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Journées LPWAN 2022

Channel assignment and traffic shaping for PDR differentiation in dense LoRaWAN deployments

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Motivations and Related works
Quality differentiation in LoRaWAN

Motivations [1]:

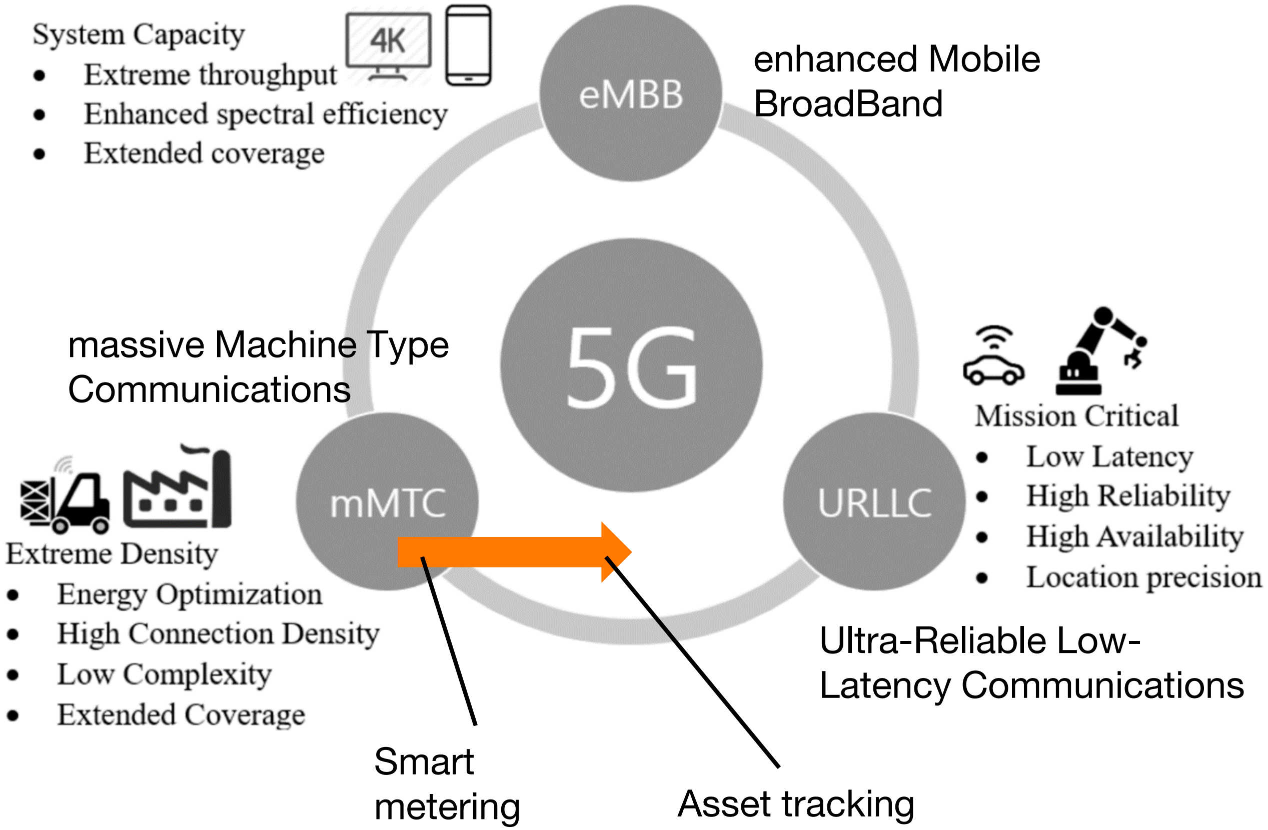
- Device population in urban scenarios is expected to grow exponentially;
- Different use cases require different traffic properties, but LoRaWAN uses a single interference domain.

Related works [2]:

- Studies on slicing exist, propose to exploit independent interference domains for clusters;
- They optimize performance with different objectives (reliability, energy, latency);
- They don't define precise requirements;
- With just ADR, LoRaWAN quality still degrades due to congestion when traffic increases.

Can we enforce precise quality requirements in LoRaWAN?

Can we have multiple requirements at the same time (quality differentiation)?



[1] Siddiqi, M. A., Yu, H., & Joung, J. (2019). 5G ultra-reliable low-latency communication implementation challenges and operational issues with IoT devices. Electronics, 8(9), 981.

[2] Dawaliby, S., Bradai, A., & Pousset, Y. (2019). Adaptive dynamic network slicing in LoRa networks. Future generation computer systems, 98, 697-707.

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Proposed approach (1/3)
Assumptions and key concepts

Assumptions:

- We focus on **Packet Delivery Ratio (PDR)** because it is a key quality metric for congestion;
- We consider clusters of devices with different minimum PDR requirements (97%, 90%, 70%);
- We produce a one-shot reconfiguration scheme to be generalized for online execution.

Main steps:

1. Exploit channels (8 is the maximum number for a SX1301 gateway) to isolate cluster traffic;
2. Regulate the amount of traffic in each cluster to obtain their desired PDR level.

Try to be as precise and fair as possible with right to clusters and devices demands.

Background:

- **Offered traffic** models the average number of concurrent transmissions at any point in time, i.e. the traffic intensity;
- The capacity model in Heusse et al. [3] relates offered traffic to PDR for each [frequency, Spreading Factor (**SF**)] pair;
- Inverting their function, we have an estimated bound on offered traffic for a desired PDR value;
- Also used for demand estimation.

$$h^{-1}(PDR) = -\frac{1}{2} \cdot \mathcal{W}\left(-\frac{\xi}{e^{\xi}} \cdot e^{g_t} \cdot PDR\right) - \frac{\xi}{2} \tag{1}$$

$$\xi = \frac{\gamma + 1}{1 + \gamma\left(1 - e^{\frac{1}{\gamma} - g_t}\right)} \qquad g_t = -\log(\mathbb{P}_H)$$

Offered traffic

Power difference for correct reception on co-SF collision

Lambert W function

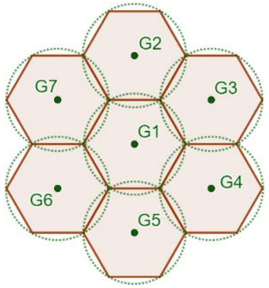
Coverage probability

[3] Heusse, Martin, et al. "Capacity of a lorawan cell." *Proceedings of the 23rd International ACM Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems*. 2020.

Proposed approach (2/3)

“Packet Delivery Ratio Guarantees for Differentiated LoRaWAN Services”

Gateway configuration:



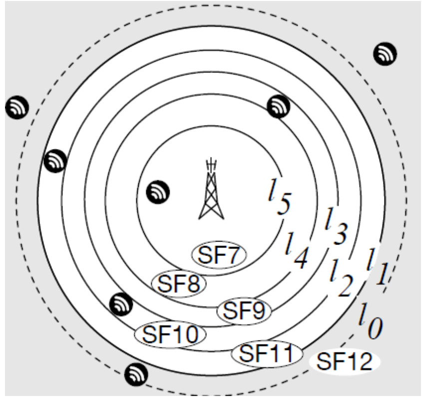
Inputs from devices:

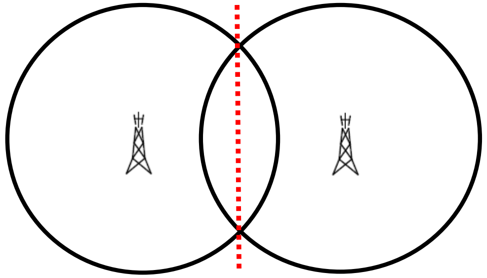
- Cluster membership;
- Maximum bit-rate.

Scenario:

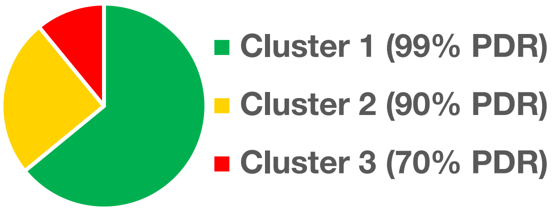
- Open field: log path loss, no variance;
- Gateways radius of 7.5km (for good coverage).

Source: [3]





$$w_{g,c} = \sum_{d \in D_{g,c}} \frac{t_d}{h^{-1}(PDR_c)} \qquad (2)$$



Partition devices into gateways using RSSI & SNR → **Compute resource demands** of each cluster (total bit-rate scaled according to offered traffic) → Optimization algorithm to assign frequencies as close as possible to the true **proportional solution** → For each cluster, **assign SFs** starting with devices with better RSSI. When one SF is full (i.e. we fill the offered traffic of formula (1)), start using the next.

Main conclusion: we can achieve cluster requirements and differentiation as a trade-off between cell range and PDR

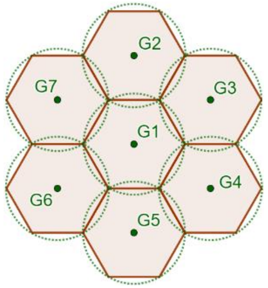
Proposed approach (3/3)

"Traffic Control and Channel Assignment for Quality Differentiation in Dense Urban LoRaWANs"

Scenario:

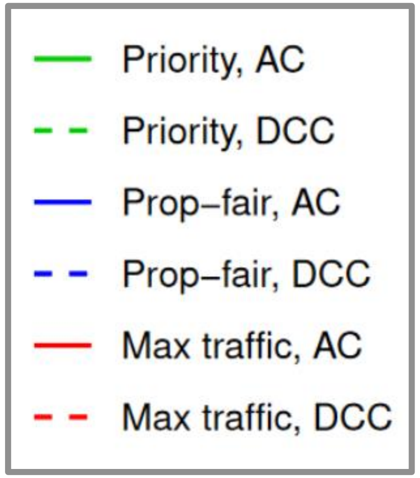
- Urban setting: Okamura-Hata path loss, Rayleigh fading;
- Gateways radius of 2.5km (for >0.98 coverage probability).

Gateway configuration:



Assuming SFs are assigned with standard ADR, we compare:

- Three **channel allocations** to clusters, spanning over the fairness spectrum:
  - Prioritizing clusters with higher requirements;
  - Kelly's Proportional-fairness [4];
  - Network throughput maximization.
- Two **traffic shaping** techniques to obtain the desired PDR by lowering offered traffic according to the model from Heusse et al. [3]:
  - Access Control (**AC**): maximization problem to exclude some devices;
  - Duty-Cycle Control (**DCC**): lower the duty-cycle (to common value).



Finally, we propose a way to measure device utility and resource efficiency to evaluate the **interest of users and operators** compared to existing techniques.

[4] Kelly, Frank P., Aman K. Maulloo, and David Kim Hong Tan. "Rate control for communication networks: shadow prices, proportional fairness and stability." Journal of the Operational Research society 49.3 (1998): 237-252.

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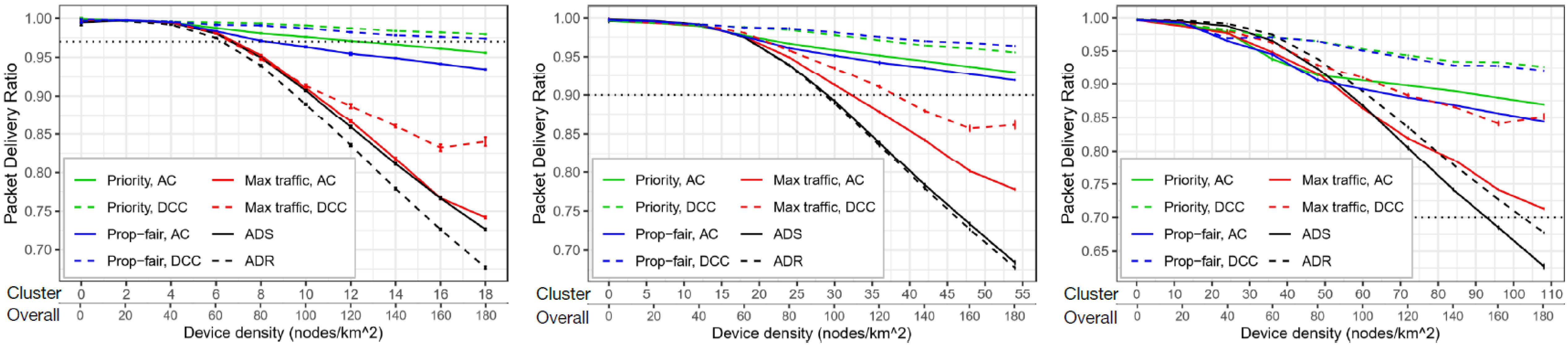
Results (1/3)
Packet delivery ratio of clusters

- We compare to Adaptive Dynamic Slicing (**ADS**) [2] and standard **ADR** (no traffic shaping or frequency allocation);
- As done in [2], in each simulation we assign 10% of devices to cluster 1, 30% to cluster 2, and 60% to cluster 3.



(a) 97% PDR cluster. (b) 90% PDR cluster. (c) 70% PDR cluster.

Fig. 2. Packet delivery ratio comparison, per cluster in the same simulation. Horizontal dotted black lines denote the required PDR level.

- Some techniques are able to maintain quality at high density, blocking more traffic (DCC being more conservative);
- We have PDR differentiation but it is not too strong;
- Max-traffic behaves similarly to ADR/ADS although we are using the same criteria to limit traffic.

[2] Dawaliby, S., Bradai, A., & Pousset, Y. (2019). Adaptive dynamic network slicing in LoRa networks. Future generation computer systems, 98, 697-707.

Results (2/3)
Impact of gateway congestion

Why is Max Traffic doing so worse, if it uses the same traffic constraining techniques?

After a certain threshold for offered traffic in the network, the gateways become **congested**:

- All parallel reception paths are occupied at the same time;
- If a cluster introduces enough traffic, it **impacts the others** undermining the isolation provided by different frequency sets.

TABLE IV
PERCENTAGE OF LOST FRAMES IN Prop-fair, AC, Max traffic, AC, AND ADR. LOSS IS CAUSED BY INTERFERENCE (I), NO AVAILABLE RECEPTION PATHS IN A CONGESTED GATEWAY (C), AND UNDER SENSITIVITY (U) DUE TO FADING. OFFERED TRAFFIC (OT) (IN ERLANG) IS INCLUDED.

Scenario		60 n/km^2	120 n/km^2	180 n/km^2
Prop-fair, AC	I	3.39%	5.10%	6.21%
	C	1.16%	3.63%	5.79%
	U	0.21%	0.25%	0.27%
	OT	7.01	9.66	11.27
Max traffic, AC	I	2.13%	5.18%	7.04%
	C	1.42%	10.07%	18.81%
	U	0.22%	0.23%	0.23%
	OT	7.34	13.57	18.58
ADR	I	0.77%	3.44%	6.97%
	C	1.55%	12.41%	24.94%
	U	0.21%	0.22%	0.21%
	OT	7.51	14.96	22.60

Results (3/3)
Resource allocation efficiency

- From an operator standpoint, resources are assigned less efficiently but we do better at high density
- Best results are achieved with proportional-fair frequency allocation and access control
- We conclude that these techniques could become interesting for the operator with ad-hoc pricing

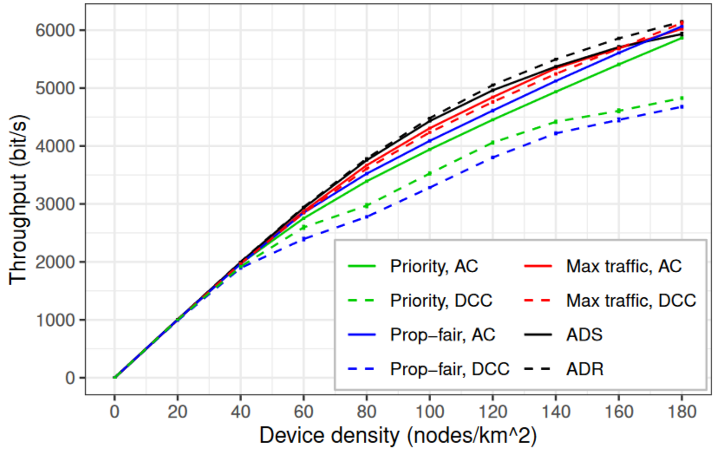


Fig. 7. Total network throughput.

- With access control the overall network throughput is comparable to ADR/ADS

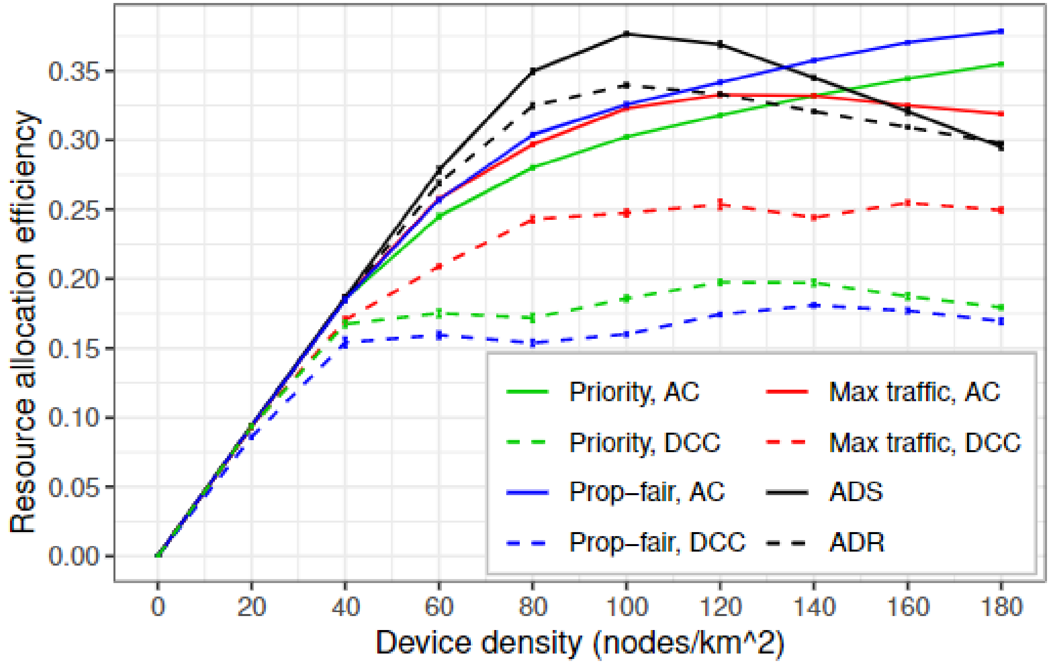


Fig. 6. Share of resources (bandwidth) contributing to satisfaction of requirements. If the operator charges users according to demands satisfaction, higher values indicate higher gain for the operator.

Conclusions

- We investigated the role of traffic shaping in mitigating interference and ensuring a PDR
- We studied the problem with multiple clusters of devices and different PDR requirements
- We can grant PDR levels, with some differentiation
- At high density, we are more cost-efficient then current LoRaWAN operation
- At low density, ad-hoc pricing for different service levels needs to be used to cover the efficiency gap

Perspectives:

- We improved DCC traffic shaping to be as accurate as AC
- We are testing the online version of the reconfiguration problem
- The model from Heusse et al. [3] does not consider gateway congestion: use measurements to optimize the trade-off between traffic intensity and PDR with a lightweight convergent algorithm
- Potentially address moving devices

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Thank you