Extensions at Broadcast Growth Codes

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Agenda

1. Introduction: Reliable Data Maintenance in WSNs
2. System Setup
3. Procedure of Broadcast Growth Codes
   - Basics
   - Encoding and Decoding
   - Optimization
4. Simulation Results & Conclusion

1.Introduction

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Reliable Data Maintenance in WSNs

- At IoT and Industry 4.0: large amount of small, autonomous, cost-efficient mobile devices
- Large-scale networks pose many challenges
  - high transmission loss rates caused by collisions
  - data forwarded and gathered in one or few sink nodes → communication medium highly stressed → bottlenecks prone to traffic congestion and failures, potential SPoF

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Key issue: Reliable Data Maintenance + Energy Efficiency

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Network Coding (NC)

Reliable Data Maintenance in WSNs

- NC:
  - combining data which has been received before (z.B. $x_1, x_2, x_3 \rightarrow x_1 \otimes x_2$)
  - send combination of data sets in data packet
- Special form of NC: Broadcast Growth Codes (BCGC) based on Growth Codes
- Growth Codes:
  - developed for distributed data collection and storage, in particular, in highly-dynamic systems
  - principle of LT-Codes
  - do not use broadcast ability of radio communication
  - codewords not adapted to current state of the network

  → optimization possible

2.System Setup

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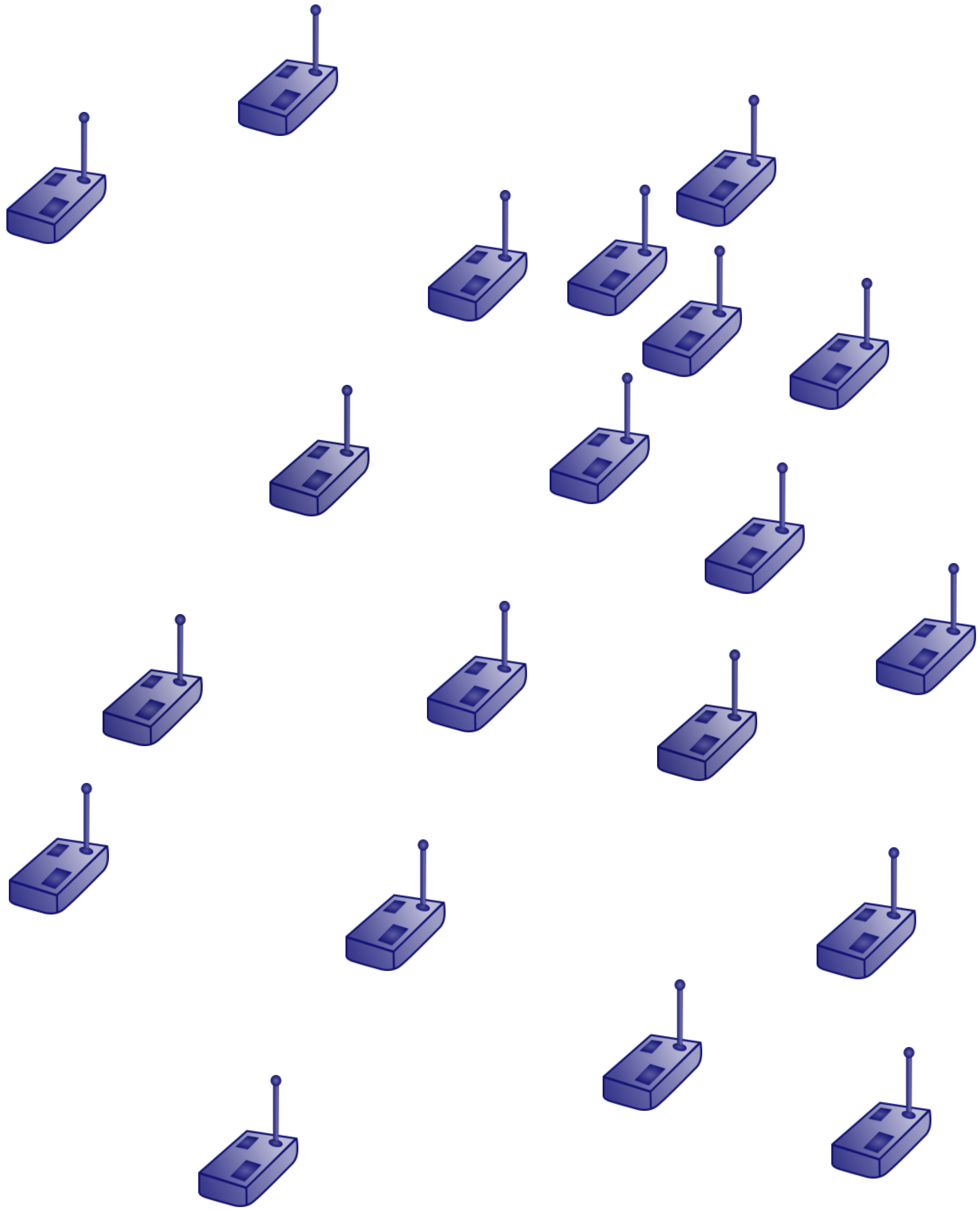
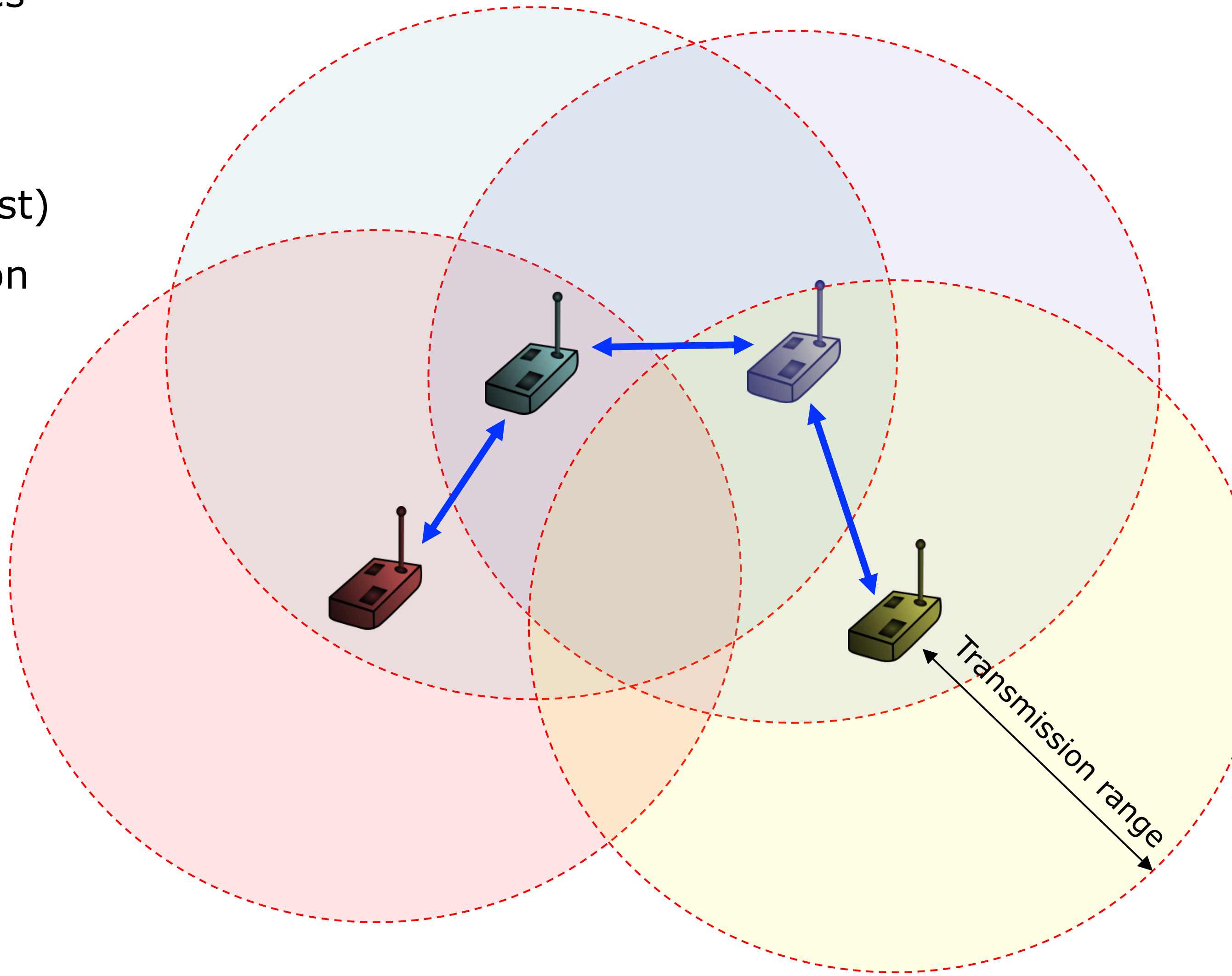
System Setup

- Homogeneous nodes



System Setup

- Homogeneous nodes
- Wireless communication between direct neighbors (broadcast)
- Circular transmission range

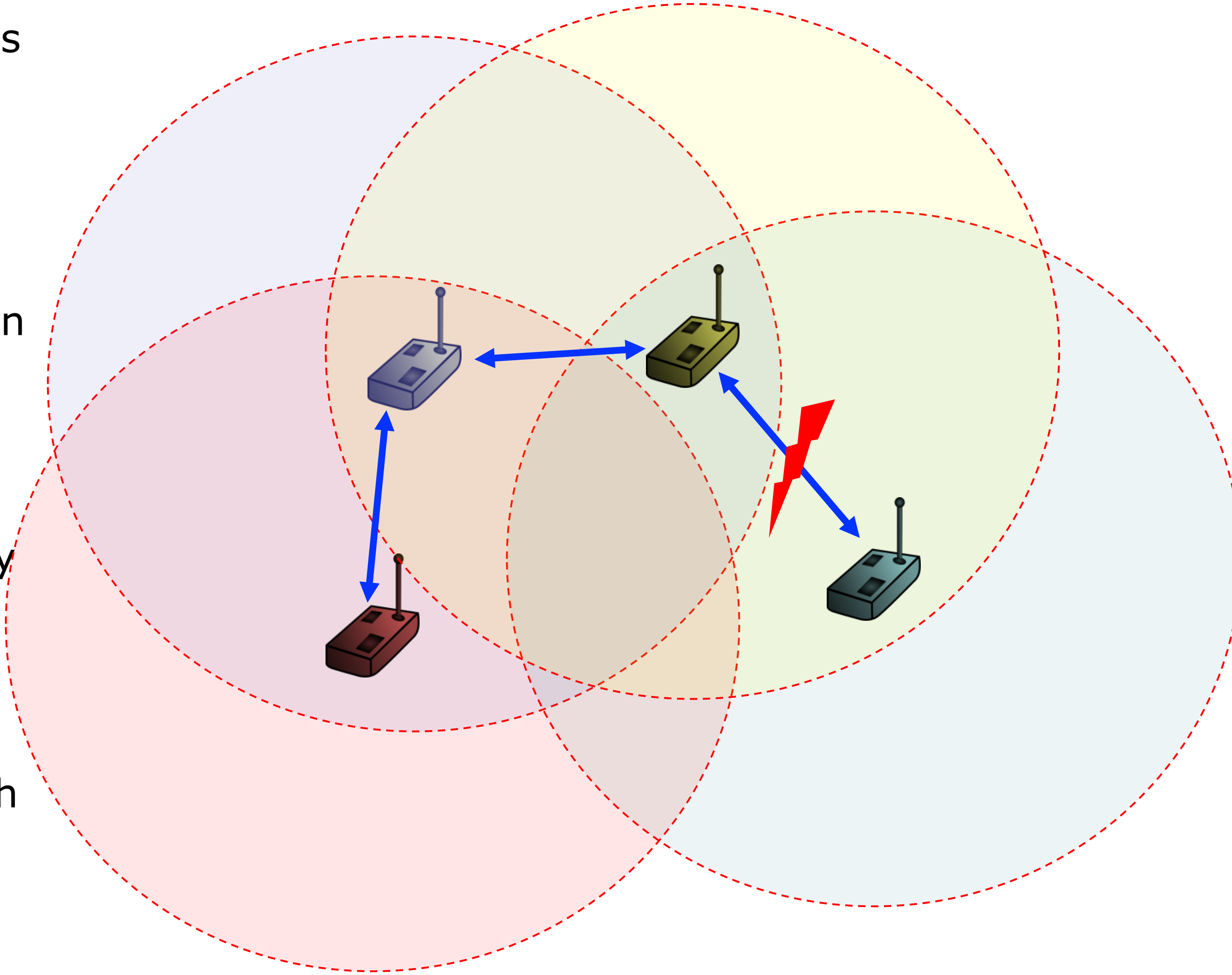


System Setup

- Homogeneous nodes
- Wireless communication between direct neighbors
- Circular transmission range
- Mobile nodes

→ dynamic network which changes topology continuously

- Link failures due to collisions
- Aim: all data in each node



3.Procedure of Broadcast Growth Codes

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Basics

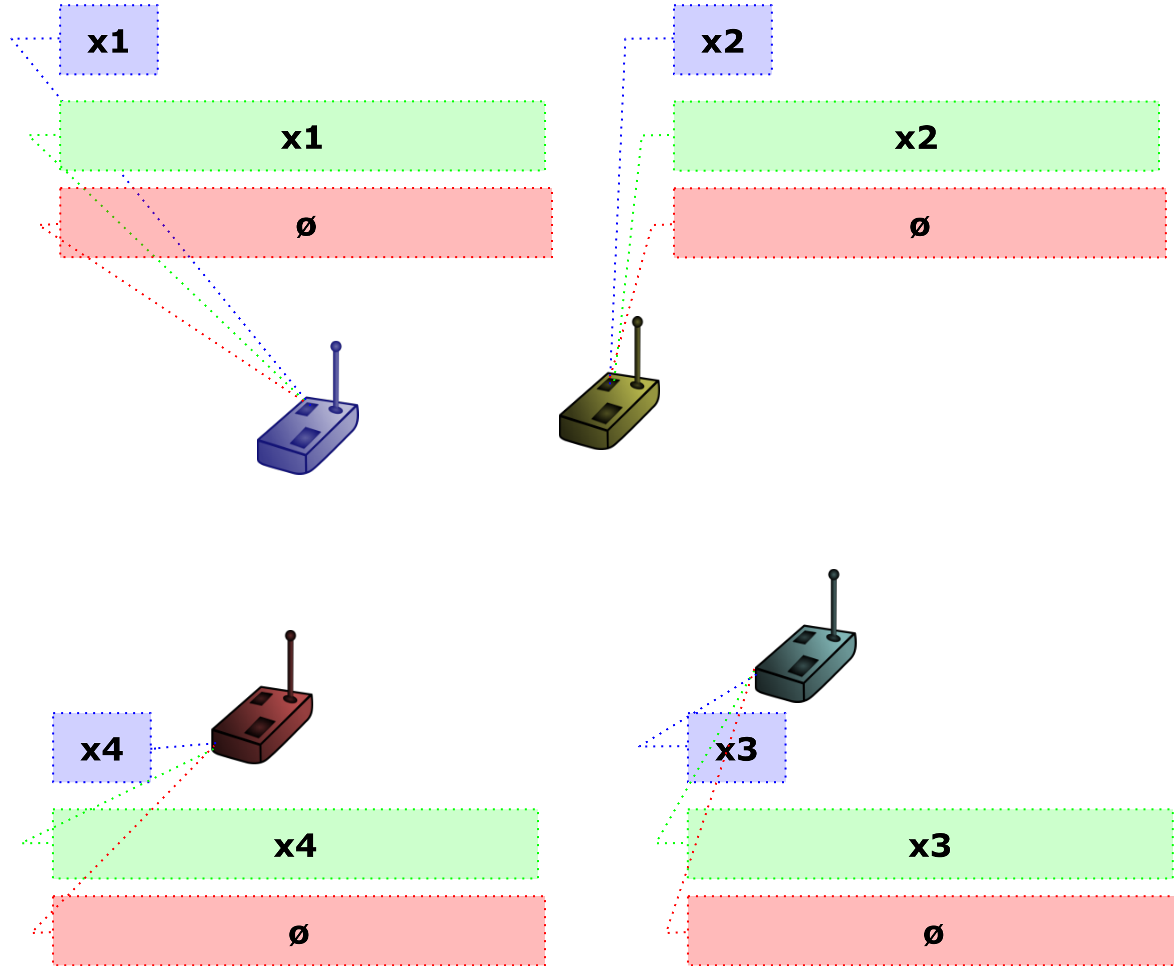
- Node generates its **own data set** of sensor data, and creates and transmits **data packets** containing a so-called codeword
- **Codeword** (cw) = bitwise XOR-combination of data sets
  - ($a \otimes b = a \cdot \neg b \vee \neg a \cdot b$)
  - can be reduced if data set is XOR-ed which is already included (XOR is self-inverse) ($a \otimes b \otimes a = b$)
  - is called **decoded** if only one data set is left → codeword is decoded and data set is **reconstructed**

- **Degree** (deg) of a cw = number of XOR-ed data sets
  - ($a \otimes b \otimes c$ → deg 3)
- **Distance** (dist) of a cw = number of data sets which have not been reconstructed in the considered node yet
  - if a is already reconstructed in considered node, $a \otimes b \otimes c$ is a dist-2-cw

- **Data packet** consists of one codeword (payload) and necessary information for encoding/decoding (overhead)

Basics

- Node’s **own data set** of sensor data
- List for already **reconstructed data sets**
- **Waiting list** for received codewords (not completely decoded yet)

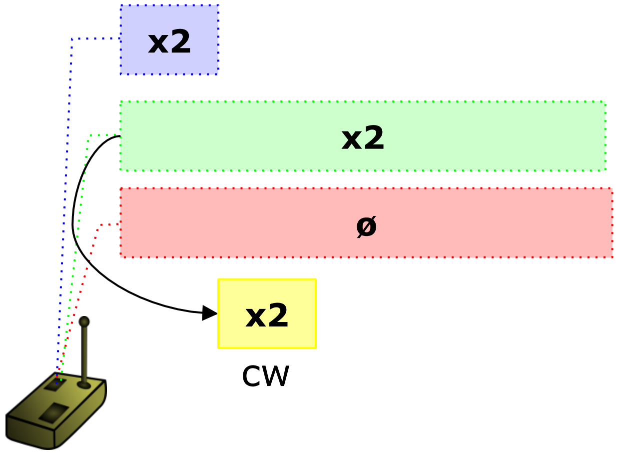


Basics

- Chosen degree d of a cw
  - depends on number of reconstructed data sets r and total number of data sets n
  - minimizes p_{Dist0}, i.e. minimizes probability for incoming dist-0-cw → redundant cw → worst case as unnecessary transmission
    - $p_{Dist0} = \frac{\binom{r}{d} \cdot \binom{n-r}{0}}{\binom{n}{d}} \leftarrow$ min
  - maximizes p_{Dist1}, i.e. maximizes probability for incoming dist-1-cw → immediately decodable
    - $p_{Dist1} = \frac{\binom{r}{d-1} \cdot \binom{n-r}{1}}{\binom{n}{d}} \leftarrow$ max
  - uses combination of both → degree starts with 1 and is continuously growing → „**Growth Codes**"
    - in the beginning: $n = 4, r = 1$ → deg: 1
    - list of reconstructed data sets contains $> \frac{n-r}{2}$ elements: $n = 4, r = 3$ → deg: 2, etc.

Encoding and Decoding

- Node composes cw using reconstructed data sets
- Deg d of cw
  - maximizes probability for dist-1-cw and minimizes probability for dist-0-cw → immediately decodable/ not redundant →
- In the beginning $n = 4, r = 1$ → deg: 1



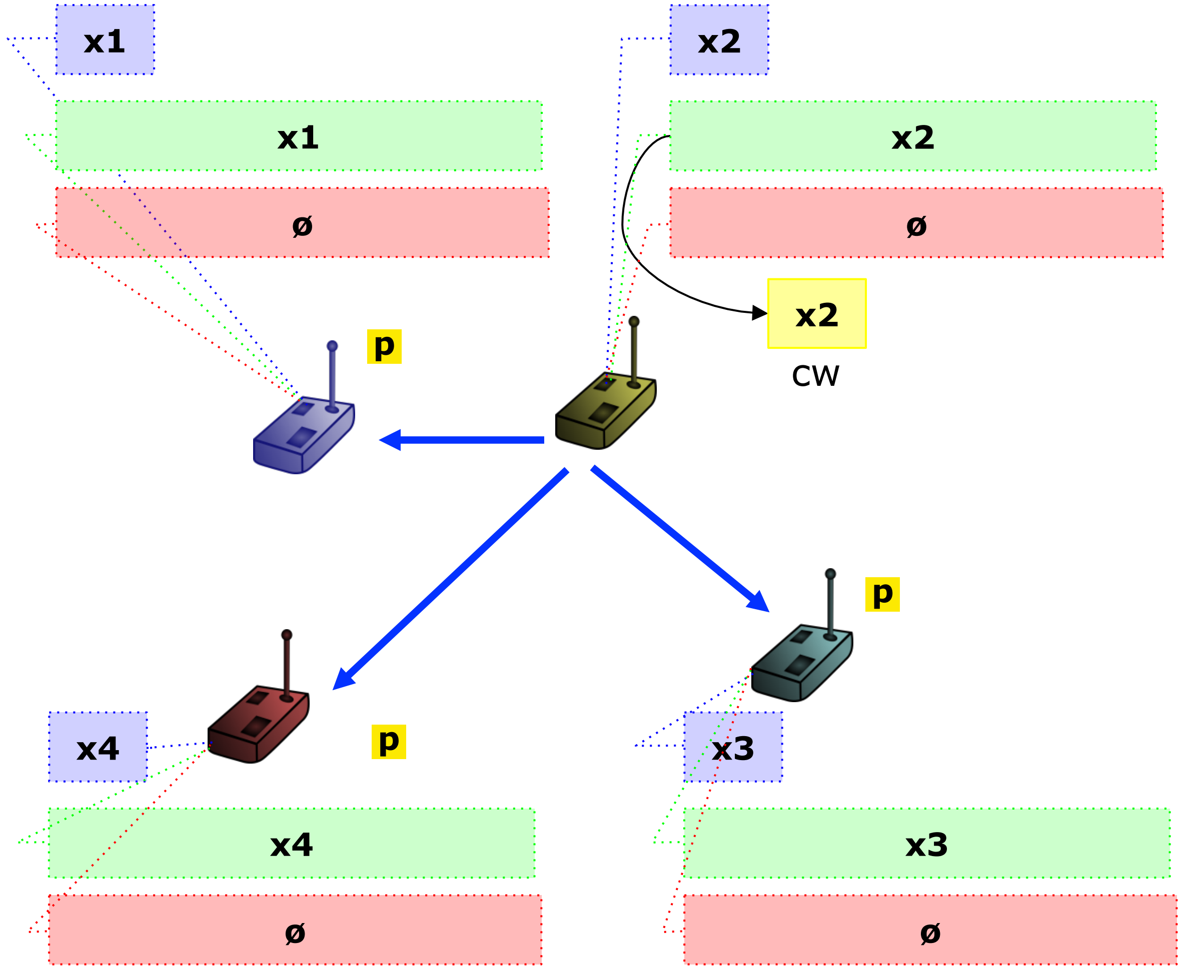
$$p_{Dist1} = \frac{\binom{r}{d-1} \cdot \binom{n-r}{1}}{\binom{n}{d}}$$

Encoding and Decoding

- Send via broadcast to all direct neighbors, no bidirectional data exchange
- Neighbors receive data packet with deg-1-cw

  → decode immediately

  → list for reconstructed data sets



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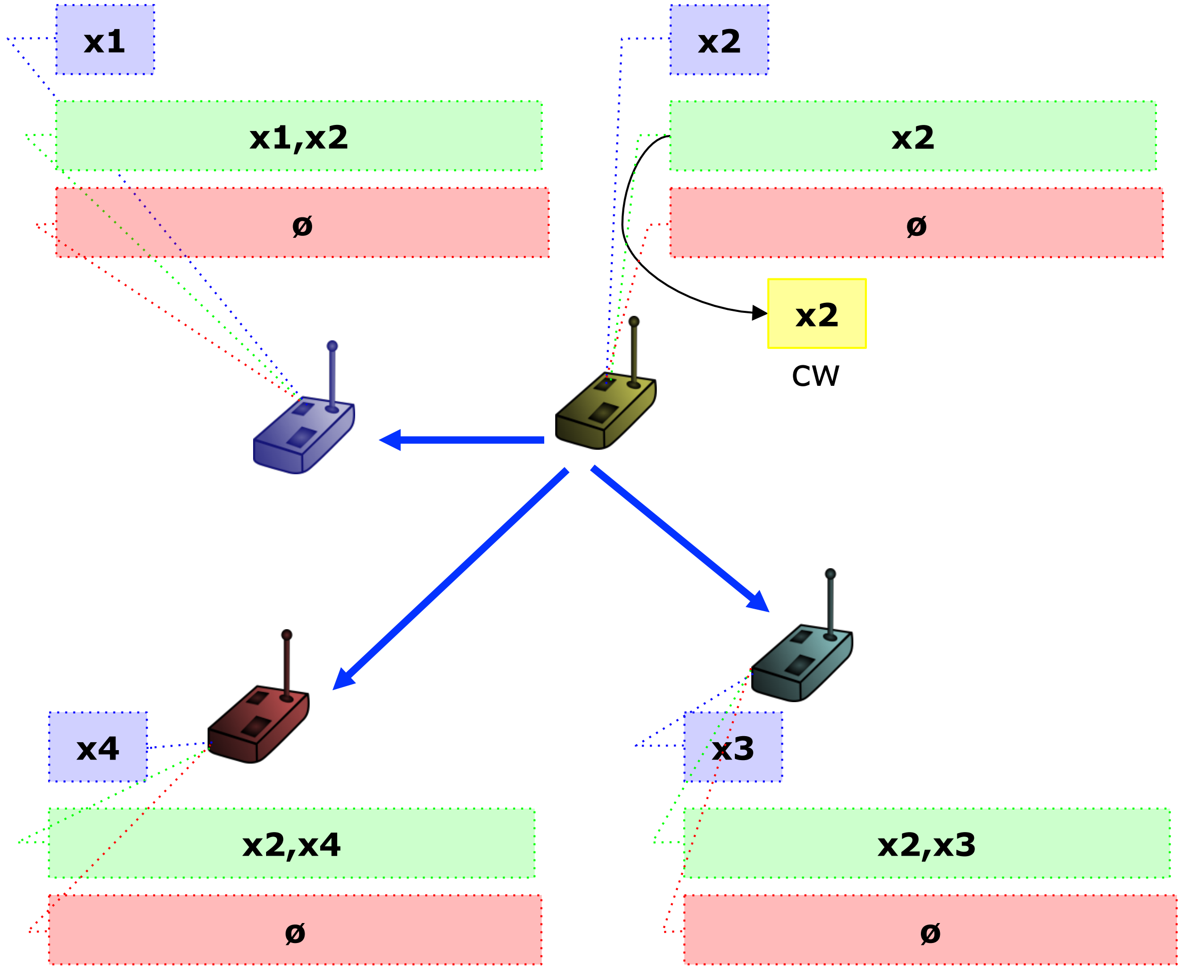
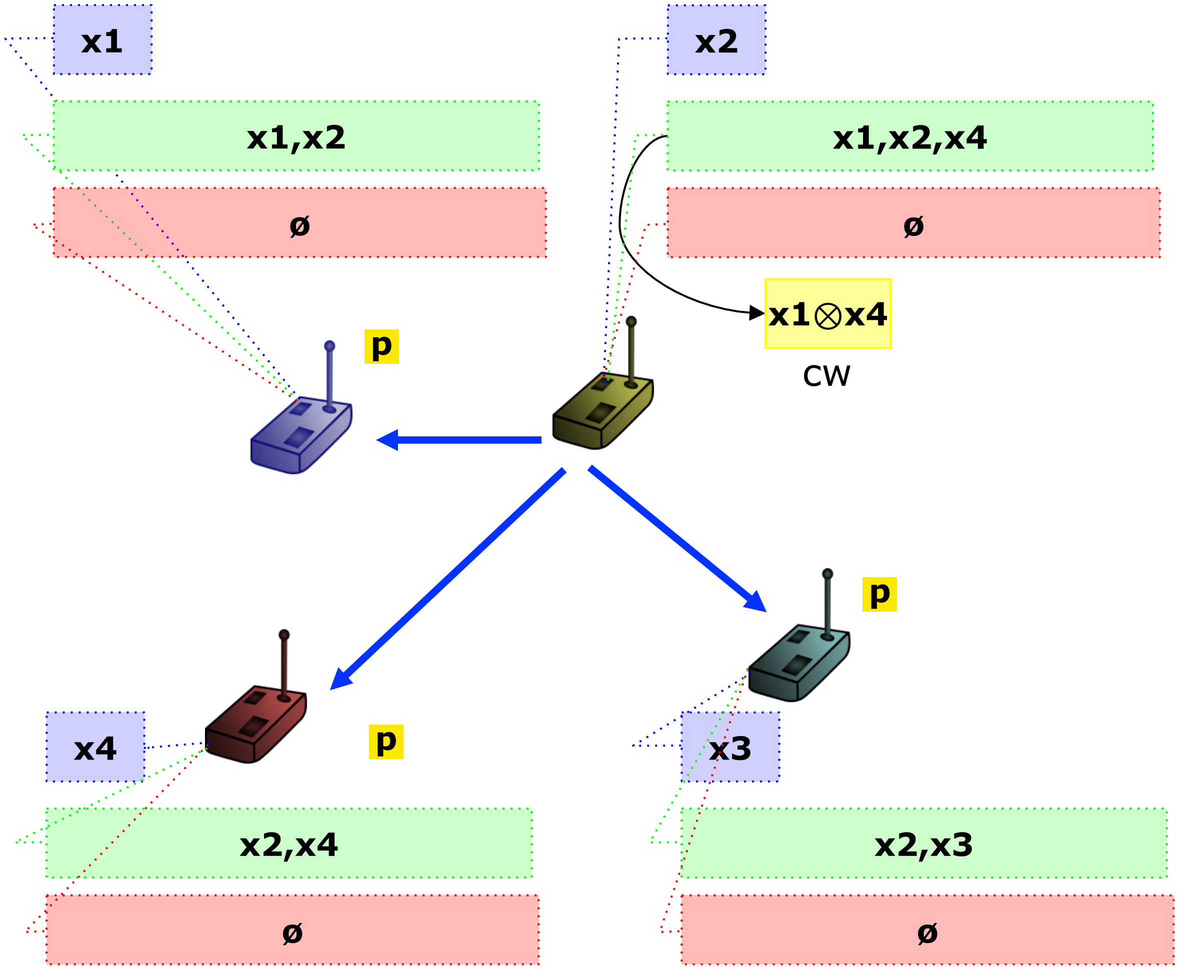


Encoding and Decoding

- Later on: list of reconstructed data sets contains $> \frac{n-r}{2}$ elements
  $n = 4, r = 3$ → deg: 2
- Neighbors receive data packet with deg-2-cw
  - **dist-0** → discard, worst case
  - **dist>1**: not able to decode yet
    → waiting list
  - **dist-1**: decode
    → list for reconstructed data sets + check waiting list



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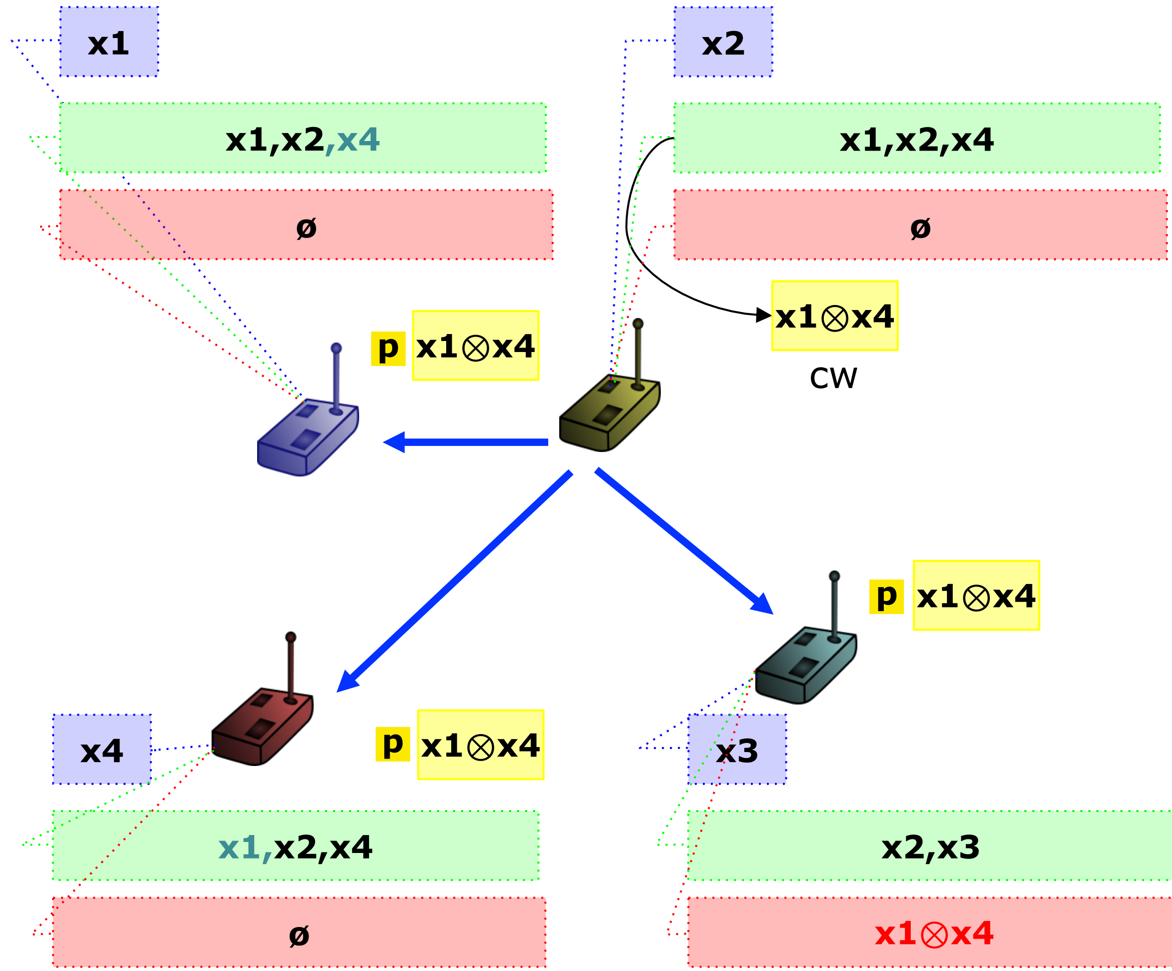

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Encoding and Decoding

Aim of each node at BCGC: gather and reconstruct all original data sets of the network

- As fast as possible → with as few received packets as possible
- Despite collisions
- Independently of the system's dynamics
- No complex calculations

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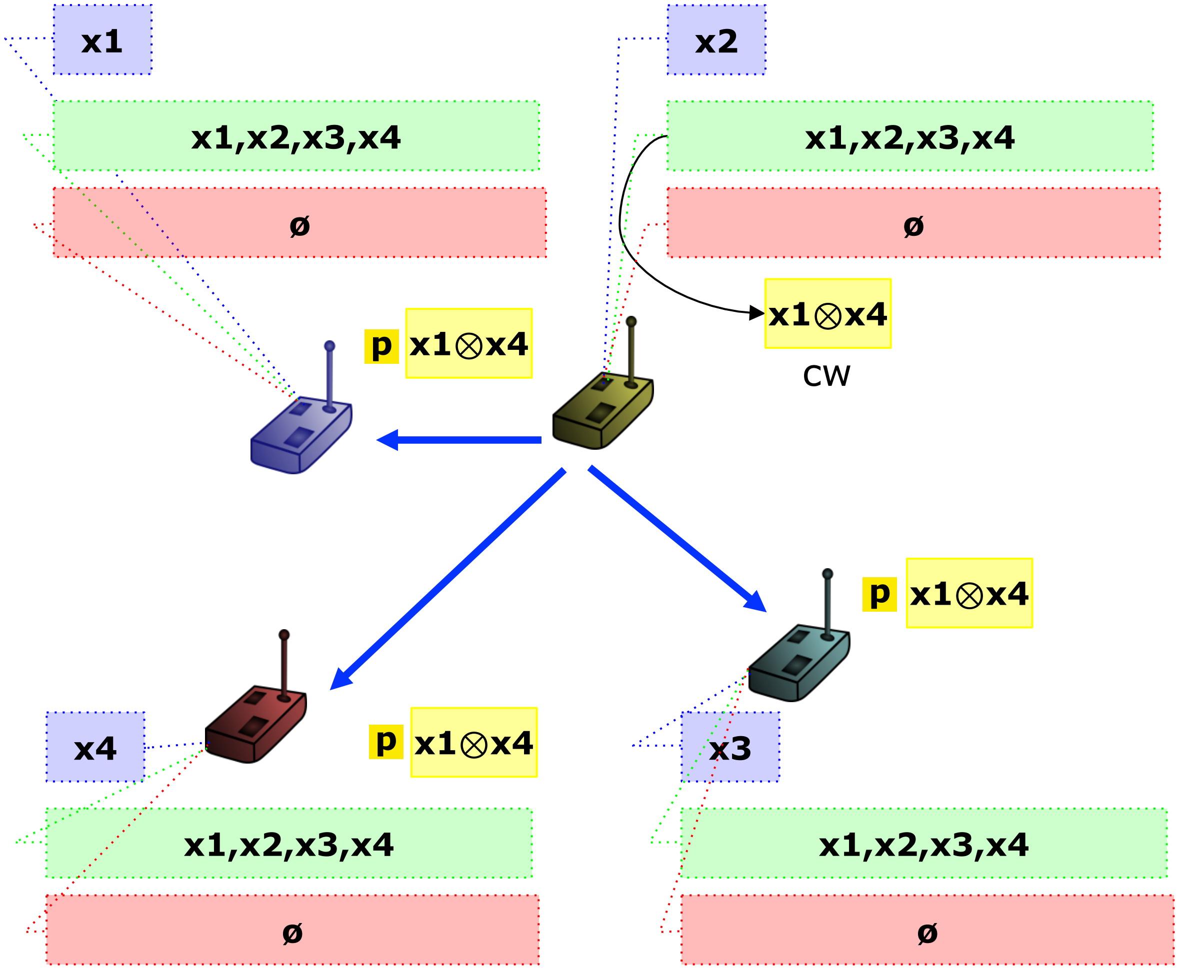
Reliable large-scale wireless network



Features

- Specific composition of cw according to num. received/sent by node
→ create cw with new information for neighbors
- Each node determines own desired, optimal degree d_{opt}(min p_{Dist0}/max p_{Dist1})
  - send d_{opt} with data packet
  - node determines deg for next cw using min of d_{opt} received from neighbors, instead of own or global d_{opt}

  → transmitted cw has suitable deg for optimal decoding in neighboring nodes

IEEE 802.15.4

- We adapted BCGC to the requirements of IEEE Std 802.15.4 which is a common standard for IoT applications → IoT Lab Testbed
- Physical layer: header 6 Bytes, payload 0-127 Bytes
- MAC sublayer: header 11 Bytes → payload 0-116 Bytes → original overhead had to be reduced
- 2.4GHz, 250kbit/s → packet transmission time 544 mikrosec (0(17) Bytes) to 4.256 ms (116(133) Bytes)

Optimization

- Time-based BCGC (CSMA/CA instead of syncronized rounds, collisions)
- Reduced overhead by limiting degree to $maxDeg$ and by only including IDs of used data sets in header → smaller packet size (transmission time) but more packets have to be received (p_{Dist0} increased)
- Dynamic packet sizes
- Reduced overhead: (if 2 Byte Short IDs)
  - maximum of $maxDeg * 2$ Bytes (IDs of used data sets)+
  - $\lceil \mathrm{ld}(maxDeg) \rceil$ Bytes (actual packet degree) +
  - $\lceil \mathrm{ld}(maxDeg) \rceil$ Bytes (desired degree) +
  - 0/2 Bytes (requested data set)

4.Simulation Results & Conclusion

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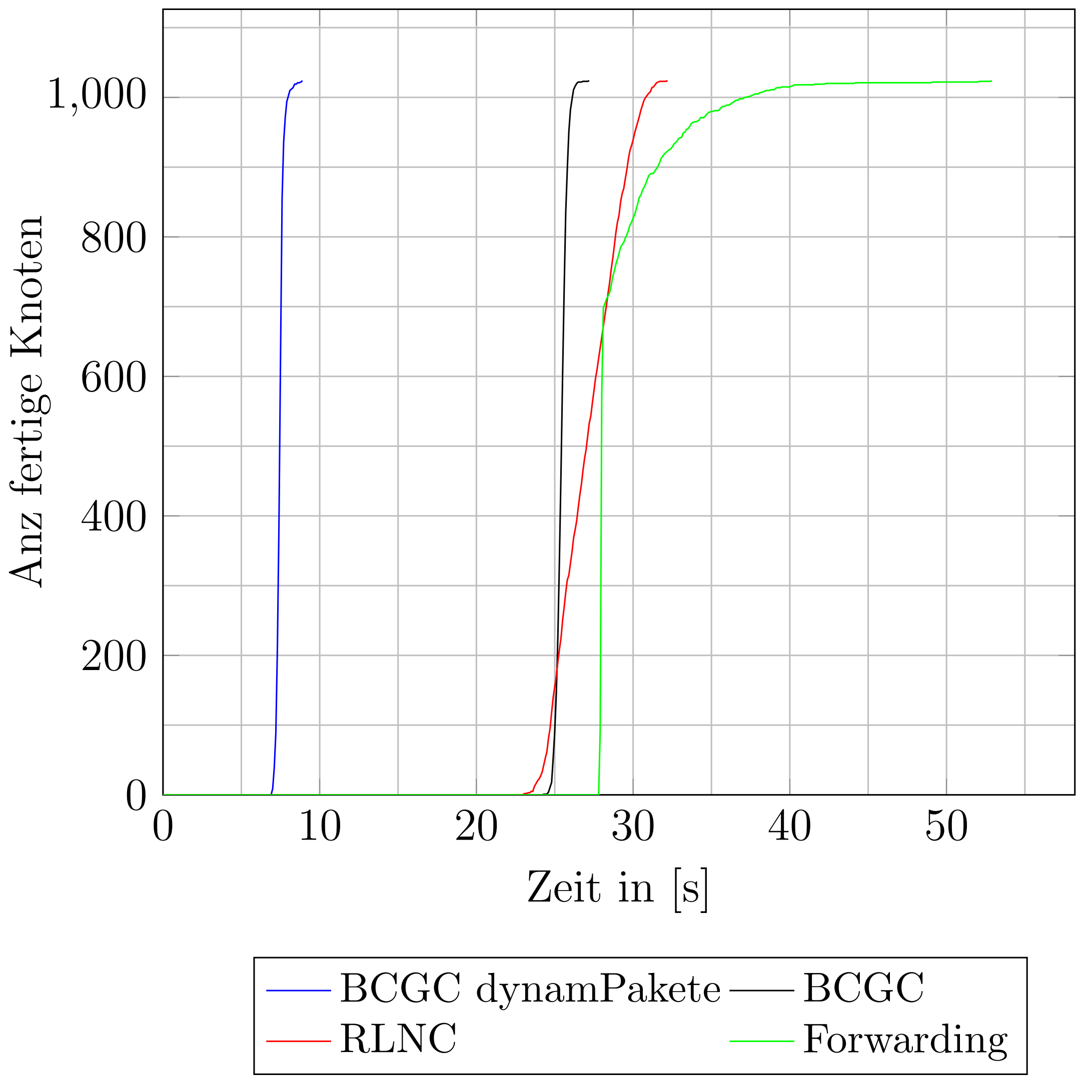
Compared Algorithms

- Random Linear Network Coding (RLNC)
  - use linear combination of previously received data sets as cw in data packet
  - randomly chosen coefficients (GF(2), GF(2^8)) → overhead: N/8 Bytes if GF(2) or 8*N/8=N Bytes if GF(2^8)
  - complex calculations necessary for decoding
- Forwarding (No Coding)
  - sending packets of unencoded data
  - forwarding algorithm where data sets are stored after reception and selected randomly for retransmission
  - data set as payload, ID of data set in header → overhead: 2 Bytes

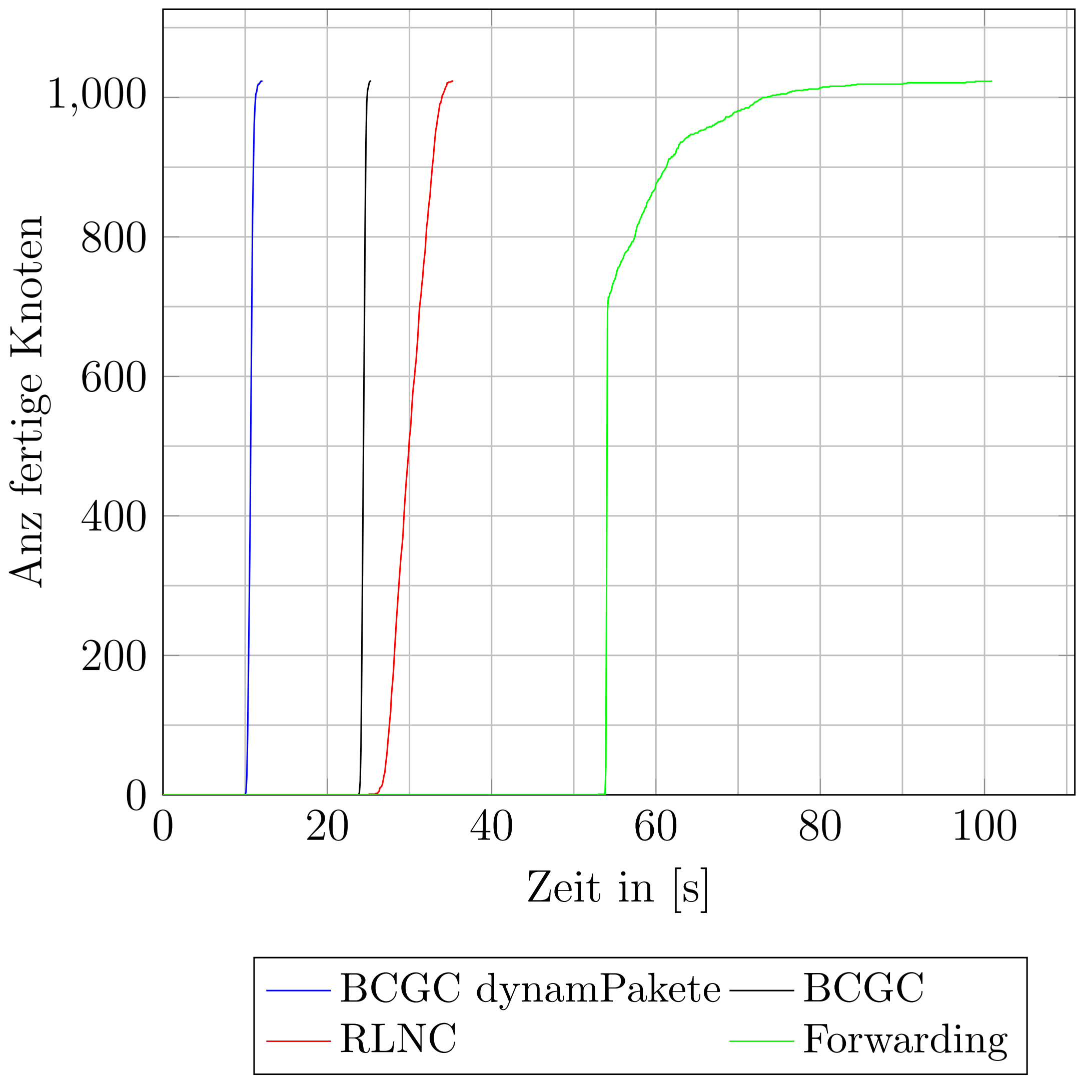
Simulation Results

- Simulative evaluation with $N = 1024$ homogeneous nodes
- Real testbed: IoT Lab Testbed (RIOT OS) with $N = 80$ nodes
- Optimization criteria: latency of the procedure and number of necessary transmissions
- Compared: BCGC dynamic packet sizes vs. BCGC static packet sizes vs. RLNC vs. Forwarding

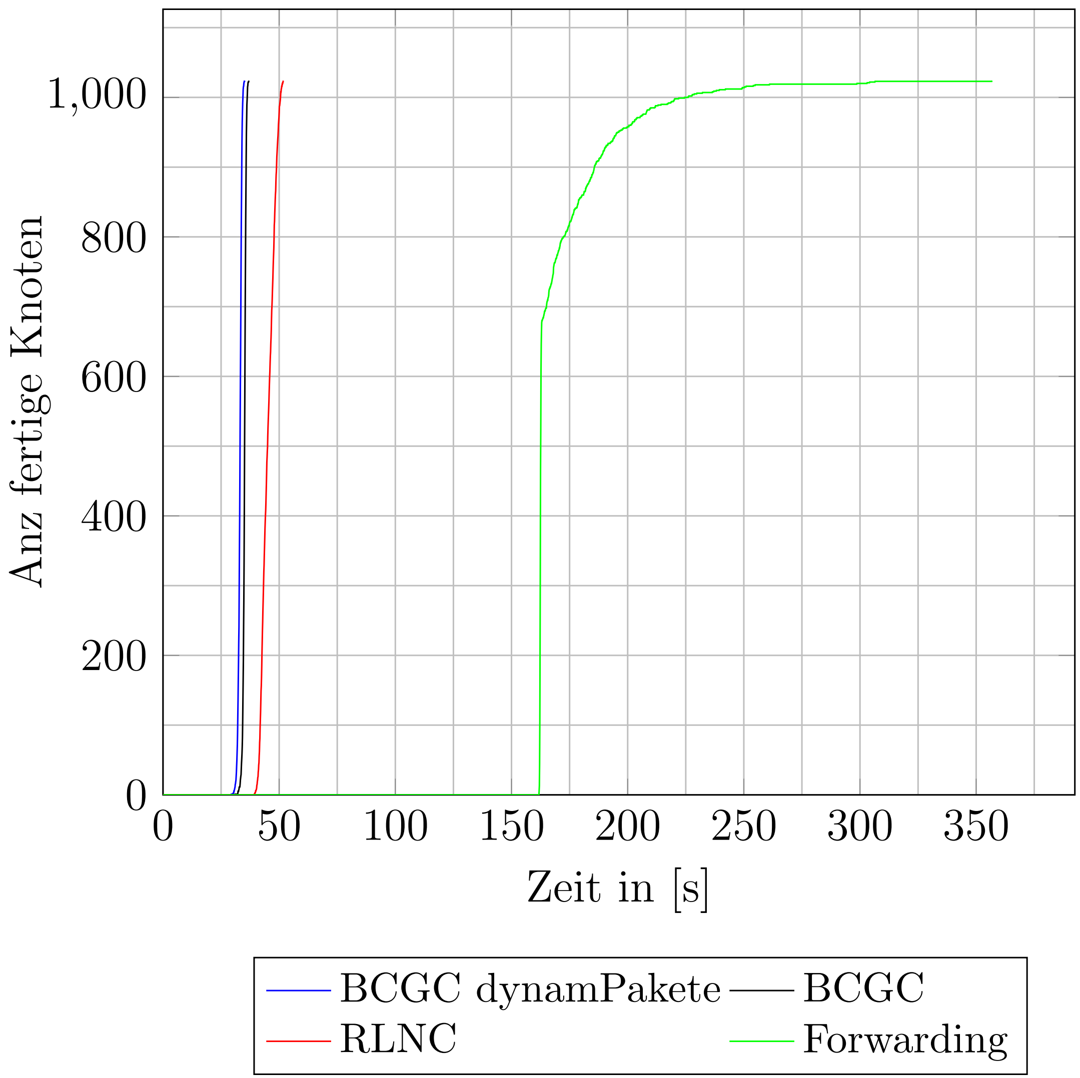
Simulation Results – 2 Bytes PL



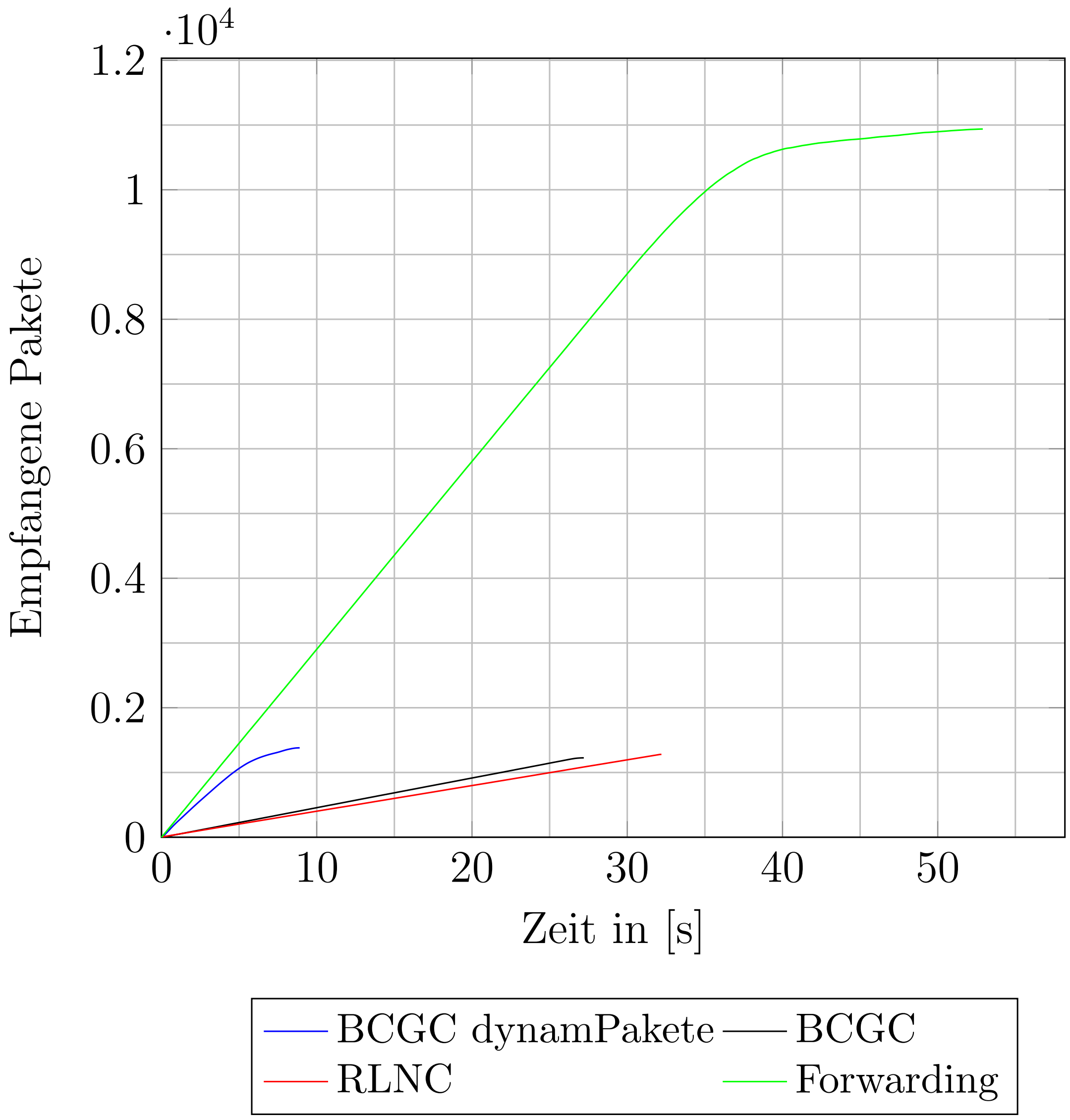
Simulation Results – 20 Bytes PL



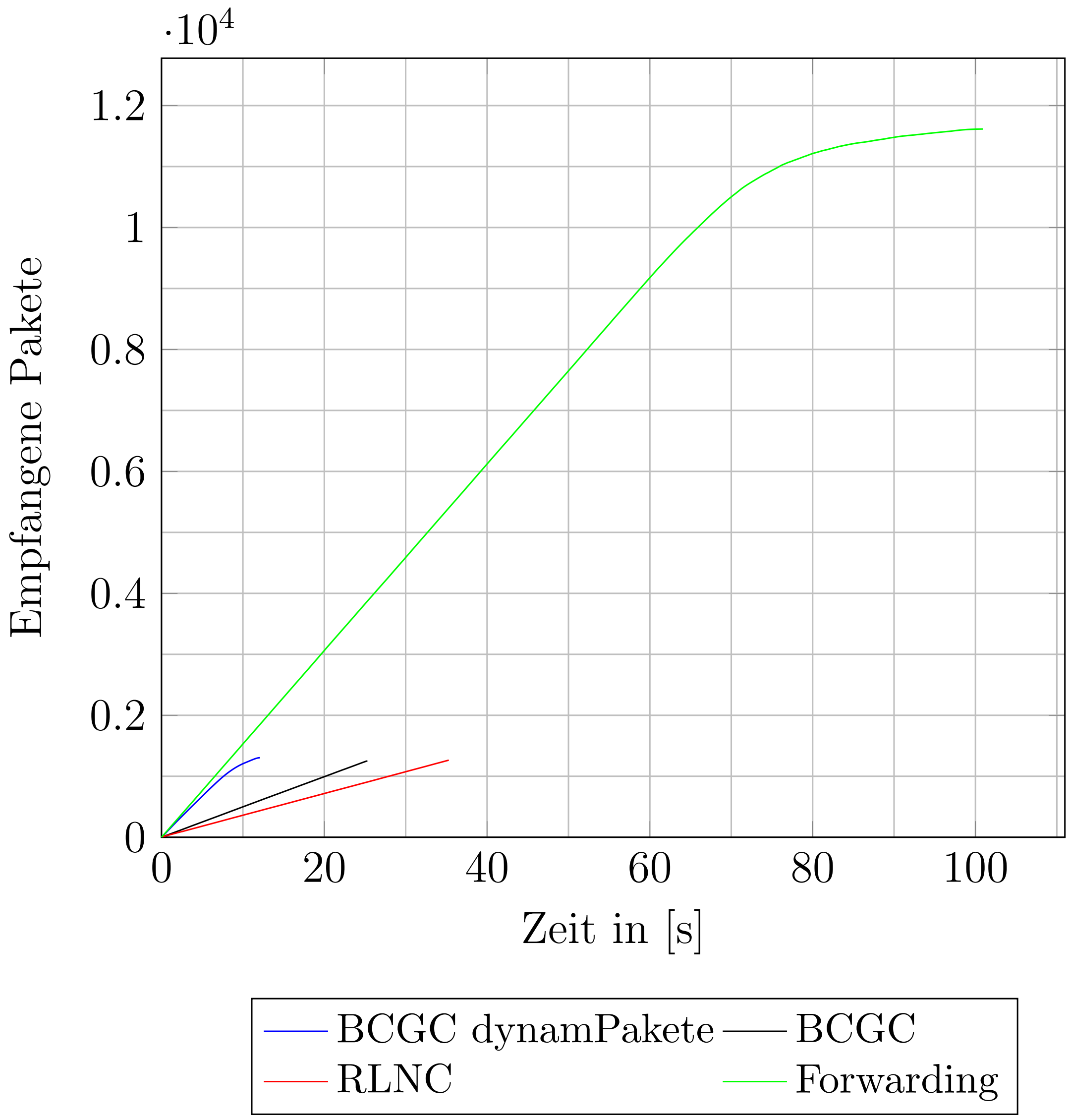
Simulation Results – 100 Bytes PL



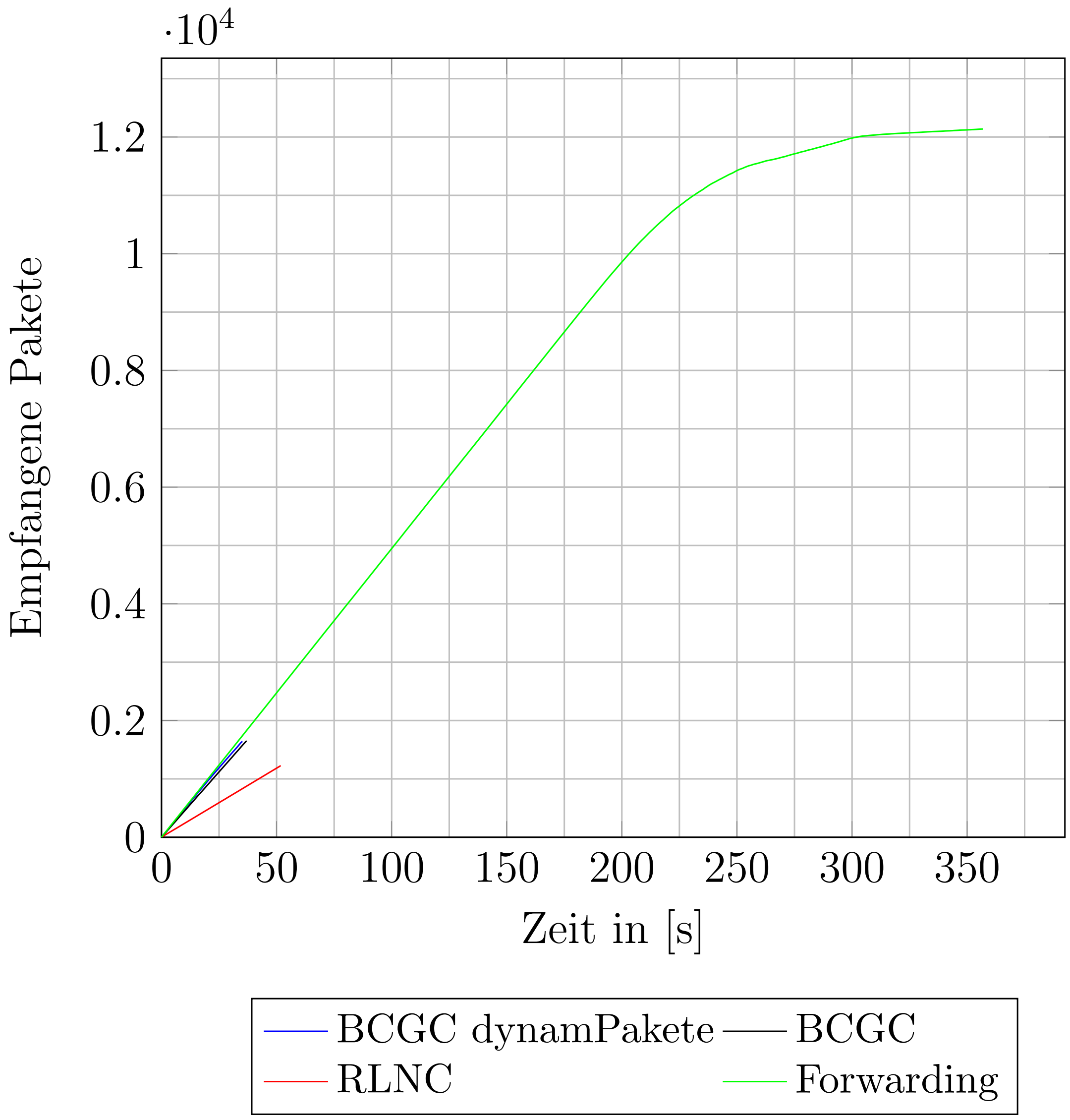
Simulation Results – 2 Bytes PL



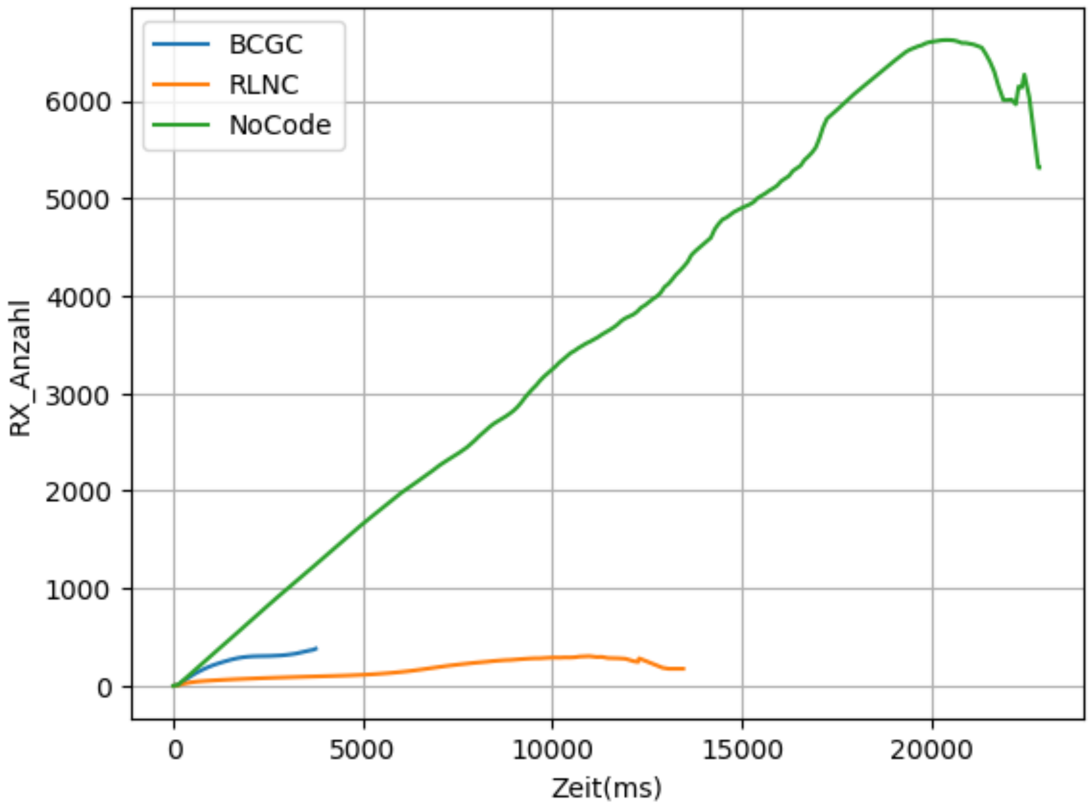
Simulation Results – 20 Bytes PL



Simulation Results – 100 Bytes PL



Simulation Results – IoT Lab Testbed



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Conclusion

- Introduced a Network Coding based all-to-all data dissemination procedure for large-scale mobile WSNs: **Broadcast Growth Codes**
- Optimization criteria: number of necessary transmissions and latency of procedure
- round-based approach (sync. nodes, slotted, no collisions) replaced by time-based approach (CSMA/CA)
- BCGC adapted to the packet size requirements at IEEE Std 802.15.4
  - by limiting the degree of used codewords
  - by using dynamic packet sizes → improved latency by approx. 30%

Thank you!

Any questions?