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Competence Center

Industrial Local 5G Networks

Reliable End-to-End 5G Network Slicing for Mission-Critical Applications

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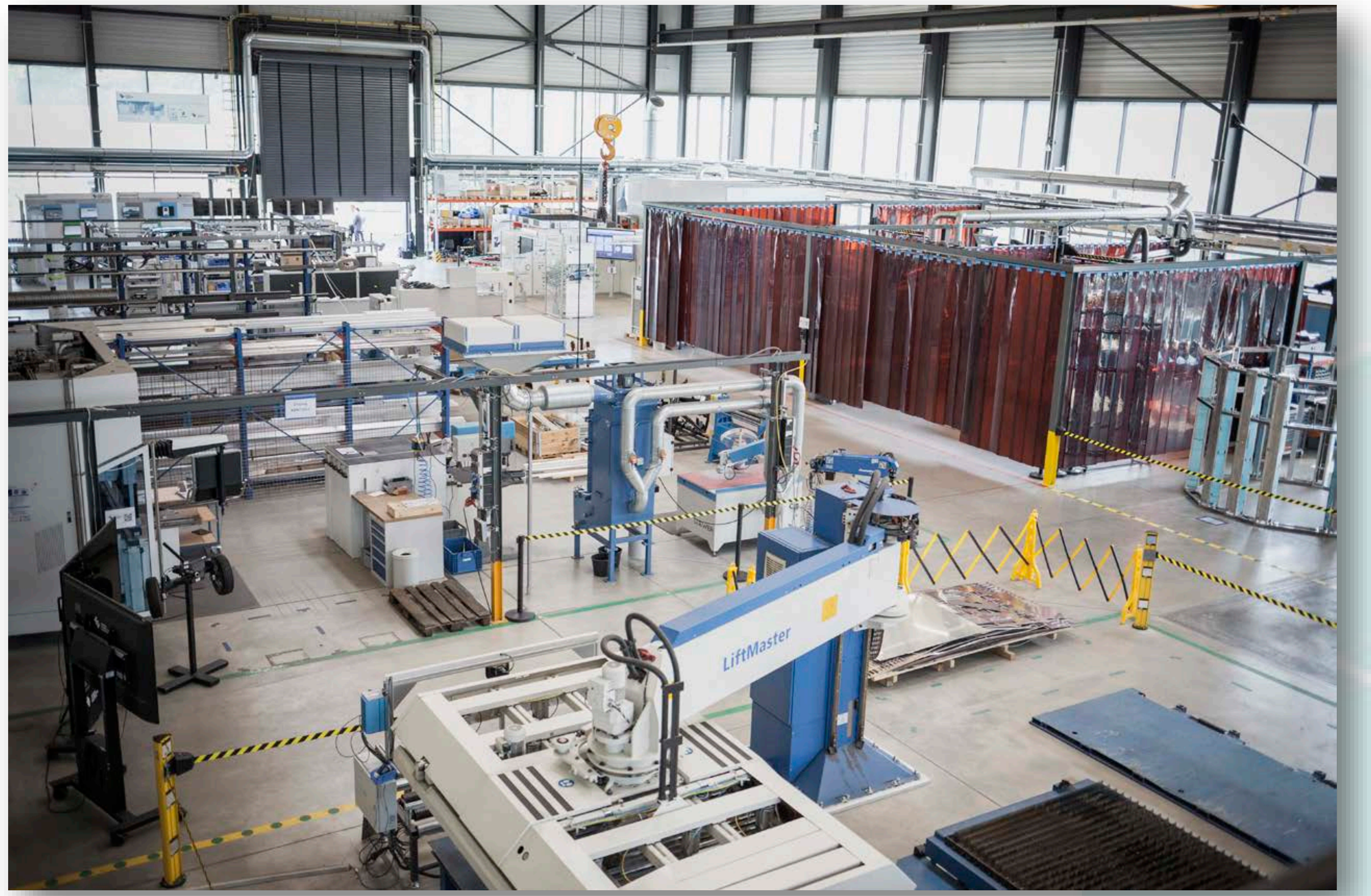
Outline

- **Introduction and Motivation**
  - Brief Introduction to 5G Campus Networks
  - 5G Network Slicing Options
- **End-to-End 5G Network Slicing**
  - Resource Scheduling in Sliced 5G Radio Access Networks
  - Laboratory Setup for Evaluation of the Developed System
  - Evaluation Scenarios and Results
- **Conclusion and Future Perspectives**

Communication in Industrial Infrastructures

Increasingly complex Industrial Infrastructures depend on:

- Real-time process monitoring and control
- Strict communication requirements
  - **Very low latencies** (<3ms)
  - High data rates (>1Gbps)
  - Robust and **reliable operation** (>99,999% availability)
  - **Hard** service guarantees
  - Co-existence of **competing services** within a unified network



Source: FIR e.V. @ RWTH Aachen

Two main options for addressing this challenge

- *Wifi (IEEE 802.11)*
- *5G Campus Networks*

Industrial Communication: Wifi vs 5G Campus

Wi Fi

+Cost: *Low*

+Deployment:
Fast and straightforward

–Spectrum:
Shared

–Service Guarantees:
Limited

–Scalability:
Mostly limited to Campus Networks

–Management:
Not standardized
(i.e. potential vendor lock-in)

5G

+Spectrum:
Dedicated

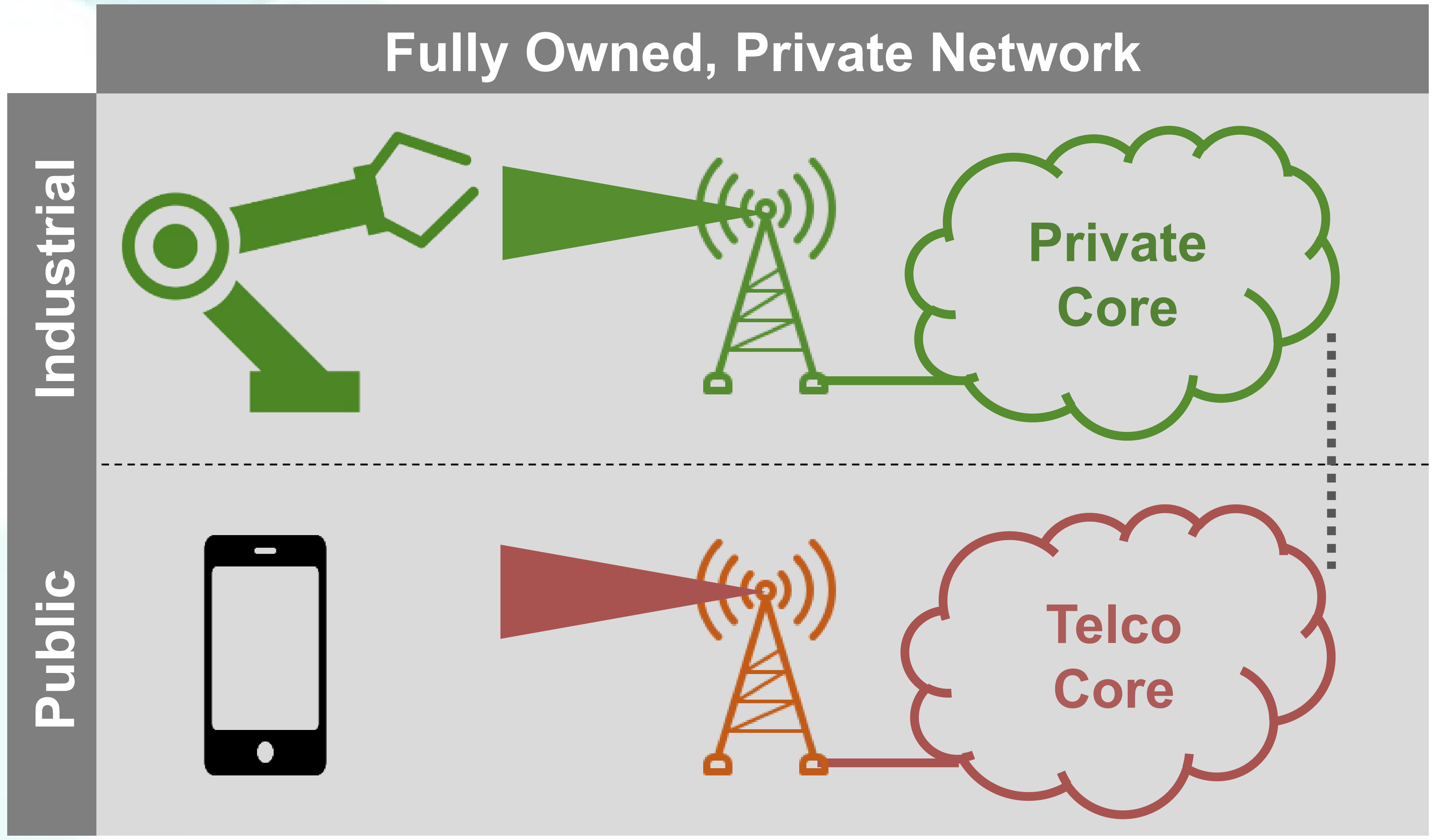
+Service Guarantees:
Hard guarantees and highly granular service prioritization

+Scalability:
Scales from campus to country

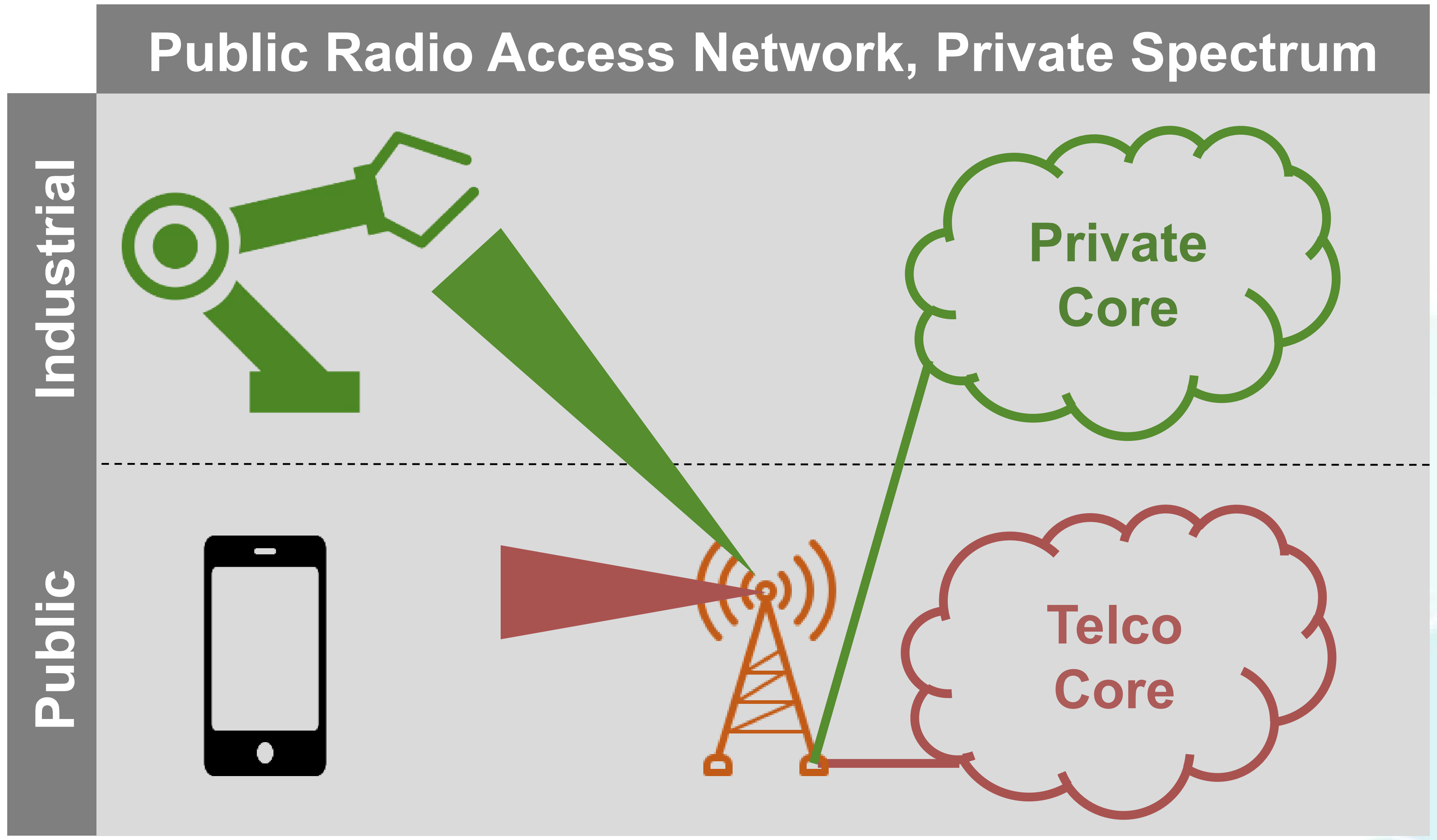
+Management:
Standardized

–Cost: *Potentially higher*

Private 5G Campus Networks - Options



+High performance
+Full control of all aspects
–Requires upfront investment
–Overhead for operation
–Does not scale easily



+Fast deployment
+Reduced management overhead
–No direct control of own resources
–Limited end-to-end guarantees

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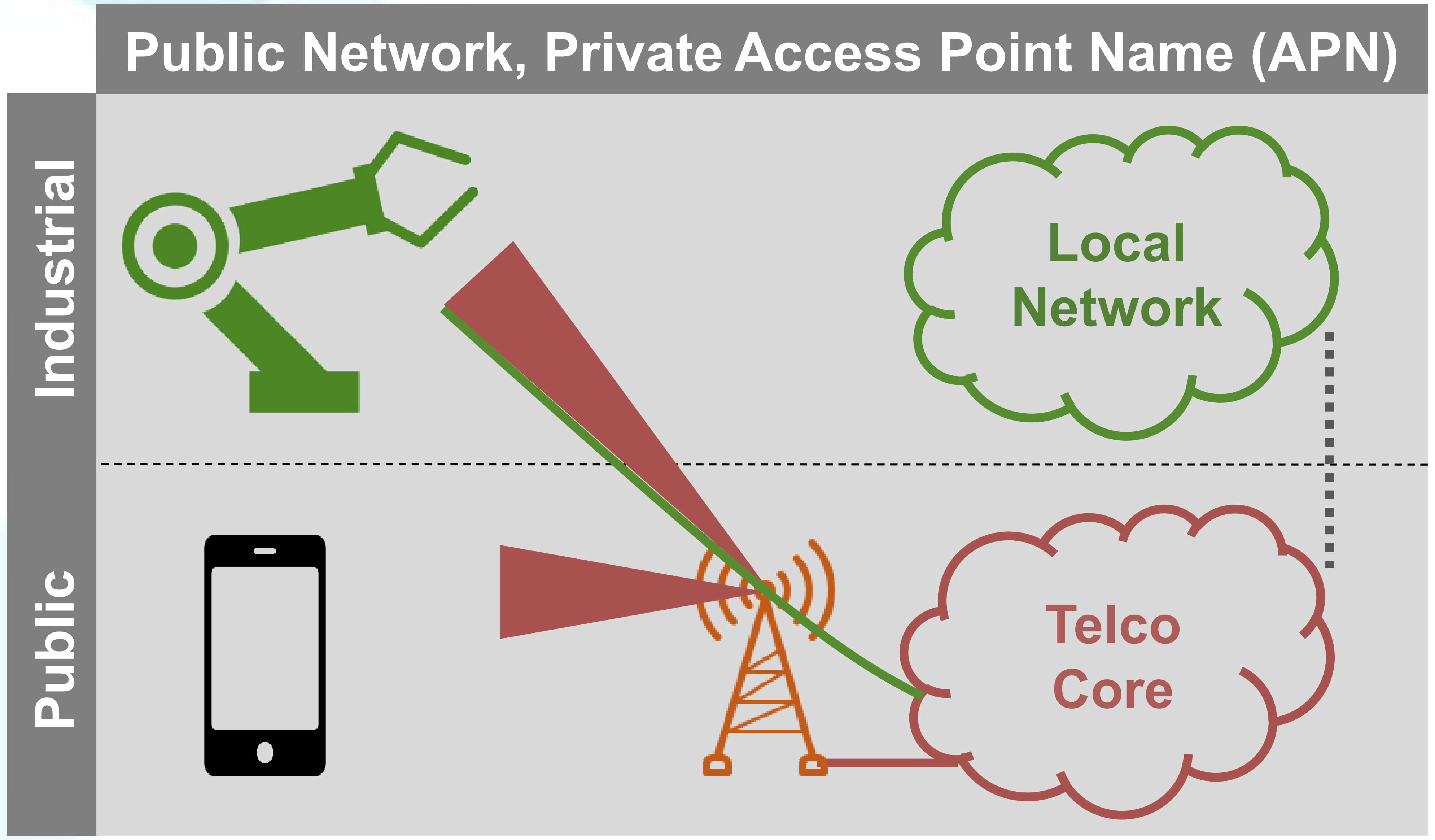
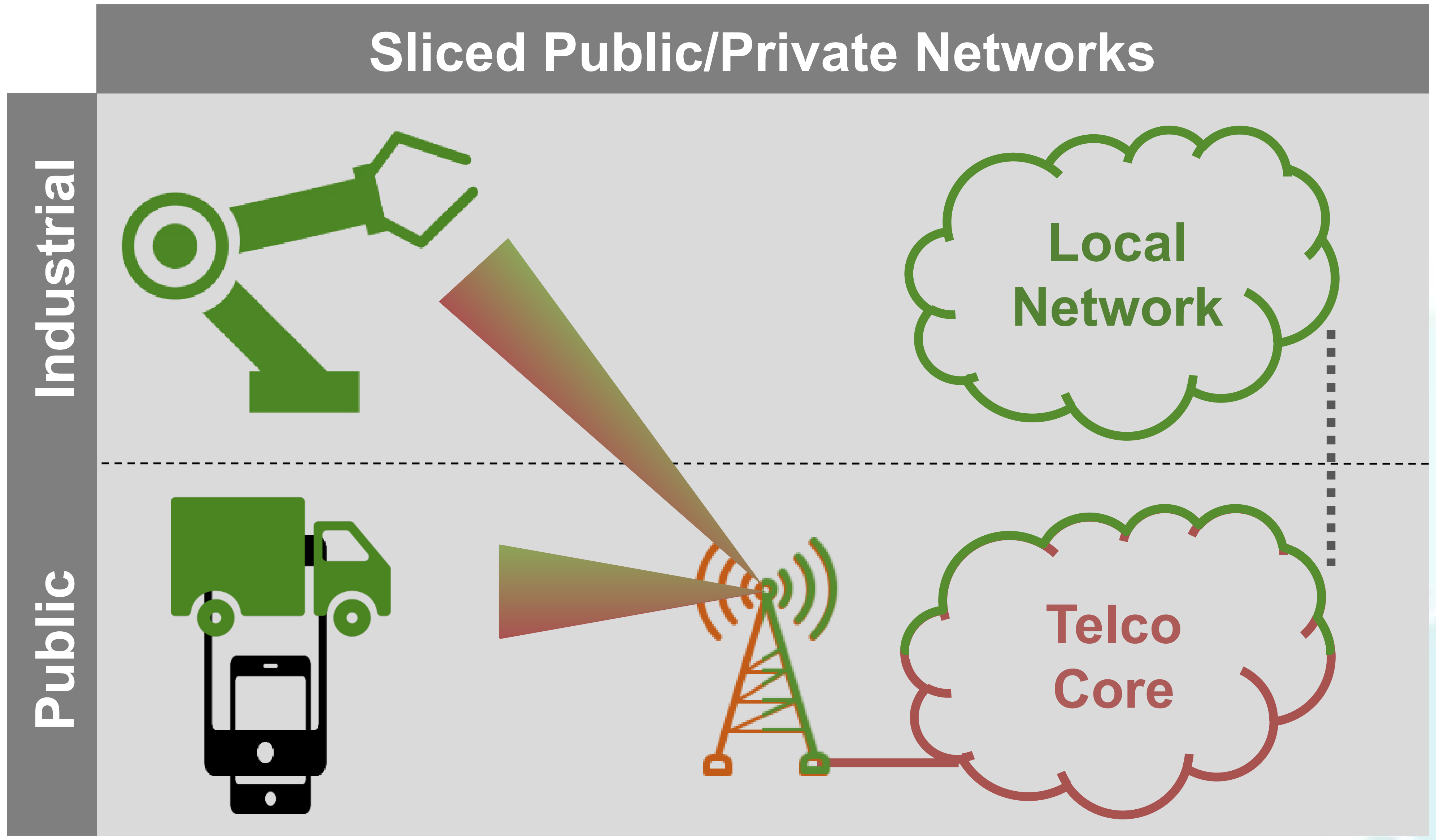
Private 5G Campus Networks - Options



- +Fast and straightforward setup
- +Low cost
- –Basic control over network
- –Limited end-to-end service guarantees



- +Full control over network
- +Hard service guarantees
- +Enables dynamic growth
- +Pay only for resources used
- +Flexible management models
- +Scales from campus to country

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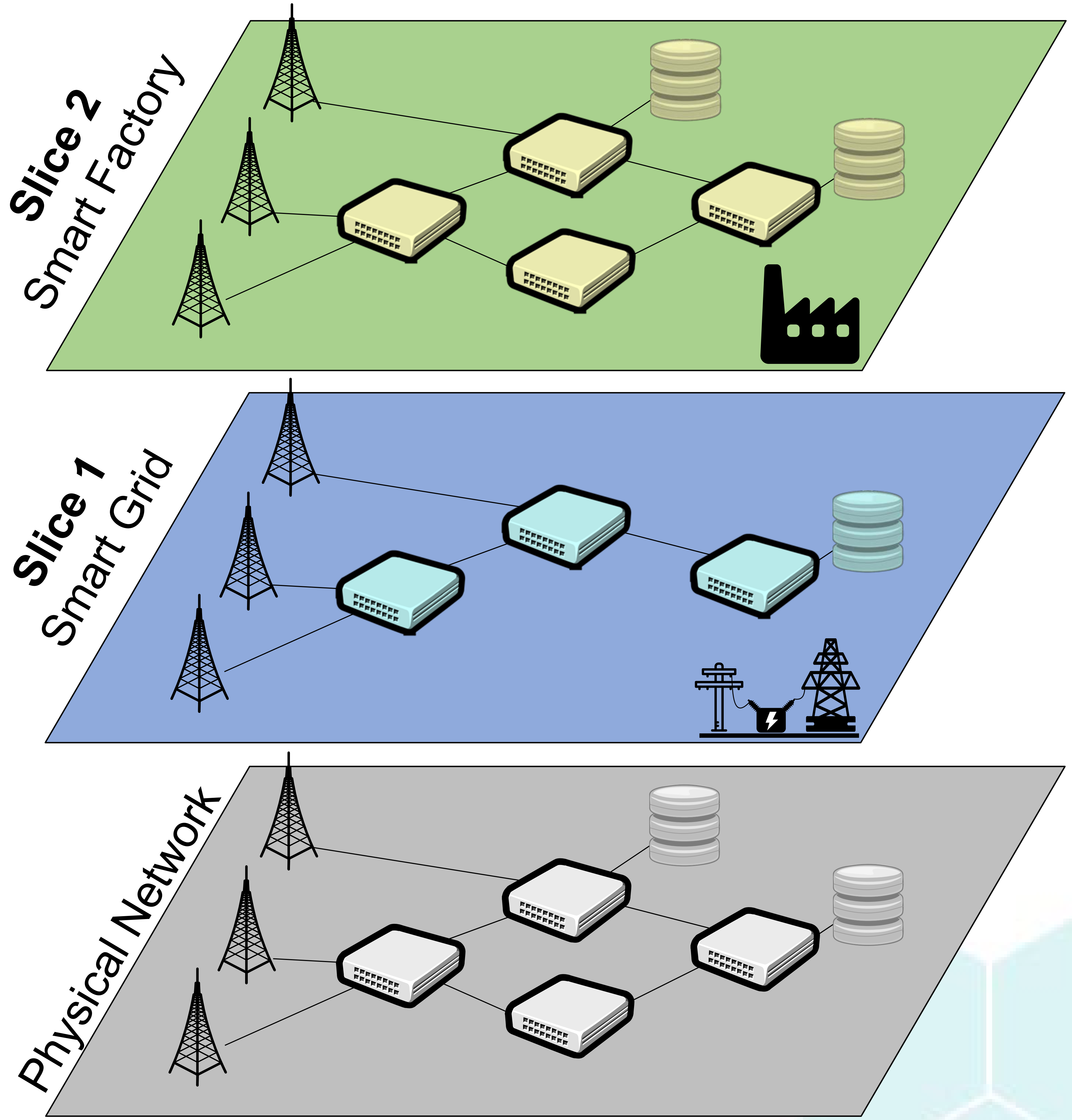
5G Network Slicing

- **Network Slicing:** Logical separation of networks and their resources in 5G
- Enables the instantiation of multiple, virtual networks on a **shared infrastructure**
- Facilitates automation, flexibility and cost reductions
- **Software-Defined Networking (SDN) / Network Function Virtualization (NFV)**: Key enablers for sliced 5G networks



Access Node | Router | Service

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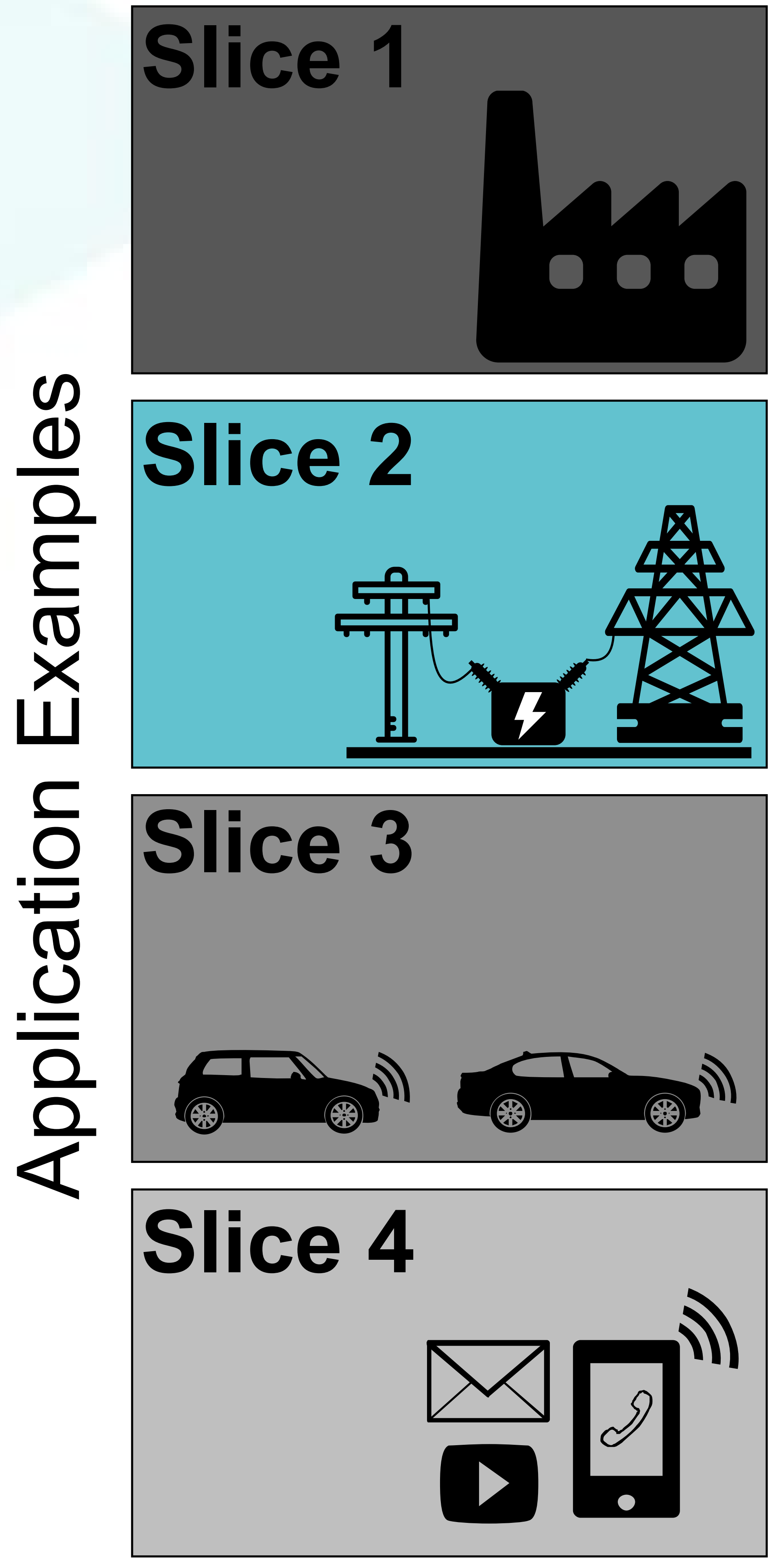
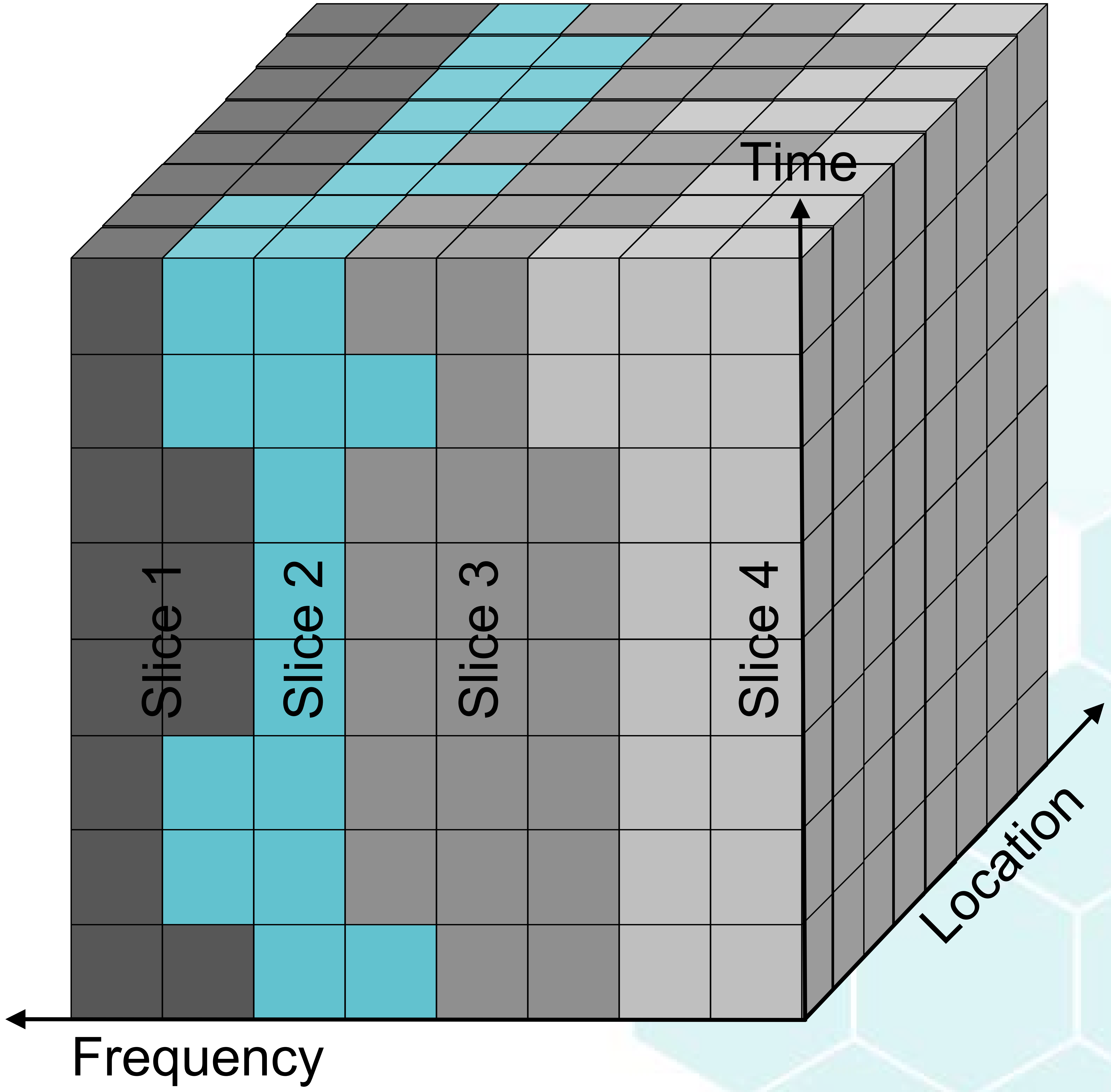
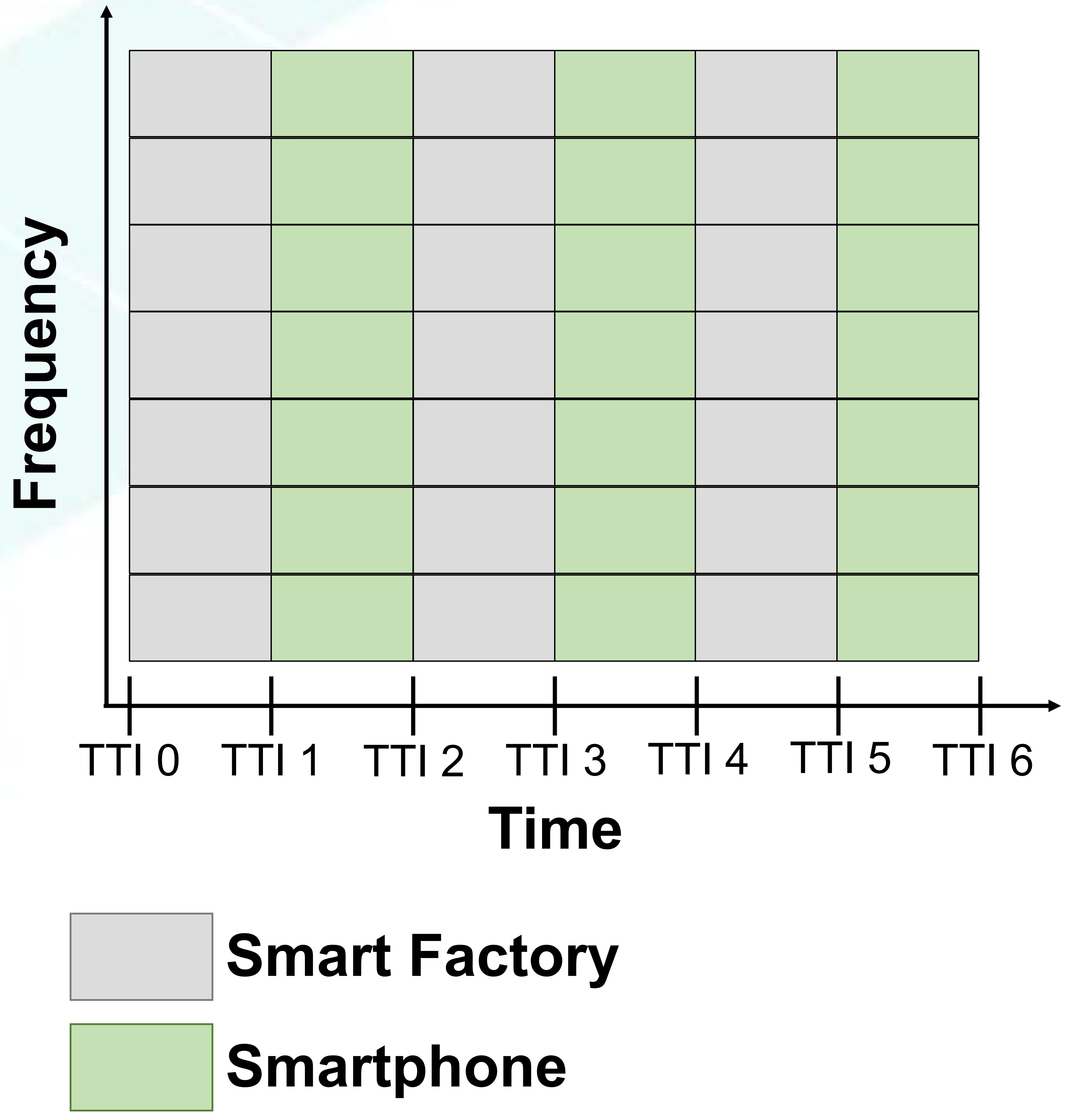
5G Network Slicing





Brief Introduction to Traditional Schedulers

Assumption:
Users utilize all available PRBs



- **Scheduler:**
  Allocates communication resources to users
- **Round Robin:**
  Fair resource allocation in an alternating manner

➢ Minimal achievable layer 2 data rate:

$$\mathrm{RoundRobinDR}(x) = \frac{1}{N} \cdot \frac{\mathrm{TBS}(x)}{\mathrm{TTI} = 1\mathrm{ms}} [\mathrm{bps}]$$

UE: User Equipment
TBS: Transport Block Size
TTI: Transmission Time Interval

x: Slice
W: Weight
N: Number of active Slices
TBS: Maximum Transport Block Size, dependent on number of Physical Resource Blocks (PRBs) and Modulation Coding Scheme (MCS) (i.e.: channel quality)
[***TTI***: Static, 1 ms on 3GPP Release 14]

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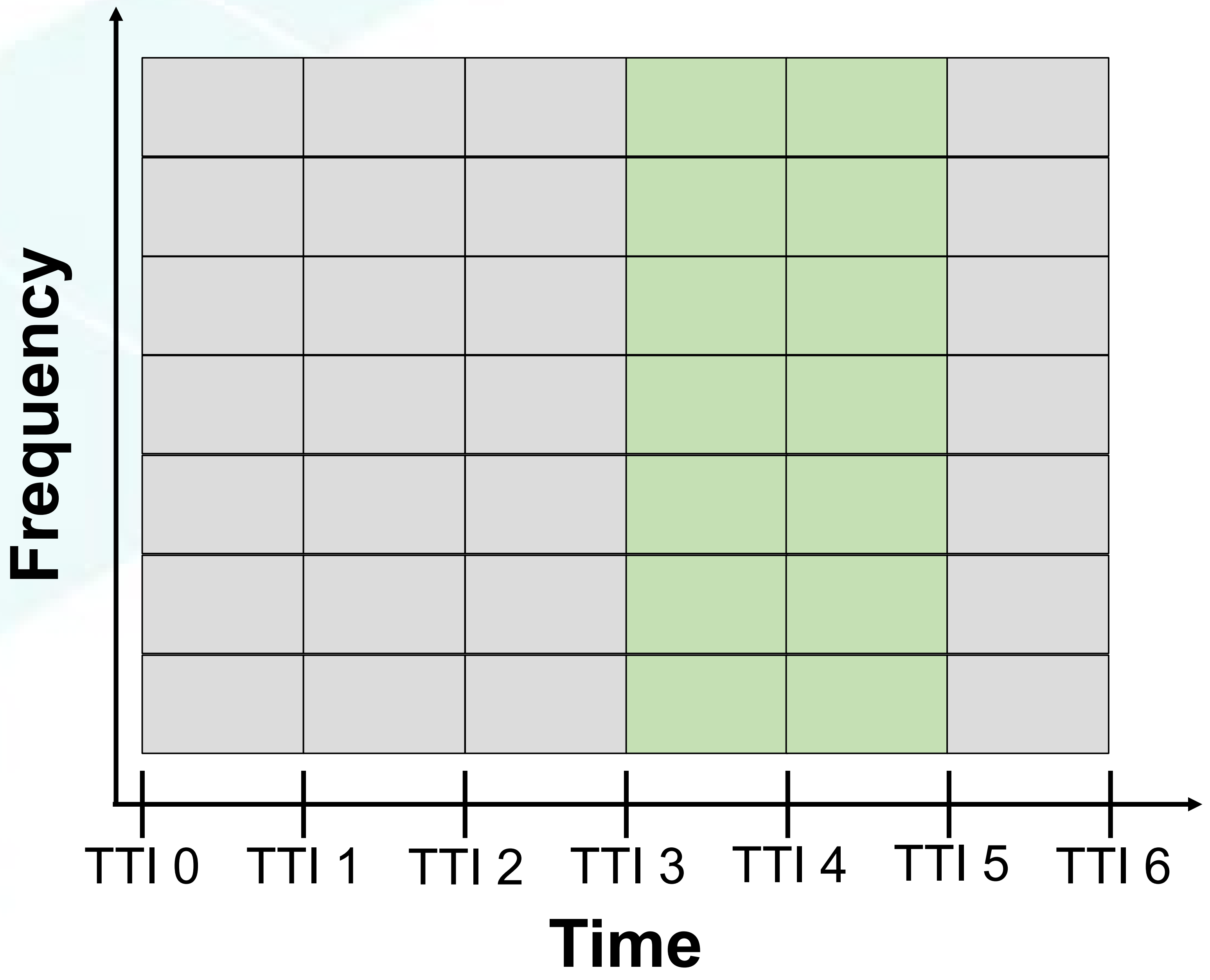
Scheduling for 5G Radio Access Network Slicing

Scenario 1:
*Slices require **all** available resources*



Smart Factory: Weight = 3

Smart Grid: Weight = 2

- **Slicing Scheduler:** Slices are assigned a **weight -** Number of consecutive channel access periods

➢ **Minimal data rate** and channel access are **guaranteed**

$$\text{MinimalSliceDR}(x) = \frac{W(x)}{\sum_{i=1}^{N} W(i)} \cdot \frac{\text{TBS}(x)}{\text{TTI} = 1\text{ms}} [\text{bps}]$$

$$\text{MaximalSliceDR}(x) = \frac{\text{TBS}(x)}{\text{TTI} = 1\text{ms}} [\text{bps}]$$

x: Slice
W: Weight
N: Number of active Slices
TBS: Maximum Transport Block Size, dependent on number of Physical Resource Blocks (PRBs) and Modulation Coding Scheme (MCS) (i.e.: channel quality)
[***TTI***: Static, 1 ms on 3GPP Release 14]

UE: User Equipment
TBS: Transport Block Size
TTI: Transmission Time Interval

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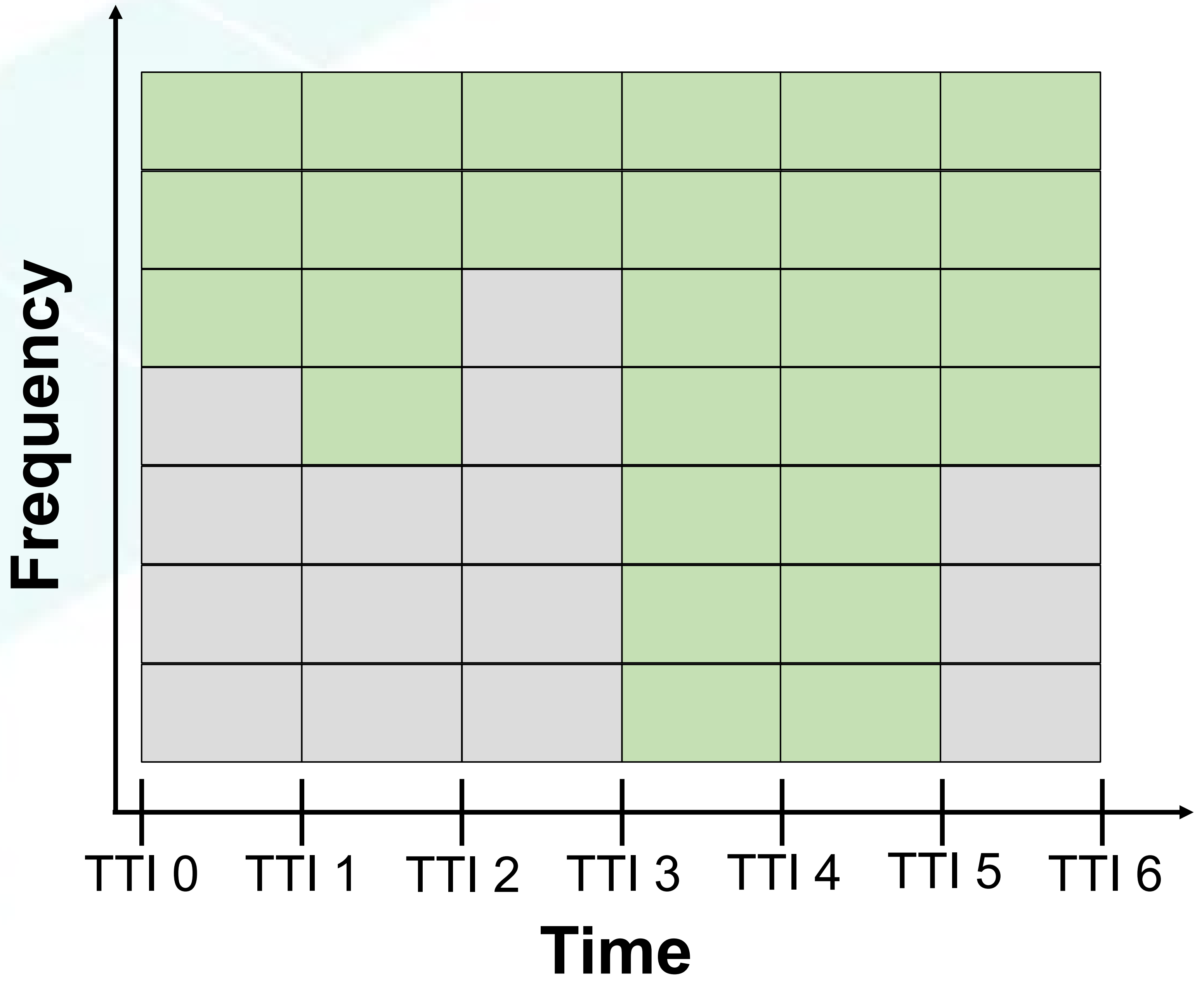
Scheduling for 5G Radio Access Network Slicing

Scenario 2: *Smart Factory Slice requires half of available resources*



Smart Factory: Weight = 3

Smart Grid: Weight = 2

- **Slicing Scheduler:** Slices are assigned a **weight -** Number of consecutive channel access periods

➢ **Minimal data rate** and channel access are **guaranteed**

$$\text{MinimalSliceDR}(x) = \frac{W(x)}{\sum_{i=1}^{N} W(i)} \cdot \frac{\text{TBS}(x)}{\text{TTI} = 1\text{ms}} [\text{bps}]$$

$$\text{MaximalSliceDR}(x) = \frac{\text{TBS}(x)}{\text{TTI} = 1\text{ms}} [\text{bps}]$$

x: Slice
W: Weight
N: Number of active Slices
TBS: Maximum Transport Block Size, dependent on number of Physical Resource Blocks (PRBs) and Modulation Coding Scheme (MCS) (i.e.: channel quality)
[***TTI***: Static, 1 ms on 3GPP Release 14]

UE: User Equipment
TBS: Transport Block Size
TTI: Transmission Time Interval

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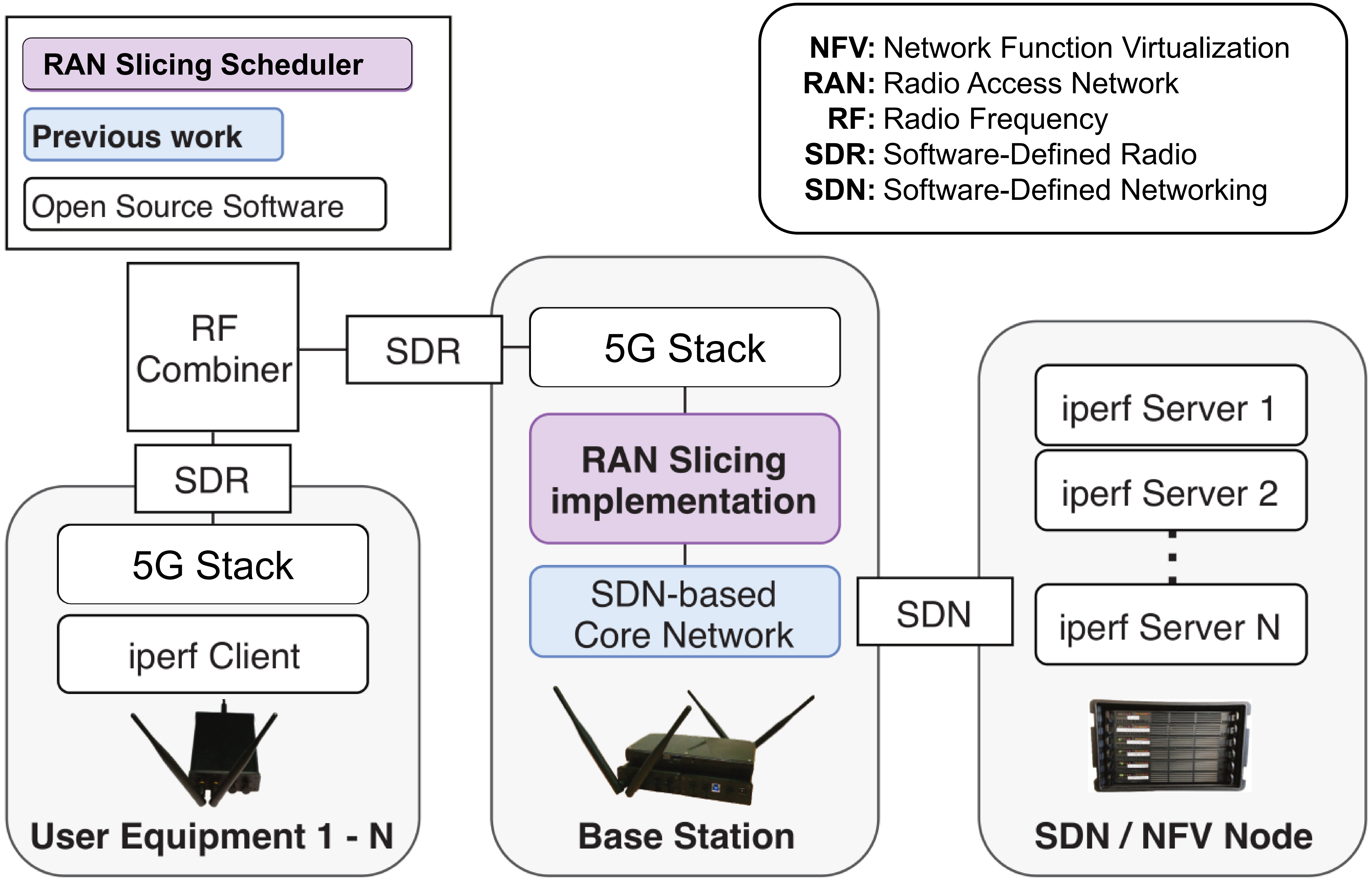
Evaluation Setup

NFV: Network Function Virtualization
RAN: Radio Access Network
RF: Radio Frequency
SDR: Software-Defined Radio
SDN: Software-Defined Networking



Scenario: Dynamic Smart Factory Slice Prioritization

Non-Critical

Slice
Best Effort (Smartphones)
Remaining Weight

Aggregate Data Rates
Max. available

Mission-Critical

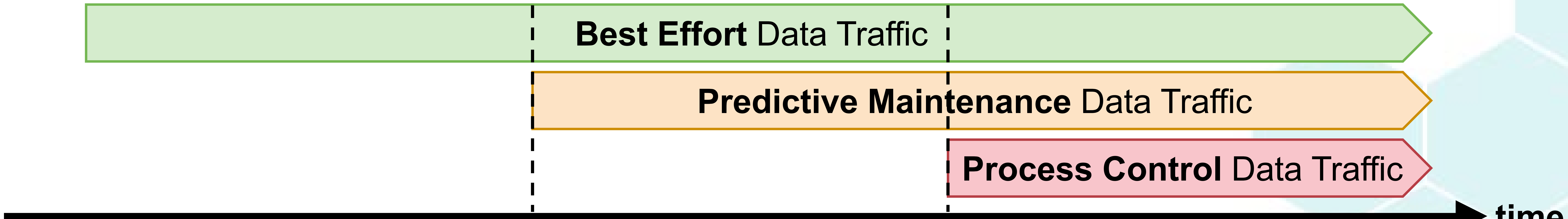
Slice
Predictive Maintenance
Weight 3

Aggregate Data Rates
0.7 Mbps

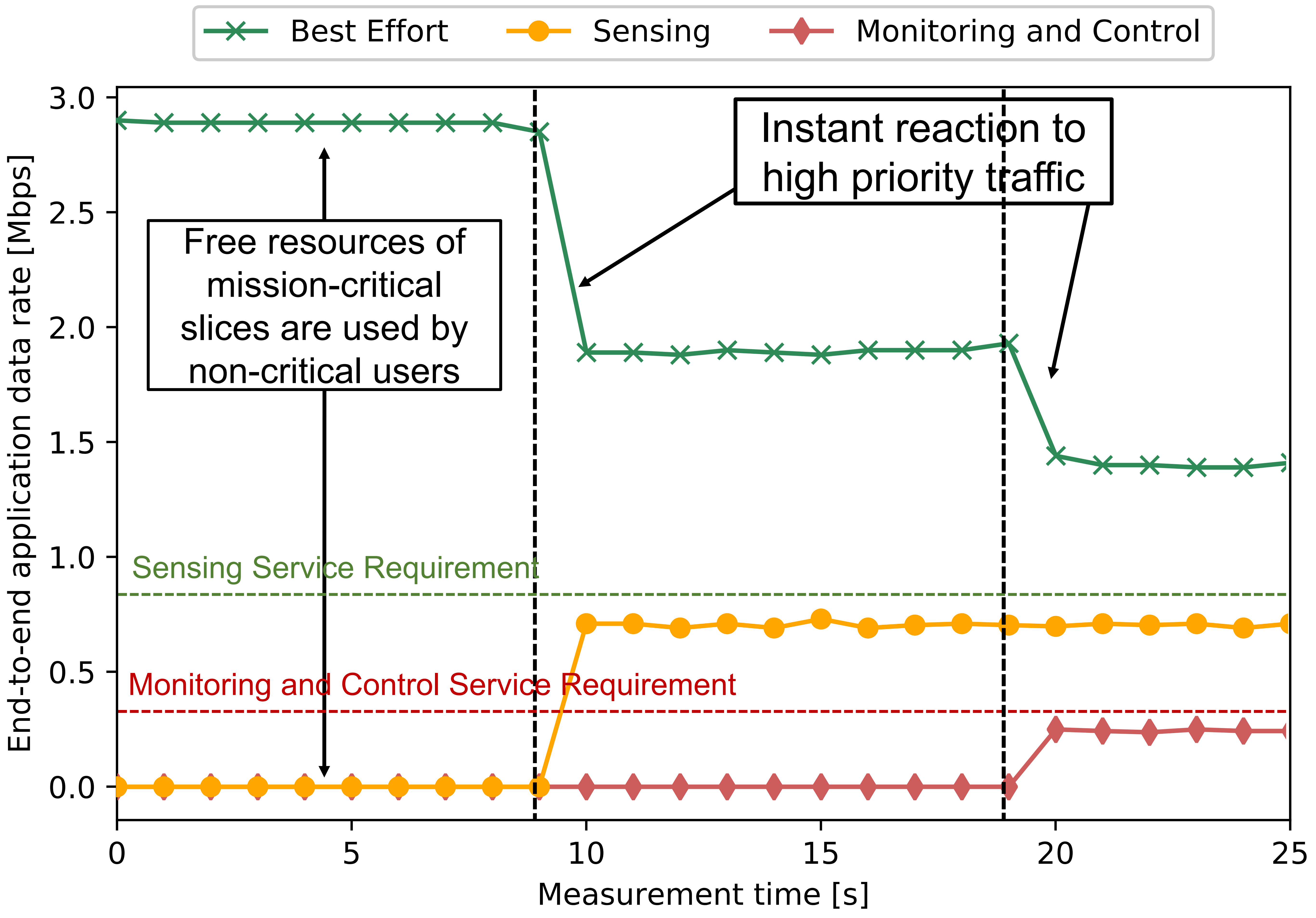
Highly Mission-Critical

Slice
Process Control
Weight 4

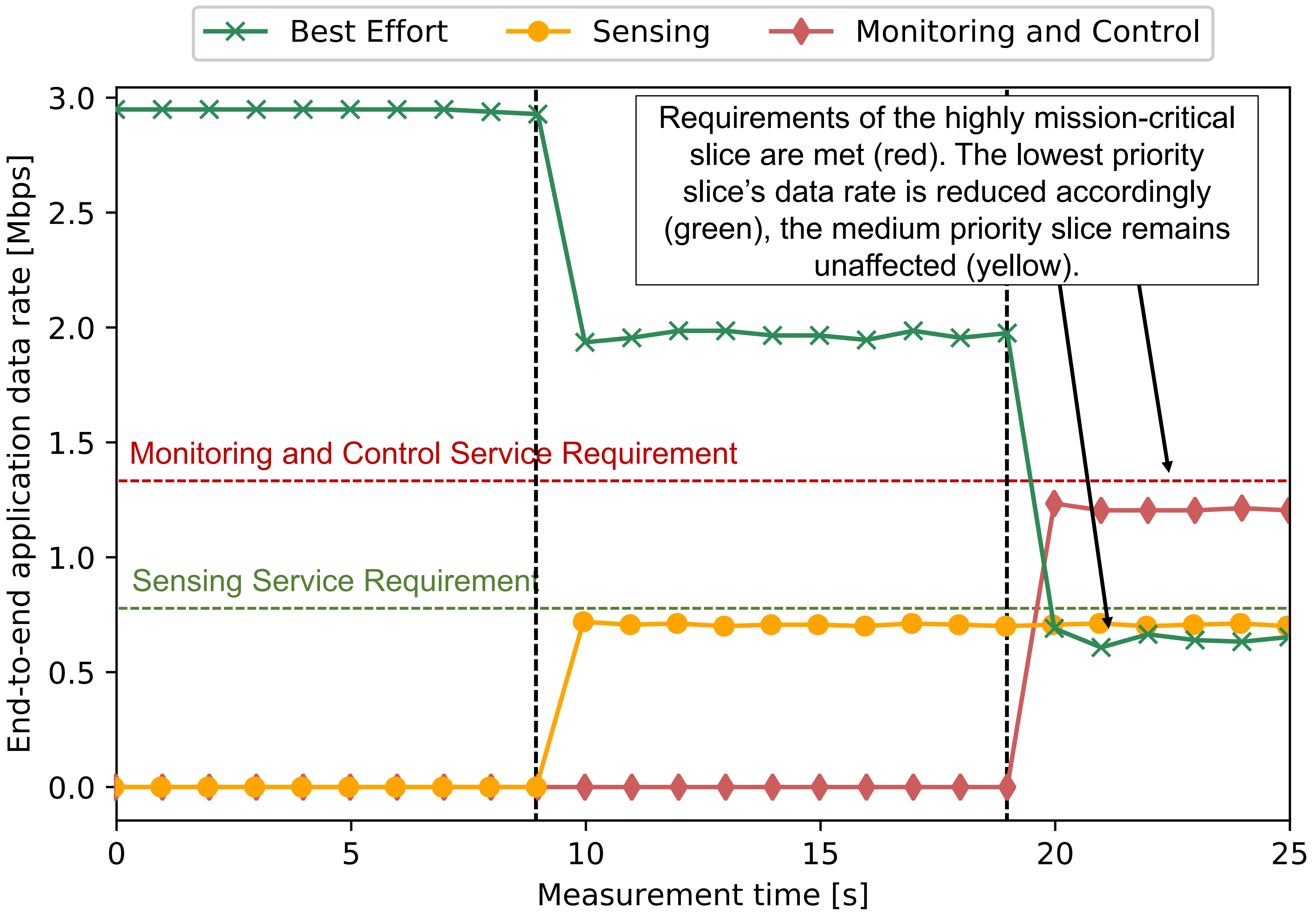
Aggregate Data Rates
0.25 Mbps (normal operation)
1.2 Mbps (critical operation)



Scenario: Dynamic Smart Factory Slice Prioritization



Scenario: Dynamic Smart Factory Slice Prioritization



Conclusion and Future Perspectives

- Design of schedules **implementing** 5G Network Slicing in the Radio Access Network
- **Reliable** data rates and latencies for mission-critical slices **by adapting Slice weights to variable channel conditions**
- **Empirical Evaluations** based on Industrial Scenarios

➢ Measurements show **reliable** support for the **coexistence of different 5G service types**

Future Perspectives

- **Usage of external data**, such as weather (e.g., renewable energy), can be used in combination with **Machine Learning** to **optimize allocation of slice resources**
- Higher TBSs and shorter TTIs in future 5G releases will be evaluated, as the **approach scales with mobile communication network improvements**

Mobile 5G Lab: On-Site Demonstration and Validation

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On-Site 5G Demonstration and Validation

- VW Transporter with **5G Base Station & Core Network** (incl. *Network Slicing*)
- Fully featured 5G Network at **3,7 GHz** on Basis of Software-Defined Radio / Networking (SDR/SDN)
- 5G-Gateways for connecting Industrial Infrastructure in **On-Site Trials**

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