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Institute of Computer Science
Chair of Communication Networks
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# LoRaWAN Network Planning in Smart Environments: Towards Reliability, Scalability, and Cost Reduction

**Frank Loh, Stefan Geißler, Tobias Hoßfeld**

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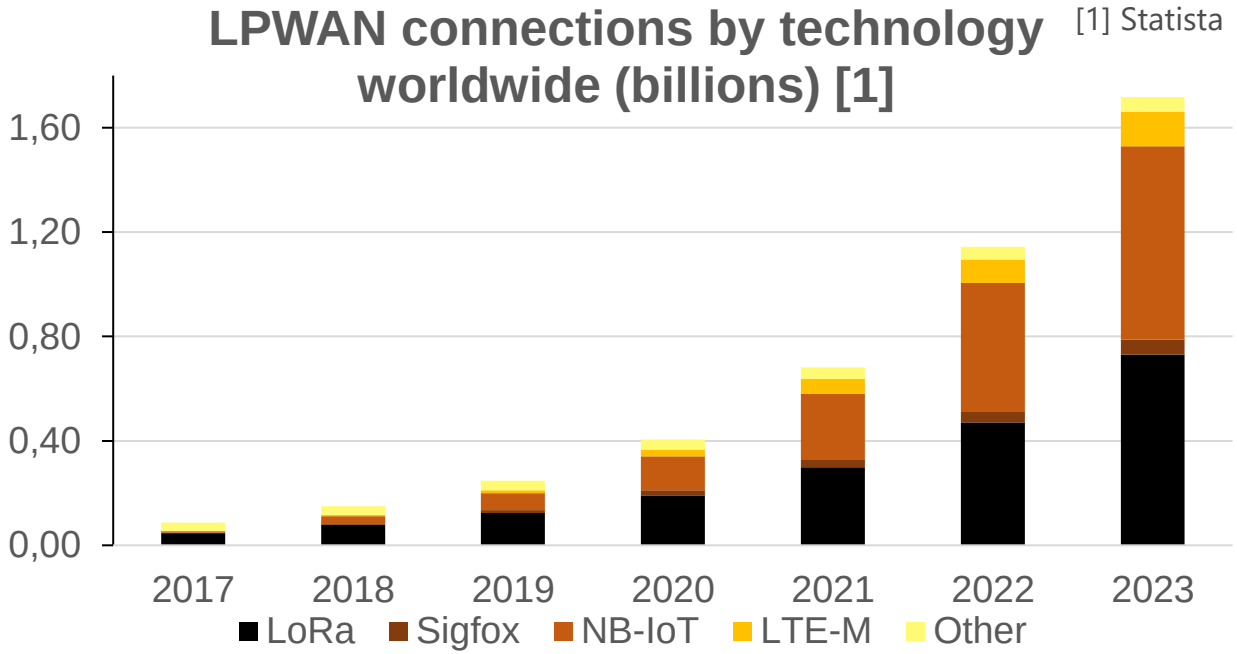
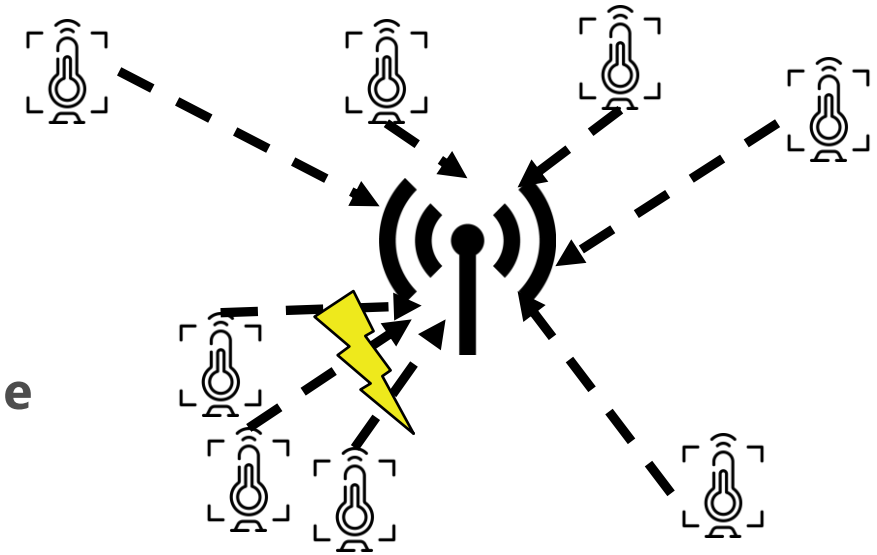
# Motivation

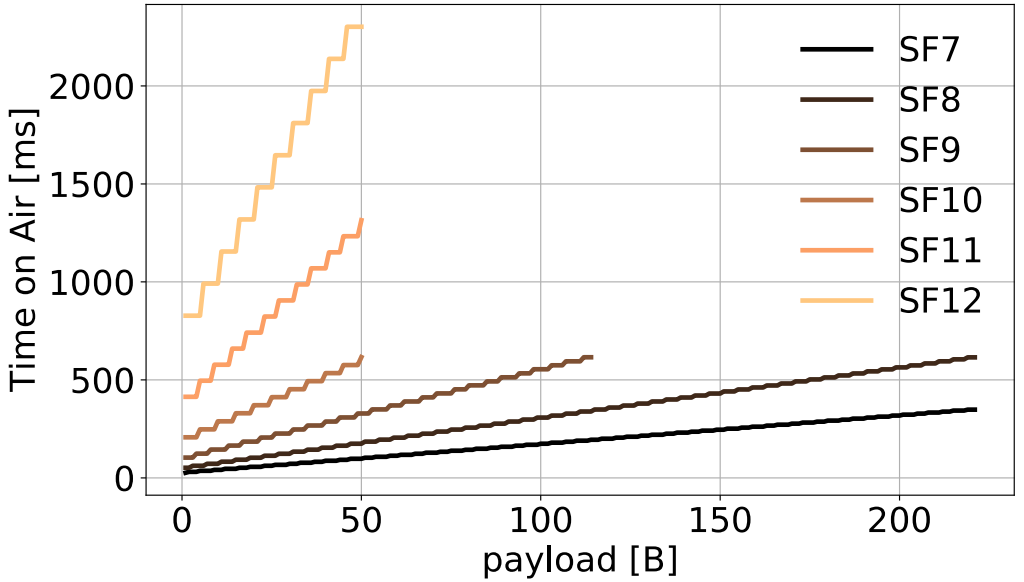
- **LoRaWAN promises**
  - Transmission across long distances
  - Little energy requirements
  - Usable in coexistence with 5G
- **Application areas include**
  - Weather and climate monitoring
  - Smart parking or street lightning
- **Data transmission**
  - In unlicensed frequency bands
  - Currently random channel access approach
  - Suffering from **message collisions and loss**
- **Research questions**
  - How can we make LoRaWAN more **reliable** and **scalable**
  - What is the influence on **cost** and **complexity**

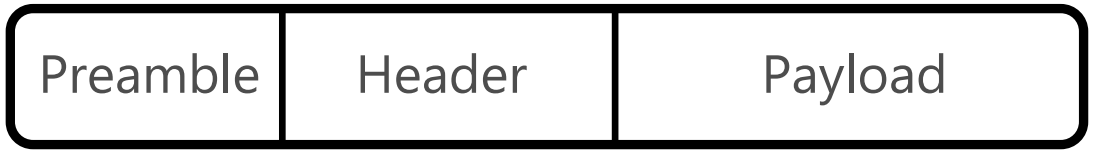


# General Background Information

- **Goal:** good network performance in LoRaWAN – for us: **little collision probability**
- Collision probability in LoRaWAN mainly influenced by **channel utilization**
- Channel utilization influenced by
  - **Number of messages** per time frame
  - **Duration** to transmit messages
- Number of messages adjustable
  - Transmission rate per sensor
  - **Number of sensors** per cell
- Duration to transmit messages mainly influenced by spreading factor
- Larger spreading factors (SFs)
  - Allow transmission across **longer distances**
  - Occupy the frequency channel longer
- **LoRa message**
  - Preamble, header and payload
  - Additional parameters influencing size (e.g. coding rate)

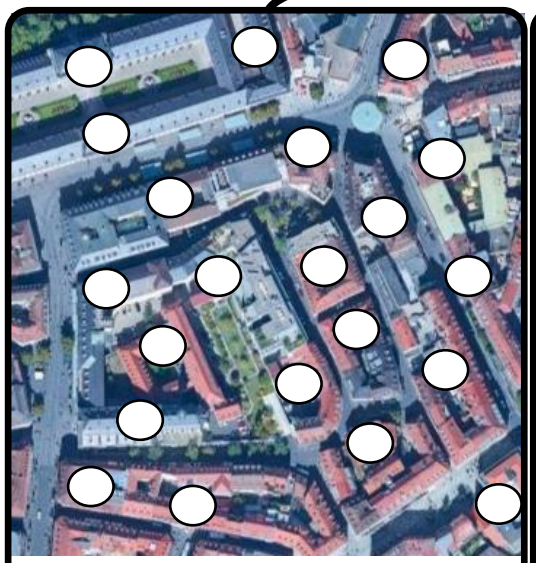


# Collision Improvement Potential in LoRaWAN

- **Load steering** in the network by intelligent **gateway placement (SDMA)**
  - **Approach 1:** Placement according to number of sensors per gateway
  - **Approach 2:** Placement according to distance between sensors and gateways
- Use intelligent **channel access** for each frequency **(TDMA)**
  - Currently LoRaWAN uses random access → **high collision potential**
  - Alternatives
    - **Channel sensing** before access: additional complexity and hidden node problem
    - Channel access in **specific slots**: overhead through synchronization
- LoRaWAN uses **eight frequency channels** in uplink direction
  - Efficient use of all frequencies **(FDMA)**
  - Efficient use of each single frequency
- Additional **loss reduction techniques**
  - **Message aggregation** (reduce overhead per message and number messages)
  - **Message retransmission** (collision detection, retransmission and thus, loss reduction)
- Any further approach ideas **open for discussion** …

# Suggested Five Phases for Performance Optimization in LoRaWAN



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- Get real data from e.g. OpenStreetMap/provider
- Place devices at these locations

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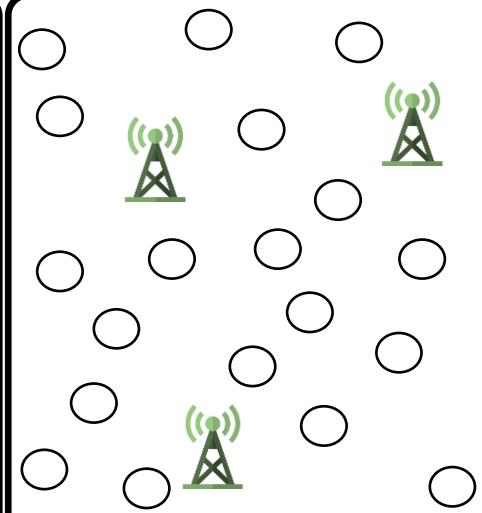

**Gateway Placement**

- Determine possible gateway locations
- Placement algorithm to select gateway locations

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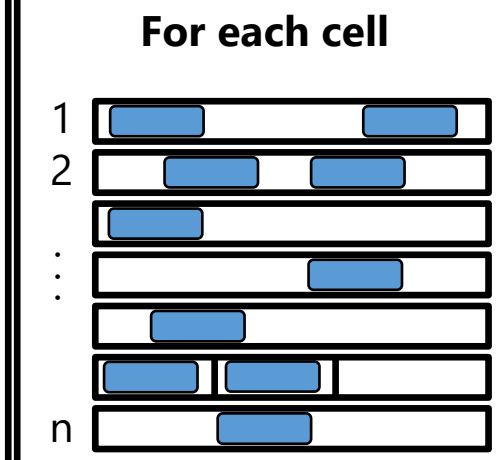


**Channel Access**

- Select frequency channel
- Select channel access approach
- Challenge: inter-cell interference

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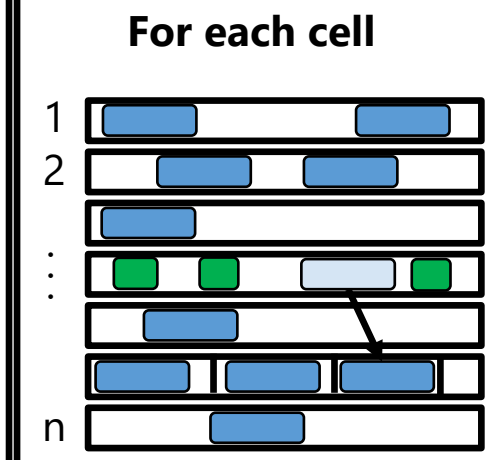


**Cell Adjustment**

- Transmission characteristics
- Channel access
- Frequency channel

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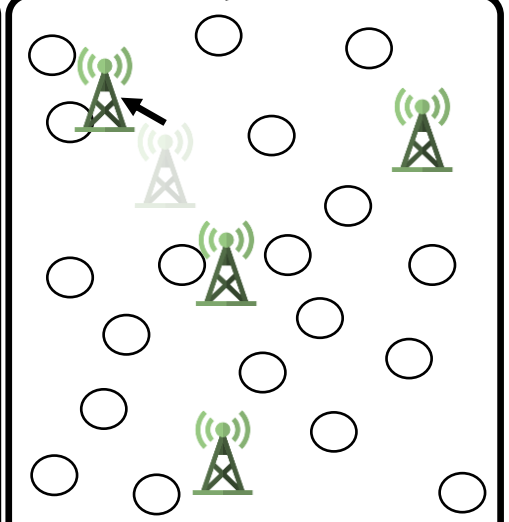


**(opt.) Replacement**

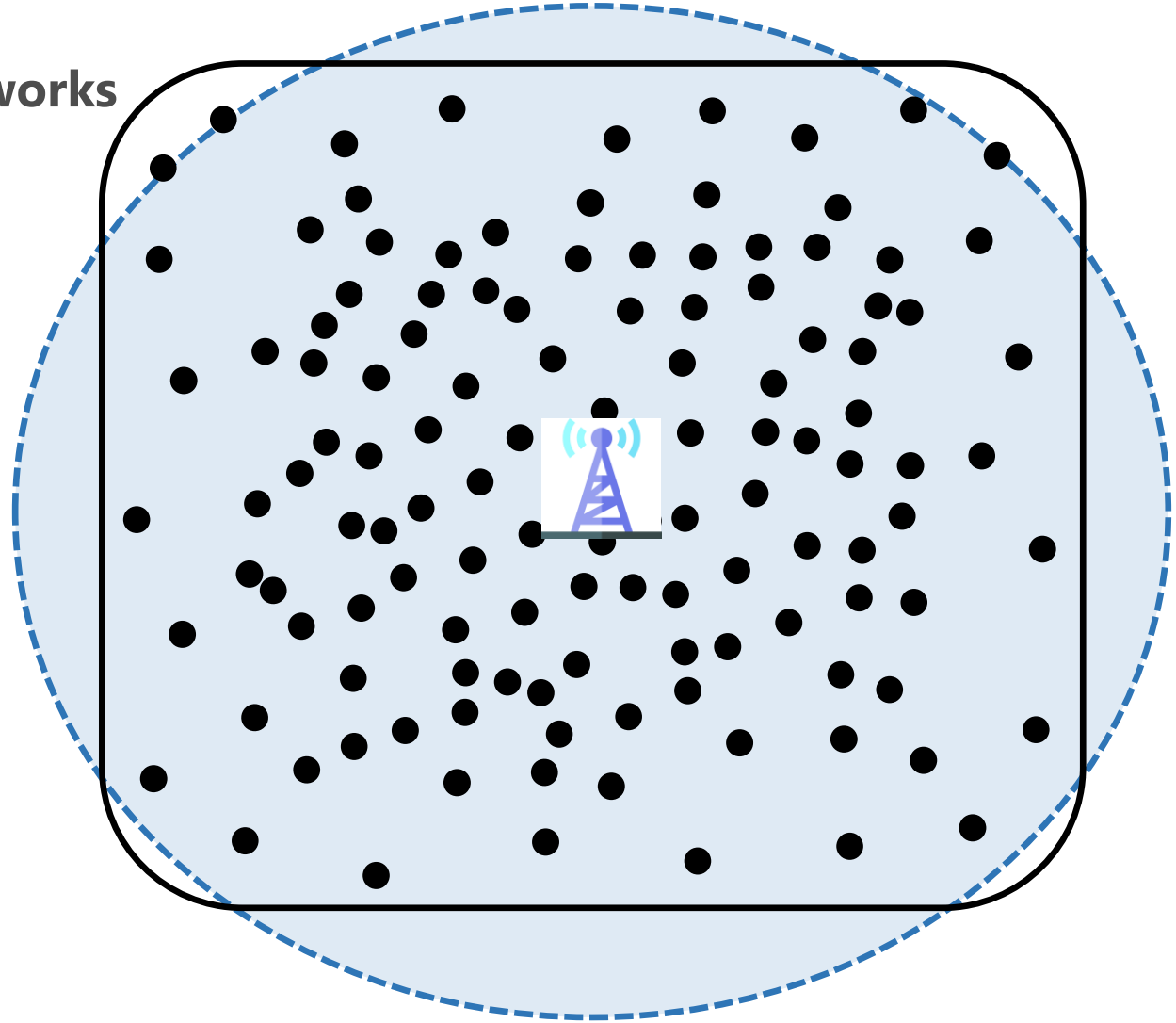
- Replace gateways with new information
- Place additional gateways if load changes

**Phase 5**

- Good initial gateway placement prefered compared to frequent replacement
- Channel access dependent on device quality and capabilities
- Why this planning sequence suggestion? → gateway placement has largest effect

# General Idea in Network Planning

- Gateway placement in **traditional cellular networks**
  - Place gateway to cover all devices
  - Created load of sensors **independent on distance to gateway**



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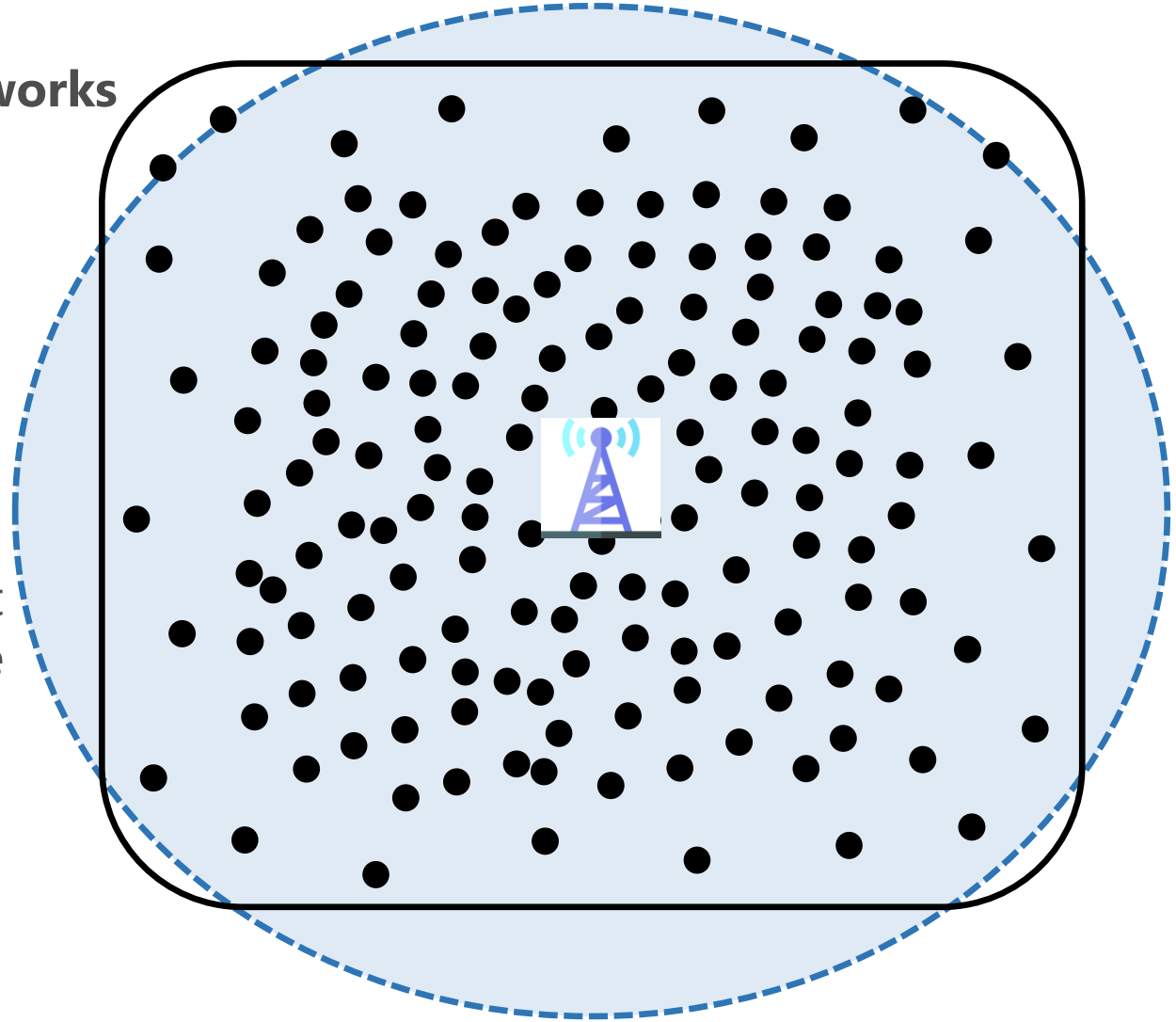

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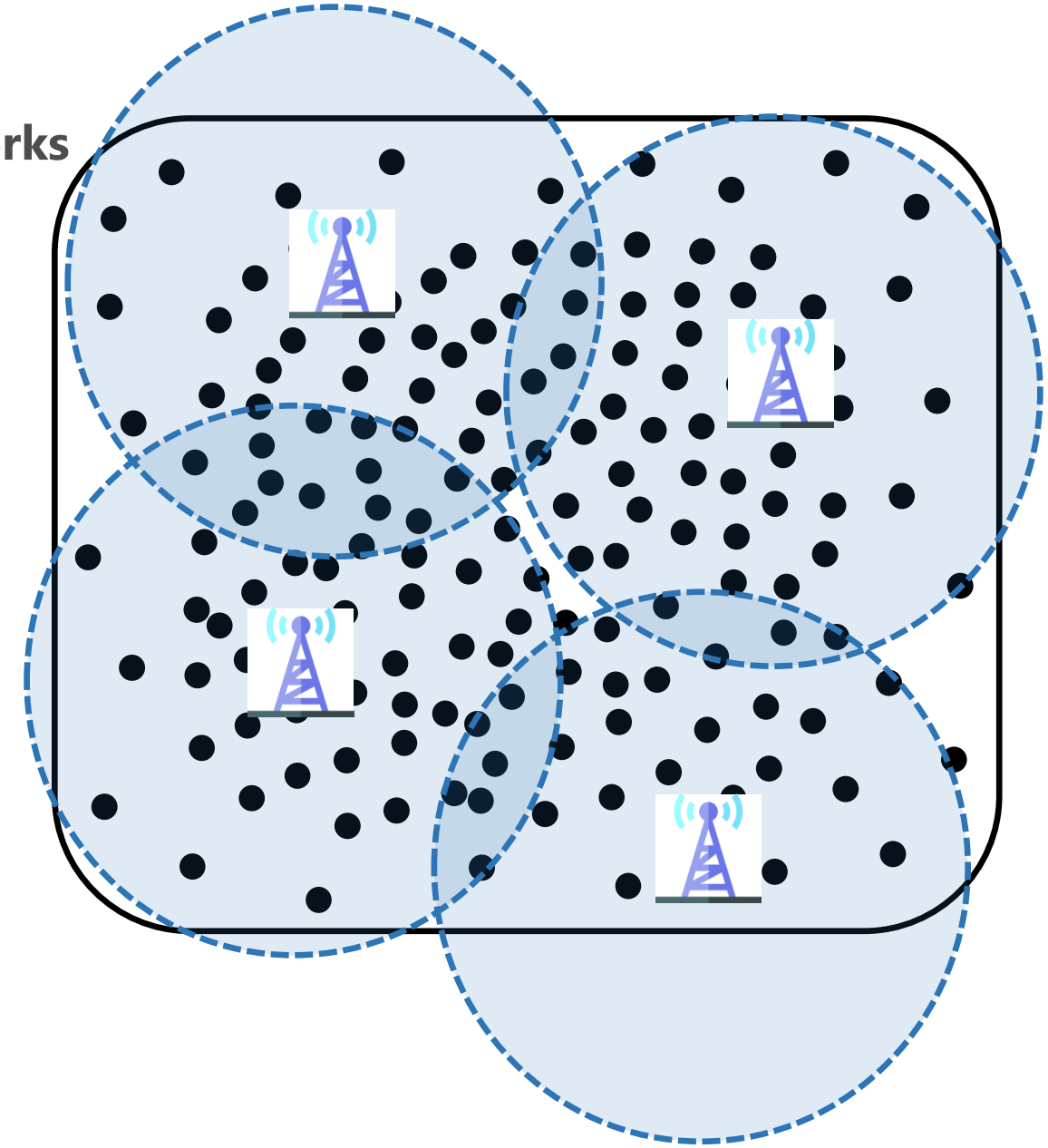

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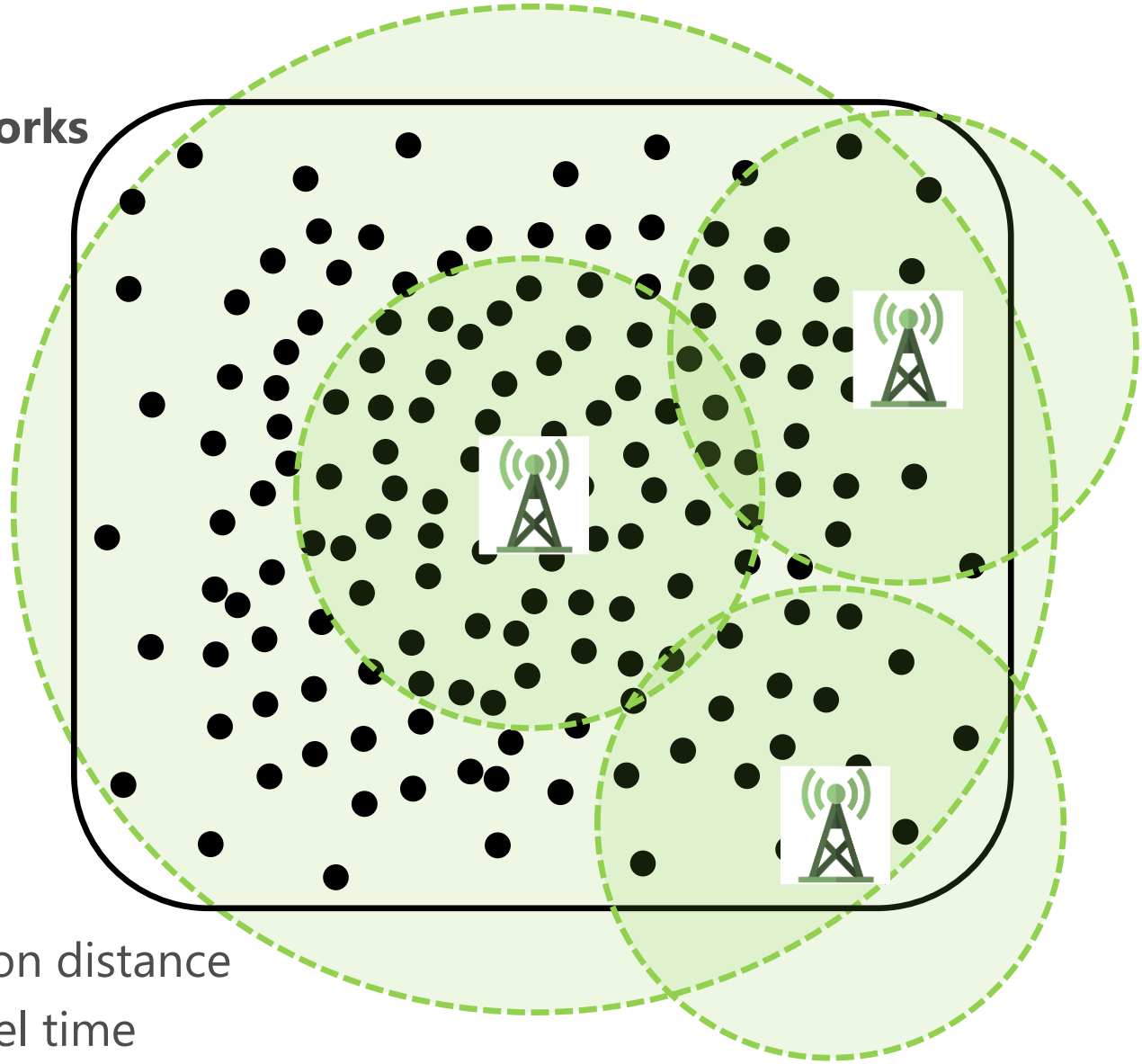

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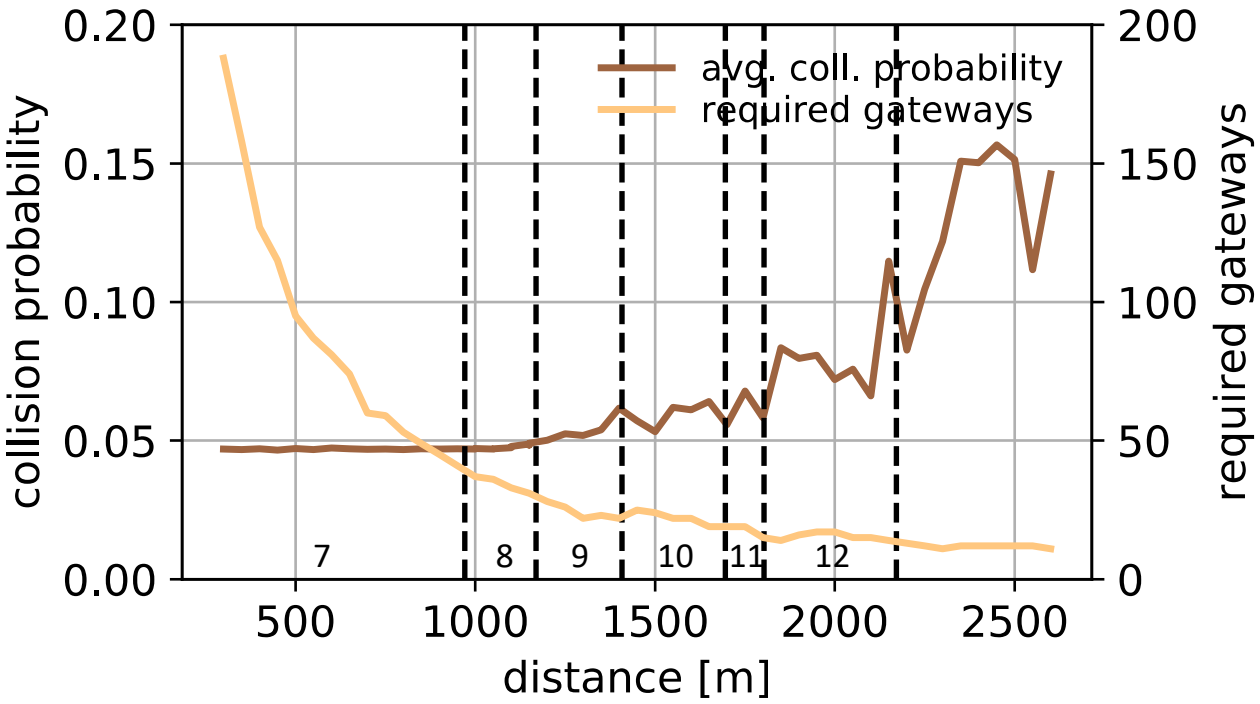
- **Situation in LoRaWAN completely different!**
  - Larger spreading factor for longer transmission distance
  - Larger spreading factor lead to longer channel time

  → Reduce number sensors transmitting with large spreading factor

# Pre-Study: Distance to Gateway

- **Collision probability** and required **number of gateways** for different distances
- Spreading factor increases with distance to gateway limit
- With larger distance
  - **Collision probability** increases
  - **Number gateways** decreases
- **Goals**
  - Minimize collision probability (reliability)
  - Reduce number of gateways (cost)

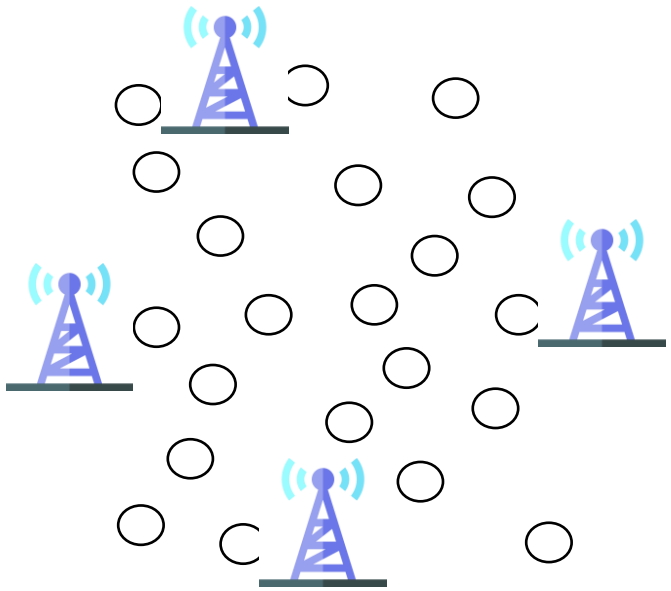



- No collision probability improvement up to 1000m distance
- Collision probability 5% up to 1150m: spreading factor 7 or 8 distance
- **Recommended distance**
  - **For performance:** spreading factor 8 limit (~1150m)
  - **For cost:** spreading factor 9 limit (~1350m)

# Gateway Placement Approaches

- **Main constraints** for gateway placement in a reliable LoRaWAN
  - Coverage
  - Number of gateways
  - Expected collision probability

- Suggestions for gateway placement approach
  - **Greedy-like approach**
    - Place gateways with device and distance limits
    - Replace or change placement if better placement is found



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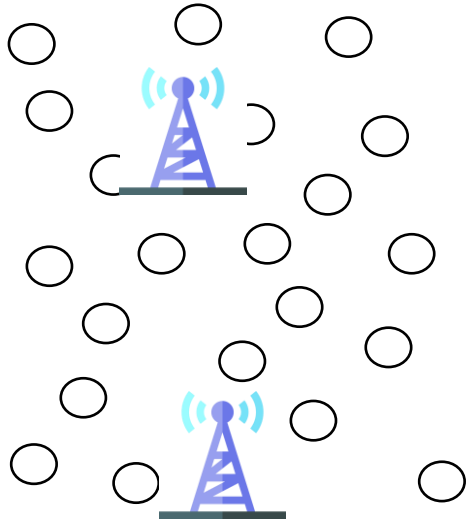

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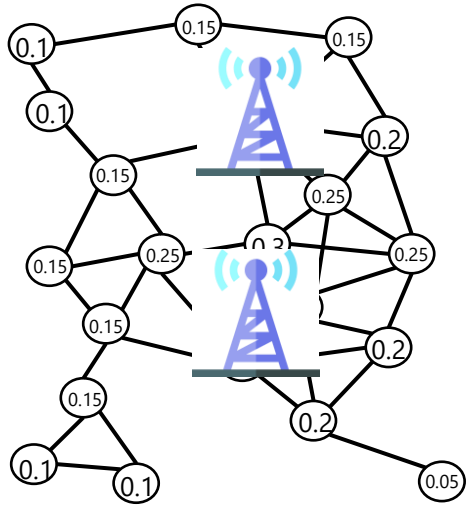


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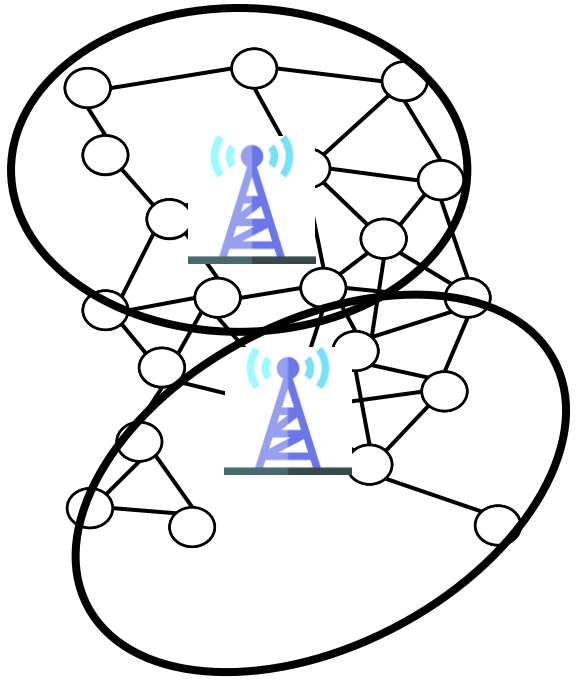

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  - **Machine Learning approaches:** e.g. clustering

- Other approaches **open for discussion** …

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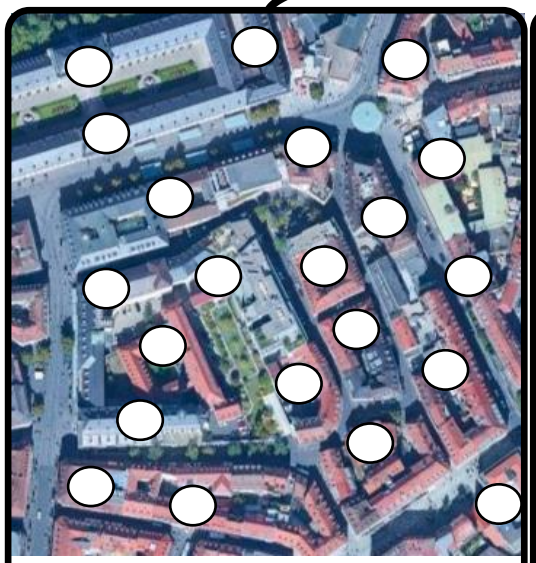

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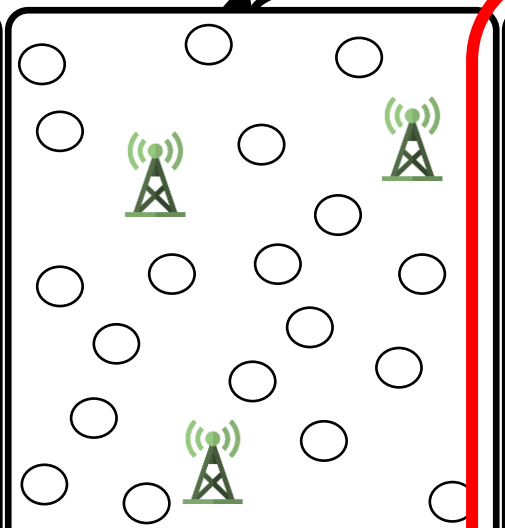

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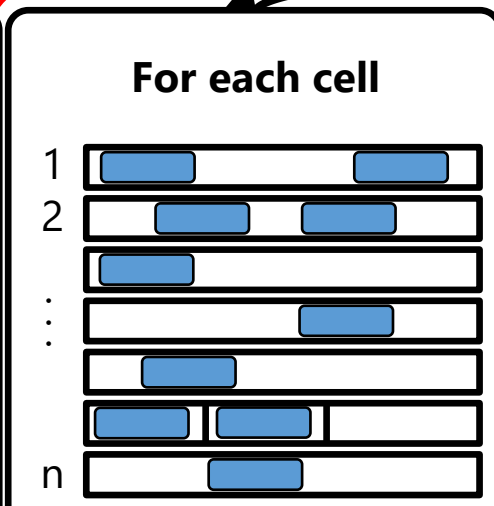


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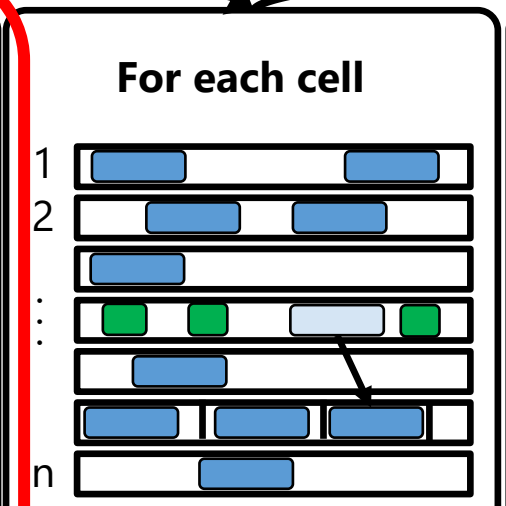


**Cell Adjustment**

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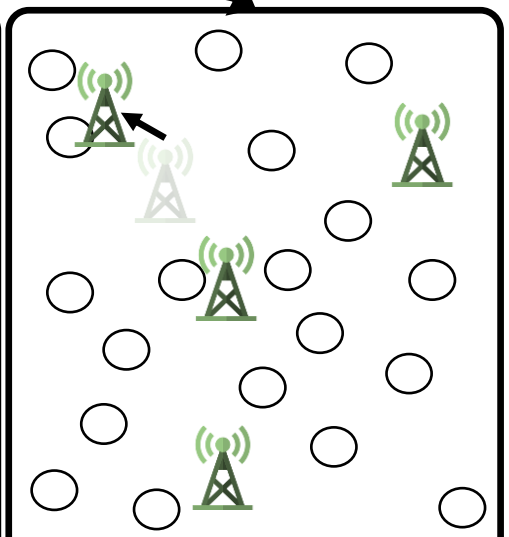

**(opt.) Replacement**

- Replace gateways with new information
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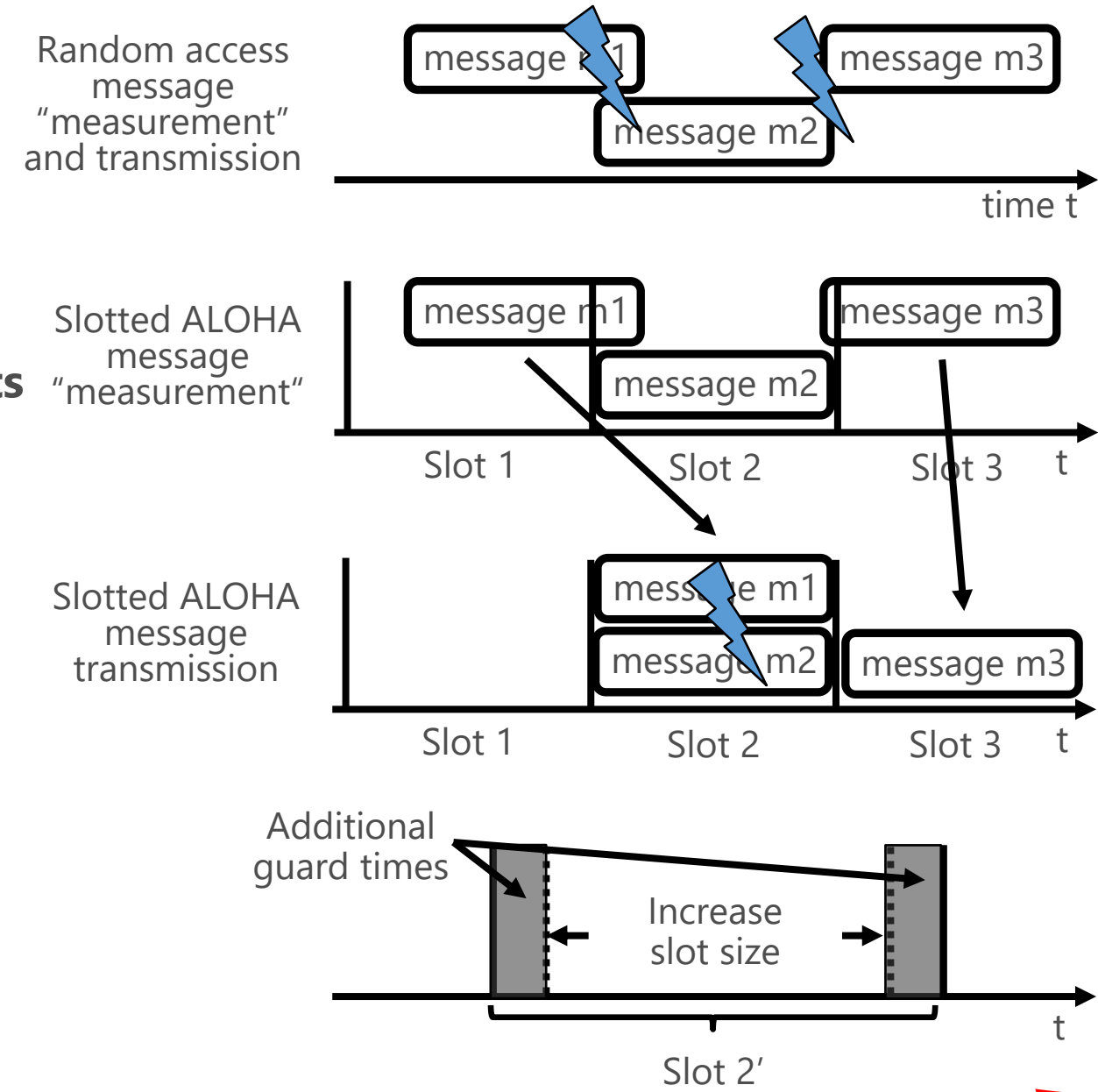
**Phase 5**

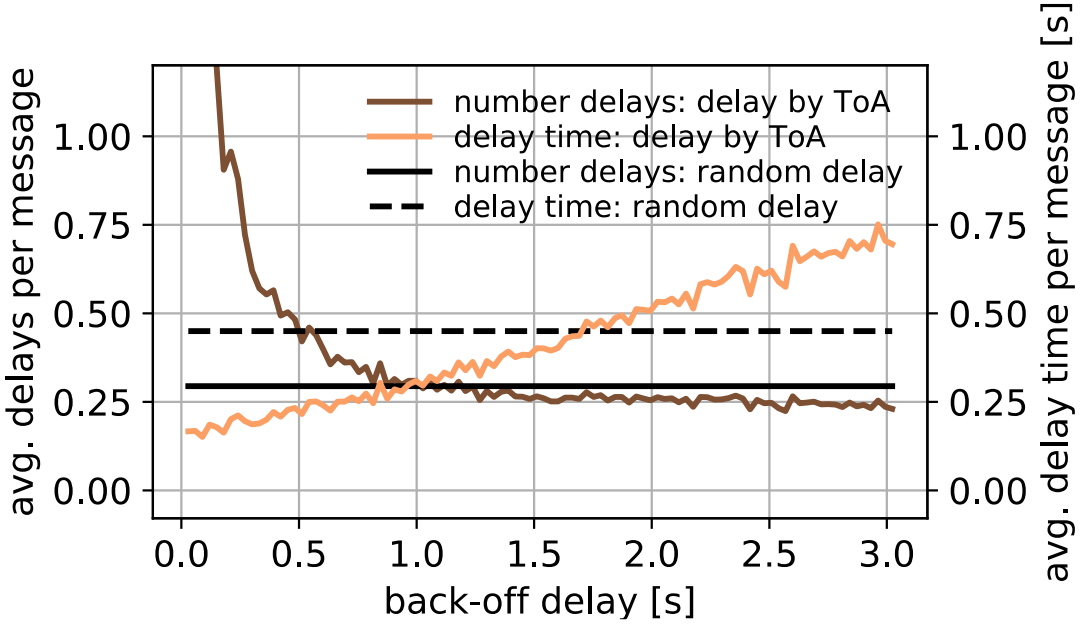
# Intelligent Channel Access in LoRaWAN

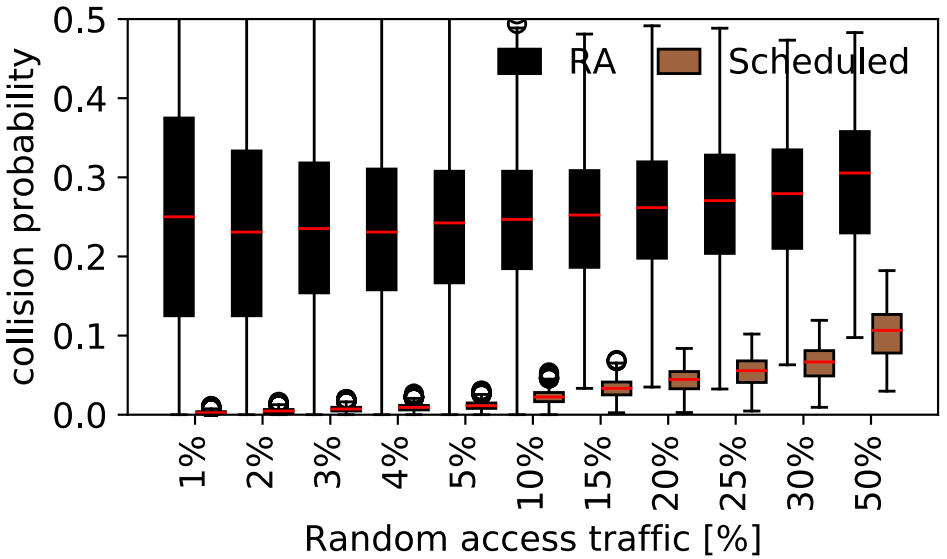
- **Channel access approaches in theory**
  - Listen before talk
  - Slotted ALOHA
  - Scheduled MAC
- **Slotted and scheduled in practical deployments**
  - Different message transmission airtimes
  - Device clock inaccuracies and difficult synchronization
- **Adjust slots in deployments** with
  - Optimal slot length
  - Guard time to compensate clock inaccuracies
  - Enough duty cycle capability for gateway to synchronize devices



# Challenges and Suggestions for LoRaWAN Channel Access

- Challenges in LoRaWAN
  - **Synchronization:** devices not always *online*
  - **Channel sensing time:** good parameter for listen before talk required
  - **Slot sizes:** Transmission duration of LoRa messages has large variance
  - **Signaling messages:** collision and loss in unreliable channels
  - **Unlicensed frequency bands:** network can suffer from cross traffic
- Select approach based on **circumstances in the network**
  - **Listen before talk** always preferable over plain **random access**
  - **Slotted ALOHA** only if time on air of messages is similar
  - Complete **scheduling** dependent on
    - Device capabilities
    - Loss of synchronization messages and cross traffic

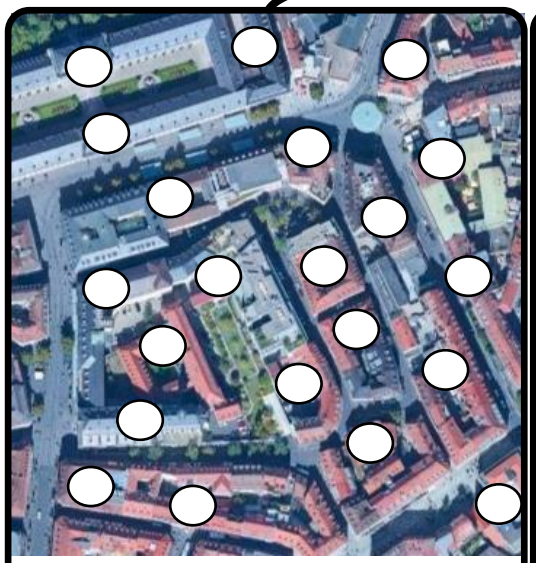


# Discussion about Intelligent Channel Access

- **Trade-off in channel access**: general complexity vs. performance
  - Good synchronization vs. complexity and device capabilities
    - Not all **cheap devices** can be synchronized in a millisecond scale
    - **Large clock drifts** increase number of synchronizations
  - Signaling messages vs. traffic overhead
    - More **signaling messages** increase total network load
    - **Additional collisions** by signaling and synchronization traffic
  - Random frequency channel assignment vs. reservation for critical traffic
    - Channel reservation **can reduce loss percentage** of important messages
    - Channel reservation **increases load in other channels**
  - **Low power wide area network!** → take energy consumption into consideration
- Any other channel access approaches **open for discussion …**
- **Overall goal:** reliable transmission with minimal energy requirements (and other cost factors)

# Suggested Five Phases for Performance Optimization in LoRaWAN



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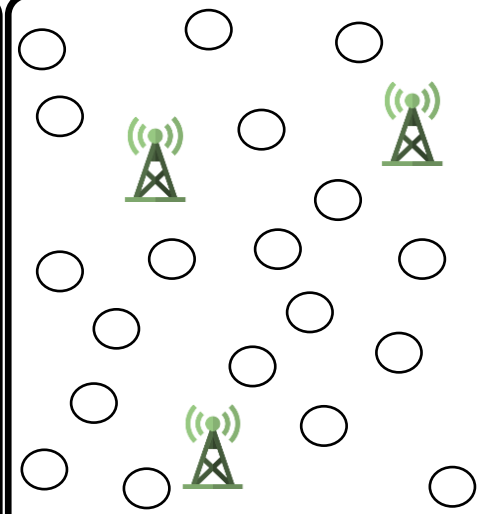

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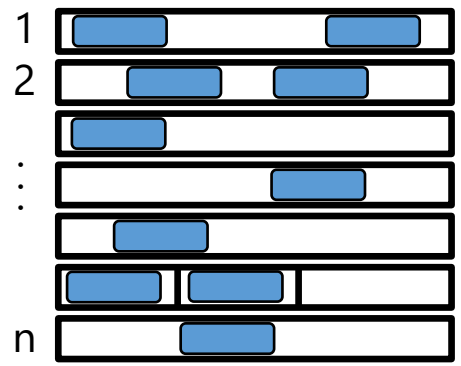


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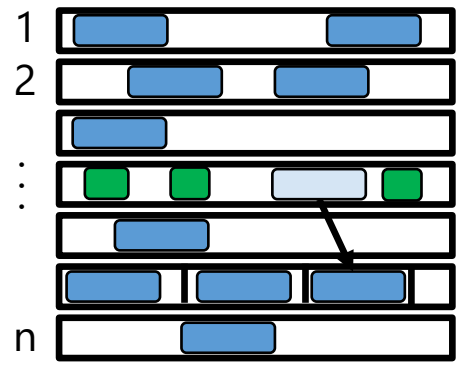


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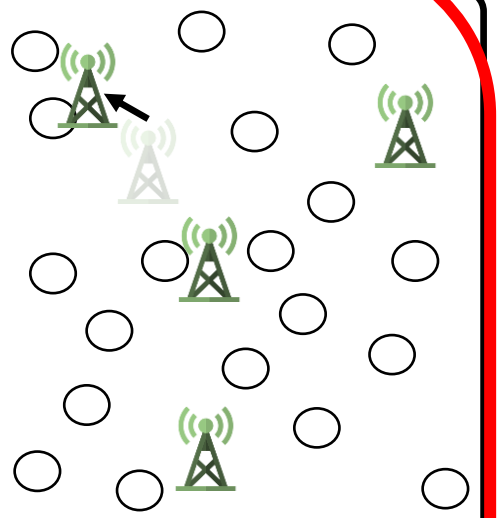

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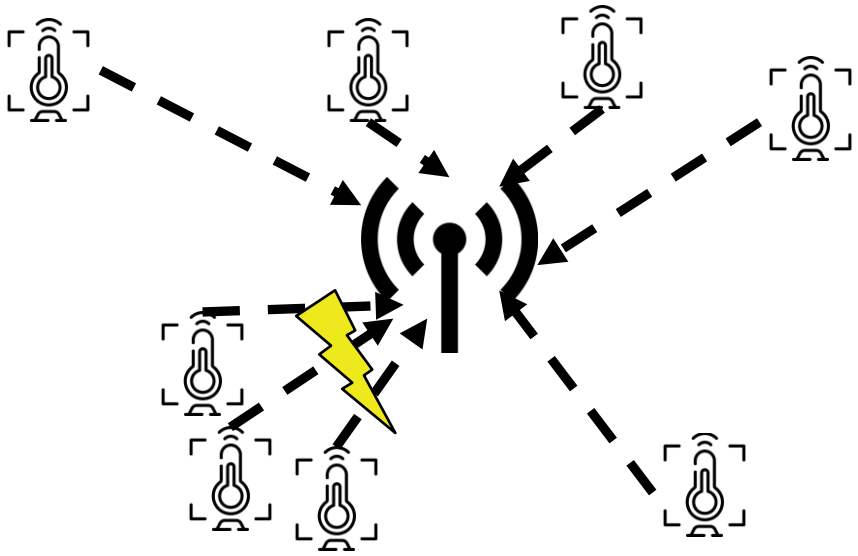

- LoRaWAN networks are **constantly growing**
- How to deal with **future load increase**?
- **Solution 1:** gateway replacement
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  - Good initial placement better than replacement
- **Solution 2:** adjust channel access based on network load
  - Random access as long as load is small
  - More complex approach when load is increasing
- **Solution 3:** intelligent network monitoring and management
  - Quality of information is important, not amount of data!
    - Adjust transmission frequency of devices
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    - Loss reduction by message aggregation and less transmissions
    - Processing possiblity at the device vs. constant message loss?
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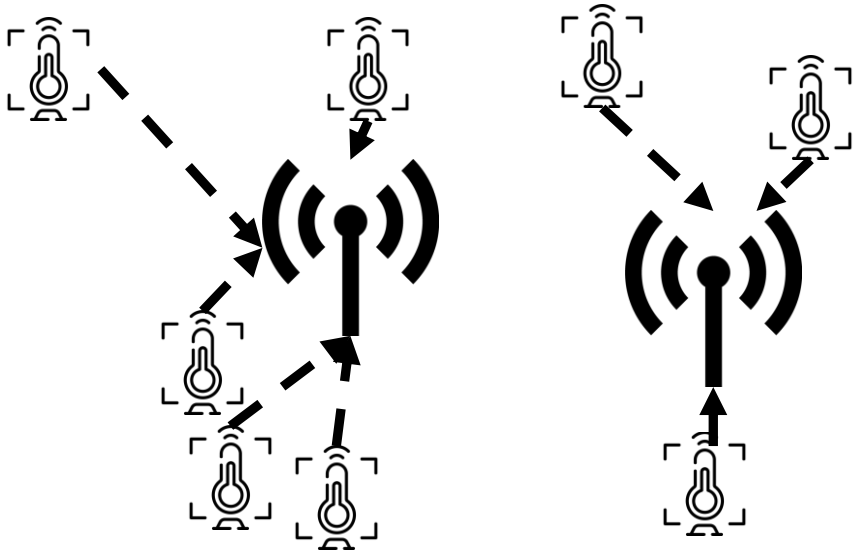

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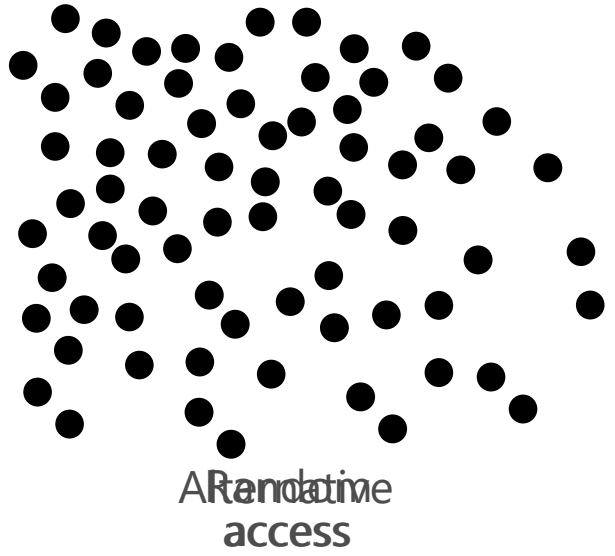

# Conclusion and Discussion

- LoRaWAN is one of the **fastest growing**, very promising **IoT access network technologies**
- In particular usable **in coexistance with 5G** for small datarates and energy efficient transmissions
- **Collision improvement potential** with
  - **SDMA** - intelligent gateway placement
  - **TDMA** – intelligent channel access
  - **FDMA** – intelligent frequency usage
- **Suggested approach**
  - **First**: good gateway placement
  - **Second**: good channel access
  - **Third**: good optimization
- Suggested **research directions**
  - **Alternatives** to FDMA, TDMA, SDMA?
  - **Extensions to gateway placement approaches**
    - Greedy based
    - Graph based (density)
    - Machine Learning based (clustering)
  - **Channel access** in LoRaWAN
  - **Network adjustments**
    - Scalability solutions
    - Network management
    - **Quality of Information** improvement