Neutrality for Sustainability:

The Promise of Neutral Hosts for Sustainable Mobile Networks

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https://suzanbayhan.github.io/

https://www.utwente.nl/en/eemcs/dacs/

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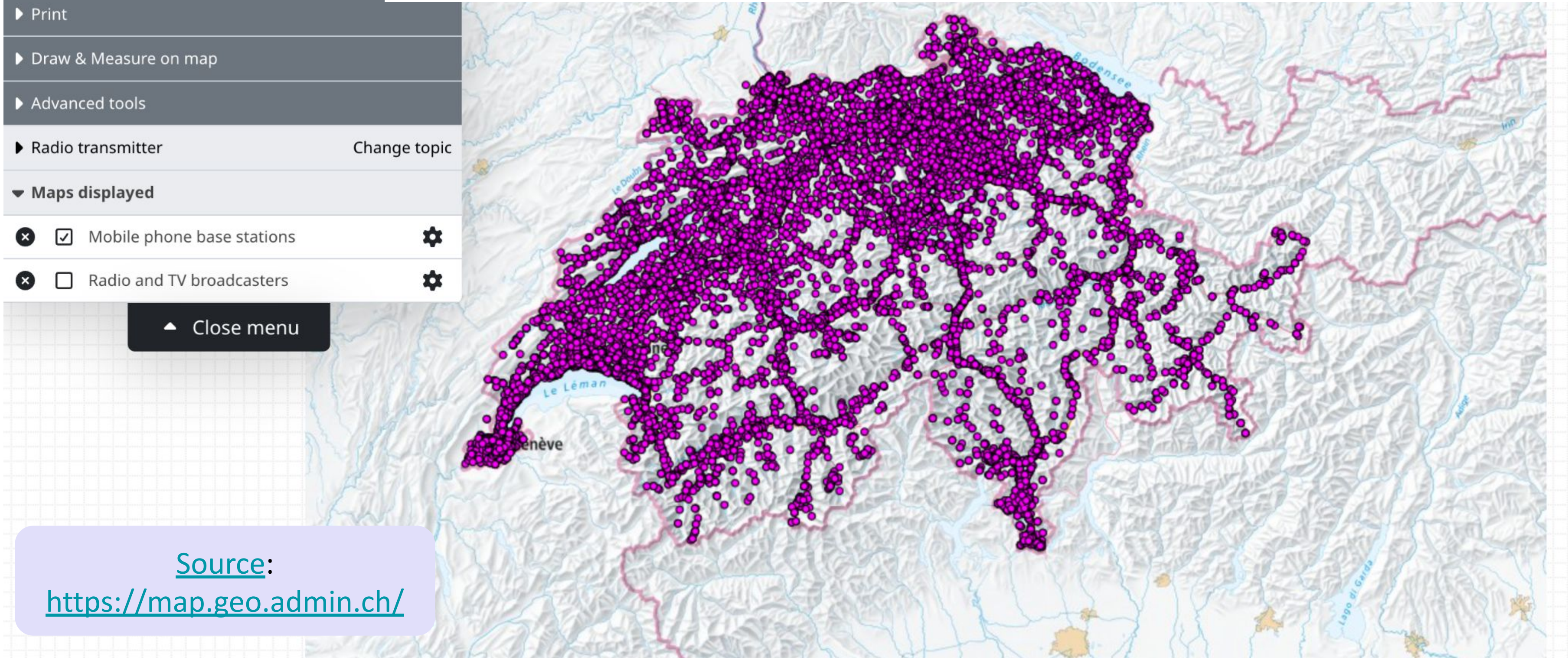
UNIVERSITY OF TWENTE.

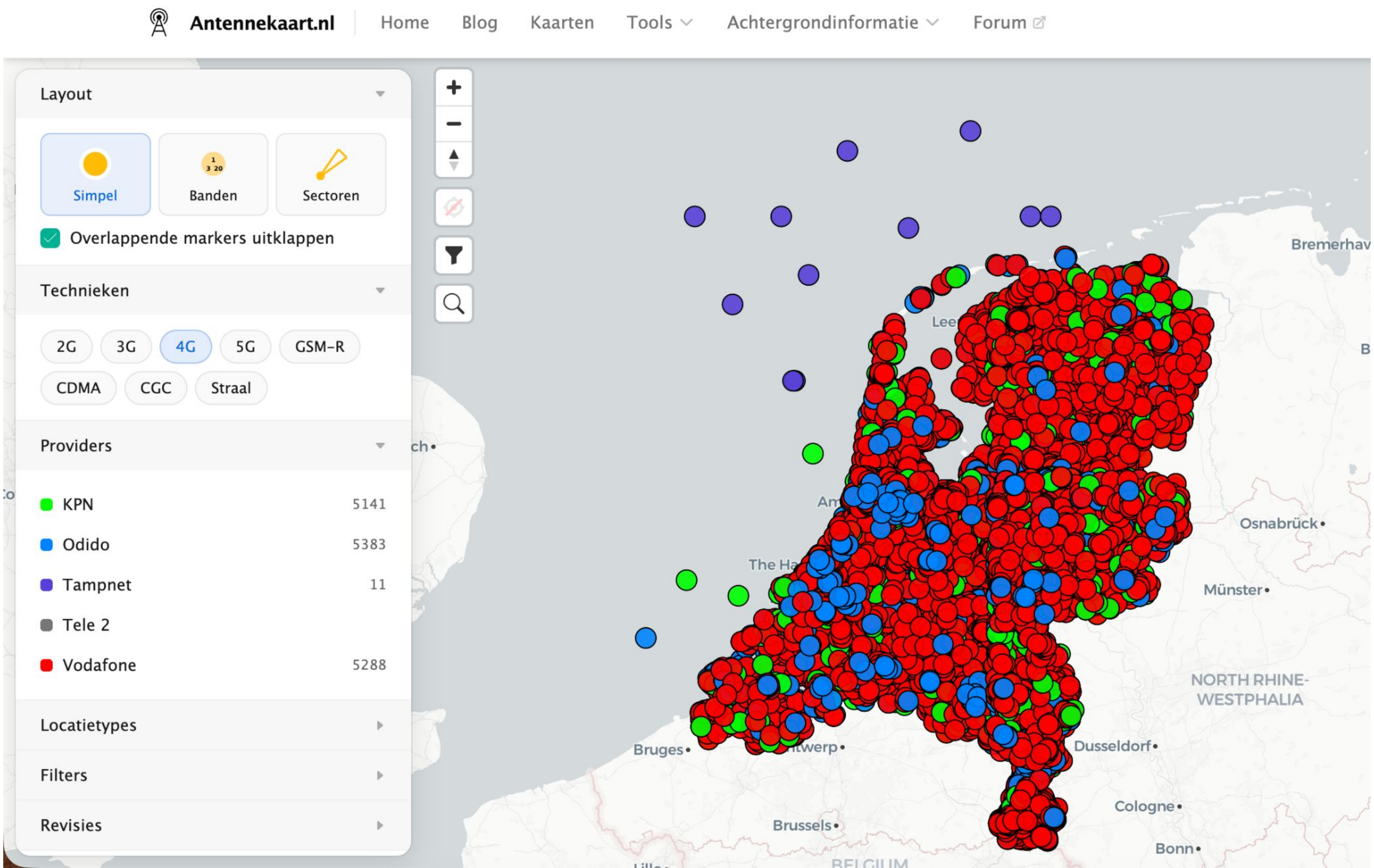
DACS
Design and Analysis of Communication Systems

FUTURE NETWORK SERVICES 6G

Mobile networks: ubiquitously deployed



Source: https://map.geo.admin.ch/



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Tele 2
Vodafone 5288
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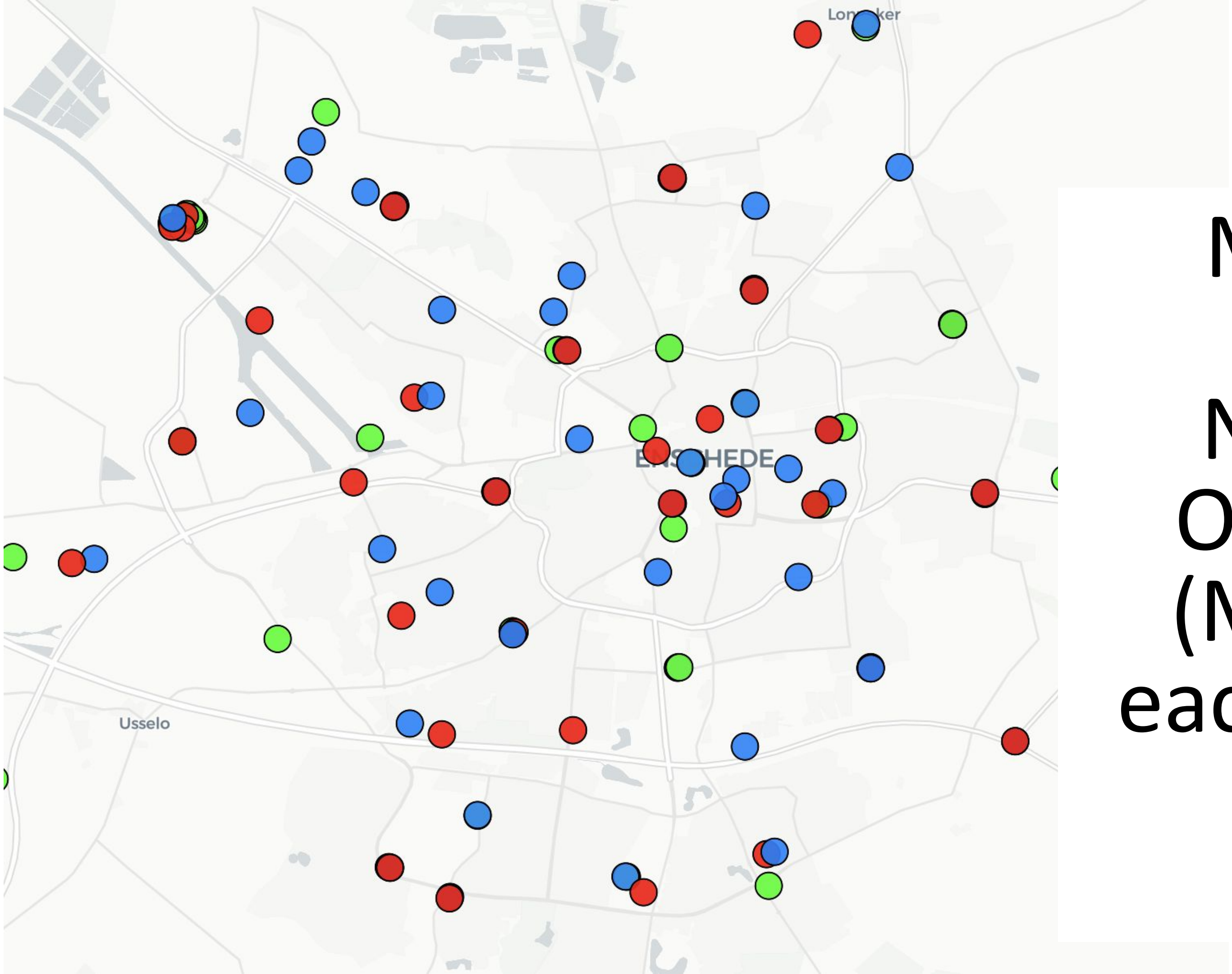


Multiple Mobile Network Operators (MNOs) in each country

Mobile networks: ubiquitously deployed

Coverage, capacity, and resilience

- A mobile user receives high quality signal from many base stations (BS), e.g., 5-10 depending on urbanity level of the device location
- Overprovisioned, e.g., mostly average load lower than 30% [1]

[1] L. Golard, J. Louveaux, and D. Bol, Evaluation and projection of 4G and 5G RAN energy footprints: the case of Belgium for 2020–2025, Annals of Telecommunications 2022.

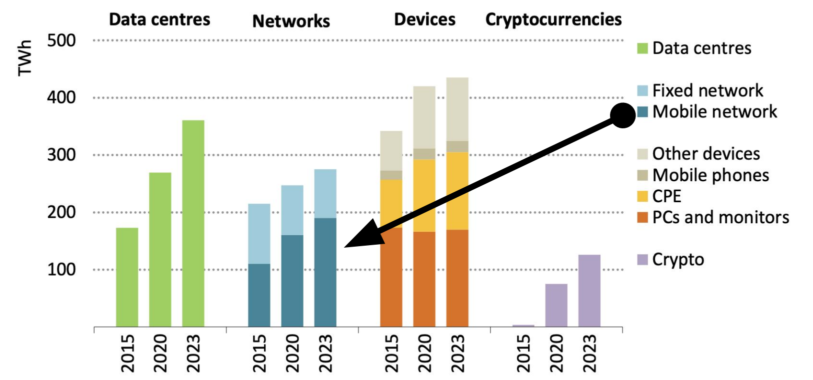
Operation with low load: not desirable due to overhead in power consumption

- A static traffic-independent power component:
  - Idle/static power
- Traffic-dependent power component:
  - Dynamic power

Growing sustainability concerns

Electricity demand (IEA 2025)

Figure 2.15 ▷ Global electricity demand from data centres, data transmission networks, devices and cryptocurrency mining, 2015-2023



Energy use by data centres and cryptocurrencies have risen sharply since 2020, while devices and networks have seen slower growth

Total carbon footprint 2024 (Malmodin et al. ICT4S 2026)

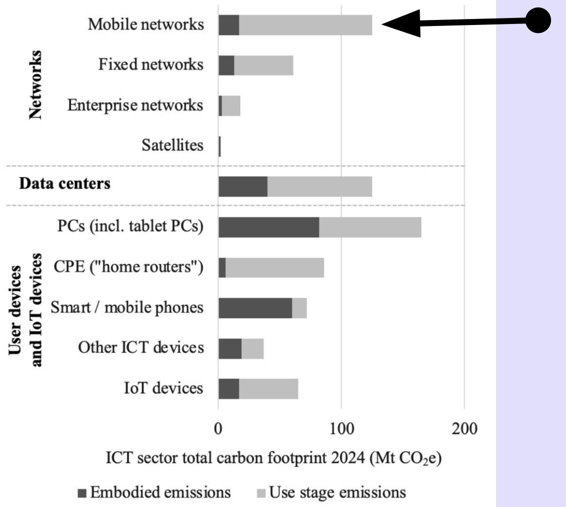


Fig. 4. Detailed view of the total carbon footprint 2024

The problem

Densely-deployed, lowly-loaded, energy-hungry mobile network infrastructures

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Infrastructure sharing for sustainability

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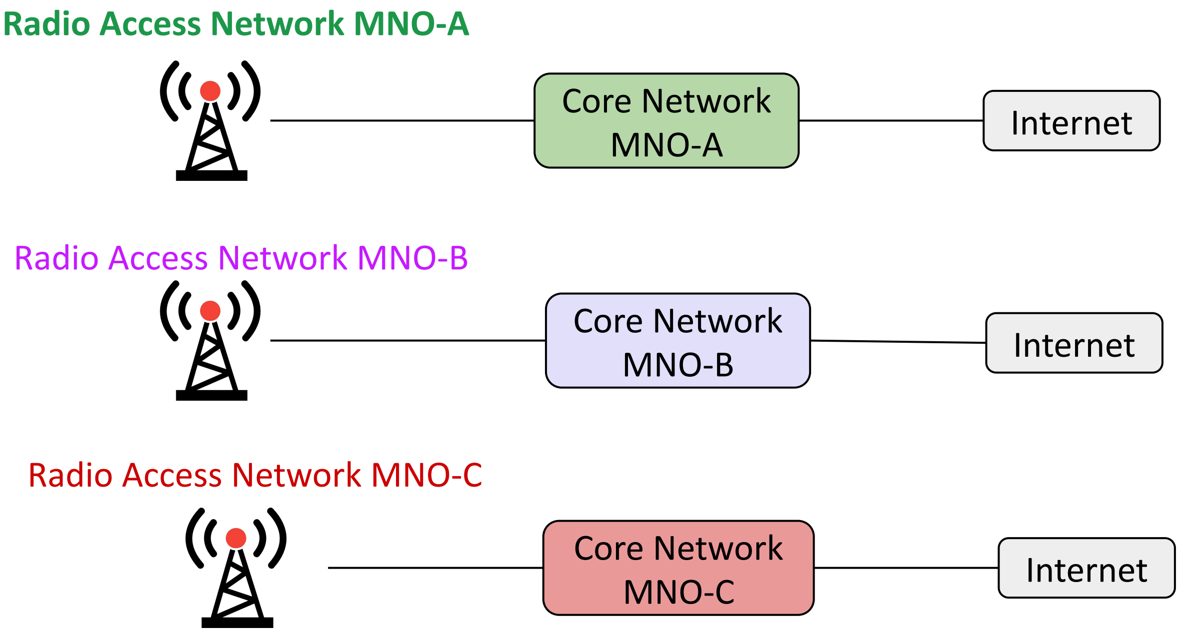
Densely-deployed, lowly-loaded, energy-hungry mobile network infrastructures

Infrastructure sharing for sustainability

N. L. Omnes, C. Adam, A. Braud, F. Latron, L. le Beller, and B. Radier, *How to favour more cooperative deployments for network infrastructures*, ICT4S 2024.

Promise of neutral host networks (NHN)

- Shared multi-tenant infrastructure operated by a third party



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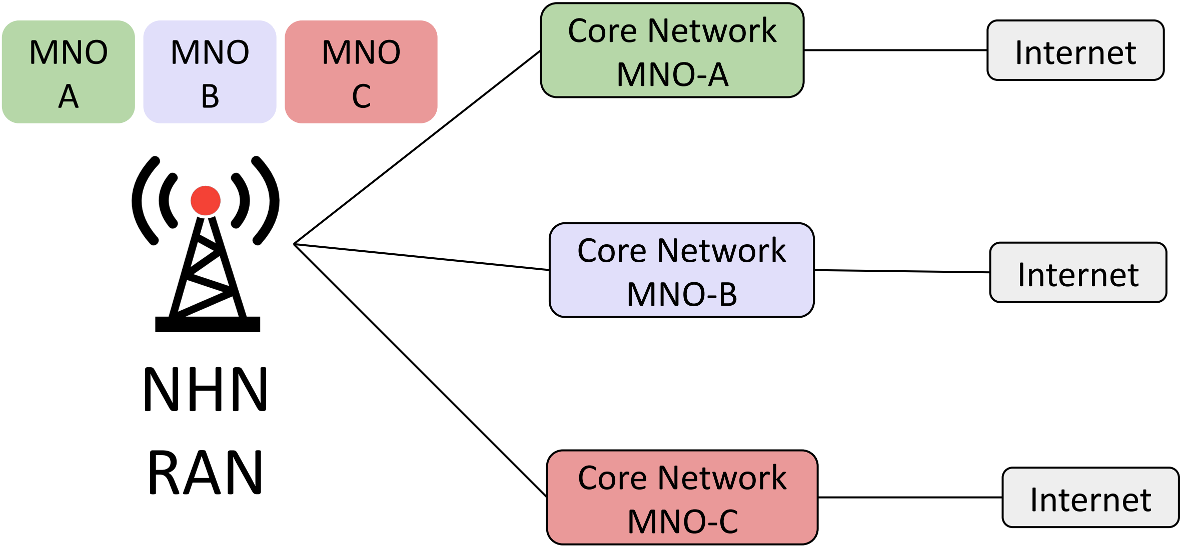

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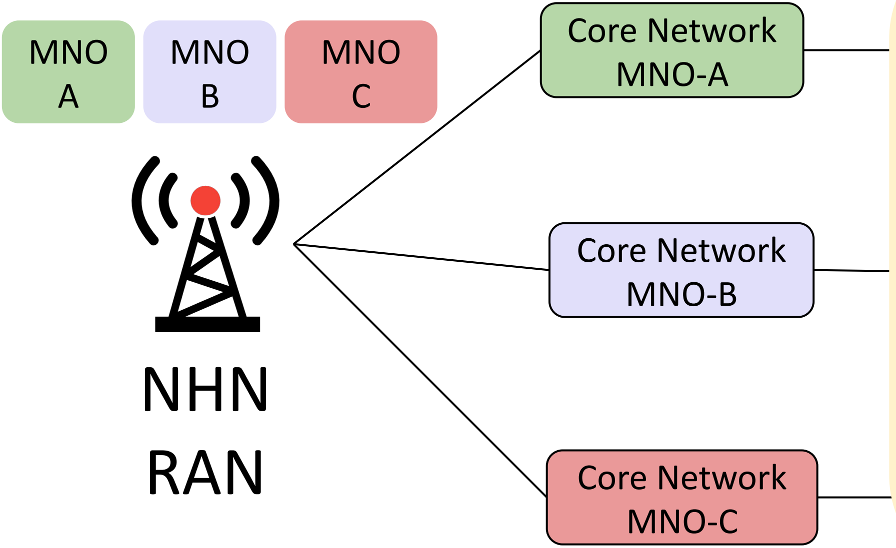

- Reduced hardware → decrease in embodied carbon
- Higher utilization of the RAN resources (more efficient use of power) → decrease in operational carbon

Promise of neutral host networks (NHN)

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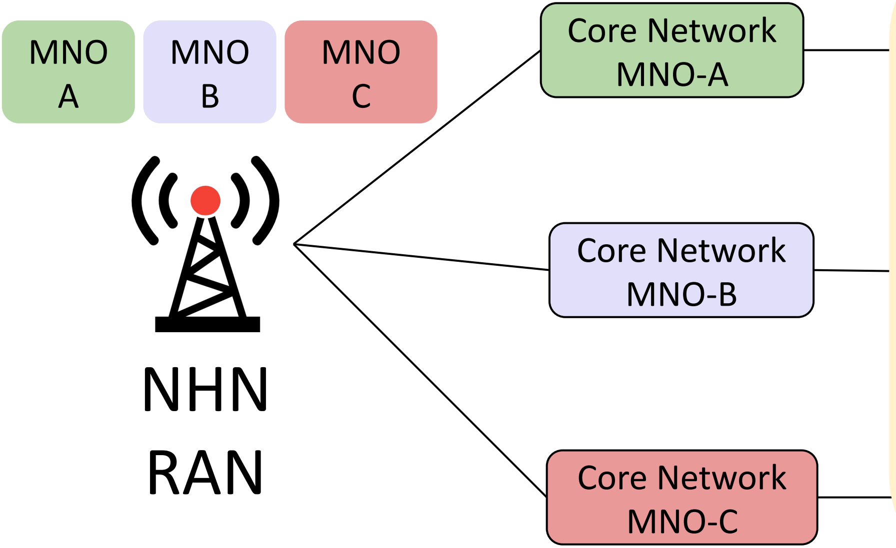
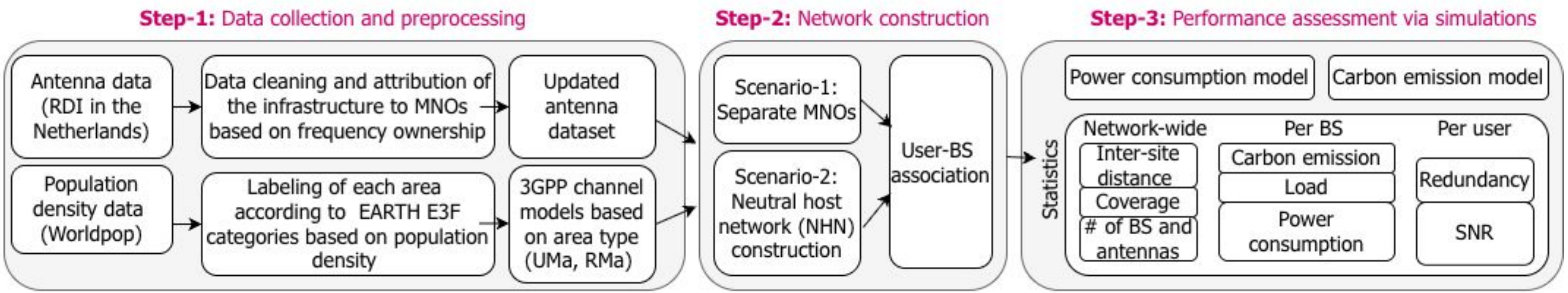


What is the resulting impact on *power consumption, carbon emissions, and network performance* in terms of *coverage, redundancy* and *SNR* when replacing separate MNOs with a single NHN?

Research Methodology

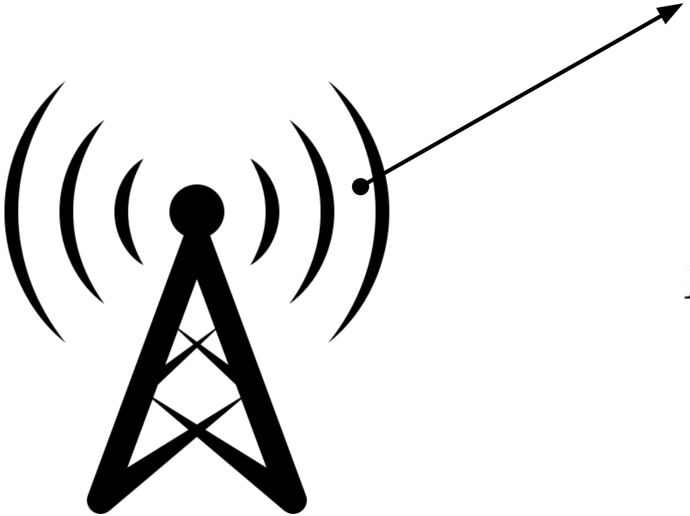


- Open data: RDI [ARCEP and BAKOM]

Research Methodology

- Realistic scenarios constructed from public data in the Netherlands combined with models
  - Open data: RDI [ARCEP and BAKOM]
- Simulations for different neutral host scenarios
- Comparison with current operation (independent RAN deployment by three operators)

Sustainability



Radio Access Network
(RAN)

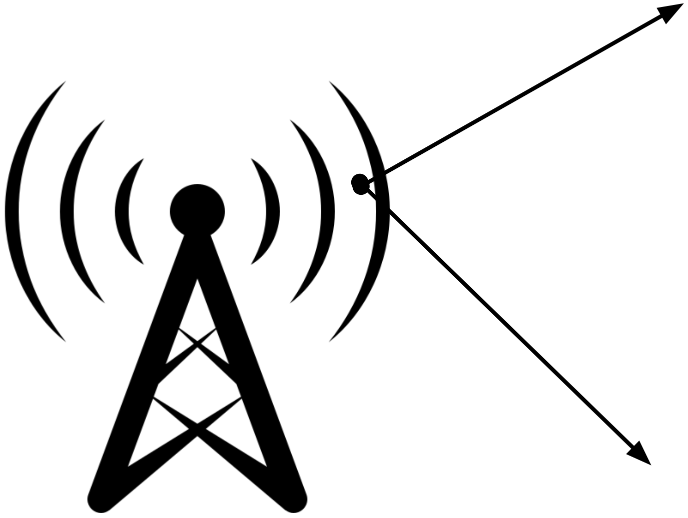
Operational carbon emission:
Average carbon intensity of the (Dutch) grid * RAN annual power consumption

$$P_{BS} = N_{TRX} \times \frac{P_{PA} + P_{RF} + P_{BB}}{(1 - \sigma_{DC}) \times (1 - \sigma_{MS})} \qquad (7)$$

$$P_{PA} = \frac{P_{out}}{\eta_{PA} \times (1 - \sigma_{feed})}.$$

$$P_{out} = P_{max} \times \rho \text{ where } \rho = \frac{D}{C}.$$

Sustainability



Radio Access Network
(RAN)

Operational carbon emission:
Average carbon intensity of the (Dutch) grid * RAN annual power consumption

Embodied carbon emission:
Life Cycle Analysis data for RAN components

Sustainability

TABLE II: Emission factors, service life, and mass of network components.

Equipment type	Emission Factor	Mass (kg)	Service life (years)	Source
Base Band Unit (BBU3900)	34.45 kg CO_2/kg	7 [20]	10	Ecoinvent 3.7. Router, internet
BBU Cabinet (APM30H)	4.04 kg CO_2/kg	72 [21]	10	Ecoinvent 3.7. Chassis, internet access equipment
PSU (3x R4850G2)	33.3 kg CO_2/unit	2 [22]	10	Ecoinvent 3.7. Power supply unit, for deskop computer
Battery cabinet	4.04 kg CO_2/kg	70 [23]	10	Ecoinvent 3.7. Chassis, internet access equipment
Batteries	89.98 kg CO_2/kg	10 [23]	10	Ecoinvent 3.7. Router, internet
Remote Radio Unit (RRU3908)	34.45 kg CO_2/kg	15 [24]	10	Ecoinvent 3.7. Router, internet
Antenna (AAU3911)	34.45 kg CO_2/kg	49 [25]	10	Ecoinvent 3.7. Router, internet

Radio Access Network (RAN)

Embodied carbon emission:

Life Cycle Analysis data for RAN components

Performance

- Receiver's signal quality: measured as Signal-to-Noise Ratio (SNR)
- Resilience: measured as the number of BSs whose SNR at the receiver is above a certain threshold SNR_{min}

Case study: Dutch national cellular infrastructure

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- Cell tower data (for infrastructure info)

Antenna data

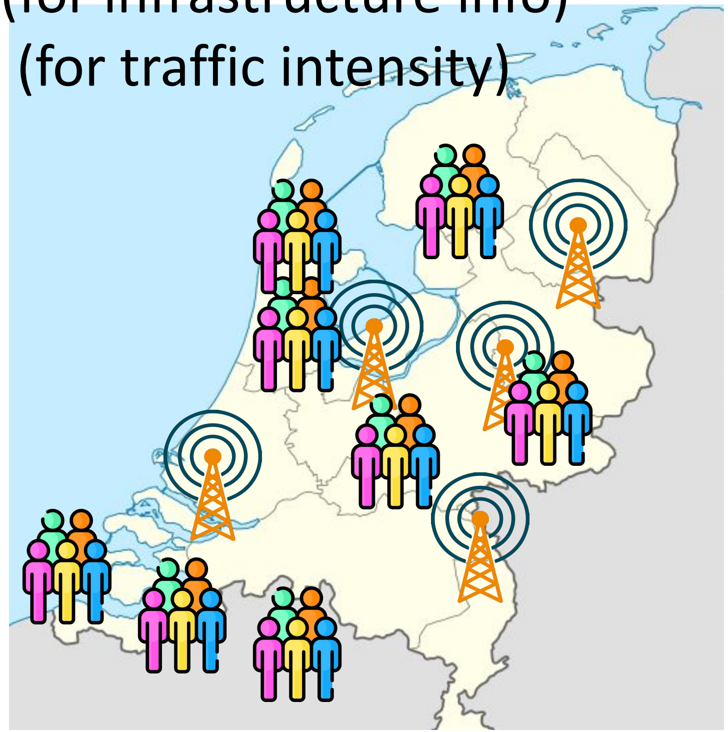
Rokramix, Kanaalstraat, Havengebied, Enschede

Provider Vodafone
Plaats Enschede
Gemeente Enschede
Postcode 7547AS
Site ID S04316
Hoogspanningsmast Nee

Hoogte	Hoek	Frequentie		Vermogen
27.2 m	90°	b28	763 MHz	28.4 dBW
27.2 m	90°	b20	806 MHz	28.4 dBW
27.2 m	90°	b3	1835 MHz	32.4 dBW
27.2 m	210°	b28	763 MHz	28.4 dBW
27.2 m	210°	b20	806 MHz	28.4 dBW
27.2 m	210°	b3	1835 MHz	32.4 dBW
29.8 m	330°	b28	763 MHz	28.4 dBW
29.8 m	330°	b20	806 MHz	28.4 dBW
29.8 m	330°	b3	1835 MHz	32.4 dBW

Case study: Dutch national cellular infrastructure

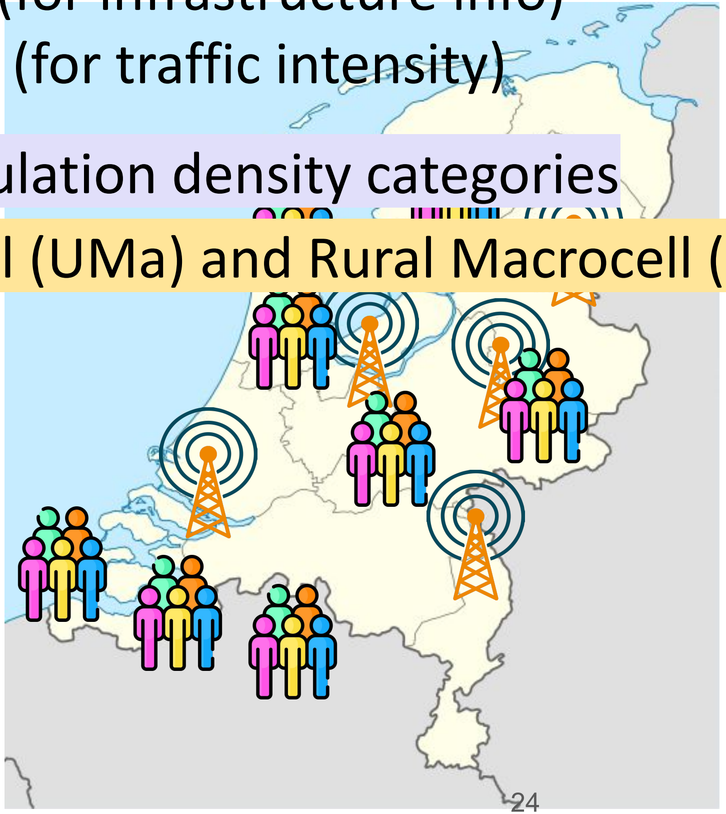
- Cell tower data (for infrastructure info)
- Population data (for traffic intensity)

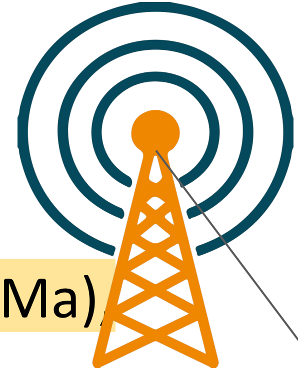


WorldPop data

Case study: Dutch national cellular infrastructure

- Cell tower data (for infrastructure info)
- Population data (for traffic intensity)
- EARTH E3F population density categories
- Urban macrocell (UMa) and Rural Macrocell (RMa)

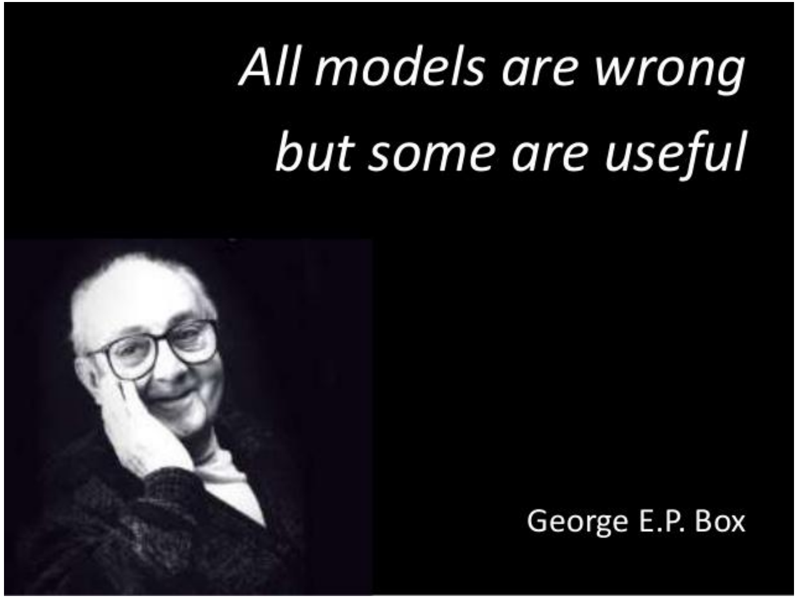




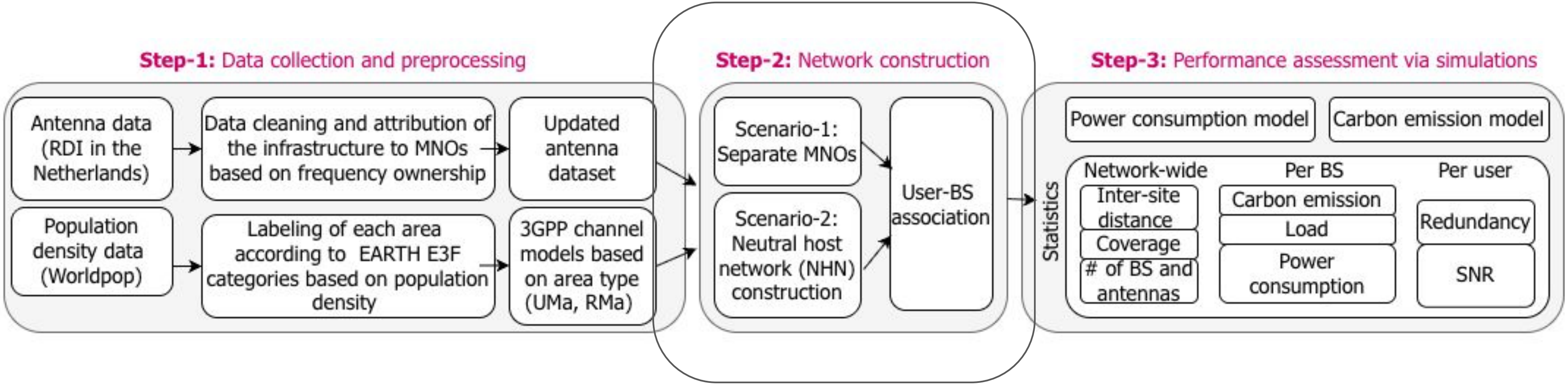
Urbanity level → 3GPP channel models

Case study: Dutch national cellular infrastructure

Many modelling decisions and assumptions



Research Methodology



NHN construction: A simple heuristic based on current cell-tower locations

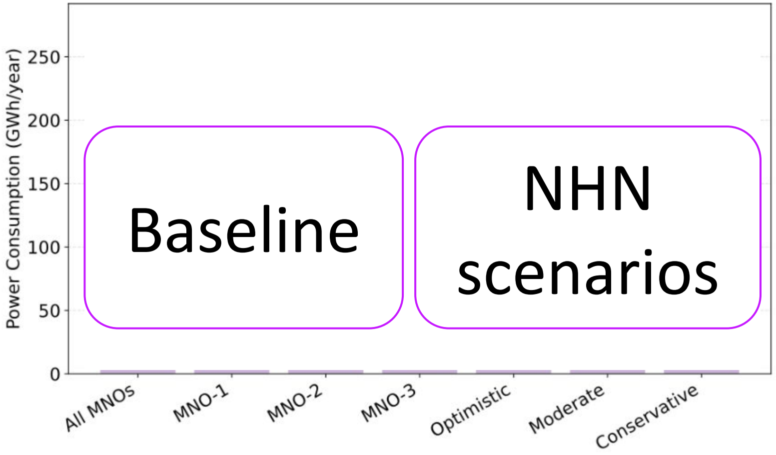
Neutral Host Construction

- 2-step heuristic:
  - Clustering the BSs based on their geographic proximity and demand served (distance below d_{thresh})
  - Merge infrastructure if
    - The BS can still satisfy the user demand: load is below max load

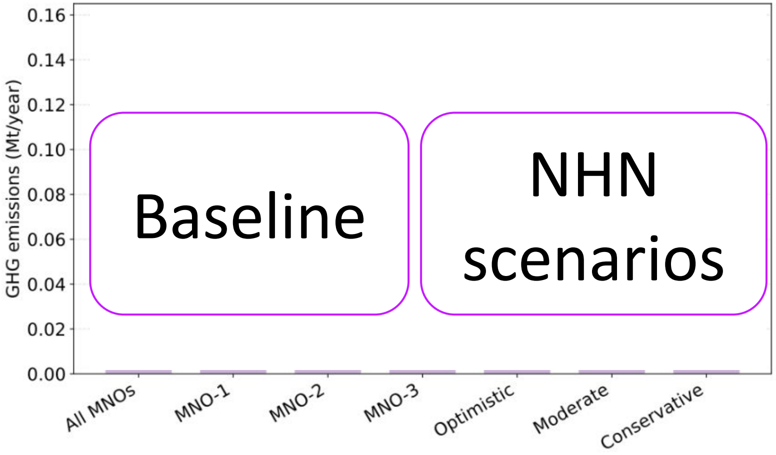
Scenarios

- Business as usual: today's separate MNOs
- NHN Optimistic (d_{thresh}= 1000 meters, max load = 0.9)
- NHN Moderate (d_{thresh}= 500 meters, max load = 0.7)
- NHN Conservative (d_{thresh}= 200 meters, max load = 0.5)

Promise: power and carbon savings

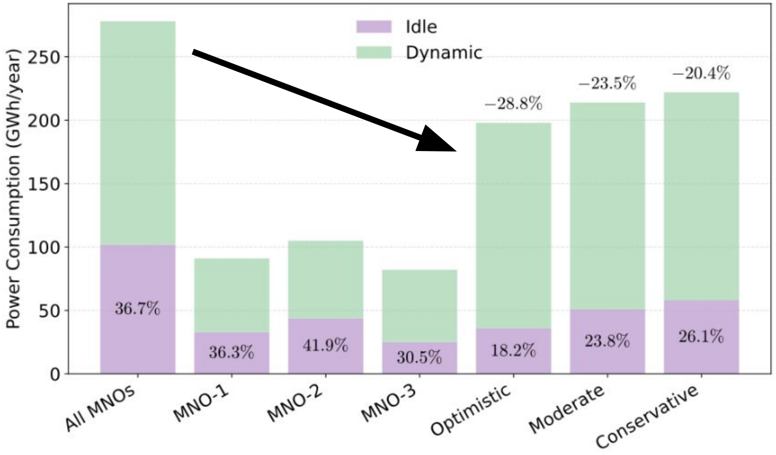


Power consumption
(idle and dynamic)



Carbon emissions
(embodied and operational)

Promise: power and carbon savings



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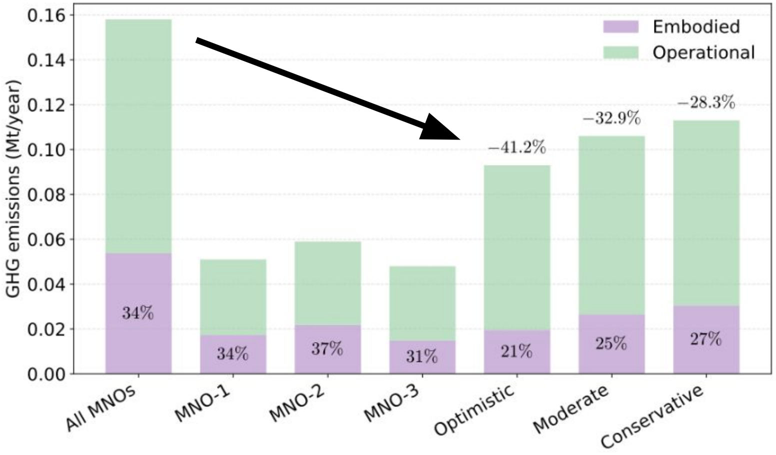

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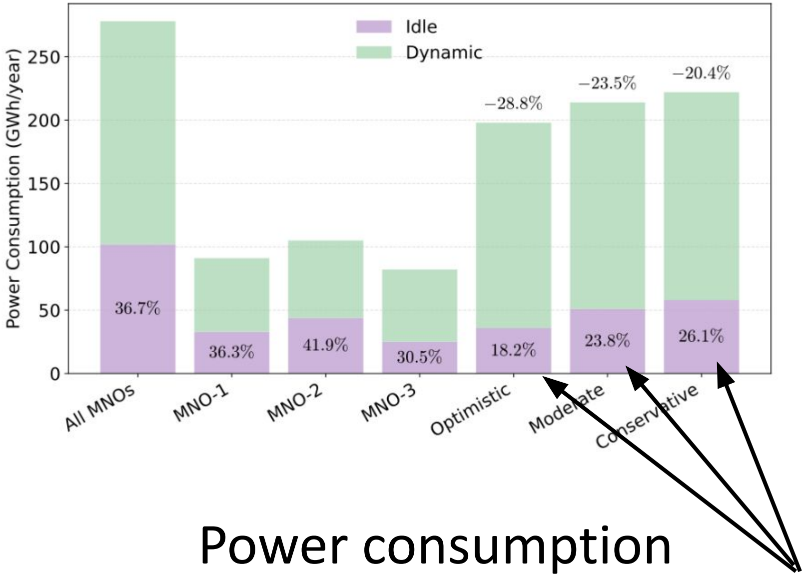

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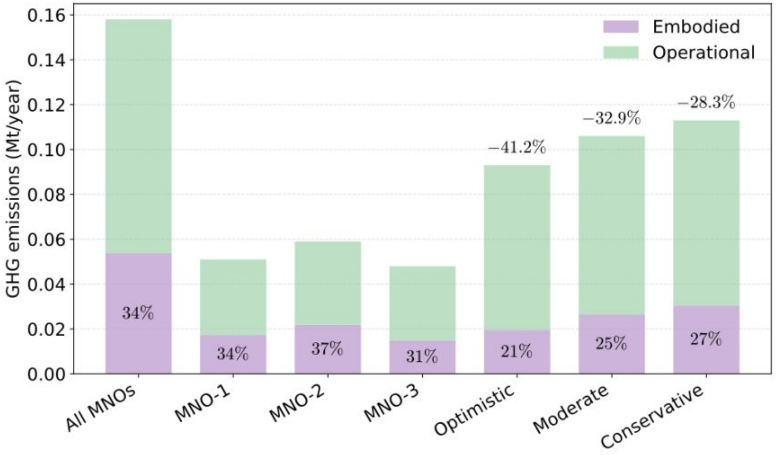
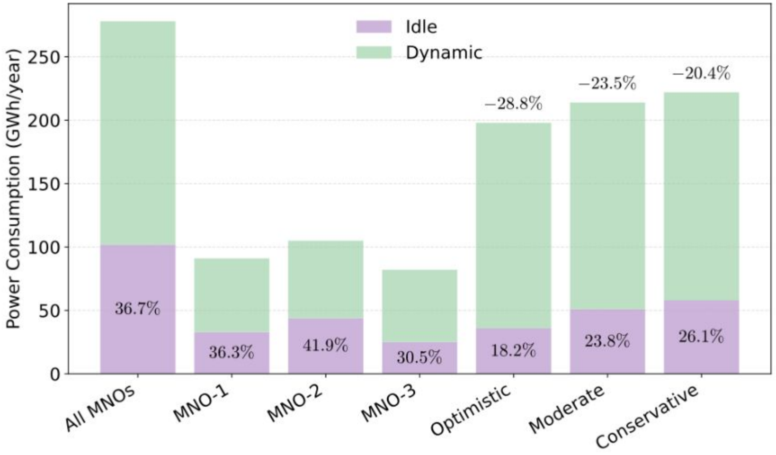


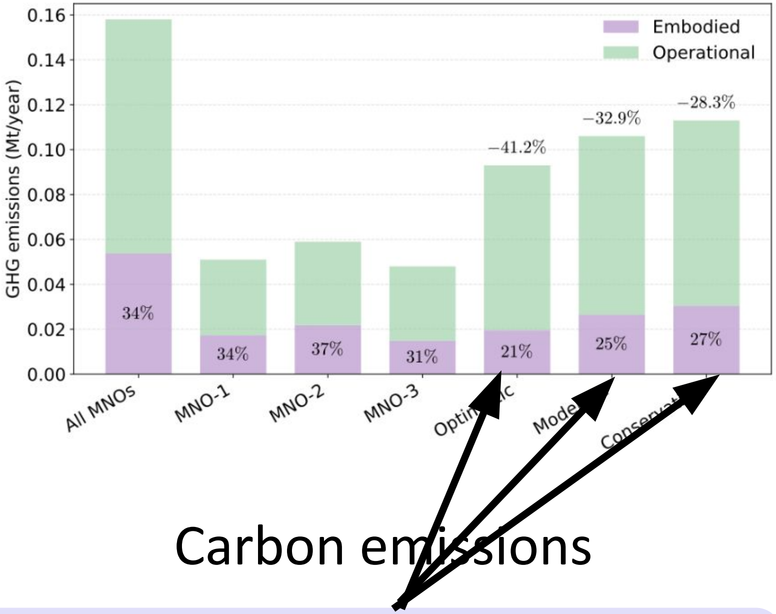
Carbon emissions

Idle power: lower proportion due to better utilization of the BSs

Promise: power and carbon savings



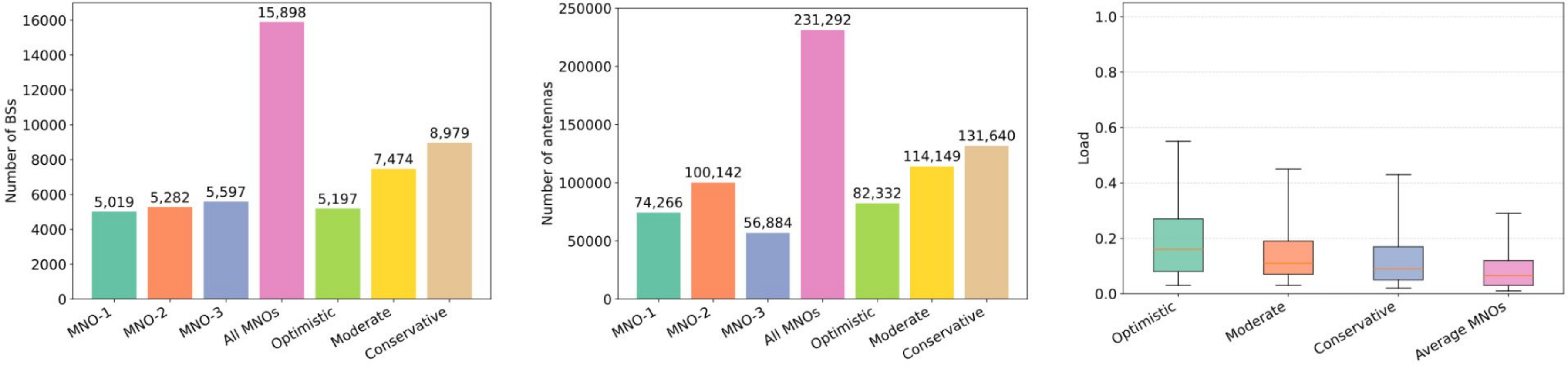
Power consumption



Carbon emissions

Embodied: Large reductions in BS and antennas across scenarios

Resulting infrastructure



(a) Number of BSs in the infrastructure.

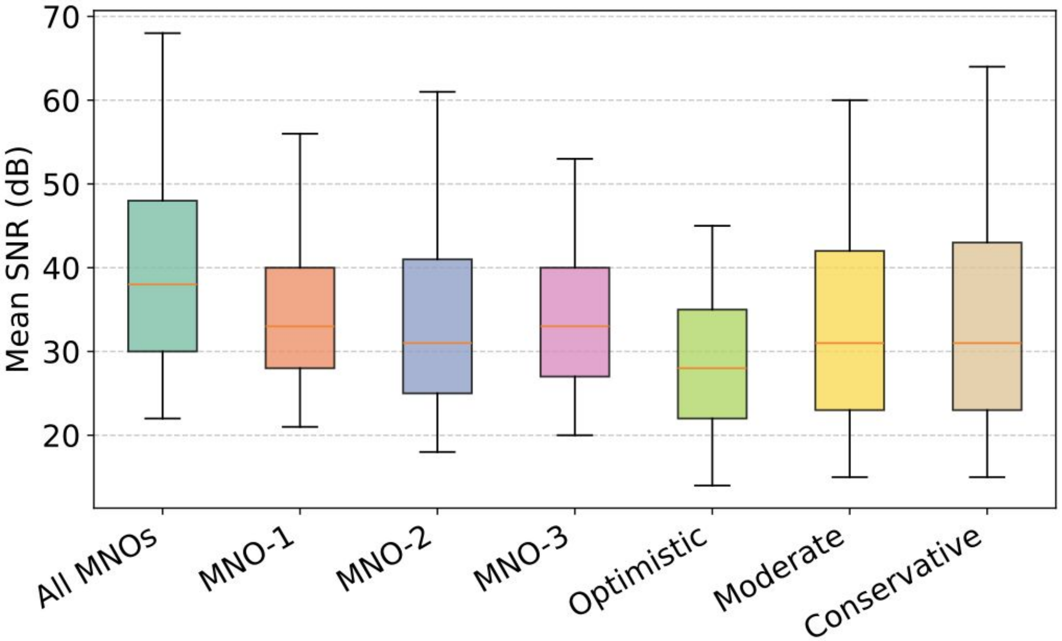
(b) Number of antennas in the infrastructure.

(c) BS load.

Fig. 4: Total number of (a) BSs and (b) antennas, and (c) BS load in each scenario.

BS load gets higher

Coverage: SNR



SNR decreases but coverage loss remains marginal

Need for a more dynamic deployment approach

Change in SNR in each density class

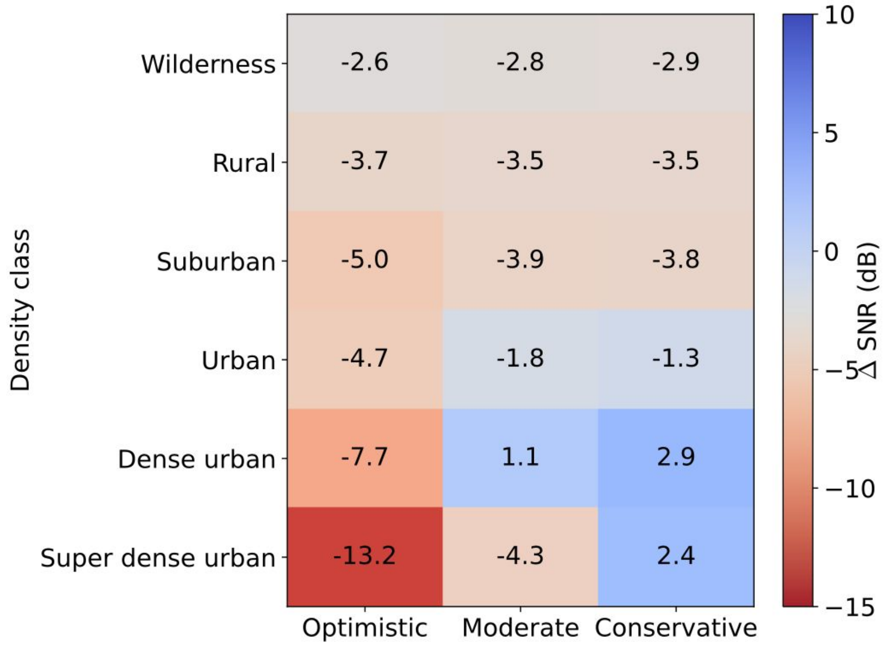
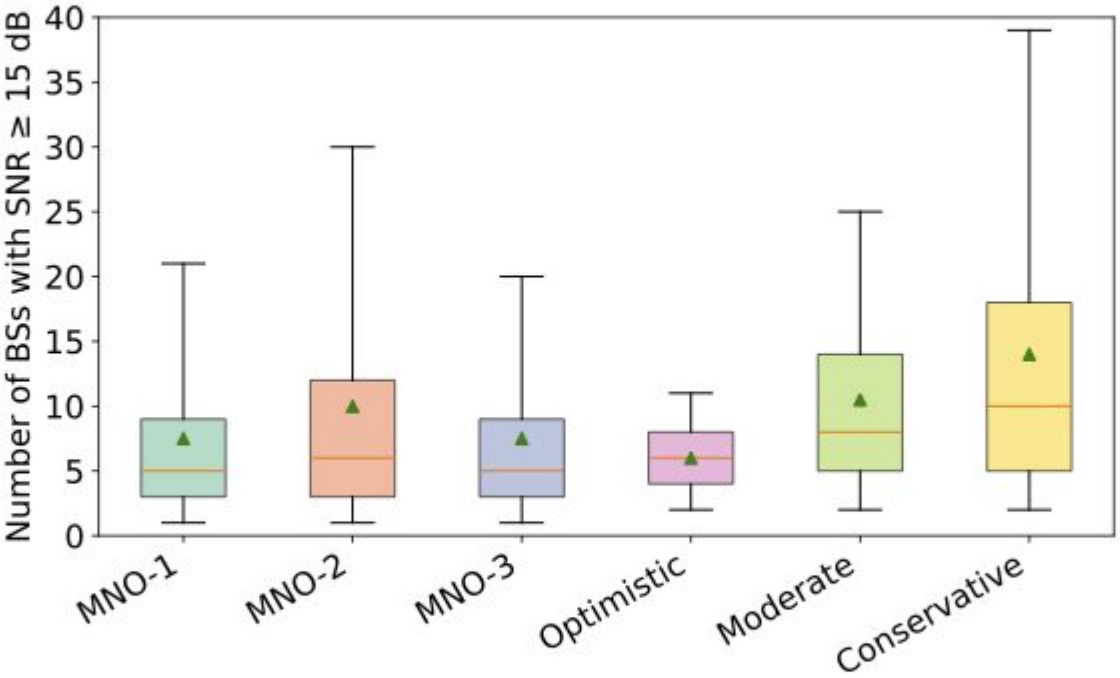


Fig. 6: SNR difference for each density class.

Resilience



Still multiple BSs in the service range

Revisiting RQs

- RQ1: How can we design an NHN that delivers adequate network performance in terms of coverage, redundancy and signal quality (SNR) on a national scale while minimizing power consumption? → A better approach considering density classes of each area

- RQ2: What is the resulting impact on power consumption, carbon emissions, and network performance in terms of coverage, redundancy and SNR when replacing separate MNOs with a single NHN? → Significant power and carbon emission decrease without a drastic reduction in SNR or resiliency

Key limitations

- More accurate information about MNO infrastructures and operations (e.g., interference, traffic dynamics)
- Neutral host: optimized deployment
- 5G models
- Decarbonization etc. impacts in the future

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