Performance gap between the optimal and TTN downlink schedulers

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LPWAN Days, Rennes 3th July,2025

SUMMARY

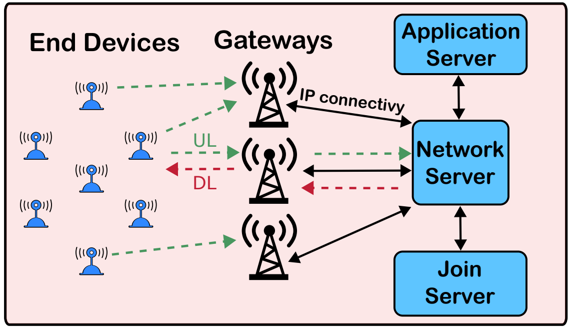
01

01 | Technology context and motivation

1.1 LoRa and LoRaWAN

- **LoRa [1]** defines the modulation and the codification of the data
  - Spreading factor as main parameter
  - Higher SF high receiver sensibility lower data rate (increase time on air)

- **LoRaWAN [2]** defines the protocol and the network architecture
  - Support bidirectional traffic, uplink from the end devices to the network server and **downlink** from network server to end devices
  - LoRaWAN use ALOHA for UL while DL is restricted



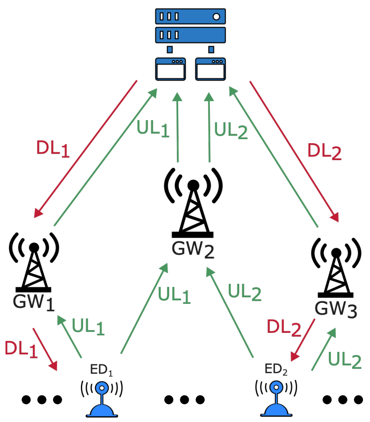
LoRaWAN network architecture

	Channel Frequency	Max Tx Power	Duty Cycle	SF	BW [KHz]
UL	868.1, 868.3, 868.5	14 dBm (27 mW)	1 %	7-12	125
DL(RX1)					
DL(RX2)	869.525	27 dBm (500 mW)	10 %	12	

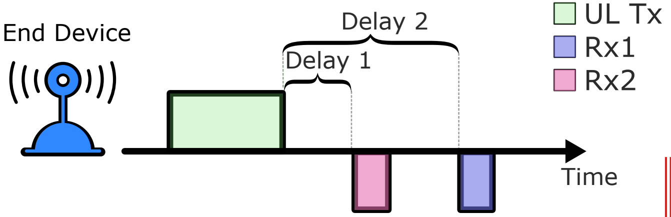
LoRaWAN regional parameters and restrictions for European band EU863-870

1.2 Scheduling problematic

- Downlink and uplink an asymmetrical relation
- Use of downlink traffic is underrated:
  - Gateway is identified as a bottleneck [3][4][5]
  - Use of downlink is discouraged
- Downlink traffic needed for:
  - LoRaWAN (OTAA, ADR, Sync)
  - Reliability (ACK)
  - Firmware Update Over the Air
  - Control of actuators
- Network server is responsible for **downlink scheduling:**
  - **Timing of class A:** Avoid conflicts
  - **Gateway selection:** Optimal use of resources
  - **Duty cycle**: Respect regulations
- **"How does downlink scheduling work in the network server, what is the gap compared to the optimal solution, and how can we approach to this optimal?**



Transmission and reception of UL and DL traffic



Class A behaviour

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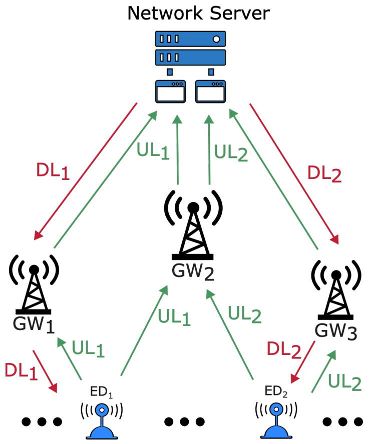

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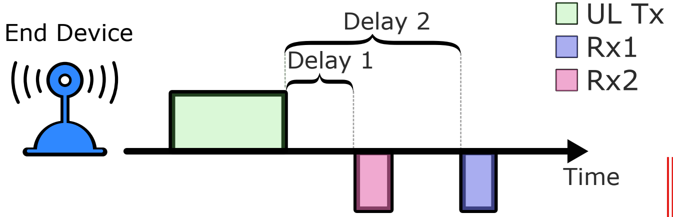
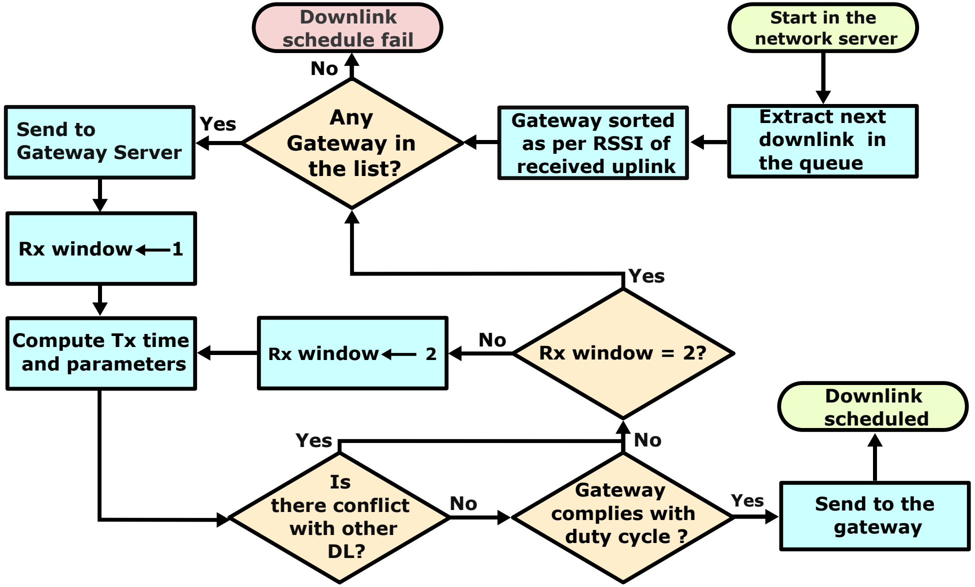


Class A behaviour

1.3 The Things Stack downlink scheduling

- Performance evaluation between Chirpstack (CS) and The things stack (TTS) [6]
- We choose TTS showed more complete scheduling algorithm
  - Implementation of duty cycle and scheduling conflict detection



The Things Stack scheduling algorithm flow

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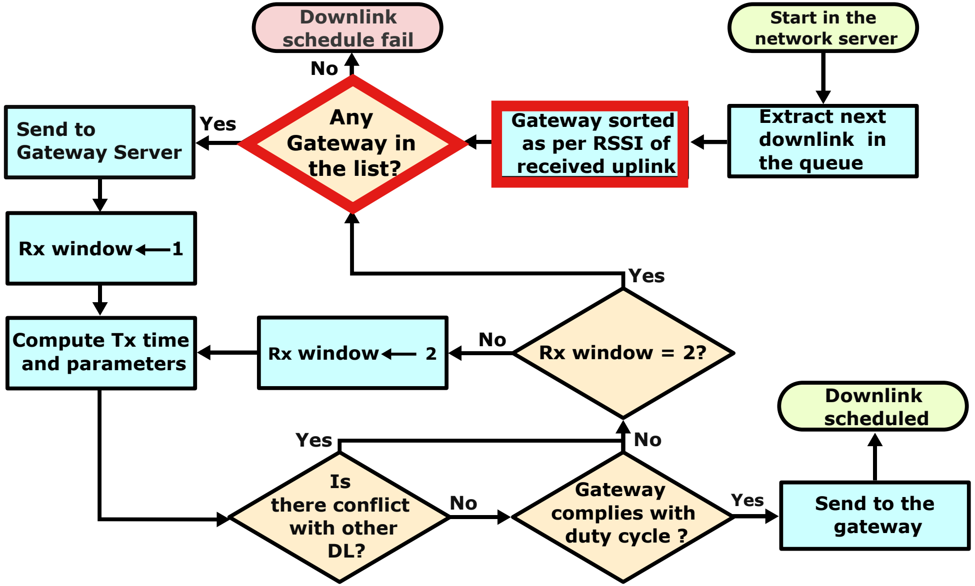

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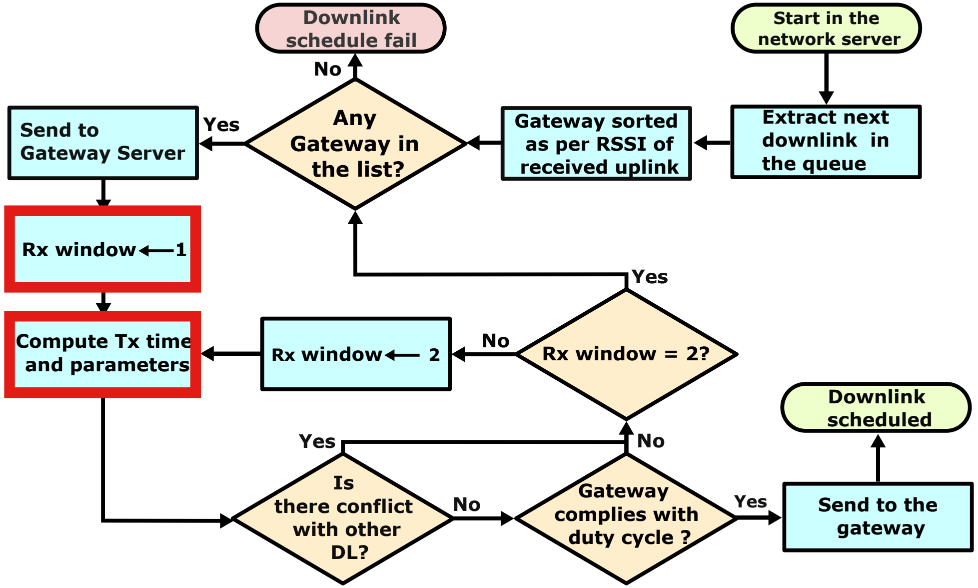

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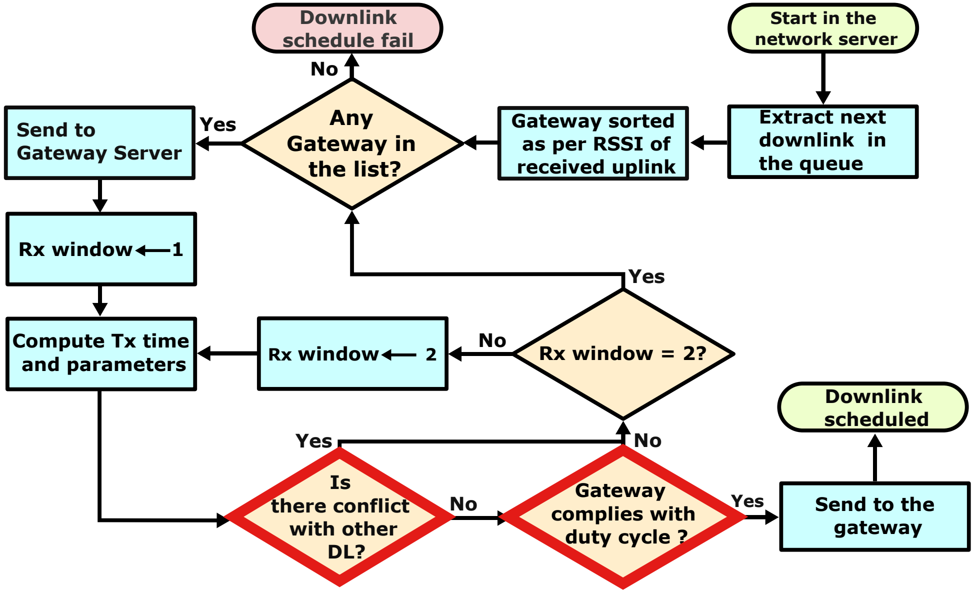


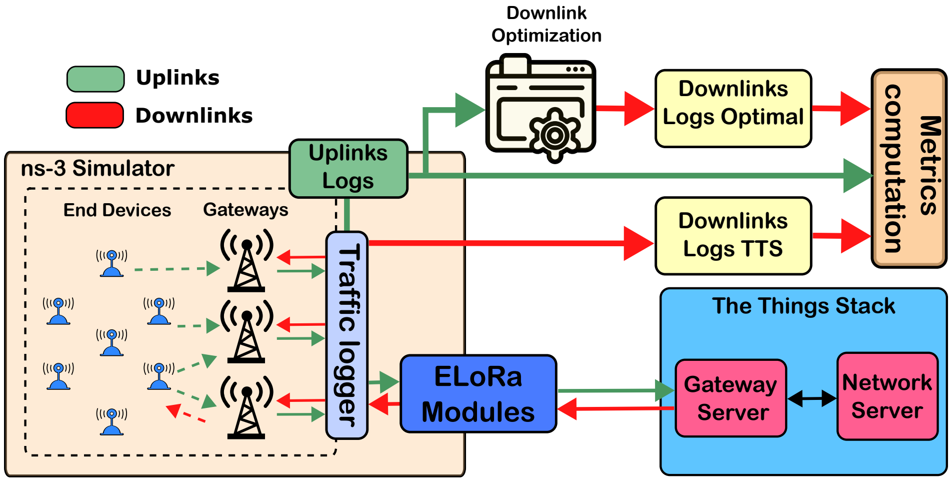
The Things Stack scheduling algorithm flow

02

02 | Performance gap between optimal and TTS

2.1 Experimental methodology for scheduler evaluation

- Quantification of gap between optimal downlink scheduler and TTS
  - Leverage optimal downlink scheduler already available [6]
- ***Fair comparison as same uplink traffic is used for generating downlinks***
- Metrics are defined for comparison and evaluation:
  - Acknowledgement percentage, Receive window usage and uplink frame delivery rate



Framework for comparison optimal Vs TTS

2.2 Optimal scheduler model

- Objective function is to maximise the amount of DL scheduled:

$$\max \sum_{t_j^i \in UL_c} \sum_{g_k \in Gr(t_j^i)} ((1+\alpha)y1(g_k, t_j^i) + y2(g_k, t_j^i))$$

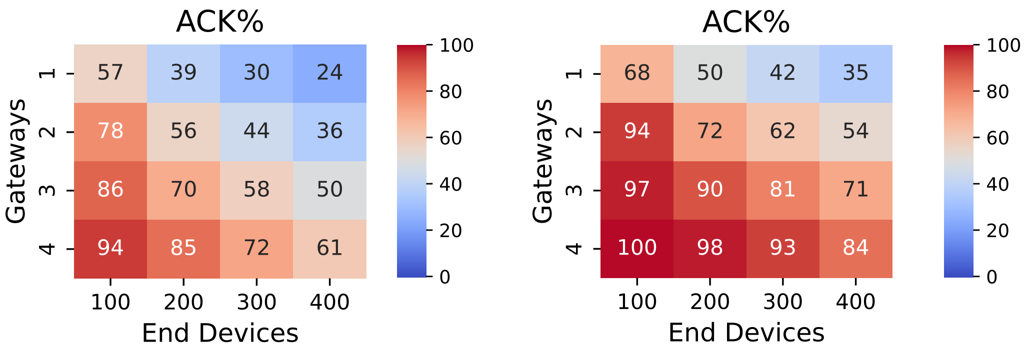
- Variables of interest
  - UL_c: Set of confirmed uplinks
  - t_j^i: Uplink frame j for end device i
  - $y1(g_k, t_j^i)$: Binary variable that is 1 if t_j^i is acknowledge in Rx1 0 if not
  - $y2(g_k, t_j^i)$: Binary variable that is if t_j^i is acknowledge in Rx2 0 if not
- Defines constraints of the Linear Program modelling:
  - **Half duplex property**: t_j^i will be lost if the gateway is already transmitting.
  - **Duty cycle restrictions**: Gateway is blocked after the transmission of a DL
  - **One downlink at the time**: There cannot be two overlapping DL in the same GW

2.3 Emulation setup

- Consider an Area of 1000 m x 1000 m where devices are distributed randomly
- End devices transmit at an average interval of 360 s poisson distribution
- SF configured based on the average Rx power of 20 transmission (ADR)
- Two types of end devices:
  - **High reliability end devices:** All uplink frames need to be acknowledged
  - **End devices with adaptive data rate (ADR):** Periodic confirm packets are transmitted (only 5% of all transmitted packets)
- Scenarios with N end devices (100, 200, 300, 400) and G gateways (1,2,3,4)
- 50 % of end devices are high reliability end devices
- Log distance path loss model

2.4 Results optimal vs TTS: Acknowledgement percentage

- Optimal achieve up to 23 % higher ACK % for the scenario with 400 end devices and 4 gateways and a minimum of 6 % for 100 end device and 4 gateways
  - On multi gateways scenarios Optimal performance is amplified
- Optimal scheduler selects Rx1 or Rx2 according to who maximises the number of DL



(a) TTS (b) Optimal

Percentage of acknowledgement for optimal and TTS

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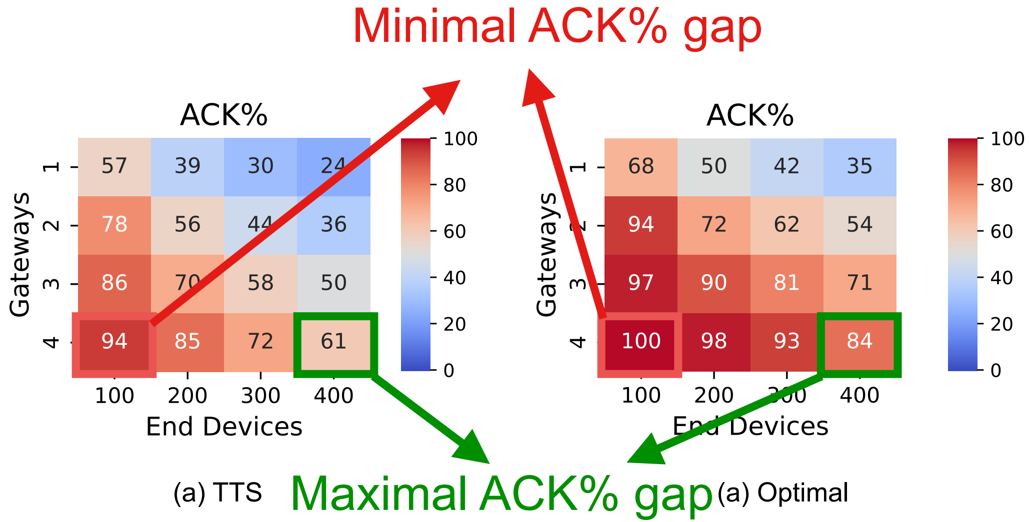

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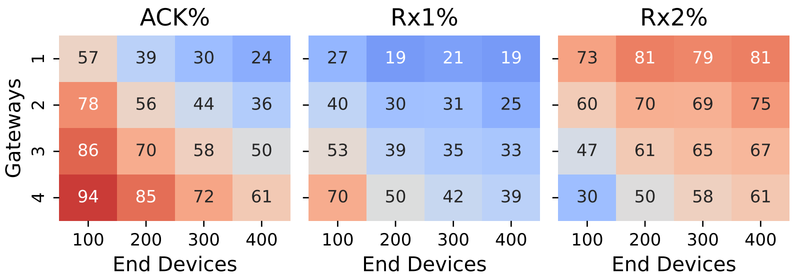
2.5 Results optimal vs TTS: Receive window usage

- Optimal scheduler selects Rx1 or Rx2 according to who maximises the number of DL
- TTS always prioritise Rx1 over Rx2
- Optimal has higher use of Rx1 over Rx2 while achieving higher ACK%
  - Is able to locate more packets in Rx1 while having less duty cycle



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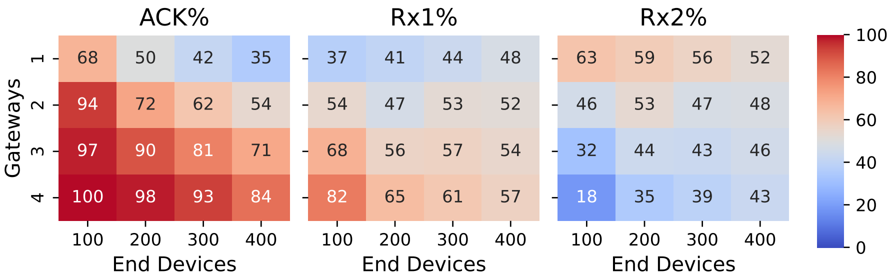

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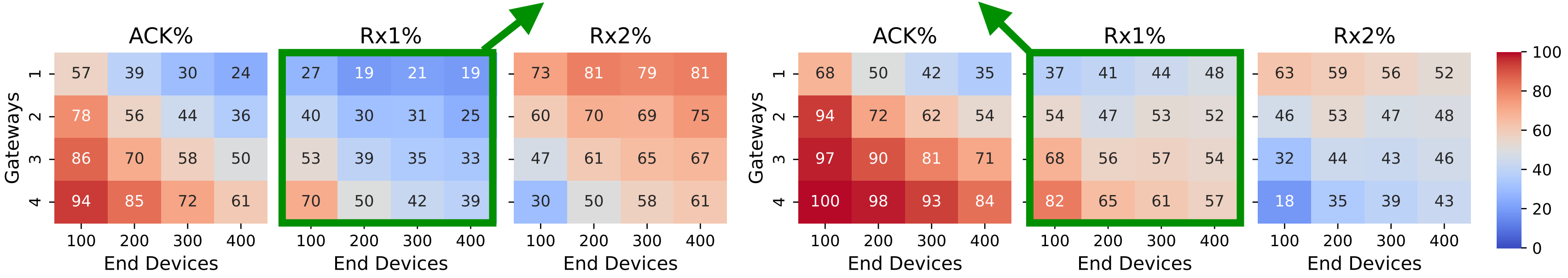
Maximal 29 % Rx1 usage gap



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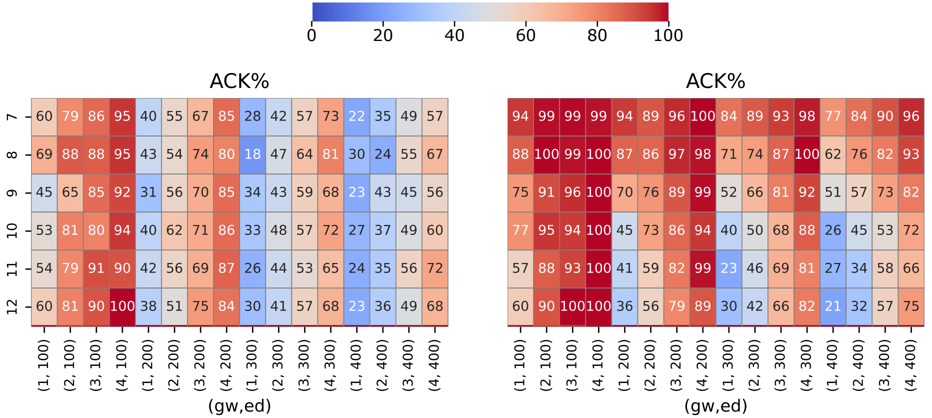
Percentage of acknowledgement for optimal and TTS

2.6 Results optimal vs TTS by spreading factor: Acknowledgement percentage

- Optimal performs notably better for low spreading factor
- TTS always prioritise Rx1 over Rx2
  - Unbalance use of receive windows and duty cycle
- Optimal tends to schedule low spreading factor to Rx1 and high spreading factor to Rx2:
  - High SF > 9
  - Low SF <=9



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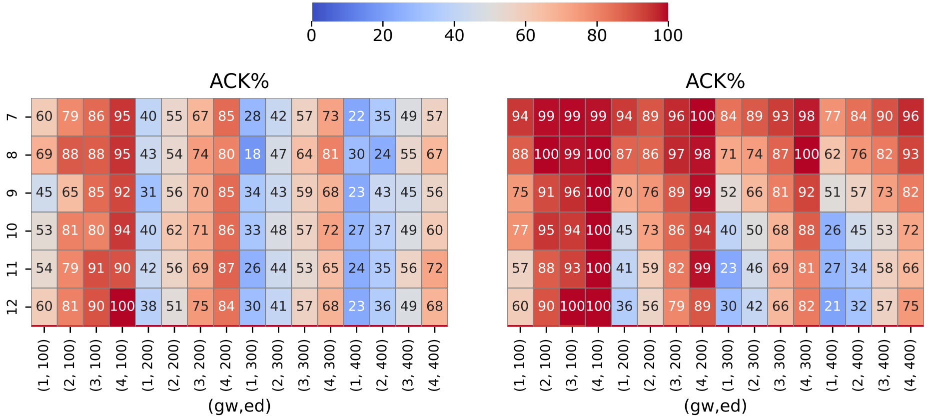

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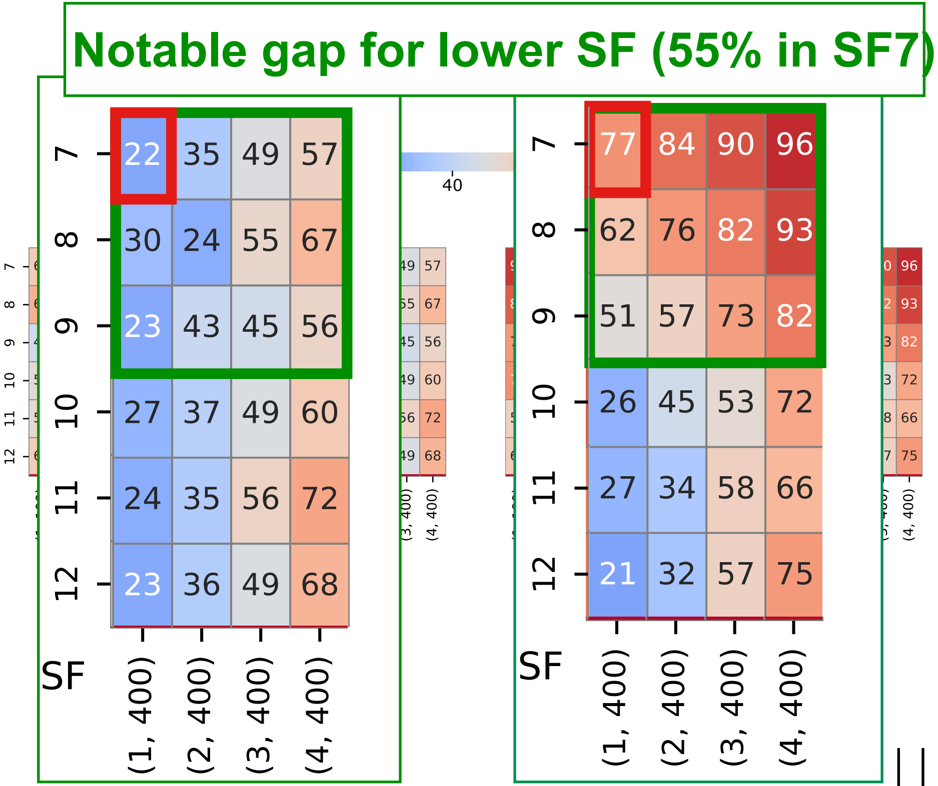

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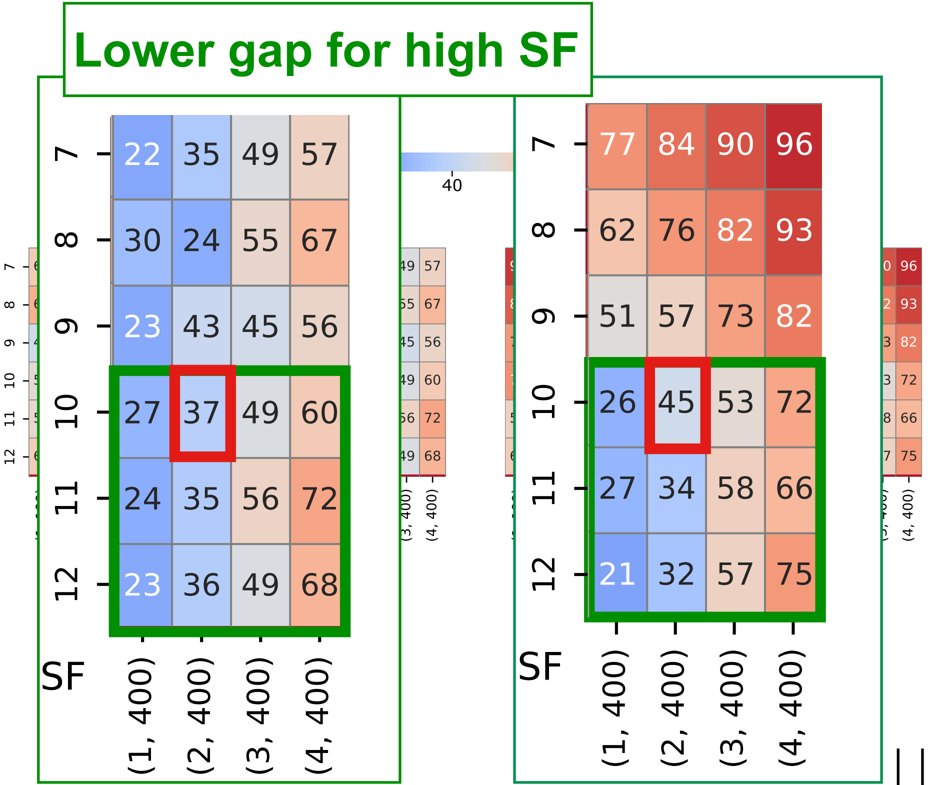

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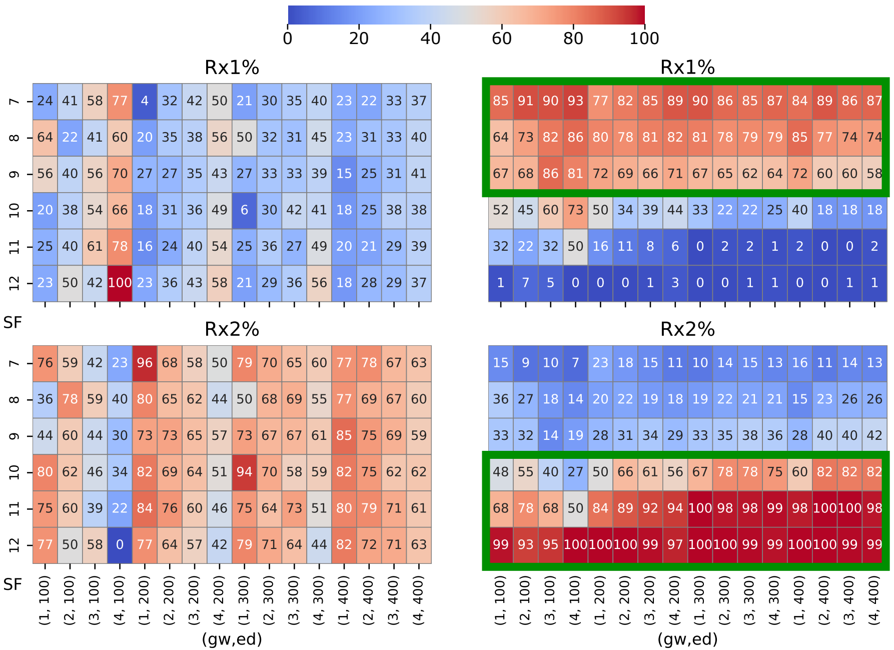

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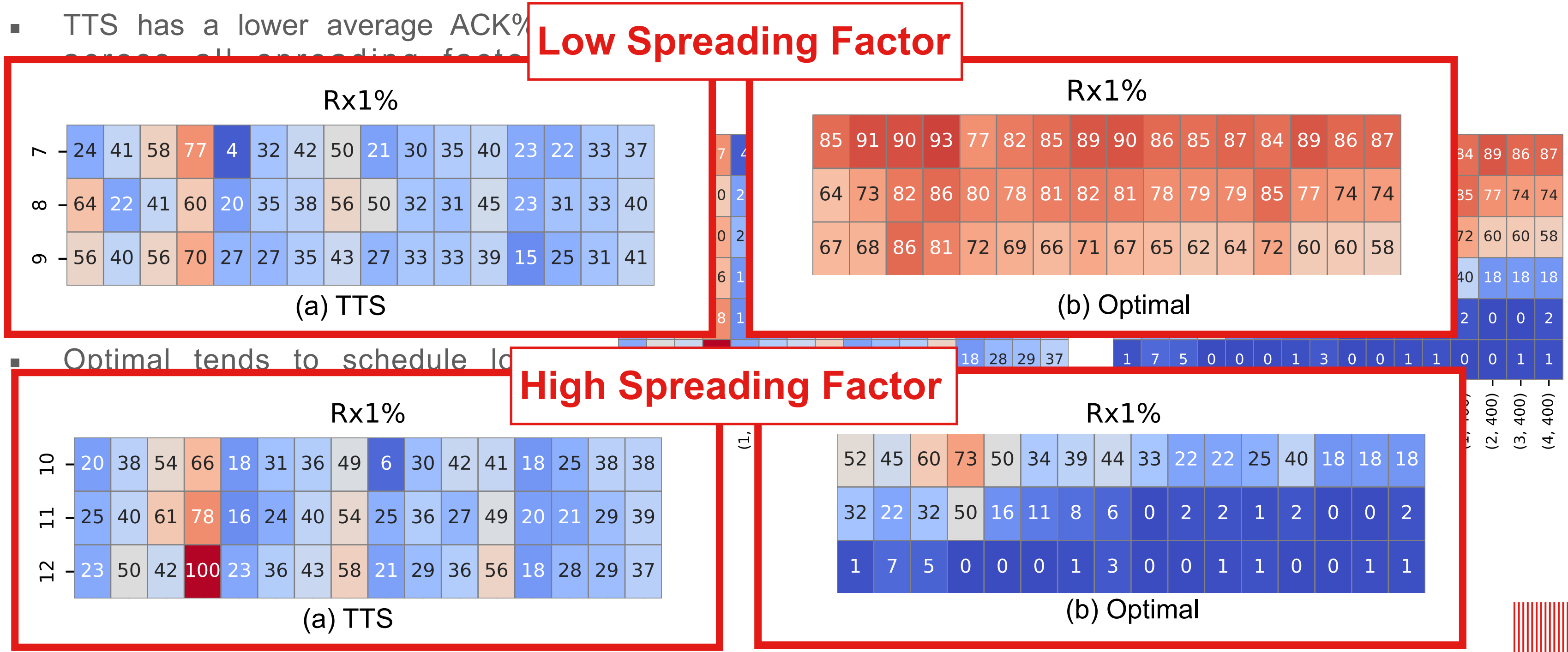

2.6 Results optimal vs TTS by spreading factor: Receive Window Usage

- TTS has a lower average ACK% across all spreading factor compared to the optimal
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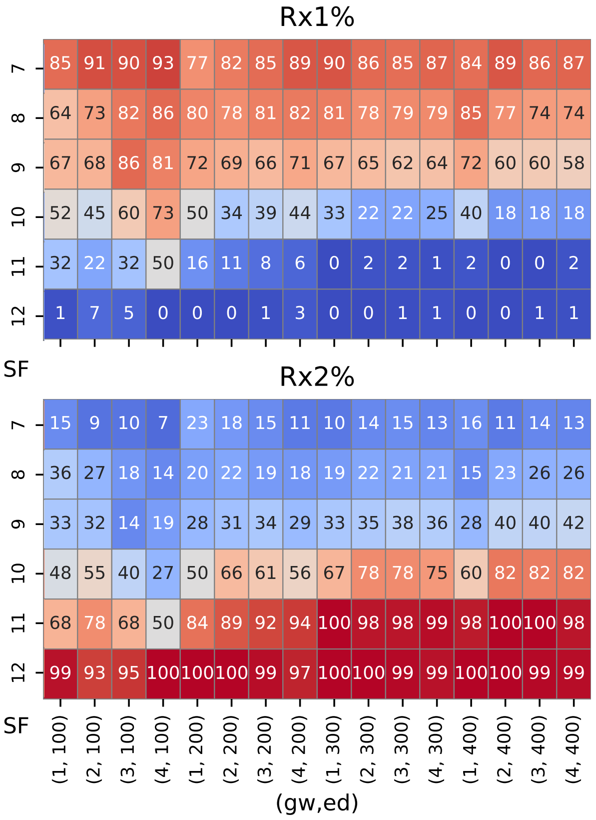
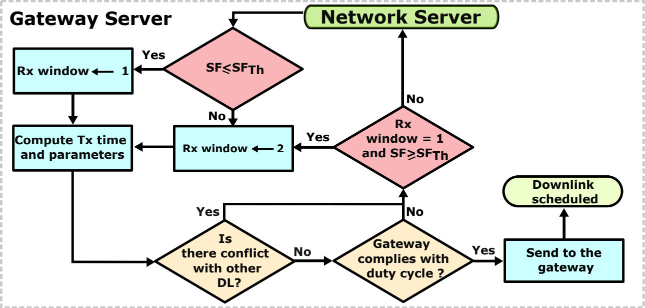


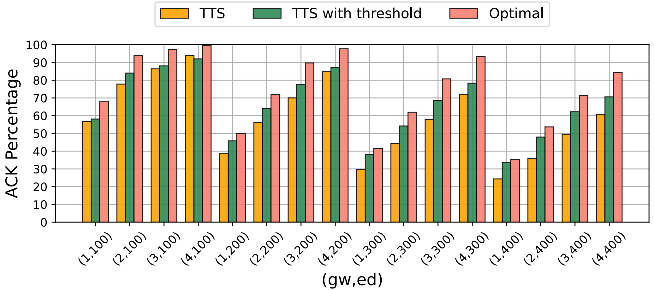
Optimal

2.7 Deterministic scheduler with Spreading Factor threshold

- We proposed modifications to the TTS scheduling algorithm to include a spreading factor threshold:
  - IF SF <= 9 downlink scheduled to Rx1
  - IF SF >=9 downlink scheduled to Rx2
  - IF SF=9 downlink scheduled to Rx1 first and then Rx2
- This will increase the amount of downlinks scheduled in Rx1
  - High spreading factor downlink in Rx1 blocked the gateway for high amount of time (due to high ToA)
- Lightweight implementation achieves up to 12% increase in ACK%



Comparison of TTS (without threshold), TTS (with threshold), and optimal scheduler.



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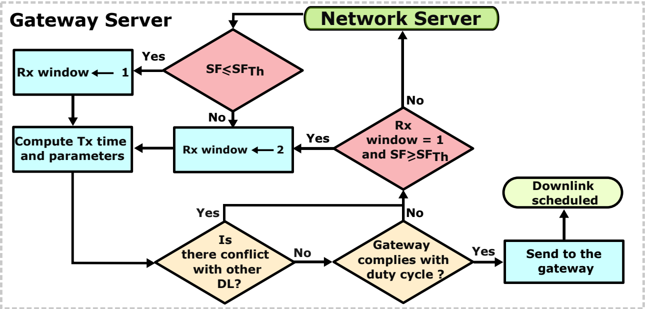

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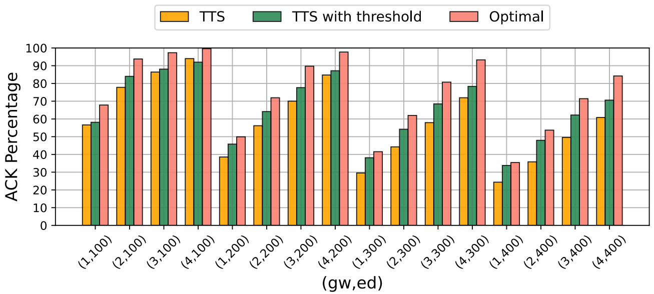

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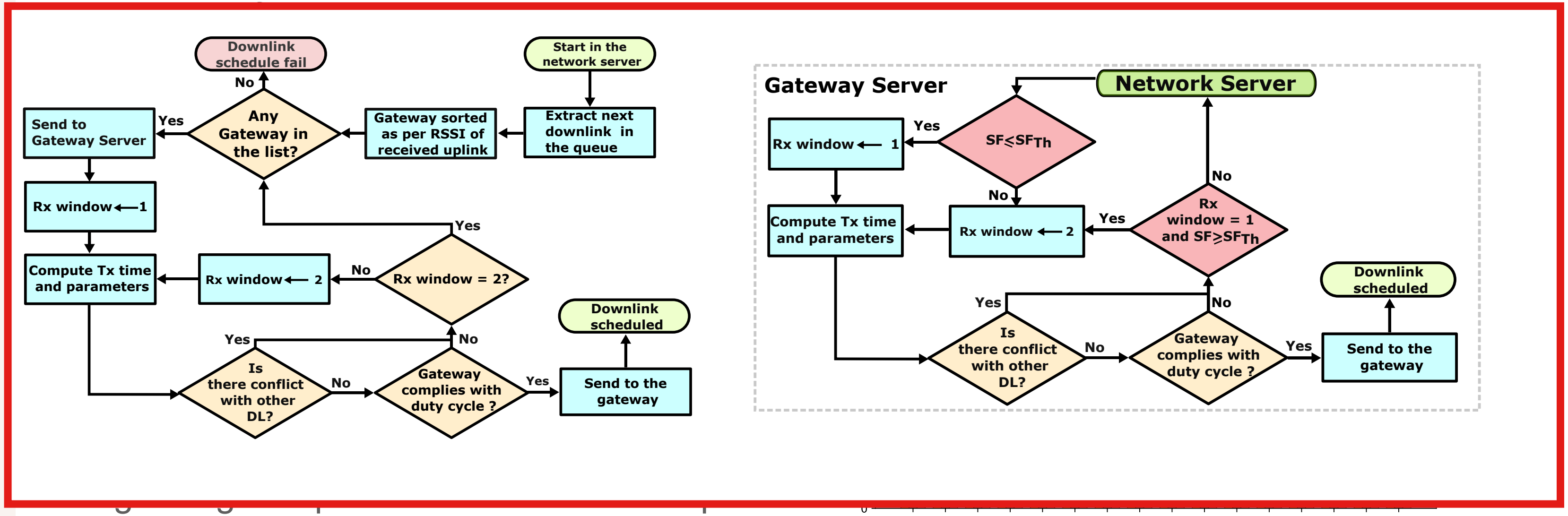

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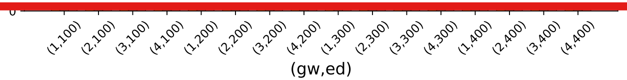

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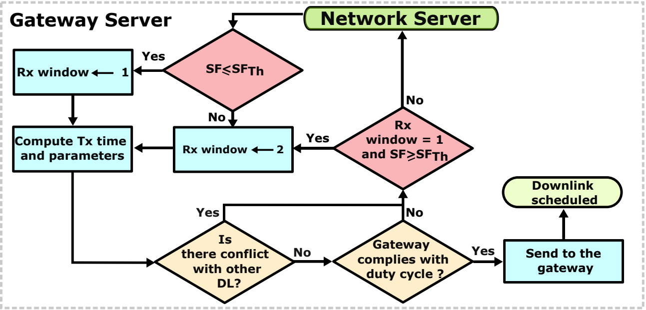

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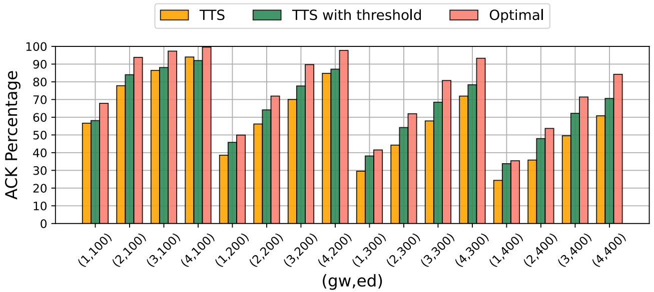

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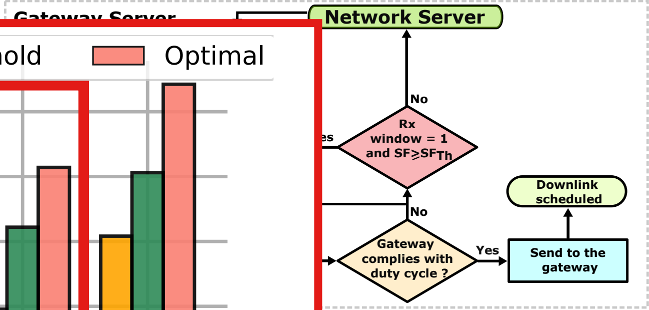

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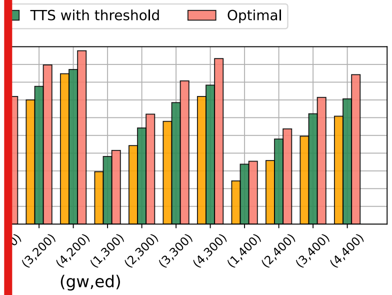

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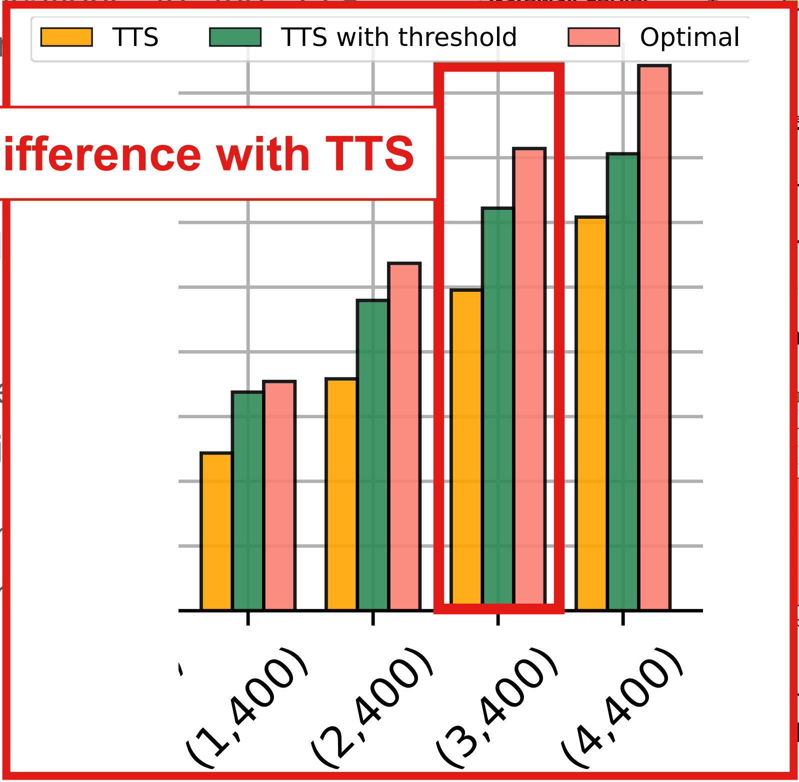
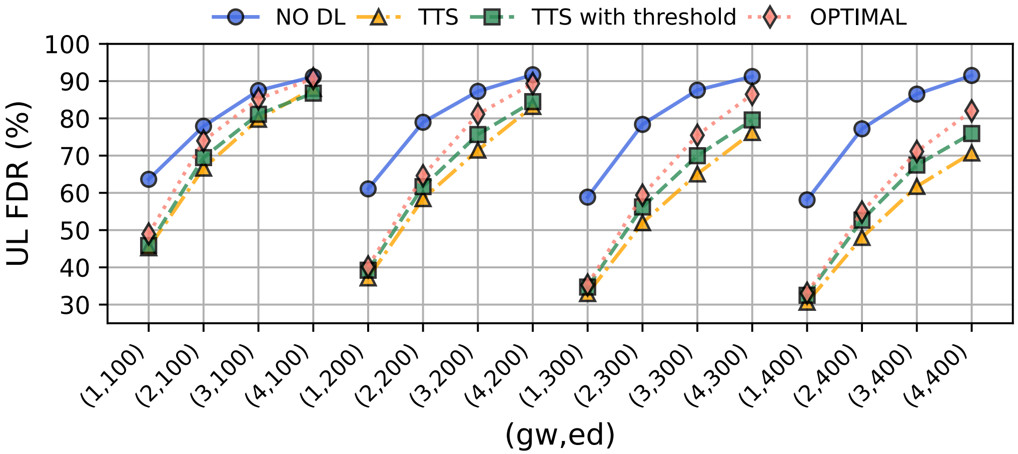


2.8 Impact on Uplink Frame Delivery Rate

- Uplink Frame Delivery rate always impacted when using downlink traffic
  - Optimal lowers this impact in comparison to TTS up to 12 %
- Proposed modification to scheduler achieves up to 6% better UL FDR than TTS
- Considerable improvement in comparison to the modification made



Uplink Frame Delivery Rate (FDR) for TTS, TTS with threshold, and optimal scheduler. The case without downlink is included as a baseline

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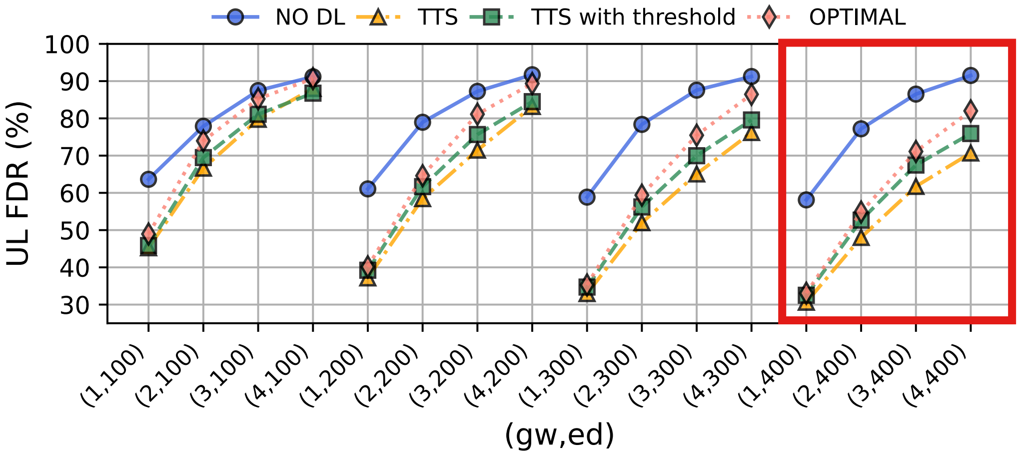

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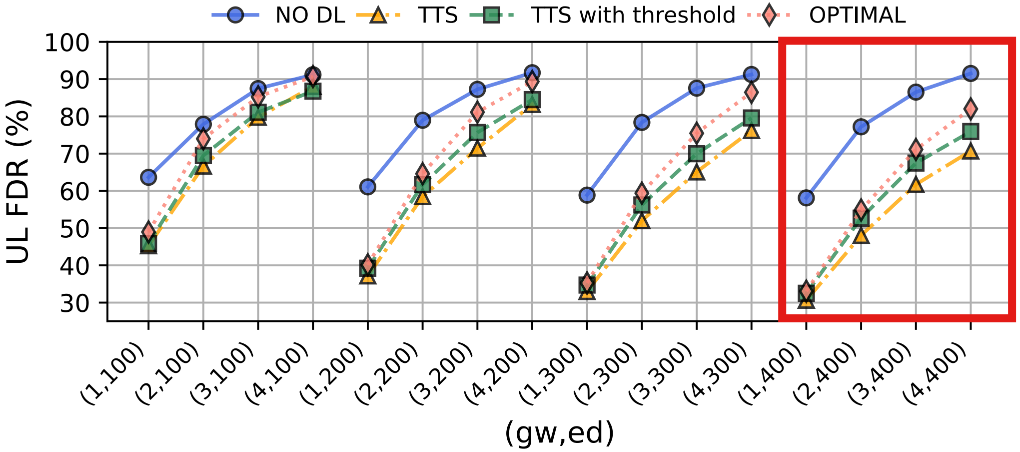

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03

03| Conclusion and perspectives

3.1 Conclusion and perspectives

- Conclusion
  - Comparison with optimal showed that there is a considerable gap for improvement in TTS up to 23 %
    - A first proposal was a deterministic scheduling according to a SF threshold that showed huge improvement compared to cost of implementation
- Future work
  - **It is possible to propose a new scheduling algorithm that solves the flaws of the existing algorithms**
    - Efficient duty cycle use
    - Downlink traffic balance across gateways

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Thank you for your attention

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