RF Mesh Systems for Smart Metering:
System Architecture and Performance Evaluation

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Agenda

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  ▪ Scalability Analysis

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  ▪ System Modules

▪ Performance Evaluation
  ▪ Models and Parameters
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  ▪ Scenario 2: Large-scale scenario

▪ Conclusion and Outlook
RF Mesh Systems for Smart Metering

System Parameter:
- 900 MHz RF Mesh
- 9.6 kbit/s per channel
- Slotted Aloha channel access
- Geo-based routing algorithm (Greedy Forwarding)
- Max. number of hops: 40

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Scalability Analysis

- The System Design Framework targets:
  - Rapid system design by early-stage evaluation
  - Performance evaluation of large-scale scenarios
  - Real-world scenario generation using geographic positions with strong real-world adaption
  - Topology optimization (number of meters per router/collector)
  - Performance evaluation / stress testing
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Key characteristics of simulation model

- **Meters, Routers, Collectors** are positioned according to real-life geographical data

- **Traffic generator**: each meter produces randomly 1 packet every 4h, 1h, 1/4h, 1/8h, 1/16h, …

- **Current RF Mesh Protocol Model** includes
  - Channel access via Slotted ALOHA
  - Packet errors due to data packet collisions
  - Back-off in case of data collisions
  - Geographical routing protocol with preference of Routers
  - Upside potential not part of current model: piggy-backing, higher data rate for routers, 4 parallel channels for collectors

- **Current Channel model** with adaptive transmission range up to 150m.
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System Design Framework

Simulation System
- GeoDatabase
- Positions (Lat./Lon.)
- Playground (NW/SE)
- Dynamic Modules
- OMNeT++ Scenario
- OMNeT++ Model Library

Geo-Position (Lat./Lon.)

Real World Scenario

Dynamic Scenario

Router

Geo Database

Meter

Collector

Sink
Key statistical data derived from simulations

- **Packet success rate of received packets** per node:
  - Example: 1 packet within 4 hours, 24 h simulation time
  - 0 packet received at collector within 24 h → 0% success rate
  - 1-5 packets received within 24 h → 16% - 83% success rate
  - 6 packets received → 100% success rate

- **Overall Ratio of successful nodes vs. number of all nodes**
  - In case one packet was received in 24 h, the node is counted to be successful, despite some packets might be lost

- **Overall Ratio of successfully received packets vs. number of sent packets**

Additional statistics:
- Number of dropped packets at a specific node → indicates bottlenecks
- Number of number of hops per packet per node → indicates, how many hops a packets travels from a node to the collector
Simulation Scenarios & Parameters

- **Scenario 1: Small-scale scenario**
  - 350 meters, one collector, 5 routers
  - Simulation duration 24 h
  - 1 packet every 4h, 1h, 1/4h, 1/8h, 1/16h
  - Used for validation purposes to confirm proper functionality of geographical routing

- **Scenario 2: Full-scale scenario**
  - 17,181 meters plus collectors & routers according to geo data
  - Simulation duration 24 h
  - Used to derive statistics for complete scenario
**Results for Small-scale Scenario**

*1 packet per node every 1 hour*

Geographical distribution of packet successful rate of nodes:

- Overall ratio: Successfull nodes vs. failed nodes = 100%
- Overall ratio: Successfully received packets vs. sent packets: 100%

Increased traffic load for validation purposes.

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Results for Small-scale Scenario

1 packet per node every 15 minutes

Geographical distribution of packet successful rate of nodes:

Overall ratio: Successful nodes vs. failed nodes ≈ 100 %
Overall ratio: Successfully received packets vs. sent packets ≈ 98 %

Increased traffic load for validation purposes
Results for Small-scale Scenario

1 packet per node every 7.5 minutes

Geographical distribution of packet successful rate of nodes:

- Overall ratio: Successfull nodes vs. failed nodes ≈ 78.5%
- Overall ratio: Successfully received packets vs. sent packets ≈ 48%
Results for Small-scale Scenario

1 packet per node every 3.75 minutes

Geographical distribution of packet successful rate of nodes:

Overall ratio: Successful nodes vs. failed nodes ≈ 70.2 %
Overall ratio: Successfully received packets vs. sent packets ≈ 25 %
Results for Large-scale Scenario

1 packet per node every 1 hour

Geographical distribution of packet successful rate of nodes:

Overall ratio: Successfull nodes vs. failed nodes = 99,1 %
Overall ratio: Successfully received packets vs. sent packets = 99,9 %
Results for Large-scale Scenario

1 packet per node every 15 minutes

Geographical distribution of packet successful rate of nodes:

Overall ratio: Successfull nodes vs. failed nodes ≈ 59.8 %
Overall ratio: Successfully received packets vs. sent packets ≈ 48 %
Results for Large-scale Scenario

1 packet per node every 7.5 minutes

Geographical distribution of packet successful rate of nodes:

Overall ratio: Successfull nodes vs. failed nodes ≈ 37.2 %
Overall ratio: Successfully received packets vs. sent packets ≈ 32 %
Results for Large-scale Scenario

1 packet per node every 3.75 minutes

Geographical distribution of packet successful rate of nodes:

- Increased traffic load for validation purposes

Overall ratio: Successfull nodes vs. failed nodes ≈ 20.1 %
Overall ratio: Successfully received packets vs. sent packets ≈ 18 %
Results for Large-scale Scenario

Geographical distribution of number of hops per node:

- 9 to 12 hops
- 7 to 8 hops
- 5 to 6 hops
- 3 to 4 hops
- 1 to 2 hops

Average number of hops: 3.7

17181 nodes
Traffic: 1 packet per node per 4 hours
Max. Meter Range: 150 m (+ adaptive range extension)
Max. Router Range: 2000 m
Reachability Analysis and Collision Detection

<table>
<thead>
<tr>
<th>Without Routers</th>
<th>With Routers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Received Packets</td>
<td>Collisions</td>
</tr>
</tbody>
</table>

Without Routers:
- Received Packets (left)
- Collisions (right)

With Routers:
- Received Packets (left)
- Collisions (right)
Conclusion

- Simulations have confirmed, that with the given traffic of 1 packet per 4 hours, the system performs well (99,99% success rate)
- Precondition: all nodes are properly meshed → connectivity gaps caused by geography need to be closed with routers/range extensions
- Data collisions occur, but do not lead to significant failures
- Detection of Point of Failure in advance to the field deployment
- Optimisation of location-based topology problems

Outlook

- BMWi E-Energy Project „E-DeMa“:
  - Geobased evaluation of ICT topologies with different technologies
  - Traffic load and protocol optimization

- DFG Forschergruppe „Neue Schutz- und Leitsysteme für Energiesysteme“:
  - Hybrid simulator for ICT and energy components
Outlook

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