Data-driven Modelling and Optimization of Green Future Mobile Networks

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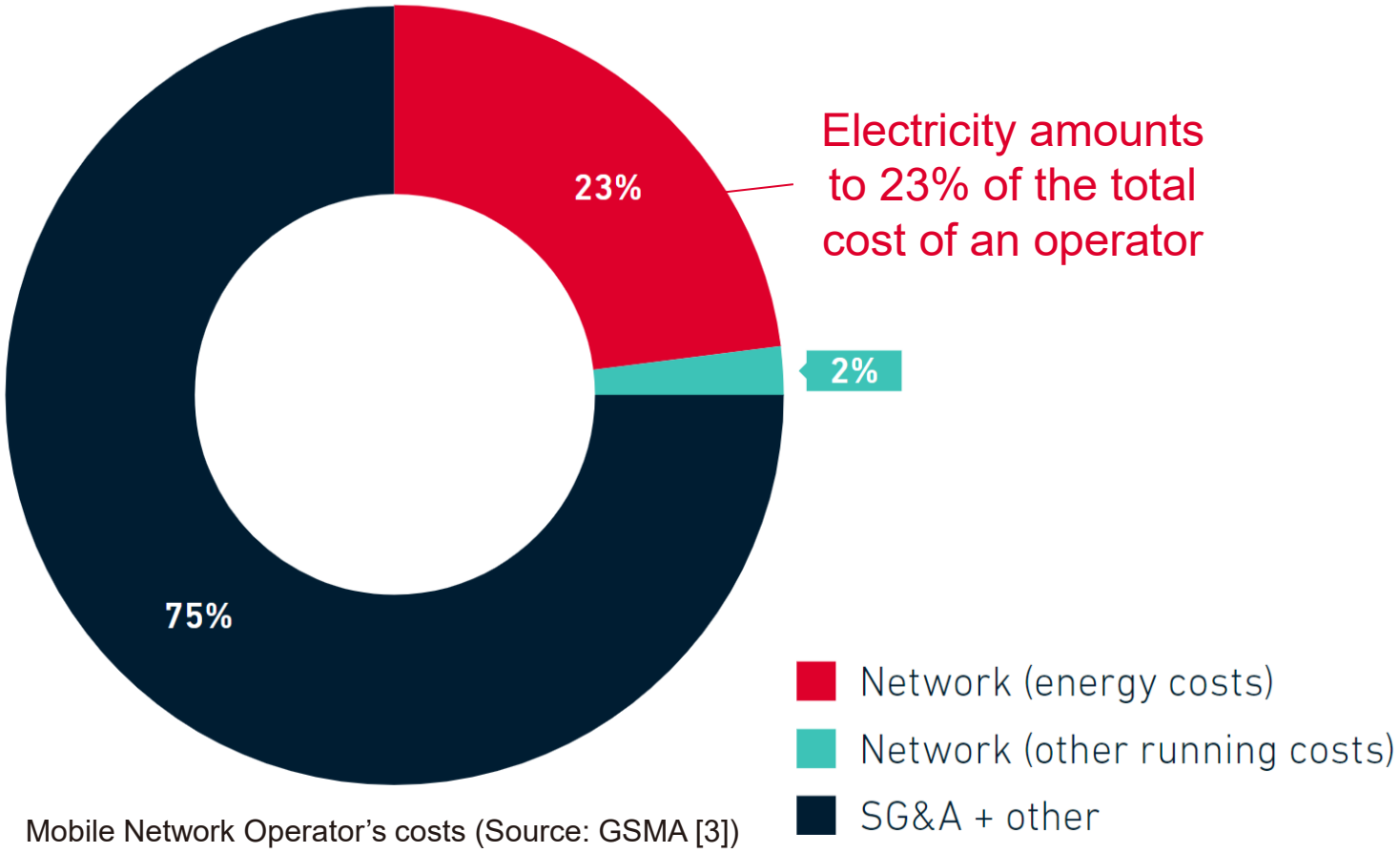
Telecom industry energy consumption

- The telecoms industry utilizes around **3% of the globally consumed energy** [1] with **corresponding CO2 emissions**
  - Telco may account for **up to 14% CO2 emission by 2040** unless significant steps are taken [2]
- The **electricity bill** of an operator accounts for 90% of its network costs and **23% of its total expenditure** [3]



Mobile Network Operator's costs (Source: GSMA [3])

[1] GSMA, the 5G guide: A reference for operators, 2019 https://www.gsma.com/wp-content/uploads/2019/04/The-5G-Guide_GSMA_2019_04_29_compressed.pdf
[2] BCG, Putting Sustainability at the Top of the Telco Agenda, June 2021 https://www.bcg.com/press/24june2021-telco-sector-game-changer-sustainability-shrinking-carbon-footprints
[3] GSMA, 5G energy efficiencies: Green is the new black, 2020 https://data.gsmaintelligence.com/research/research/research-2020/5g-energy-efficiencies-green-is-the-new-black

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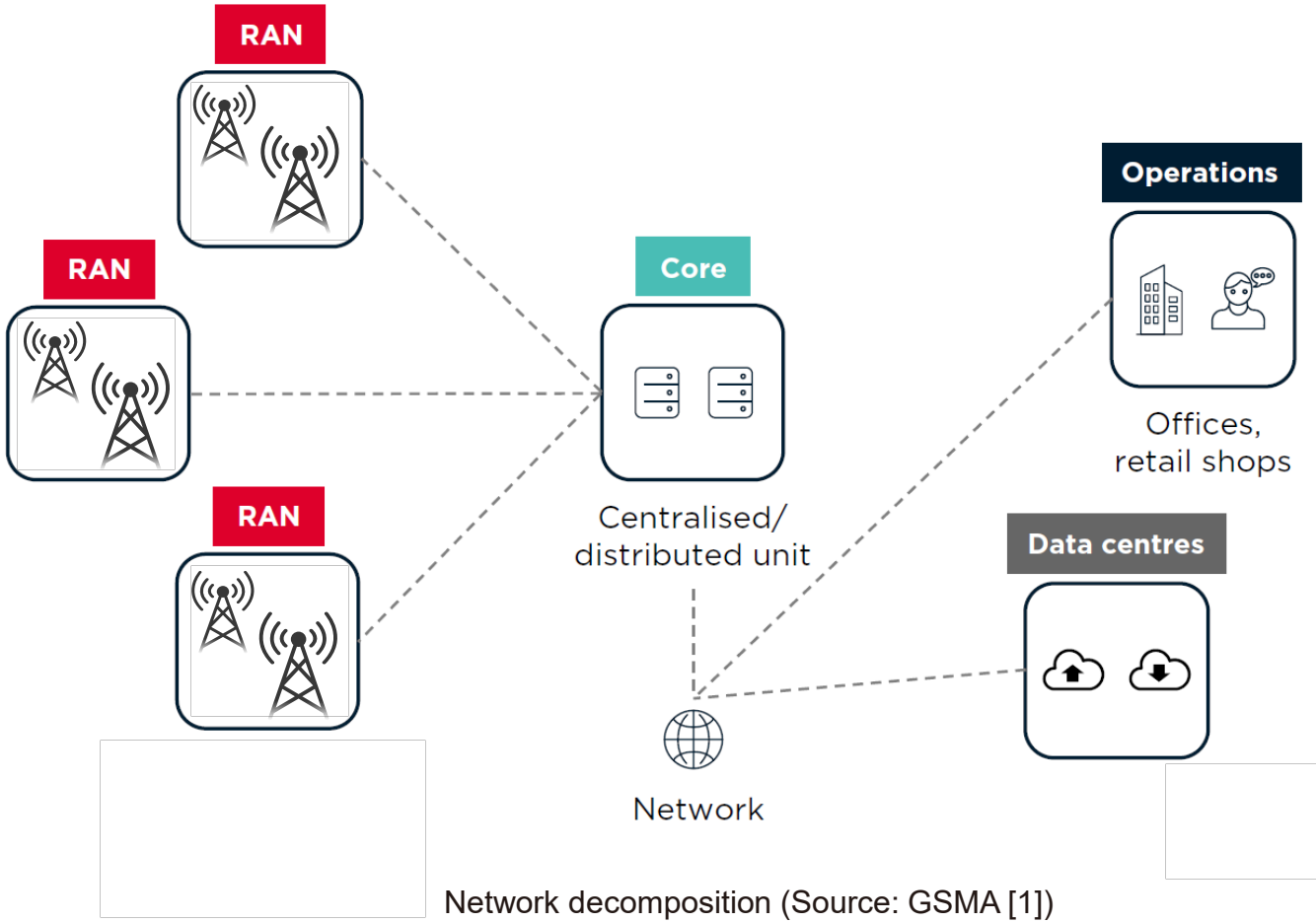
Which elements of the network consume the most?

- The **radio access network (RAN)** consumes most of the energy in a network
  - **76%** of the energy is consumed in the **RAN**
- The **radios** consume more than 65% of the energy in a base station (BS) [2]



Network decomposition (Source: GSMA [1])

[1] GSMA, Going green: measuring the energy efficiency of mobile networks, Feb. 2024 https://data.gsmaintelligence.com/research/research/research-2024/going-green-measuring-the-energy-efficiency-of-mobile-networks

[2] NGMN, Network Energy Efficiency Phase 2, Oct. 2023 https://www.ngmn.org/wp-content/uploads/NGMN_Network_Engergy_Efficiency_Phase2.pdf

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4G LTE versus 5G NR

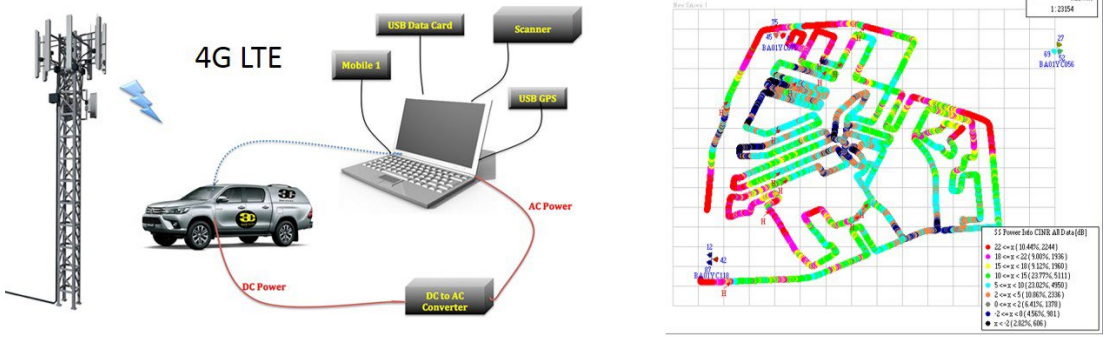
- 5G is **16× faster** than 4G thanks to wider bandwidth (100 MHz vs 20 MHz) and increased multiplexing capabilities, and **4× more energy efficient**
- 5G sites **consume up to 4× more energy** than 4G ones due to the more energy required to power the **more bandwidth** and the **more transceivers**

Transmission power /bandwidth	MIMO	Total power (W)		Throughput (Mbps)	
4G LTE (40 W @ 20 MHz)	8T8R	1,100	x4	120	x16
5G NR (240 W @ 100 MHz)	64T64R	4,297		1,963	

[1] C. Lin I, S. Han, and S. Bian, “Energy-efficient 5G for a greener future,” Nature Electronics, vol. 3, pp. 182–184, Apr. 2020
https://www.nature.com/articles/s41928-020-0404-1

Tools for modelling and optimizing mobile networks

- **Drive-test (DT)** and **simulation-based** approaches have been traditionally used to optimize networks
  - DTs require large **measurement campaigns**
  - Networks simulation tools are usually aimed at coverage and capacity, but **not targeted at energy efficiency**



Drive test setup
(Source: http://www.ntsiwireless.com/)

RF radio propagation prediction
(Source: Siradel)

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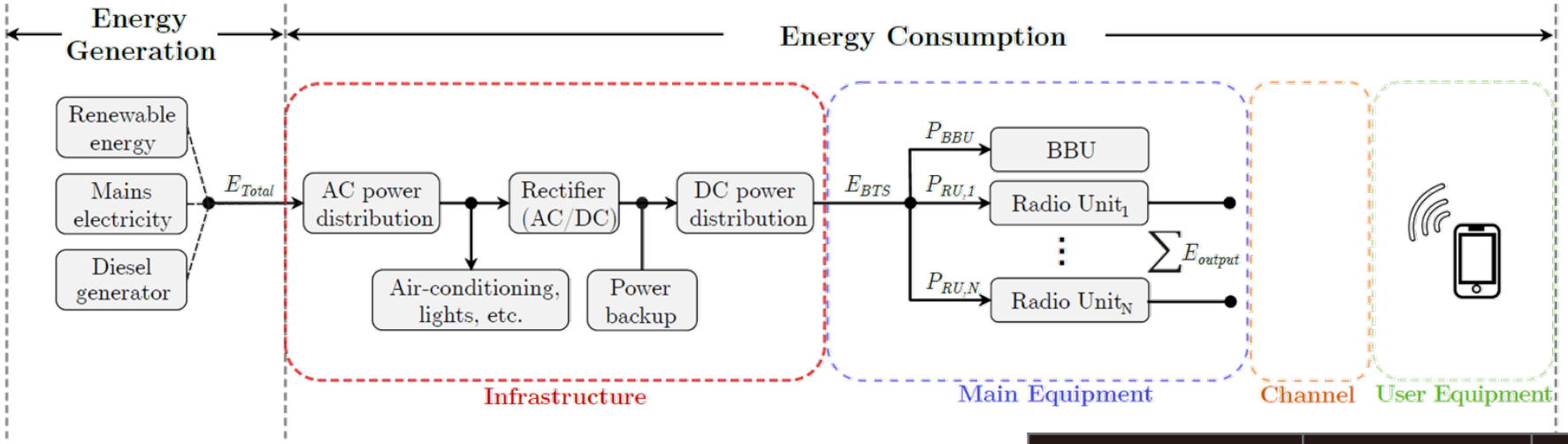
State of the art energy efficiency metrics



Standards Working Group	Document ID	Energy efficiency metric
ETSI EE	ES 203 228 [1]	$\mathrm{EE}_{\mathrm{Network}} = \frac{\text{Performance Metric}_{\text{ Network}}}{\text{Energy Consumption}_{\text{ Network}}}$
ITU-T SG5	L.1350 [2]	$\mathrm{EE}_{\mathrm{Site}} = \frac{\text{Energy Consumption}_{\text{ Telecom Equip}}}{\text{Energy Consumption}_{\text{ Total}}}$
ETSI EE	TS 103 786 [3]	$\mathrm{EE}_{\mathrm{BTS}} = \frac{\text{Data Volume}_{\text{ BTS}}}{\text{Energy Consumption}_{\mathrm{BTS}}}$
ITU-T SG5	L.1310 [4]	$\mathrm{EE}_{\text{RF Unit}} = \frac{\text{Energy}_{\text{ Output}}}{\text{Energy Consumption}_{\text{ RF Unit}}}$

[1] ETSI ES 203 228, Environmental Engineering (EE); Assessment of mobile network energy efficiency https://www.etsi.org/deliver/etsi_es/203200_203299/203228/01.03.01_60/es_203228v010301p.pdf
[2] ITU, L.1350 : Energy efficiency metrics of a base station site https://www.itu.int/rec/T-REC-L.1350/en
[3] ETSI TS 103 786, "Environmental Engineering (EE); Dynamic energy performance measurement method of 5GBase Station (BS)" https://www.etsi.org/deliver/etsi_ts/102700_102799/10270602/01.06.01_60/ts_10270602v010601p.pdf
[4] ITU, L.1310 : Energy efficiency metrics and measurement methods for telecommunication equipment https://www.itu.int/rec/T-REC-L.1310/en

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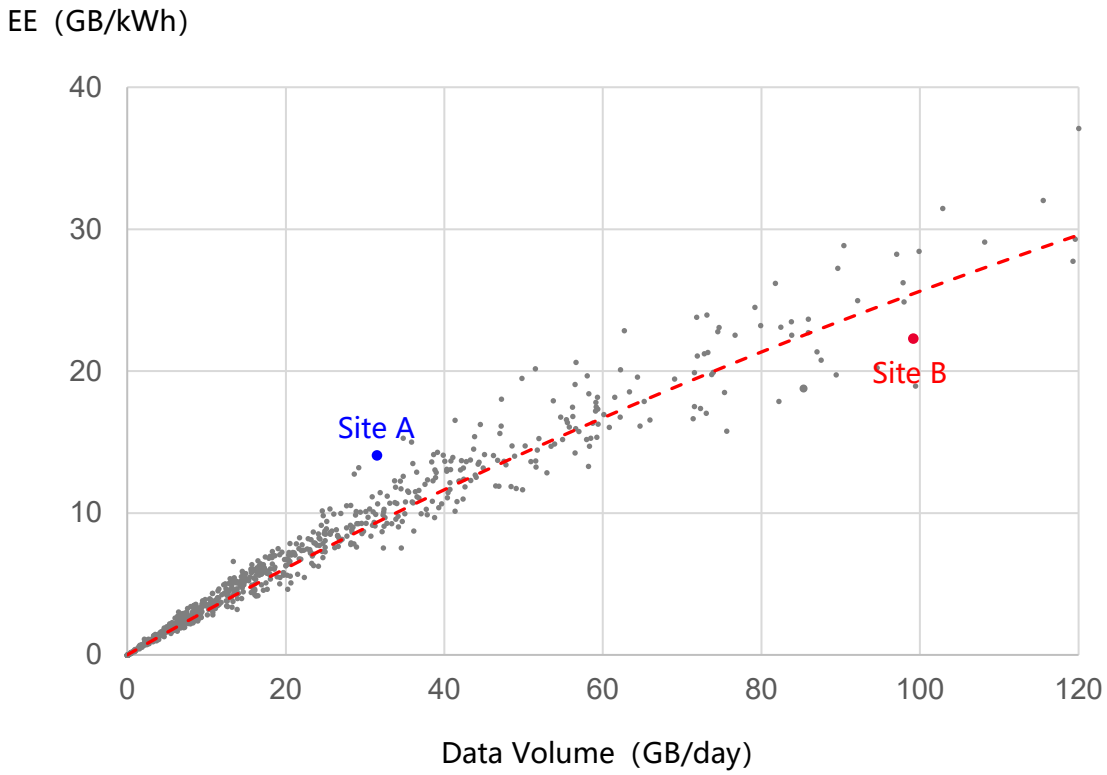
Poor optimization with traditional metrics

- The EE metric in bit/J [1] may **be misleading for network optimization**
  - Site A has a better site efficiency than site B. However, due to its **lower volume load**, site A results in a **lower traditional EE metric**
  - Optimization techniques attempt to **move traffic towards the most EE cell**, in this case, towards Site B and not Site A
  - Moving traffic towards site A would be more beneficial



[1] ETSI, TS 103 786 Measurement method for energy efficiency of wireless access network equipment https://www.etsi.org/deliver/etsi_ts/103700_103799/103786/01.01.01_60/ts_103786v010101p.pdf
[2] NGMN, Network Energy Efficiency Phase 2, Oct. 2023 https://www.ngmn.org/wp-content/uploads/NGMN_Network_Engergy_Efficiency_Phase2.pdf

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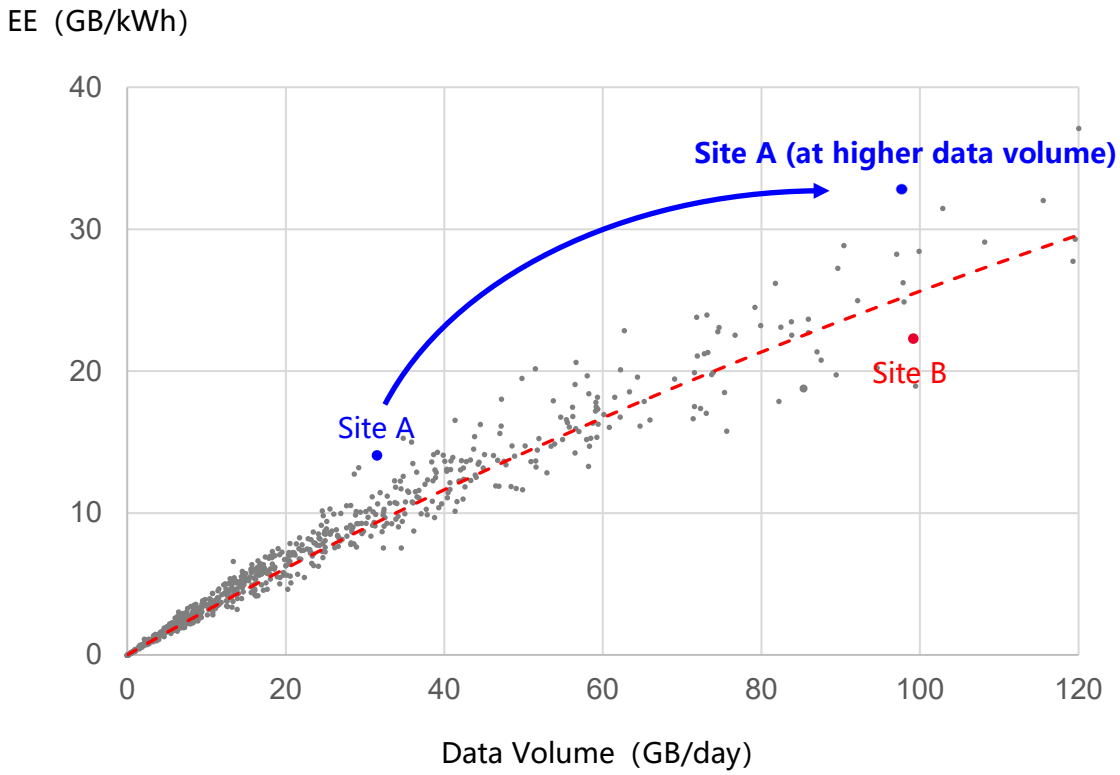

[1] ETSI, TS 103 786 Measurement method for energy efficiency of wireless access network equipment https://www.etsi.org/deliver/etsi_ts/103700_103799/103786/01.01.01_60/ts_103786v010101p.pdf
[2] NGMN, Network Energy Efficiency Phase 2, Oct. 2023 https://www.ngmn.org/wp-content/uploads/NGMN_Network_Engergy_Efficiency_Phase2.pdf

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IEEE Open Journal of the Communications Society

Waste Factor and Waste Figure: A Unified Theory for Modeling and Analyzing Wasted Power in Radio Access Networks for Improved Sustainablity

Theodore S. Rappaport [1] ***(Fellow, IEEE)***, **Mingjun Ying** [1] ***(Graduate Student Member, IEEE)***,
Nicola Piovesan, [2] ***(Member, IEEE)***, **Antonio De Domenico,** [2] ***(Member, IEEE)*** **AND**
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[2]Huawei Technologies, Paris Research Center, Boulogne Billancourt 92100 France

The Waste Factor (W) or Waste Figure (WF) is a unifying analysis method for evaluating the energy efficiency of ANY communication device or cascaded network. W and WF do not depend on the carried traffic.

[1] T.S. Rappaport, M. Ying, N. Piovesan, A. De Domenico, D. Shakya, "Waste Factor and Waste Figure: A Unified Theory for Modeling and Analyzing Wasted Power in Radio Access Networks for Improved Sustainability", submitted to IEEE OJ-COMS https://arxiv.org/abs/2405.07710

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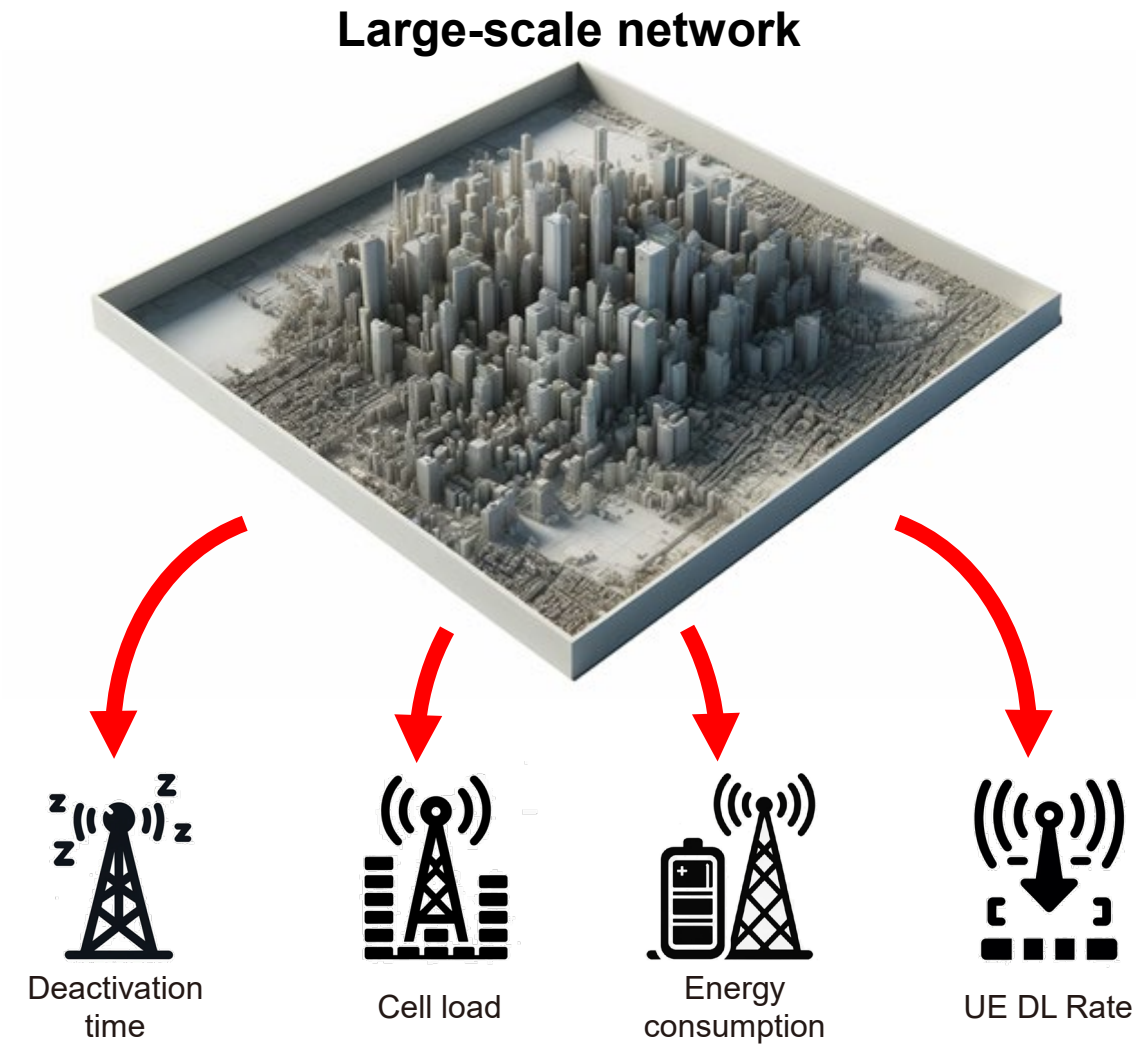
Our Target

- **Given**
  - a large-scale network
  - a carrier-shutdown energy saving policy
  - mobility management policy
  - a traffic profile

- **Predict in each hour**
  - the capacity cells deactivation time
  - the cells traffic load
  - the user equipment (UE) downlink (DL) data rate
  - the network energy consumption

- **Optimize**
  - The average network energy consumption while keeping QoS stable



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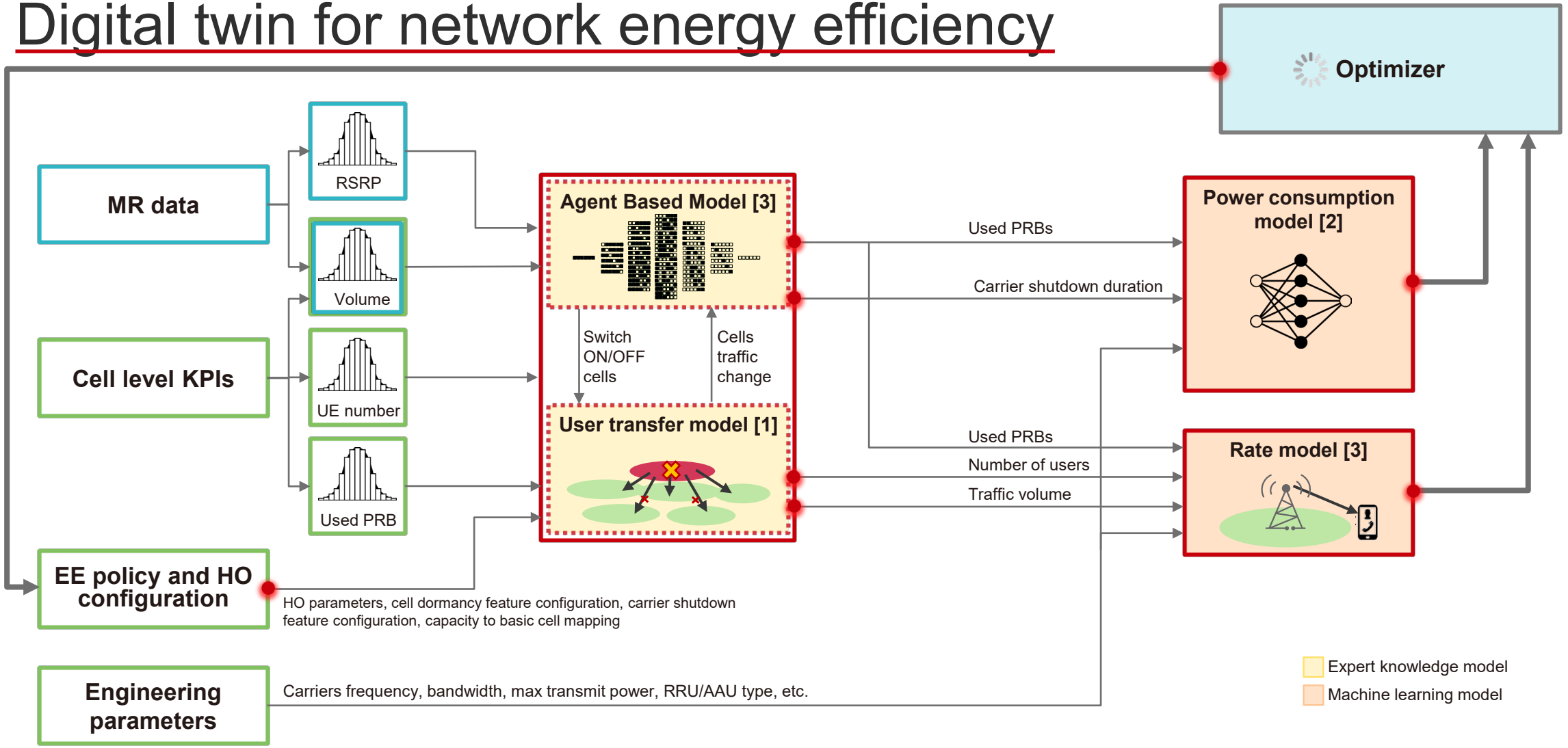
Digital twin for network energy efficiency



[1] A. De Domenico et al., 'Modelling User Transfer during Dynamic Carrier Shutdown in Green 5G Networks,' IEEE Transactions on Wireless Communications, June 2022, https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=10017182

[2] N. Piovesan, et. al., "Machine Learning and Analytical Power Consumption Models for 5G Base Stations", in IEEE Communication Magazine, 2022 https://ieeexplore.ieee.org/abstract/document/9928089

[3] D. Lopez-Perez et al., Data-driven Energy Efficiency Modelling in Large-scale Networks: An Expert Knowledge and ML-based Approach, IEEE Transactions on Machine Learning in Communications and Networking, https://arxiv.org/abs/2401.00443

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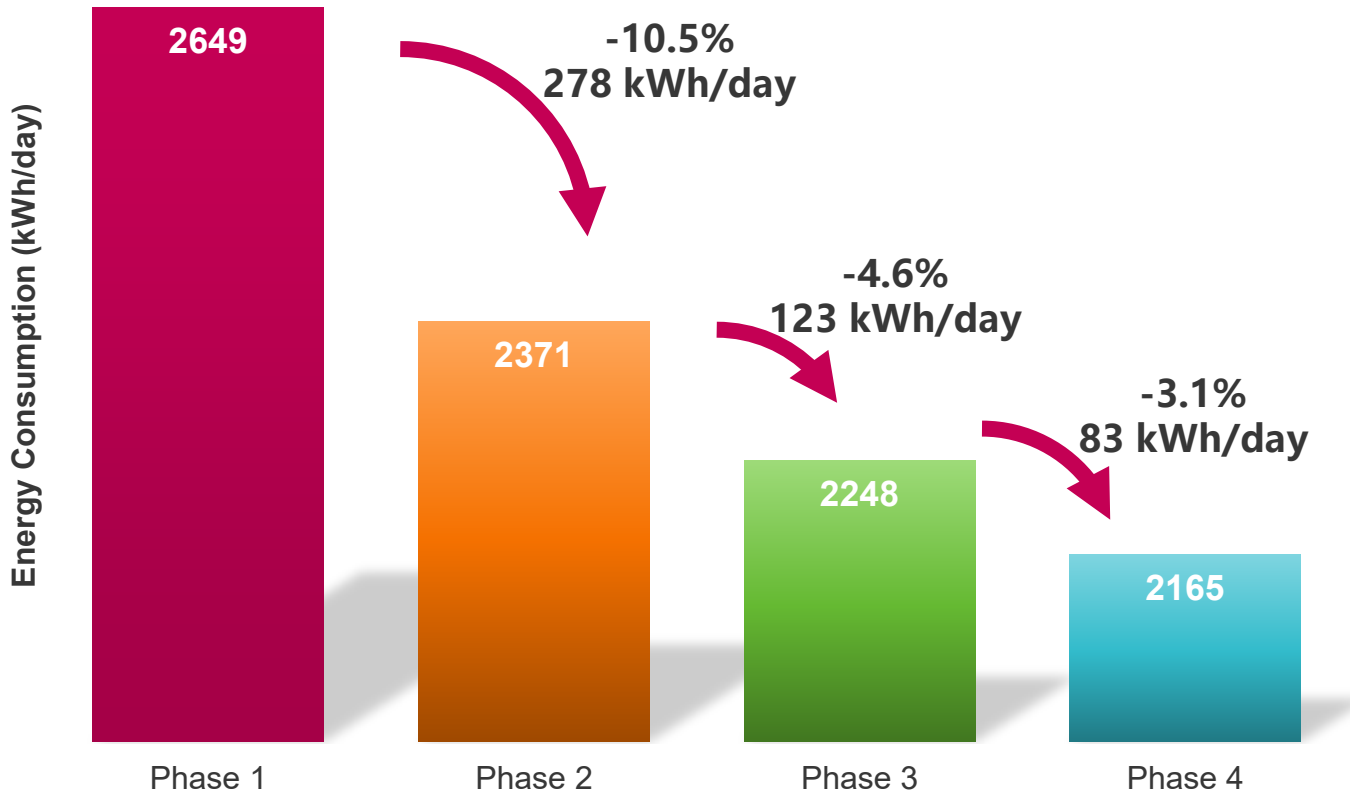
Network energy consumption optimization results

- Framework applied to a **real network comprising 134 sites**
  - 400 **4G LTE cells**
  - 155 **5G NR cells**
- **Phase 1**: No energy saving
- **Phase 2**: Energy saving based on expert configuration
- **Phase 3**: Data-driven optimization of energy saving parameters
- **Phase 4**: Hierarchical energy efficiency optimization [1]



[1] NGMN, Green future networks: A Roadmap to Energy Efficient Mobile Networks, 2024 https://www.ngmn.org/wp-content/uploads/GFN_Energy_Efficiency_Roadmap_V1.0.pdf

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Conclusions and standardization perspectives

Network Digital Twins powered by AI can achieve **up to 9% energy saving gain** with respect to the best configuration achieved by **expert engineers**

Need for harmonized and well accepted datasets and metrics

Network energy efficiency studies should be complemented

- Integration of renewables energies (not only about CO2)
- Waste factor solve the static power consumption flaw

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Thank you.

Key references

[1] GSMA, the 5G guide: A reference for operators, 2019 https://www.gsma.com/wp-content/uploads/2019/04/The-5G-Guide_GSMA_2019_04_29_compressed.pdf

[2] BCG, Putting Sustainability at the Top of the Telco Agenda, June 2021 https://www.bcg.com/press/24june2021-telco-sector-game-changer-sustainability-shrinking-carbon-footprints

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[4] GSMA, Going green: measuring the energy efficiency of mobile networks, Feb. 2024 https://data.gsmaintelligence.com/research/research/research-2024/going-green-measuring-the-energy-efficiency-of-mobile-networks

[5] NGMN, Network Energy Efficiency Phase 2, Oct. 2023 https://www.ngmn.org/wp-content/uploads/NGMN_Network_Engergy_Efficiency_Phase2.pdf

[6] C. Lin I, S. Han, and S. Bian, “Energy-efficient 5G for a greener future,” Nature Electronics, vol. 3, pp. 182–184, Apr. 2020 https://www.nature.com/articles/s41928-020-0404-1

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[10] ITU, L.1310 : Energy efficiency metrics and measurement methods for telecommunication equipment https://www.itu.int/rec/T-REC-L.1310/en

[11] T.S. Rappaport, M. Ying, N. Piovesan, A. De Domenico, D. Shakya, “Waste Factor and Waste Figure: A Unified Theory for Modeling and Analyzing Wasted Power in Radio Access Networks for Improved Sustainability”, submitted to IEEE OJ-COMS https://arxiv.org/abs/2405.07710

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[15] NGMN, Green future networks: A Roadmap to Energy Efficient Mobile Networks, 2024 https://www.ngmn.org/wp-content/uploads/GFN_Energy_Efficiency_Roadmap_V1.0.pdf

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