QUALITY OF SERVICE BASED MINIMAL LATENCY ROUTING FOR INDUSTRIAL WSNS

Seminari i parë shkencorë i Fakultetit të Inxhinierisë Elektrike dhe Kompjuterike

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SAL
SILICON AUSTRIA LABS

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Silicon Austria Labs is a research center and pioneer in electronic based systems.

Silicon Austria Labs propels ideas into innovation in the fields of

- Sensor Systems
- RF Systems
- Power Electronics
- System Integration Technologies
- Embedded Systems
  - Wireless Communications

WIRELESS COMMUNICATIONS RESEARCH UNIT

- Research focus:
  - Wireless sensor and actuator networks
    - Industrial applications
    - Automotive domain
    - Localization and tracking
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  - ☐ Multihop communication
  - ☐ Seamless integration of wireless and wired communication networks
  - ☐ Various technologies such as Bluetooth, ITS-G5, 5G
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OUTLINE

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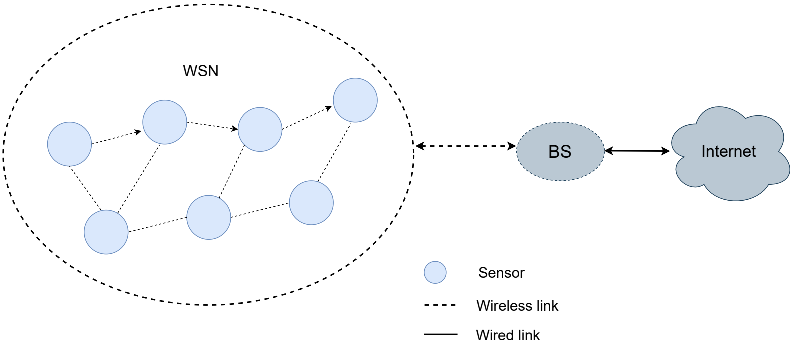
WIRELESS SENSOR NETWORKS

- Low-cost nodes capable of sensing, processing and communication



WSN Wireless Sensor Network
BS Base station

WIRELESS SENSOR NETWORKS

- Benefits:

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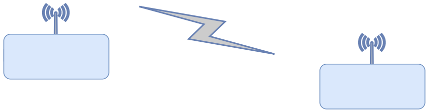

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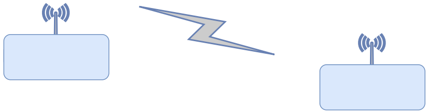

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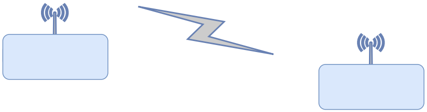

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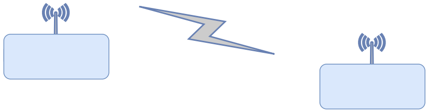
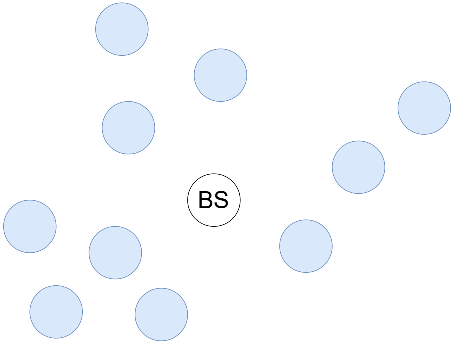


- Unique nature of operating WSN imposes challenges at different layers of the protocol stack
  - Fading, multipath effects, equipment noise, interference

MULTIHOP COMMUNICATION

- Optimized routing with respect to various parameters
  - ☐ A distributed algorithm for the network discovery
  - ☐ Centrally planned routes
  - ☐ Optimized latency for topology
  - ☐ Energy balanced routing
  - ☐ Minimal queuing on the routing/relay nodes



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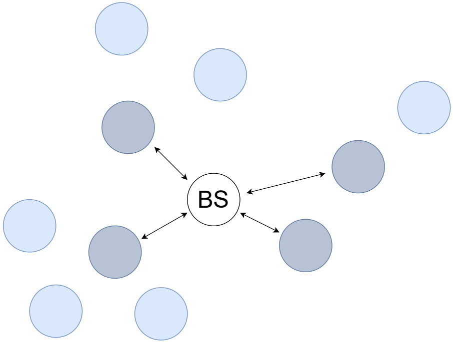

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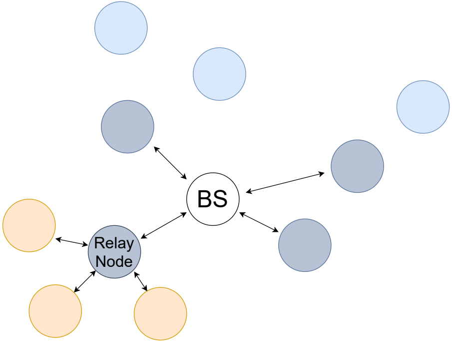

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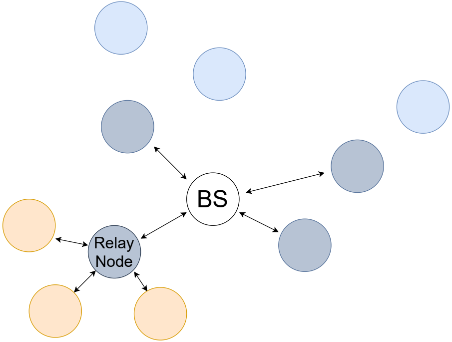

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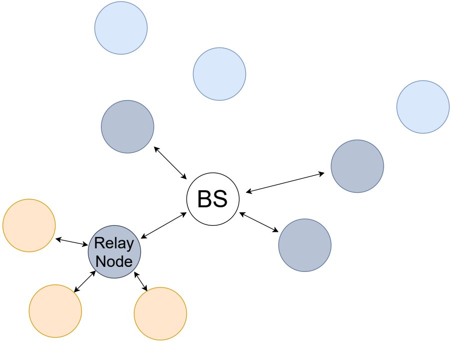
  1. **Network discovery stage**
  2. **Network link stage**



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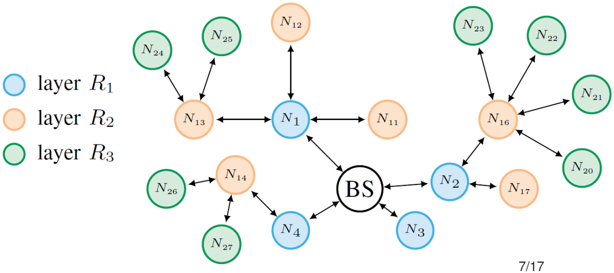
  $\mathbf{R}_{n+1} = \left(\mathbf{R} \setminus \cup_{m=1}^{n} \mathbf{R}_m\right)$ **respond to** $\mathbf{R}_n$
  - ☐ Step 1: Nodes in Layer 1 ($\mathbf{R}_1$)
  - ☐ Step 2: Nodes in layer 2 ($\mathbf{R}_2$)...

  $\mathbf{R}^p = \{\mathbf{R}_1, \mathbf{R}_2, \ldots, \mathbf{R}_{n_{\max}}\}$



γ SNR threshold
n Number of (relay) layers

DISTRIBUTED NETWORK DISCOVERY

Algorithm 1 Distributed network discovery at BS

1: **function** GETSTRUCTURE($\mathbf{R}$)
2: $\mathbf{R}_f = \mathbf{R} \backslash N_0$
3: $n_{\max}, \mathbf{R}^p, \mathbf{F}^K, \mathbf{B}^K \leftarrow$ FINDMAPS($\mathbf{R}_f, N_0, 0, \emptyset$)
4: **return** $n_{\max}, \mathbf{R}^p, \mathbf{F}^K, \mathbf{B}^K$

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Algorithm 2 Distributed network discovery at sensor node

function FINDMAPS($\mathbf{R}_f, N_n, n, N_{n-1}$)
  N_n.relay $\leftarrow$ *true*
  SENDTO ($\mathbf{R}_f$, RESPONDSTO(N_n))
  for all $N_c \in \mathbf{R}_f$ **do**
    if N_c **respond to** N_n **then**
      $\mathbf{R}_{n+1} \leftarrow \mathbf{R}_{n+1} \cup N_c$
      $\mathbf{F}_{N_n} \leftarrow \mathbf{F}_{N_n} \cup N_c$
  $\mathbf{R}_f \leftarrow \mathbf{R}_f \backslash \mathbf{R}_{n+1}$
  $n_{\max} \leftarrow n$
  for all $N_c \in \mathbf{R}_{n+1} \wedge \neg(N_c.\text{relay})$ **do**
    SENDTO (N_c, FINDMAPS($\mathbf{R}_f, N_c, n+1, N_n$))
  for all $N_c \in \mathbf{R}_{n+1} \wedge \neg(N_c.\text{relay})$ **do**
    $n_{\max}, \mathbf{R}^p, \mathbf{F}^K, \mathbf{B}^K \cup \leftarrow$ RECEIVEDFROM (N_c)
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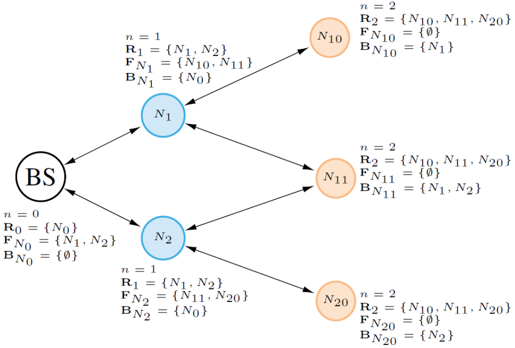
function RESPONDSTO(N_{n-1})
  $\mathbf{B}_{N_n} \leftarrow \mathbf{B}_{N_n} \cup N_{n-1}$
  return

DISTRIBUTED NETWORK DISCOVERY

- Example of the network discovery after the execution of Algorithm 2
- Output of the function FINDMAPS consisting of $\{n, \mathbf{R}, \mathbf{F}, \mathbf{B}\}$

n	Layer
$\mathbf{R}$	Set of nodes comprising a layer
$\mathbf{F}$	Set of forward nodes
$\mathbf{B}$	Set of backward nodes



NETWORK LINK PHASE

- Key features: (1) centrally planned routes, (2) minimized latency and (3) energy balanced routing

Algorithm 3 Network link phase

function SETROUTES($n_{\max}, \mathbf{R}^p, \mathbf{F}^K, \mathbf{B}^K$)
  for $n = n_{\max} - 1; n > 0; n \leftarrow n - 1$ **do**
    for all $N_k \in \mathbf{R}_n$ **do**
      $\mathbf{F}^u_{N_k} \leftarrow \mathbf{F}_{N_k} \setminus \left(\bigcup_{N_g \in \mathbf{R}_n \setminus N_k} \mathbf{F}_{N_g} \right)$
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      $L \leftarrow \min\{\max_{\#} \mathbf{B}_{N_k}, \#N_k\}$
      for all $N_g \in \{\mathbf{F}^u_{N_k}, \mathbf{F}_{N_k} \setminus \mathbf{F}^u_{N_k}\}$ **do**
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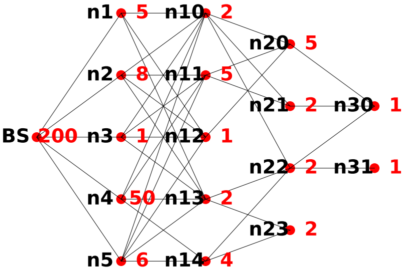

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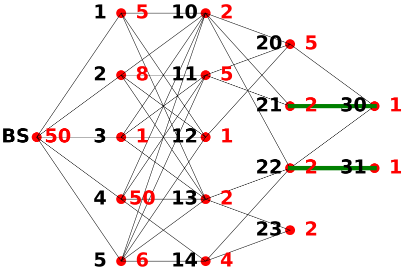

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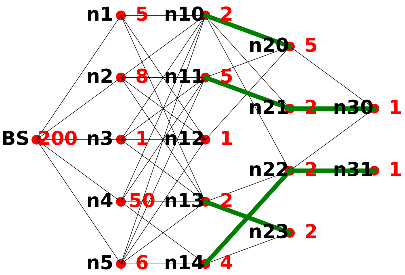

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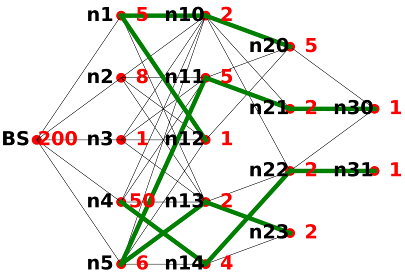

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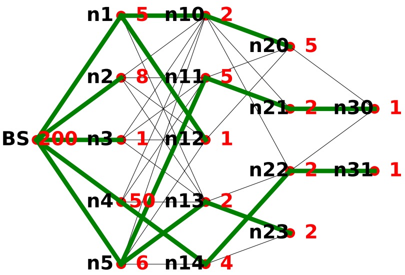
      $\#\mathbf{B}_{N_k} \leftarrow \#\mathbf{B}_{N_k} - \min_{\# N_i}\{N_i \in \mathbf{B}_{N_k} \wedge \# N_i > \#\mathbf{T}\}$

  return $\mathbf{R}^p, \mathbf{F}^K$



OUTLINE

Multihop Communication: QoS-based Routing

Network Discovery Evaluation and Modeling Aspects

Demonstrator

MODELING ASPECTS

- An area of $50\,\mathrm{m} \times 50\,\mathrm{m}$
- A single base station (BS)
  - located at the center $(0, 0)$
- N sensor nodes
  - uniformly distributed with density λ

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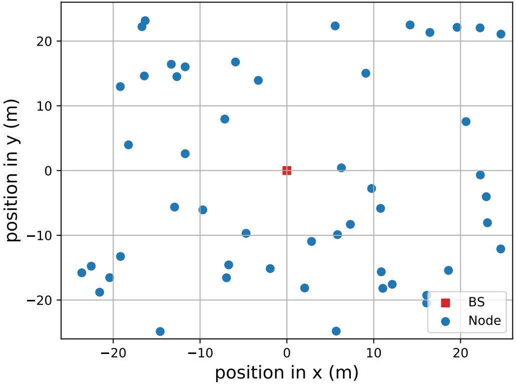

PROPAGATION MODEL

- Wireless channel characterization in industrial environments:

[1] NIST Channel Sounder Overview and Channel Measurements in Manufacturing Facilities, National Institute of Standards and Technology, Tech. Rep., 2017.

PROPAGATION MODEL

- Wireless channel characterization in industrial environments:
  - Two-slope path loss model from NIST[1]

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$$\mathrm{L}(d) = \begin{cases} a_1 10\log_{10}(d) + b_1, & d \leq d_{\mathrm{BP}} \\ a_2 10\log_{10}(d) + (b_2 + d_{\mathrm{BP}}\,(a_2 - a_1)\,, & d > d_{\mathrm{BP}}) \end{cases} \tag{1}$$

- Distinguish between LOS and NLOS

a_1, a_2	path loss exponents
b_1, b_2	path gain
d_{BP}	breakpoint distance

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- Distinguish between LOS and NLOS
- SNR of each link

$$\mathrm{SNR}_{0,k} = \frac{P_0 L_{0,k}(d)\mathcal{X}}{S_0}$$

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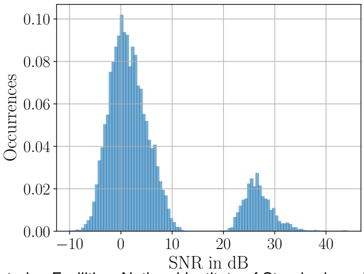
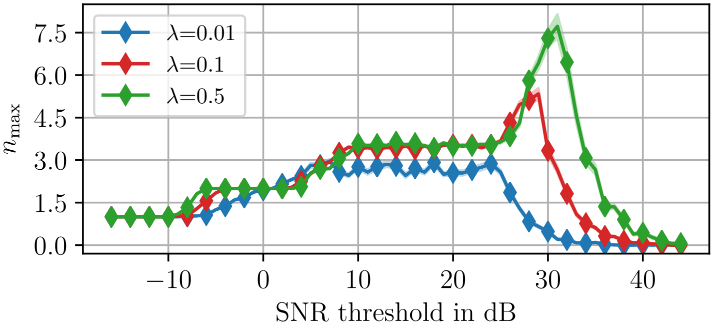


[1] NIST Channel Sounder Overview and Channel Measurements in Manufacturing Facilities, National Institute of Standards and Technology, Tech. Rep., 2017.

NUMBER OF RELAYING LAYERS

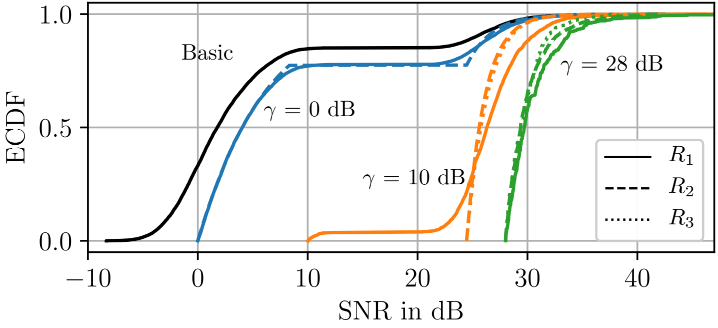
- Maximum number of layers achieved based on the applied SNR threshold (γ)
- From sparse to dense networks



λ Node density

SNR DISTRIBUTION AT DIFFERENT LAYERS

- The SNR distribution at different layers in the network for SNR threshold $\gamma = \{0, 10, 28\}$ dB and node density $\lambda = 0.1$.



OUTLINE

Multihop Communication: QoS-based Routing

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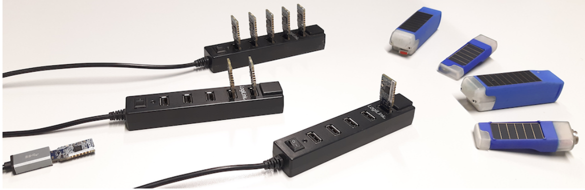
DEMONSTRATOR IMPLEMENTATION

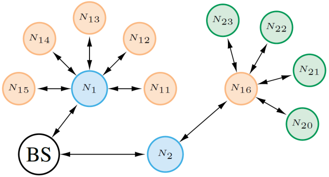
- Using standalone wireless nodes
- Nodes are equipped with CortexM0 micro-controller
  - Nordic NRF51822 CortexM0
- Nodes are powered by solar panels using ambient light or standard power supply
- Routing algorithm added to the EPhESOS protocol[2] implementation
- EPhESOS is a TDMA-based protocol and is optimized for low power sensor network applications



[2] H. Bernhard, A. Springer, A. Berger and P. Priller, "Life cycle of wireless sensor nodes in industrial environments", 2017 IEEE 13th International Workshop on Factory Communication Systems (WFCS), Trondheim, 2017, pp. 1-9, doi: 10.1109/WFCS.2017.7991943.

DEMONSTRATOR IMPLEMENTATION

- Example of a three-layer network
  - Discovery phase at BS (0 to 15s)
  - Synchronization (of Layer 1 nodes) starts at 15s until 30s
  - Sync duration of 15s



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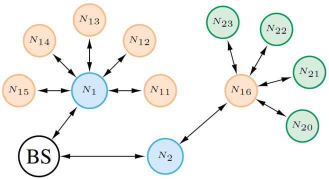

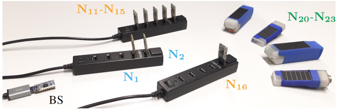

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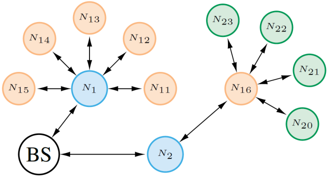

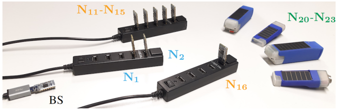

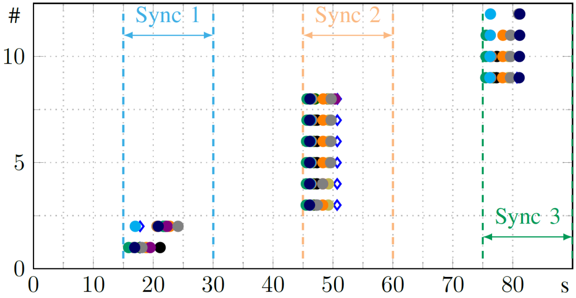

Thank you for your attention!

- InSecTT project https://www.insectt.eu/
- Workshop on Wireless Intelligent Secure Trustable Things: bringing IoT and AI together, hosted by the IEEE 7th World Forum on Internet of Things taking place 20-24 June 2021 in New Orleans, Louisiana, USA: https://wfiot2021.iot.ieee.org/
- Conference WFCS 2021 in Linz, Austria: 17th IEEE International Conference on Factory Communication Systems (WFCS), June 9-11 2021 https://konferenzen.jku.at/wfcs2021/