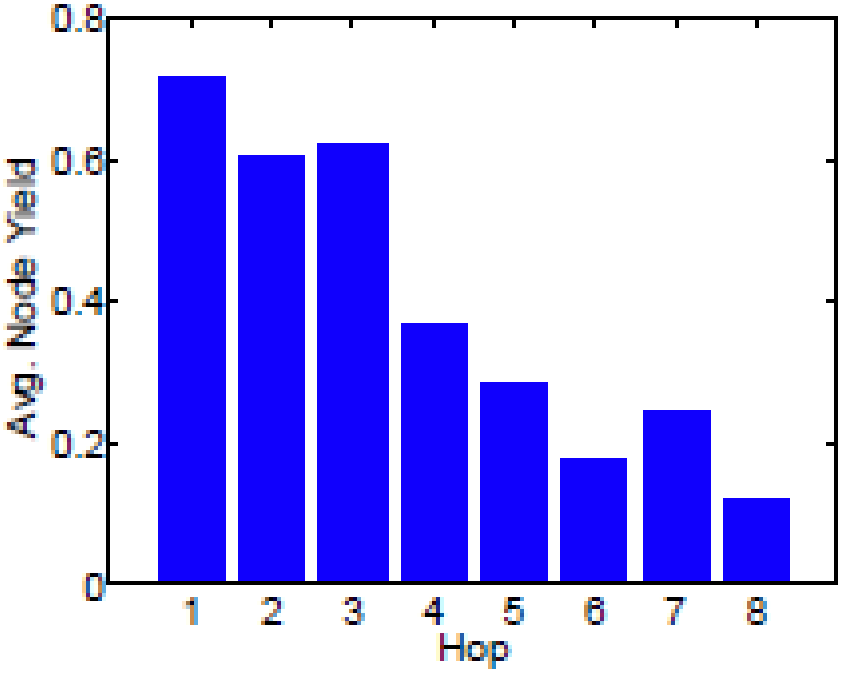
GreenOrbs Topology



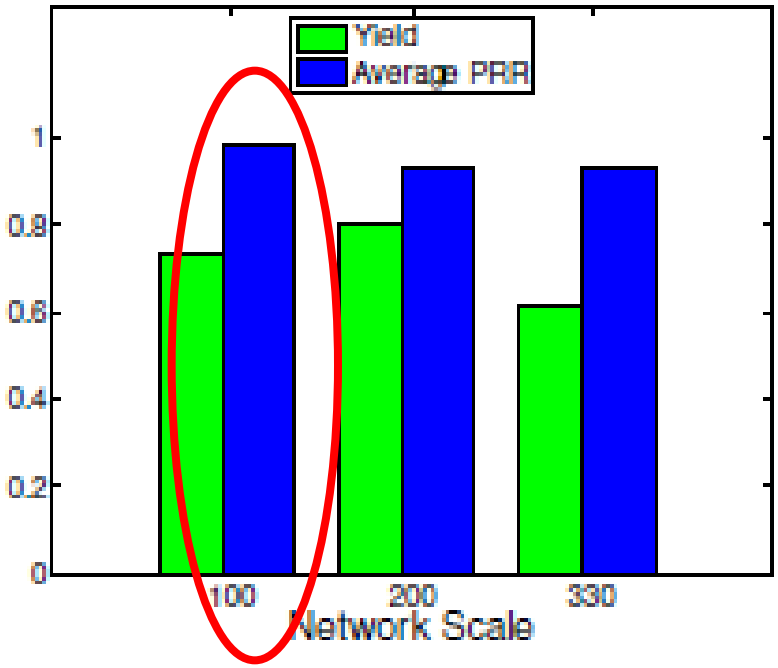
- 330-node network topology
- The deployment area is about 40,000 m^2.

Performance in Early Deployment

Node Yield



Network Yield

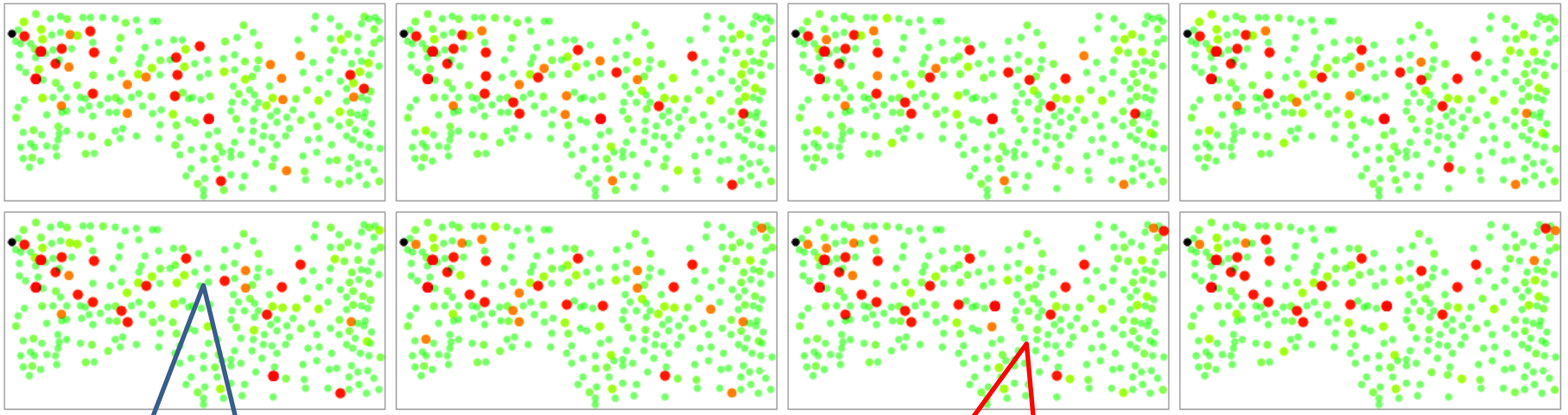


$$yield = \frac{\#\text{ of data pkts received at the sink during } w}{\#\text{ of data pkts sent by all nodes during } w}$$

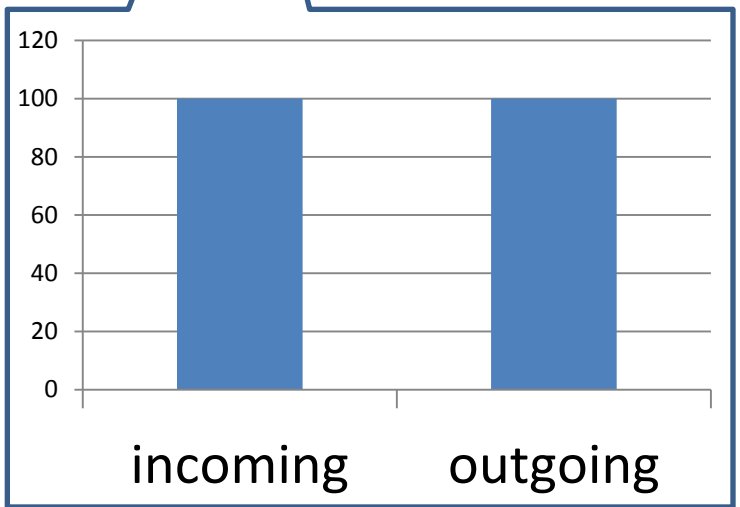
Why unexpected performance?

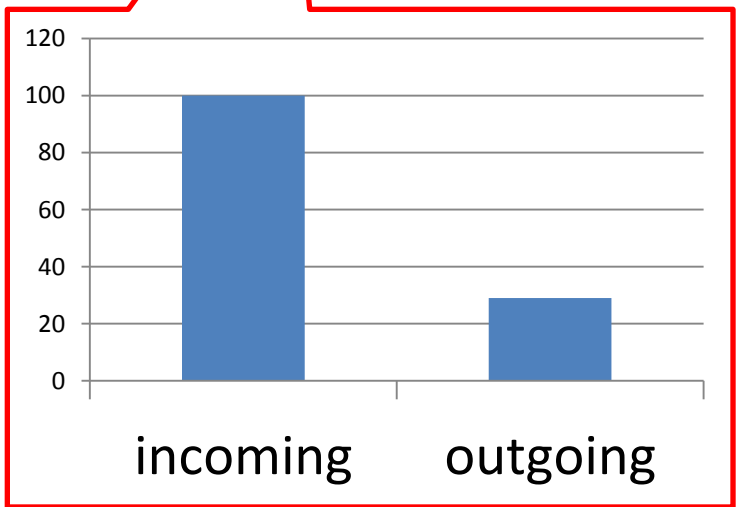
Observation 1

- Traffic distribution



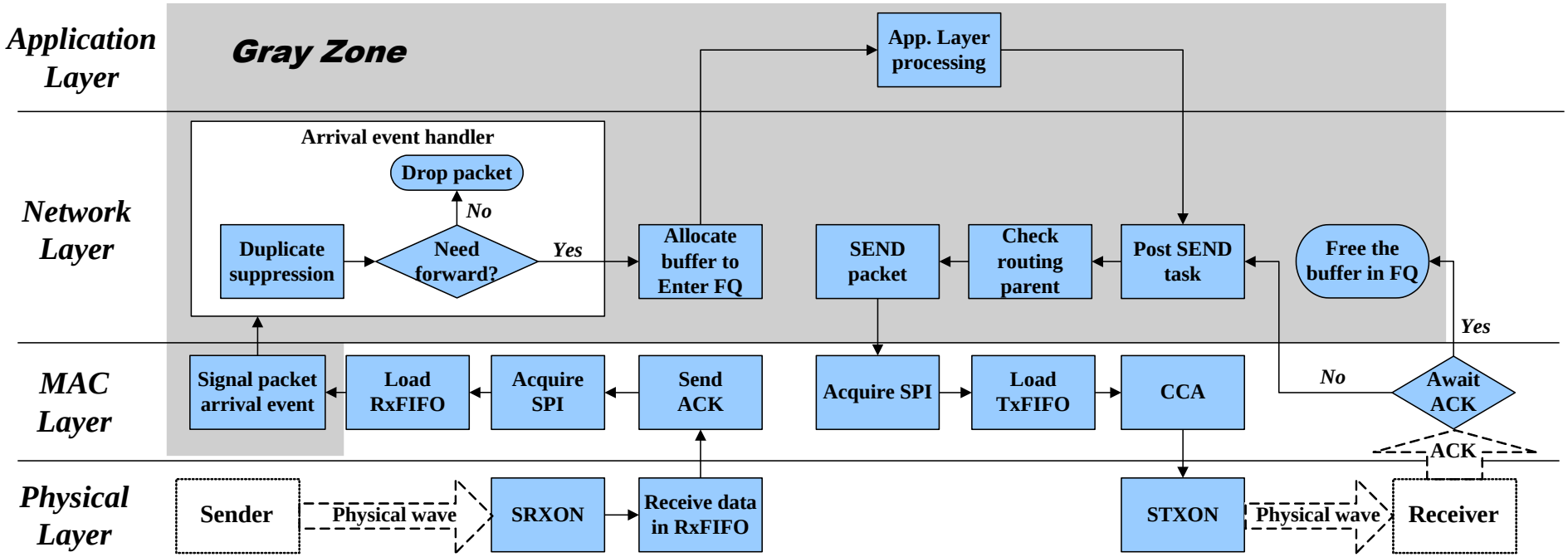
Red dots denote nodes that carry a lot of traffic.





Observation 1

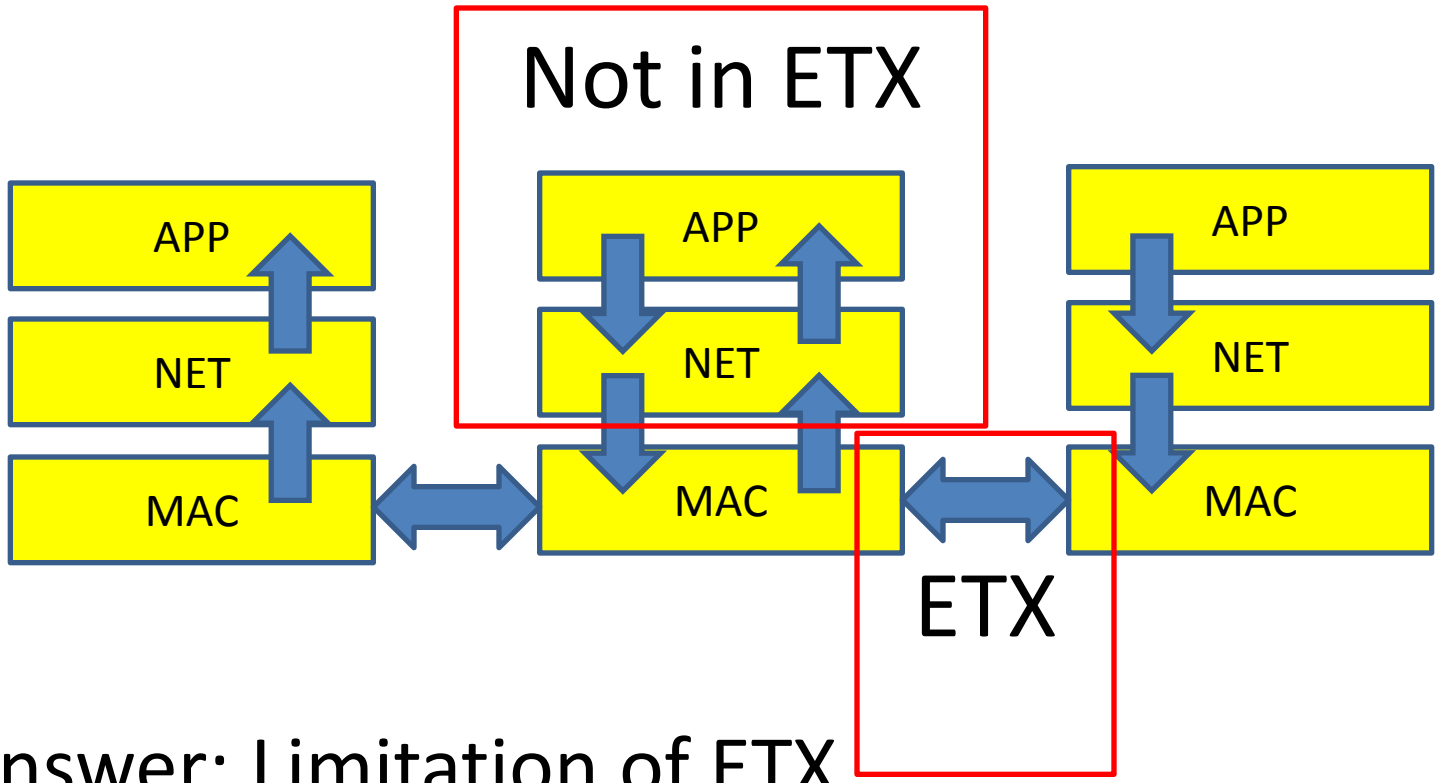
- Why packets are lost?



- Grey Zone indicates the area where packets may get lost

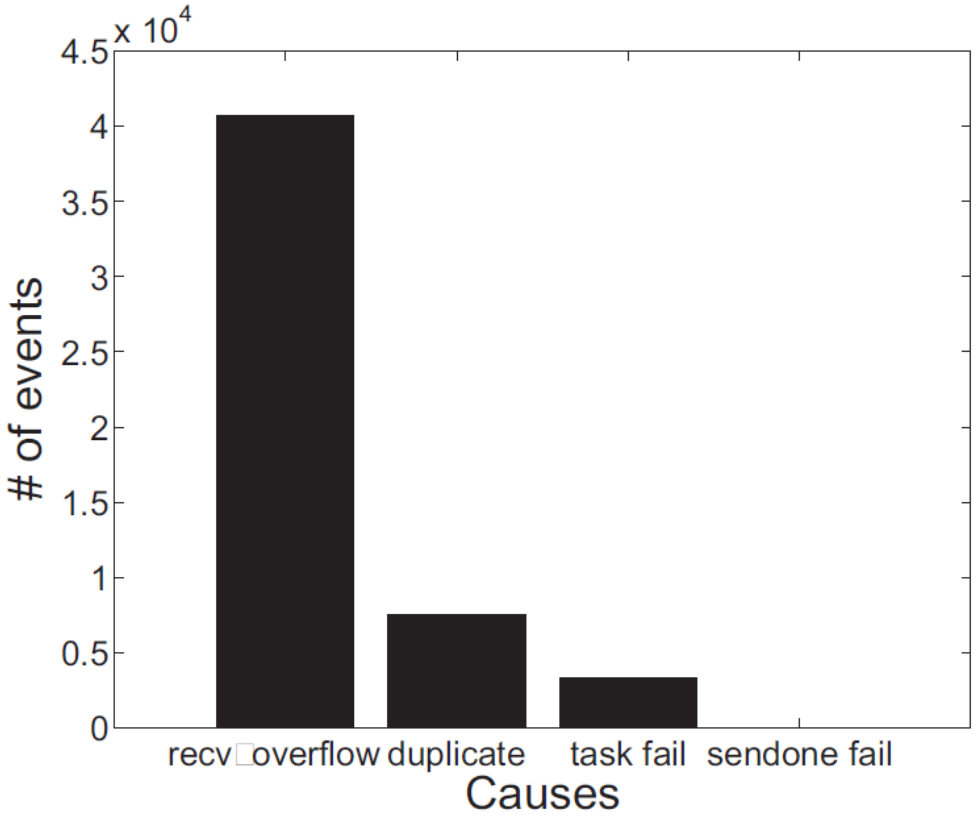
Observation 1

- Why those nodes are still used in CTP?



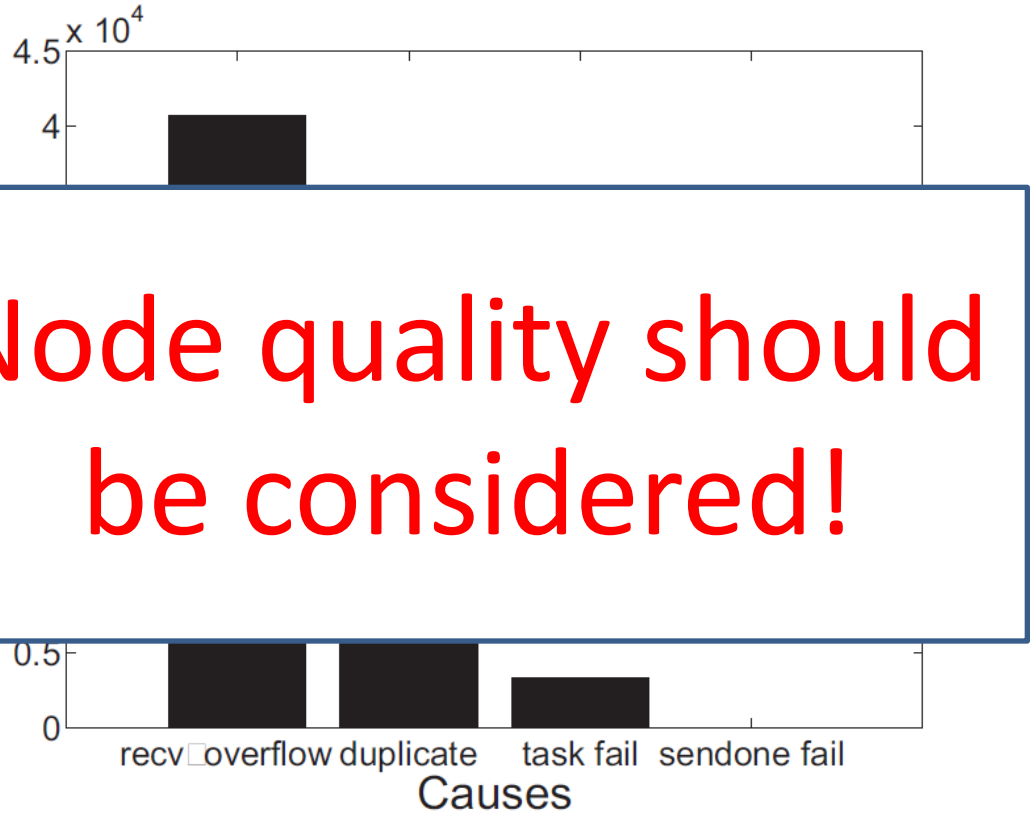
- Answer: Limitation of ETX

Observation 1



Causes of packet loss on sensor nodes

Observation 1

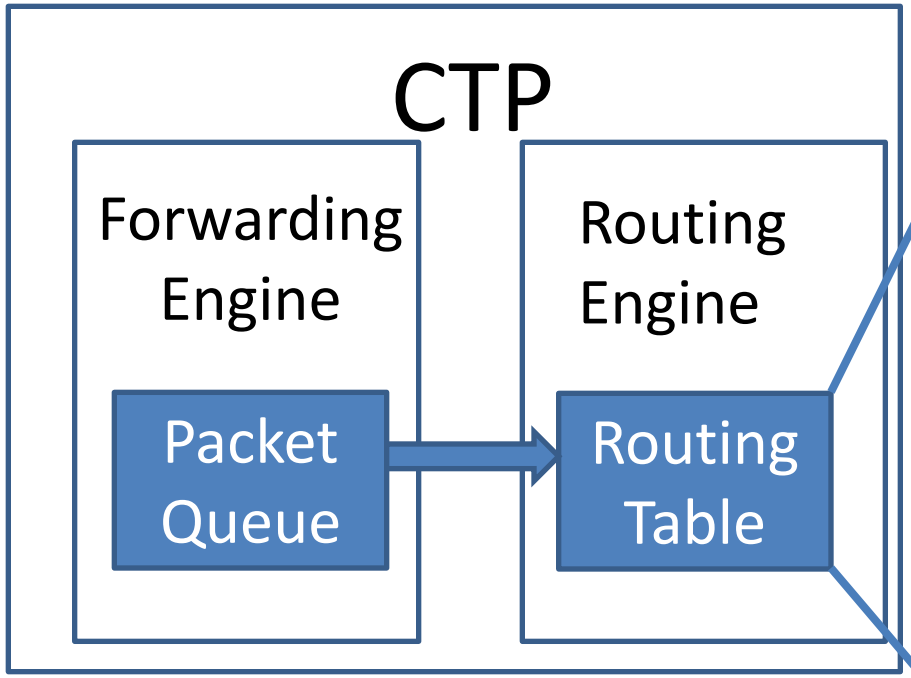


Node quality should be considered!

Causes of packet loss on sensor nodes

Observation 2

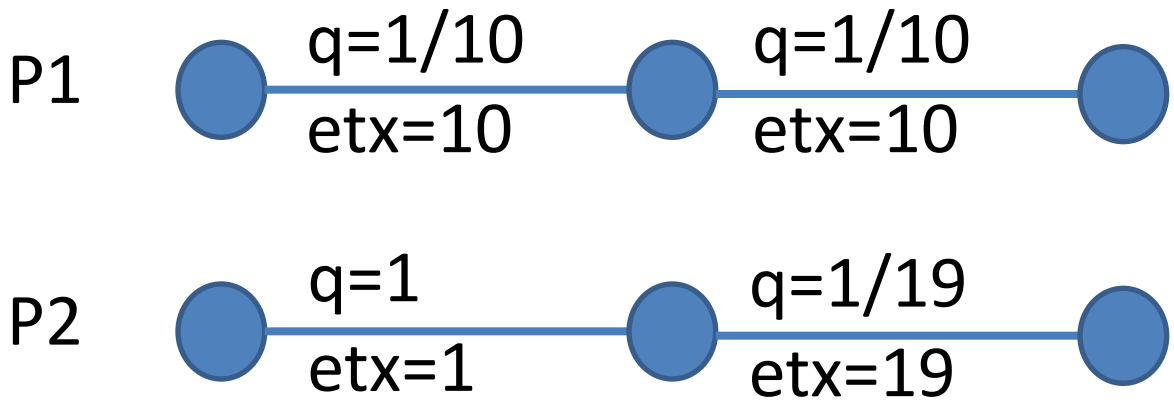
- CTP mechanism



Neighbor ID	ETX
1	100
2	50
3	20
4	20
…	…

Observation 2

1900 packets sent from the source

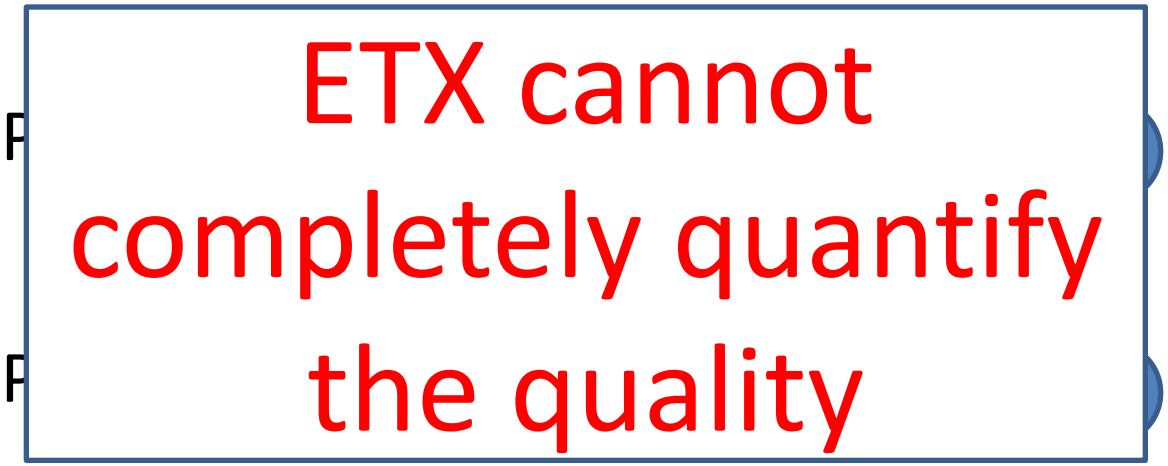


P1: 19 packets received in expectation

P2: 100 packets received in expectation

Observation 2

1900 packets sent from the source

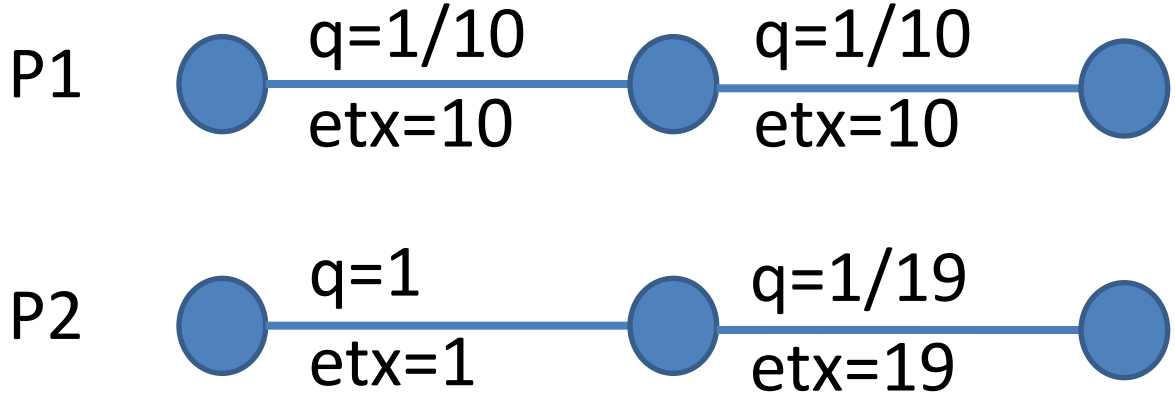


P1: 19 packets received in expectation

P2: 100 packets received in expectation

Observation 3

- Impact of retransmission threshold
- We measure the Packet Reception Ratio (PRR)



- r=1: PRR(P1) = 1/100, PRR(P2)=1/19
- r=30: PRR(P1) = PRR(P2) = 1

Observation 3

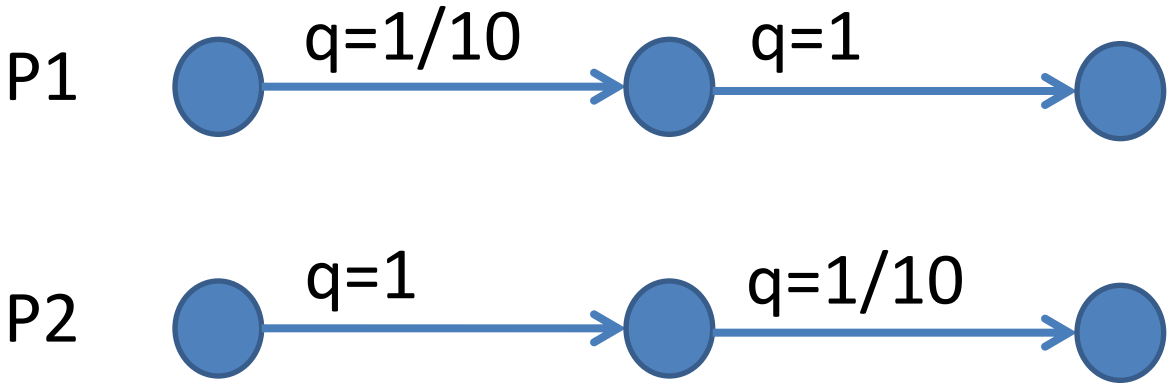
- Impact of retransmission threshold
- We measure the Packet Reception Ratio (PRR)

Retrans threshold matters

- r=1: PRR(P1) = 1/100, PRR(P2)=1/19
- r=30: PRR(P1) = PRR(P2) = 1

Observation 4

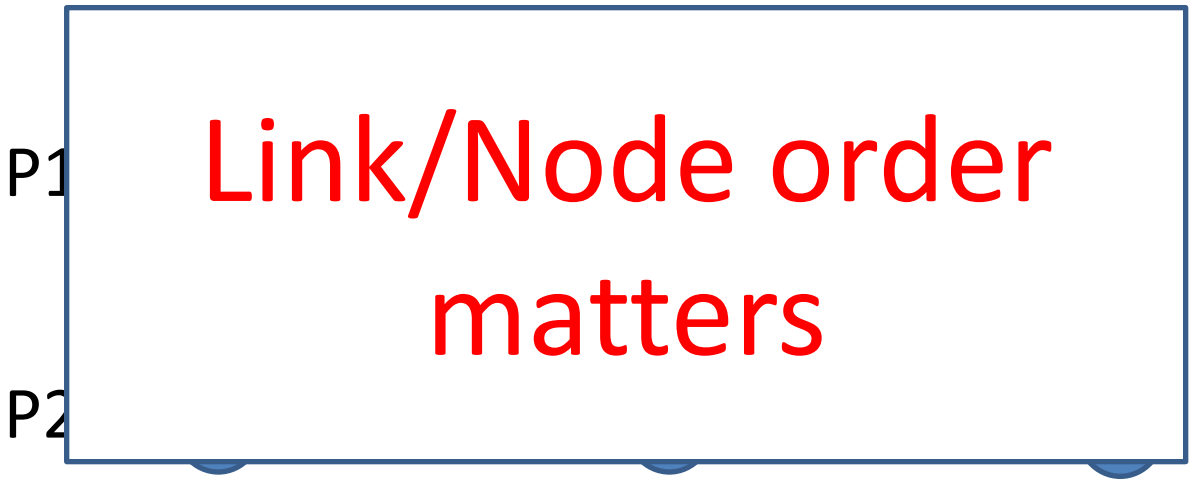
- Link and node order?



- Cost more if a packet lost near the sink after a long journey.

Observation 4

- Link and node order?

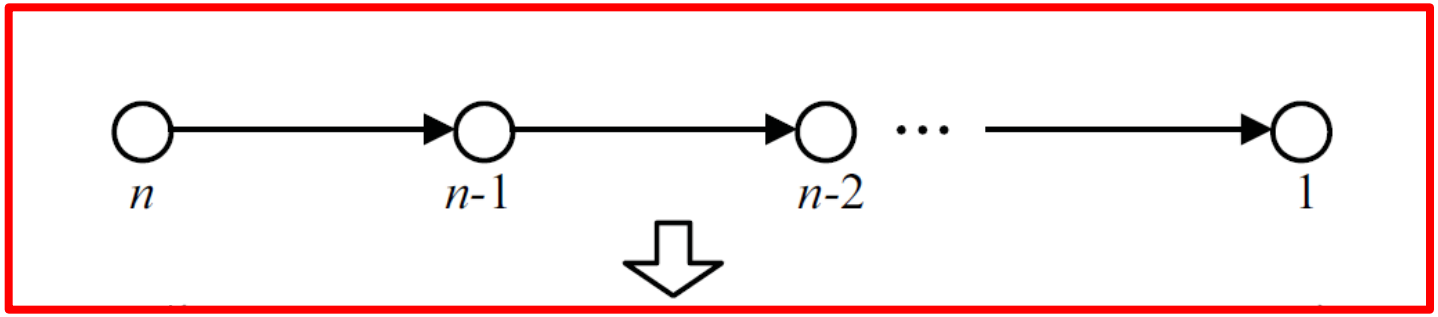


- Cost more if a packet lost near the sink after a long journey.

Outline

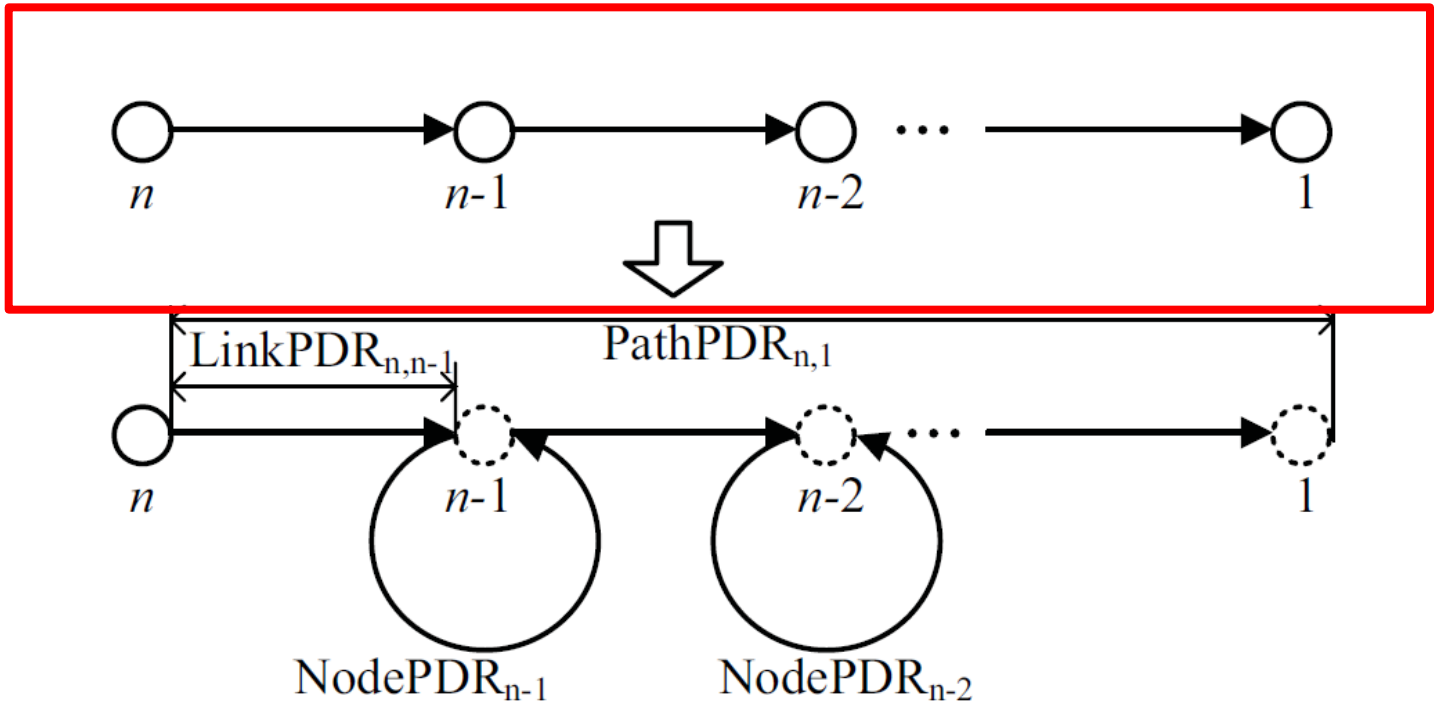
- Background
- Motivation
- QoF Design
- Evaluation
- Conclusion

QoF Model



- Path = link + link +…
- Path = link + node + link+…

QoF Model



- Path = link + link +…
- Path = link + node + link+…

Measuring link PDR and ETC

- Packet Delivery Ratio (PDR)
  - For a node, PDR = *outCtr* / *inCtr*
  - For a link, PDR=1-(1-*q*)$^{r+1}$, *q* is link quality, *r* is retransmission limit
- Expected Transmissions (ETC)
  - The number of expected transmissions for any packet, under the retransmission limit of *r*

$$\mathrm{ETC} = \sum_{k=1}^{r} kq(1-q)^{k-1} + r(1-q)^{r} = \frac{1-(1-q)^{r+1}}{q}$$

QoF: Quality of Forwarding

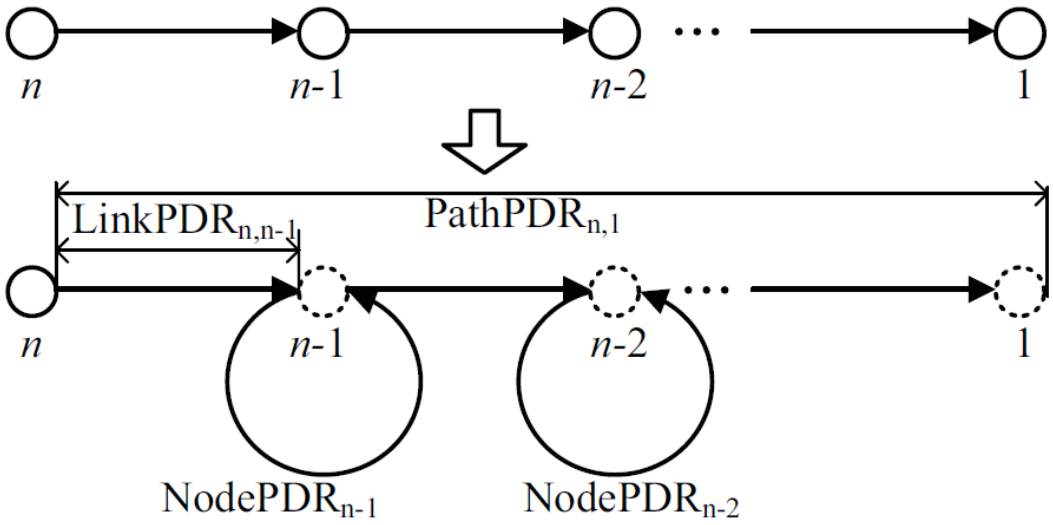
- QoF^{-1}: the expected transmission count for a successful end-to-end transmission on a path.

$$\text{QoF}=\frac{x\times PDR}{x\times ETC}=\frac{PDR}{ETC}$$

QoF: the expected successful end-to-end transmission for a transmission count.
QoF is in the range of [0 1].

QoF: Quality of Forwarding

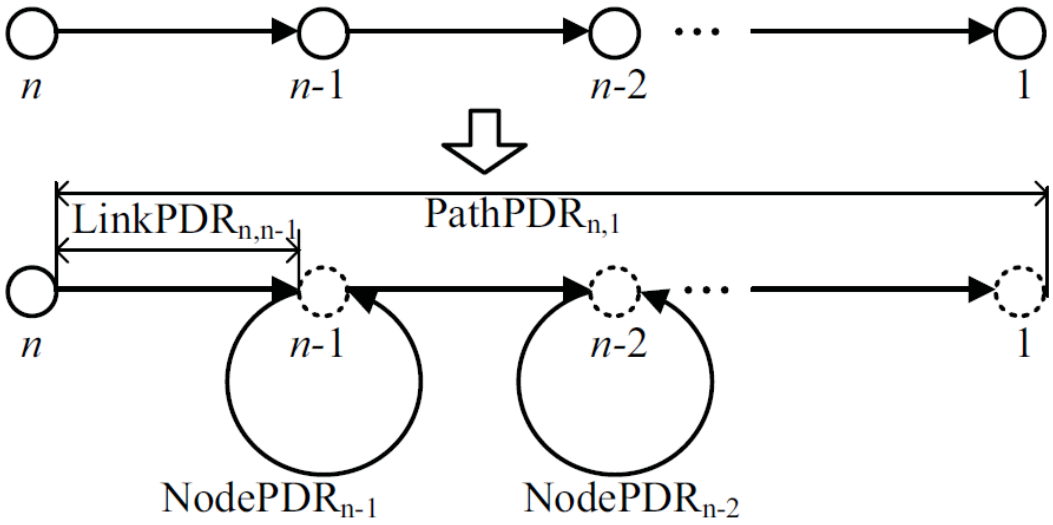
- QoF^{-1}: the expected transmission count for a successful end-to-end transmission on a path.
- PDR: packet delivery ratio



$$PDR_{n->1} = PDR_{n,n-1} \times PDR_{n-1,1.} \times PDR_1$$

QoF: Quality of Forwarding

- QoF^{-1}: the expected transmission count for a successful end-to-end transmission on a path.
- PDR: packet delivery ratio

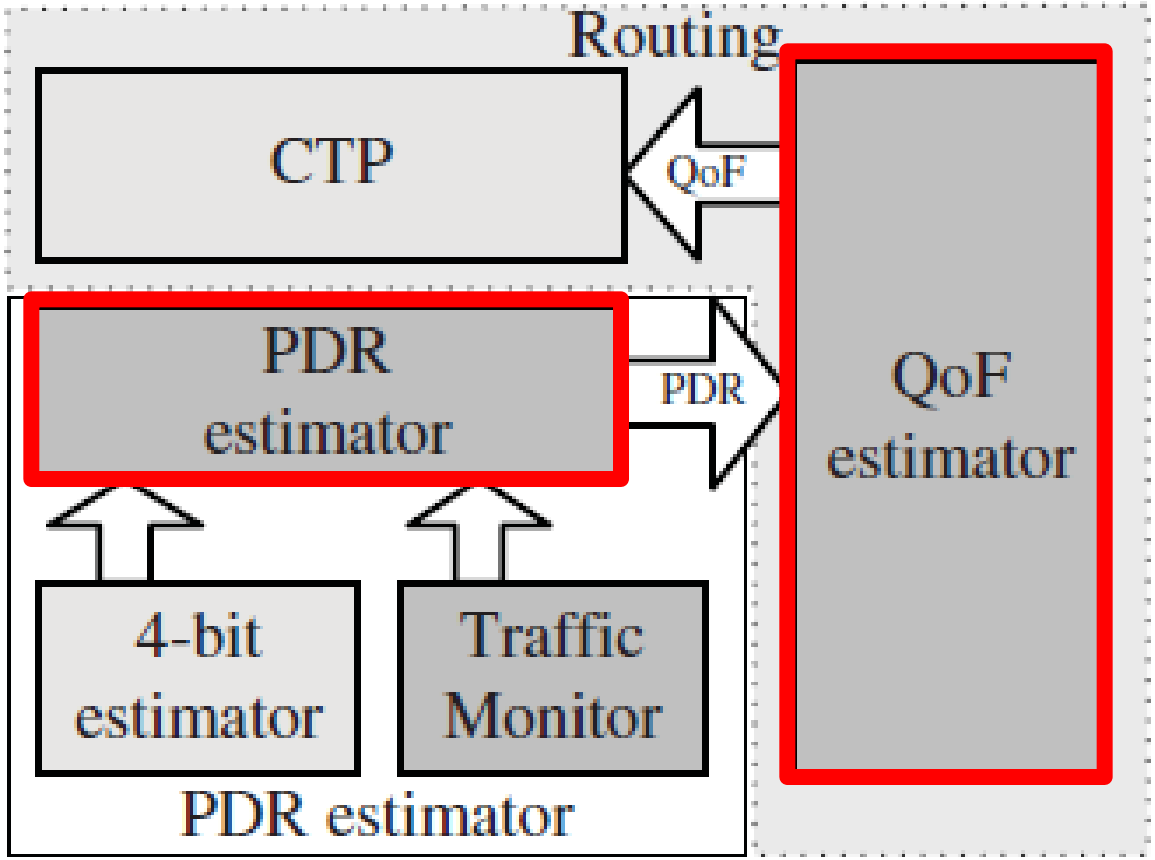


$$PDR_{n->1} = PDR_{n,n-1} \times PDR_{n-1,1.} \times PDR_1$$

$$QoF_n = \frac{PDR_{n->1}}{ETC_{n,n-1} + \frac{PDR_{n->1}}{QoF_{n-1}}}$$

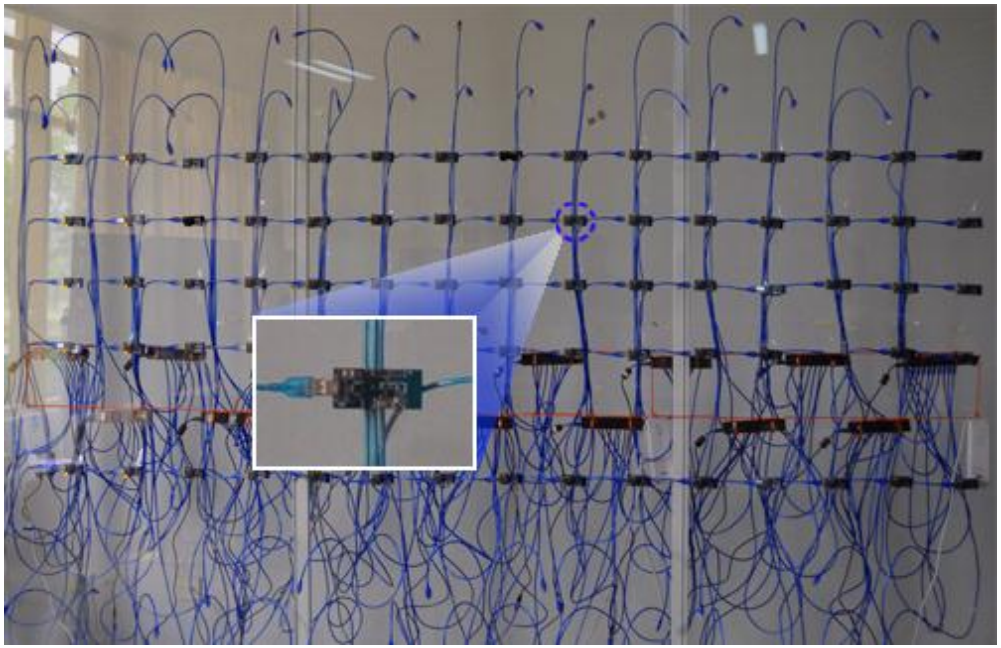
Implementation

- Integrating QoF with CTP in TinyOS



Evaluation

- GreenOrbs test-bed
  - Experiments with 50~150 nodes



Evaluation Settings

- Two settings:
  - Case I: streaming application case.

    retrans threshold = 1,

    transmission frequency = 3Hz.
  - Case II: real-world deployment case.

    retrans threshold = 30,

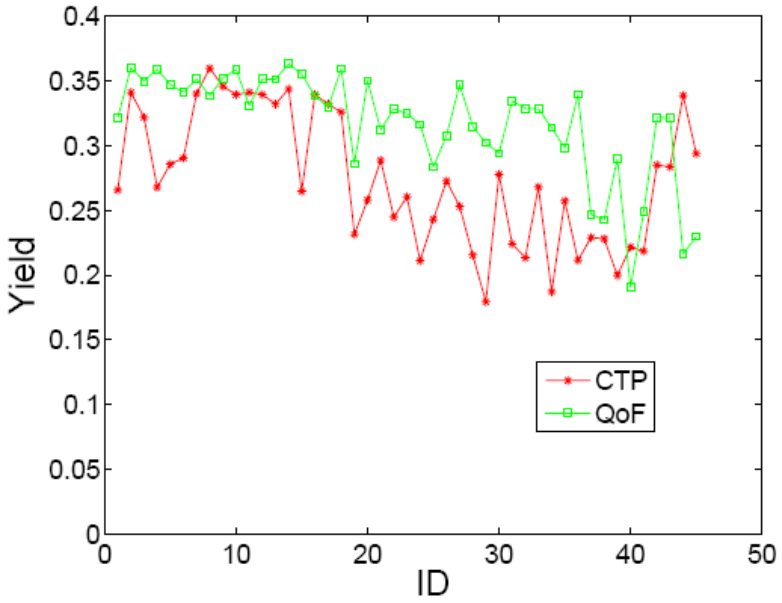
    transmission frequency = 3Hz,

    We use an old version program of GreenOrbs,

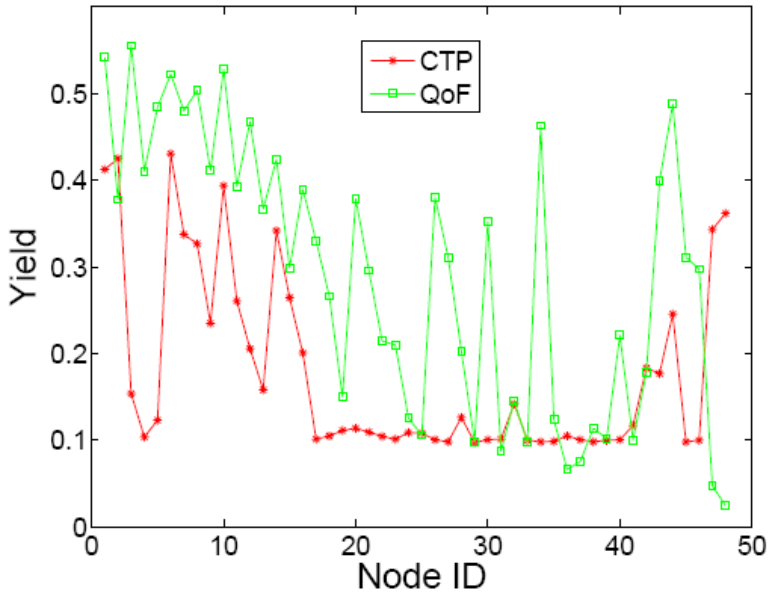
    which has a bug resulting in some “problematic” nodes.

Evaluation

- Data yield: the percentage of successfully received packets at the sink



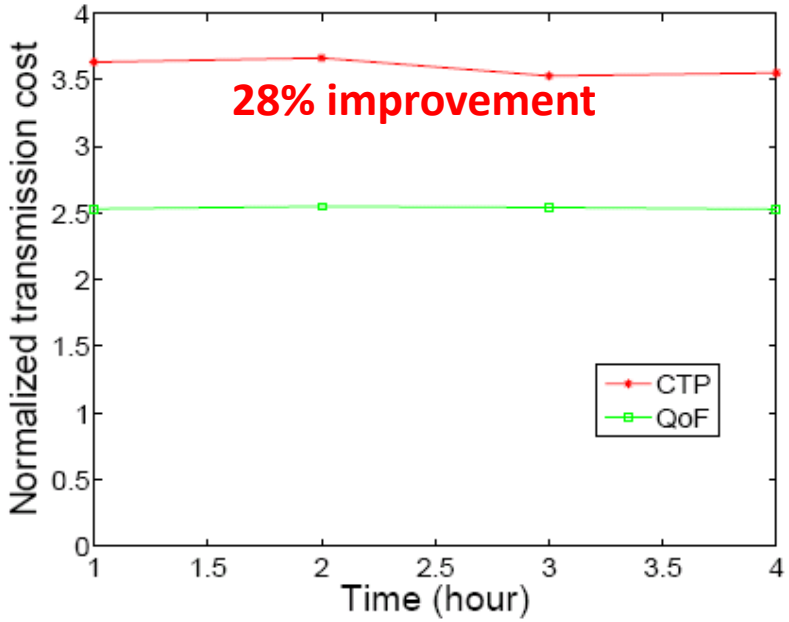
Case I: High traffic pressure and low retransmission threshold (*r*=1)



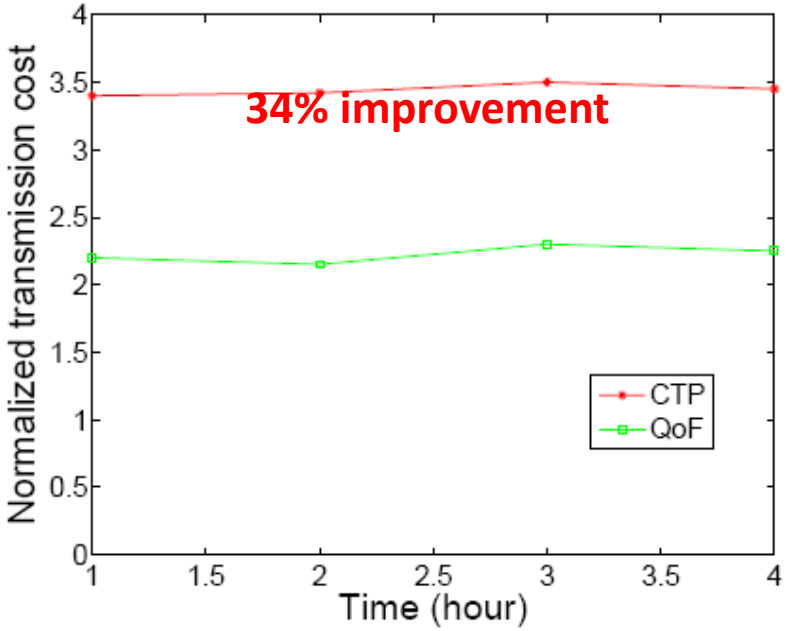
Case II: When faulty nodes are present & *r*=30

Evaluation (cont.)

- Average number of transmissions for a successful end-to-end delivery



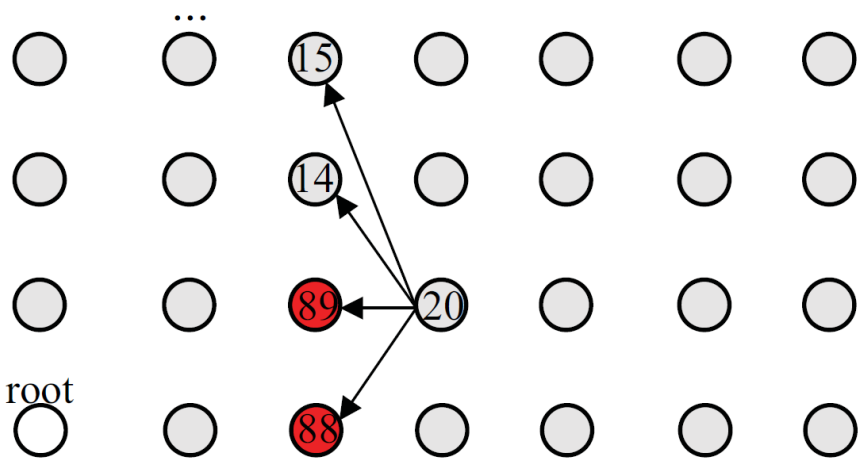
Case I: High traffic pressure and low retransmission threshold (*r*=1)

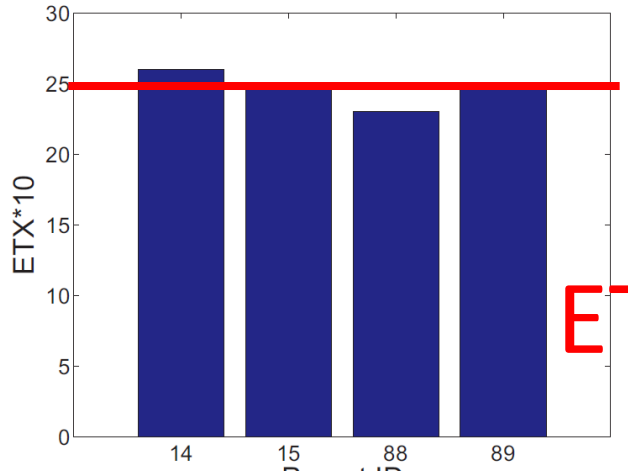


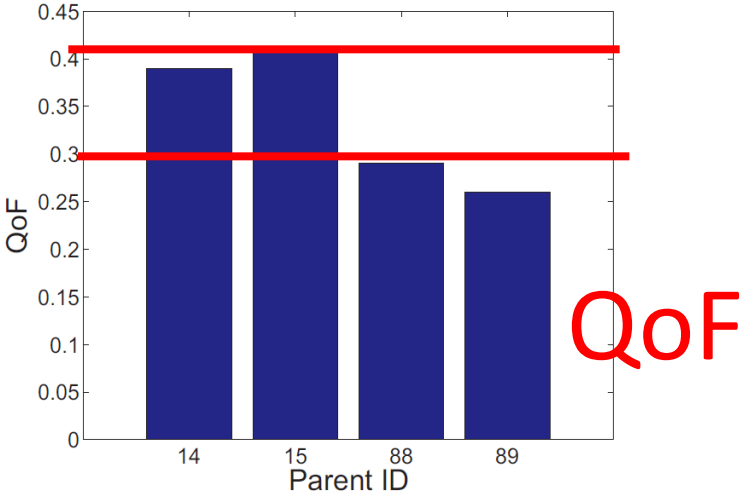
Case II: When faulty nodes are present & *r*=30

Evaluation

- Routing behavior of CTP(+ETX) vs. QoF

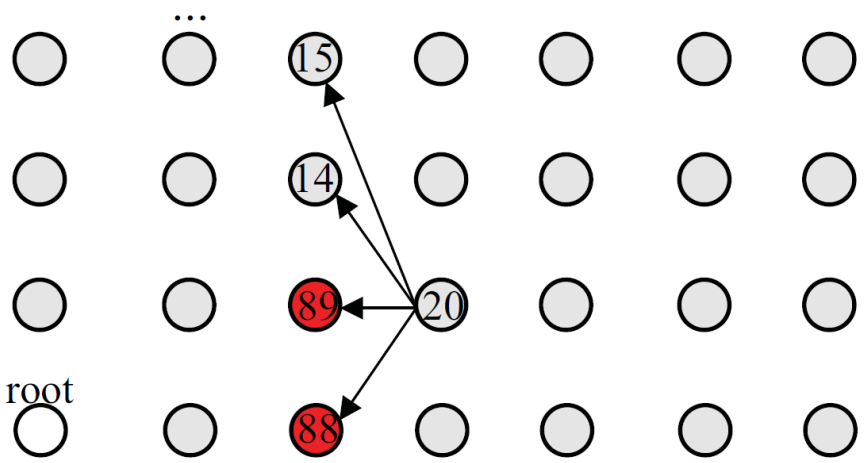


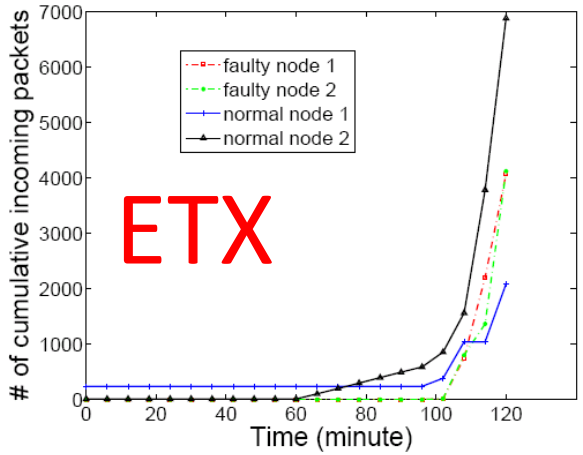


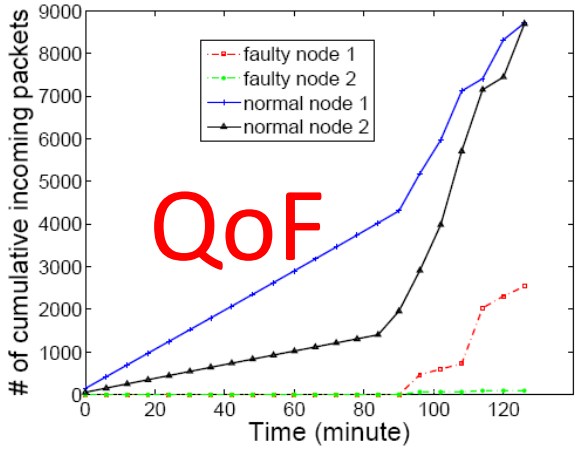


Evaluation

- Routing behavior of CTP(+ETX) vs. QoF







Conclusion

- We measure practical performance of ETX in a large scale sensor networks in the wild.
- We find the limitation of state-of-the-art metric.
- We propose the QoF design that comprehensively measure the path quality.

Thanks

Jiliang Wang
aliang@cse.ust.hk