CSMA-CA vs TSCH Orchestra

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Project

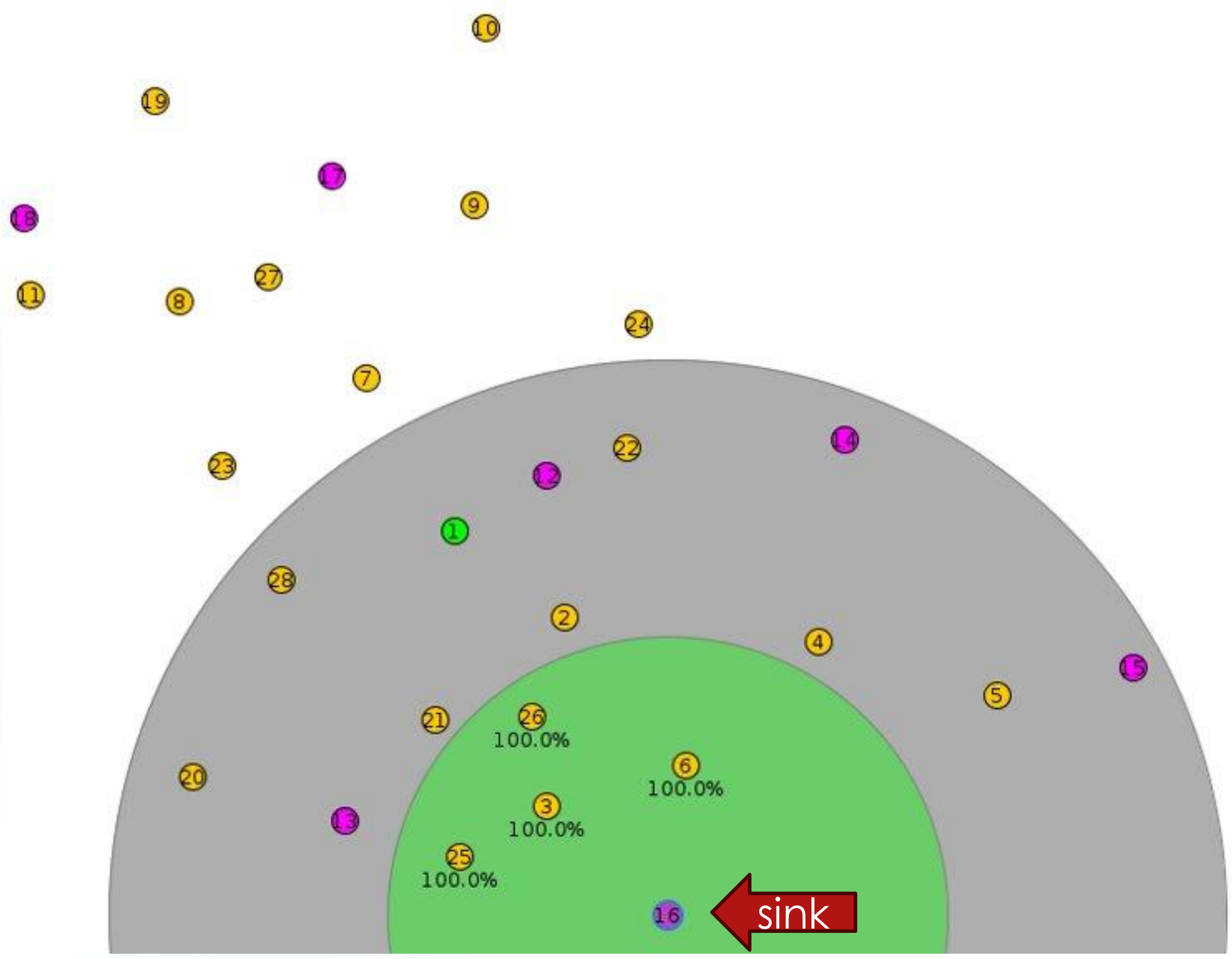
- Goal- Compare two MAC protocols in WSN
  - Unslotted CSMA-CA
  - TSCH with Orchestra Scheduler

- Focus metrics
  - Packet Delivery Ratio (PDR)
  - **Latency**
  - **Throughput**

- Objective

Evaluate performance and **breaking point** under **increasing** network **load**.

EXPERIMENTAL WSN SETUP

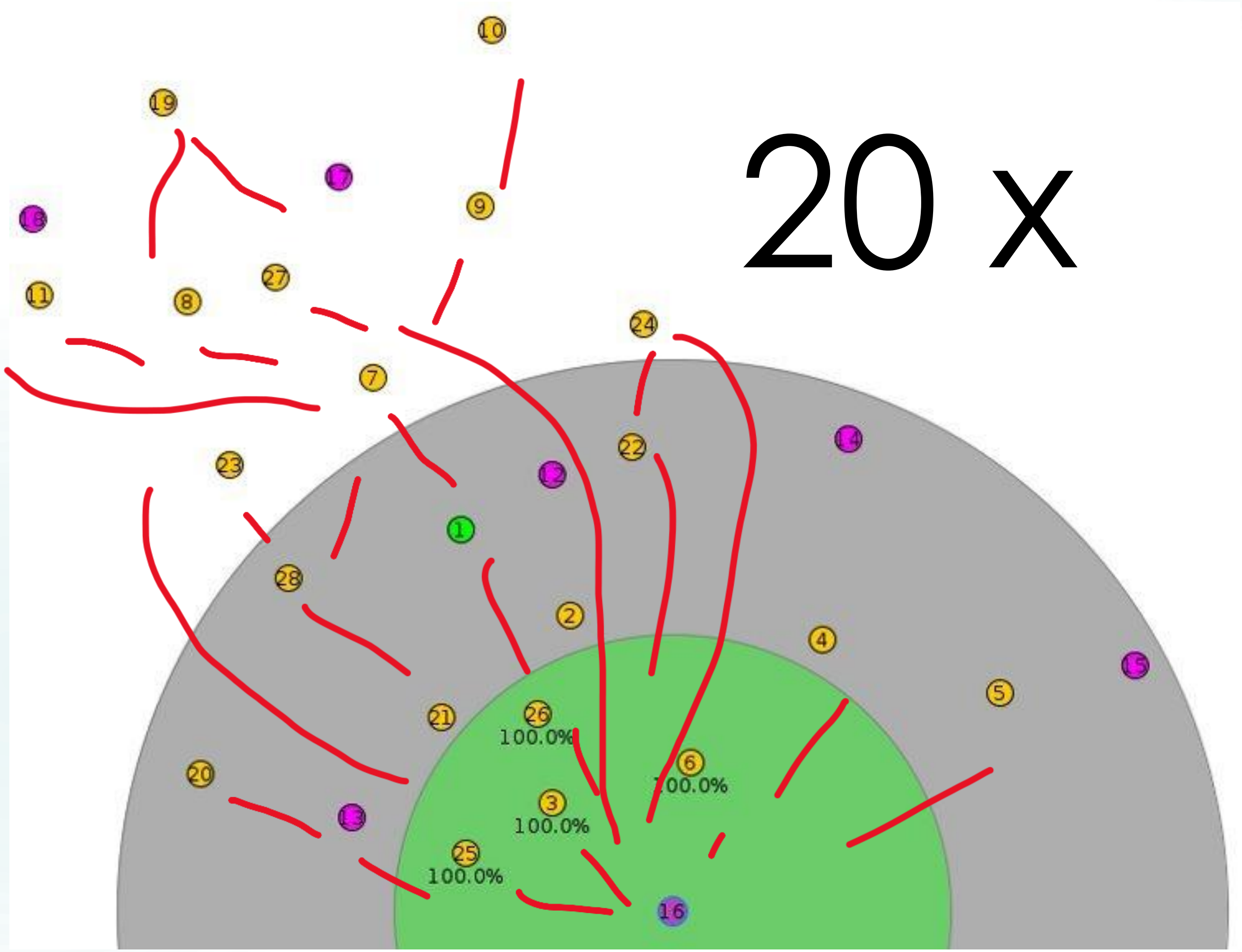


Multi-tier star, acting as a Mesh WSN

- 20 senders
- (6 receivers)
- 1 sink
- 1 root

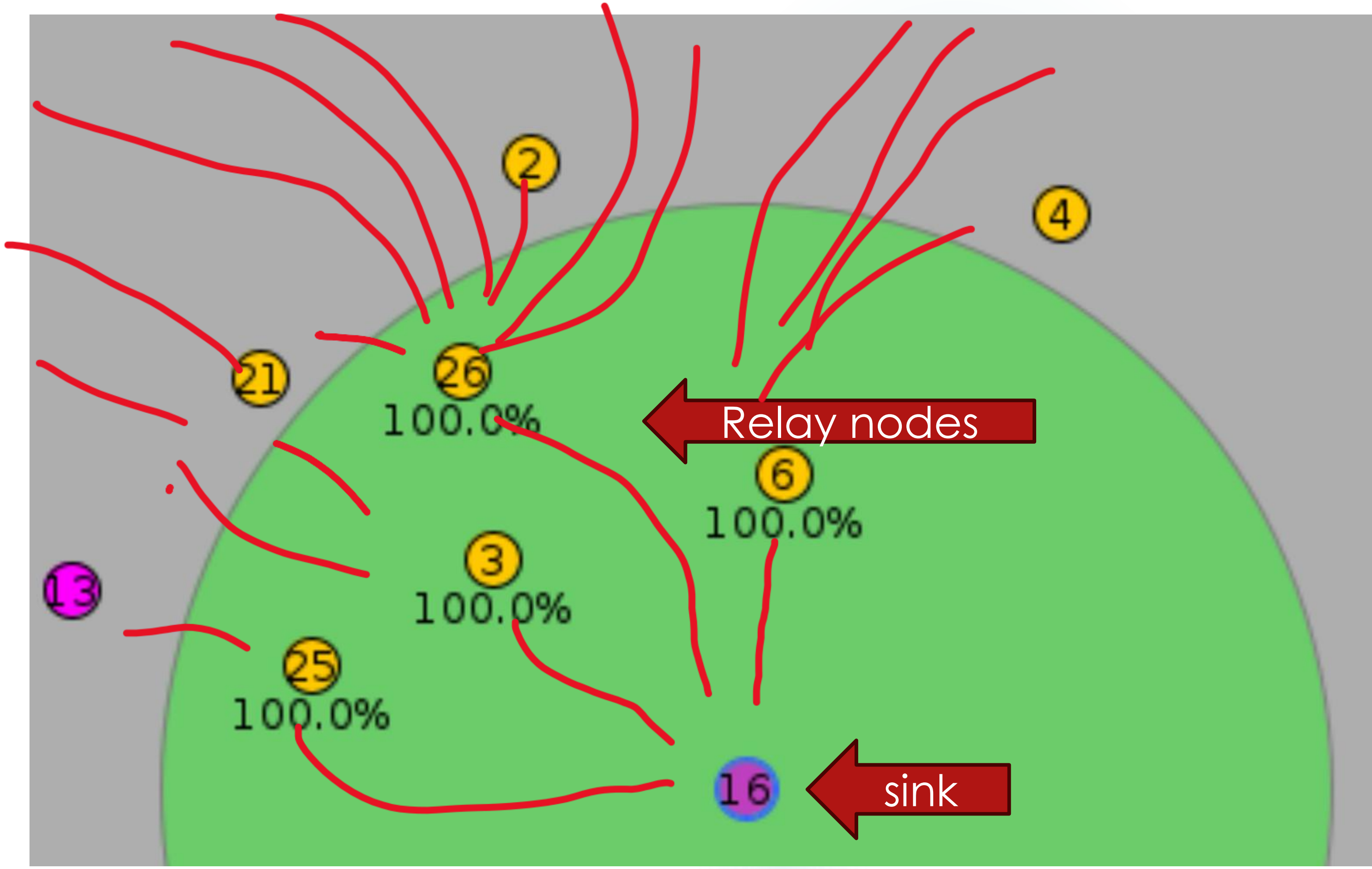
Problem!

Networks start sending @ 20 x messages per sending node



Role of Relay nodes

- Relay Nodes (3, 6, 25 and 26)
- 1 sink node 16

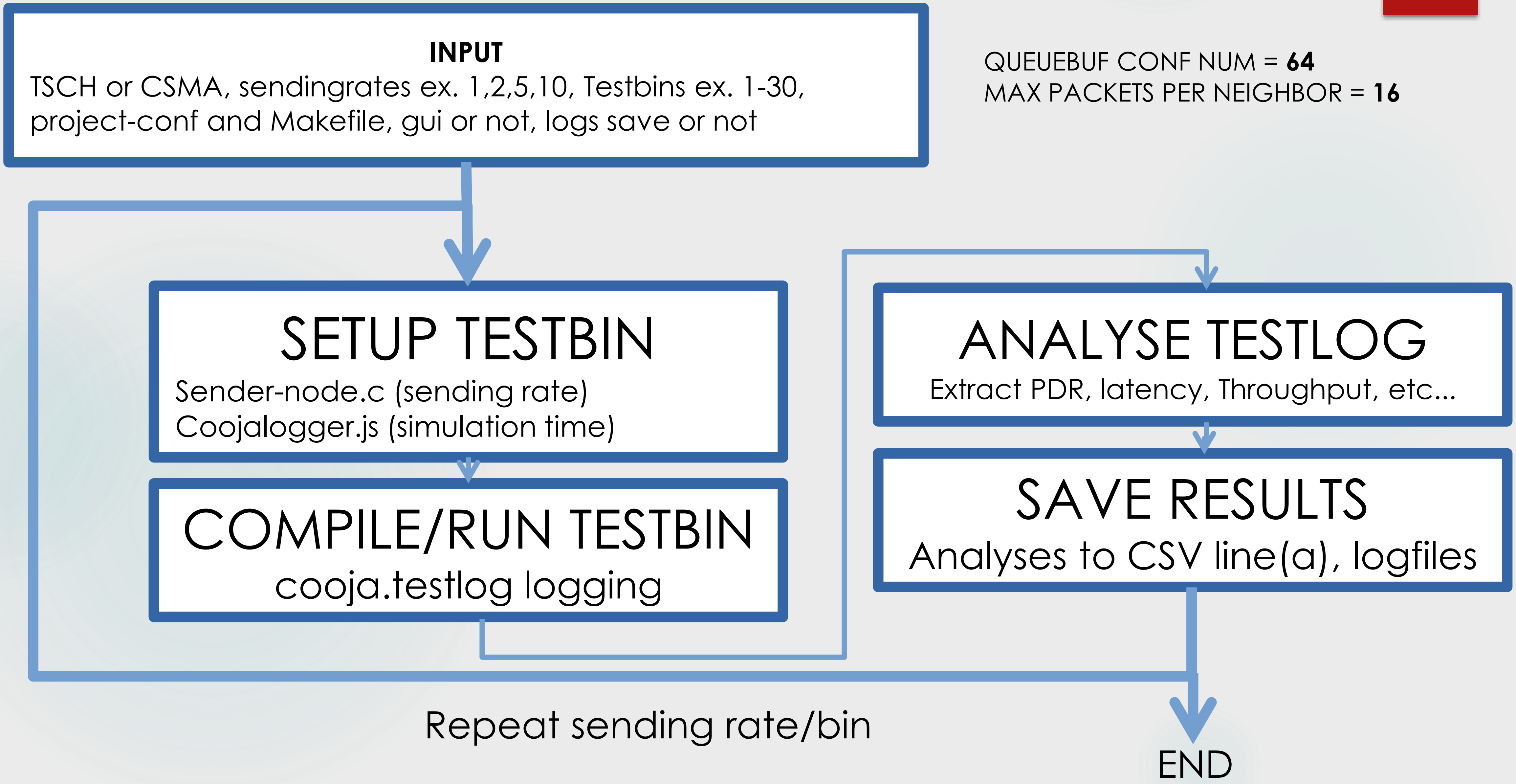


Predefined Requirements for Measurements

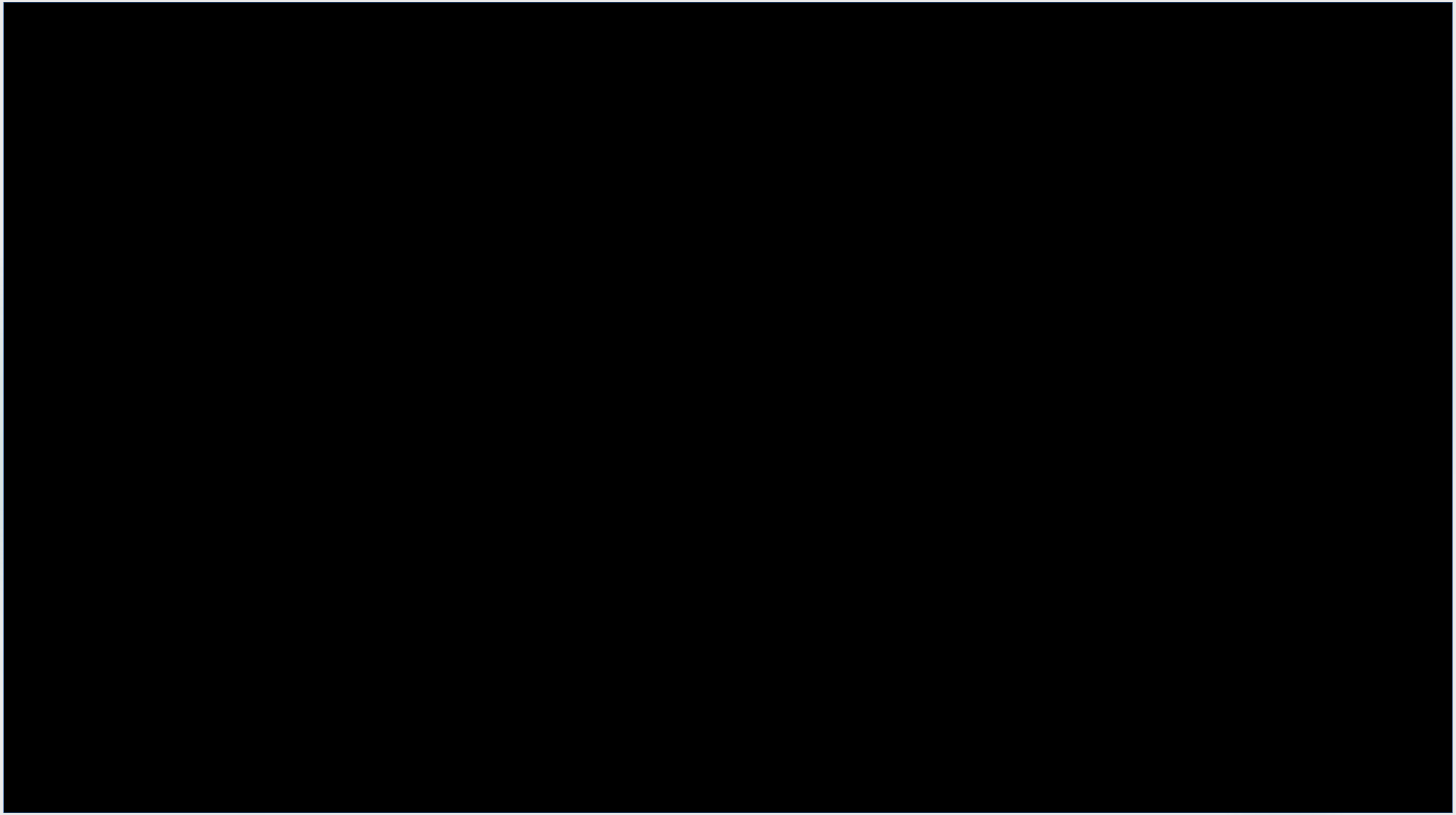
- **100% correct time measurements**
  - unique message strings
- **Netto vs bruto msg. Receiving**
  - Confirmed message transmission
- Random and statistically correct
  - At least 100 messages per sendersnode/bin
- **Realistic uniform sending pattern**
  - 100% JITTER
- **Full process, including steady state**
  - Steady state monitoring

Fully Automated process

QUEUEBUF CONF NUM = **64**
MAX PACKETS PER NEIGHBOR = **16**



Live Dashboard

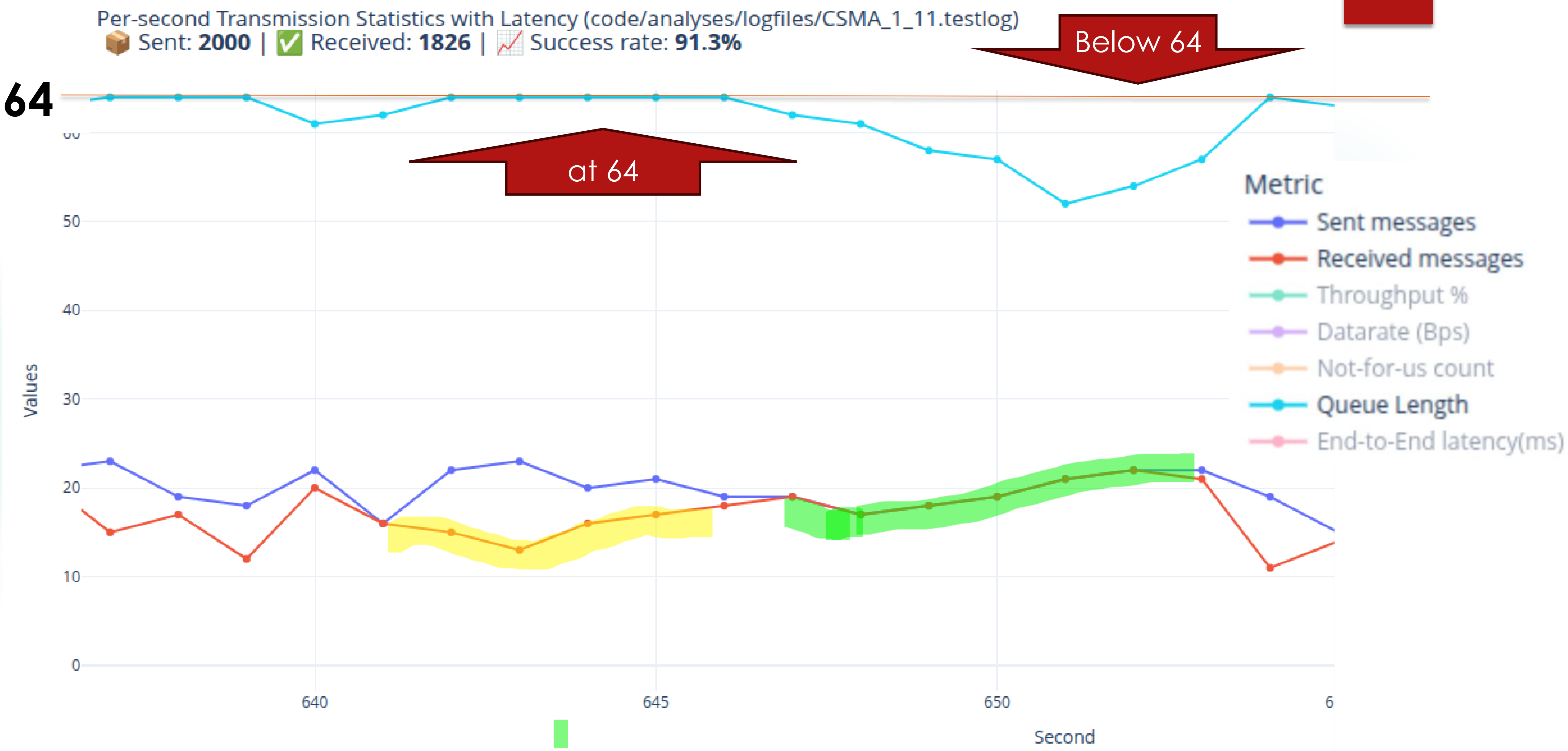


Next : Why 80% critical breaking point

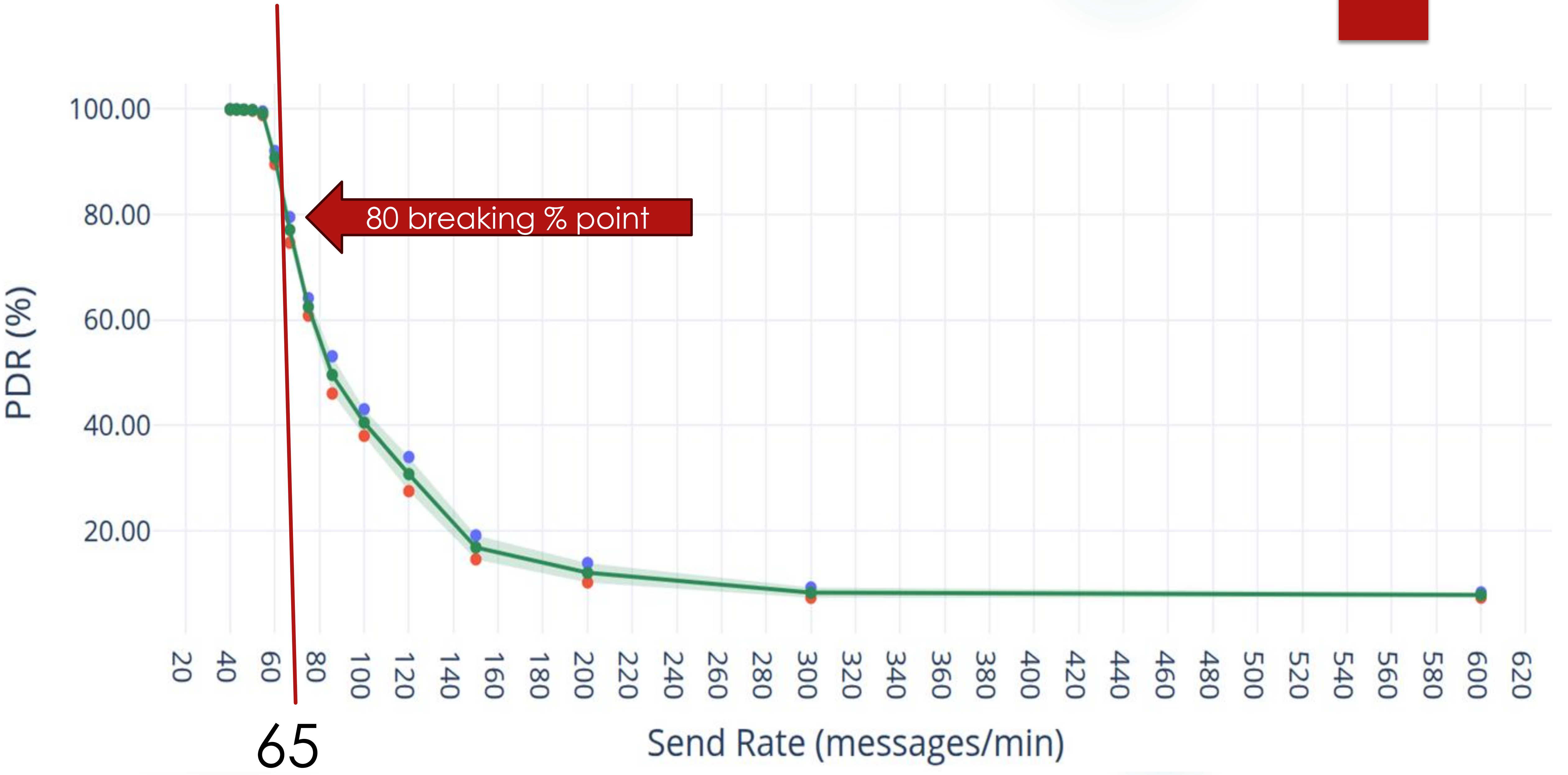
- PDR (Packet delivery ratio) in % and its critical breaking point 80%
  - Latency (ms)
  - Throughput in bits/second

IMPORTANT NOTE :
All measured values are per sender node (20x)

CSMA at near saturation (ex.60 msgs/min)



PDR with 95% Confidence Interval(CSMA)



PDR CSMA (package delivery ratio)

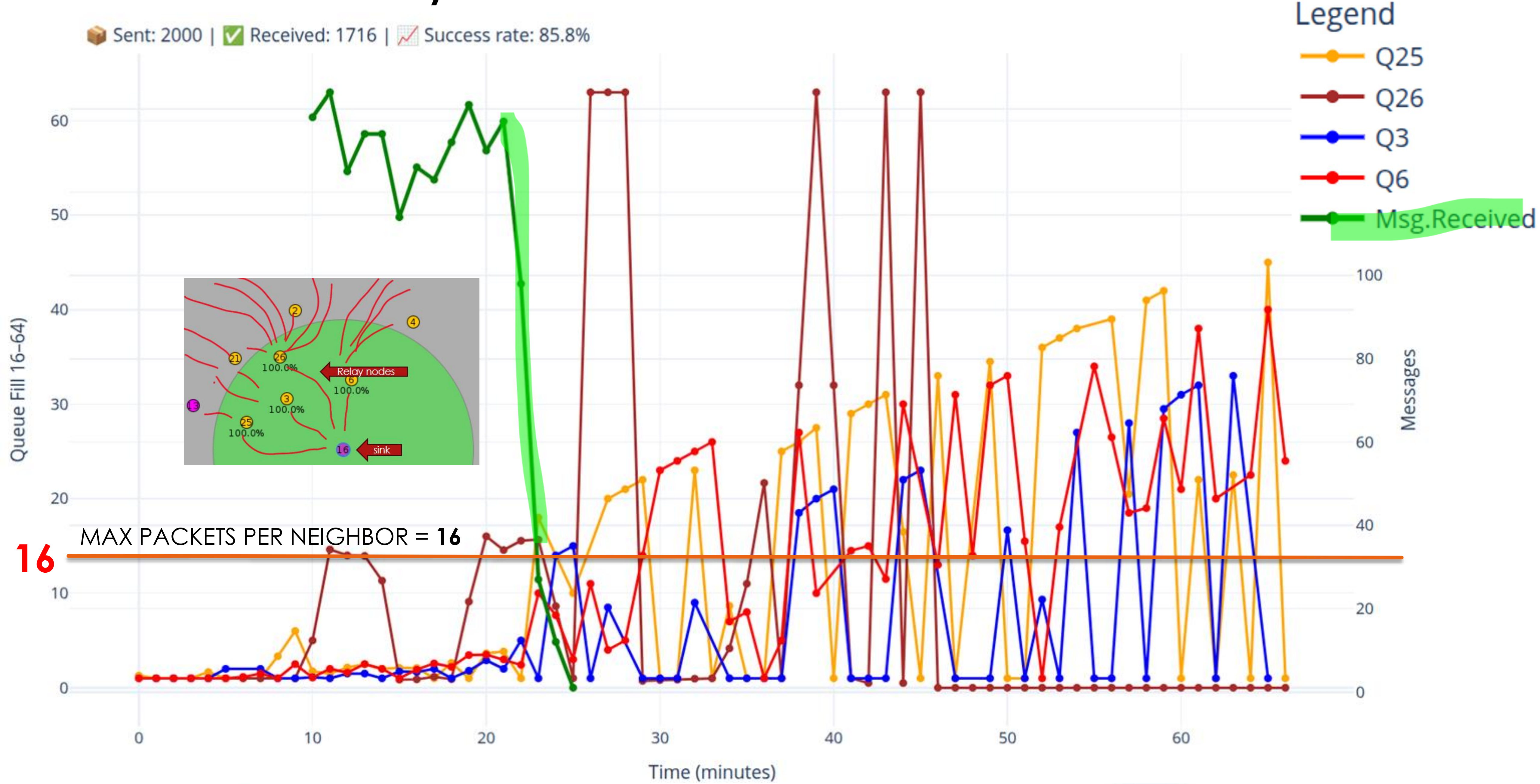
- Critical Breaking Point @ 80%

  65 msgs/min per sender node

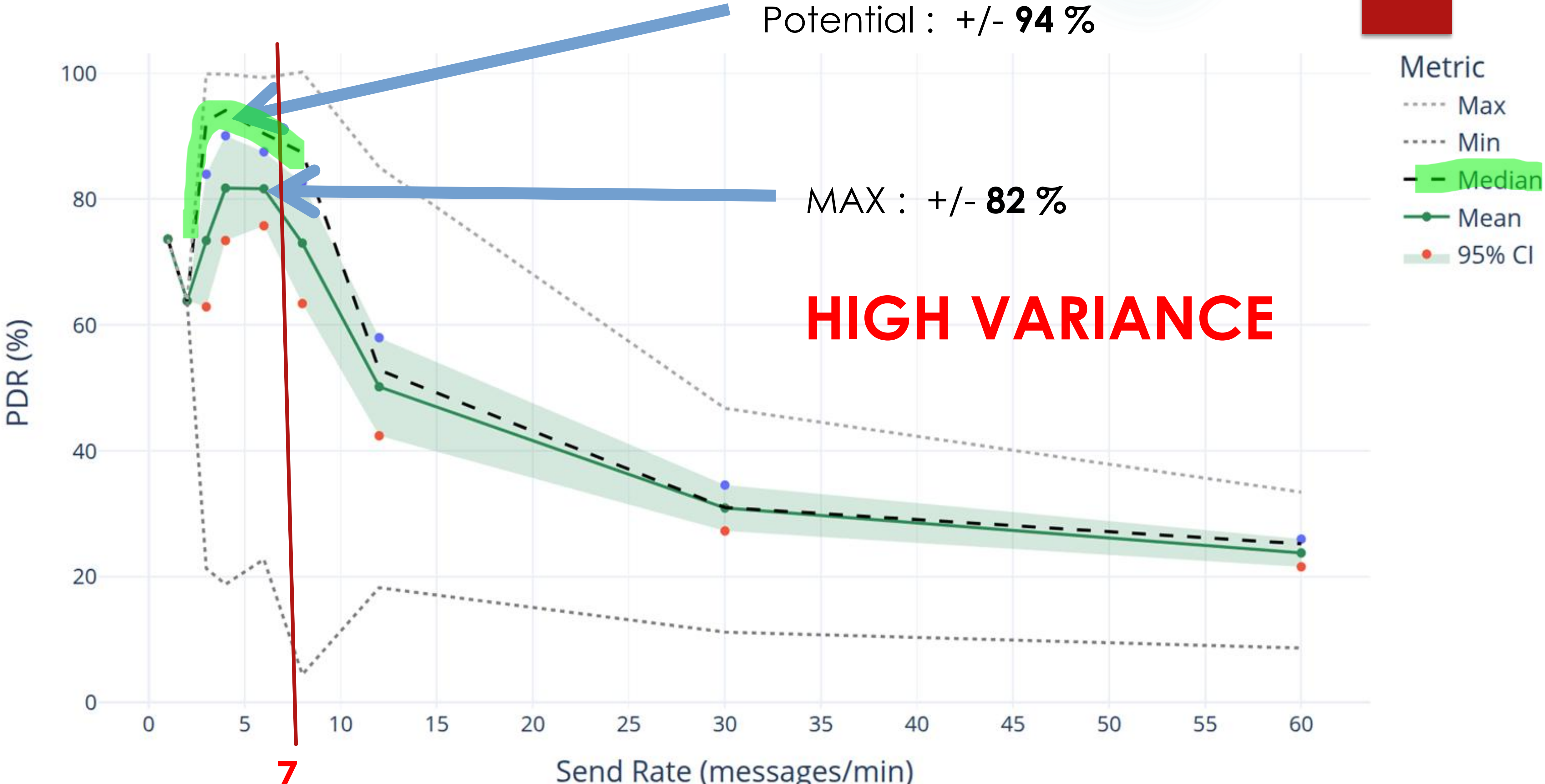
- Max PDR

  +99%

TSCH - Relay nodes bottleneck



TSCH PDR(%) by send rate



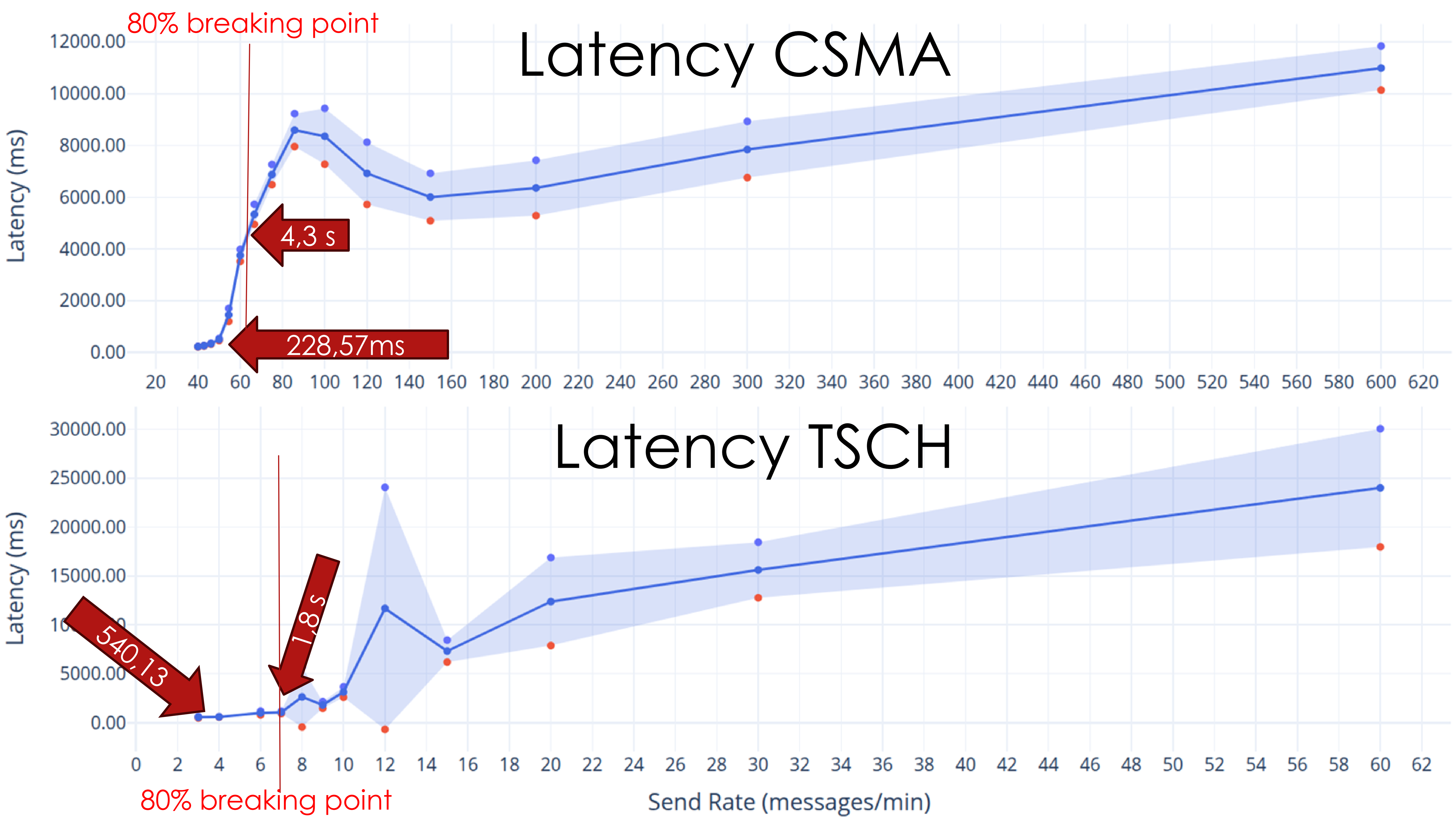
PDR TSCH(package delivery ratio)

- Critical Breaking Point @ **80%**

  7 msgs/min per sender node

- Max PDR

  81,3% (6 msgs/min per sender node)



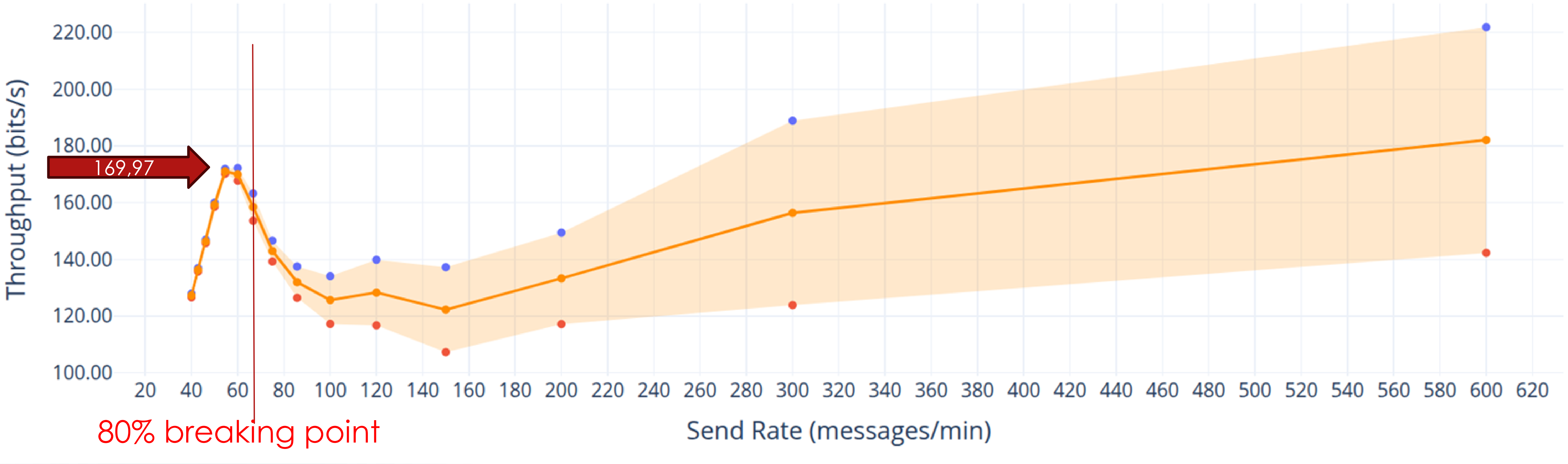
80% breaking point
Latency CSMA
Latency (ms)
12000.00
10000.00
8000.00
6000.00
4000.00
2000.00
0.00
4,3 s
228,57ms
20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 460 480 500 520 540 560 580 600 620
Latency TSCH
Latency (ms)
30000.00
25000.00
20000.00
15000.00
5000.00
0.00
540,13
1,8 s
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62
80% breaking point
Send Rate (messages/min)

Latency (ms)

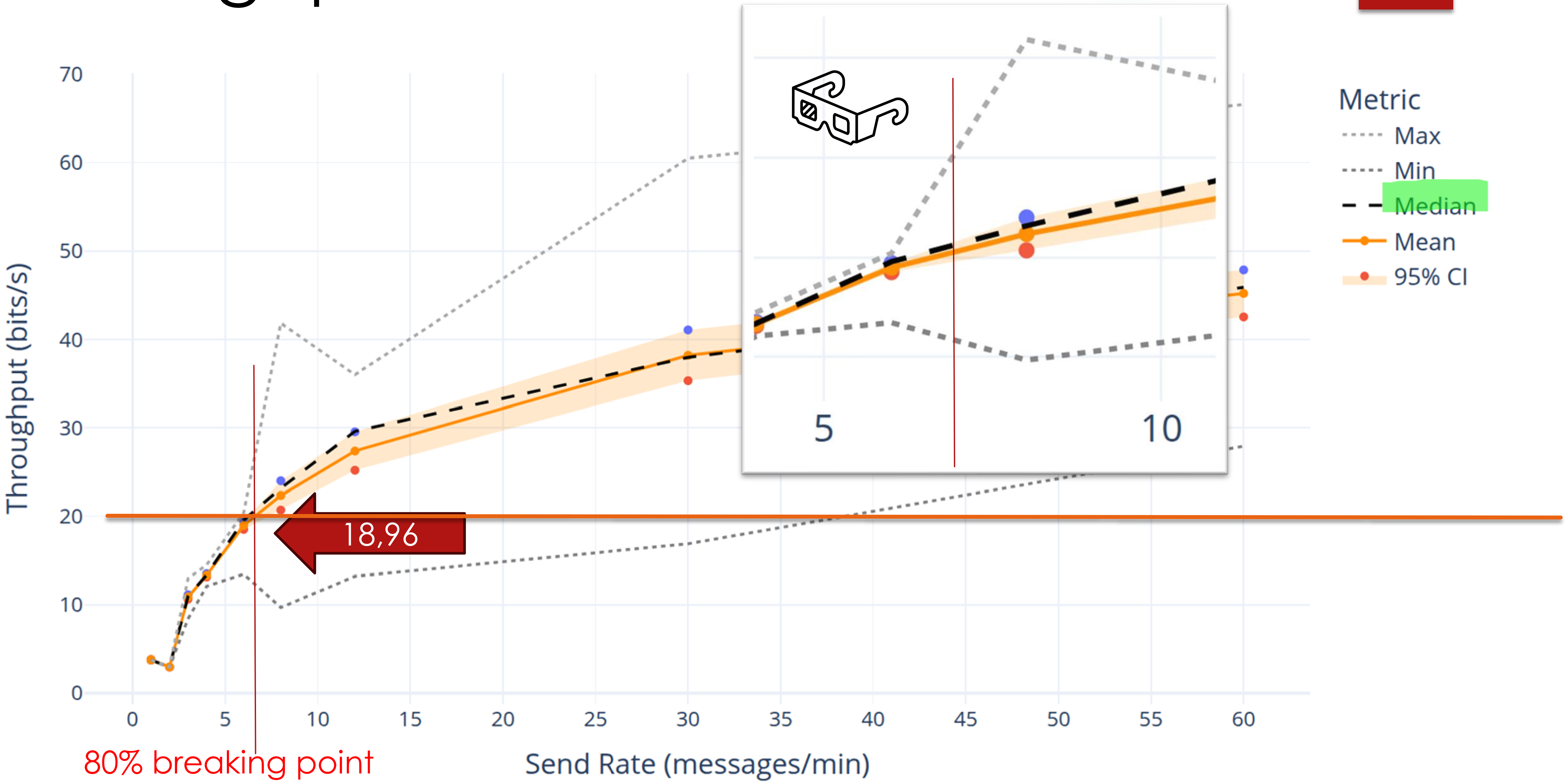
- Minimal Latency
  - CSMA : 228, 57ms @ 40 msgs/min*
  - TSCH : 540,13ms @ 3 msgs/min*
- At breaking point (80% PDR)
  - CSMA : ~4,3 seconds @ 65 msgs/min*
  - TSCH : ~1.8 seconds @ 7 msgs/min*

* per sender node

Throughput CSMA with 95% CI



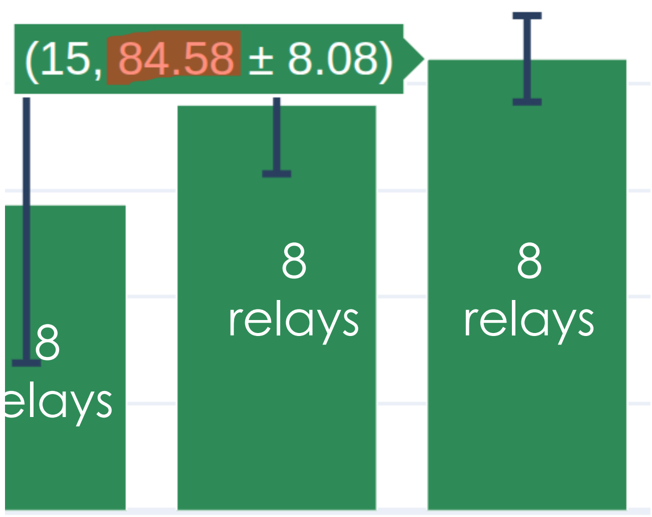
Throughput TSCH with 95% CI



Throughput (bits/second)

$$\text{Throughput (bits/s)} = \frac{\text{Total received bytes} \times 8}{\text{Time span (s)}}$$

- CSMA
  - **169,97** bits/s @ 60 msgs/min*
  - => effective delivery ratio : 84,99%
- TSCH
  - Theoretical MAX (**bruto**) : 20 nodes x 25 bytes
  - => **20** bits/second @ 6msgs/min
  - Measured: **18,96** bits/s. @ **6** msgs/min*
  - => 94,8% **ideally tuned** vs **netto** 81,3% **(PDR @ 7)**



* per sender node and payload +/- 25 bytes or 200 bits)

Conclusion

Aspect	CSMA	TSCH
PDR breaking point 80%	65 msgs/min/sender	7 msgs/min/sender
PDR (Mean)	+99% at low rate	81,3%
PDR(Median)	-	94%
Queue sensitivity	Lower then TSCH	Sensitive to overflow at high send rates
Energy efficiency	low	Very high
Conclusion	Better for high throughput scenarios	Offers energy efficiency if well-tuned

5. Behaviour under disturbance

What are disturbances?

- Unexpected changes in the network environment that can disrupt normal communication patterns.
- Examples:
  - **Interference** from external source
  - **Mobility** of nodes
  - …
- Impact?
  - Latency increase
  - Reduced PDR (Packet delivery ratio)
  - Low throughput

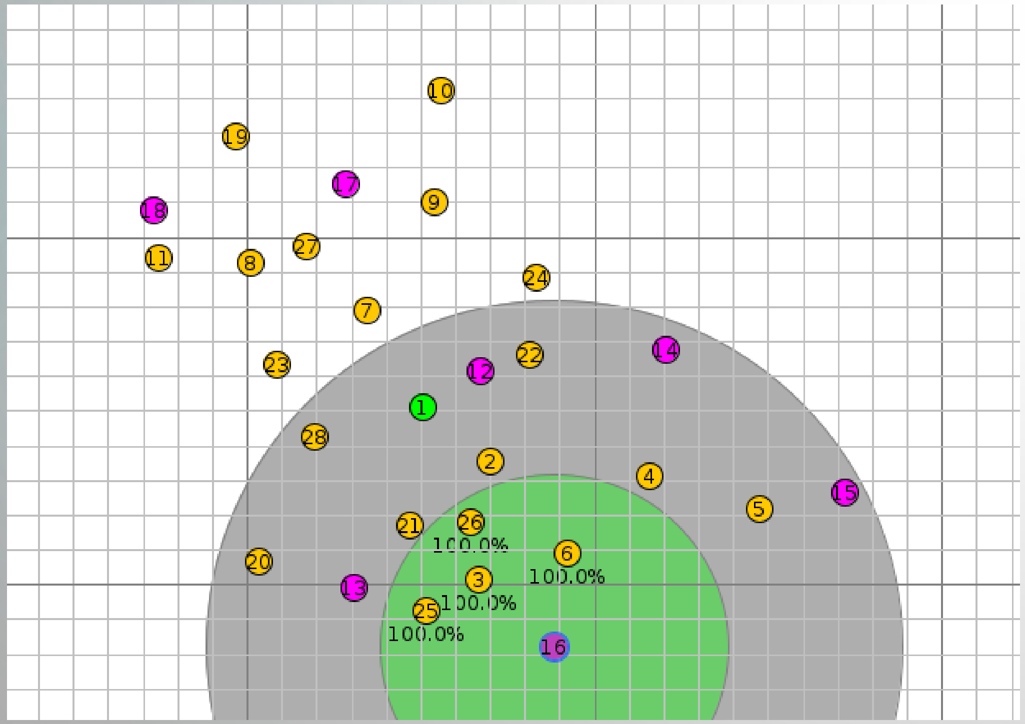
CSMA and TSCH vs Disturbance

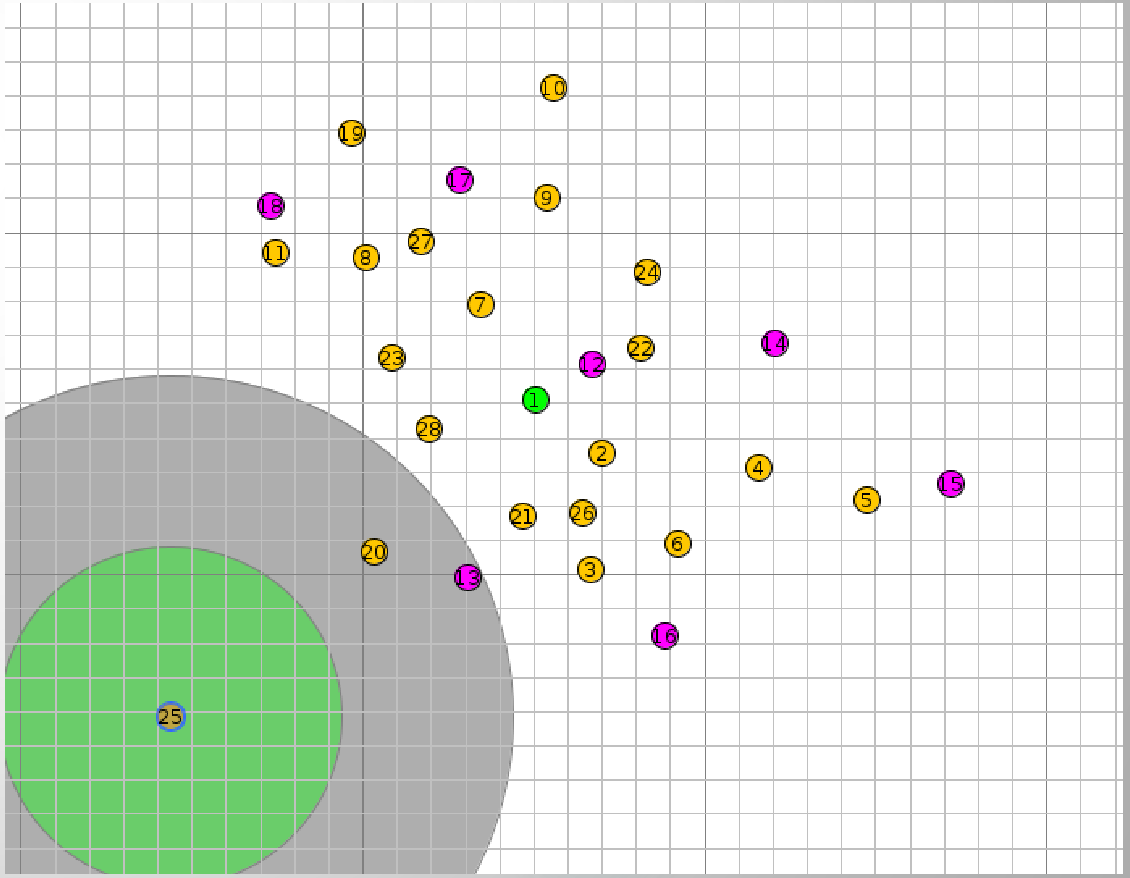
- **CSMA:**
  - Reacts with exponential backoff
  - Can adapt fast but suffers under load
- **TSCH:**
  - Uses predetermined time slots and channel hopping
  - Avoid collisions in normal conditions
  - But adapt less quickly

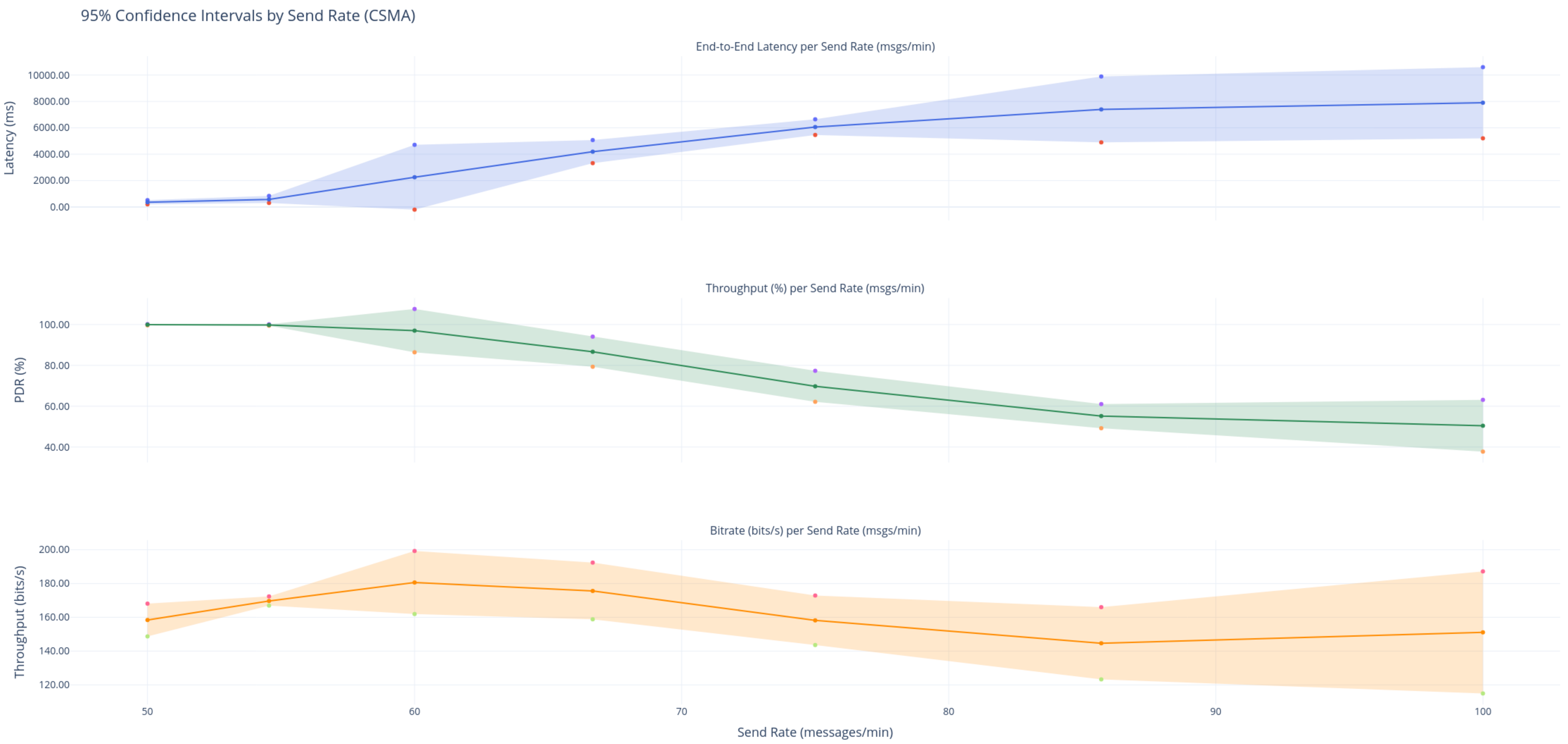
Aspect	CSMA (Unslotted)	TSCH with Orchestra
Adaptability to Topology Change	High	Low
Reaction Mechanism	Exponential backoff on collision	Schedule-based, limited fallback in shared slots
Collision Avoidance	Reactive (after collision occurs)	Proactive (via scheduling and channel hopping)
Recovery Speed	Fast – reattempts quickly after interference	Slow – schedule doesn’t change dynamically

First disturbance experiment

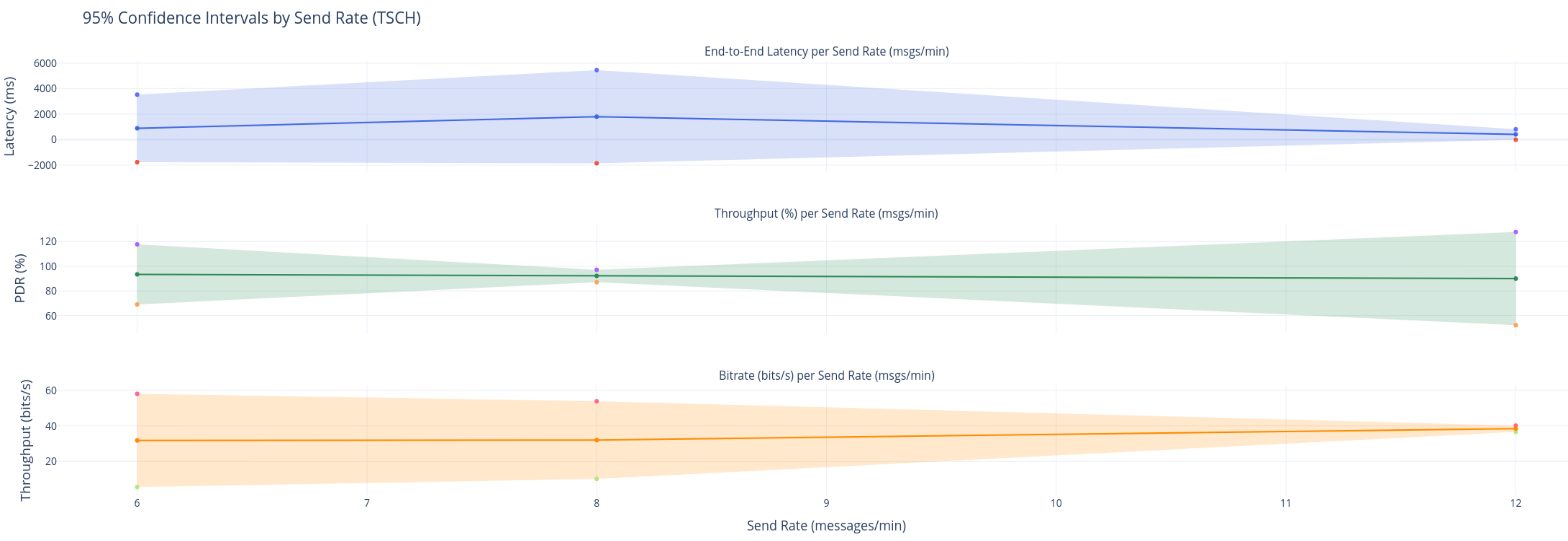
- Moving away one node (initially near the sink)
  - Node 25
  - After 300s (After network stabilization)







95% Confidence Intervals by Send Rate (CSMA)
End-to-End Latency per Send Rate (msgs/min)
Latency (ms)
10000.00
8000.00
6000.00
4000.00
2000.00
0.00
Throughput (%) per Send Rate (msgs/min)
PDR (%)
100.00
80.00
60.00
40.00
Bitrate (bits/s) per Send Rate (msgs/min)
Throughput (bits/s)
200.00
180.00
160.00
140.00
120.00
50
60
70
80
90
100
Send Rate (messages/min)


95% Confidence Intervals by Send Rate (TSCH)
End-to-End Latency per Send Rate (msgs/min)
Latency (ms)
6000
4000
2000
0
−2000
Throughput (%) per Send Rate (msgs/min)
PDR (%)
120
100
80
60
Bitrate (bits/s) per Send Rate (msgs/min)
Throughput (bits/s)
60
40
20
6
7
8
9
10
11
12
Send Rate (messages/min)

First disturbance experiment

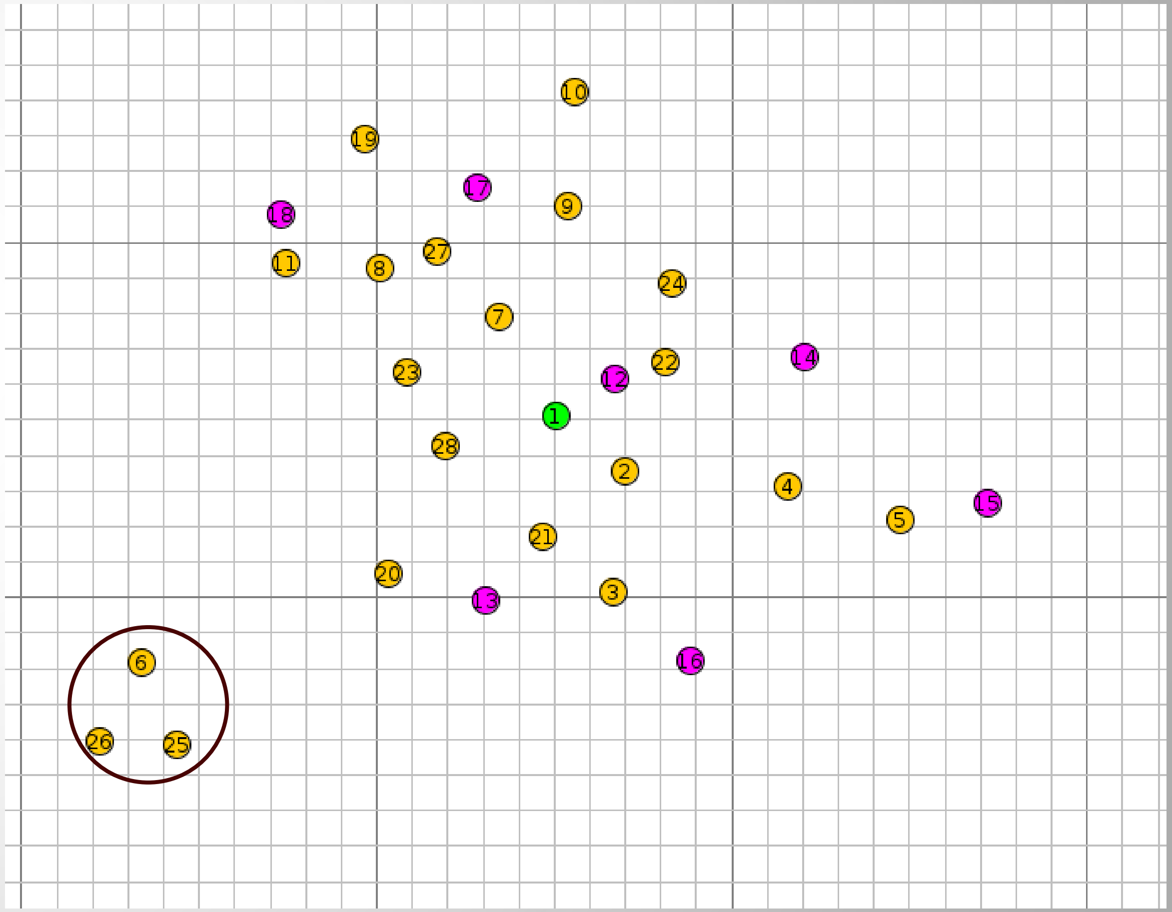
- **Observations:**
  - Surprisingly, no significant performance drop in either CSMA or TSCH
  - PDR and latency remained stable
  - In some test runs, performance even slightly improved

First disturbance experiment

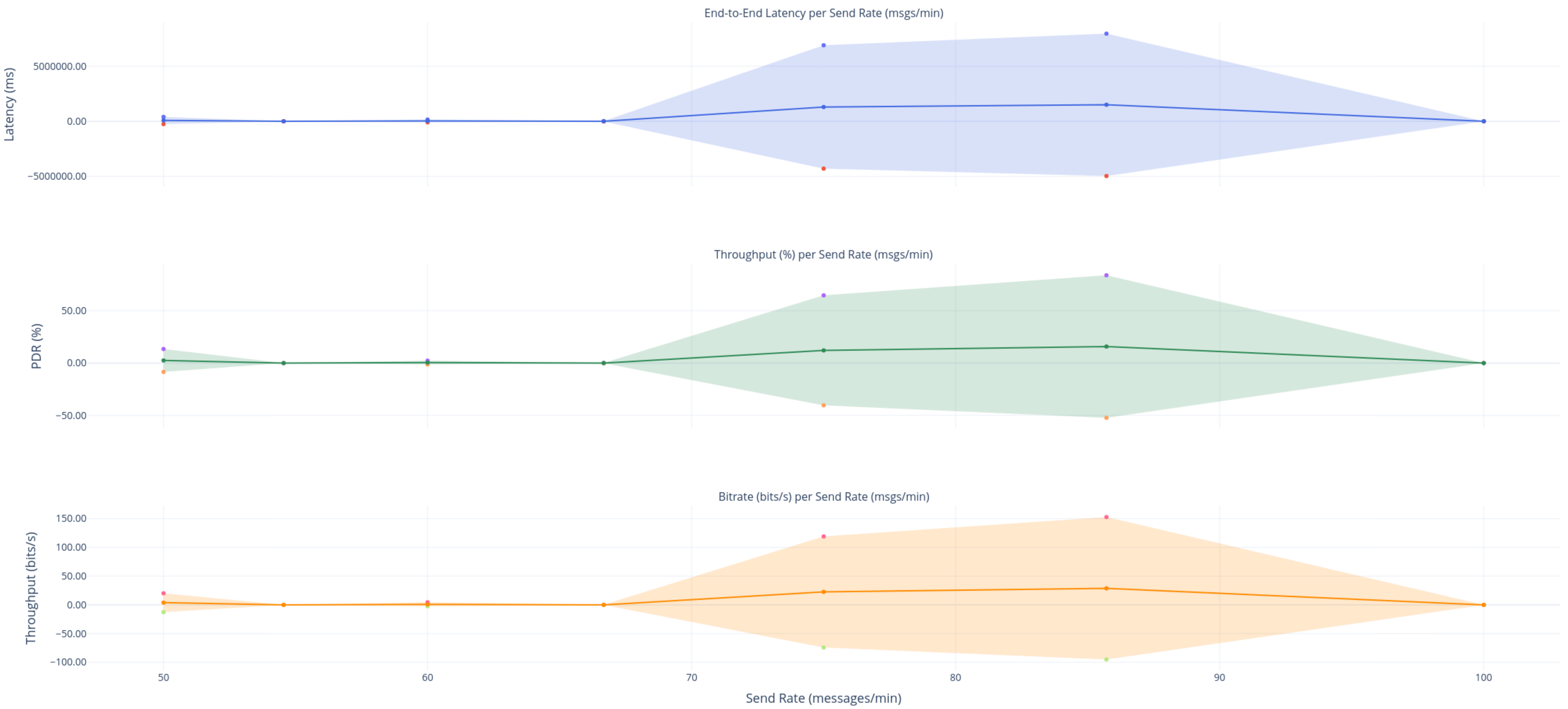
- **Possible Explanation:**
  - Node 25 may not have been a critical relay
  - RPL adapted quickly
  - Since there a are 4 different senders near the node, removing only 1 node may have reduced local congestion near the sink

Extended disturbance experiment

- Moving away 3 nodes (initially near the sink)
  - Node 25, 6, 26
  - After 300s (After network stabilization)
  - Node 3 is the only sender still near the sink
- Goal: simulate a stronger disruption, to see more effects

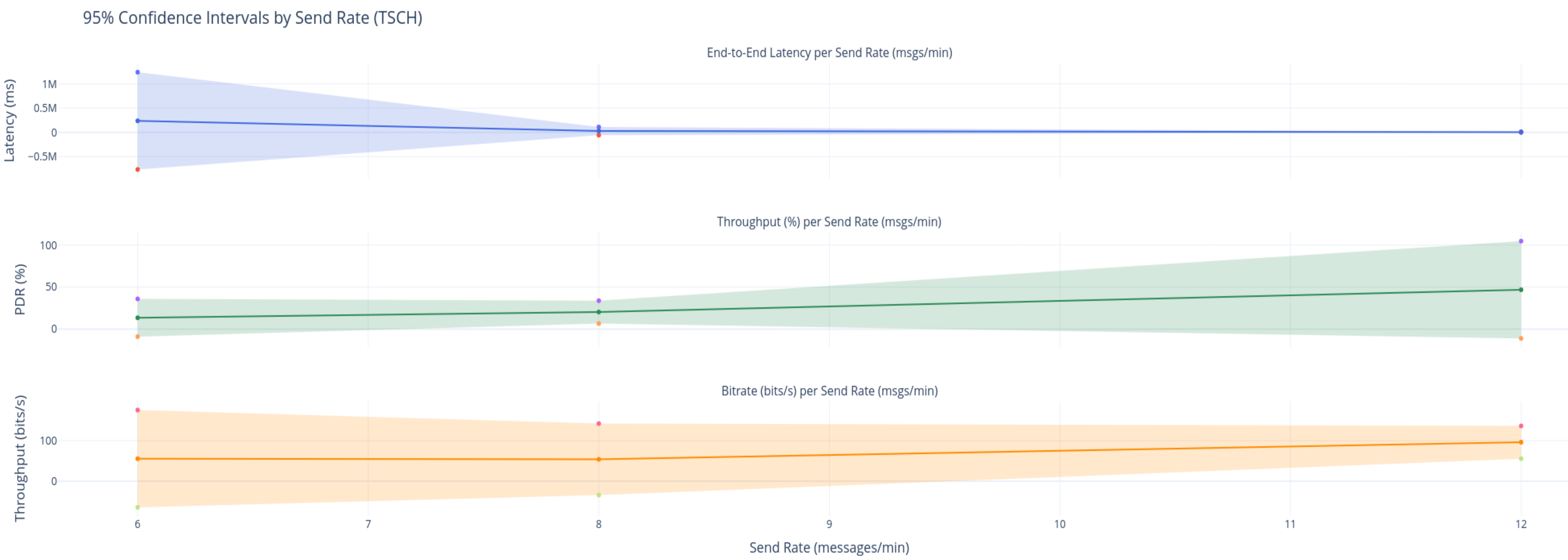


95% Confidence Intervals by Send Rate (CSMA)



Extended disturbance experiment

- **Observations:**
- **CSMA:**
  - Performance dropped severely
  - Many packets were lost entirely



95% Confidence Intervals by Send Rate (TSCH)
End-to-End Latency per Send Rate (msgs/min)
Latency (ms)
1M
0.5M
0
−0.5M
Throughput (%) per Send Rate (msgs/min)
PDR (%)
100
50
0
Bitrate (bits/s) per Send Rate (msgs/min)
Throughput (bits/s)
100
0
6
7
8
9
10
11
12
Send Rate (messages/min)

Extended disturbance experiment

- **Observations:**
- TSCH with Orchestra:
  - Severe performance drop, lower PDR and Throughput, higher latency
  - Some messages were still able to arrive in comparison with CSMA
  - PDR 15% to 45%
- Grafiek resultaten

Extended disturbance experiment

- **Possible explanation:**
- **CSMA**
  - The removed nodes were important
  - Remaining 1 node linked with receiver caused a lot of traffic
  - This leads the network to collapse entirely
- **TSCH**
  - More resilient than CSMA, but still negative impact
  - Fixed slotframe schedule
  - Only senders whose slots matched Node 3 receive slots could transmit.

6. Exponential Backoff

What is exponential backoff?

- Used to avoid repeated collisions
- When collision happens, the sender waits a random **‘wait time’** before sending again
- The range of the **wait time grows exponentially** after each failed send
- **Formula** of the range of the wait time: **[0, 2^BE–1]**
  - BE = Backoff exponent

Backoff in CSMA and TSCH

- **CSMA (unslotted):**
  - It always checks if the channel is free
  - If it is busy, it uses exponential backoff
  - Backoff is the key method to avoid collision in CSMA
- **TSCH (Orchestra):**
  - Uses predefined schedules
  - No backoff needed in normal slots
  - Is only used in **shared slots** (slots that are used by multiple senders)

Impact on performance

- Positive:
  - Helps reduce repeated collisions
  - More fairness, random time give a fair chance to all nodes to send
- Negative:
  - Increased latency: Each attempt leads to a longer wait time
  - While waiting the channel is not used
  - In very busy situations a channel may have to wait too long and never be able to send

7. Impact of Slotframe Size on TSCH Performance

What is a Slotframe?

- Repeating sequence of time slots used for scheduling communication
- Each time slot can be dedicated for receiving, transmitting or both
- Each device knows when to wake up or sleep
- Benefits:
  - Energy efficient
  - Predictable
- Used in TSCH

Choosing the right slotframe

- Small slotframe:
  - Quicker access to the channel
  - Sends more often
  - **Lower latency**
  - **But higher risk of collision!!!!!**
- Larger slotframes
  - Less competition, **less collision**
  - Lower energy use, wakes up less often
  - **Higher Latency!!!!!!!!!!**

Choosing the right slotframe

- Make a balanced choice between speed and risk of collision.
- Dependent on:
  - Network density
  - Traffic load
  - Energy constraints