Constructing Customized Multi-Hop Topologies in Dense Wireless Network Testbeds

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Introduction

Validation of Research

Experimental validation of novel concepts in a realistic environment forms an important step in identifying flaws in theoretical assumptions and implementation problems

- Execution environments are often hard to accurately model through simulations
- Set-up of experiments with large systems comes with a high effort
- Solution: Remotely usable test environments

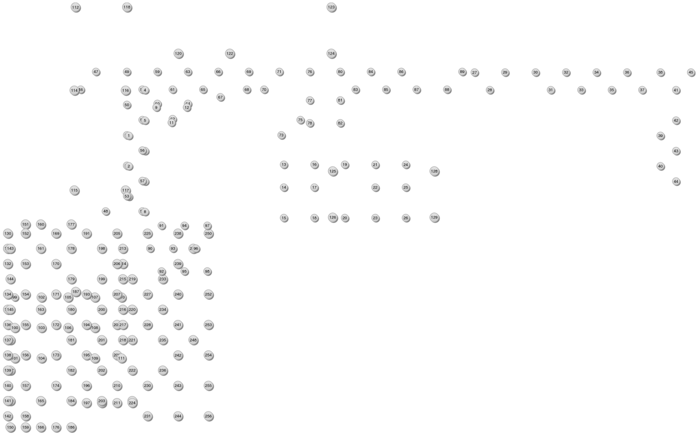
Wireless Network Testbeds

- Over the years, multiple small scale wireless sensor testbeds were set up and torn down in the scope of various projects
- Instead of setting up a new testbed it is advisable to resort to existing testbeds providing convenient remote control
- Conducting experiments in existing testbeds gives reproducible results
- This allows a fair comparison of algorithms and protocols

Issues with Wireless Network Testbeds

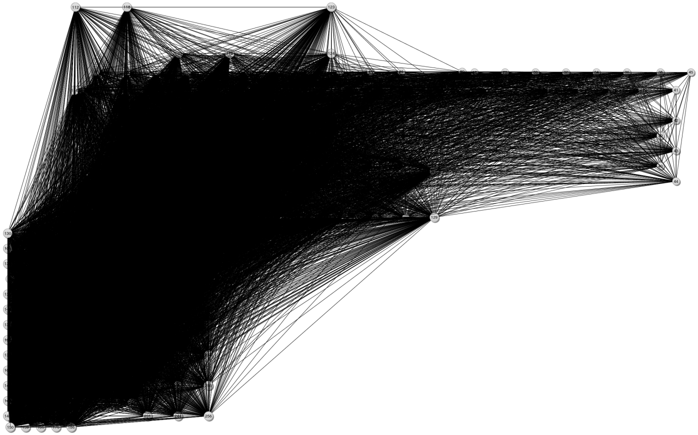
- Most testbeds span a comparatively small area where every transceiver often can reach every other node in one hop
- Validating protocols often requires very specific topologies
  - Fixed network density or diameter
  - Symmetric or asymmetric links
  - Regular or irregular structure
- Our contribution
  - Approach to construct topologies in existing testbeds satisfying given conditions for evaluating multi-hop protocols
  - Implementation provided as open-source software

Example: Lille Testbed of FIT/IoT-LAB



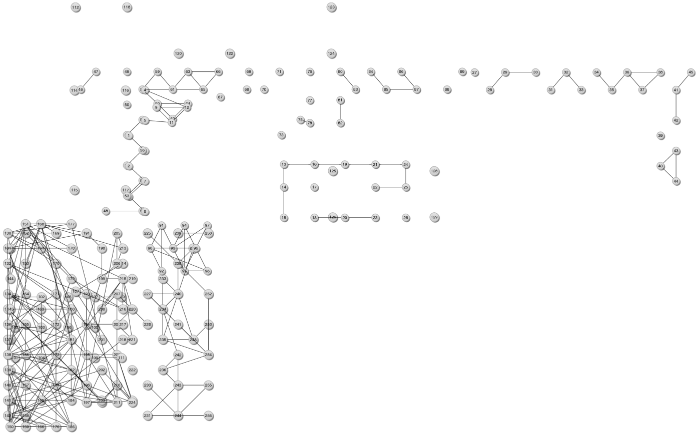
- Requirement: Topology where each node has three neighbors

Example: Lille Testbed of FIT/IoT-LAB



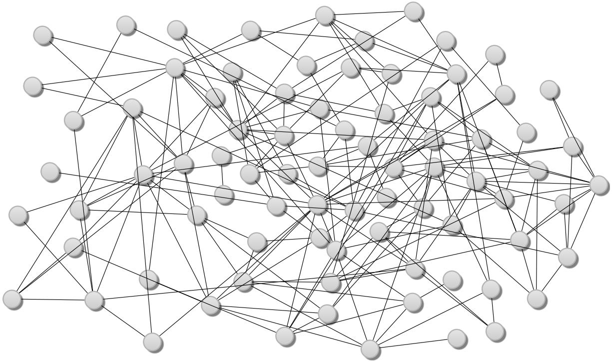
- All possible links

Example: Lille Testbed of FIT/IoT-LAB



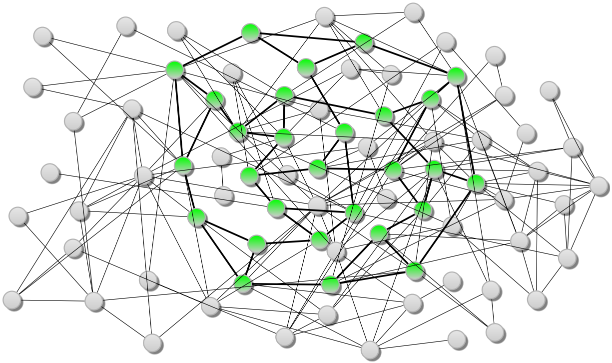
- Possible links after reduction of transmission power and sensitivity

Example: Lille Testbed of FIT/IoT-LAB



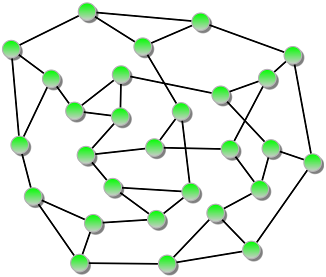
- Largest connected component (rearranged)

Example: Lille Testbed of FIT/IoT-LAB



- Selected topology where each node has three neighbors

Example: Lille Testbed of FIT/IoT-LAB



- Selected topology where each node has three neighbors

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Topology Generation Procedure

Emulating Channel Conditions

- Channel conditions are created by manipulating transmission power and sensitivity of transceivers
- Example: IoT-LAB
  - Hardware: M3 Open Node (ARM Cortex M3, Atmel AT86RF231)
  - Transceiver can be configured with output power from -17 to 3 dBm and reception sensitivity from -48 to -101 dBm
- $\Lambda_{a,b}$: Reduction of signal power between nodes *a* and *b*
- $\Lambda_{a,b}$ depends on losses between transceivers and antennas, gain of antennas, path loss, etc.
- Communication between *a* and *b* is possible if

$$\Lambda_{a,b} \leq \text{transmission power} - \text{sensitivity}$$

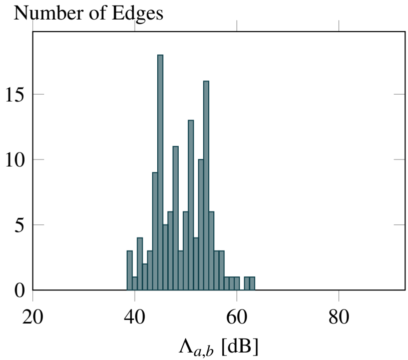
Topology Generation Procedure

1. Measure $\Lambda_{a,b}$ between every pair a, b of nodes
2. Define neighborhood graphs depending on transmission power and sensitivity setting
3. Use neighborhood graphs to construct a topology by selecting a subset of nodes and corresponding transceiver settings
4. Verify selection in real testbed

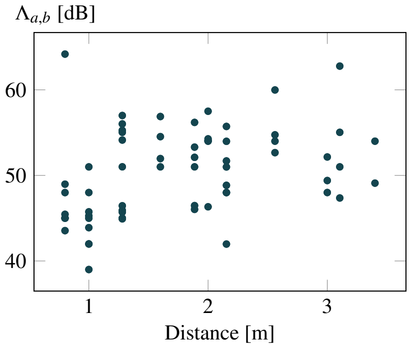
Pairwise $\Lambda_{a,b}$ Measurements

- Every node repeatedly sends out packets with full transmission power
- Nodes where signal is strong enough to be received, measure RSSI of packet
- $\Lambda_{a,b}$ = transmission power − RSSI
- Repeat and compute average

Pairwise $\Lambda_{a,b}$ Measurements



Distribution of $\Lambda_{a,b}$ for Saclay testbed

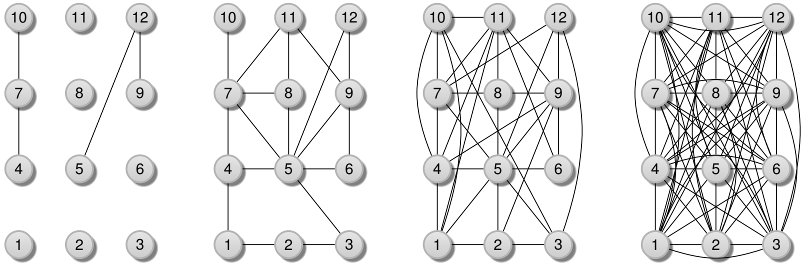


$\Lambda_{a,b}$ in relation to euclidean distance

Realizable Graphs

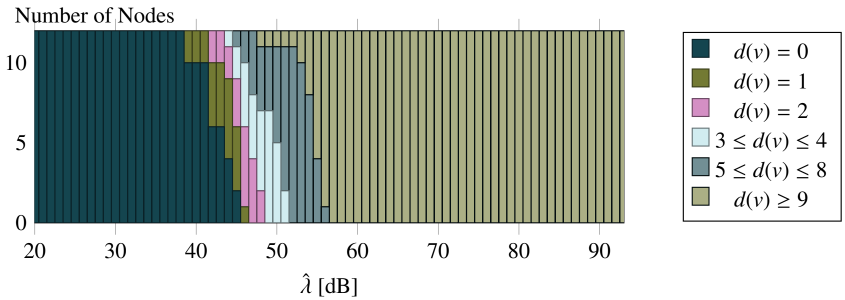
- Measurements determine usable bidirectional links for each link budgets
- For given $\hat{\lambda} > 0$ define $E_{\hat{\lambda}} = \{(a, b) \mid \Lambda_{a,b} \leq \hat{\lambda} \wedge \Lambda_{b,a} \leq \hat{\lambda}\}$
- $G_{\hat{\lambda}} = (V, E_{\hat{\lambda}})$ is the neighborhood graph for $\hat{\lambda}$

Neighborhood Graphs for the Saclay Testbed



G_{42} $(\Lambda_{a,b} \leq \hat{\lambda} = 42\,\text{dB})$ G_{46} $(\Lambda_{a,b} \leq \hat{\lambda} = 46\,\text{dB})$ G_{50} $(\Lambda_{a,b} \leq \hat{\lambda} = 50\,\text{dB})$ G_{104} $(\Lambda_{a,b} \leq \hat{\lambda} = 104\,\text{dB})$

Distribution of Node Degrees (Saclay Testbed)



Constructing Dedicated Topologies

- Evaluation and debugging of protocols often require dedicated topologies with specific properties
- Examples
  - Topologies with constant neighborhood size
  - Tree shaped topologies, e.g., line graphs
- Procedure
  - Select subset of nodes of suitable neighborhood graph

Example I: Topologies with Density c

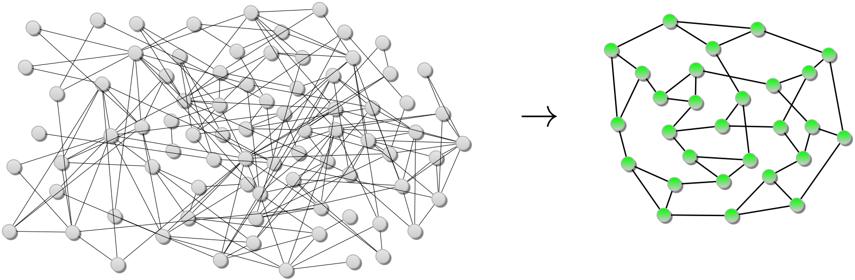
- ILP problem: Binary indicator variable $x(u)$ for node u of $G_{\hat{\lambda}}$

$$\max_{x} \sum_{u \in V} x(u) \quad \text{s.t.}$$

$$c\,x(u) \leq \sum_{v \in \mathcal{N}_{u,\hat{\lambda}}} x(v) \leq c + (m - c)(1 - x(u)) \quad \forall u \in V$$

- Solution gives maximal subset of V such that induced graph is regular of degree c

Application



Example II: Tree Topology with Given Shape

- Goal
  - Tree with root v_0 such that number of nodes with distance δ from v_0 equals $\kappa(\delta)$
- Examples
  - $\kappa(\delta) = \delta + 1$: Breadth of tree increases
  - $\kappa(\delta) = 1$: Linear topology
- Additional requirement: Make topologies robust against fluctuations
  - There are no links with $\Lambda_{a,b} \leq \hat{\lambda} + \Delta$ that would change topology if conditions change slightly

Example II: Tree Topology with Given Shape

procedure MonitoredBFS($V, E, v_0, \hat{\lambda}, \Delta, \kappa$)

  $V_{sub}(0) \leftarrow \{v_0\}, \delta \leftarrow 0$

  do

    $V_{sub}(\delta+1) \leftarrow \{\}$

    for all $u \in V_{sub}(\delta)$ **do**

      for all $v \in \mathcal{N}_{u,\hat{\lambda}}$ **do**

        if $v \notin \bigcup_{i=0}^{\delta+1} V_{sub}(i)$ **then**

          if $\mathcal{N}_{v,\hat{\lambda}+\Delta} \cap \bigcup_{i=0}^{\delta-1} V_{sub}(i) = \emptyset$ **then**

            $V_{sub}(\delta+1) \leftarrow V_{sub}(\delta+1) \cup \{v\}$

    $\delta \leftarrow \delta + 1$

  while $|V_{sub}(\delta)| \geq \kappa(\delta)$

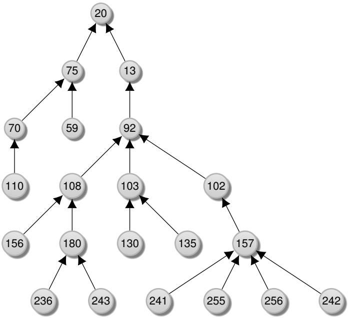
  $V_{sub}(\delta) \leftarrow \{\}, \delta_{\text{best}} \leftarrow \delta - 1$ ▷ remove partially filled layer

  return $(\delta_{\text{best}}, V_{sub})$

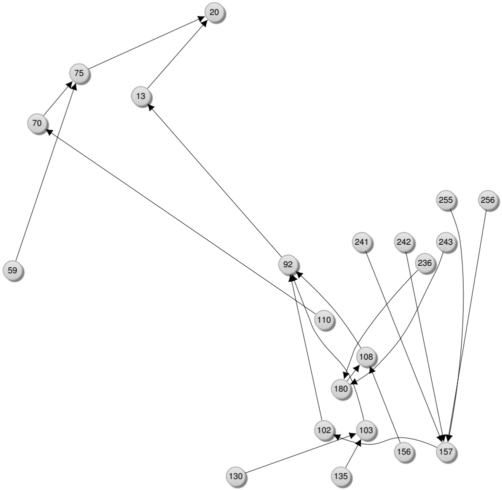
Example II: Tree Topology with Given Shape

- Constructed graphs can be very large
- Procedure to reduce number of nodes, while maintaining requirements is based on ILP
  - Strip away all nodes not on a path to a higher depth with additional constraint of maintaining $\kappa(\delta)$ nodes for depth δ

Application: Tree of Depth 5 at Lille Site



Real Positions of Lille Tree



FIT/IoT-LAB Testbed Overview

Testbed	Nodes (available)		$\kappa(\delta) = \delta + 1$			$\kappa(\delta) = 1$		
			$\Delta = 15$	$\Delta = 10$	$\Delta = 5$	$\Delta = 15$	$\Delta = 10$	$\Delta = 5$
Grenoble	364	δ_{best}	8	13	15	15	37	38
		$\hat{\lambda}$	73-74	70	69-73	71	69	61
Lille	229	δ_{best}	5	7	8	8	10	12
		$\hat{\lambda}$	70-74	73-74	64-70	64-74	64-66	67-69
Paris	69	δ_{best}	2	3	4	3	5	9
		$\hat{\lambda}$	46-66	49-53	48-51	46-49	49	48
Strasbourg	63	δ_{best}	2	3	4	3	4	7
		$\hat{\lambda}$	48-74	50-57	49-56	50-53	46-52	51-52
Lyon	17	δ_{best}	-	2	2	2	2	4
		$\hat{\lambda}$		54-58	49-63	45-60	45-65	51
Saclay	12	δ_{best}	-	2	2	2	3	4
		$\hat{\lambda}$		46	46-51	45-51	46	46

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Conclusion

Conclusion & Outlook

- Proposal to generate multi-hop topologies in dense wireless network testbeds
- Based on measurements of signal strengths power and sensitivity values are selected
- Suitable subsets of nodes are selected using ILP

- Future work
  - More node selection methods
  - Application to more testbeds

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