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Paving the Way for an Energy Efficient and Sustainable Future Internet of Things

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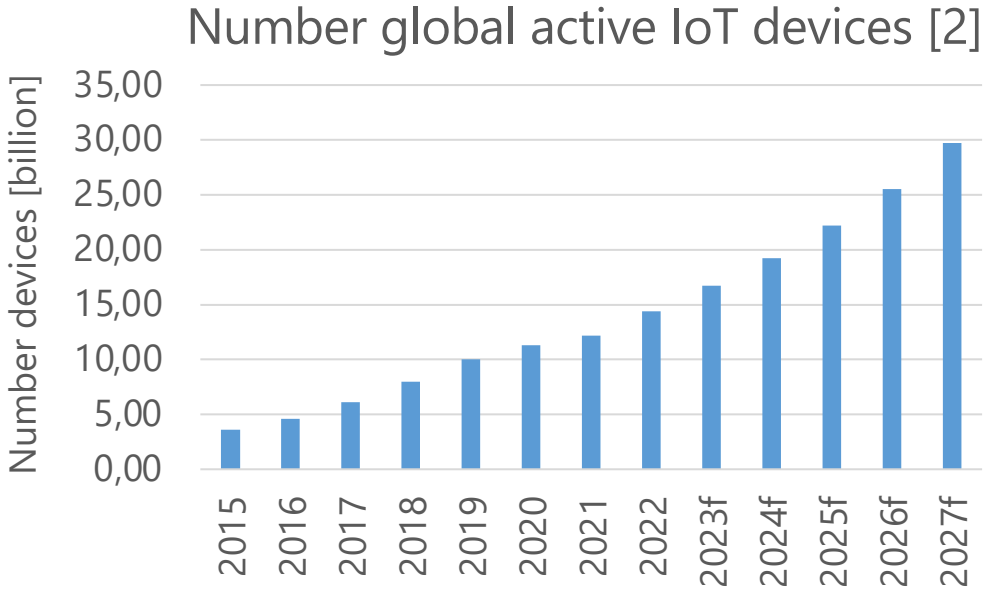
Motivation

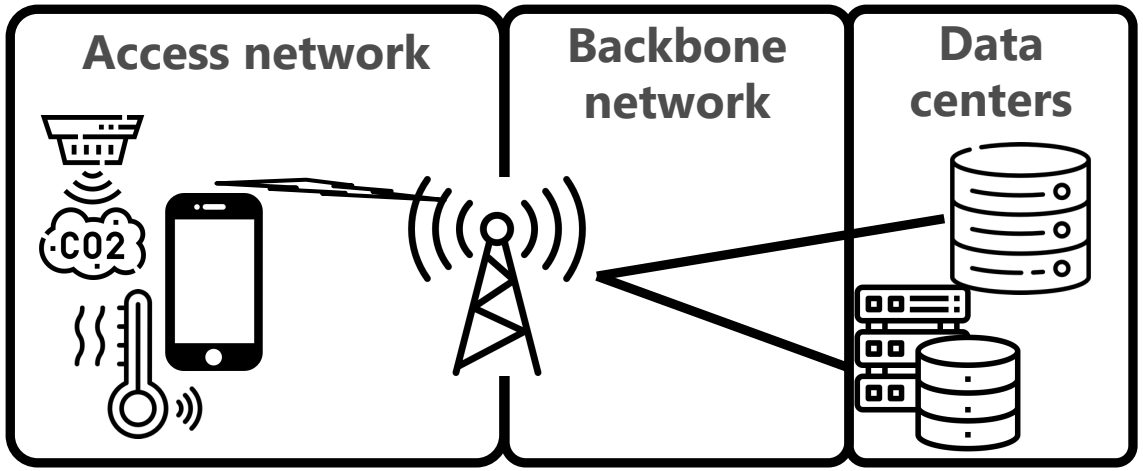
- **Energy consumption of ICT sector**
  - Globally estimated to 4% – 6% in 2020 [1]
  - Challenging to reduce required energy
  - **In the future:** more entities, load, tasks

- Nearly 15 billion active IoT devices worldwide [2]
- **Expected growth** of 16% per year by 2027

- Internet of Things influences
  - Access network
  - Backbone network
  - Data centers

- **Research question:** How can we **quantify** and **improve** energy efficiency in the IoT?





[1] Parliamentary Office of Science and Technology, UK; [2] IoT Analytics

Background: Relevant Network Layers

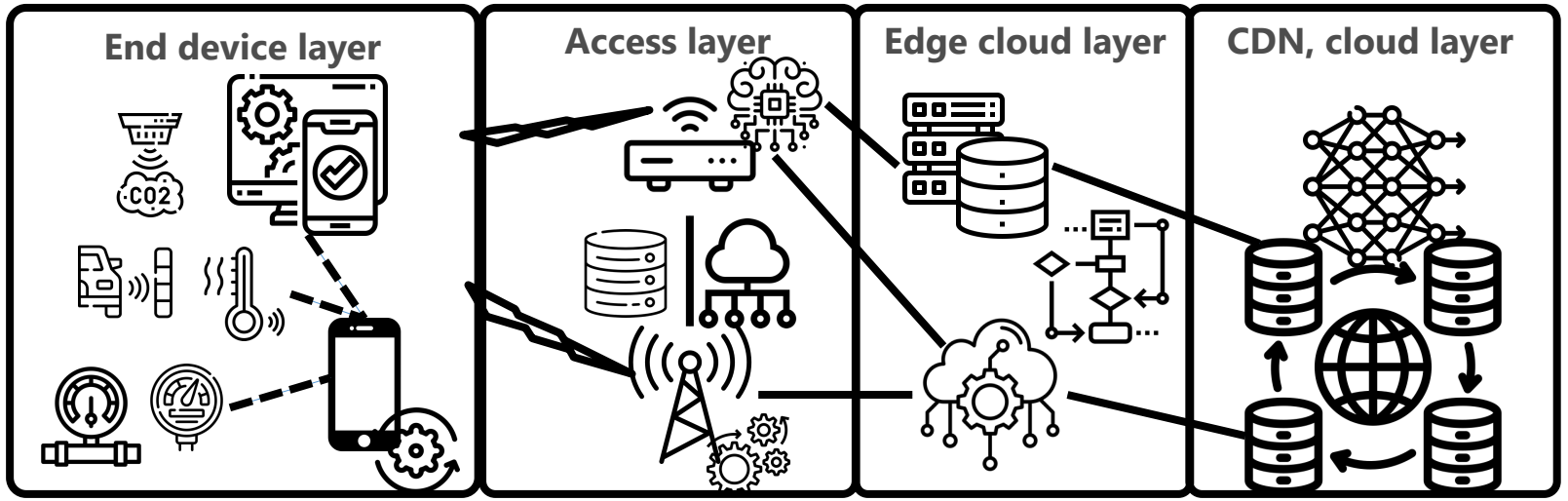
- **Task:** determine energy efficiency of IoT applications

- **Question:** Good energy efficiency definition?
  - Energy per packet/per GB of traffic?
  - Energy to operate instance for specific time?
  - Energy per (server) instance per task?

- Quantify **energy consumption** first
  - Measurement strategy?
  - Where can we measure?

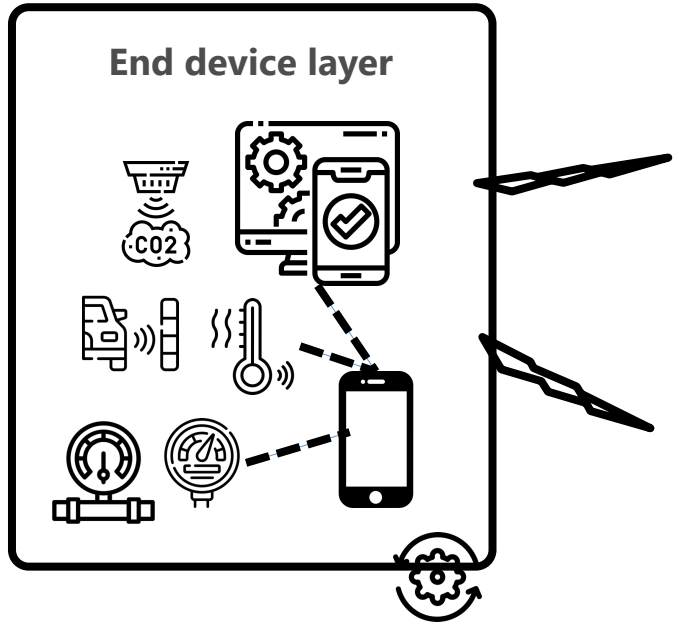
- Where can we **reduce** energy consumption?
- Split network in layers and **improve individually**

- **Different layers**
  - End device layer
  - Access layer
  - Edge cloud layer
  - Cloud layer
  - Investigation of each individual layer first

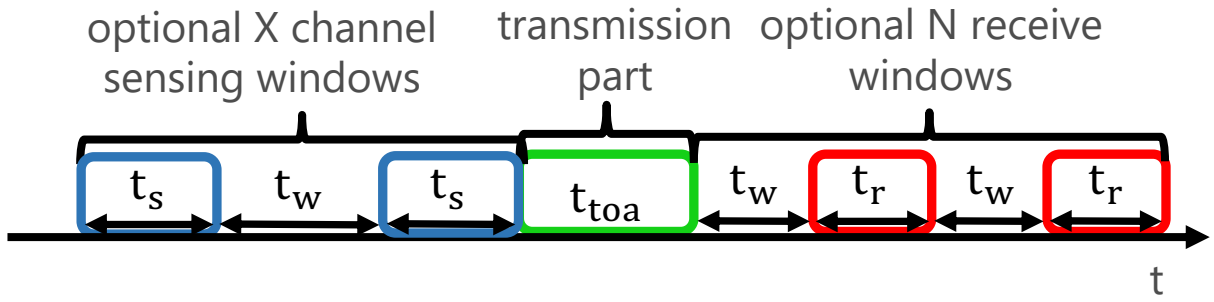


Energy Consumption: End Device Layer

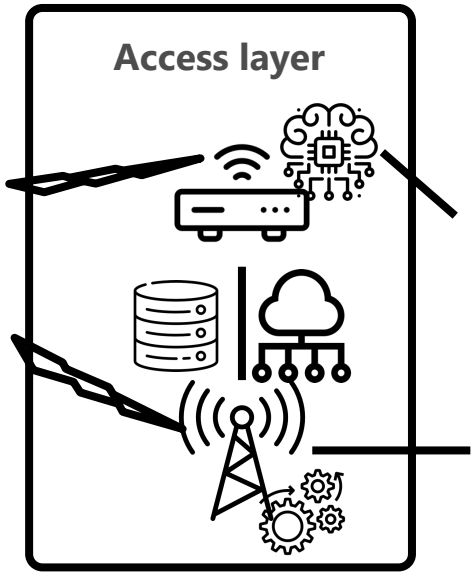
- **Direct energy consumption reduction** (of single device) by
  - Reduce energy for data monitoring
    - Apropriate hardware
    - Intelligent monitoring, idle, and sleep intervals
  - Limit **required processing** at the end devices
  - Usage of **Low Power Wide Area Networks (LPWANs)**
  - Limit **number, size,** and **overhead** of data transmissions



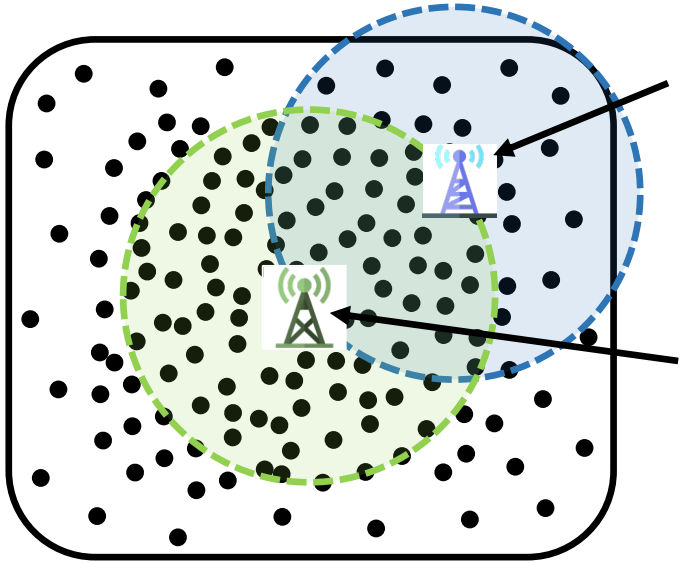
- **Indirect energy reduction**
  (for the complete layer) by
  - Smaller cells or better cell design
  - Less end devices or more intelligent placement



Energy Consumption: Access Layer



- **Efficient data processing and storage** in the access layer
  - **Turn** not used devices and links **off**
  - Data pre-selection with simple models
  - Limit usage of high **energy consuming processing approaches**
  - **Limit overhead** for communication within the layer and back to end devices
  - Move specific data to edge or cloud



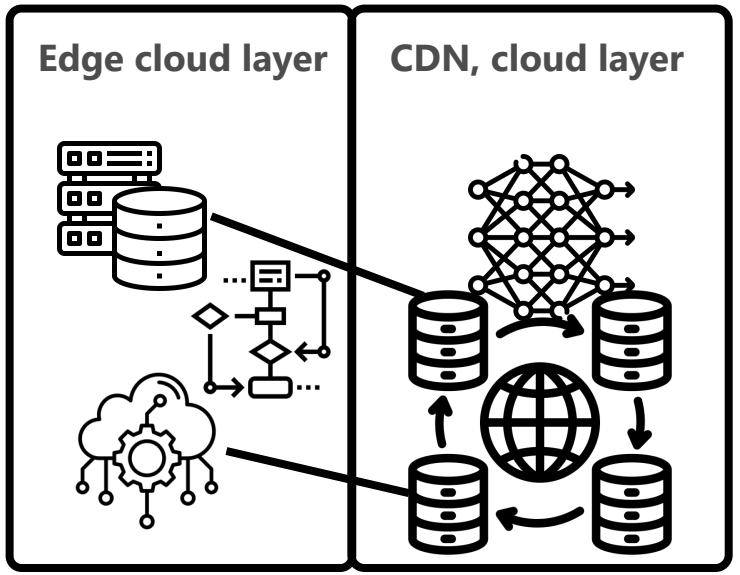
Example gateway in traditional mobile networks (blue)
First gateway placement priority: reduce number of sensors per cell

Example coverage LoRaWAN (green)
First placement priority: reduce distance between sensors and gateways

- **Energy consumption reduction: gateways**
  - Good gateway placement
  - Use gateways supporting **several technologies**
  - Turn gateways occasionally off

Energy Consumption: Edge and Cloud Layer

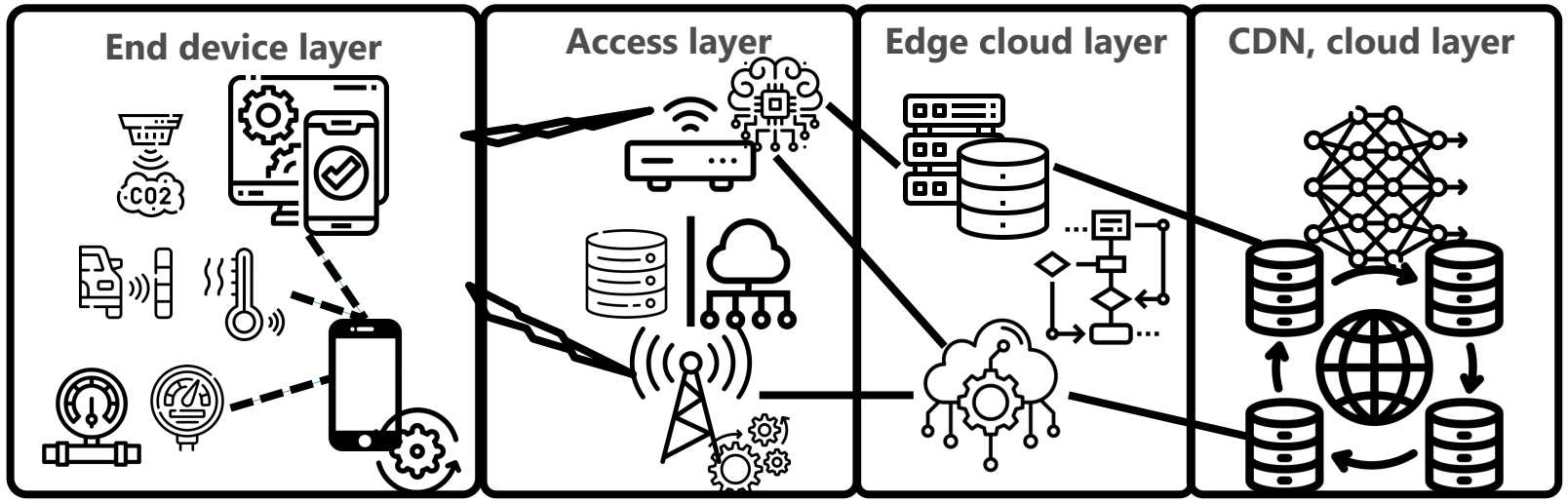
- Carefully select
  - **If** and **where** an edge cloud is required
  - Which data can be transmitted to large data centers



- **Cloud or data center deployment**
  - Critical: efficient **allocation** and **orchestration of resources**
    - Service placement within datacenters or geographic regions
    - Communication between services or regions
  - **Limit overhead**
    - For complex, occasionally unnecessary tasks
      Example: machine learning, model training in video streaming
    - For data processing and storage

- In general: **turn instances off** if not needed

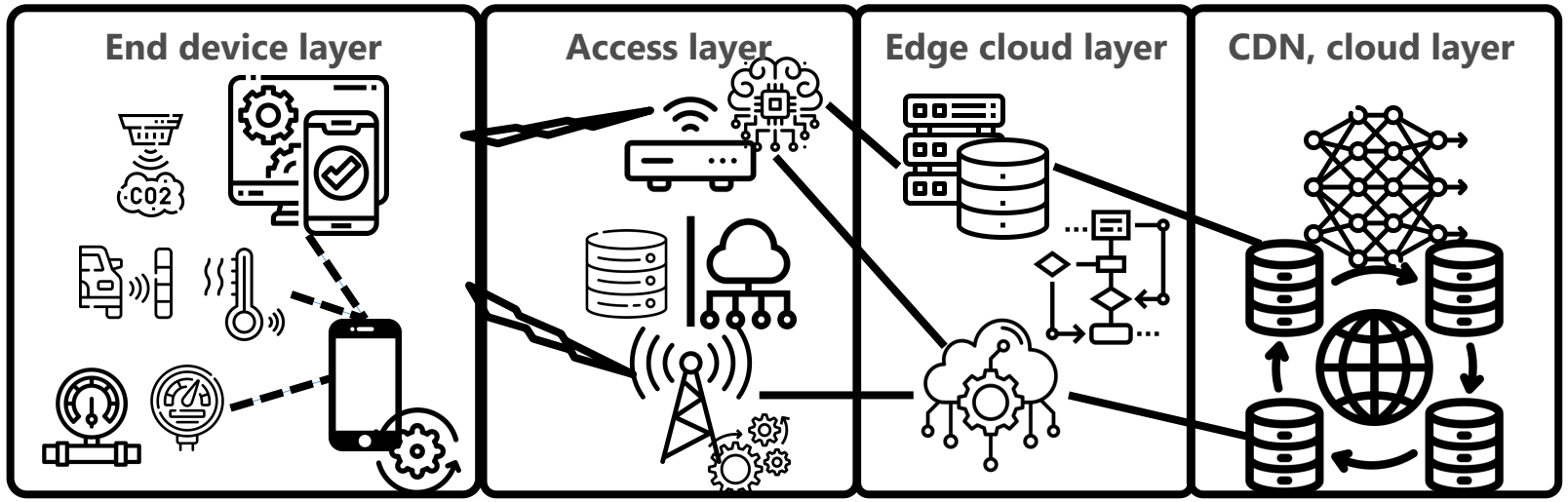
Energy Consumption and Efficiency: Internet of Things (the Extreme Case)



- **End device layer**
  - Short monitoring intervals
  - Random channel access
  - Low power wide area network
  - No data processing
- **Access layer**
  - Single gateway type and large cells
  - No data pre-processing
  - Move data to backbone network
- **Edge cloud layer**
  - Not required
  - Process all data in access or cloud layer
- **CDN, cloud layer**
  - Highly optimized deployment
  - Always turn machines off when not needed
  - Limit machine learning or overhead data storage

→ Specific services not possible and **bad Quality of Service** for the end user

Energy Consumption and Efficiency: Internet of Things (the Optimal Case)



1. Understand application and requirements
2. Optimize each **individual layer**
3. Consider **dependencies** among layers
4. Quantify energy consumption in **best case**
5. Compare to **actual energy consumption**

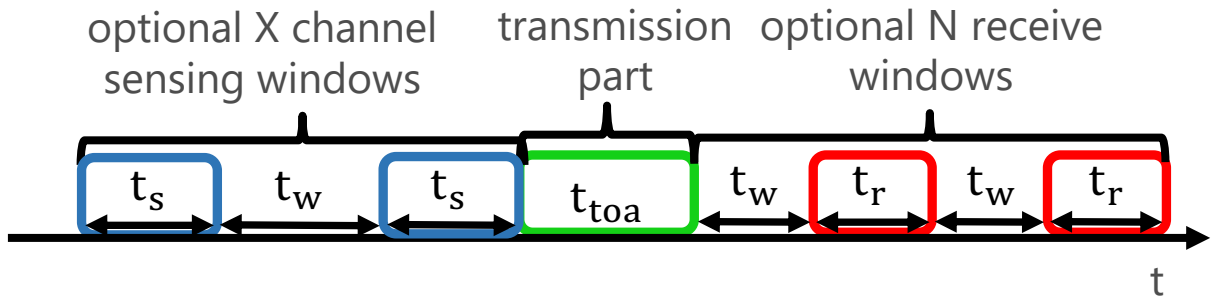
- Also consider performance and resource consumption **trade-offs**

- Required **access network considerations**
  - Which access network technology?
  - Gateway type and deployment strategy?
  - Sensor deployment, measurement interval?

  → Improvement of **Quality of Information**
- **Cloud considerations**
  - Edge vs. Cloud (SLA based)
  - Processing (Machine Learning required?)

Example: LoRaWAN – Idea

- **Consideration:** Channel access and data transmission in LoRaWAN
- Channel access options
  - Random access
  - Listen before talk
  - Time scheduled

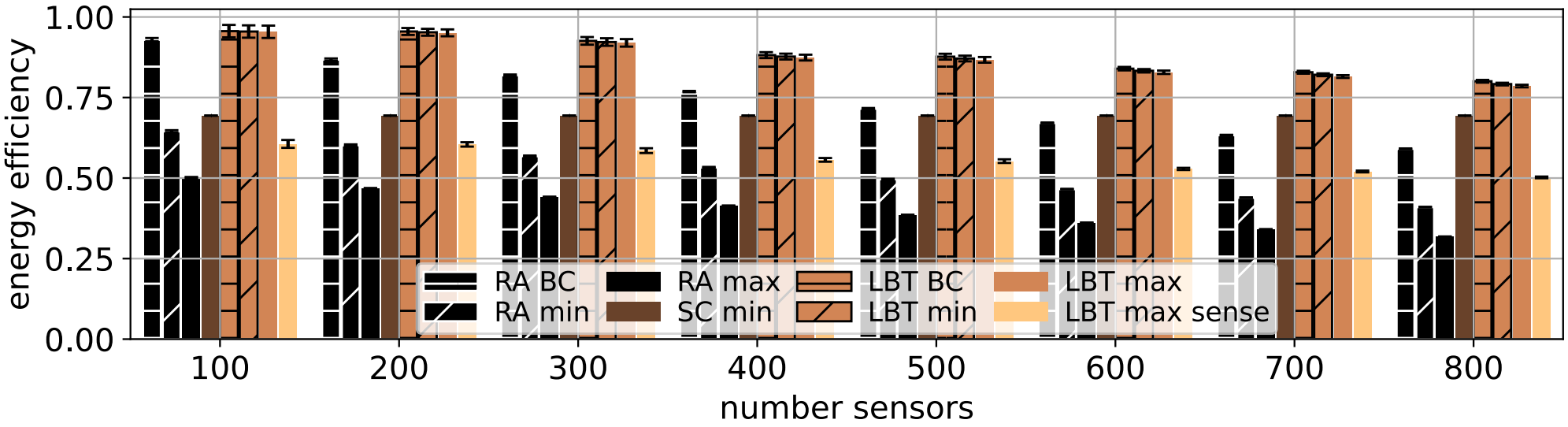


- Determination of **energy consumption** and **energy efficiency**
- Energy efficiency as ratio of **best case** energy consumption and **actual consumption**
- **Best case consumption:** only transmission, no overhead for channel sensing, receptions, collisions

- **Actual consumption** includes
  - Data transmission
  - **Channel sensing** (listen before talk) and **synchronization** (time scheduled)
  - Optional receive windows
  - Message collision in an unreliable channel

Example: LoRaWAN – Results

- Comparison of **energy efficiency** among different channel access approaches



- **Random access** (black) best case (RA BC) less energy efficient for more sensors
- Worse result when receive windows for random access (RA min, RA max) added

- **Time scheduled** approach (SC min – brown) constant among number of sensors
- **Listen before talk** (LBT – orange) energy efficiency drops slower with more load, large impact by listening to the channel (yellow)

- To be determined next: how many **gateways** required; location for **processing**?

Discussion and Conclusion

- **Energy efficiency improvement** required in future IoT and 6G networks
  - Reduction of **energy consumption** in each layer and in the network in general required
  - Improvement of **energy efficiency**
    - Identify **best case operation** of service or application
    - Quantify this **energy consumption**
    - Compare to actual energy consumption

    } Challenging task
  - Identify dependencies, benefits, and drawbacks among layers

- **General goals**
  - Improve **Quality of Information** with same resource requirements
  - Keep **Quality of Information** with less required resources
  - Avoid worse **Quality of Service** or service quality
- **Additional considerations:** Usage of renewable or "free" energy

→ Improvement of energy efficiency of IoT requires **improvement of complete network**

→ Its key to **understand** future applications, networks, and services in detail