Universität Rostock Traditio et Innovatio

Enabling the Management of IEEE 802.11s Wireless Mesh Networks

Michael Rethfeldt, Benjamin Beichler, Peter Danielis,
Christian Haubelt, Dirk Timmermann

Institute of Applied Microelectronics and Computer Engineering
Faculty of Computer Science and Electrical Engineering
University of Rostock, Germany

Motivation: City-Area WLAN Mesh Backbone

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Commercial WLAN Mesh Products

Home

Google Wifi
Home Wi-Fi solution

Netgear Orbi


Asus Lyra


Linksys Velop


Ubiquiti AmpliFi

eero TrueMesh

AVM Fritz! Mesh


Engenius
EnMesh


Luma Whole Home


TP-Link Deco

Commercial WLAN Mesh Products

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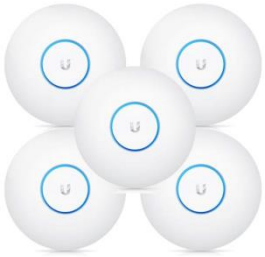
Enterprise

cisco Meraki

ABB / Tropos

firetide



Ubiquiti UniFi

Motorola
MotoMesh

Aruba
AirMesh

Open Mesh

CLOUDTRAX

Ruckus Wireless

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OpenMesh
CLOUDTRAX

Ruckus WIRELESS

Motorola MotoMesh

IEEE 802.11s WLAN Mesh Standard

Higher Layers

IP, TCP, UDP, ...

Data Link (OSI Layer 2)

IEEE 802.11 MAC + 802.11s Mesh

- **Mesh Channel Access**
- **Mesh Peering**
- **Mesh Path Selection**
- **Optional Features**

Google Wifi
Home Wi-Fi solution

Physical (OSI Layer 1)

IEEE 802.11 PHY (IEEE 802.11 a/b/g/n/ac)

IEEE 802.11s - Path Selection

- Hybrid Wireless Mesh Protocol (HWMP)
- Distance vector protocol
- Forwarding via best neighbor based on cost metric
- Default reactive mode
- Optional proactive mode

IEEE 802.11s Management Solution [1,2]

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Mesh Agents

Bootstrapping

IEEE 802.11s Management Solution [1,2]

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Mesh Agents

- Bootstrapping
- Error Recovery

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IEEE 802.11s Management Solution [1,2]

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Mesh Manager

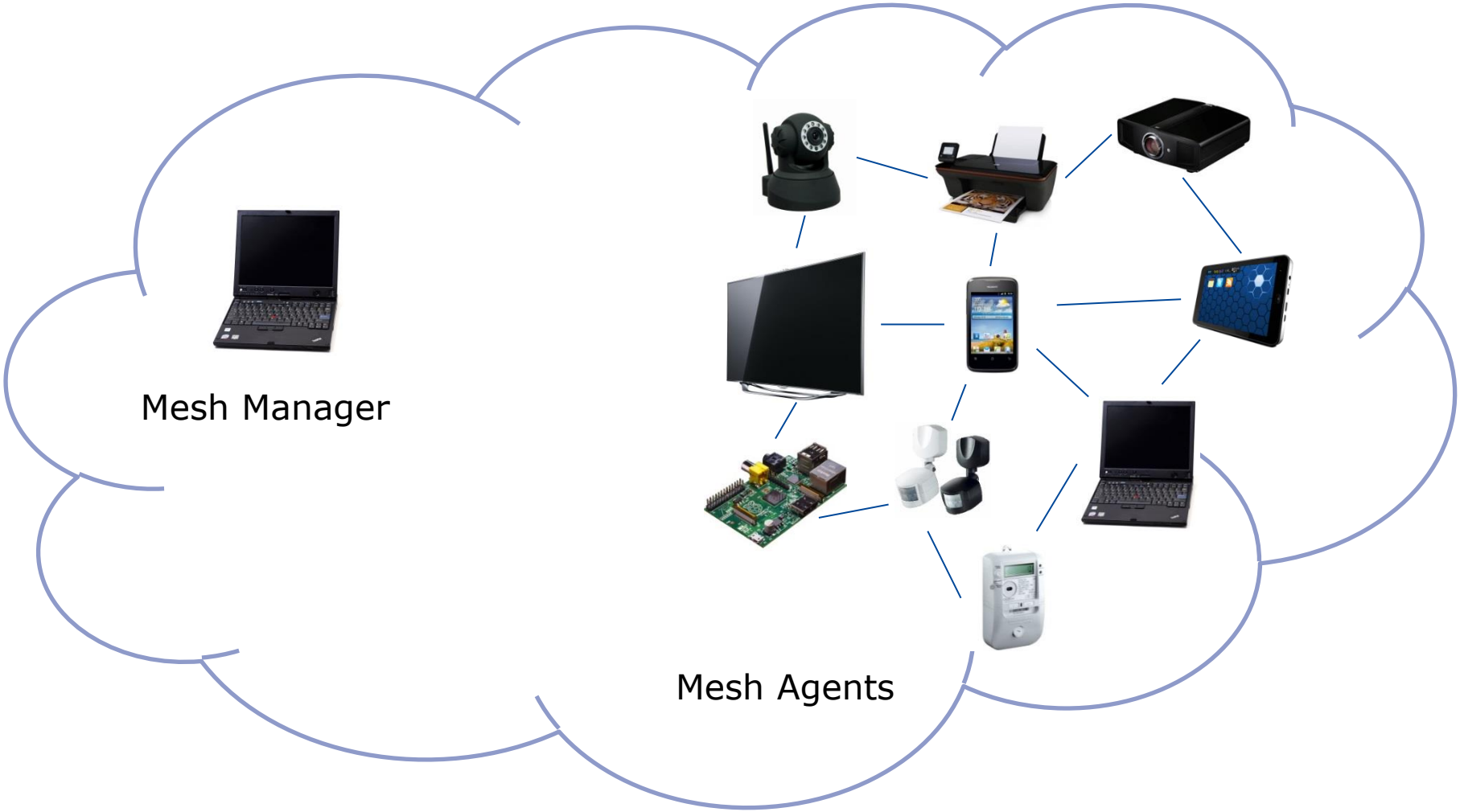
Maintenance / Administration?

IEEE 802.11s Management Solution [1,2]

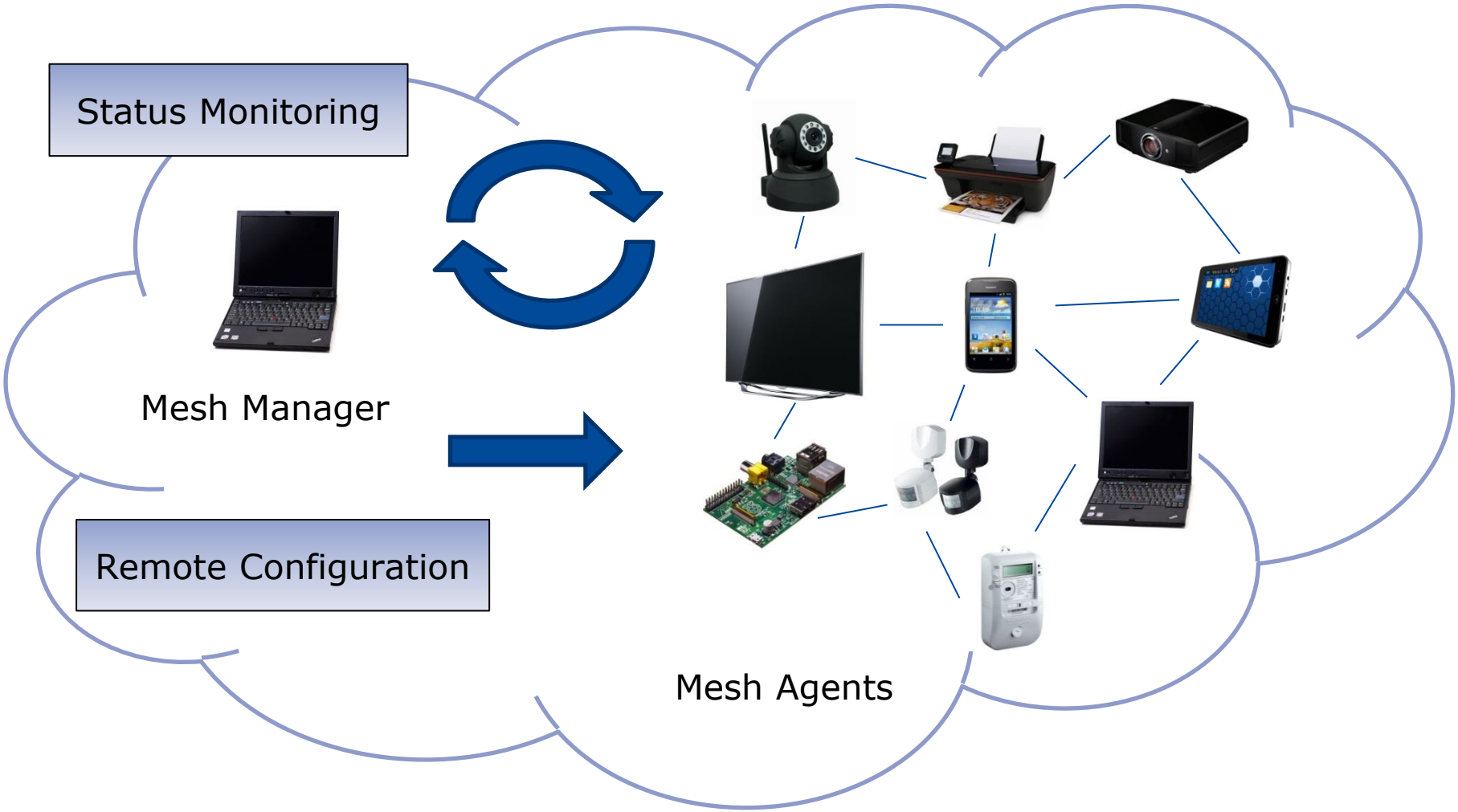
Mesh Manager

Mesh Agents

IEEE 802.11s Management Solution [1,2]

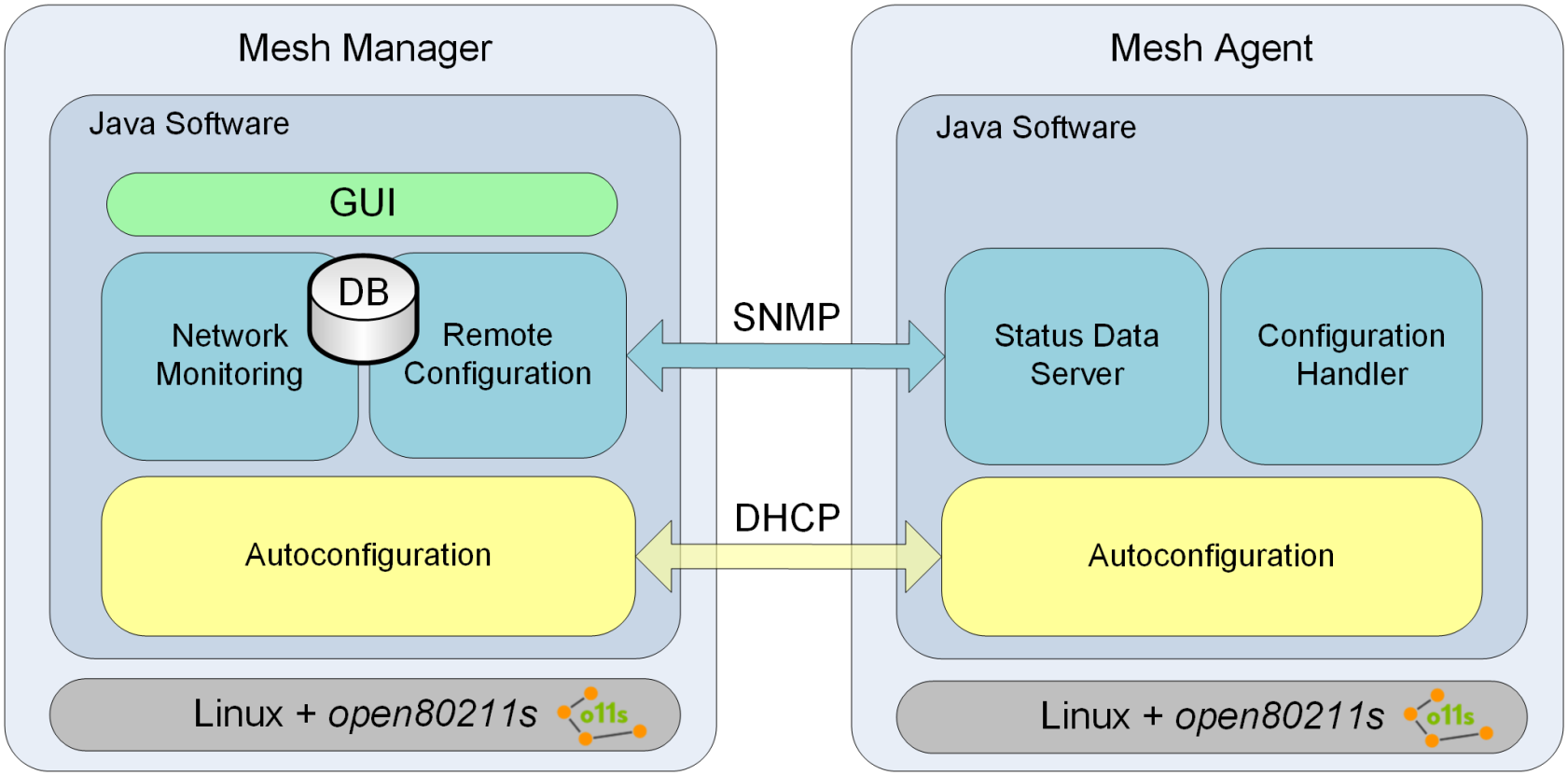


IEEE 802.11s Management Solution [1,2]



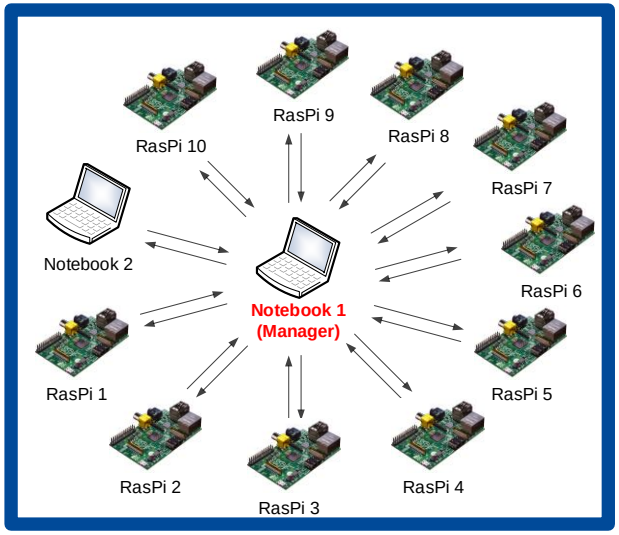
IEEE 802.11s Management Solution [1,2]

Prototype Architecture



IEEE 802.11s Management Solution [1,2]

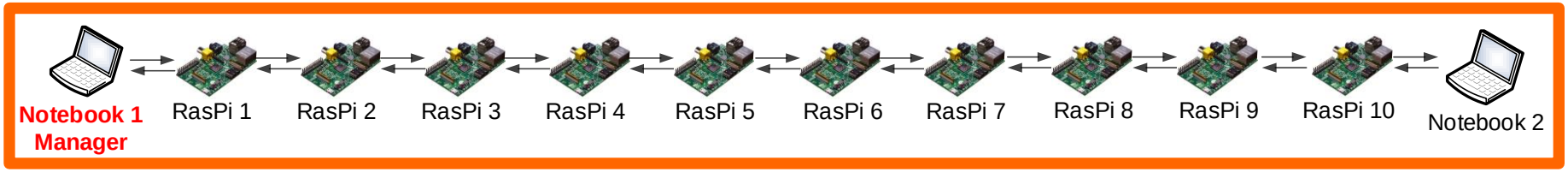
Scalability Evaluation

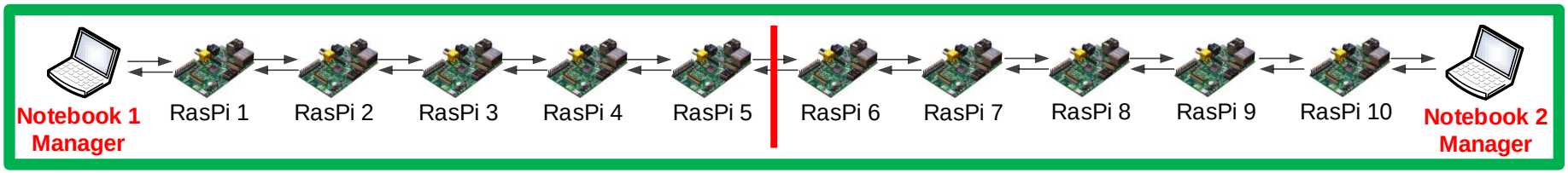


1: Centralized Single-Hop Monitoring

2: Centralized Multi-Hop Monitoring

3: Distributed Multi-Hop Monitoring





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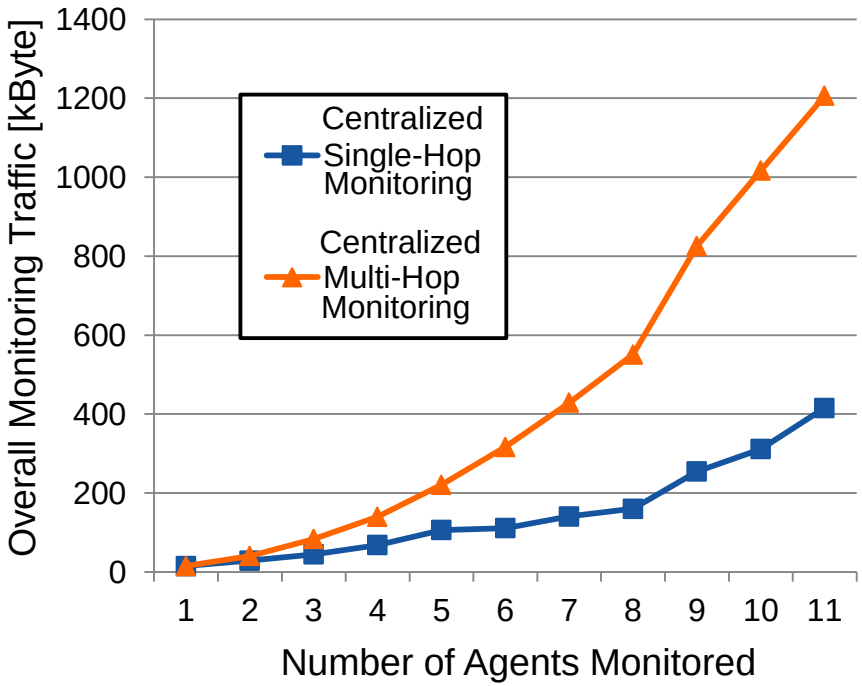
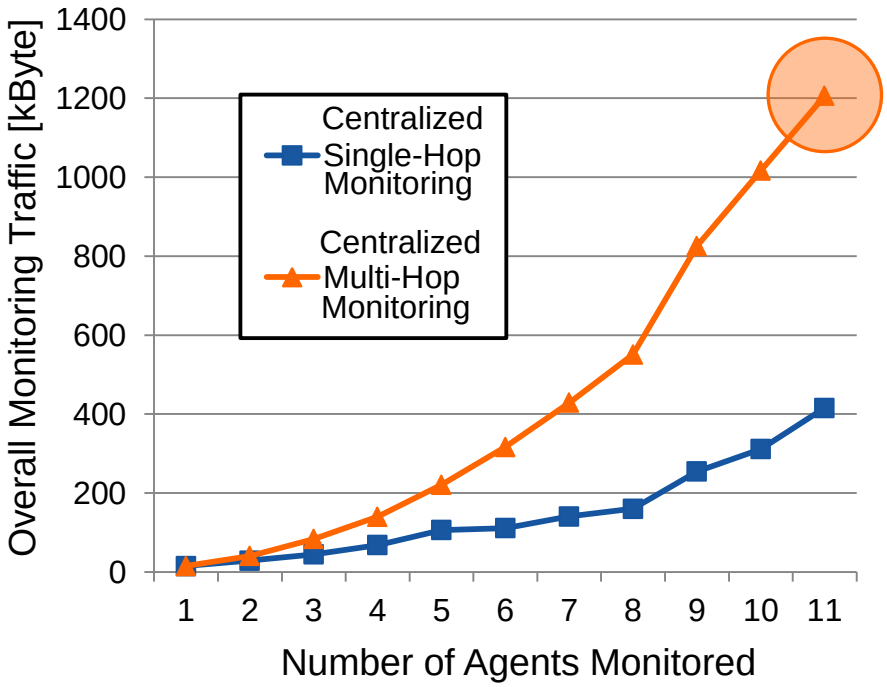


Setups 1 & 2:
Overhead trend of centralized monitoring
(Data sent per query cycle, 25 cycles averaged)

IEEE 802.11s Management Solution [1,2]

Scalability Evaluation



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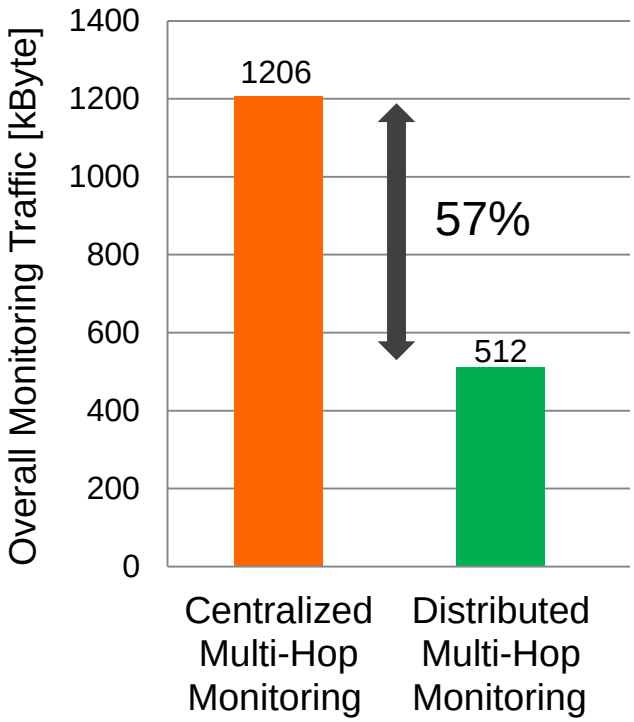
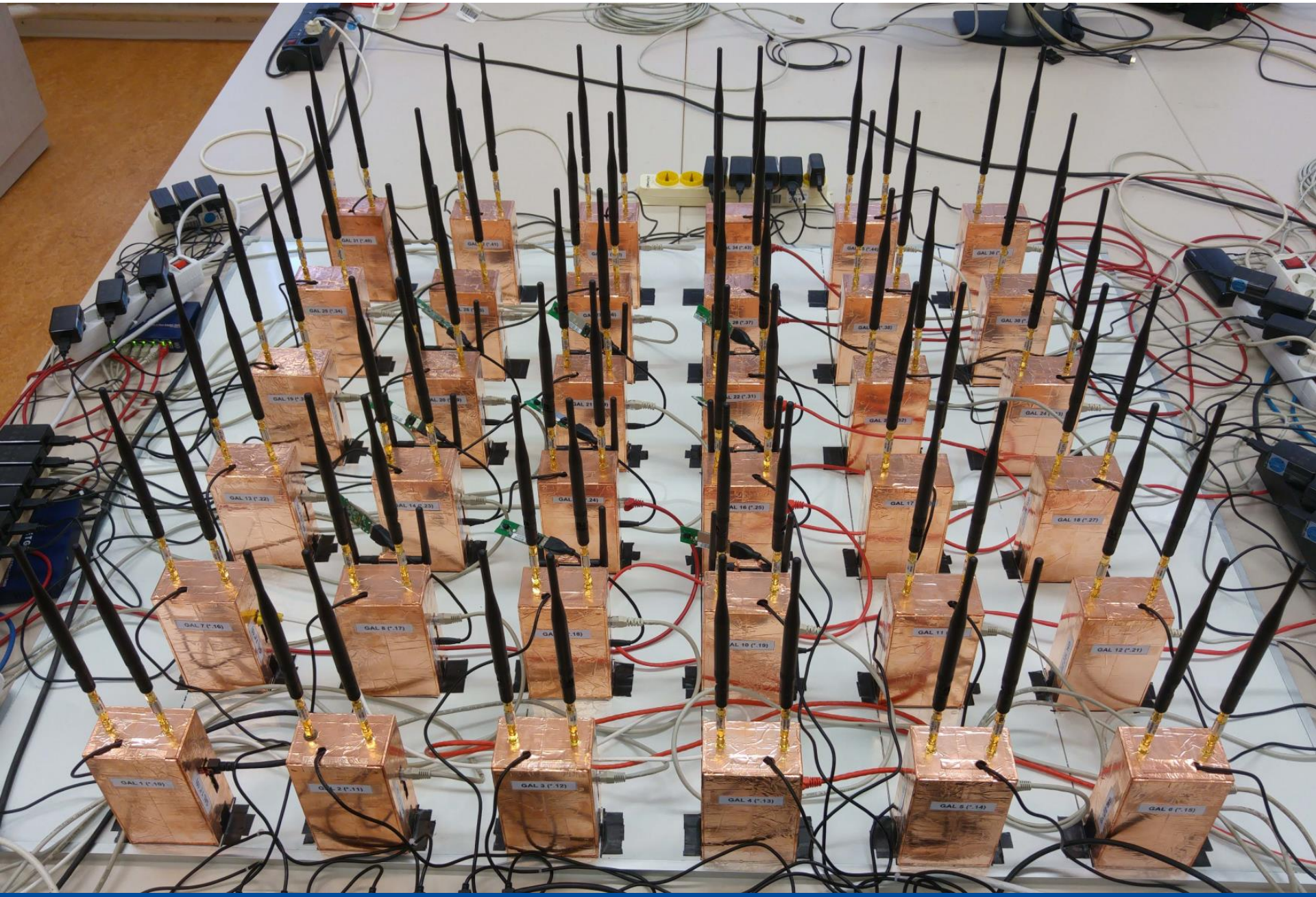
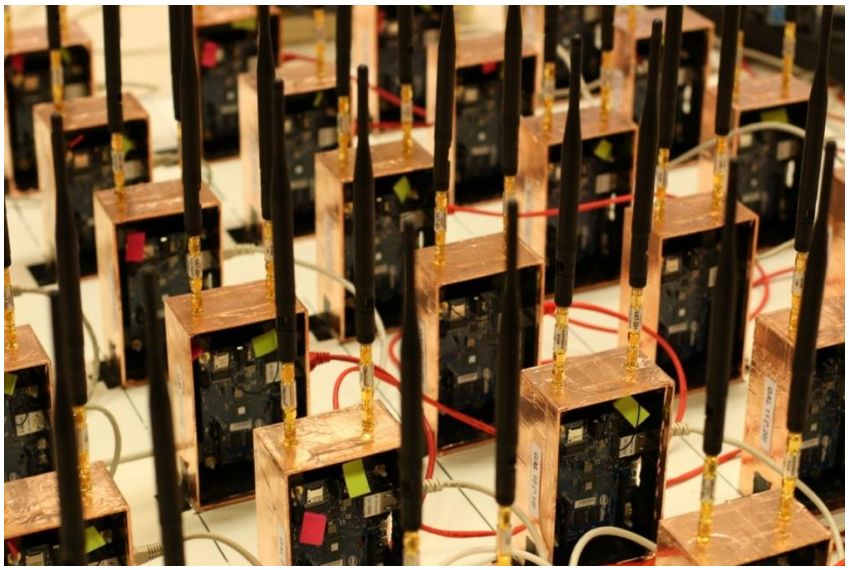


Setup 3:
Distribution benefit
(Data sent per query cycle, 25 cycles averaged)

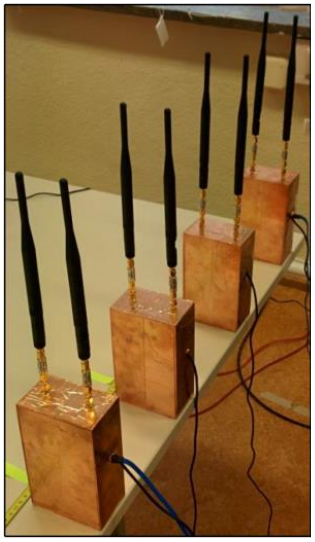
Mini-Mesh ^{3} - Miniaturized 36-Node 802.11n/s Testbed

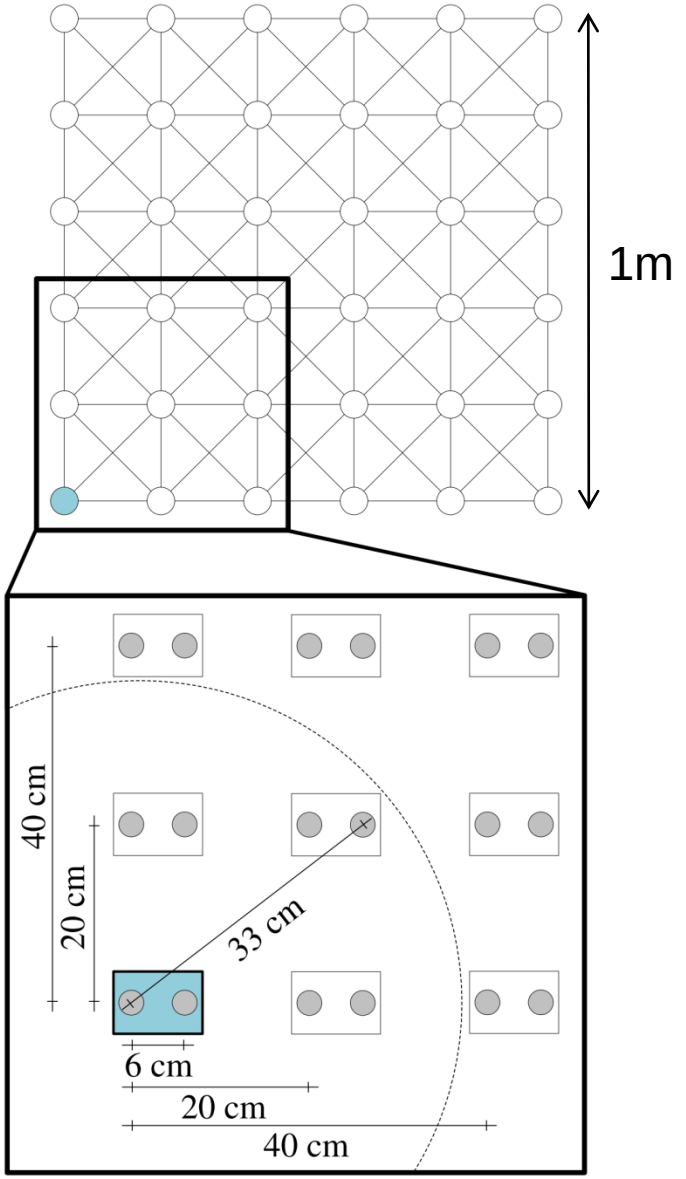


Mini-Mesh [3]: Setup & Testbed Geometry

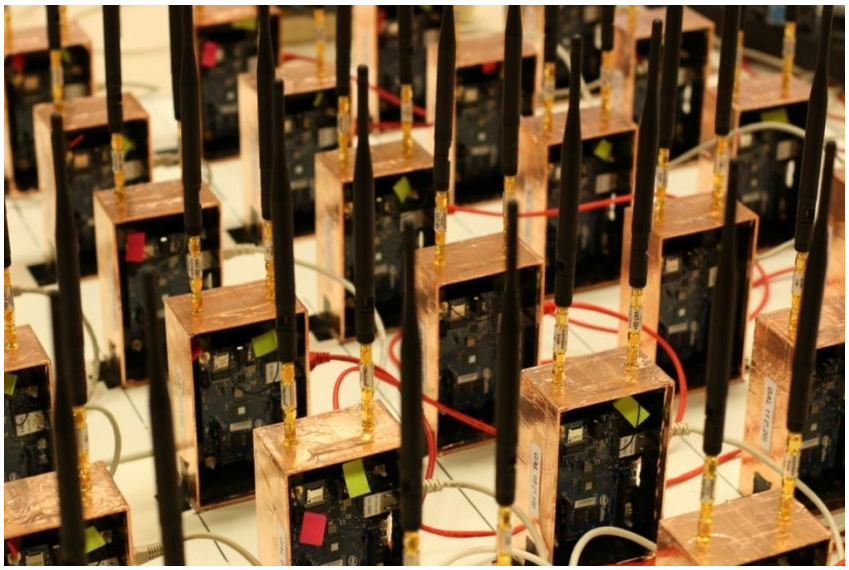


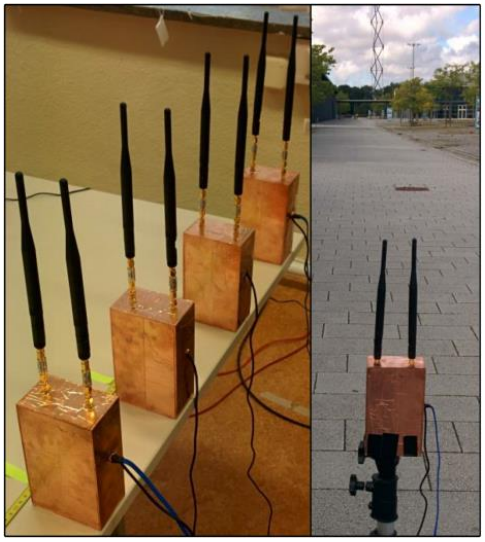
Indoor (Lab)





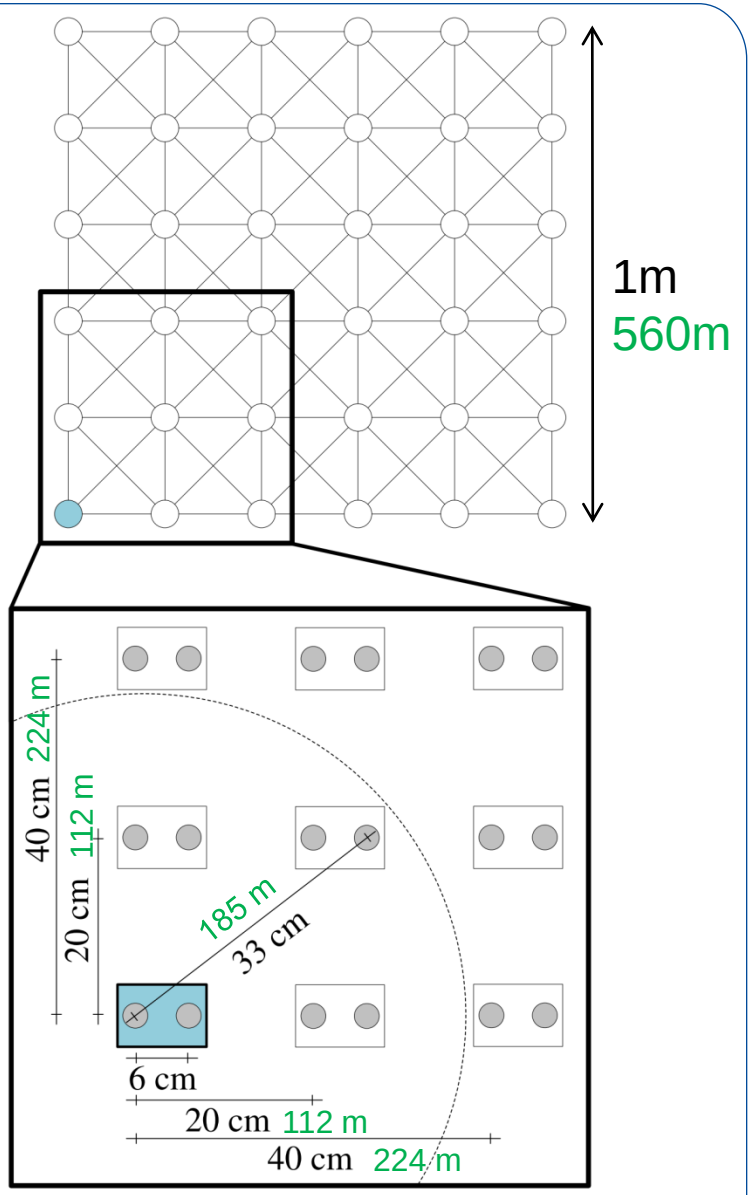
Mini-Mesh ³: Setup & Testbed Geometry





Indoor (Lab)

Outdoor (IGA Park)



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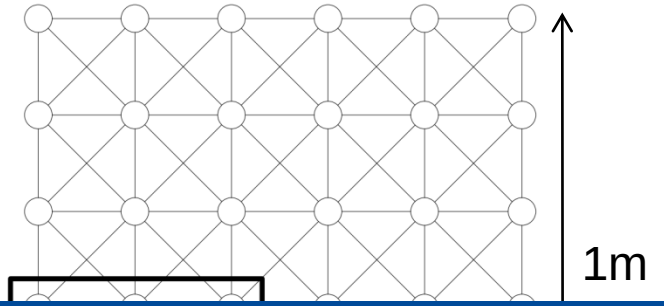
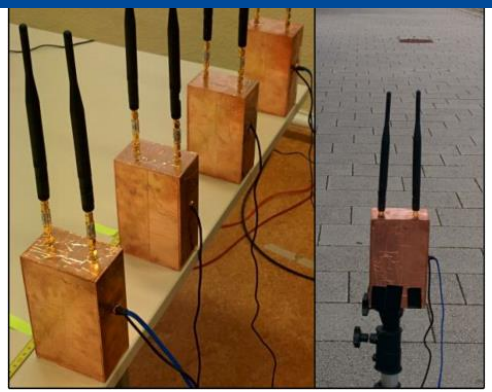


- Optimized for reproducible measurements
- Reduced communication range (attenuators, TX power)
- Line-of-sight miniaturization scale ~ 1 : 560

Indoor (Lab)



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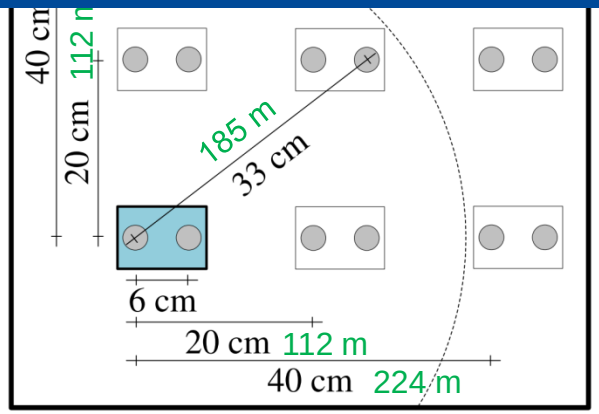
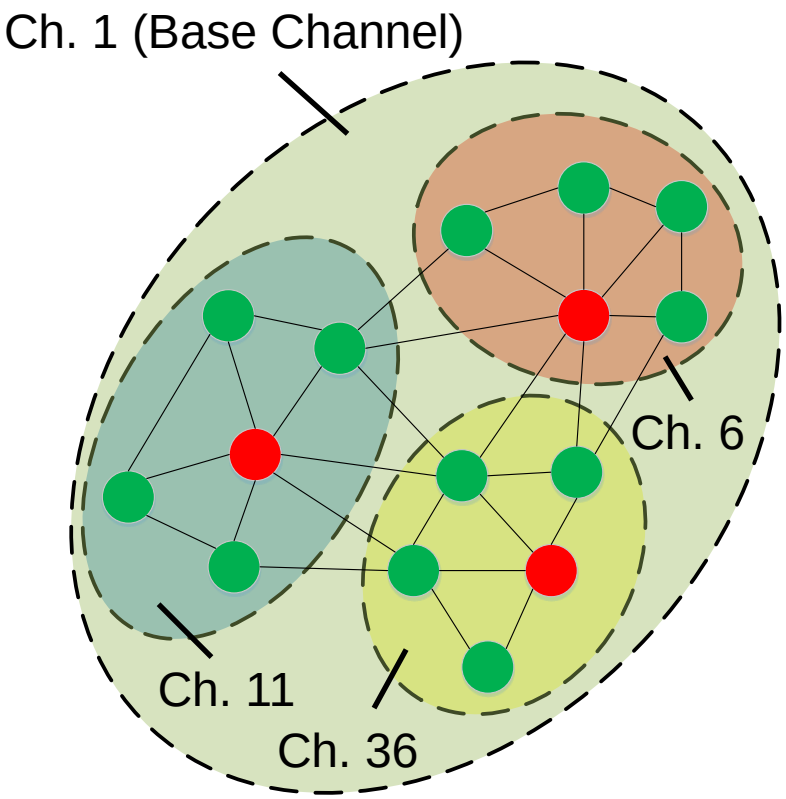
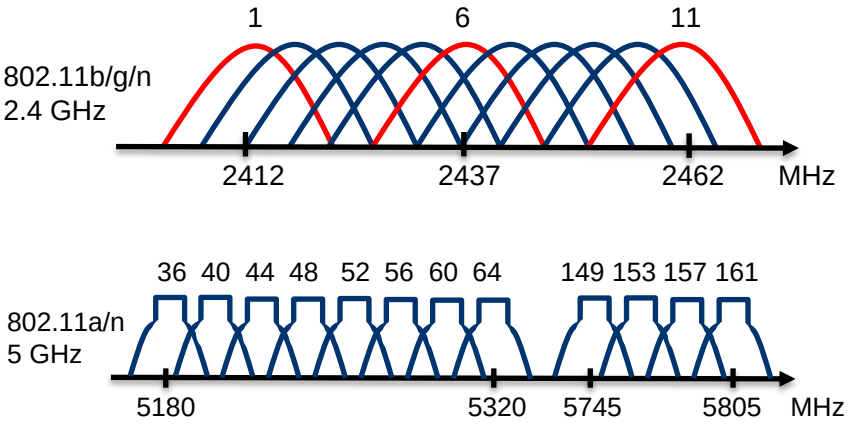


CHaChA [4]: Clustering Heuristic & Channel Assignment for 802.11s NW





- Spatial clustering
- Spectral separation

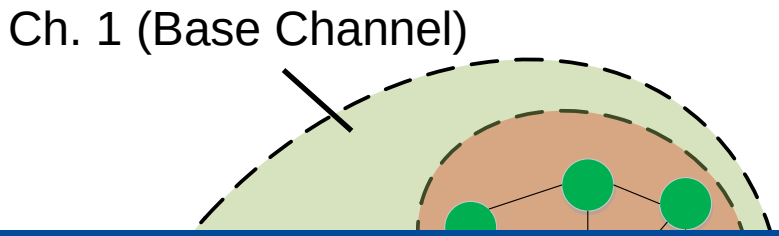
→ Parallel cluster communication

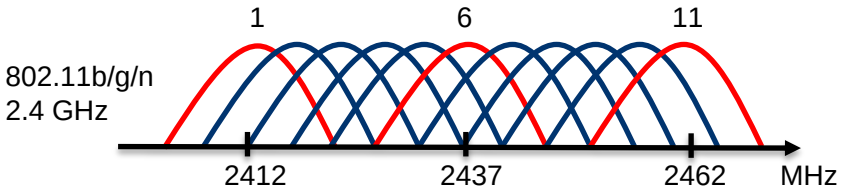
→ Reduced interference

→ Smaller collision & broadcast domains

→ Improved scalability & robustness

CHaChA [4]: Clustering Heuristic & Channel Assignment for 802.11s NW





- Standard-compliant distributed clustering algorithm based on 802.11s link info & path metrics
- Evaluation in Mini-Mesh test bed (5x5 grid)
  - Reproducible cluster formation
  - Distributed monitoring: 20-35% reduced cycle time

Cluster Head (Manager)

Cluster Member (Agent)

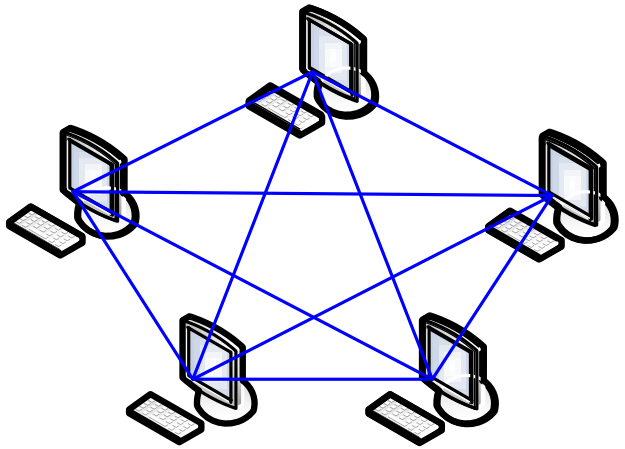
→ Smaller collision & broadcast domains

→ Improved scalability & robustness

MeNTor [5,6]: Mesh-Network-Aware BitTorrent-Based Data Distribution

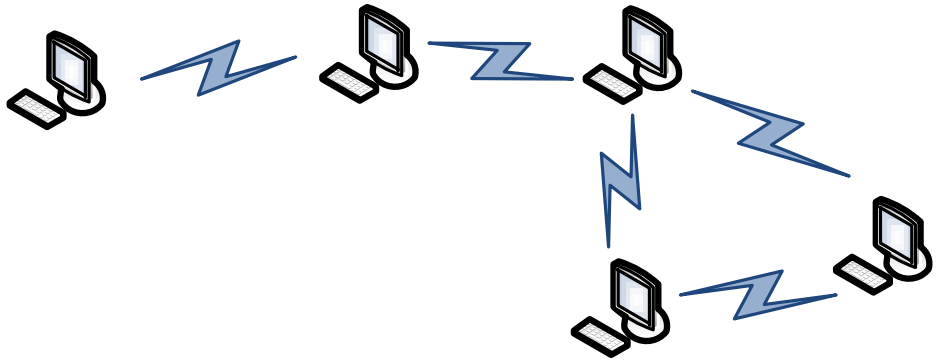
BitTorrent™

Logical
P2P Overlay

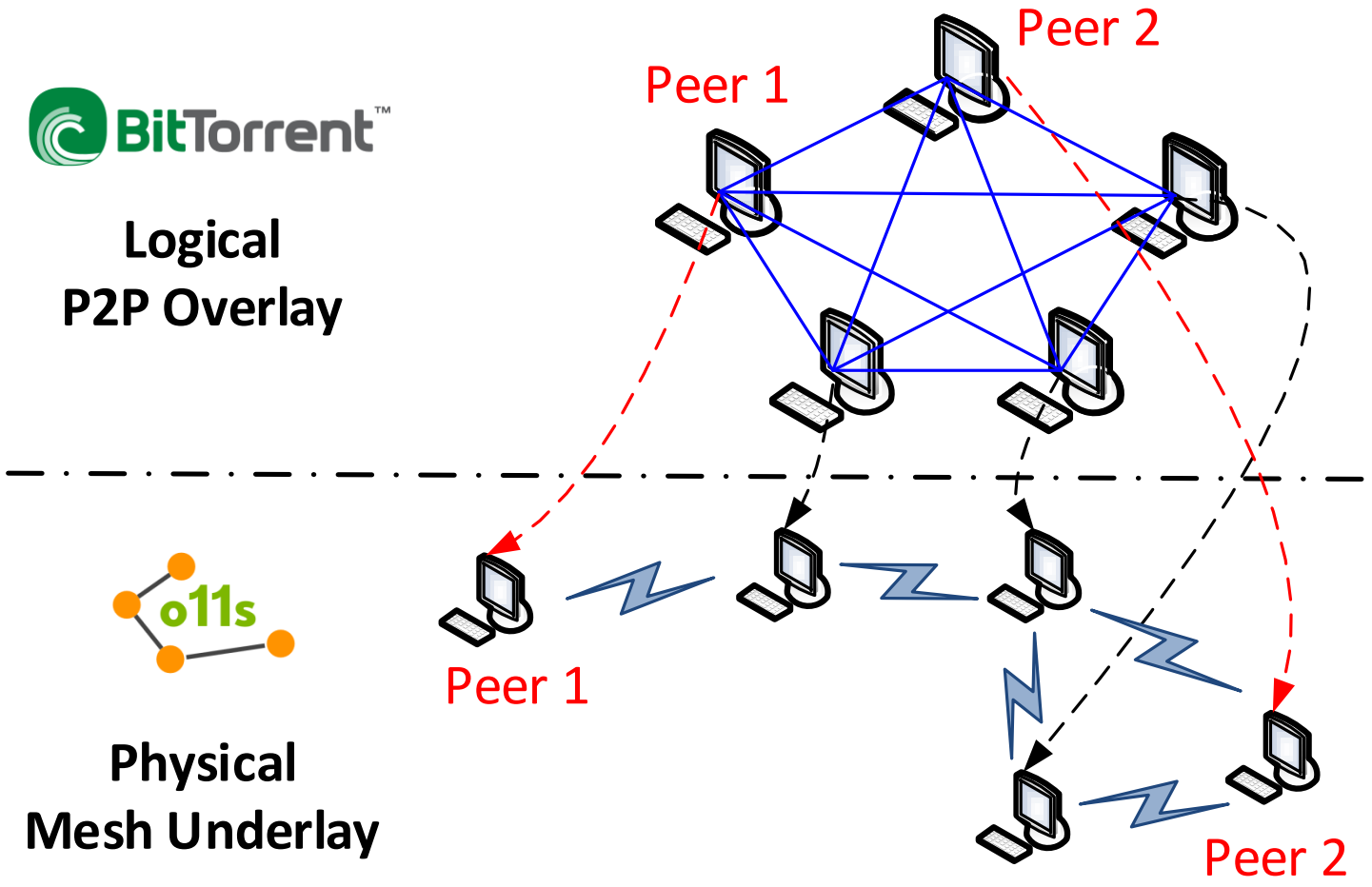


o11s

Physical
Mesh Underlay



MeNTor [5,6]: Mesh-Network-Aware BitTorrent-Based Data Distribution



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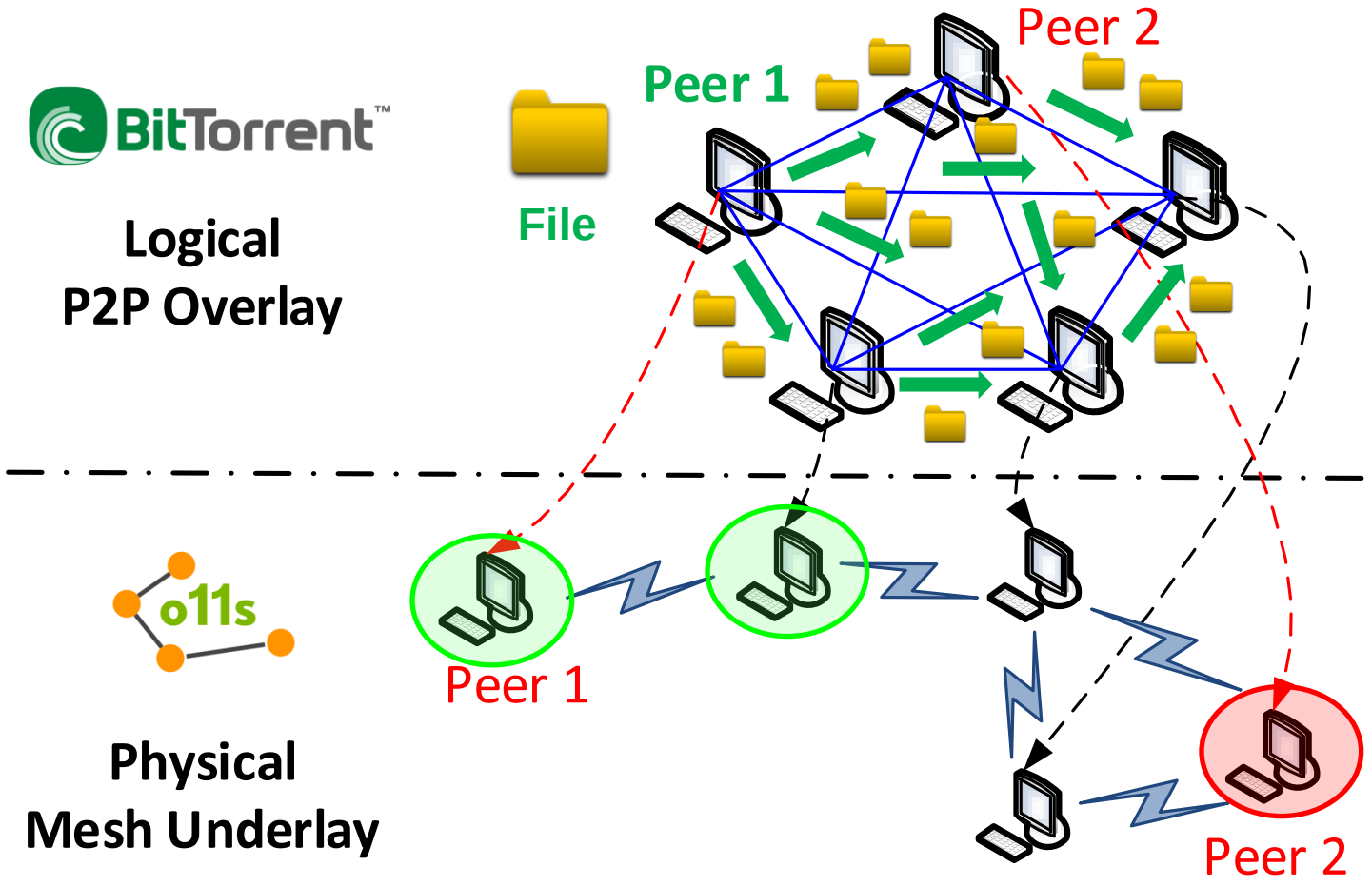

MeNTor [5,6]: Mesh-Network-Aware BitTorrent-Based Data Distribution

- Standard-compliant topology-aware BitTorrent peer selection based on 802.11s link info & path metrics
- Evaluation in Mini-Mesh test bed (5x5 grid)
  - 10 overlay scenarios (seed position, swarm size)
  - Up to 40% reduced data distribution time

Physical
Mesh Underlay

Summary & Outlook

IEEE 802.11s

- Low-level WLAN mesh interoperability
- MAC-layer routing based on HWMP/ALM
- Limited network view per mesh node
- Network management out of standard‘s scope

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Standard–compliant optimization approaches

- Centralized management / monitoring solution [1,2]
- Distributed clustering and channel assignment (CHaChA) [4]
- Collaborative underlay-aware data distribution (MeNTor) [5,6]

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Standard–compliant optimization approaches

- Centralized management / monitoring solution [1,2]
- Distributed clustering and channel assignment (CHaChA) [4]
- Collaborative underlay-aware data distribution (MeNTor) [5,6]

Evaluation environments

- Miniaturized 802.11n/s real-world testbed (Mini-Mesh) [3]
- Virtual prototyping framework (ViPMesh) [7]

List of Publications

(1) Michael Rethfeldt, Peter Danielis, Guido Moritz, Björn Konieczek, Dirk Timmermann
Design and Development of a Management Solution for Wireless Mesh Networks based on IEEE 802.11s
14th IFIP/IEEE Symposium on Integrated Network and Service Management (IM), Ottawa, Canada, May 2015

(2) Michael Rethfeldt, Arne Wall, Peter Danielis, Björn Konieczek, Dirk Timmermann
AKadeMesh: Software-defined Management Overlay Adaptation for IEEE 802.11s Networks
13th Annual IEEE Consumer Communications & Networking Conference (CCNC), Las Vegas, USA, January 2016

(3) Michael Rethfeldt, Benjamin Beichler, Hannes Raddatz, Felix Uster, Peter Danielis, Christian Haubelt, Dirk Timmermann
Mini-Mesh: Practical Assessment of a Miniaturized IEEE 802.11n/s Mesh Testbed
16th IEEE Wireless Communications and Networking Conference (WCNC), Barcelona, Spain, April 2018

(4) Michael Rethfeldt, Benjamin Beichler, Peter Danielis, Tim Brockmann, Christian Haubelt, Dirk Timmermann
CHaChA: Clustering Heuristic and Channel Assignment for IEEE 802.11s Mesh Networks
9th IEEE Annual Information Technology, Electronics & Mobile Communication Conference (IEMCON), Vancouver, Canada, November 2018

(5) Michael Rethfeldt, Peter Danielis, Björn Konieczek, Felix Uster, Dirk Timmermann
Integration of QoS Parameters From IEEE 802.11s WLAN Mesh Networks Into Logical P2P Overlays
14th IEEE Int. Conference on Ubiquitous Computing and Communications (IUCC), Liverpool, GB, October 2015

(6) Michael Rethfeldt, Benjamin Beichler, Peter Danielis, Felix Uster, Christian Haubelt, Dirk Timmermann
MeNTor: A Wireless-Mesh-Network-Aware Data Dissemination Overlay based on BitTorrent
Elsevier Ad Hoc Networks, Volume 79, pp. 146-159, ISSN: 1570-8705, Elsevier B. V., Amsterdam, Netherlands, October 2018

(7) Michael Rethfeldt, Hannes Raddatz, Benjamin Beichler, Björn Konieczek, Dirk Timmermann, Christian Haubelt, Peter Danielis
ViPMesh: A Virtual Prototyping Framework for IEEE 802.11s Wireless Mesh Networks
12th IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), New York, USA, October 2016

Thank you for your attention!

Questions?