Routing in Wireless Sensor Networks

Octav Chipara

Two practical routing protocols

- **Taming the Underlying Challenges of Reliable Multihop Routing in Sensor Networks.**
  - Alec Woo, Terence Tong, David Culler -- Berkeley
- **Collection Tree Protocol (CTP)**
  - Omprakash Gnawali, Rodrigo Fonseca, Kyle Jamieson, David Moss Philip Levis -- Stanford
- **With a little help from**
  - RSSI is Under Appreciated. Kannan Srinivasan and Philip Levis.
  - Four-Bit Wireless Link Estimation. Rodrigo Fonseca, Omprakash Gnawali, Kyle Jamieson, Philip Levis

Routing in the wireless domain

- **A fundamental challenge for wireless networks (including WSNs)**
  - years of research efforts to develop a **robust** solution

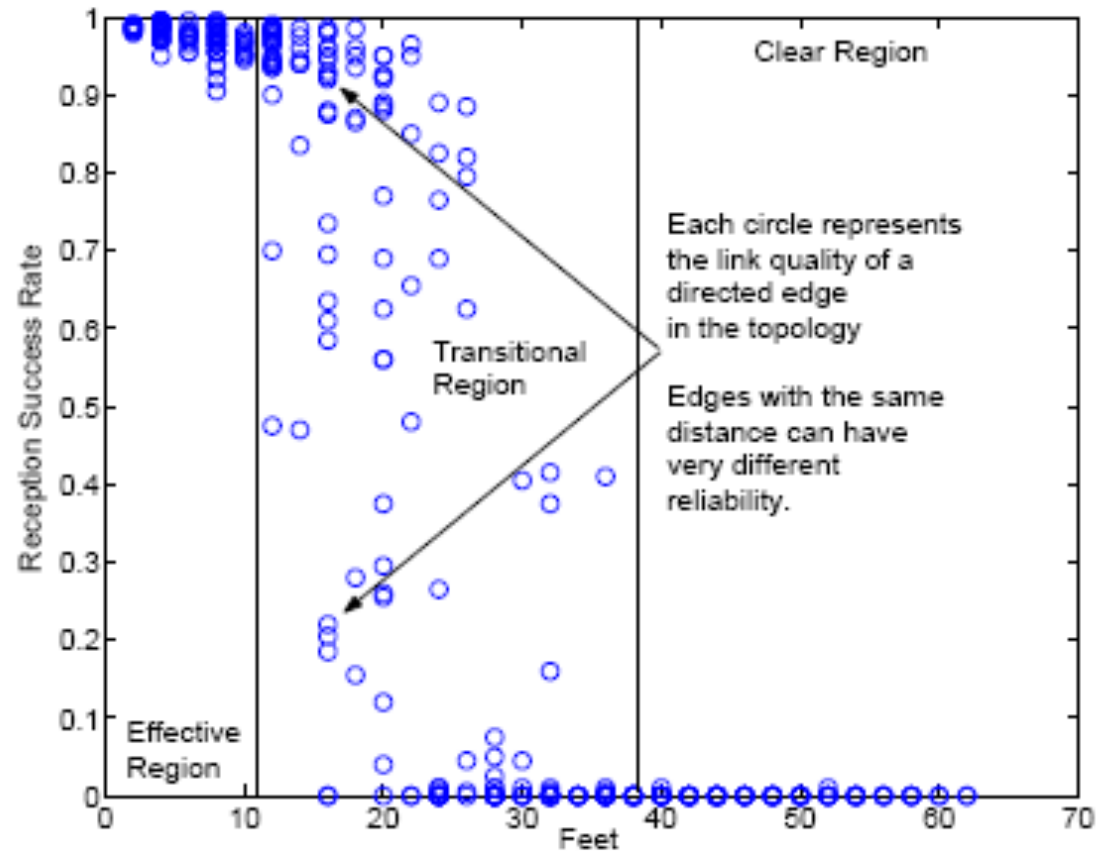
- **Challenges**
  - dynamics wireless channels
  - multiple optimization goals (reliability, delay, energy)
  - mobile users
  - limited memory (particularly on WSNs)

Anatomy of a routing protocol

- **Link estimation**
  - identify good quality links
- **Path cost metrics**
  - determine the quality of a path
- **State maintenance**
  - achieving a consistent state across nodes
  - minimizing overhead
  - limited memory

Link Estimators

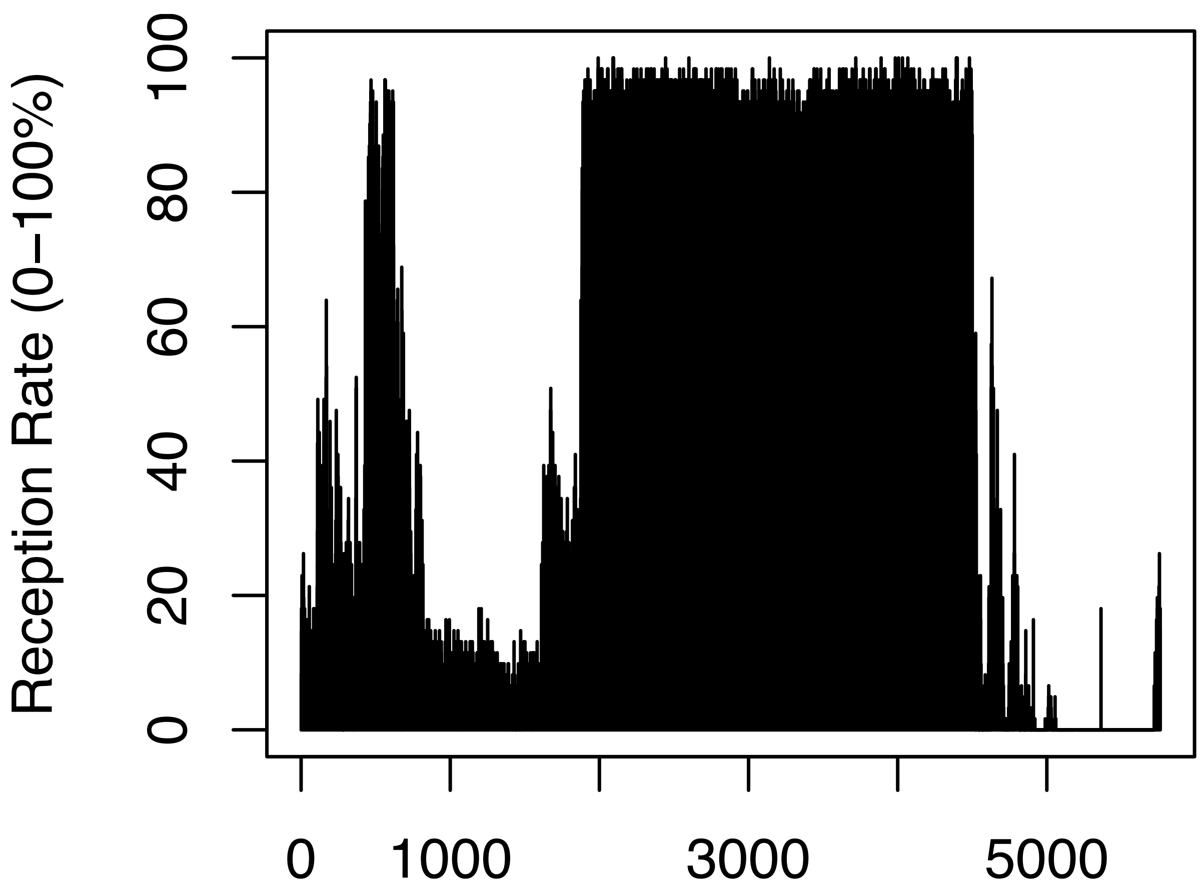
Empirical properties of wireless links



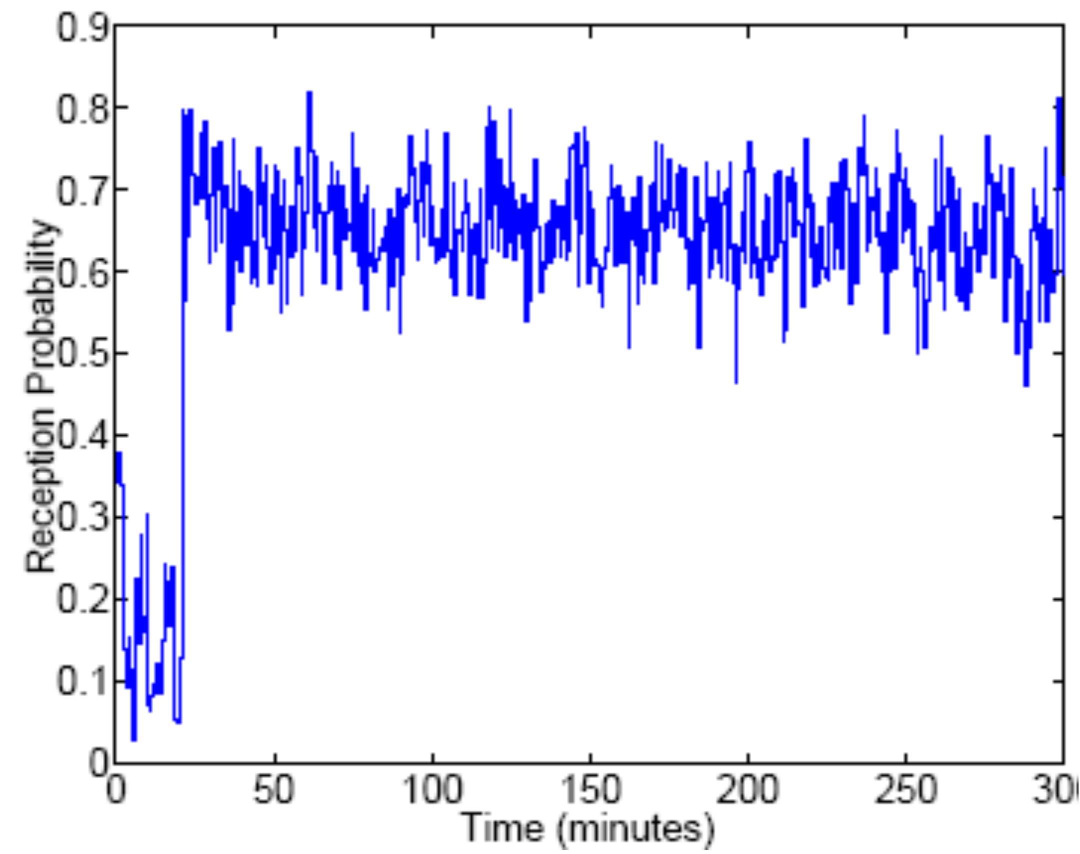
(a) Reception probability of all links in a network with a line topology.

- **Effective region - good link quality, short distances**
- **Transitional region - high variability in link quality, long distances**
    - these links may be essential for efficient routing solutions

Empirical properties of wireless links



noise variation



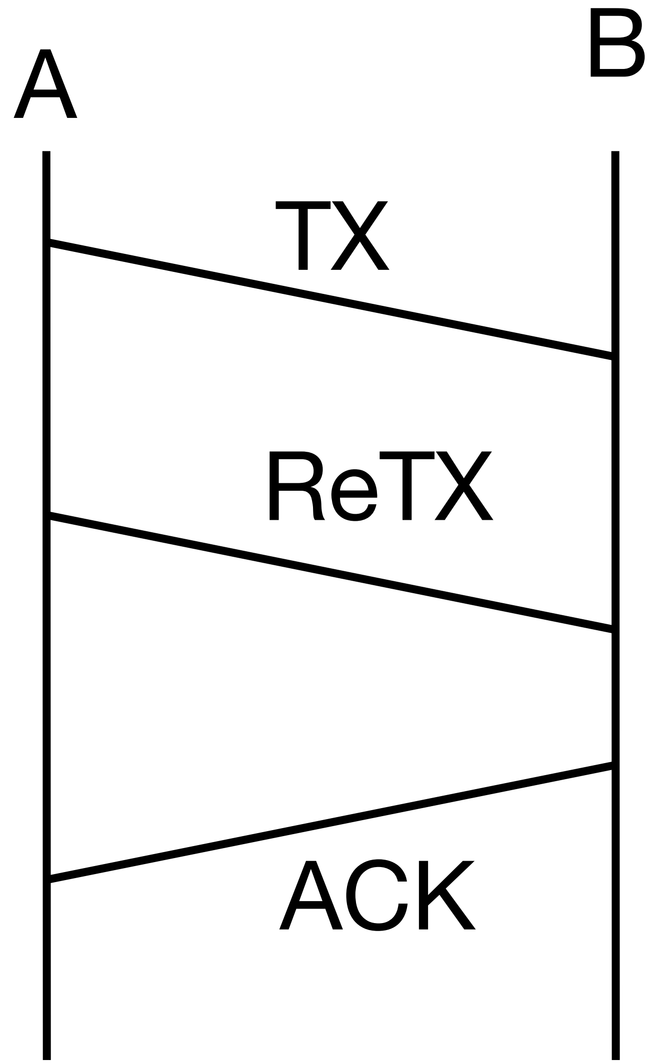
mobility

- **Link variability**
  - due to changes in the noise levels over time
  - due to mobility

Link Quality Estimation

- **Identify good links**
- **ETX: Expected Transmission Count [Mobicom 2003]**

$$ETX(L) = \frac{1}{PRR(AB) * PRR(BA)}$$



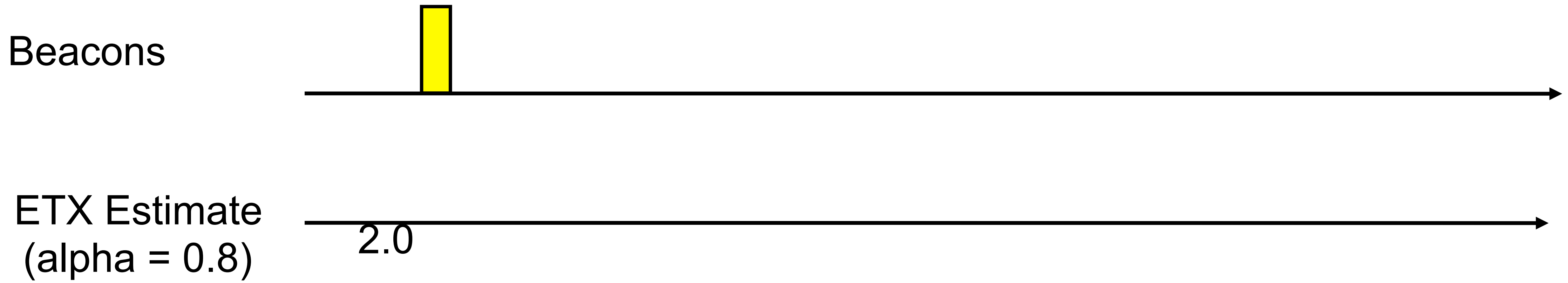
ETX and EWMA

Beacons

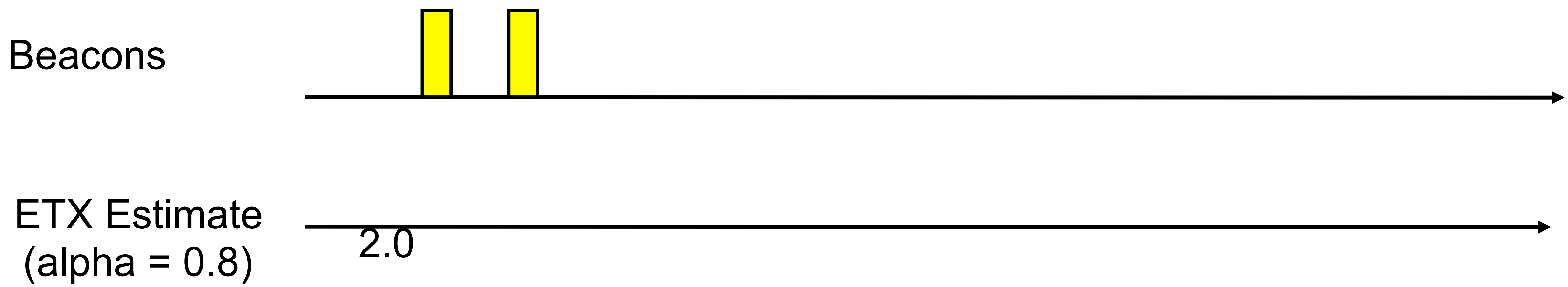
ETX Estimate
(alpha = 0.8)

2.0

ETX and EWMA



ETX and EWMA



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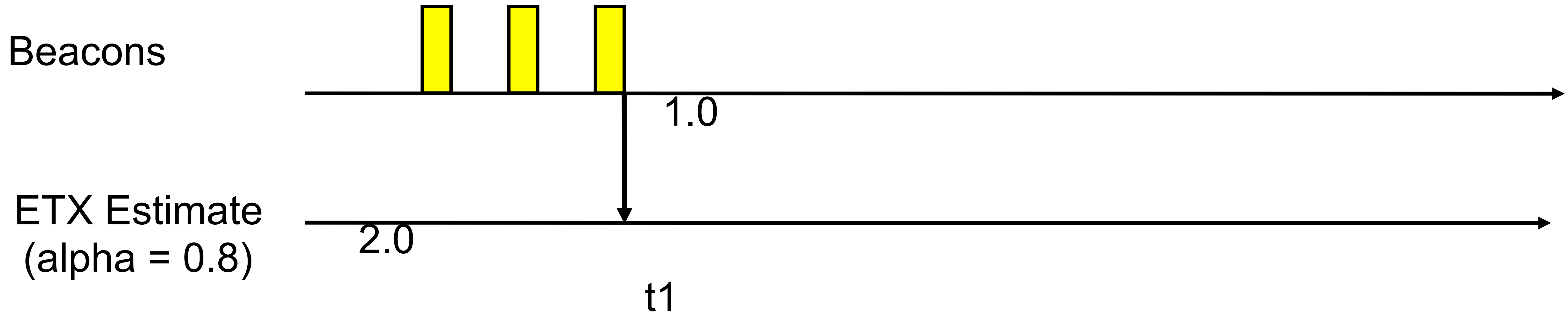

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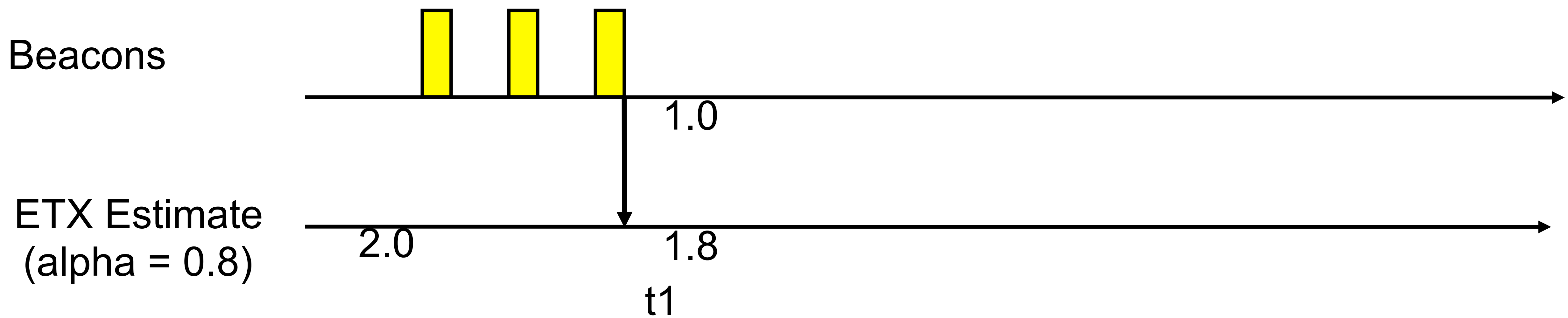

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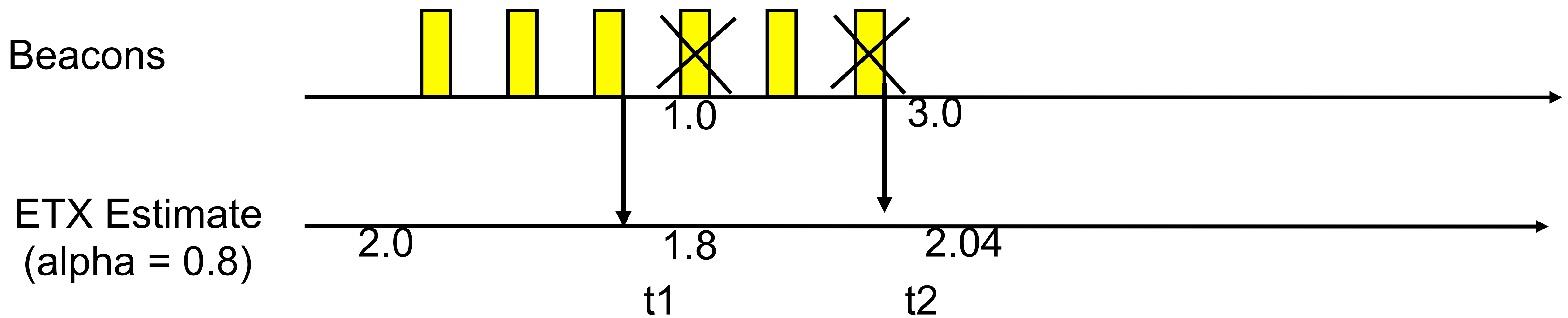
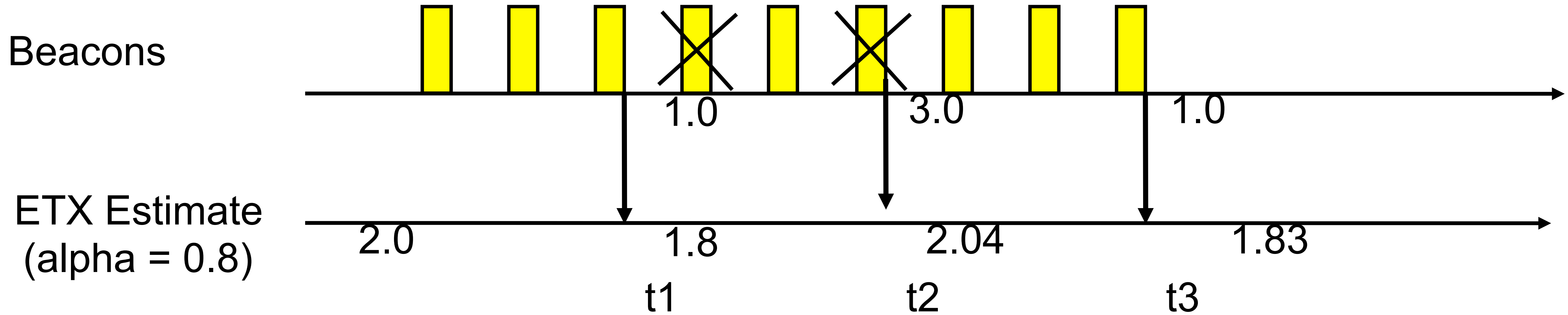


ETX and EWMA



WMEWMA Estimator

- **Link quality is measured as the percent of packets that arrived undamaged on a link.**
- **Compute an average success rate over a time period, T, and smoothes with an exponentially weighted moving average (EWMA)**
- **Average calculation**

$$\frac{Packets\ Received\ in\ t}{max(Packets\ Expected\ in\ t, Packets\ Received\ in\ t)}$$

- **Tuning parameters:**
  - Time window t and history size of the estimator α

WMEWMA tracks the empirical trace fairly well

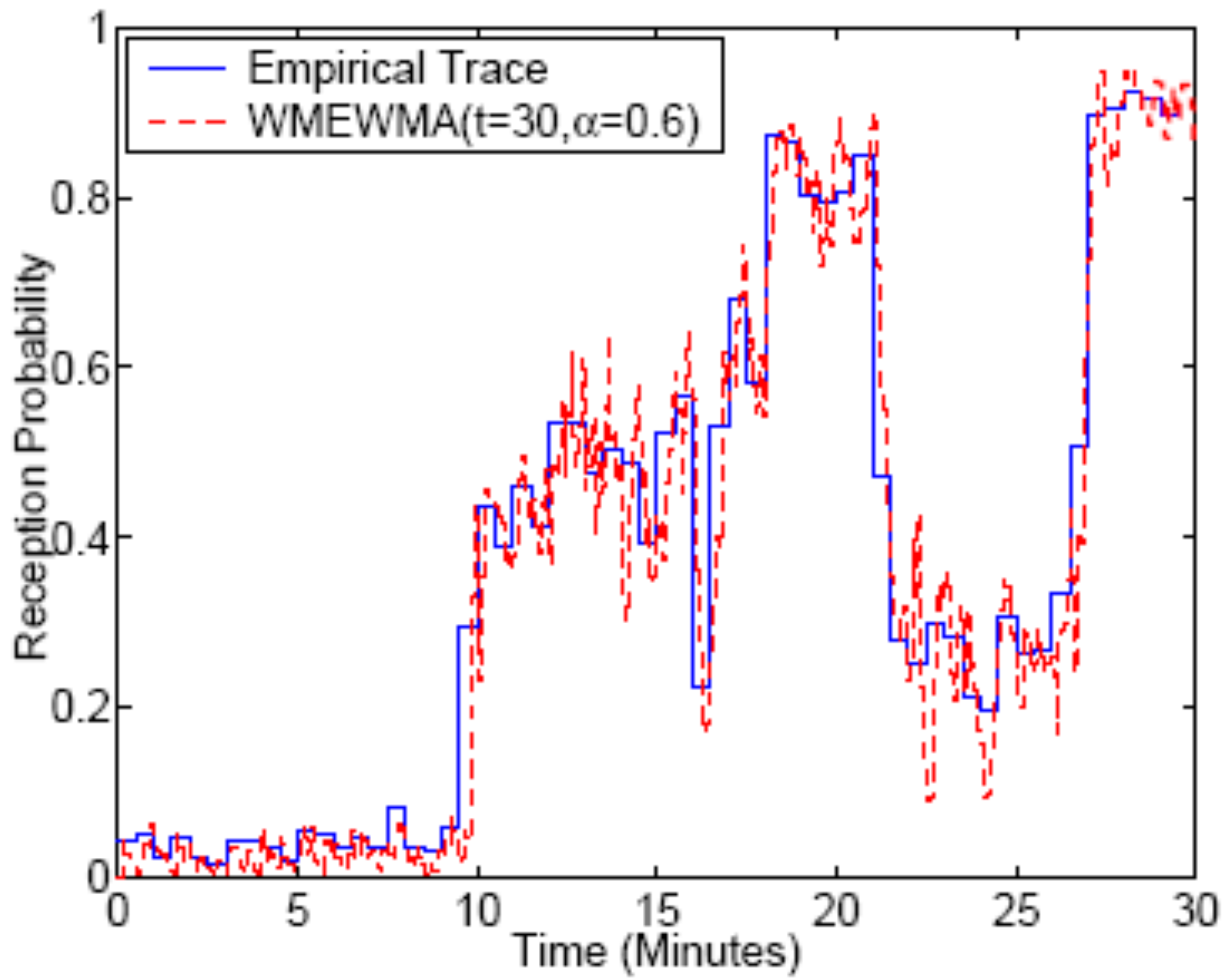


Figure 3: WMEWMA($t = 30, \alpha = 0.6$) **with stable setting using empirical traces.**

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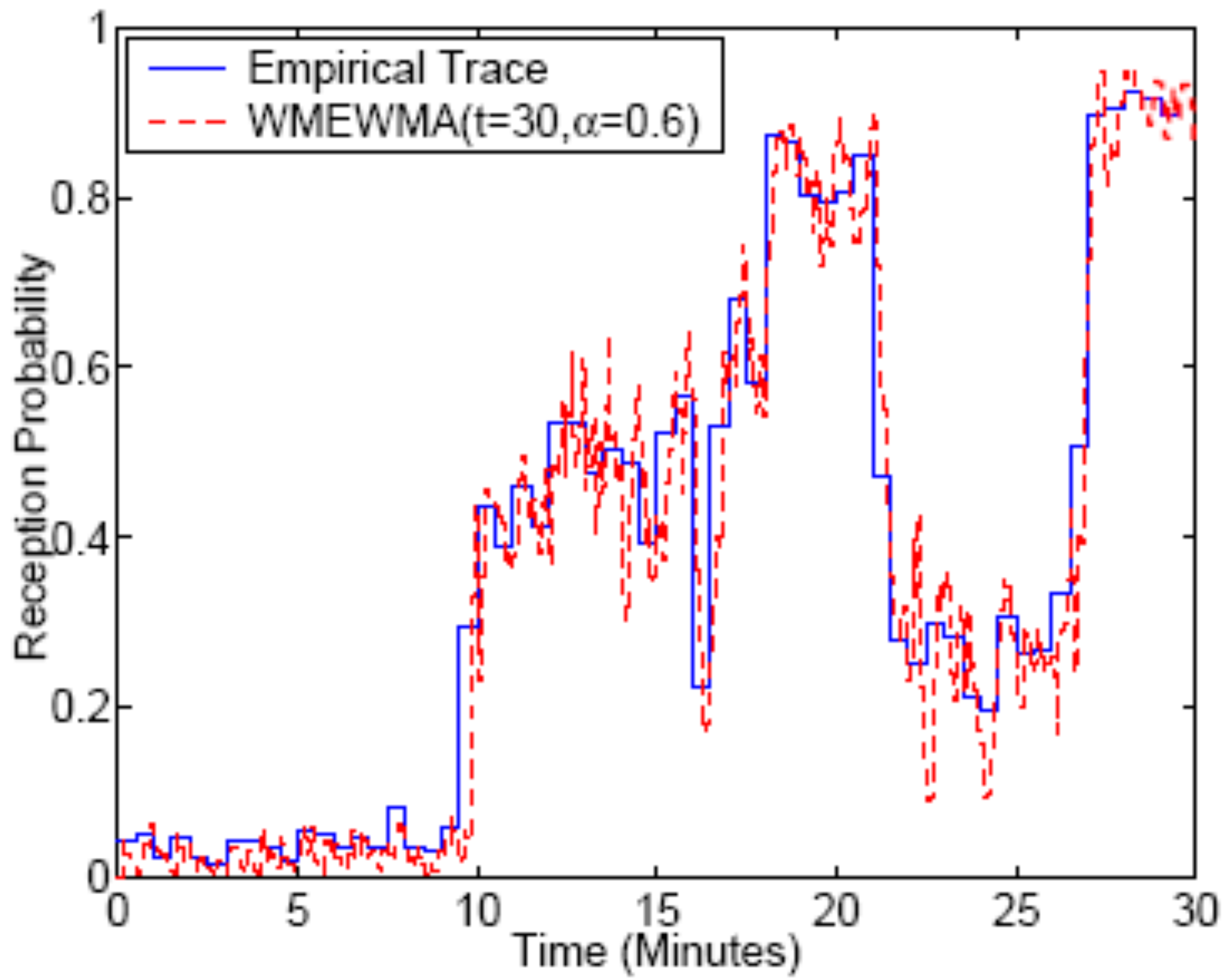

Figure 3: WMEWMA($t = 30, \alpha = 0.6$) with stable setting using empirical traces.

Is this a good estimator?

WMEWMA Critique

- **Advantages:**
  - simple algorithm
  - minimal memory usage
- **Disadvantages**
  - it requires at least W packets before making a quality estimation

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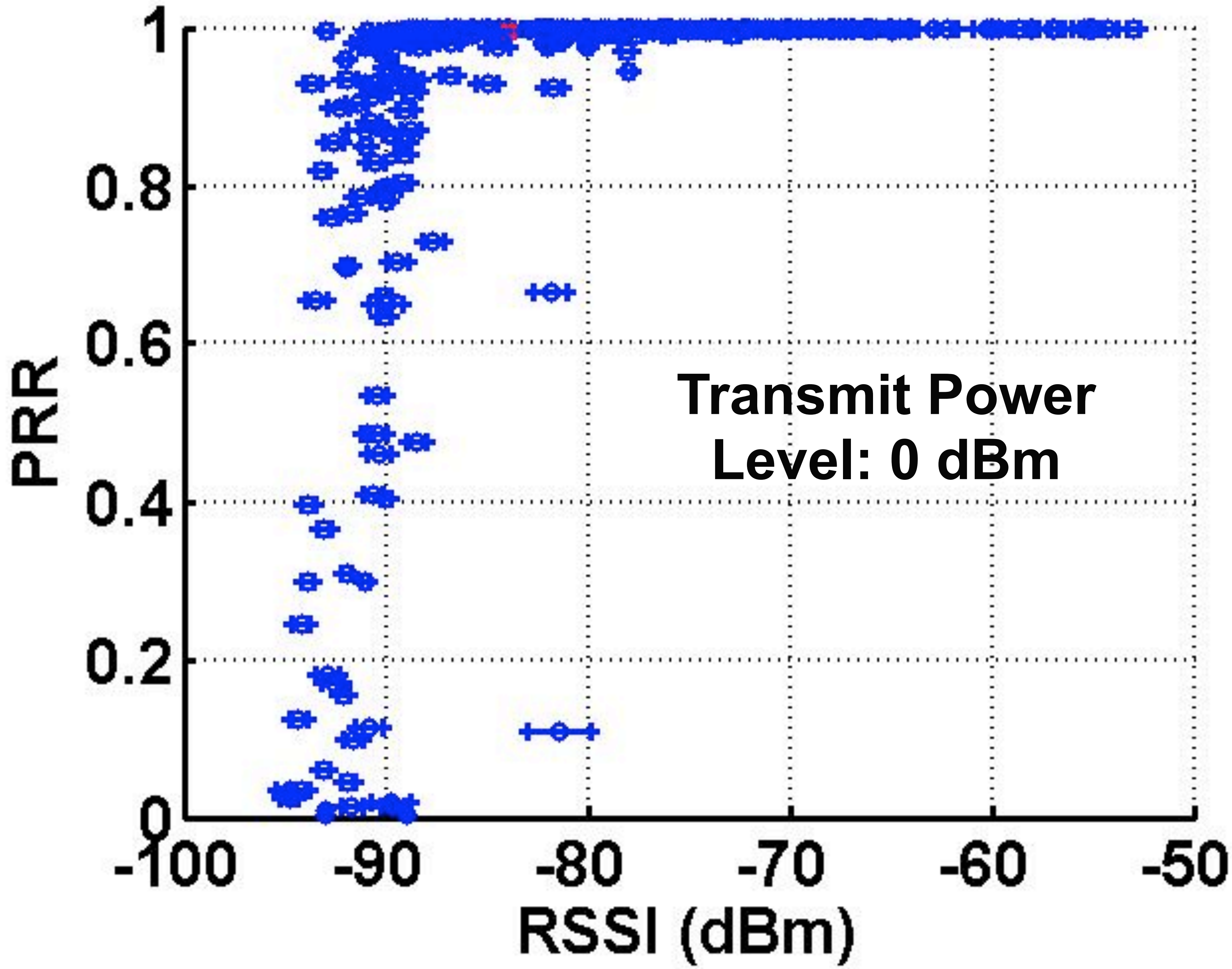
Can we estimate link quality based on PHY measurements?

Is RSSI indicative of PRR?



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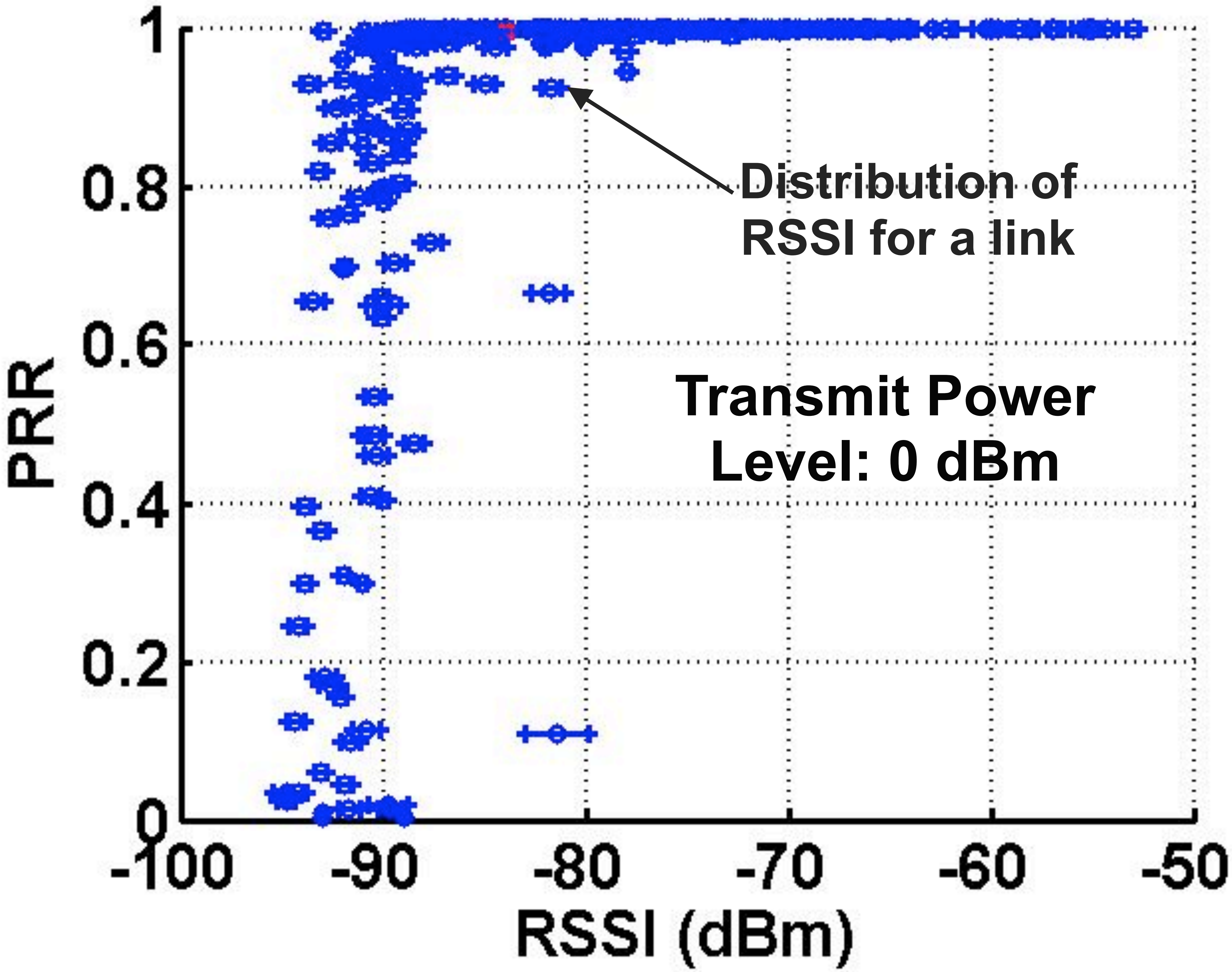

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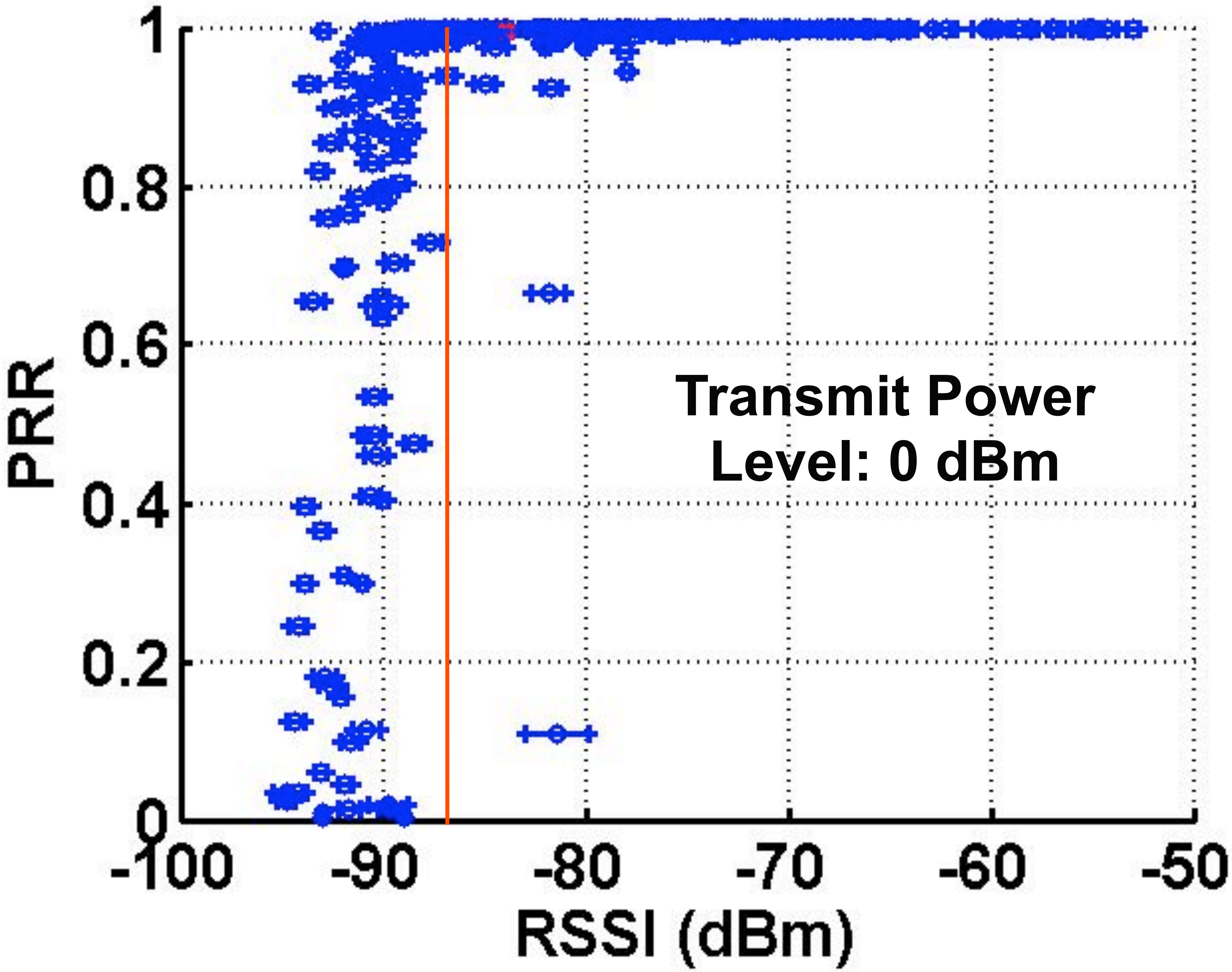

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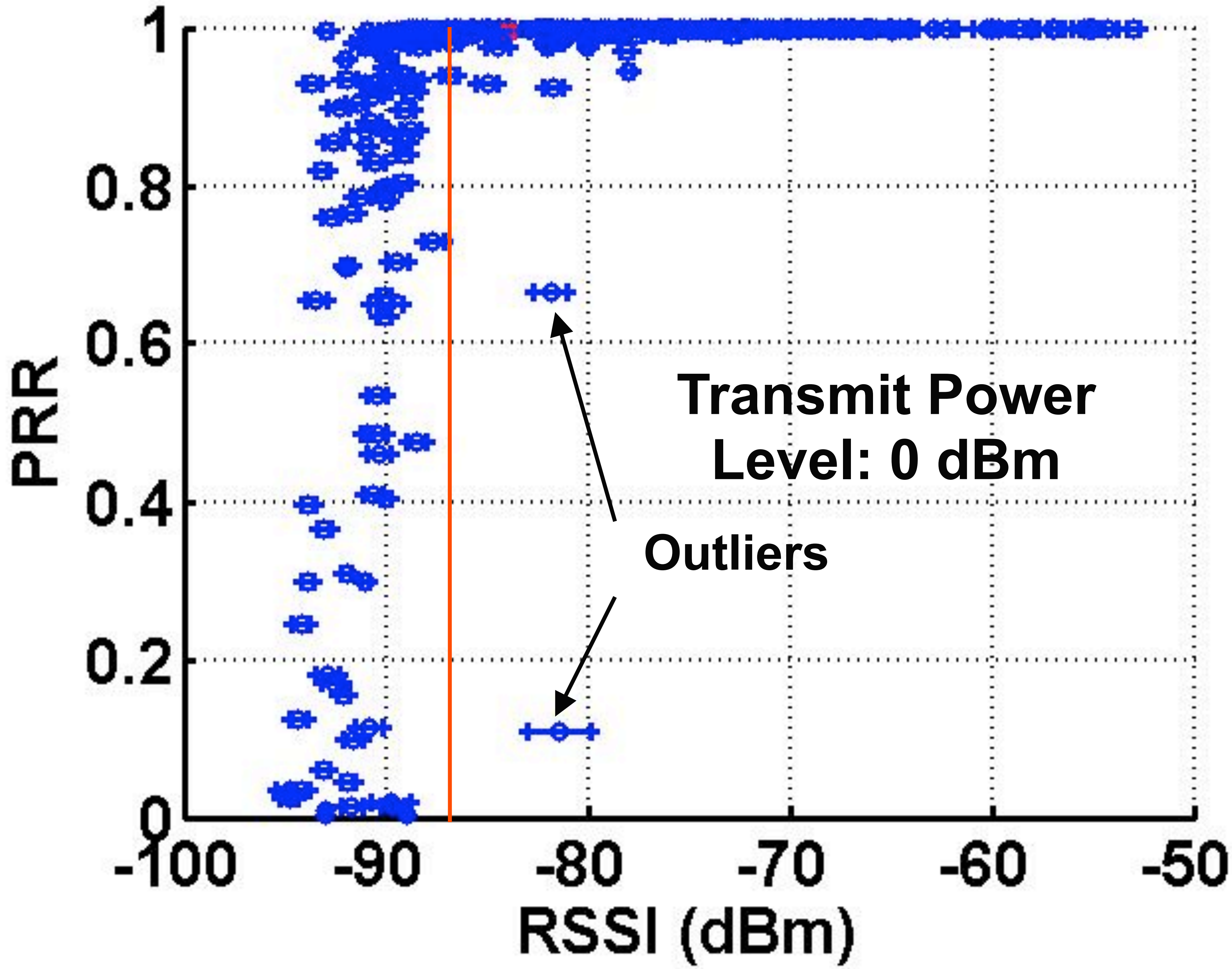

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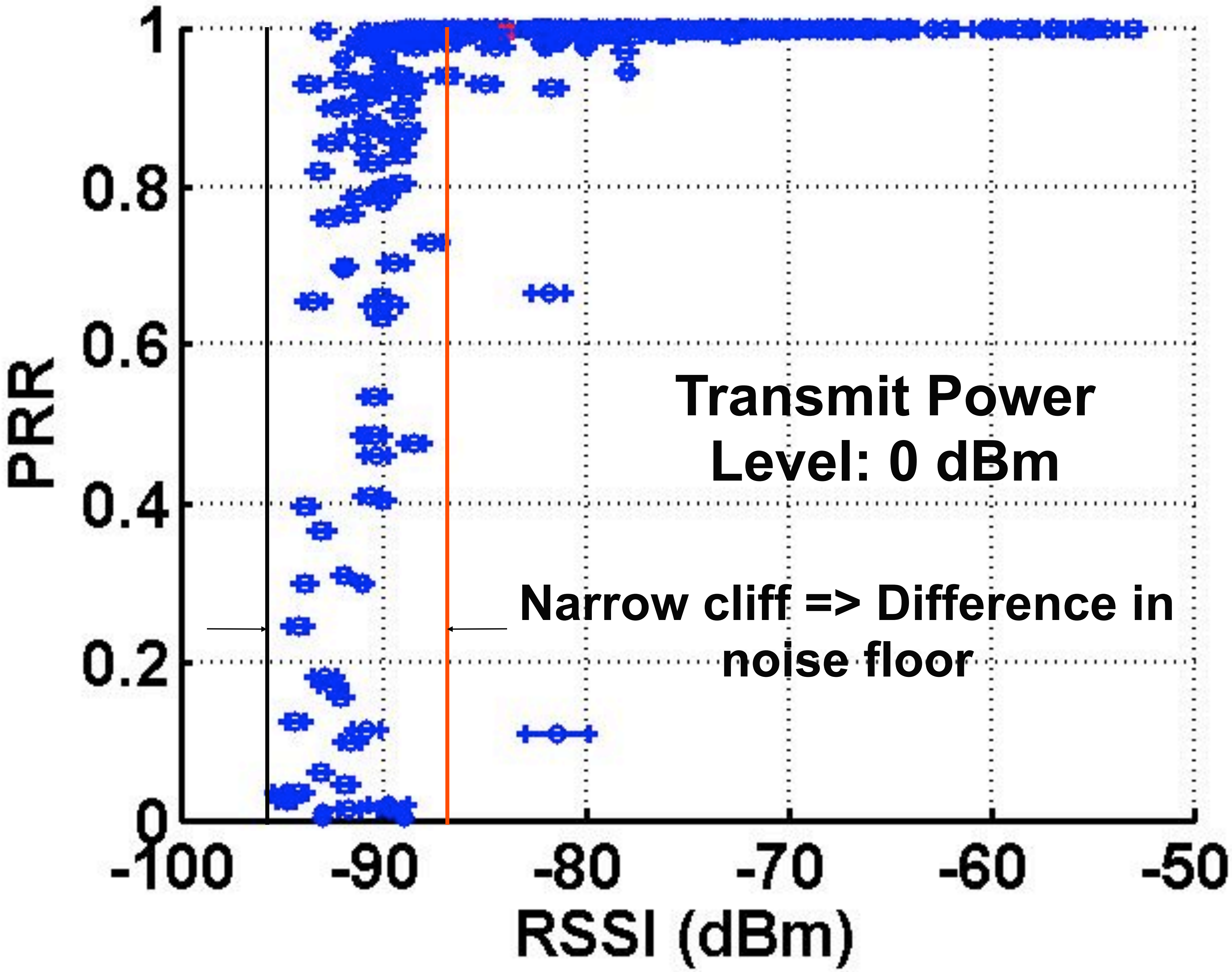

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Noise floor at different nodes

Noise (dBm)	-98	-97	-96	-95	-94	-93	-92
# of Nodes	5	8	4	3	2	3	1

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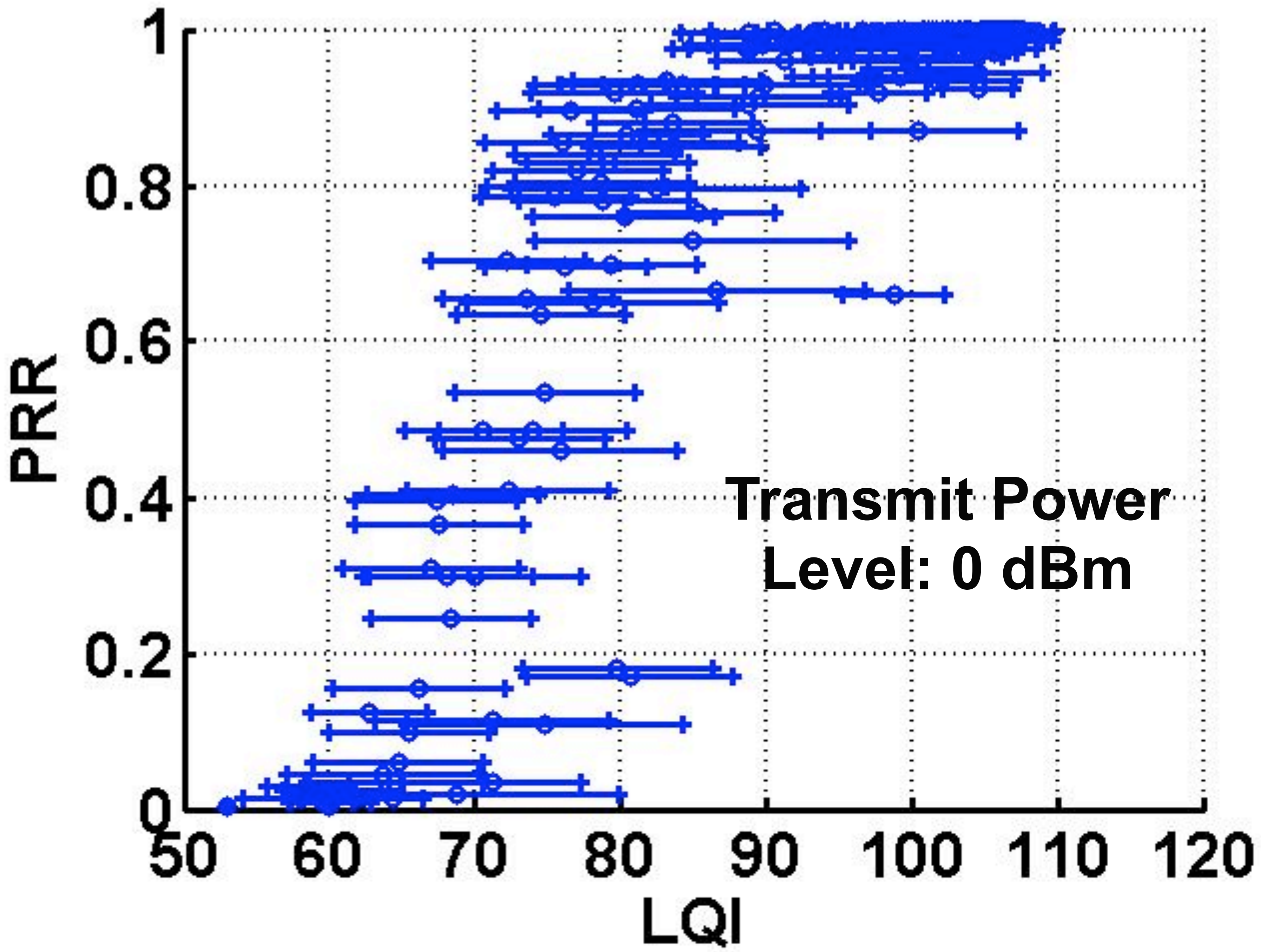
Is LQI indicative of PRR?



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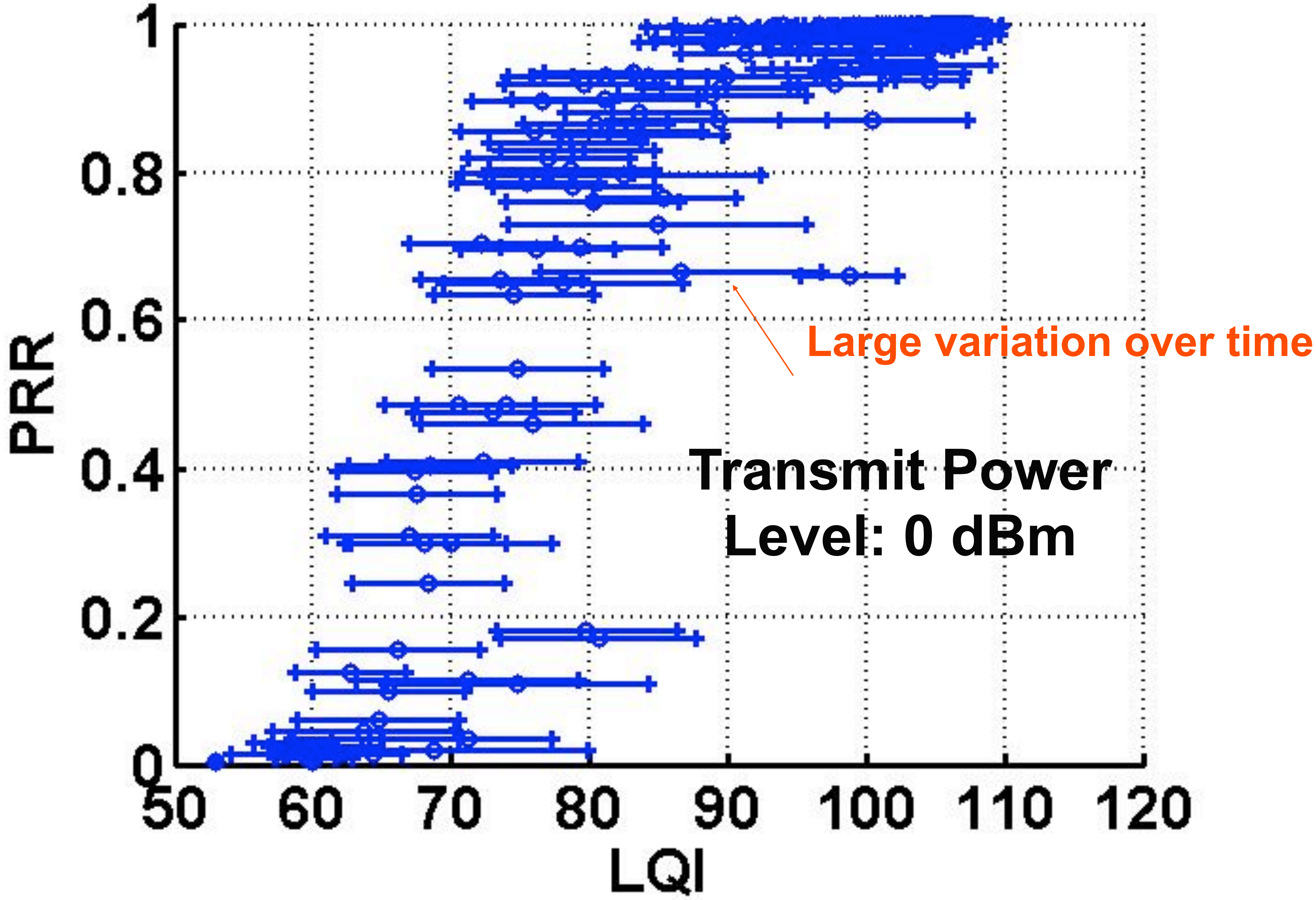

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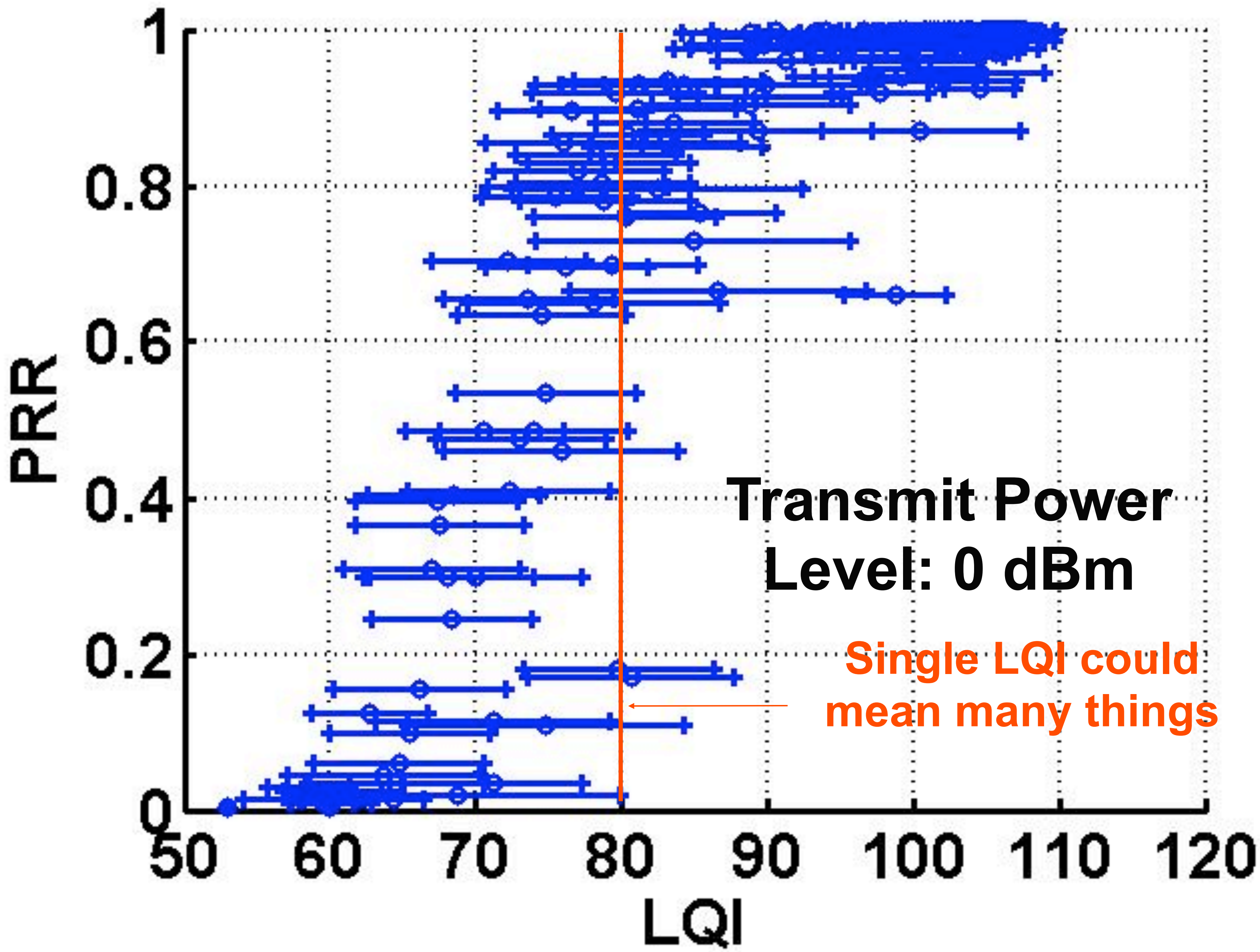

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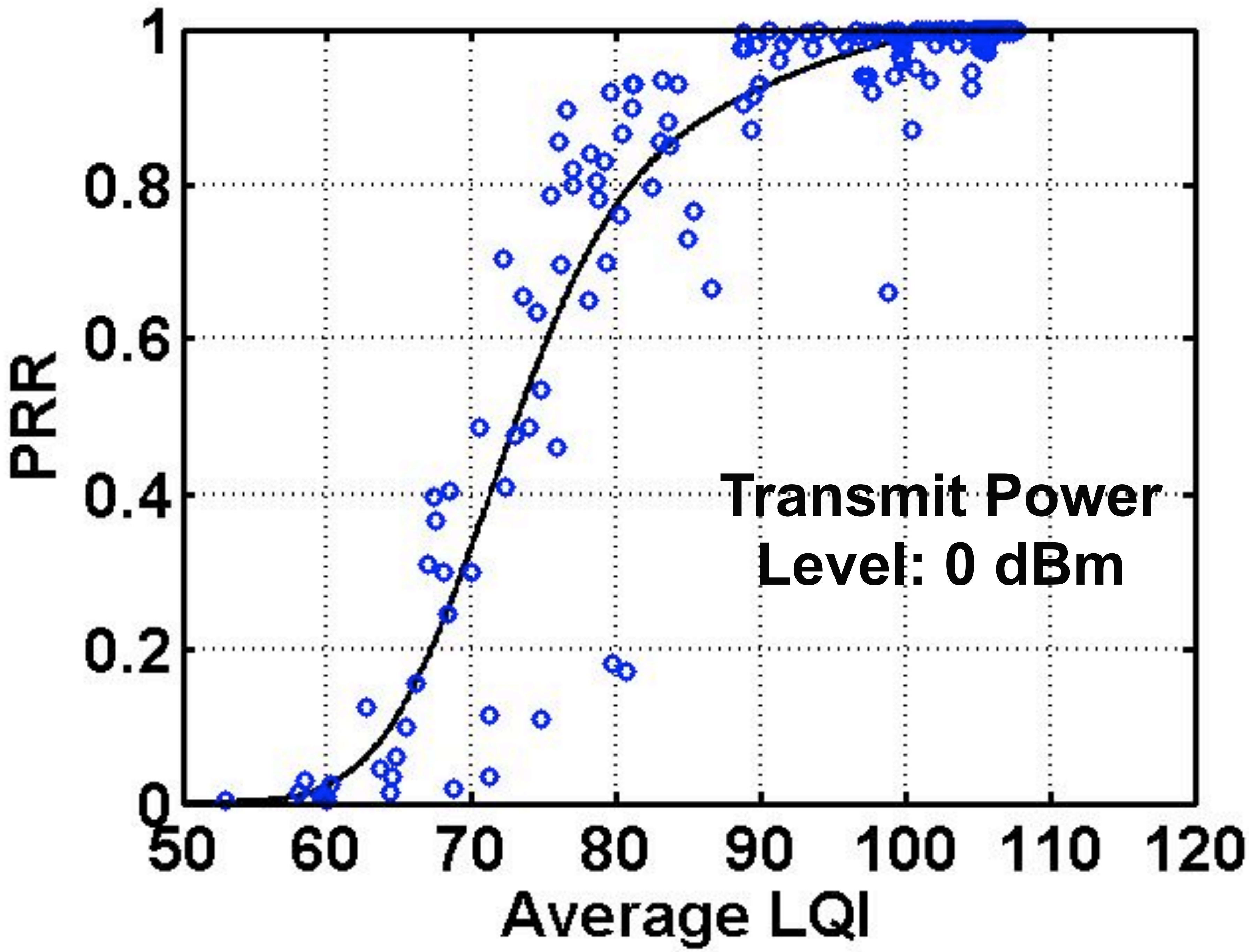
Average LQI



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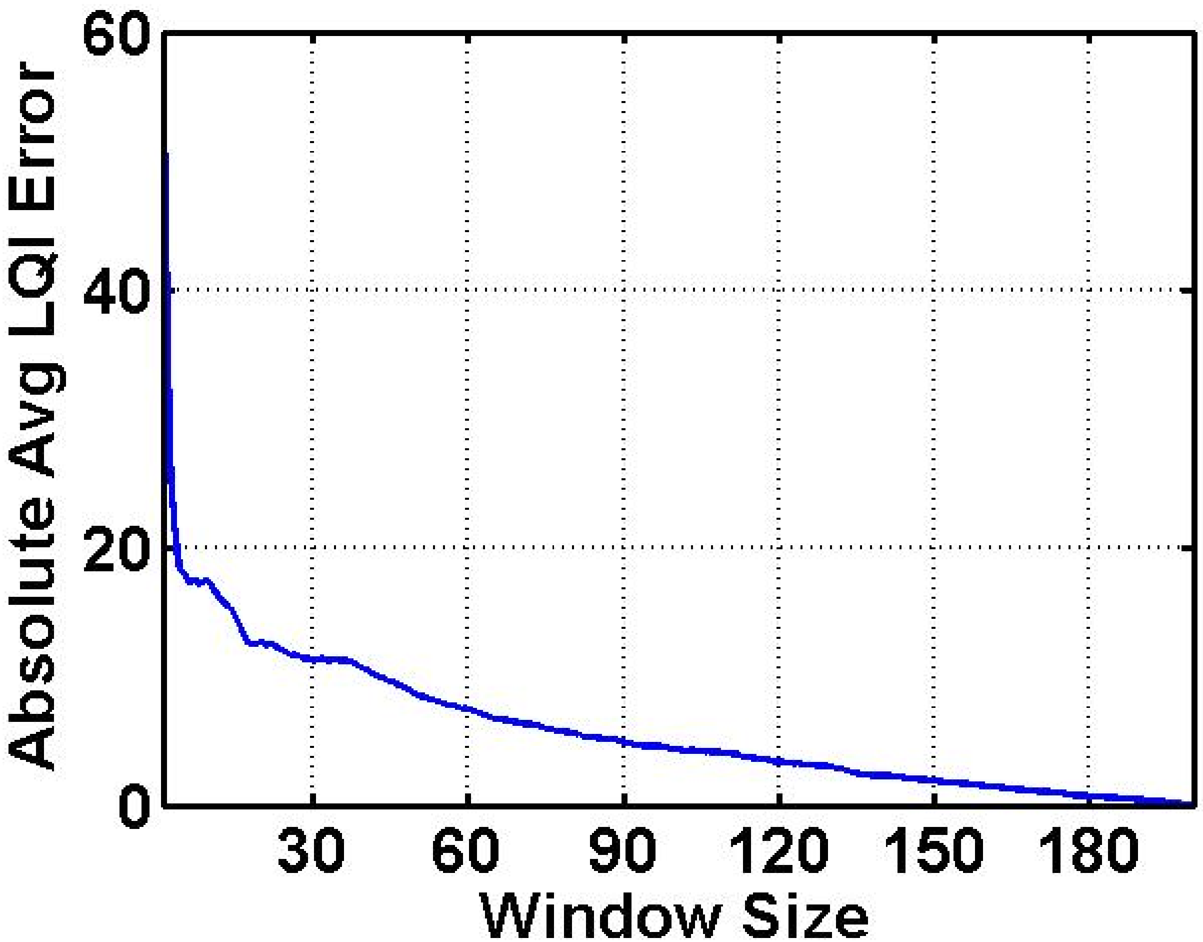
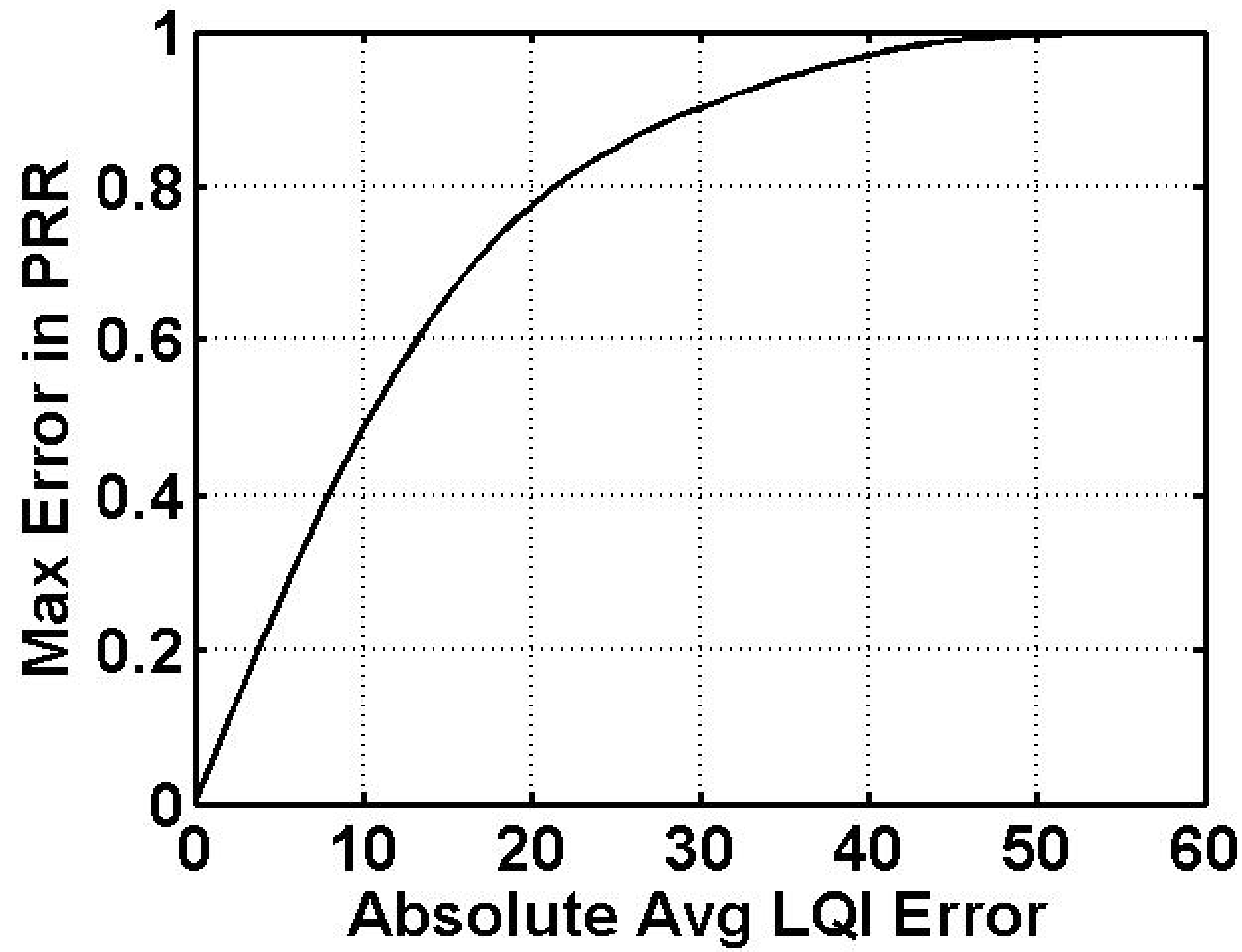
Errors in using LQI as an indicator of PRR





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Using PHY layer information

- **PHY layer indicators are attractive => provide instant feedback**
- **Our current understanding:**
    - RSSI may be used to determine if a node is the connected region
    - RSSI is not very useful in determining the quality in the transitional region
    - LQI has poor correlation with PRR due to poor resolution (few bits)
- **Research is ongoing on how to incorporate LQI and RSSI information into link estimators**

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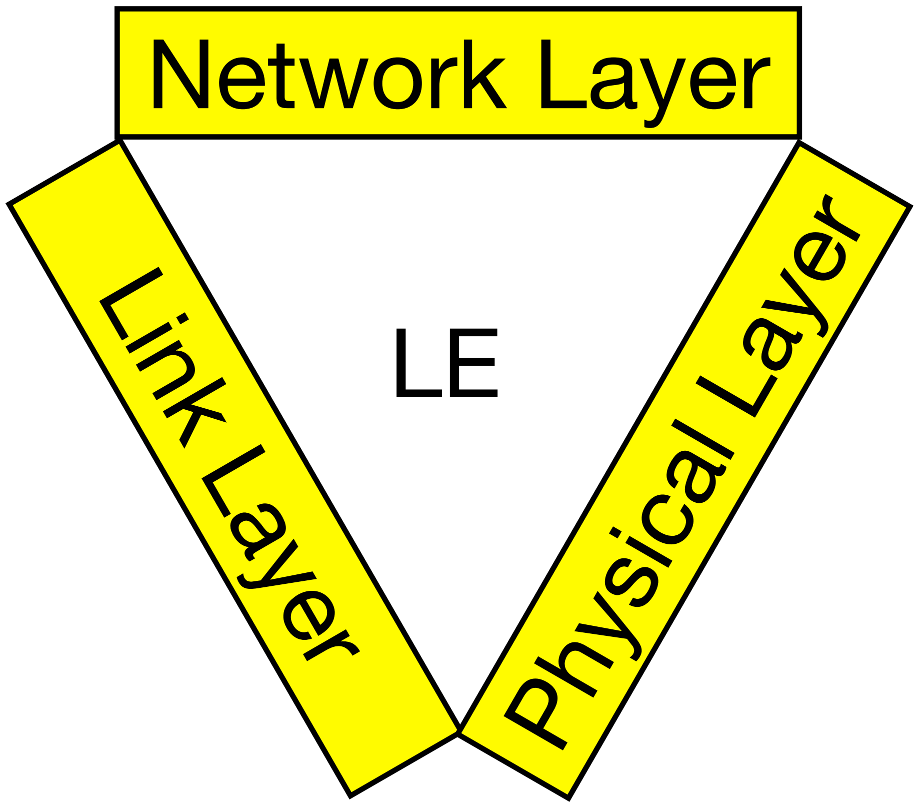
Can we integrate information from multiple layers?

State of the Art Today

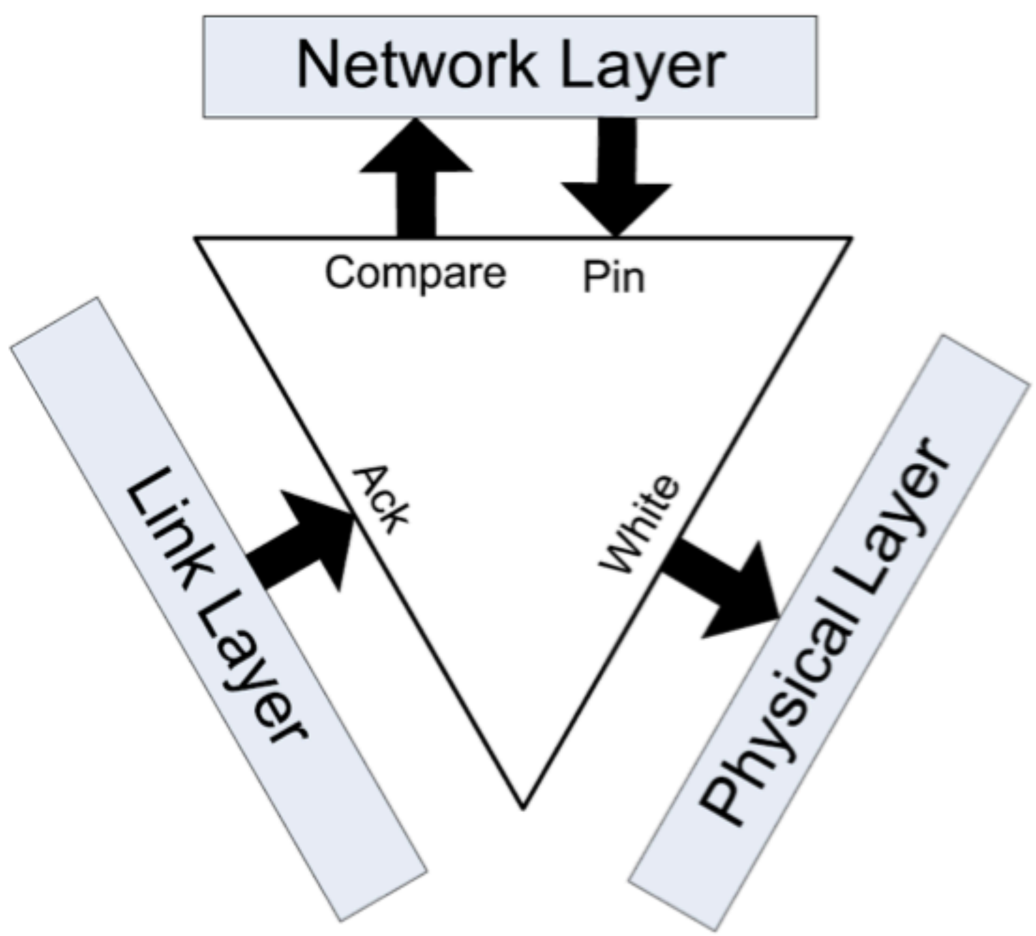
- **Not all information used**
- **Coupled designs**

- **MLQI**
  - Physical layer (LQI)
  - Coupled implementation



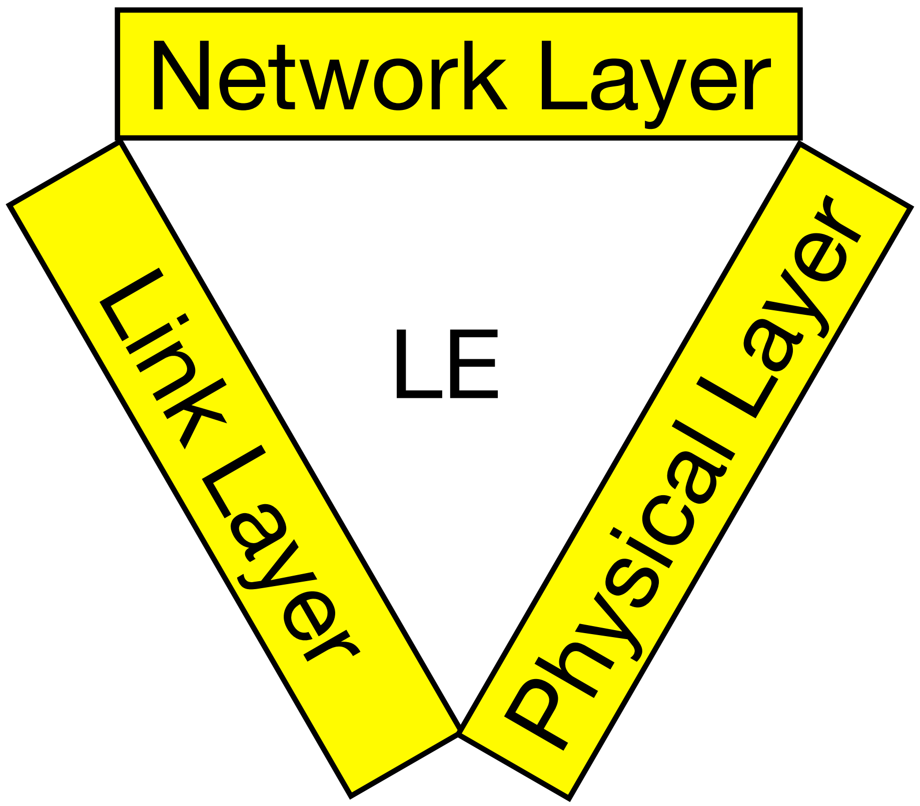
Scope

- Identify the information different layers of the stack can provide
- Define a narrow interface between the layers and the link estimator
- Describe an accurate and efficient estimator implemented using the four bit interface

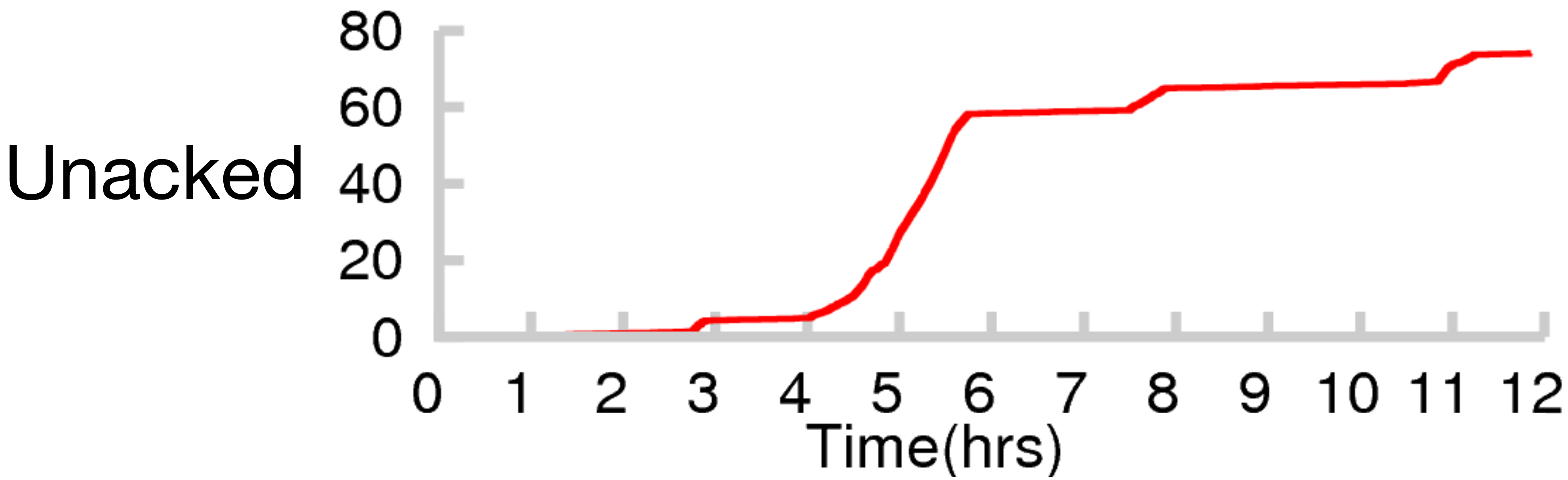


Layers and Information

- **Better estimator with information from different layers?**
  - Physical Layer - packet decoding quality
  - Link Layer - packet acknowledgements
  - Network Layer - relative importance of links



PHY Info Not Sufficient



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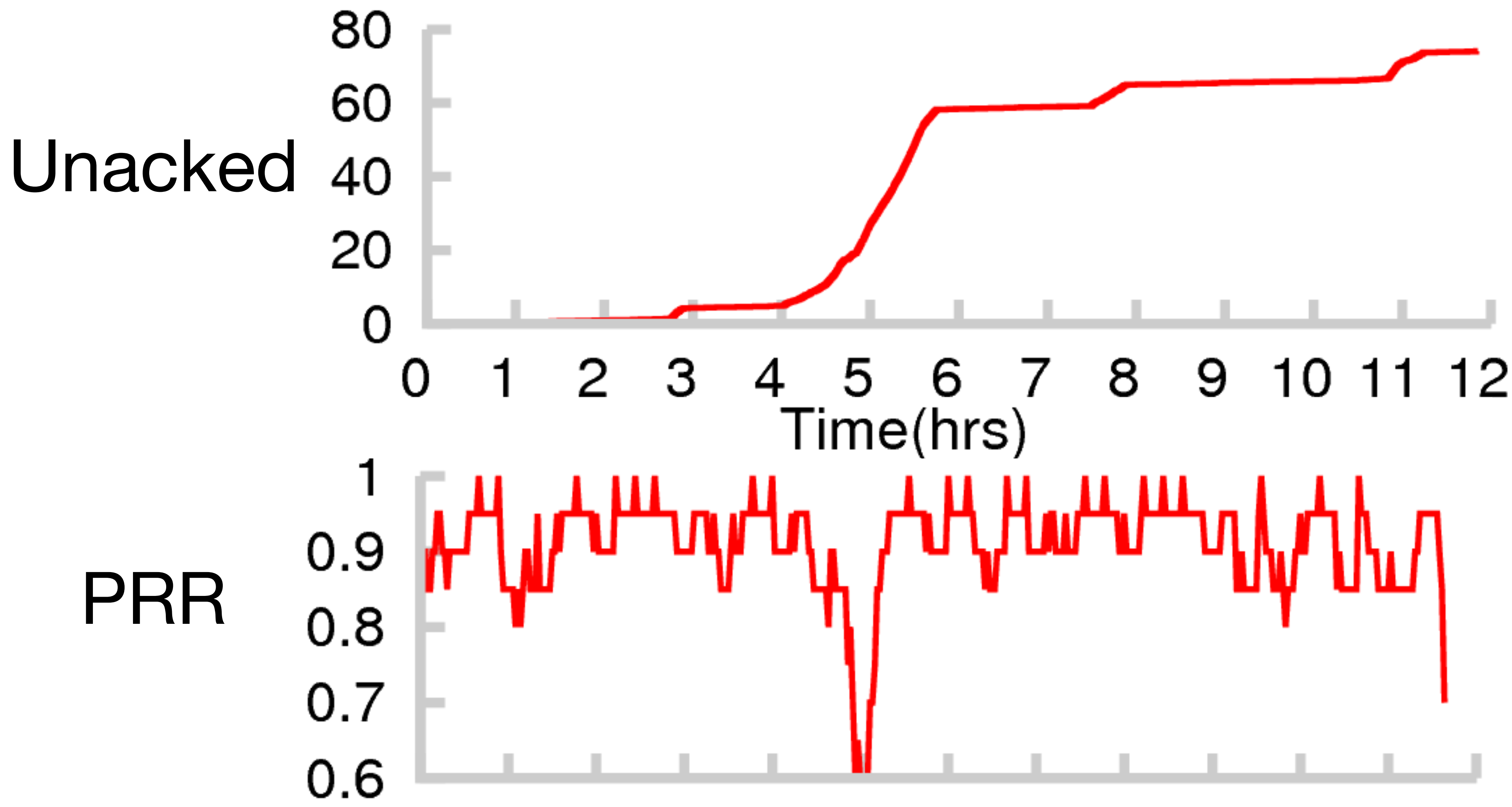

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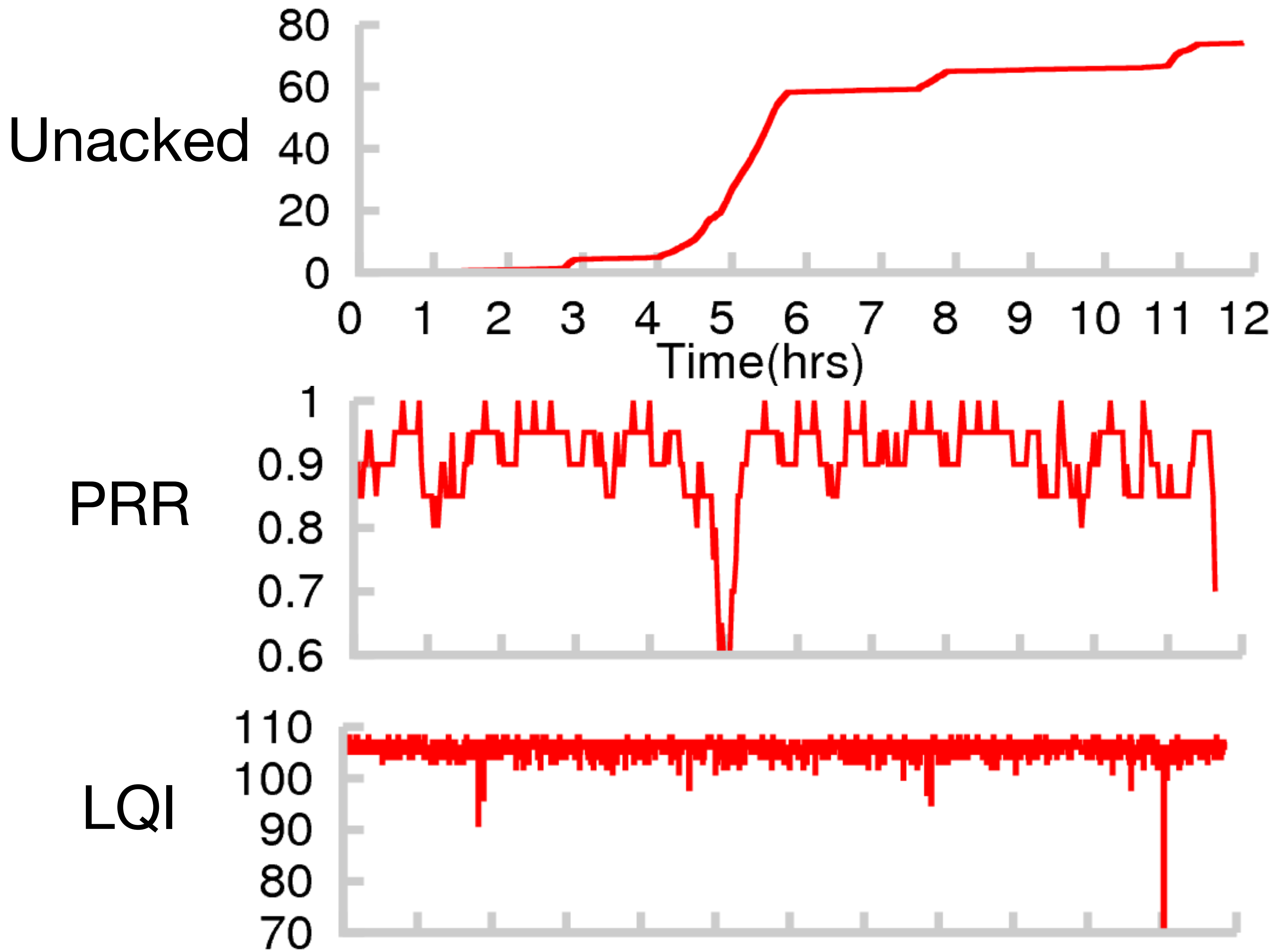

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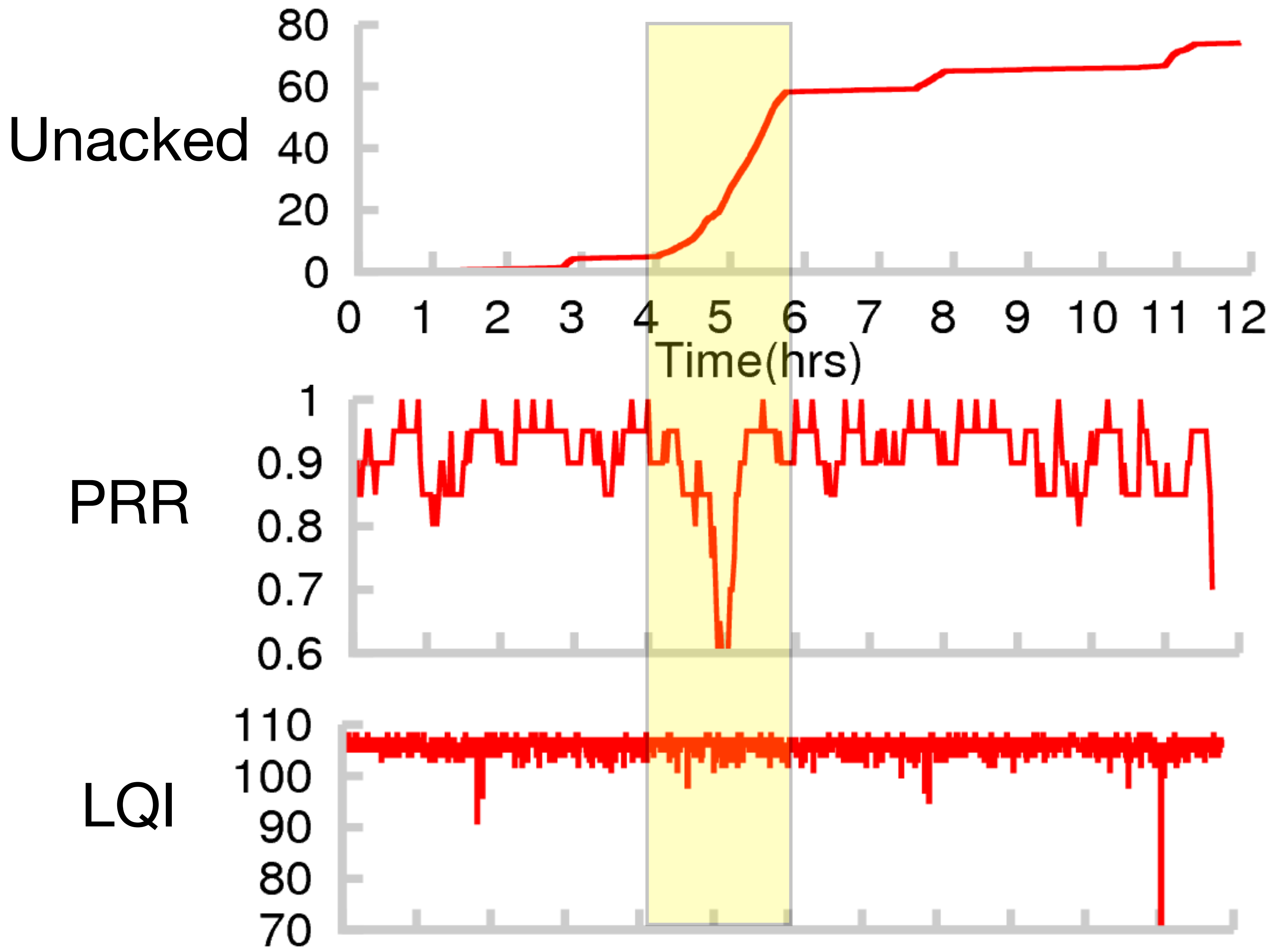

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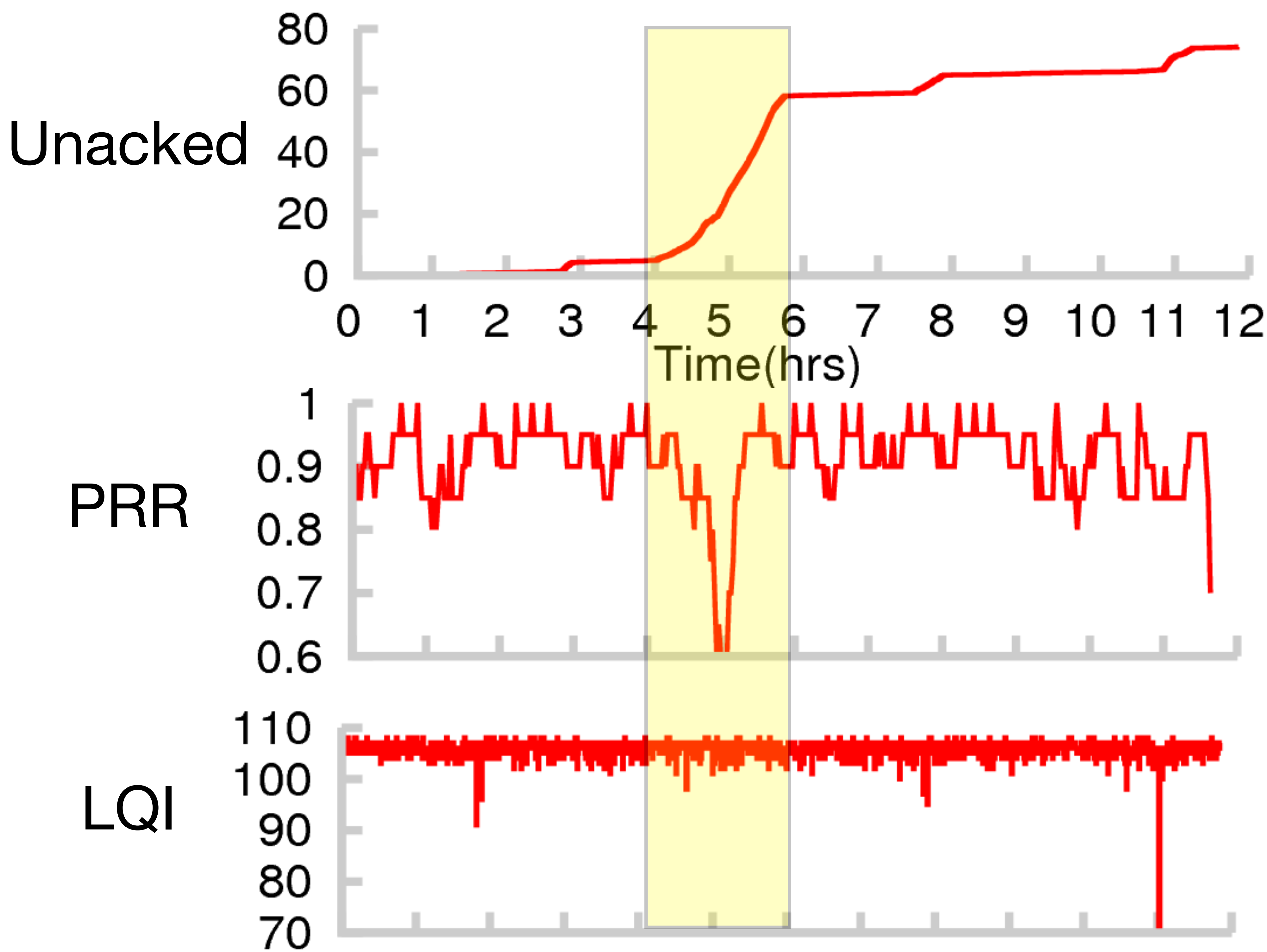
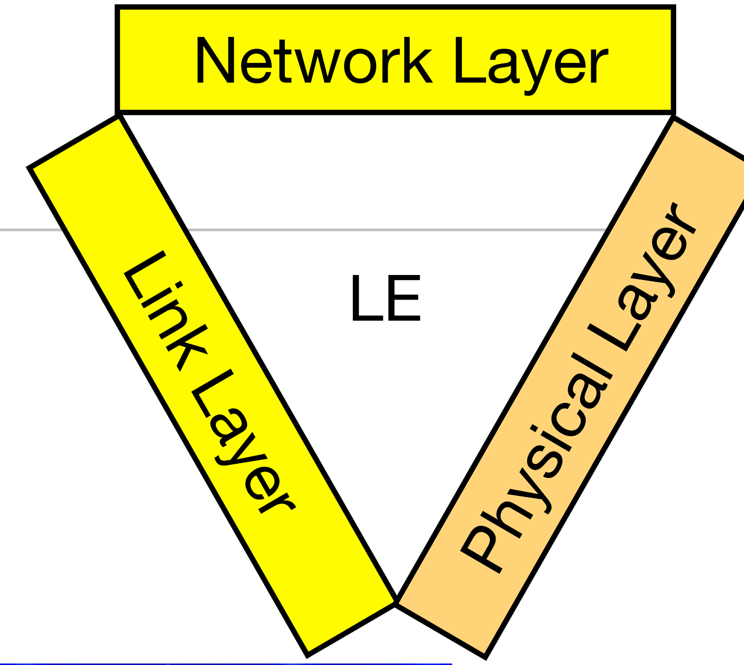


PHY can measure the RSSI/LQI of received pkts

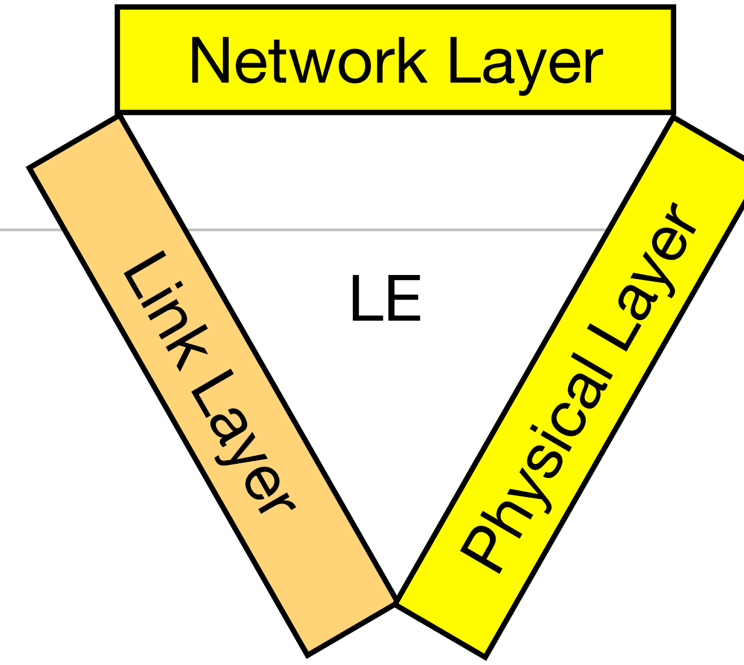
Physical Layer

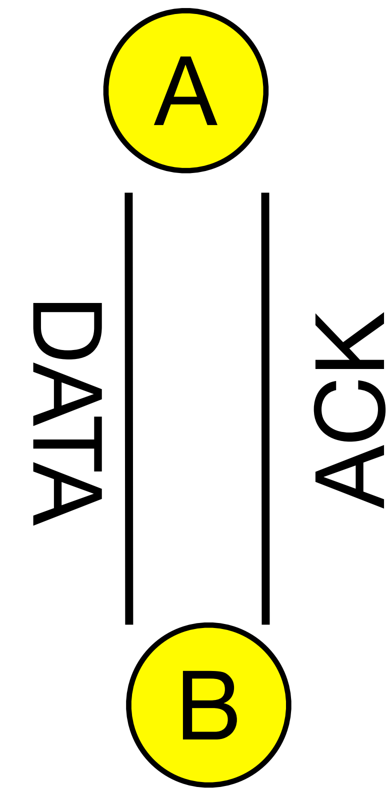


- **Decoding Quality**
  - Agile
  - Free
  - Asymmetric (receive) quality
  - Radio-specific
- **Examples**
  - LQI, RSSI, SNR

Link Layer

- **Outcome of unicast packet transmission**
- **Higher quality links**
  - Successful TX
  - Successful ACK reception
- **Example**
  - EAR [Mobicom 2006]

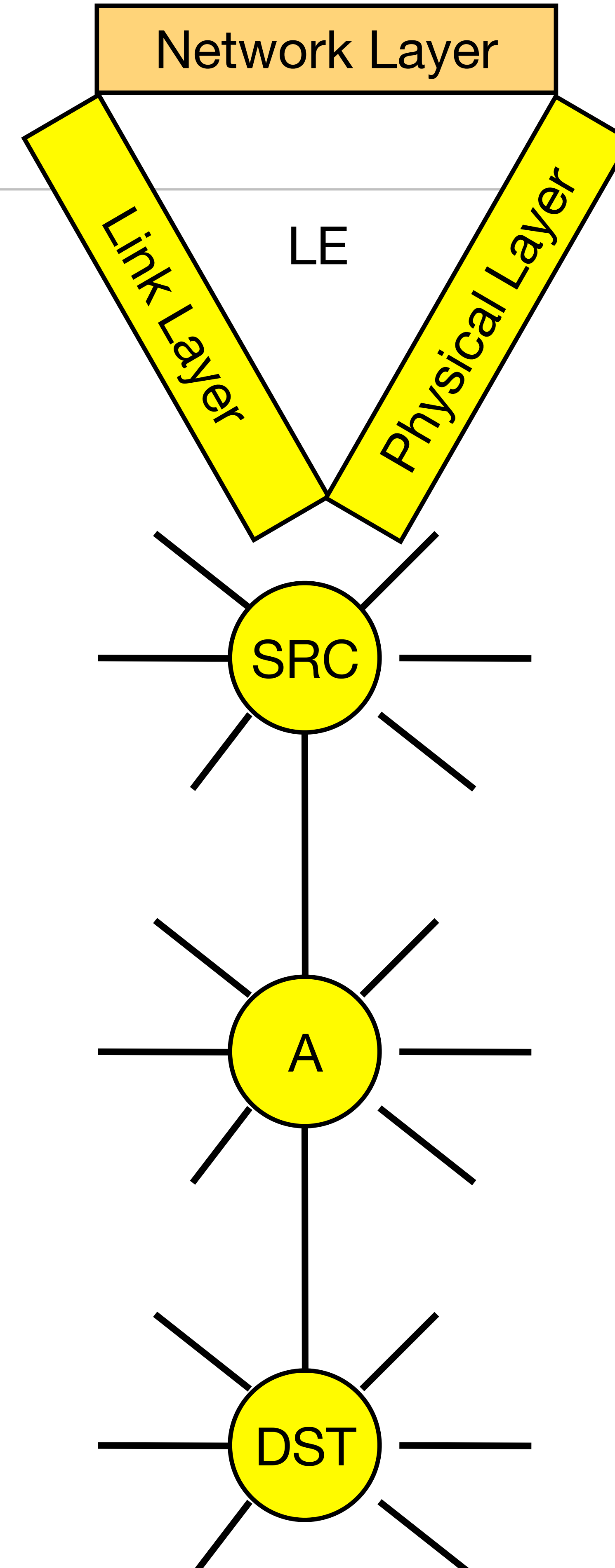




Network Layer

- **Is a link useful?**
- **Keep useful links in the table**

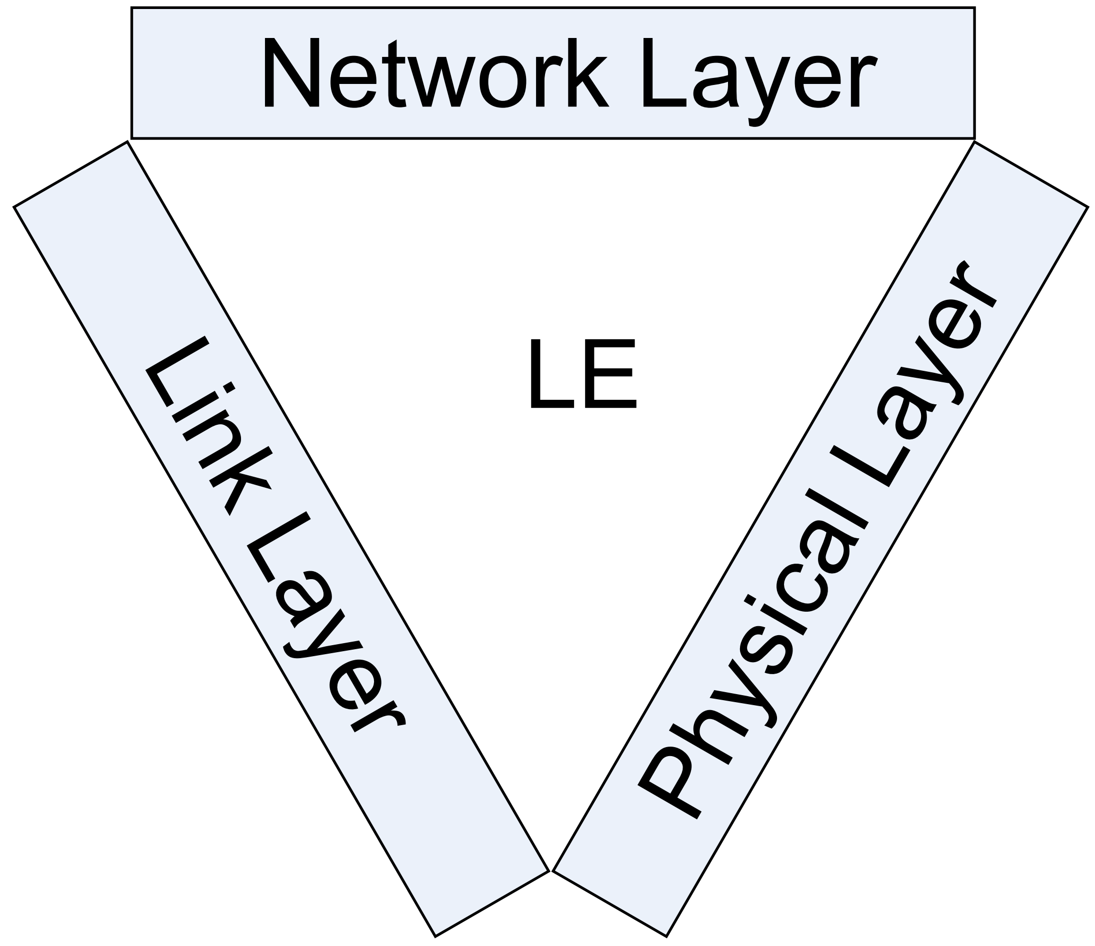
- **Network layer decides**
  - Geographic routing
    - Geographically diverse links
  - Collection
    - Link to the parent
    - Link on a good path



The Interfaces

LE

The Interfaces



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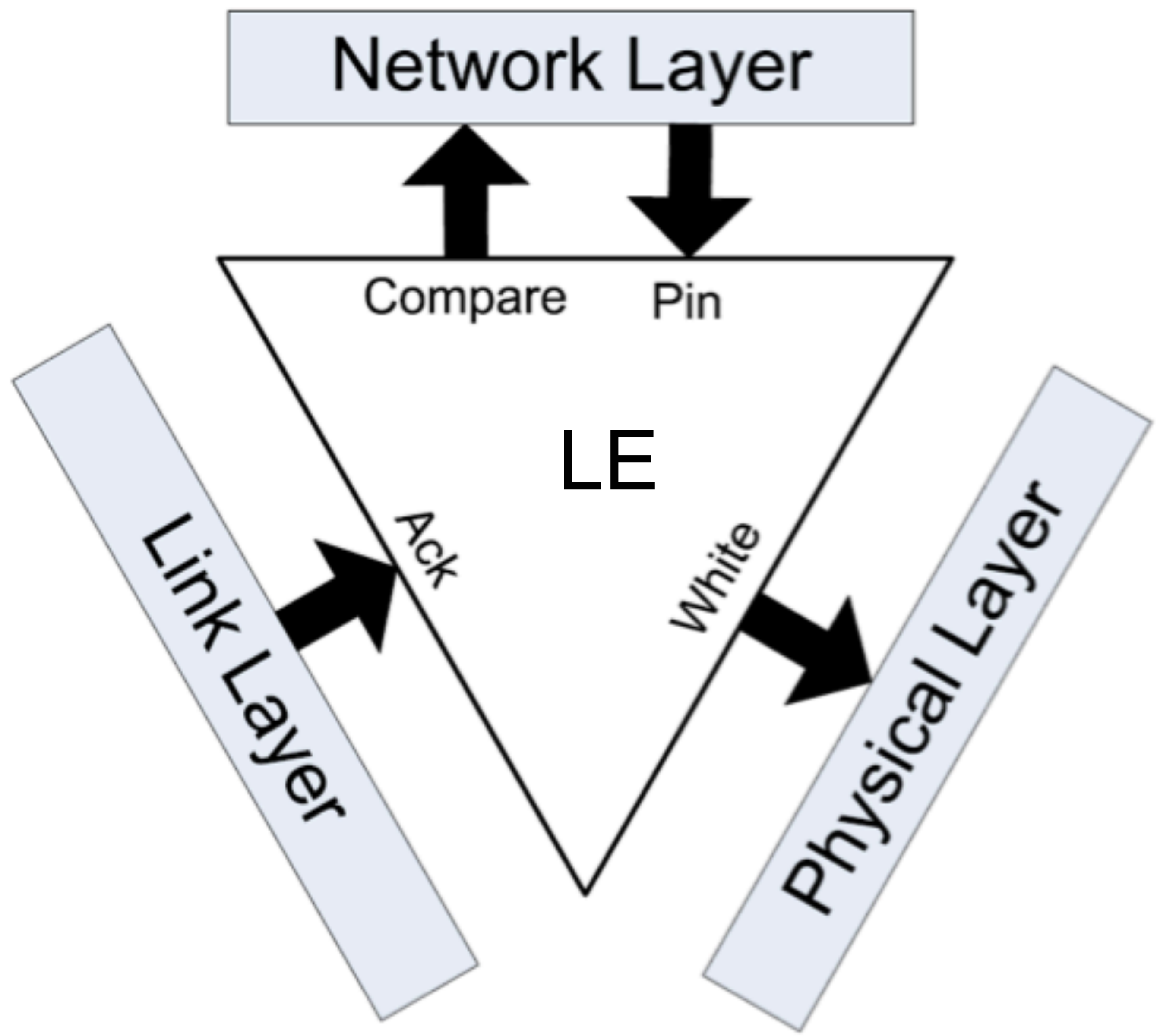

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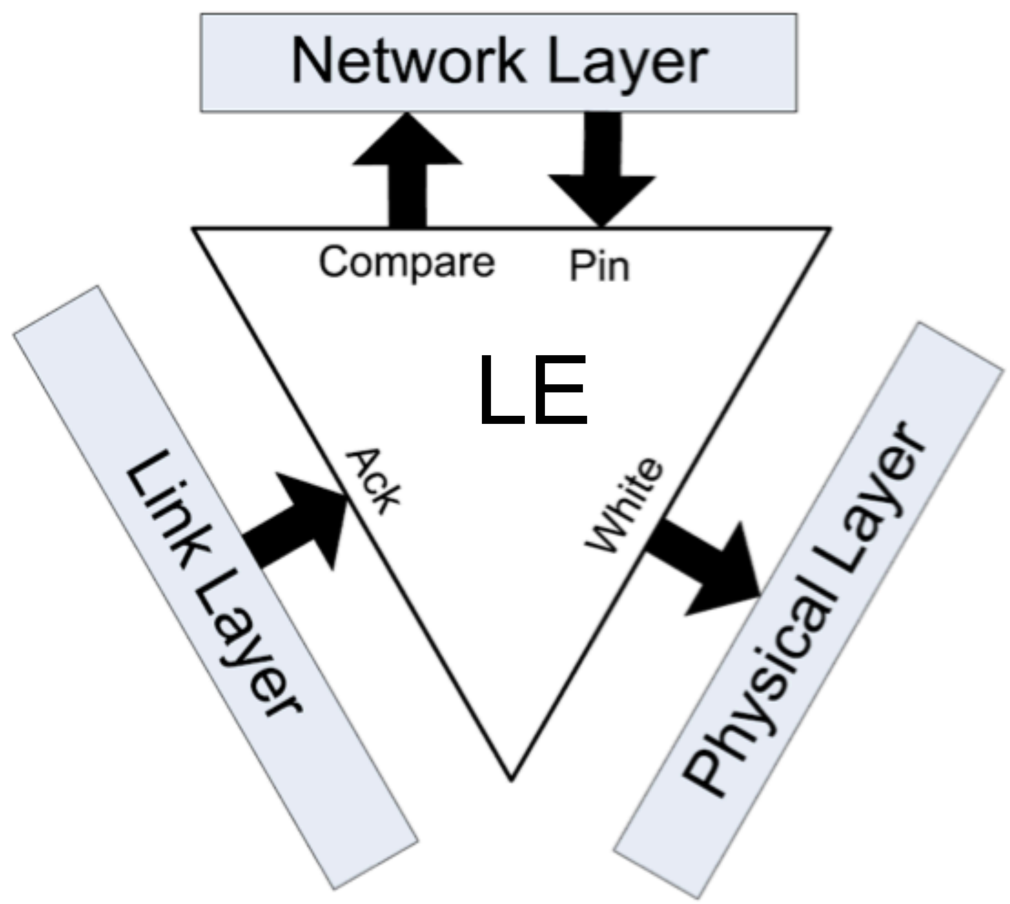
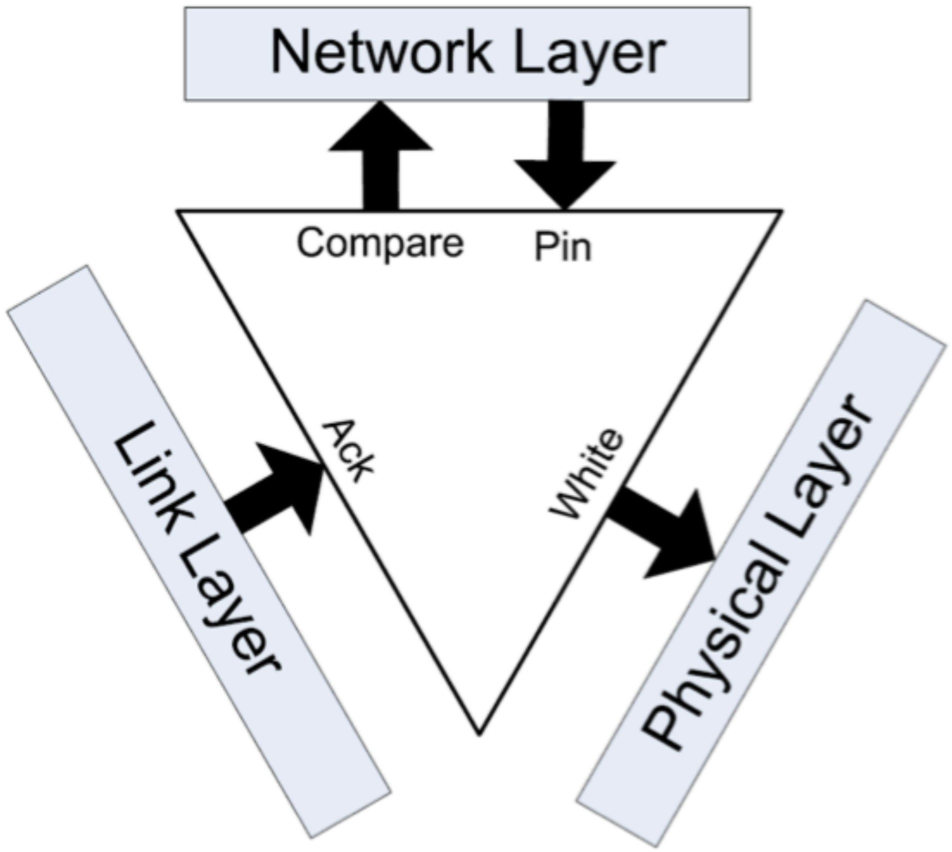


Interface Details



PIN

Keep this link in the table

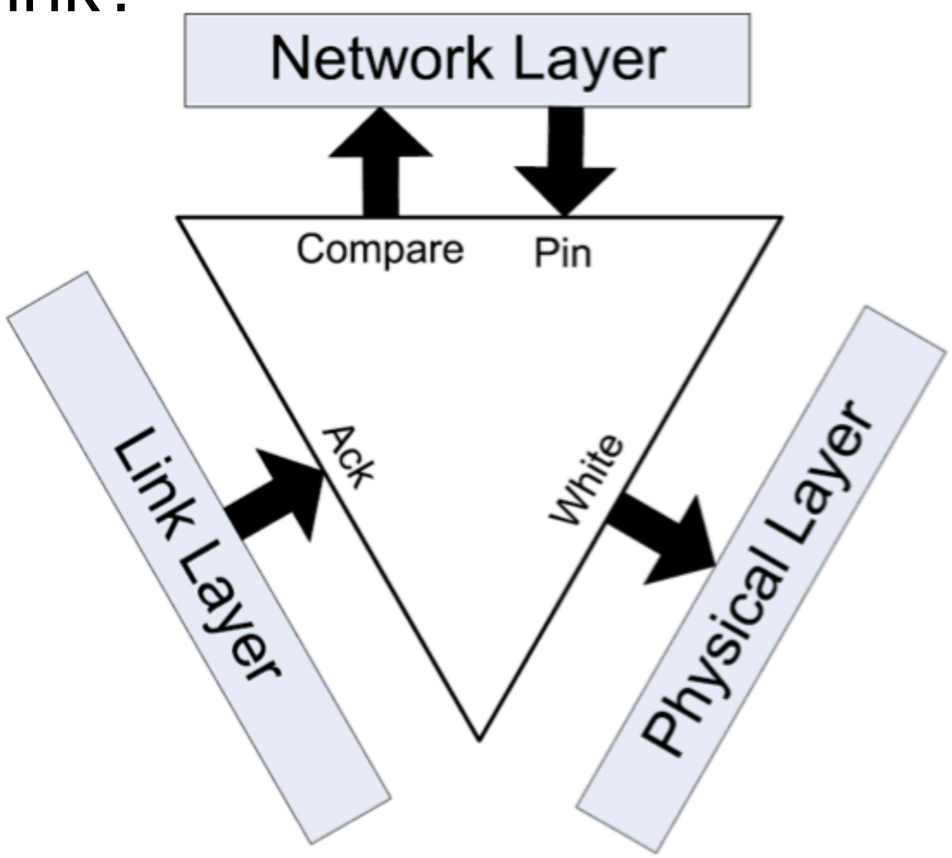
Interface Details

COMPARE

Is this a useful link?

PIN

Keep this link in the table



Interface Details

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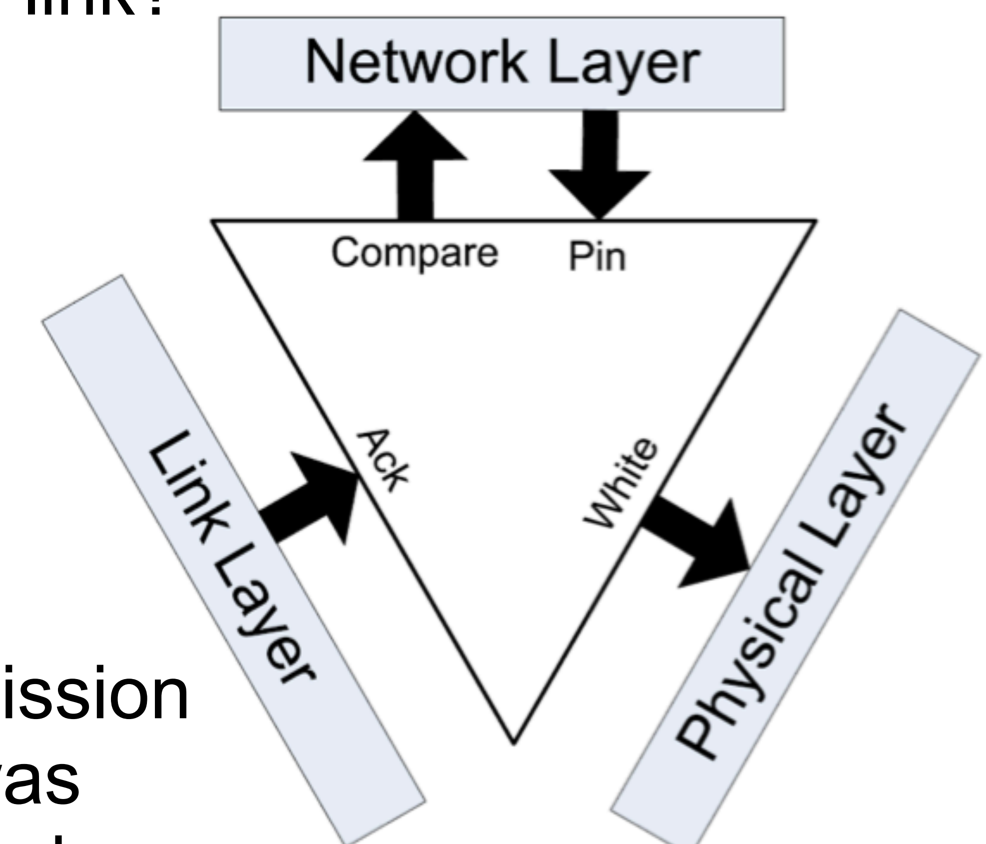

ACK
A packet transmission on this link was acknowledged

Interface Details

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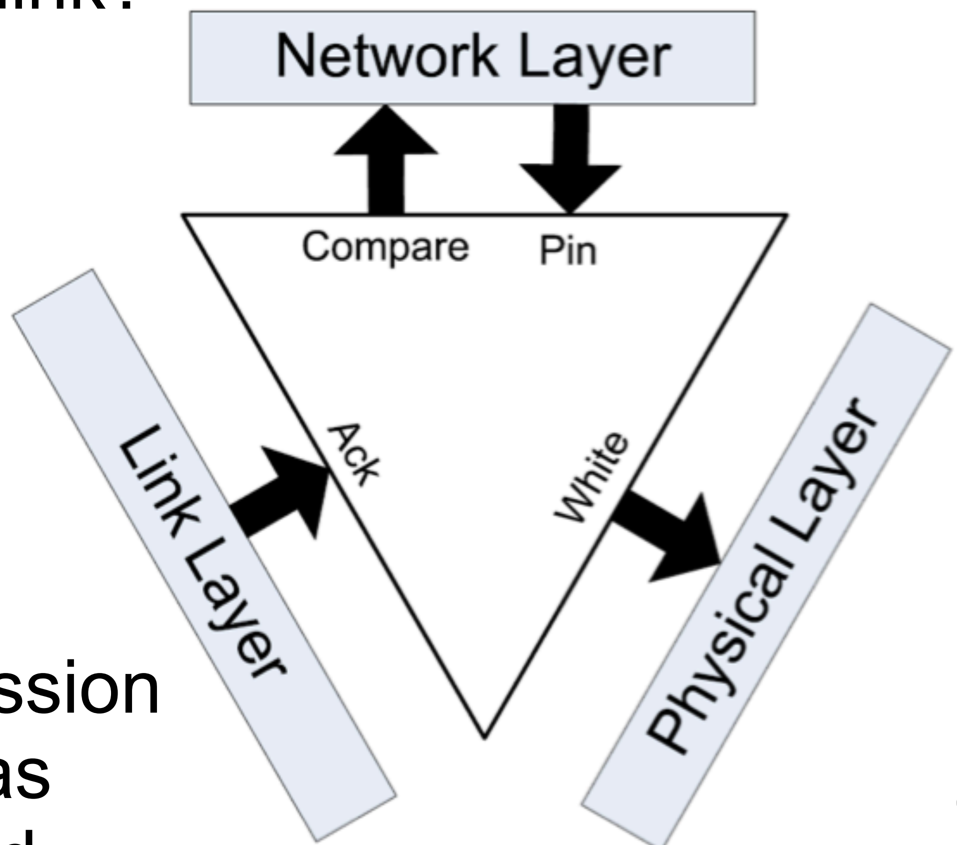
Is this a useful link?

PIN
Keep this link in the table



ACK
A packet transmission on this link was acknowledged

WHITE
Packets on this channel experience few errors

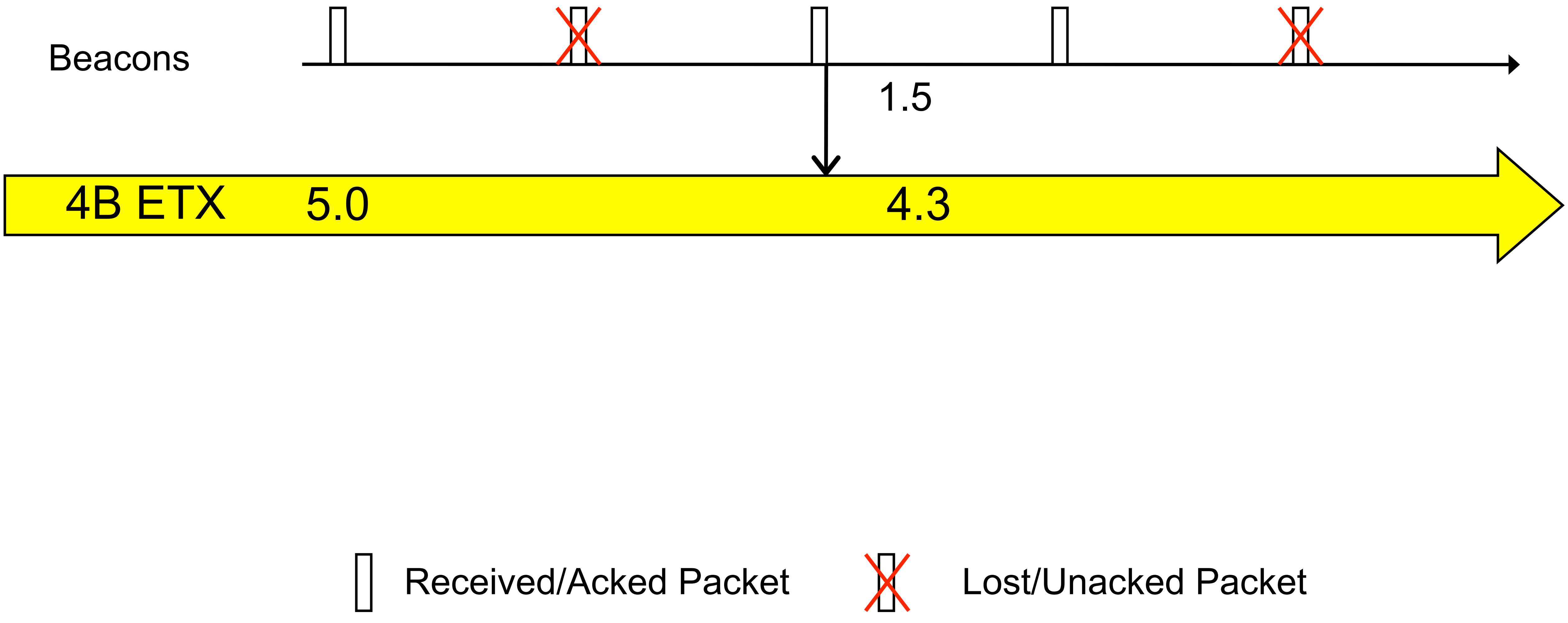
The 4-bit link estimator

The 4-bit link estimator

- **Combines information from data packets and beacons**
- **Uses feedback from the**
  - phy layer - white-list a link as having low prob. of decoding errors
  - link layer - acknowledgments
  - network - what links to estimate

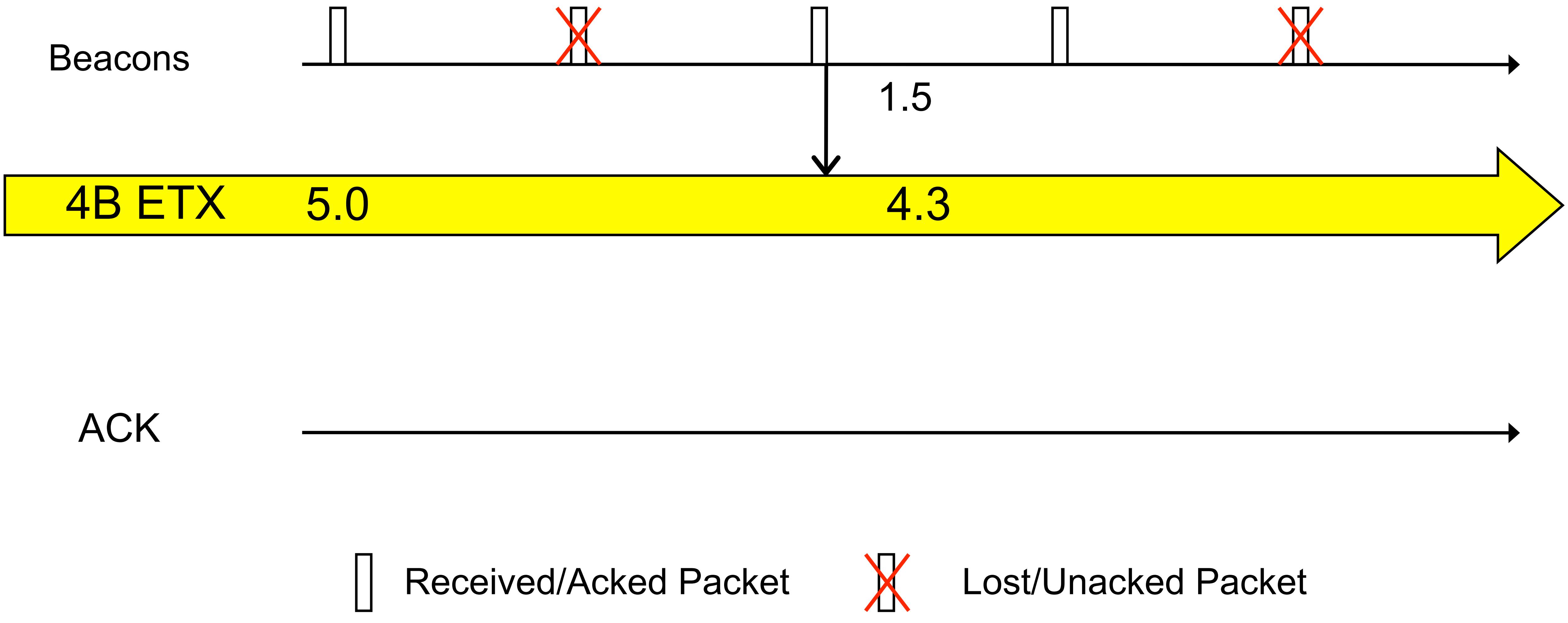
- **Hybrid estimator**
  - ETX for unicast packets: window size / num of acked unicast pkts
  - Beacon packets: EWMA(window size/num of received beacons)
  - Combined using: EWMA

Using ACK



Beacons
1.5
4B ETX
5.0
4.3
Received/Acked Packet
Lost/Unacked Packet

Using ACK



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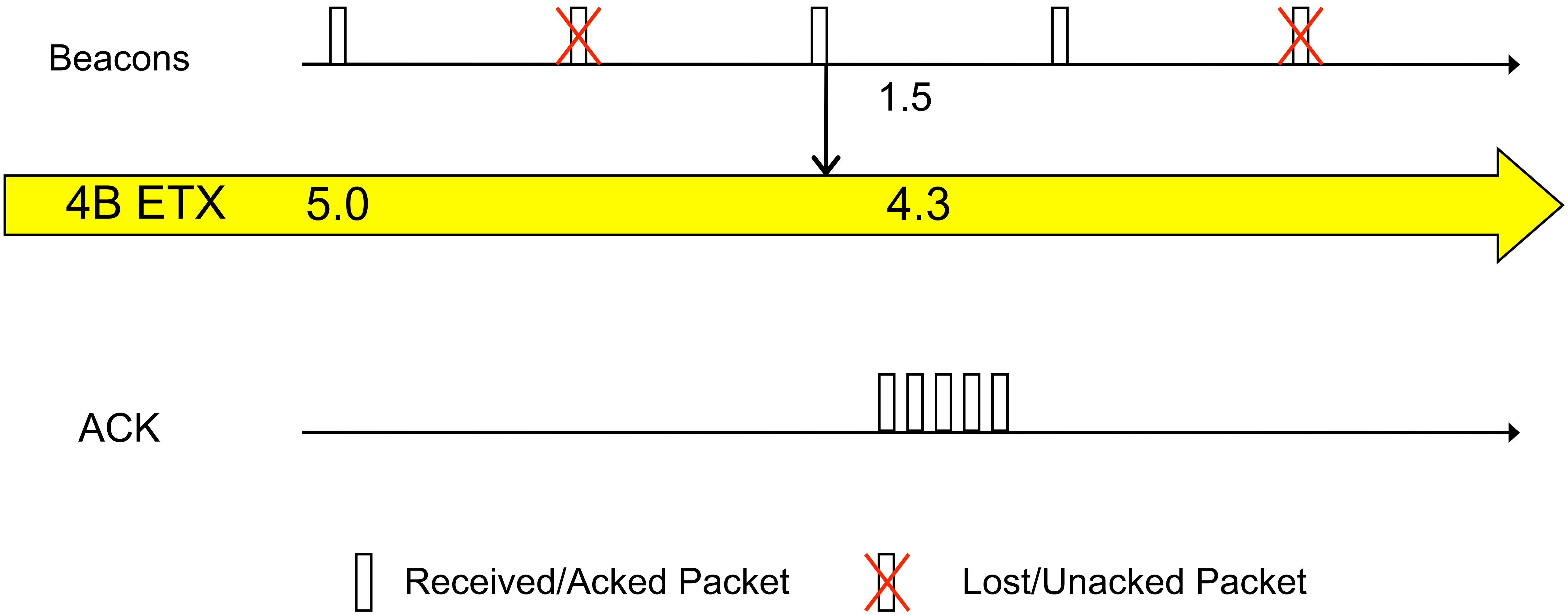

Beacons
1.5
4B ETX
5.0
4.3
ACK
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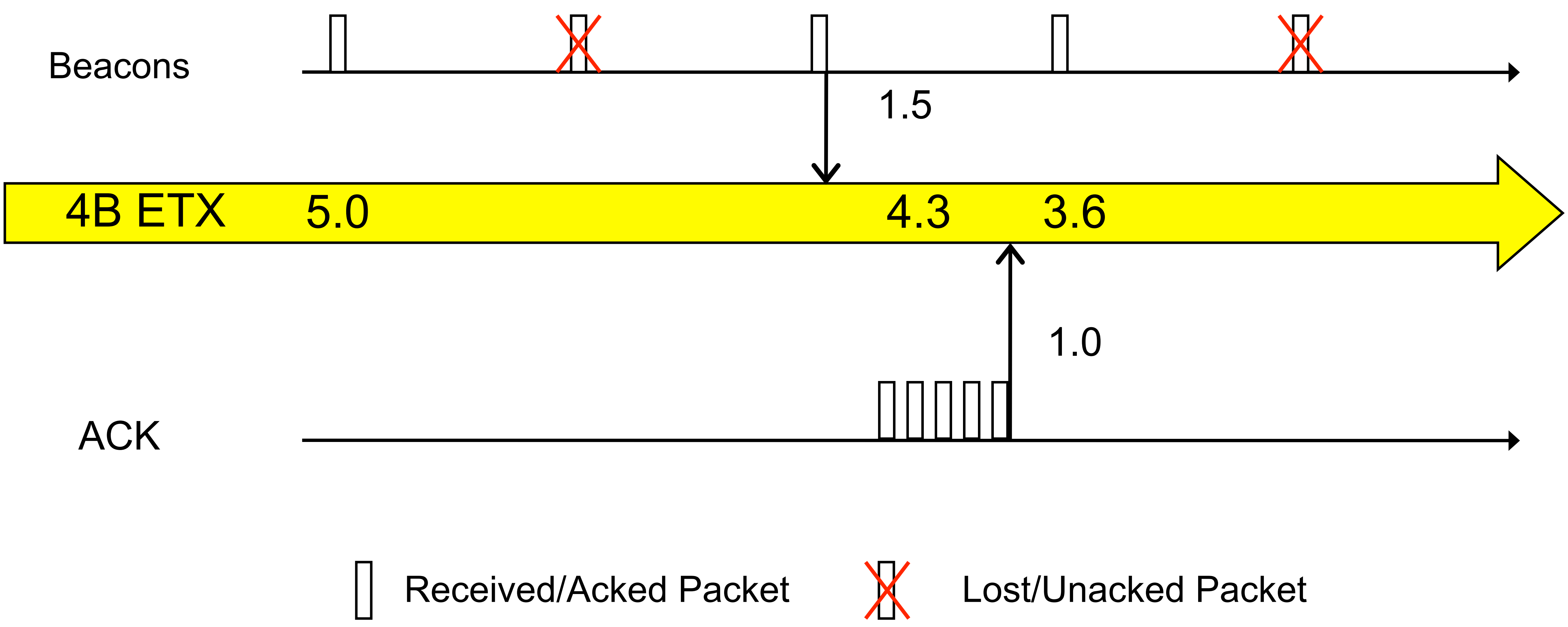
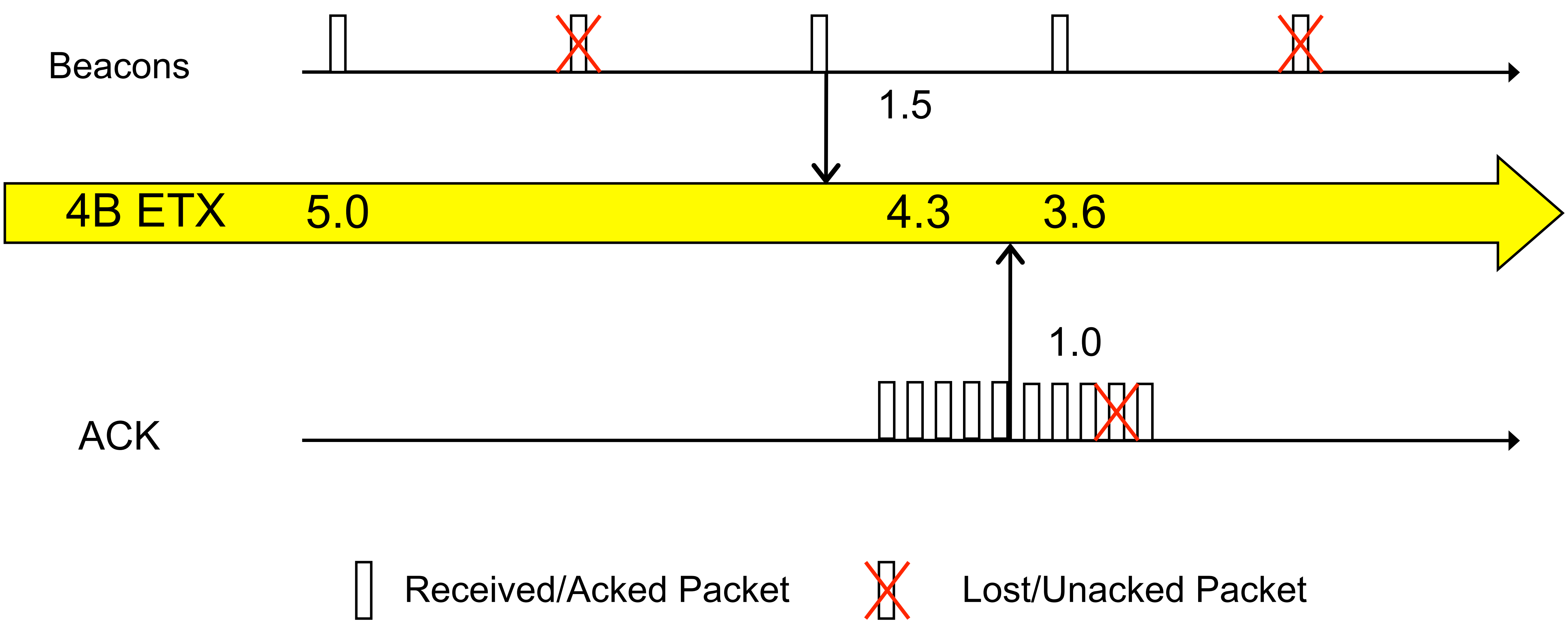
Lost/Unacked Packet

Using ACK



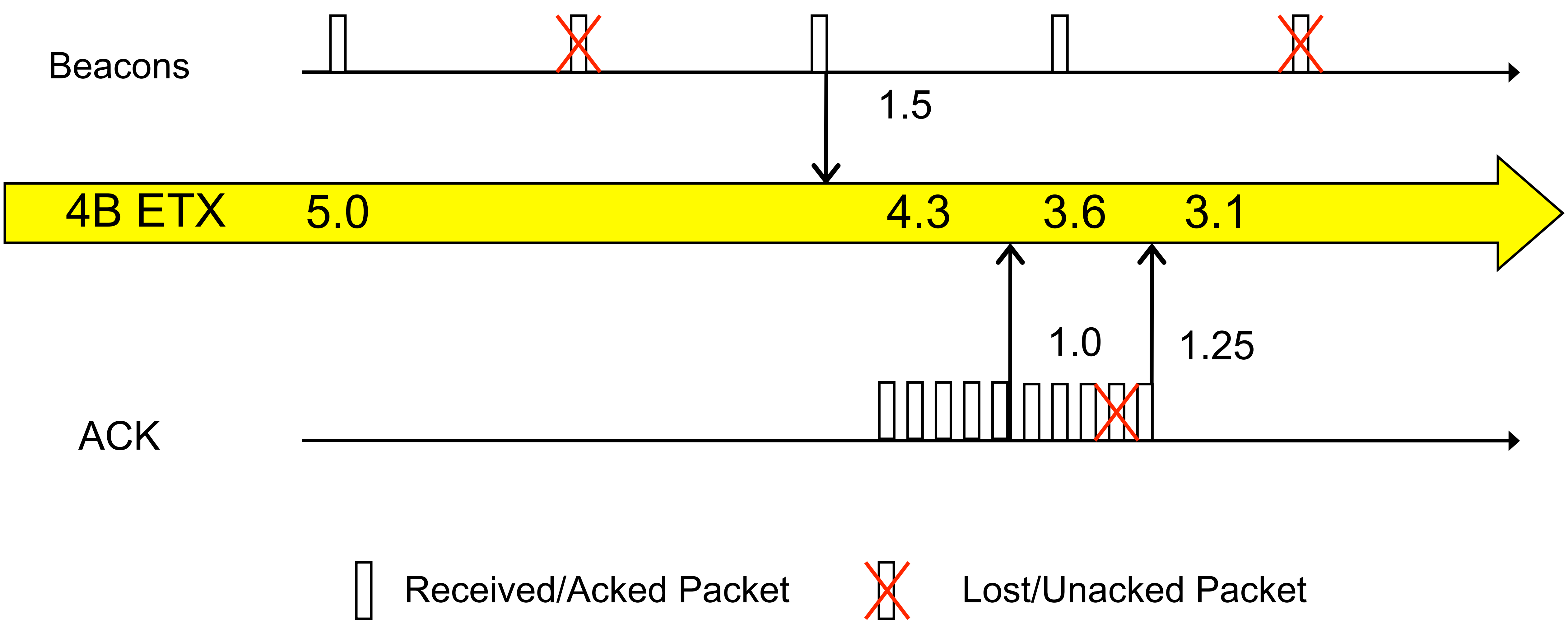
Beacons
1.5
4B ETX
5.0
4.3
3.6
1.0
ACK
Received/Acked Packet
Lost/Unacked Packet

Using ACK



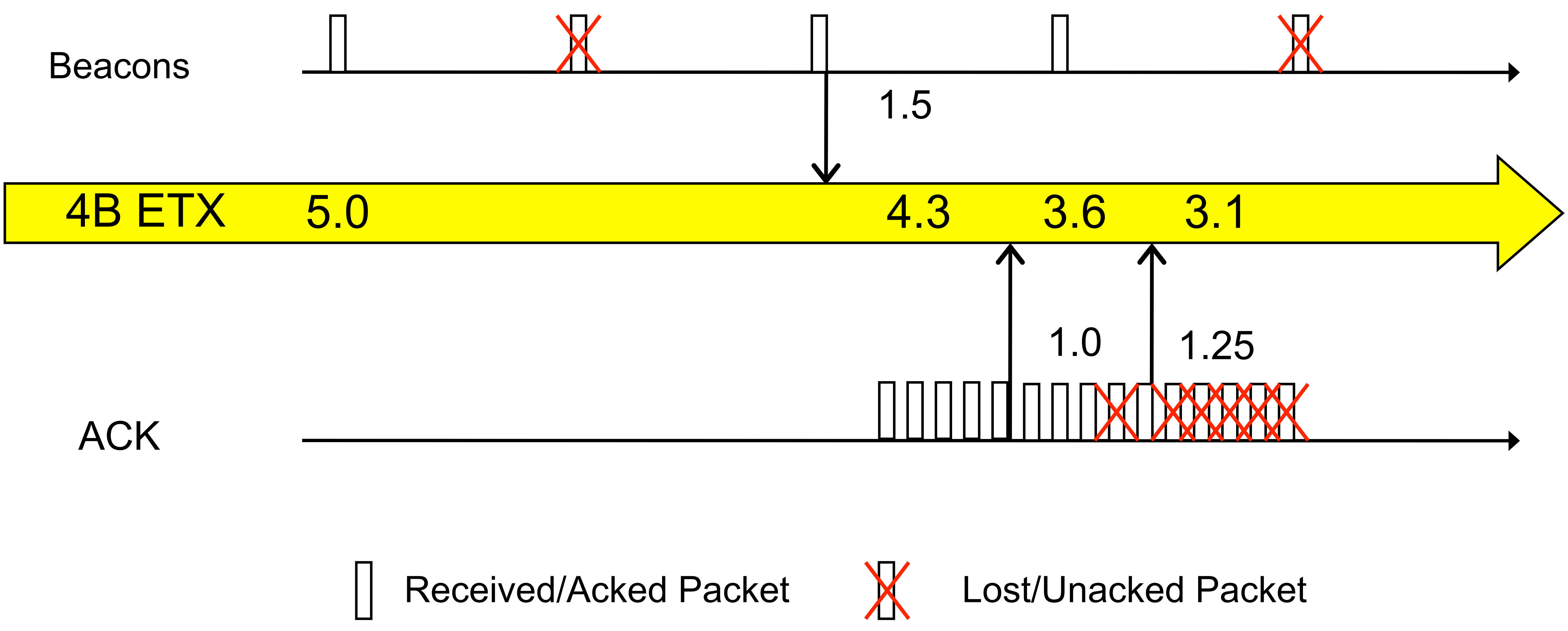
Beacons
1.5
4B ETX
5.0
4.3
3.6
1.0
ACK
Received/Acked Packet
Lost/Unacked Packet

Using ACK



Beacons
1.5
4B ETX
5.0
4.3
3.6
3.1
1.0
1.25
ACK
Received/Acked Packet
Lost/Unacked Packet

Using ACK



Beacons
1.5
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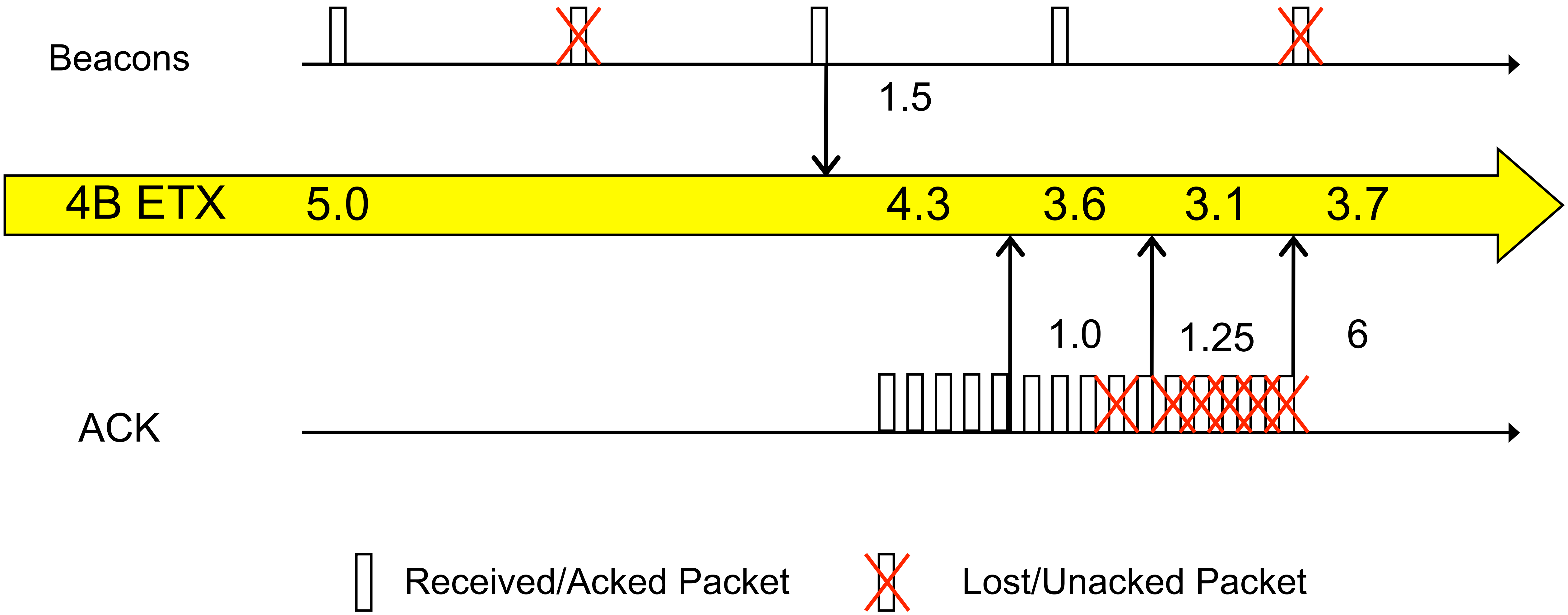
5.0
4.3
3.6
3.1
1.0
1.25
ACK
Received/Acked Packet
Lost/Unacked Packet

Using ACK



Beacons
1.5
4B ETX
5.0
4.3
3.6
3.1
3.7
1.0
1.25
6
ACK
Received/Acked Packet
Lost/Unacked Packet

Neighbor Table Management

Neighbor Table

- **Maintain link estimation statistics and routing information of each neighbor**
- **Issue:**
  - Density can be high but memory is limited
  - At high density, many links are poor or asymmetric
- **Question:**
  - Can we use constant memory to maintain a set of good neighbors regardless of cell density?
  - when table becomes full,
    - should we add new neighbor?
    - If so, evict which old neighbor?

Management Algorithm: FREQUENCY

- **When we hear a node, if**
  - In table: increment a counter for this node
  - Not in table
    - Insert if table is not full
    - down-sample if table is full
      - down-sample scheme: $$P_{insert} = \frac{\text{table size } T}{\text{\# of neighbours } N}$$
      - If successful, insert only if some nodes can be evicted
- **Eviction: (FREQUENCY)**
  - Decrement counter for each table entry
  - Nodes with counter = 0 can be evicted
    - Otherwise, all nodes stay in the table

FREQUENCY is very effective

- **utilize 50% to 70% of the table space to maintain a set of good neighbors**
- **Even for densities much greater than the table size**

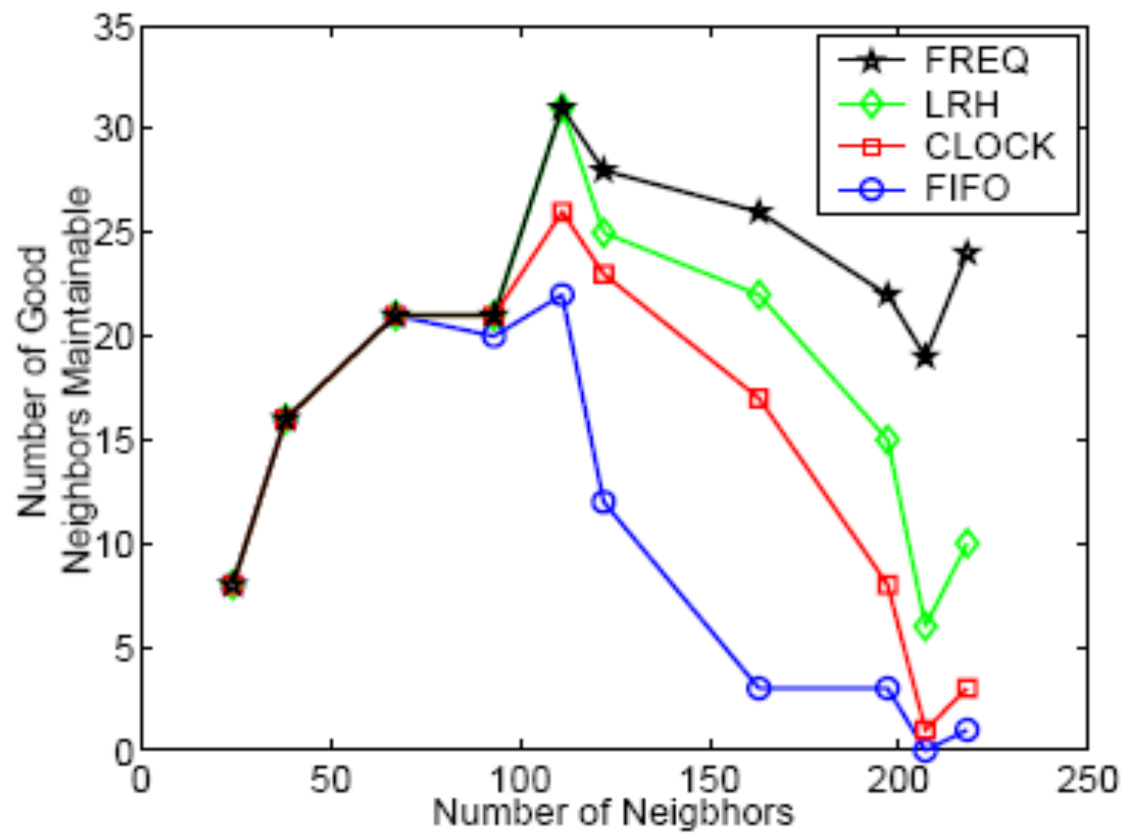


Figure 5: Number of good neighbors maintainable at different densities with a table size of 40 entries.

Good neighbor: nodes most useful for routing