How-to (not) Smart City

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Previously

- 2003-2009: Universität Würzburg
  - Chair of Distributed Systems
- 2010-2015: Universität Wien
  - Future Communication Research Group
- 2015-2018: Universität Duisburg-Essen
  - Chair of Modeling of Adaptive Systems
- 2018++: Universität Würzburg
  - Chair of Communication Networks

- P2P
- LTE
- TCP video streaming
- Crowdsensing
- Context-based monitoring
- Crosslayer mobility
- Cloud gaming evaluation
- TSN
- LPWAN

Our Smart City Projects

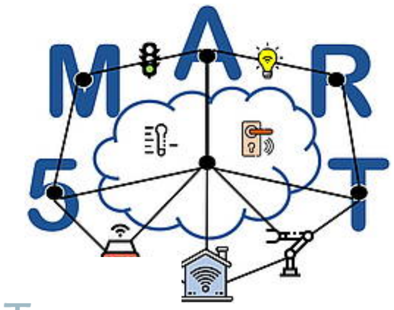
IOT4WUE

- With (and funded by) **WVV**, **MFN** (municipal company of Würzburg)
- LoRaWAN deployment and practical problems

5MART

5G-fähiges Management Aller Regionaler Tätigkeiten

- Funded by bavarian **STMWI**, with **Infosim**
- Viability, scalability of LPWAN approaches for Smart Cities



WVV Energie. Verkehr. Umwelt.

STADT WÜRZBURG

infosim®

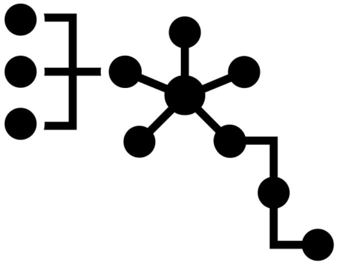
Gefördert durch

Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie

Our Goals

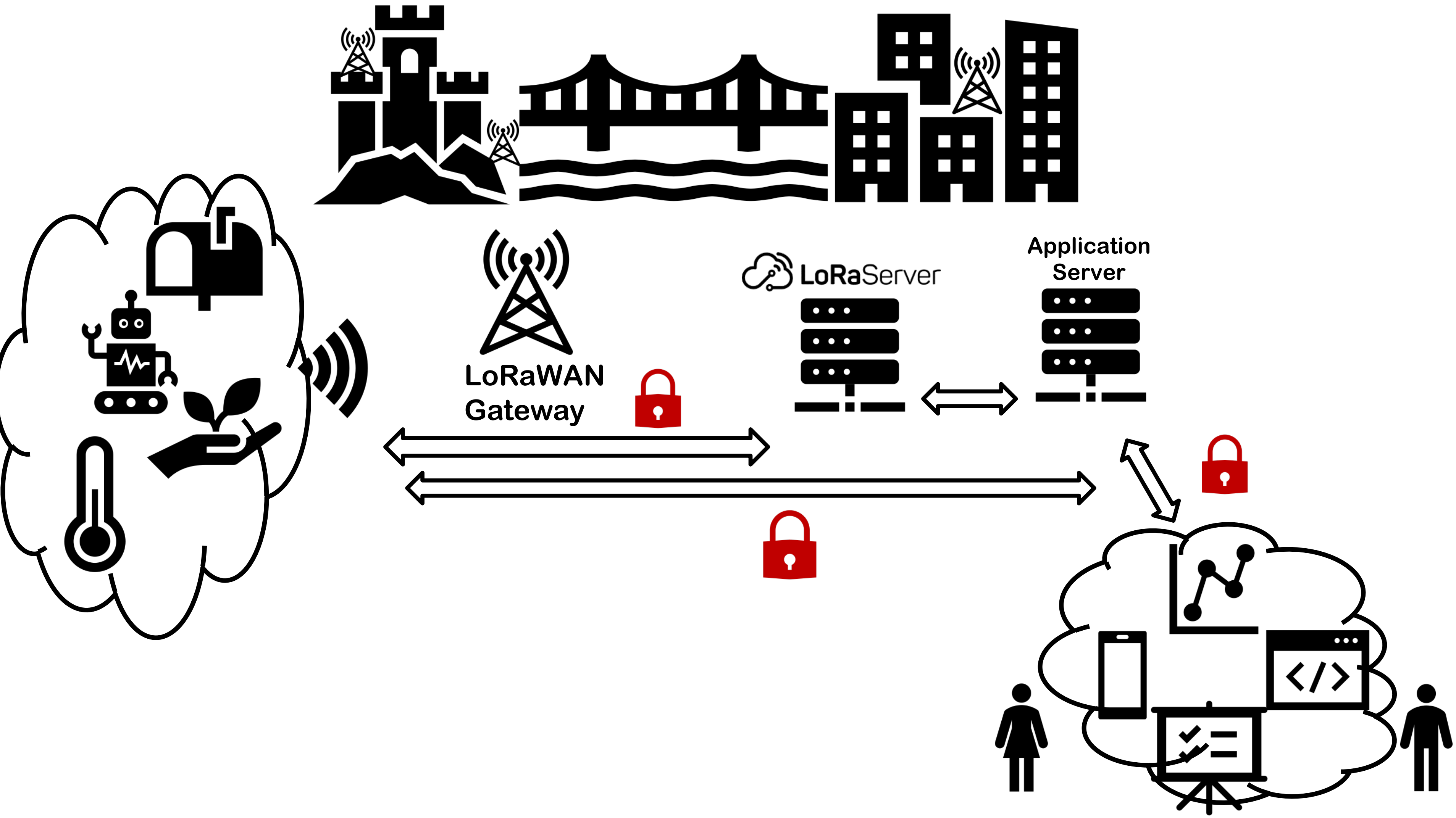
- Appropriate communication systems for Smart Cities
  - LoRaWAN
  - NB-IoT and 5G
  - …
- Coverage testing
- Network and device management
- Identifying, prototyping practical use cases
- IoT transport protocol evaluation

- SRD band radio propagation properties
- Node placement and coverage evaluation
- Live open data platform akin to Node-RED
  - Open to use and provide data
- Energy efficiency
- Smart City simulator
- Open data platform



- Performance evaluation, modeling, designing mobile control plane and signaling for IoT and smart cities
- Scalability and dimensioning
- Resource scarcity vs quality of information
- Reinvestigating the case of mobility management for IoT
  - Network-assisted vs. decentralized

Our Architecture



LORAWAN, DEPLOYMENT, COVERAGE

LPWAN - Low-Power Wide-Area Network

IoT on a Smart City scale

- Typical requirements: large coverage, low power draw, many devices
  - But often low bandwidth, and favors aggregation instead of meshes
- But limited coverage of existing tech with low power consumption
  - 3GPP not ideal for low power, cost and high density (in the past)
- Now: new(-ish) transceiver and PHY design on unlicensed lower RF bands with high receiver sensitivity
  - E.g. Sigfox, LoRa, DASH7, but also IoT 3GPP variants

Standard	f	**Range**	**BW**
BT 4.0 LE	2.4 GHz	$<$ 100 m	1 Mbit/s
ZigBee / 802.15.4	868, 2400 MHz	10 m to 100 m	20, 250 kbit/s
Z-Wave	900 MHz	30 m	9.6, 40, 100 kbit/s
WiFi /802.11n/ac	2.4, 5 GHz	100 m	1.27 Gbit/s for 80 MHz 6.77 Gbit/s with MU-MIMO
NFC	13.56 MHz	10 cm	100 kbit/s to 420 kbit/s
LoRaWAN	433, 868 MHz	$<$ 15 km	0.3 kbit/s to 50 kbit/s
SigFox	900 MHz	$<$ 50 km	10 kbit/s to 1000 kbit/s

3GPP Cellular Networks (and Variants) for IoT

- From 2G to LTE
  - Long range, high throughput
  - Not tuned for low energy appliances
    - Fixed, deep protocol stack
    - Users/SIMs are associated to a person/identity
    - Older networks might be turned off soon
    - Scaling issues to many devices
    - Vertical integration and signaling
- Newer, IoT-friendlier variants
  - E.g. random access channels, narrower RF bandwidth, guard-band usage, cost reductions
  - Core mostly unchanged
    - Specific IoT data can now alternatively be routed through the control plane over the MME, not passing the P-GW nor using bearers
    - Ratio of regular vs new style data flows? Effects on load?

- EC-GSM-IoT
- eMTC/LTE-M
- NB-IoT
- 5G?
  - 5G requirements documents demand 1M devices per square kilometer
  - 5G NR concerns just the radio link
  - 3GPP release 15/16 aims at larger core changes

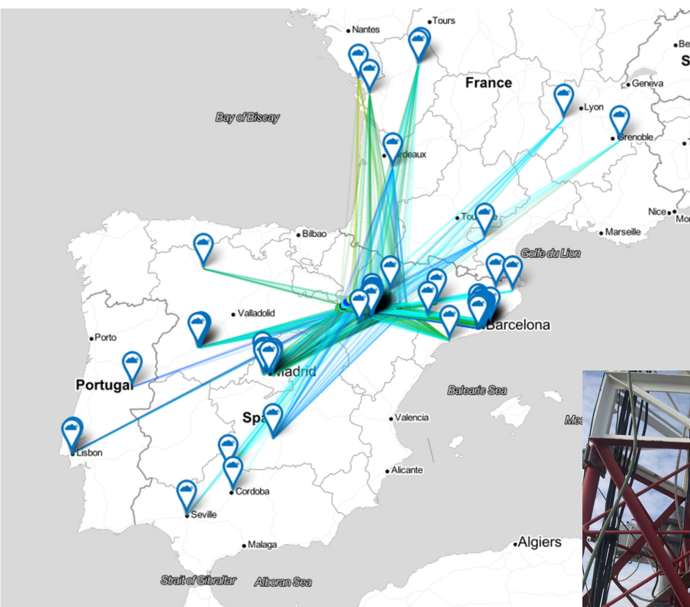
LoRa / LoRaWAN

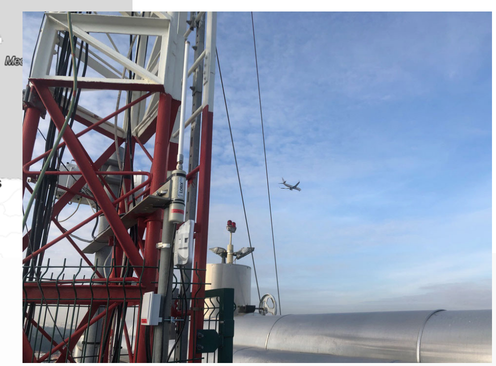
LoRa

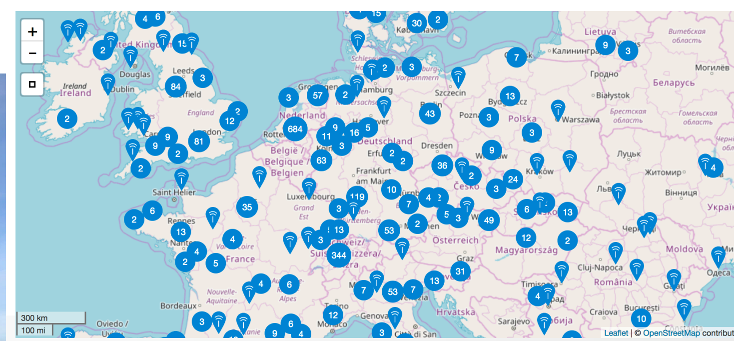
- Proprietary (Semtech) PHY
- Operation in unlicensed SRD, LPD, ISM bands
- (Usually) 8 channels for gateways

LoRaWAN (1.1)

- Standardized MAC layer on top
- 32 bit addressing scheme,
- Session and data encryption (AES128)
- Reliability (ACKs)
- Three device classes
  - From continuous reception to short window after transmission
- Commercial and participatory deployments (e.g. TTN)

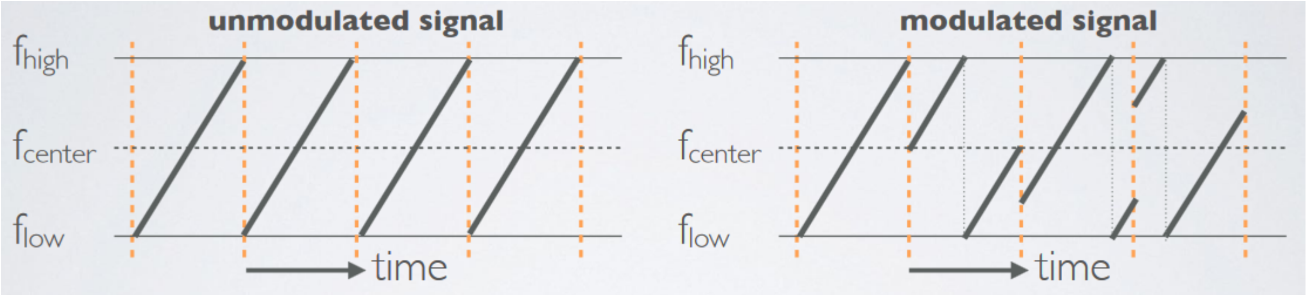






Important Concepts

Chirp Spread Spectrum



- Spreading Factor to adapt between throughput and resilience/range
- Larger SF, longer transmission time
- SF7-12

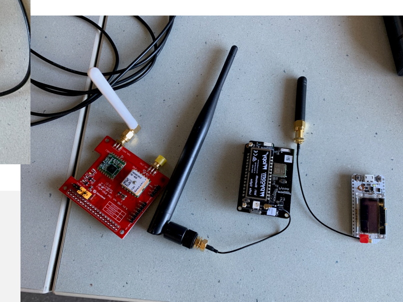
Duty Cycle

- Maximum allowed transmission time (per hour)
- Scaling questions

Name	Band (MHz)	Limitations
G	863.0 – 868.0	EIRP<25 mW – duty cycle < 1%
G1	868.0 – 868.6	EIRP<25 mW – duty cycle < 1%
G2	868.7 – 869.2	EIRP<25 mW – duty cycle < 0.1%
G3	869.4 – 869.65	EIRP<500 mW – duty cycle < 10%
G4	869.7 – 870.0	EIRP<25 mW – duty cycle < 1%

Deploying a Municipal LoRaWAN Network

- Politics
- Gaining support of city council and municipal company
- Agreeing on deployment requirements
  - System architecture
  - Data processing toolchain
  - Hosting
  - Gateway management
  - Device management and activation (technology neutral vs LoRaWAN OTAA/ABP)
- Prototype everything in a **separate testbed**



Deploying a Municipal LoRaWAN Network

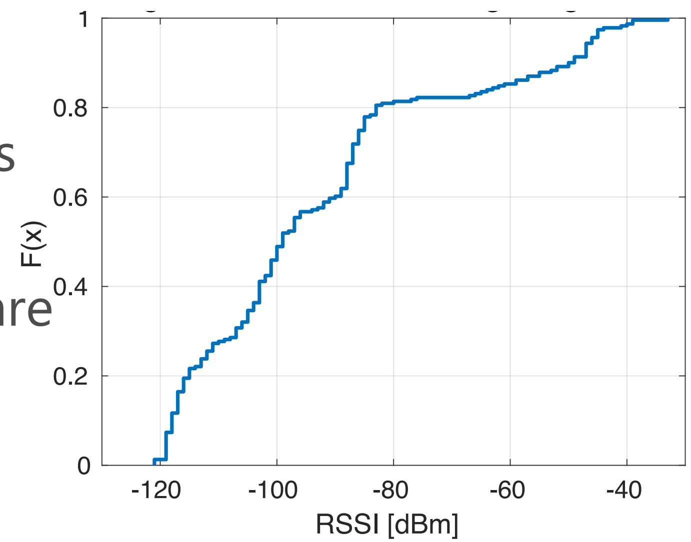
- (Should) Use cellular network and RF propagation planning tools
- Set up initial (outdoor, roof-mounted!) base stations
  - Surge protection, PoE, uplink
- Test if actual propagation maps to projections
- Prototype coverage test devices

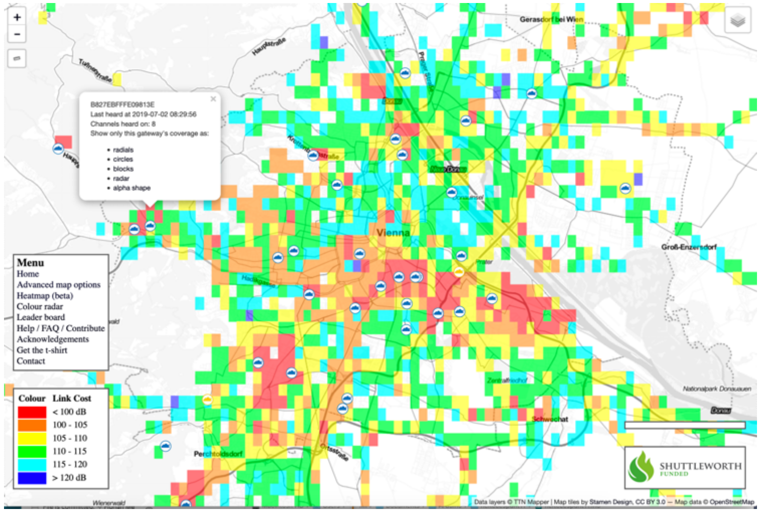
Coverage testers

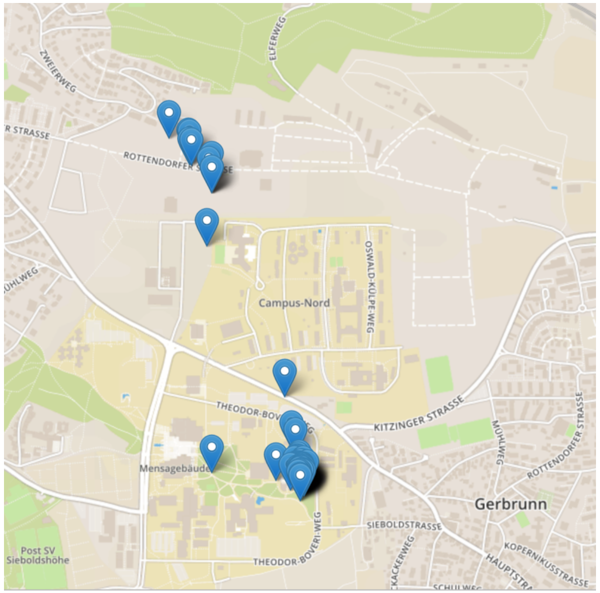
- Time, position, SNR (on base station and device)
- Receiving base station and TX params
- Manual and automatic modes
- Ruggedness and water resistance
- General coverage tests and additional tests at locations with expected device deployment
  - Mount to tram, hand out devices to municipal maintenance staff
  - Service shafts, transformators
- Ready-made ones might not satisfy requirements
  (E.g. no logging on Field Test Device)
- Prototype in several stages

Deploying a Municipal LoRaWAN Network

- Visualize coverage, identify blind spots
- Extend network with further base stations
- Prototype actually useful test devices
  - Or find some ready-made ones that are not locked into the vendor's cloud
  - Appropriate design choices for constrained devices and network
  - **See use cases**



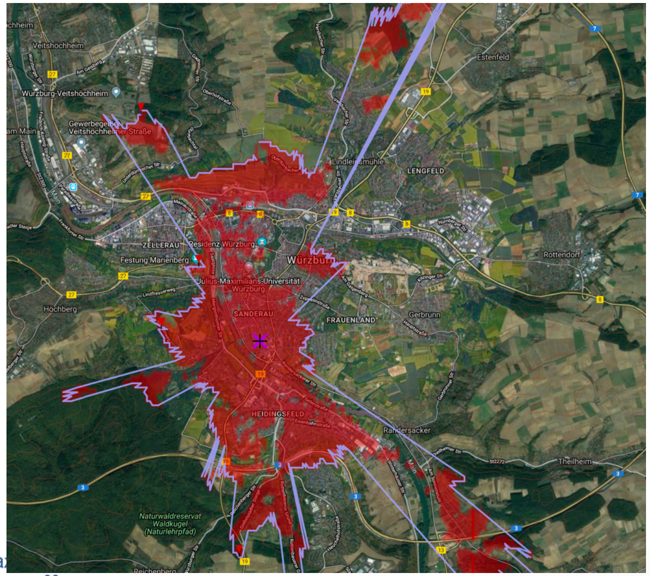


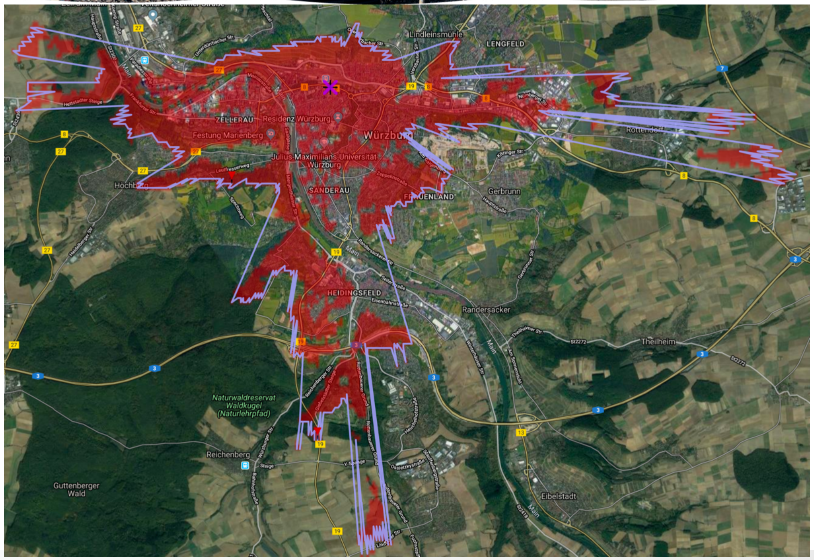


https://ttnmapper.org/

Base Station Placement Challenge

- Goal: Coverage at least for the city area
- Reuse existing sites from our partner as much as possible
- Main valley and slopes





Considerations for LPWAN (Transport) Protocols

- Addressing
  - MAC, IPv6 over LPWAN, ...
- Chattiness
  - For channel usage, duty cycle and sleep time
  - Per frame overhead and number of round trips, keepalives...
- Mode of communication
  - Pull (HTTP) vs push/subscribe
- Security on constrained devices
  - AES128 might be the best achievable
- Data format
  - Compactness vs readability (e.g. RFC7049 CBOR)
- System independendcy
- Protocol examples
  - MQTT(-SN)
  - CoAP
  - "None"/LoRaWAN
- See also e.g. IETF lp-wan WG

USE CASES, PITFALLS, CONSIDERATIONS

LoRaWAN Use Cases

Appropriate (not necessarily useful)

- Garbage bin sensors
- Maintenance light pole sensors
- Traffic info
- Environmental
- Geiger counters
- Damage detection in roadside junction cabinets

Probably not appropriate

- Alarm button for stuck doors in buildings with WiFi
- Live data from firefighter respiratory masks
- Realtime traffic control
  - Realtime anything

Undecided

- Geo-fencing for nursing homes, pets, bikes
- …

Difficult to judge appropriateness for the layperson

Use Case Considerations

- Privacy first
  - Do not expose anyone
  - E.g. smart follow-the-pedestrian street lights
  - E.g. parking time tracking through license plate reading cameras
  - E.g. time-accurate smart meter data to identify your home activities and movies you watch
  - Data aggregation and blurring
- Low bandwidth, long time periods
  - But might be possible to rethink and process most data locally
- Low-energy
  - LPWAN often means battery-operated
- Use existing infrastructure
  - Existing access links and WiFi should be preferred
- Open data licenses
- Participatory aspects

Practical Pitfalls and Considerations

- Legal & Certification
  - E.g. „ Verordnung über das Nachweisverfahren zur Begrenzung elektromagnetischer Felder (BEMFV)“ (EMC), §6 Standortmitbenutzung (must notify when co-location >10W EIRP)
  - Can‘t colocate, e.g., with TETRA base stations
    - Recertification or minimum safety distance (even if it‘s on a different band)
  - E.g. Electric meters
    - Gesetz über den Messstellenbetrieb und die Datenkommunikation in intelligenten Energienetzen (MsbG) in Germany
  - E.g. „ISO/IEC 27001 Information technology – Security techniques – Information security management systems – Requirements (ISMS)“
    - when interfacing with the electrical grid
    - Even just at the doors
    - „Certified security/cryptography“ by the german BSI
    - LoRaWAN might satisfy this, but not fully resolved yet
    - TLS on top?

Practical Pitfalls and Considerations

- Technical
  - We're not electrical engineers… or even engineers at all!

  - Identifying the right and most practical components for the given requirements
    - Integration, ruggedness
    - Power management
      - Avoid GPS cold boot and long search time
      - Deep sleep modes and GPS standby

Practical Pitfalls and Considerations

- Device, SW security, CVEs, updatable?
  - FW update over the air (FOTA, LoRaWAN 1.1)?
- Parameter selection and scaling
  - Long term operation and scaling to many devices
  - Duty cycle, channels, SF
  - TX power: (14dBm to 27dBm)
  - Transmission periods: longer periods are better
  - Message size should not exceed max payload, msg overhead
  - Network management overhead (OTA activations, device registrations)
  - Multicast benefits

DR	modulation	bw	datarate	Max payload
DR0	SF12	125	250	59
DR1	SF11	125	440	59
DR2	SF10	125	980	59
DR3	SF9	125	1760	123
DR4	SF8	125	3125	230
DR5	SF7	125	5470	230
DR6	SF7	250	11000	230
DR7	FSK	250	50000	230

Practical Pitfalls and Considerations

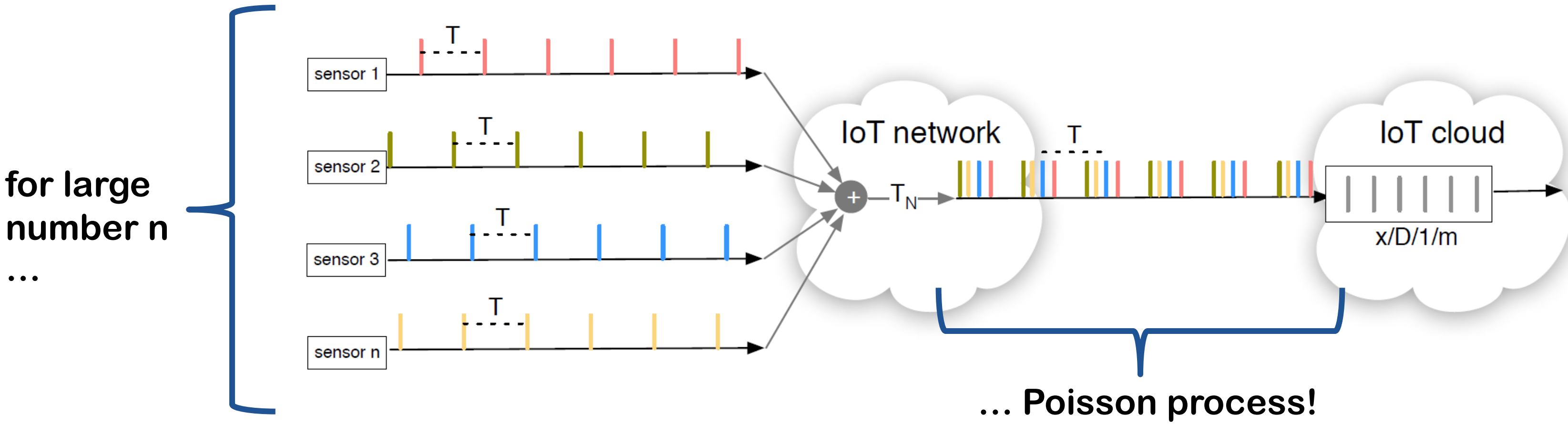
- Shared medium, stochastic multiplexing, collisions
  - Collision chance interacts with SF and others
  - No CSMA possible (hidden nodes)
  - No coordinator, but could be interesting
- More base stations
  - More duty cycle
  - Potential for more collisions if not coordinated well
  - Spatial multiplexing with sector antennae
- Fault detection and management
  - E.g. report remaining energy over the air
- Need for transmission error detection?
  - Round trips and ACKs are expensive
- Efficient SF selection
  - Lowest possible for current distance
  - Use LoRaWAN Adaptive Data Rate (ADR)

F. Metzger, T. Hoßfeld, A., S. Kounev, P. E. Heegaard, **Modeling of Aggregated IoT Traffic and Its Application to an IoT Cloud**, Proceedings of the IEEE, 2019.

IOT TRAFFIC MODELING

Superposition of Traffic

- 3GPP [1] notes that "[...] for a large amount of users the overall arrival process can be modelled as a Poisson arrival process regardless of the individual arrival process."



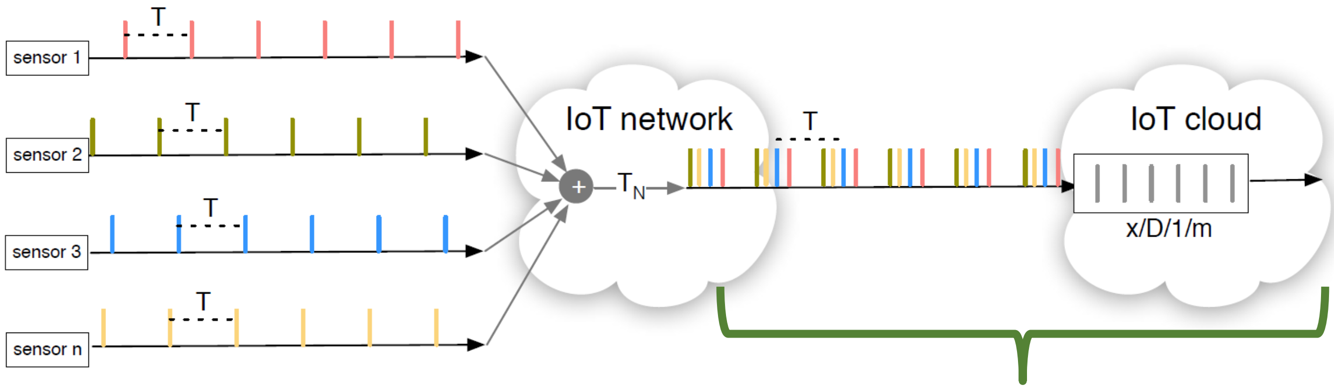
Theorem 1 (Palm-Khintchine Theorem)**.** *Let* $\{N_i(t), t \geq 0\}$ *be independent renewal processes for* $i = 1, 2, \ldots, n$ *with iid interarrival times* T_i *for each renewal process. The superposition* $\{N(t) = \sum_{i=1}^{n} N_i(t), t \geq 0\}$ *is asymptotically a Poisson process for* $n \to \infty$*, if:*

1) *Overall load is finite,* $k = n / \sum_{i=1}^{n} E[T_i]$.
2) *No single process dominates the superposition process,* $E[T_i] \ll 1/k$.

[1] 3GPP. GERAN improvements for Machine-Type Communications (MTC). TR 43.868. Feb. 2014.

IoT Load Balancer

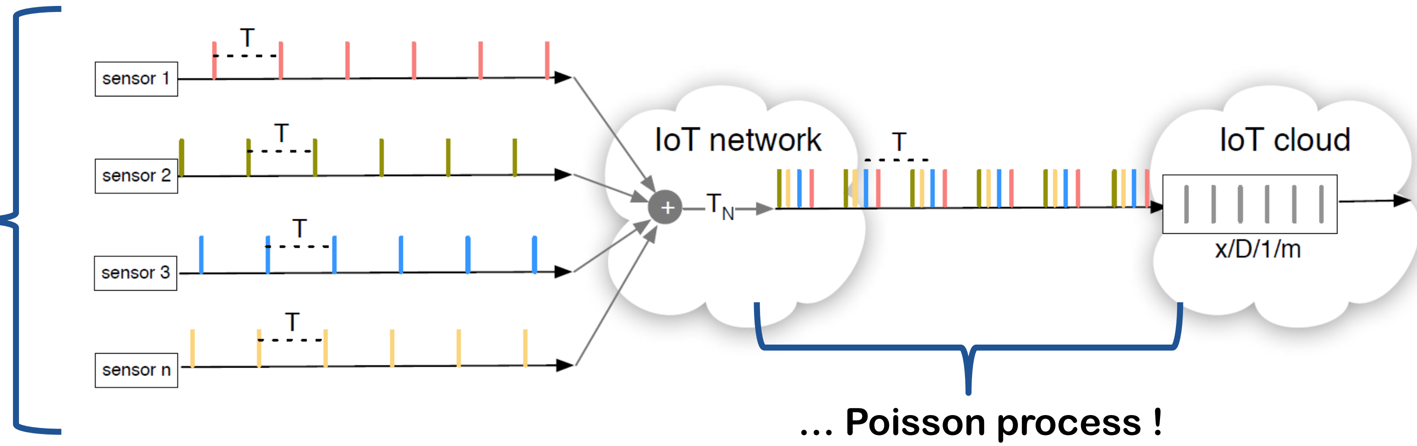
- Constant processing time of messages
- Aggregated periodic traffic: nD/D/1
- Poisson process: M/D/1



- Use Case: Load Balancer at IoT Cloud
- Waiting times: Poisson Process vs. Aggregated Periodic Traffic
- Impact of Network Transmissions

Superposition of Periodic Traffic

for large number n …



… Poisson process !

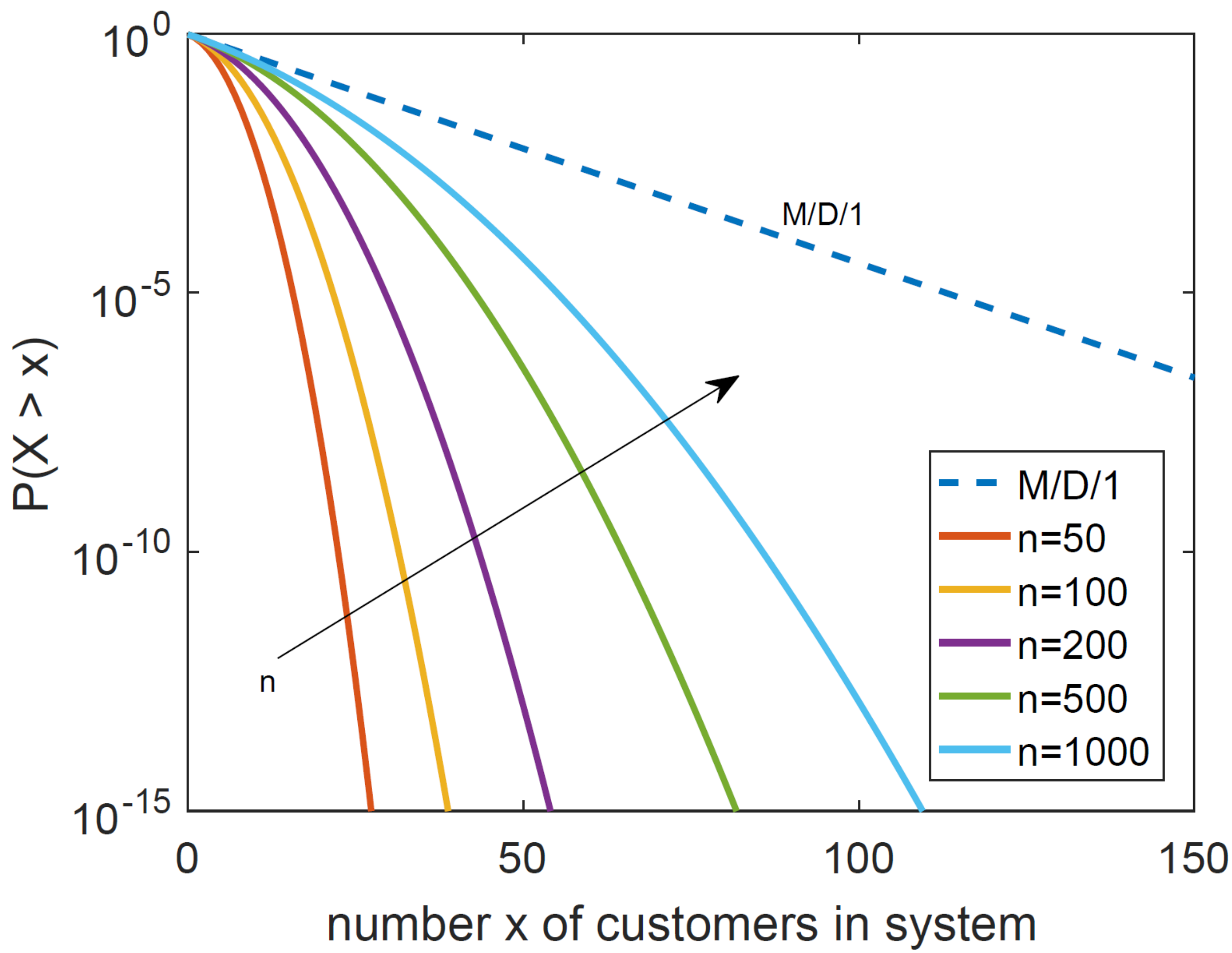
When is n large enough so that the Poisson process is a proper assumption?

How much bias is introduced by this assumption?

Which traffic characteristics are affected?

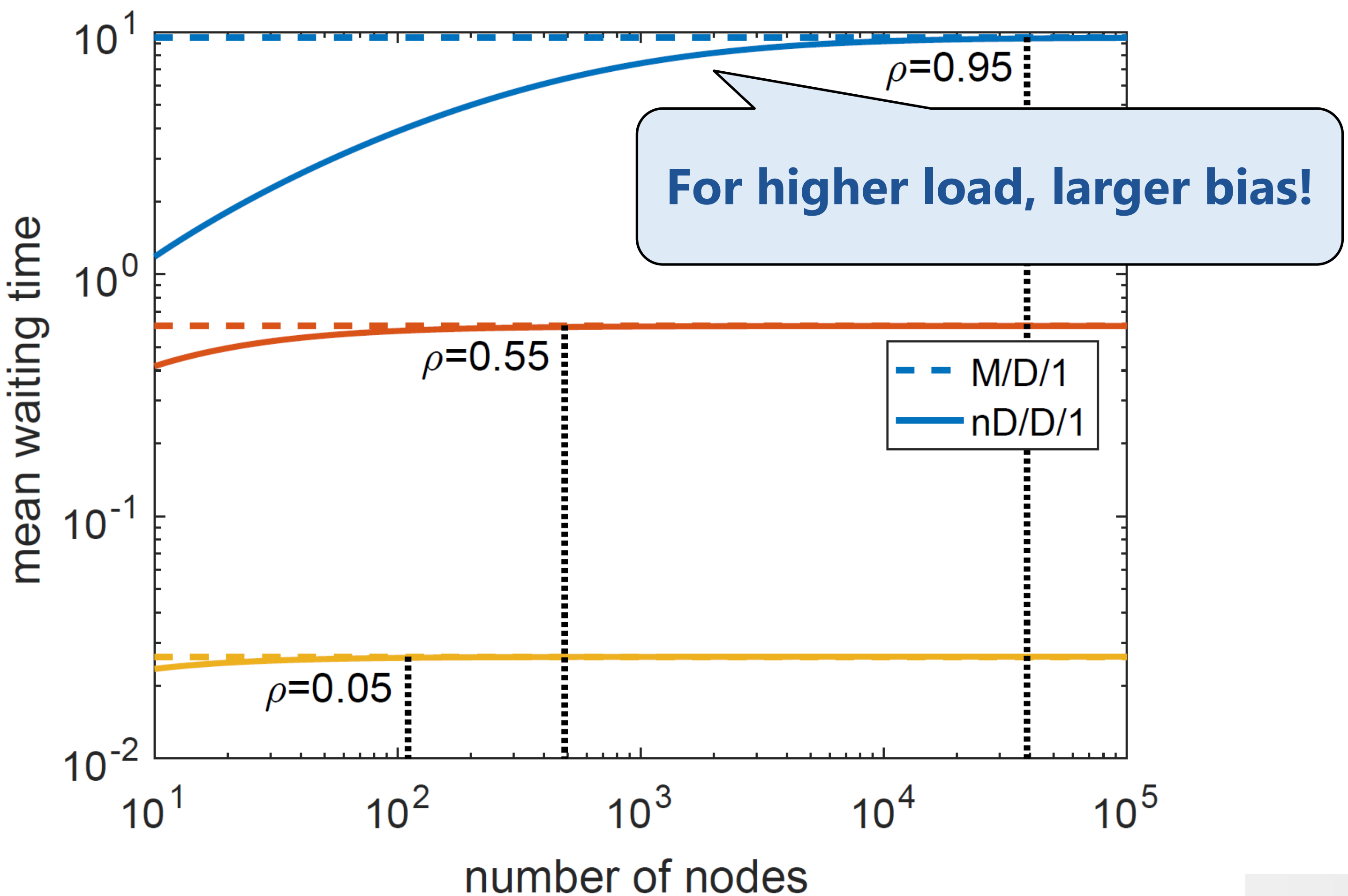
Number of Customers in the System

- Overdimensioning due to Poisson process assumption!



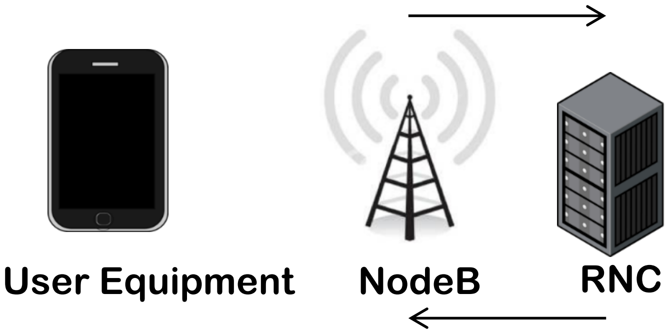
Bias due to Poisson Assumption

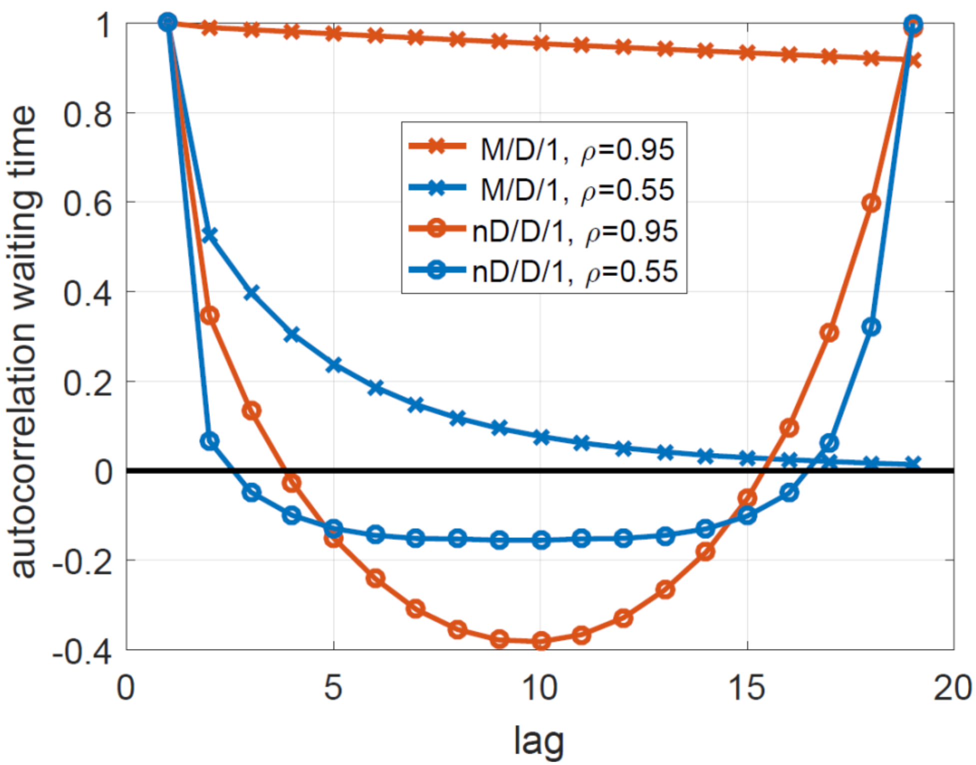
- Bias depends on number of nodes and system load



Traffic Pattern: Autocorrelation

- Autocorrelation and traffic pattern „destroyed“
- May be crucial for some characteristics like signaling load





Traffic Modeling Conclusions

- Analytical methods appropriate for investigating scalability
- Poisson approximation only valid for large number of nodes …
- … but not for all characteristics like autocorrelation
- Bias strongly depends on considered characteristic

- Future work integrates those results
  - **Adaptive** sending frequency: energy vs. quality of information
  - **Scalable** systems e.g. hierarchical architecture
  - **Heterogeneous** nodes
  - Impact of security mechanisms

Measure	**Description**	**Formula**	$\epsilon = 0.1$
Bias of Poisson process to approximate APP arrival pattern			
r_A	mean interarrival time (IAT)	$r_A = 0$	any $n > 0$
$\bar{S}$	avg. shift of IAT	$n > T/2\epsilon$	$n/T > 50$
r_c	CoV of IAT Eq. (14)	$n > 1/\epsilon$	$n > 100$
c_{N^*}	CoV number arrivals in T	$n > 1/\epsilon^2$	$n > 10000$
Example: Waiting times at IoT load balancer			
$r_W(\rho)$	rel. error waiting time	numerically	depends on ρ
		for $\rho = 0.95$	$n > 38{,}899$
		for $\rho = 0.55$	$n > 486$
		for $\rho = 0.15$	$n > 110$

DL4TCP

https://www.tru42.org/fm/

florian.metzger@uni-wurzburg.de C98A 32B7 554F C5CC 4E5A 60FB 1CE5 B541 7B20 99C7