Exploring Link Correlation for Efficient Flooding in Wireless Sensor Networks

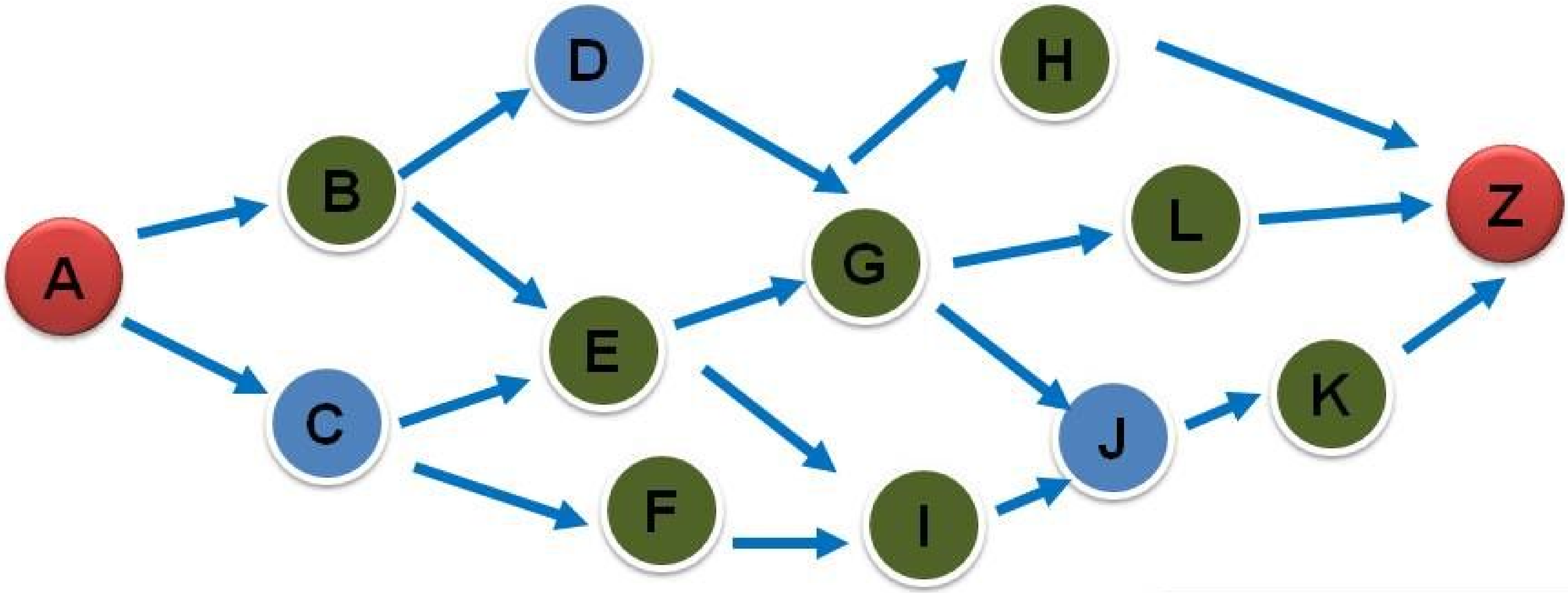
Ting Zhu, Ziguo Zhong, Tian He, Zhi-Li Zhang

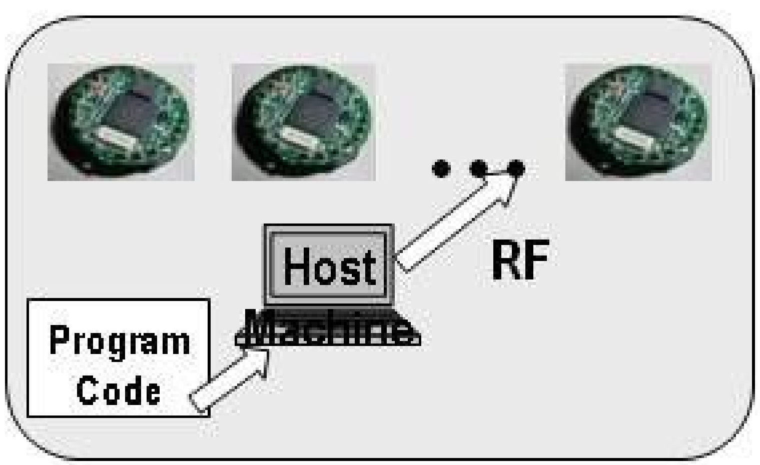
Minnesota Embedded Sensor Systems

Department of Computer Science and Engineering

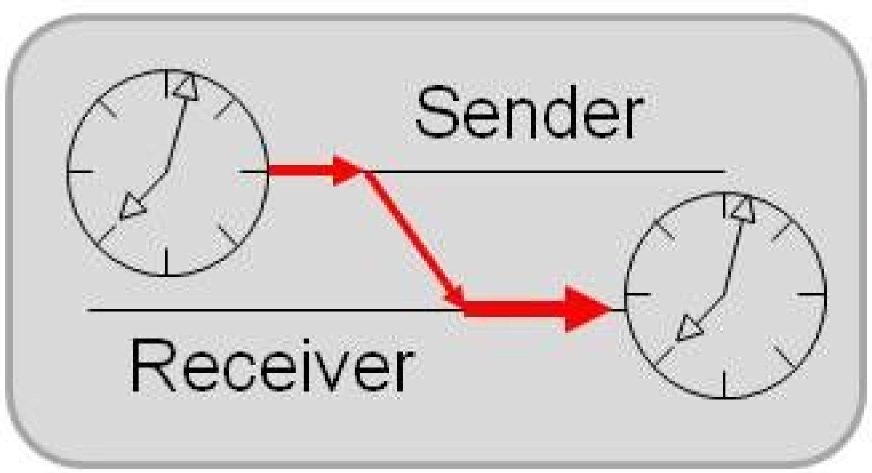
University of Minnesota

Background

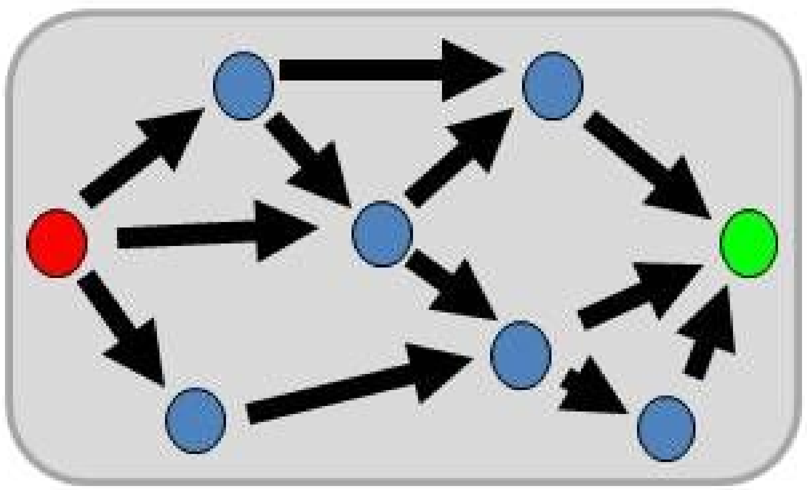




Network Programming



Global Time-Sync



Routing Tree Formation

Design Challenges & The State of the Art

- Design challenges
  - Provide high reliability using unreliable wireless links
  - Reduce the number of redundant retransmissions
- Deterministic approaches

  Dominating Set (MobiHoc '02), DCB (INFOCOM '04), Sprinkler (RTSS '05)
- Probabilistic approaches

  Predefined prob (MobiCom '99), Gossip-based (ICDCS '01), RBP (SenSys '06)

Assumption: Packet receptions are independent

Empirical Study: Packet receptions are correlated!

Reduce redundant retransmissions

High reliability

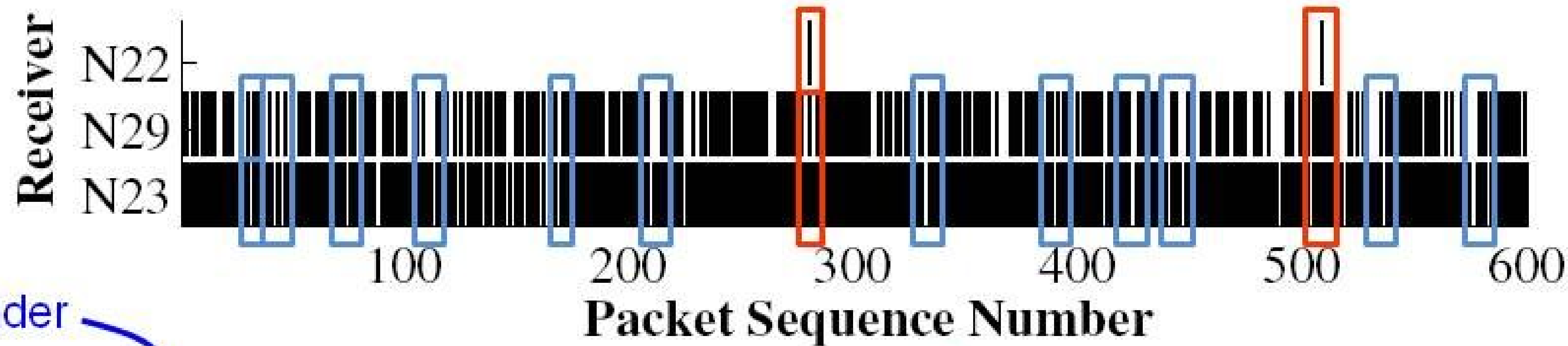
Measurement of Link Behavior

Indoor

Outdoor

- Experiment setup
  - Hardware: 42 MICAz motes
  - Number of packets: 6000

Correlated Packet Reception

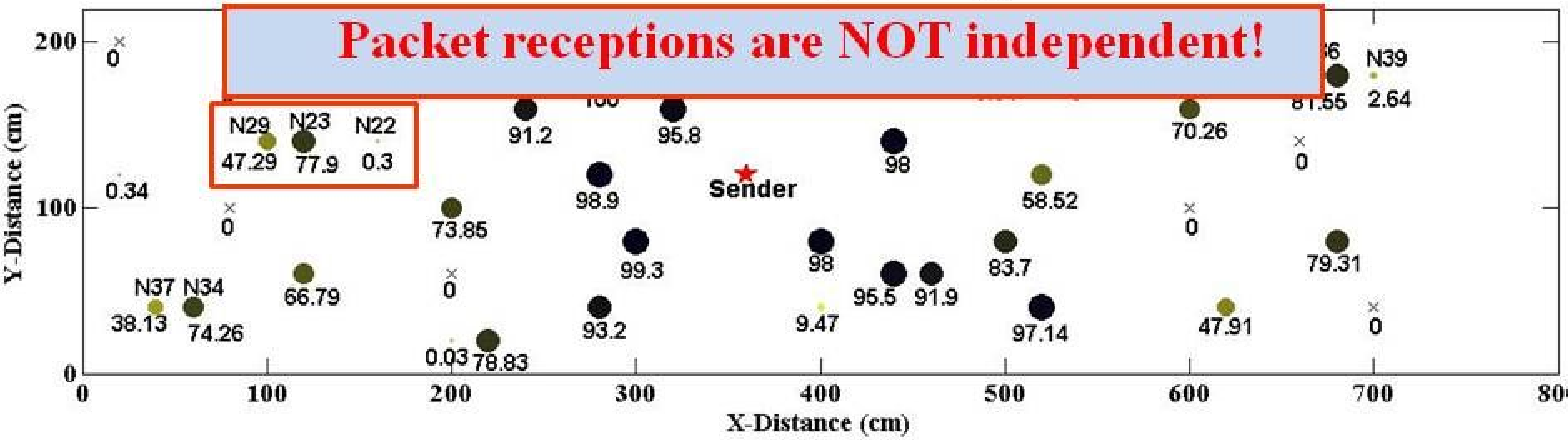


Sender

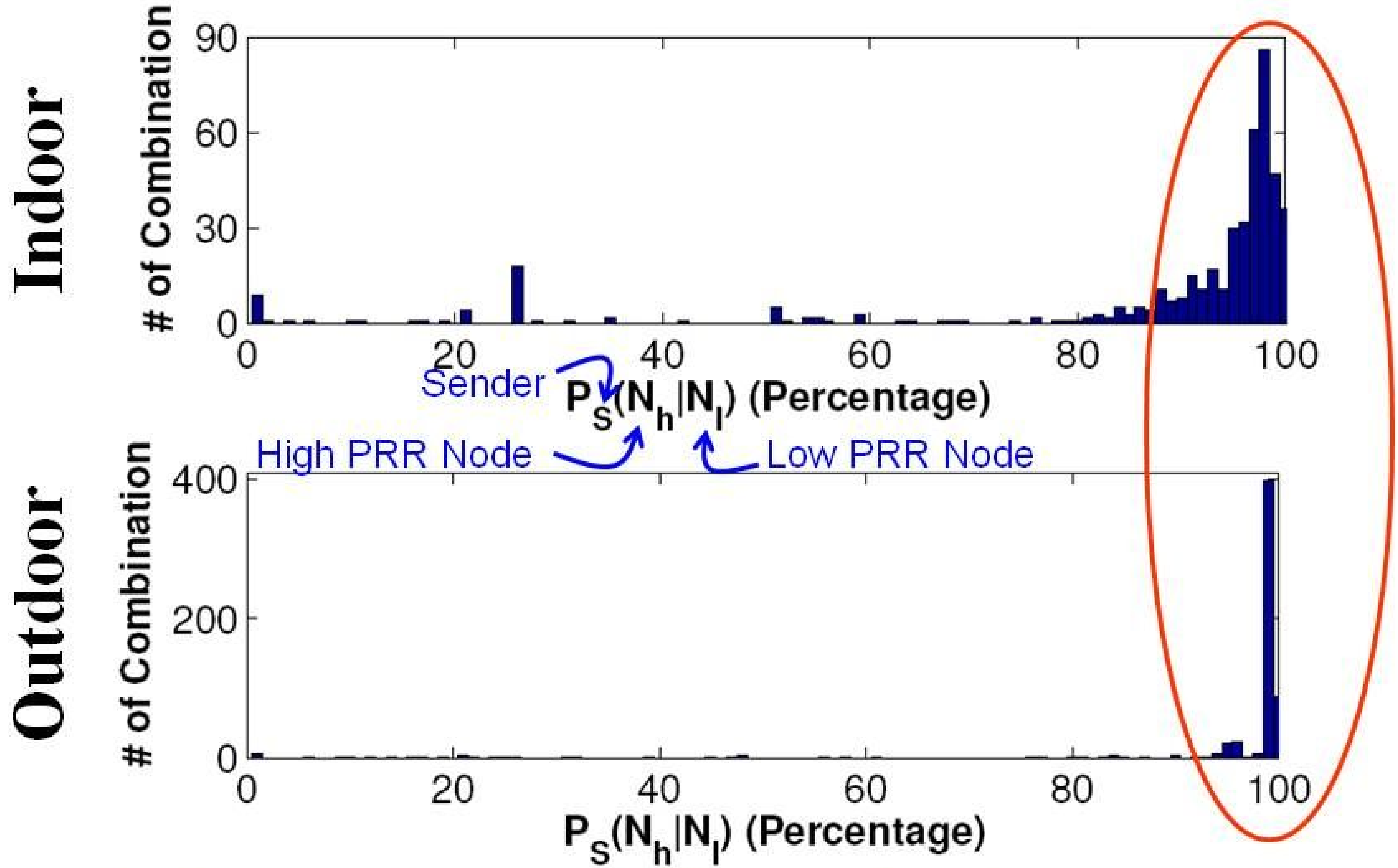
$$P_S(N29 \mid N22) = 100\% \neq P_S(N29) = 47.29\%$$

$$P_S(N23 \mid N22) = 100\% \neq P_S(N23) = 77.9\%$$

Packet receptions are NOT independent!



Distribution of $P_S(N_h|N_l)$



Packet receptions are highly correlated among receivers!

Principle Design Challenge

How to utilize the highly correlated packet receptions?

Collective acknowledgement (CA)

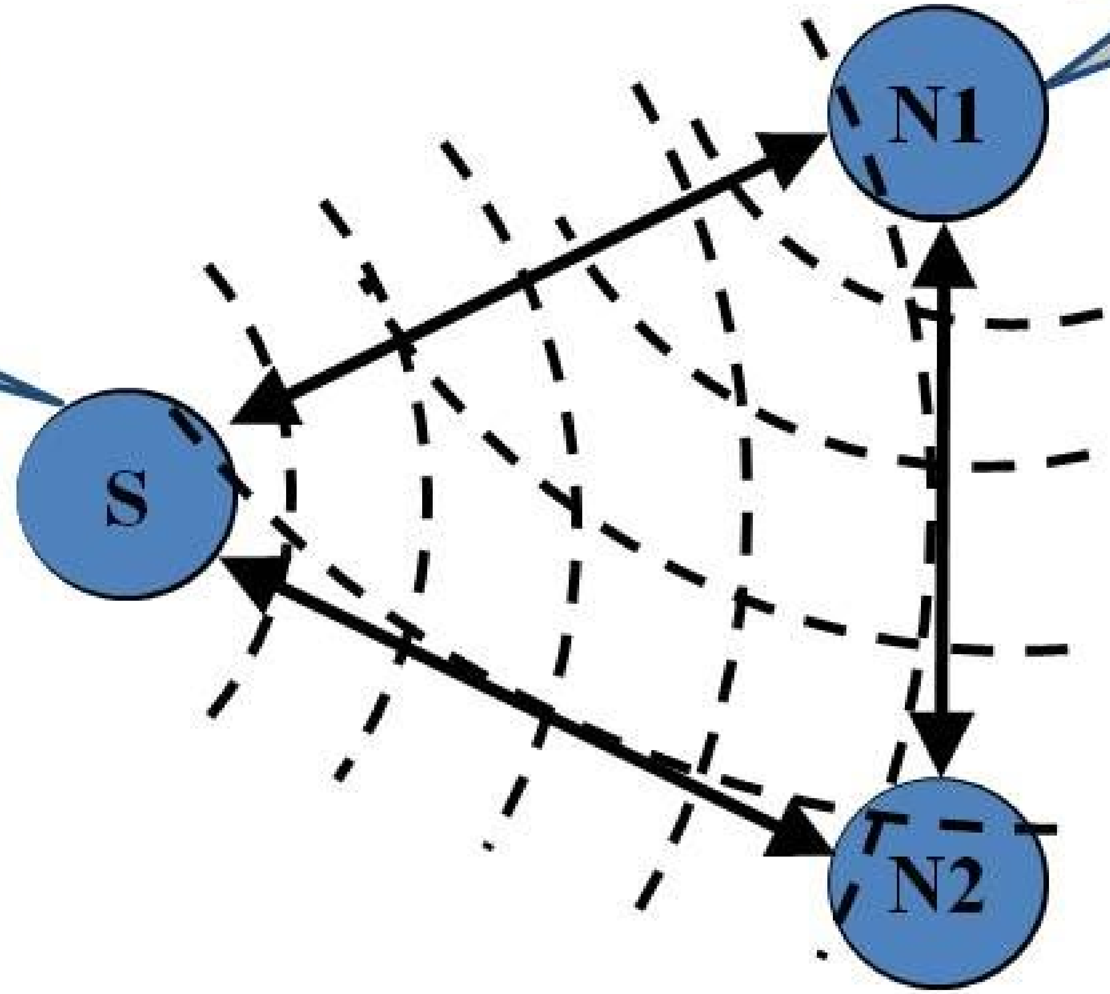
Dynamic Forwarder Selection

… details in the paper!

Traditional Reliable Flooding

Node	Covered
N1	Yes
N2	?

Node	Covered
S	Yes
N2	?



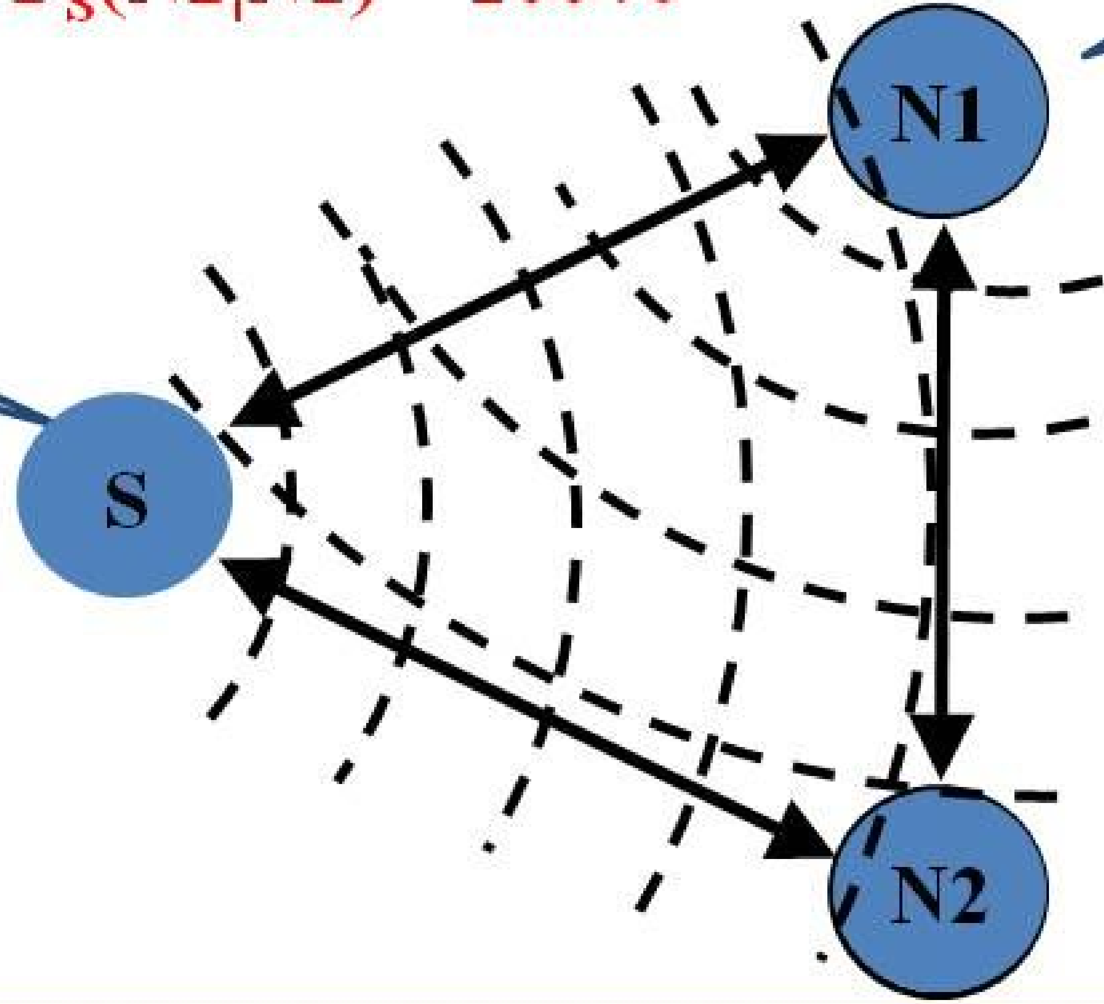
CA: Utilizing Link Correlation

Conditional Packet Reception Probability

$$P_S(N2|N1) = 100\%$$

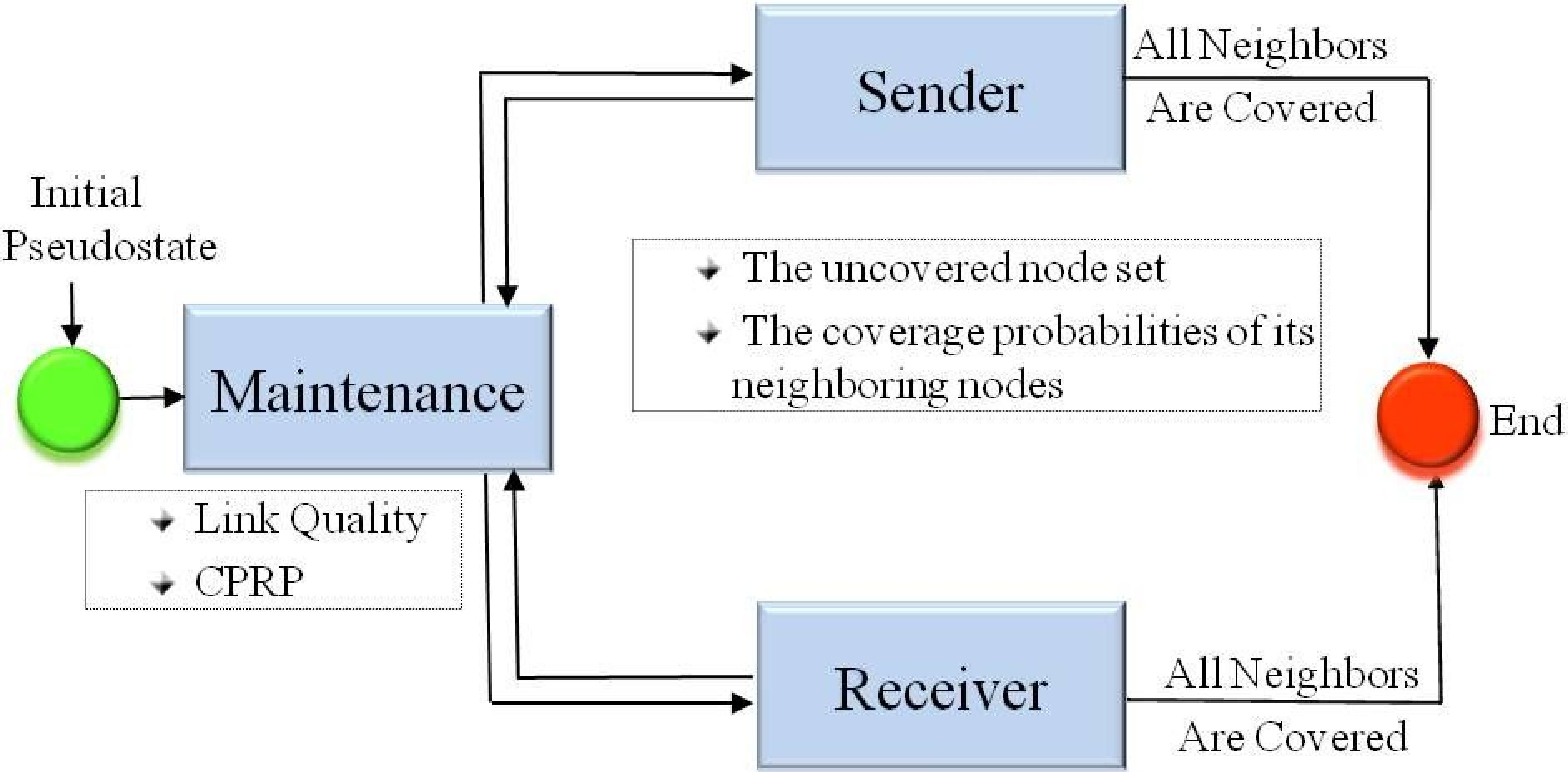
Node	Covered
N1	Yes
N2	Yes

Node	Covered
S	Yes
N2	Yes



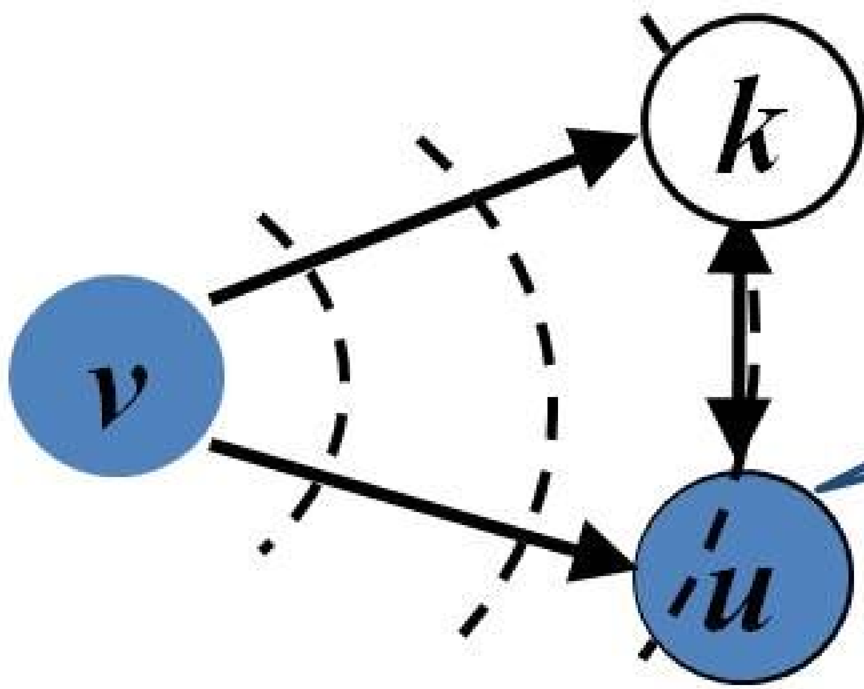
Provides high reliability with fewer transmissions!

CF Protocol Overview



Receiver State

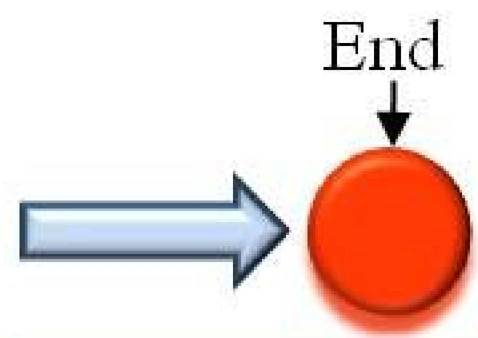
- Passively maintain 2 pieces of information
  - Coverage probability $CP_u(k)$ for all its 1-hop neighbors $\boldsymbol{k \in N(u)}$
  - Estimated uncovered node set $\boldsymbol{U(u) \subseteq N(u)}$



Node	CP	Covered
v	1	Yes
k	X	No

$\mathrm{CP}_u(k) = \mathrm{X} = \mathrm{P}_v(k|u)$

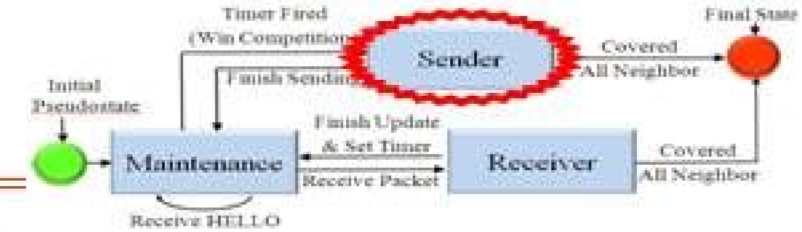
- *If* $\mathrm{CP}_u(k) \geq \alpha$, k is covered



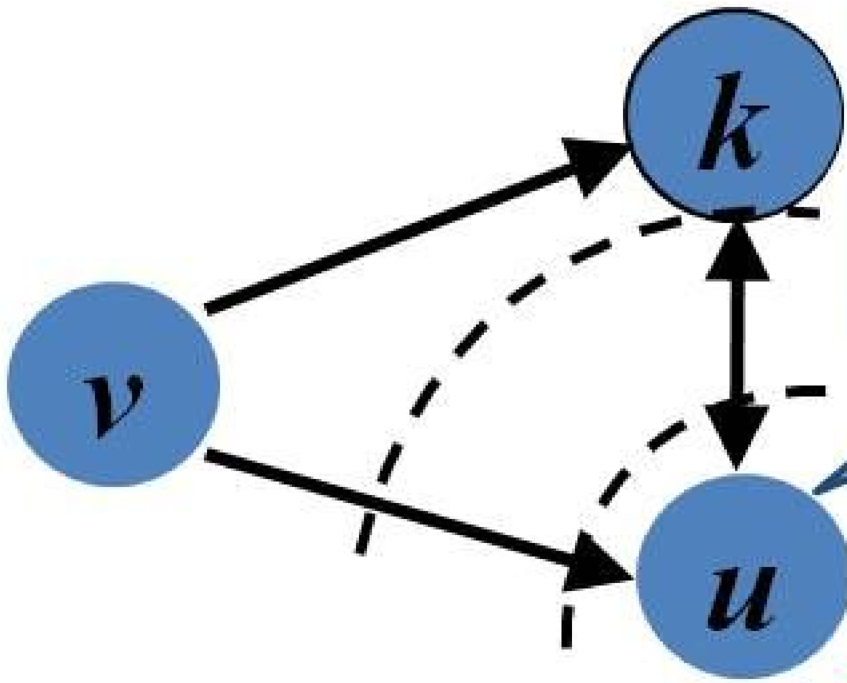
- *Else* Set Timer

Maintenance

Sender State



- Actively maintain 2 pieces of information
  - Coverage probability $CP_u(k)$ for all its 1-hop neighbors $k \in N(u)$
  - Estimated uncovered node set $U(u) \subseteq N(u)$



Node	CP	Covered
v	1	Yes
k	X	No

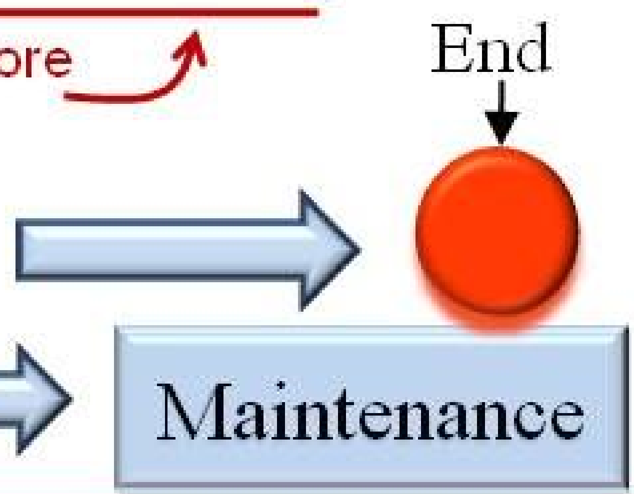
Uncovered probability before current transmission

Uncovered probability after current transmission

$$CP_u(k) = X \longleftarrow 1 - \boxed{(1-X)} \cdot \boxed{(1-L(u,k))}$$

Probability that k is covered either before or after current transmission

- *If* $CP_u(k) \geq \alpha$, k is covered
- *Else* Set Timer



CF Protocol

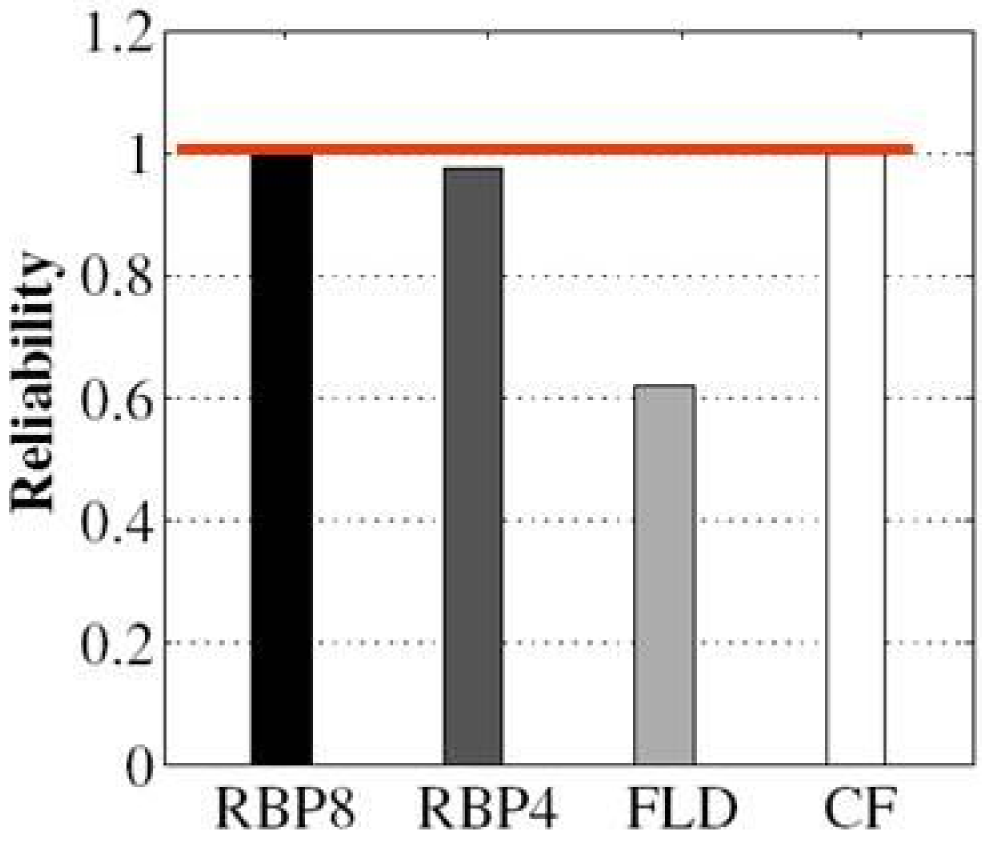
- Maintenance State
- Receiver State
  - Passively maintain 2 pieces of information
    - Coverage probability $CP_u(k)$ for all its 1-hop neighbors
    - Estimated uncovered node set
- Sender State
  - Actively maintain 2 pieces of information
    - Coverage probability $CP_u(k)$ for all its 1-hop neighbors
    - Estimated uncovered node set
- Back-off Timer

. . . details in the paper!

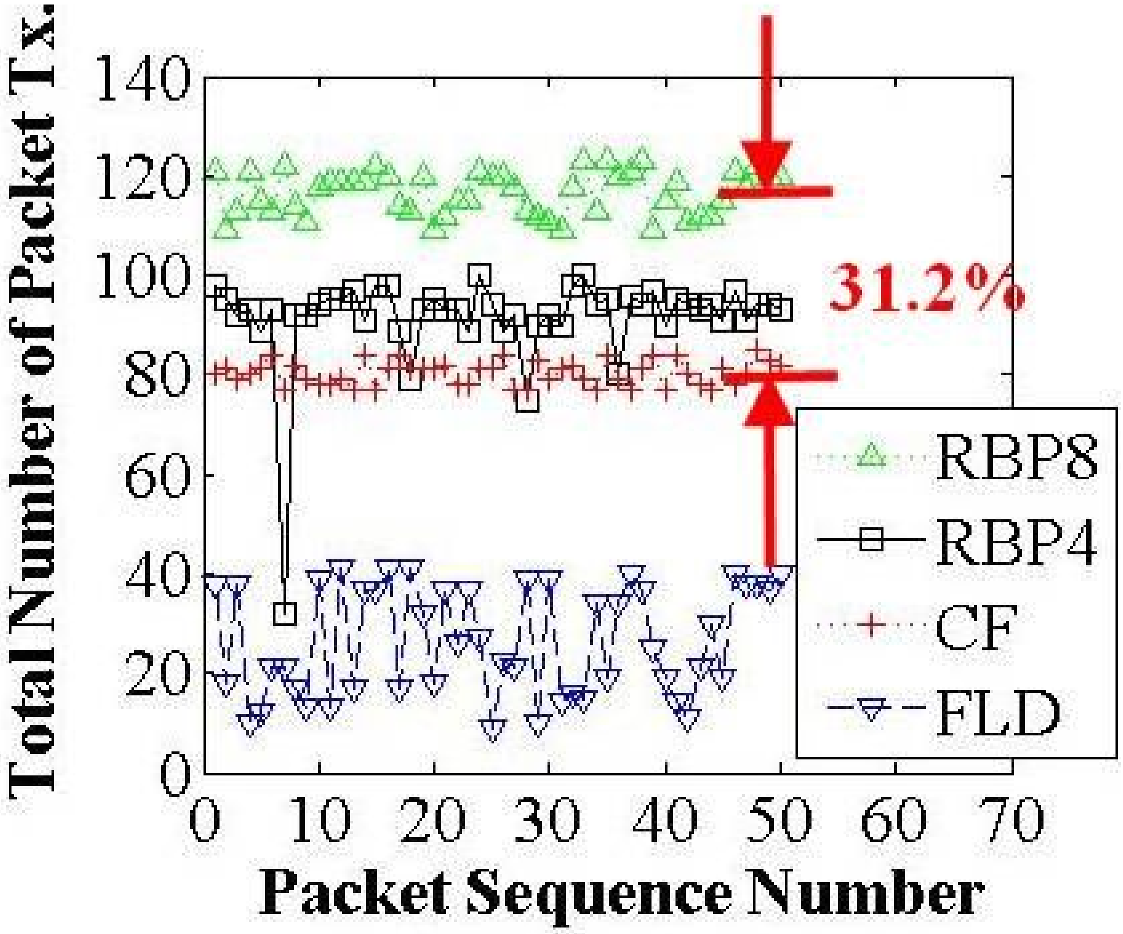
Evaluations

- Testbed implementation & large-scale simulations
  - Indoor : 37 MICAz motes
  - Outdoor: 48 MICAz motes (326-meter-long-bridge)
- Baseline solutions:
  - Standard Flooding (**FLD**)
  - **RBP** by F. Stann et al. in SenSys'06
- Evaluation Metrics:
  - Reliability
  - Message Overhead
  - Dissemination Delay
  - Load Balance

Outdoor Experiment Results

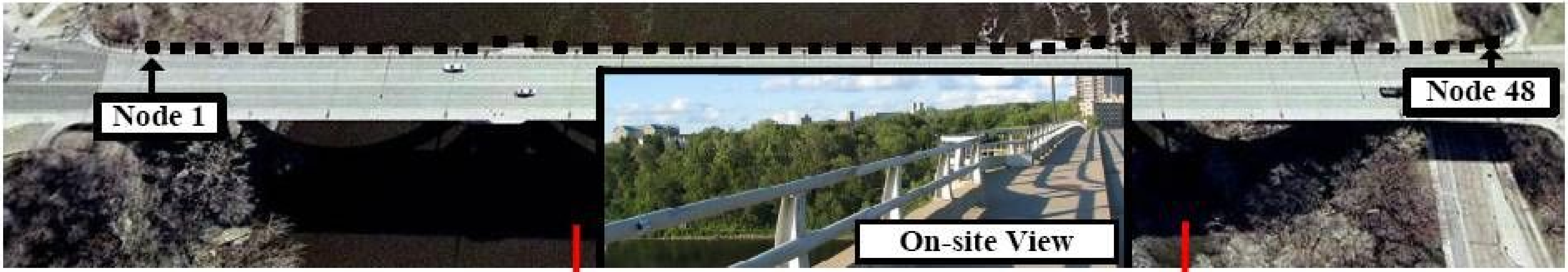


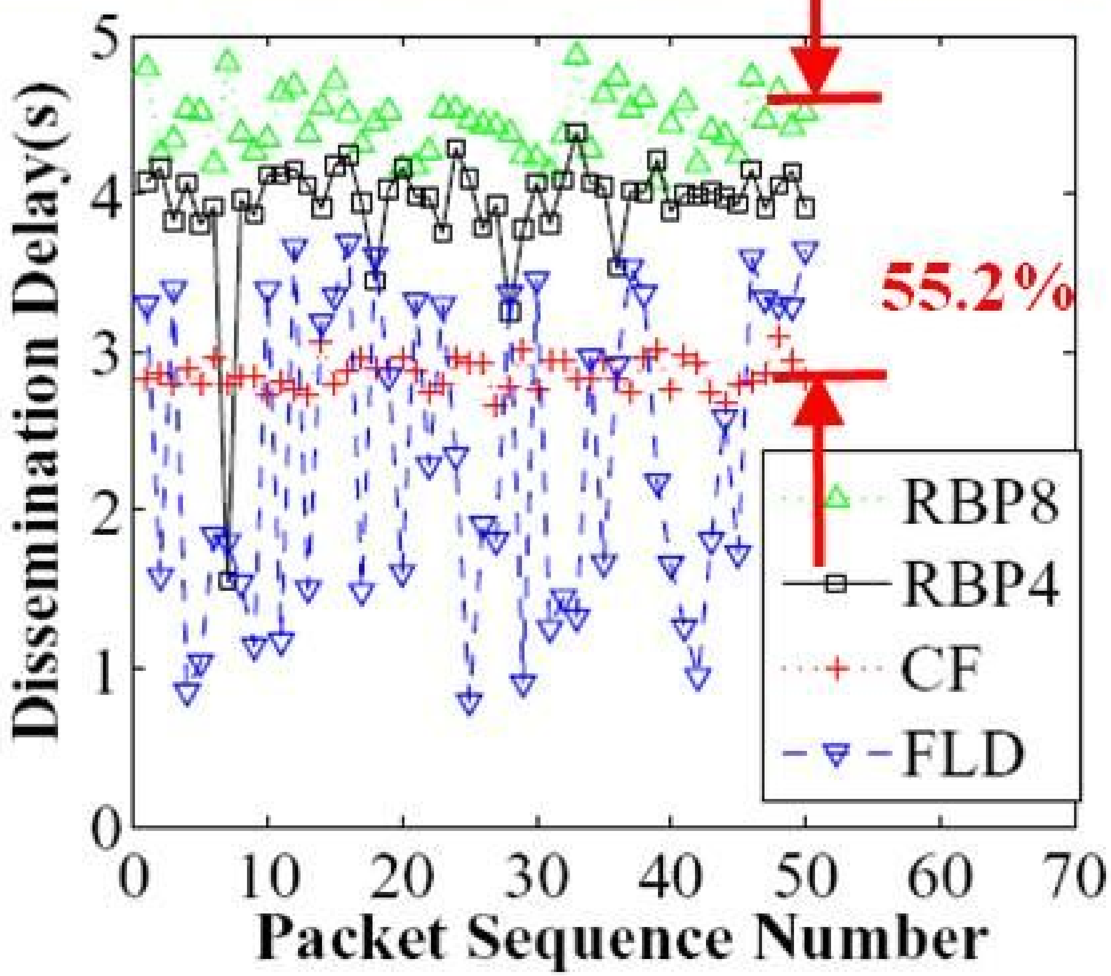
Reliability



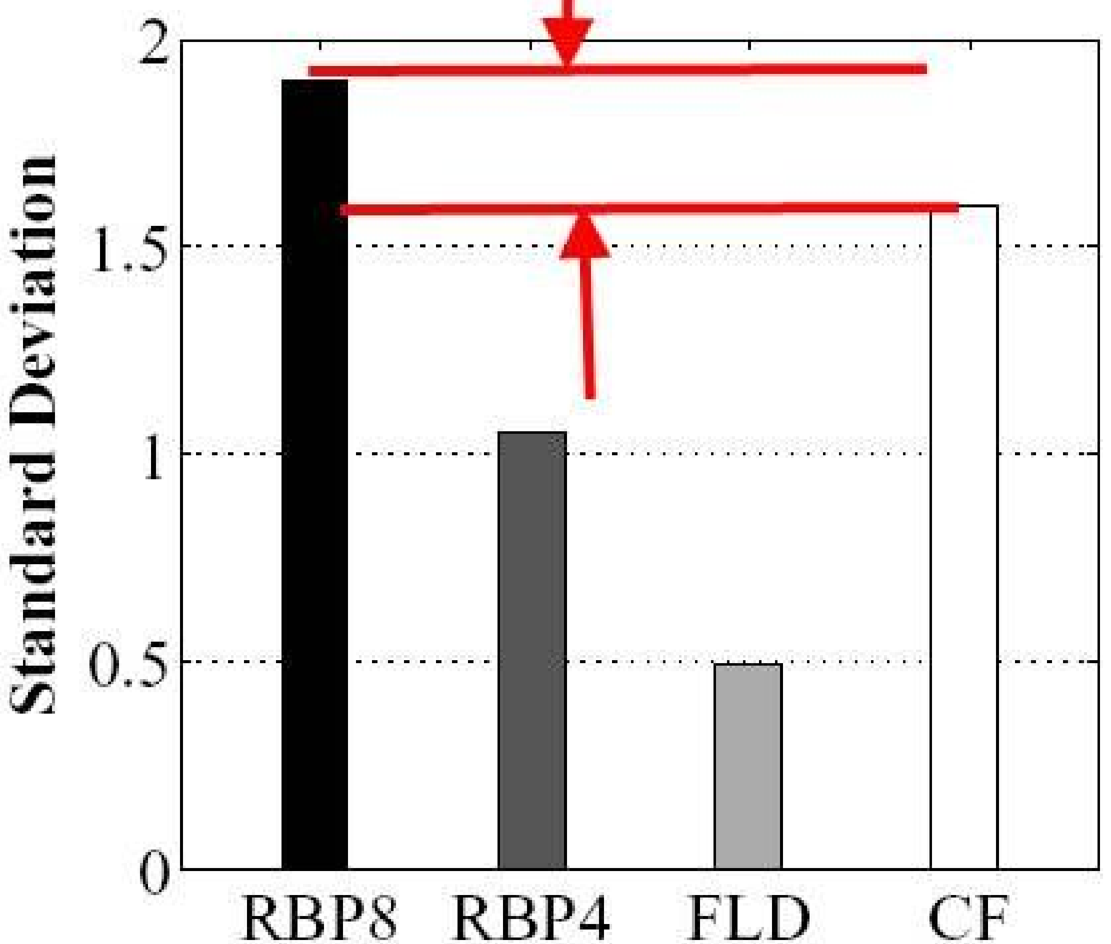
Total Number of Tx.

Outdoor Experiment Results



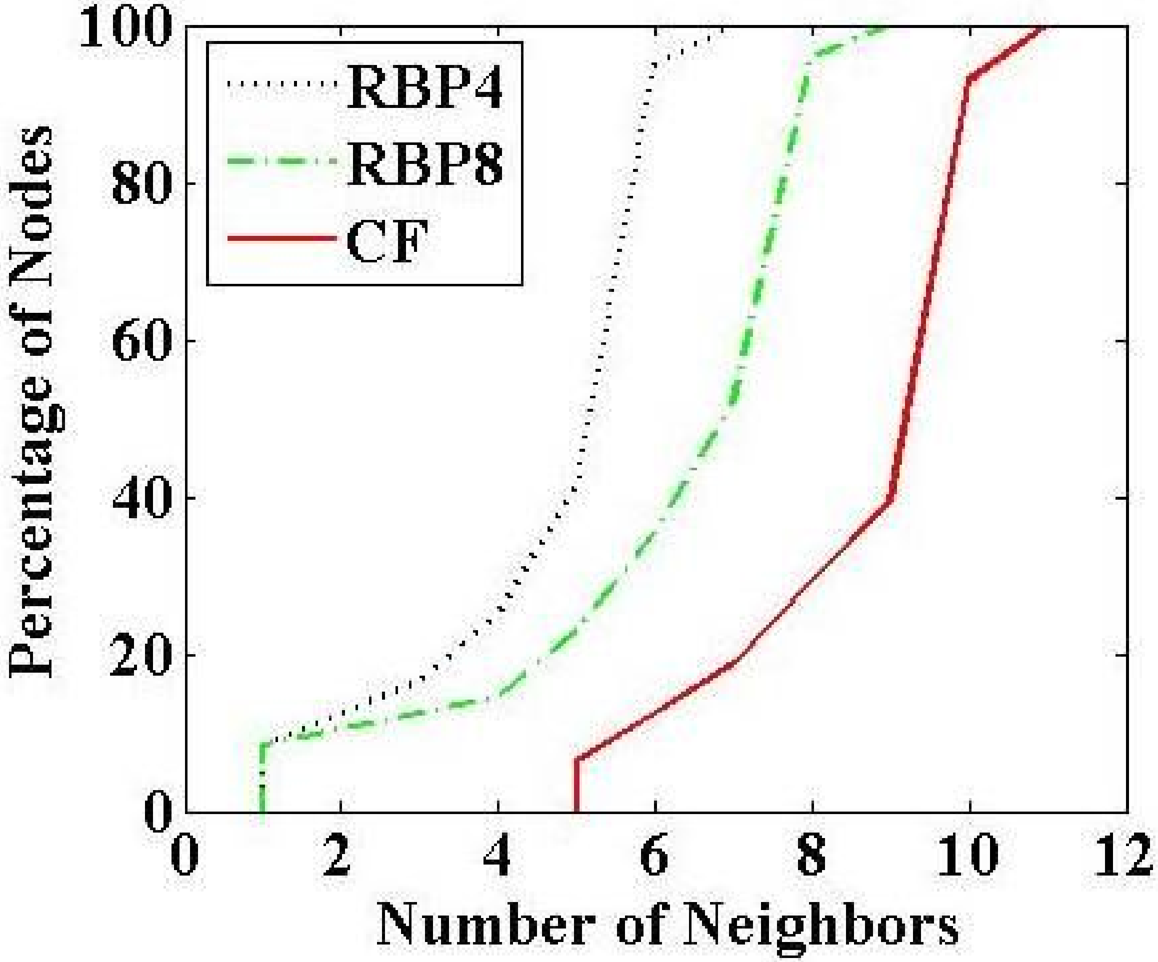


Dissemination Delay

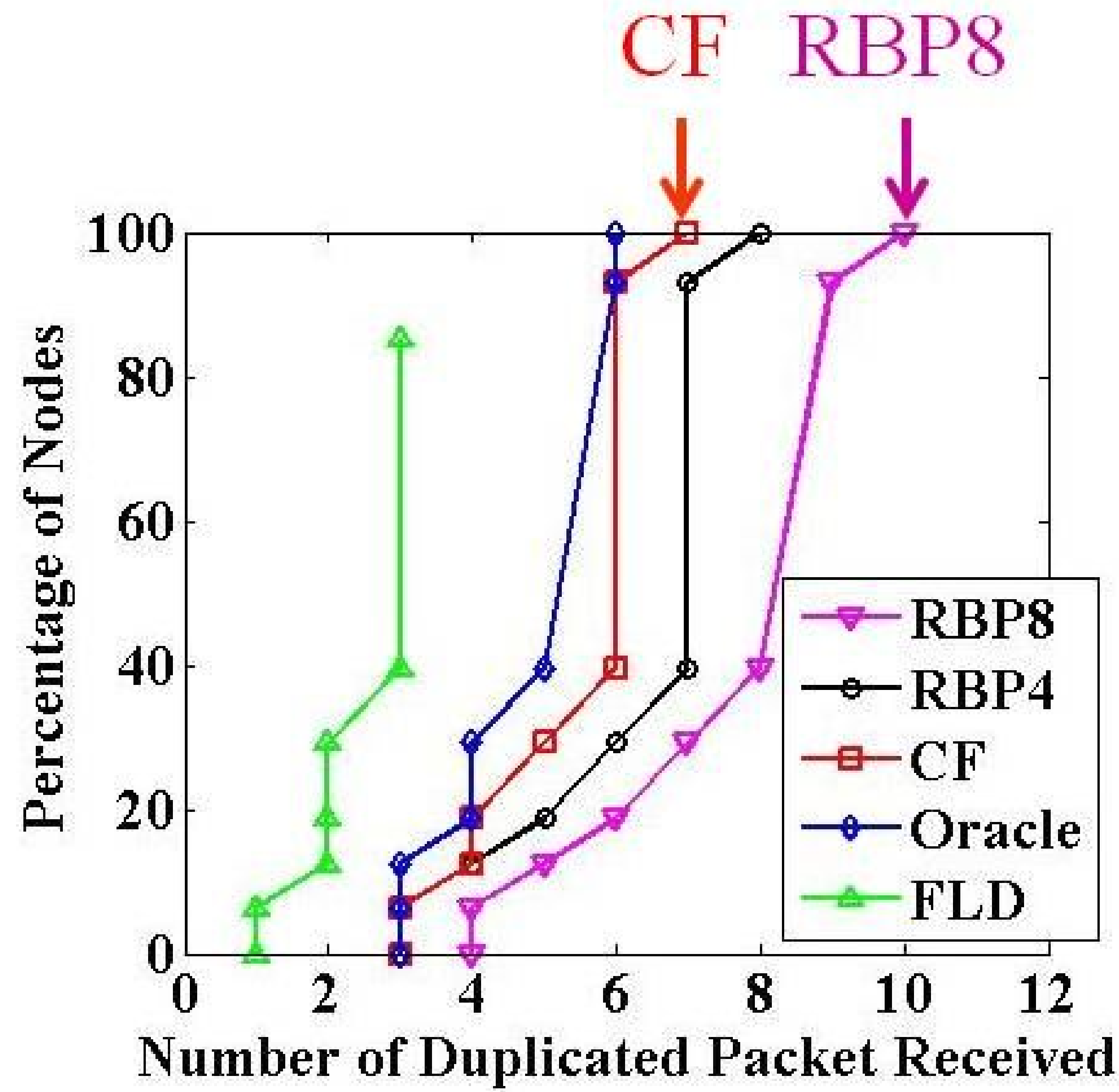


Load Balance

System Insight Analysis



CDF of Neighbor Size



CDF of Dup. Packets Received

Conclusion

- Provided the first extensive study to exploit the link correlation for communication improvement through:
  - Collective acknowledgement
  - Dynamic forwarder selection
- Proposed collective ACKs
  - A new concept to improve the efficiency of reliable flooding
  - Transform traditional direct ACKs per receiver into correlated and accumulative ACKs
- CF design is simple, symmetric, and highly scalable.
  - Reduced total number of packet transmissions by 30~50%

Questions ?

More at: www.cs.umn.edu/~tzhu

Acknowledgements: