The IPv6 Routing Protocol for Low-power and Lossy Networks (RPL) under Network Partitions

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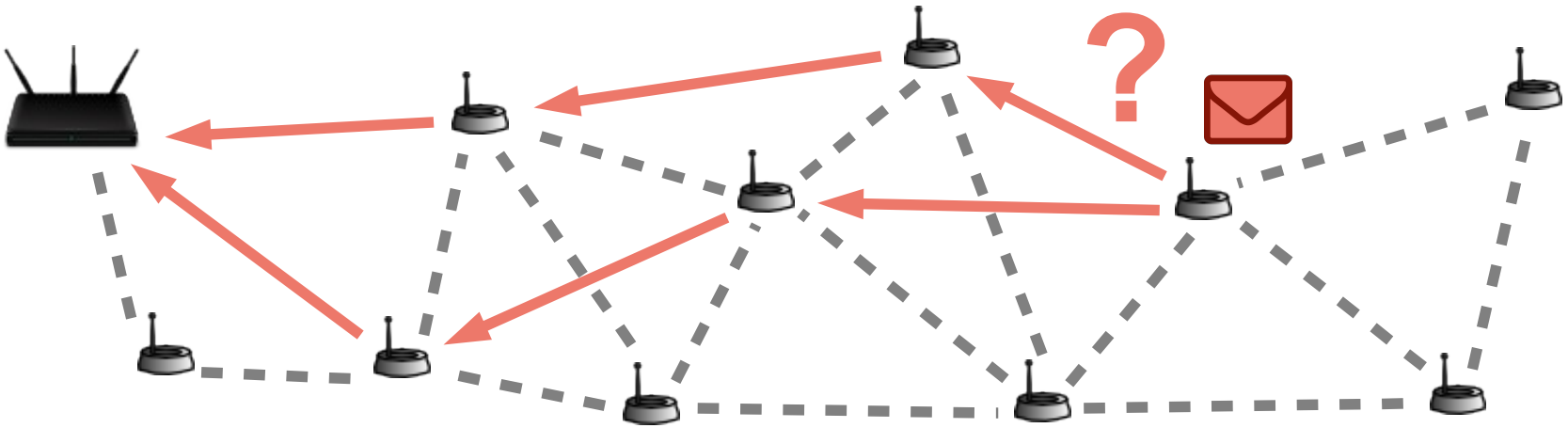
Introduction

- A routing protocol finds paths in a network along which data can be sent.
- RPL [*RFC 6550 and several more*] is the current standard for routing in low-power wireless networks:
  - A lot of research attention.
  - Several implementations (e.g., ContikiRPL & TinyRPL).
- In industrial apps, routing protocols must be reliable.
- Our work aims at improving RPL's reliability.



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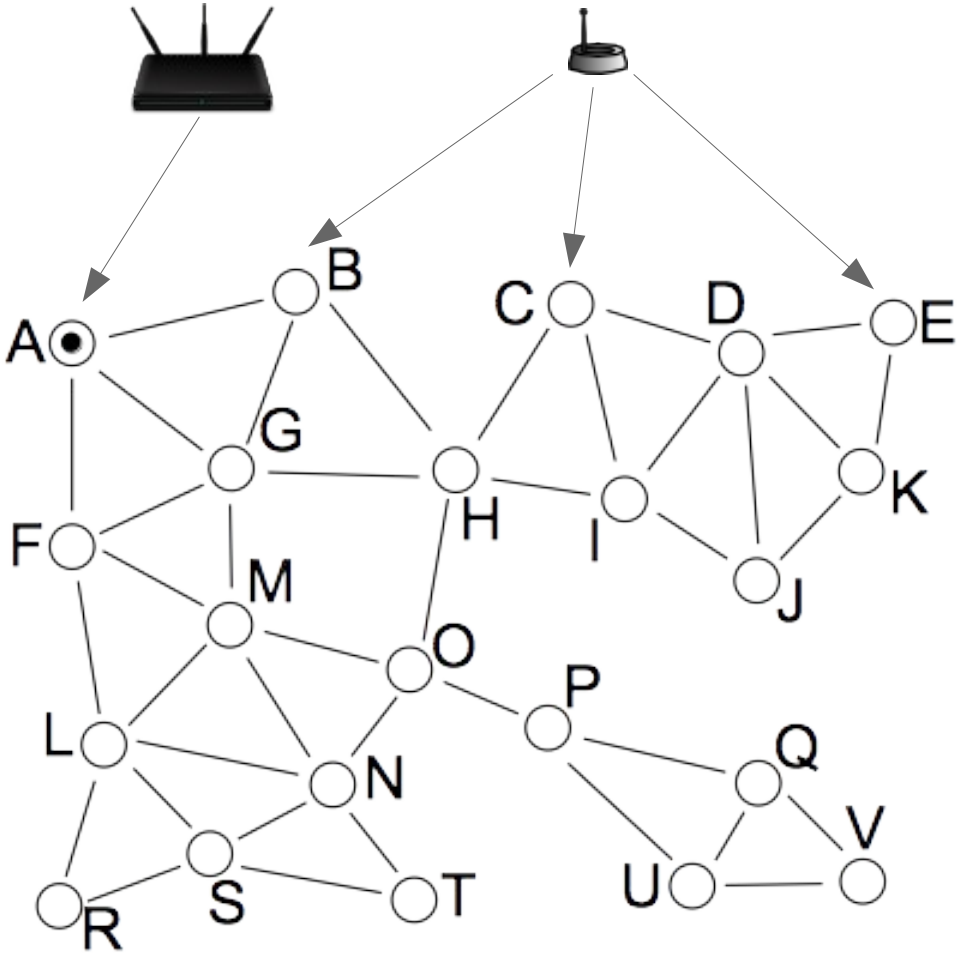

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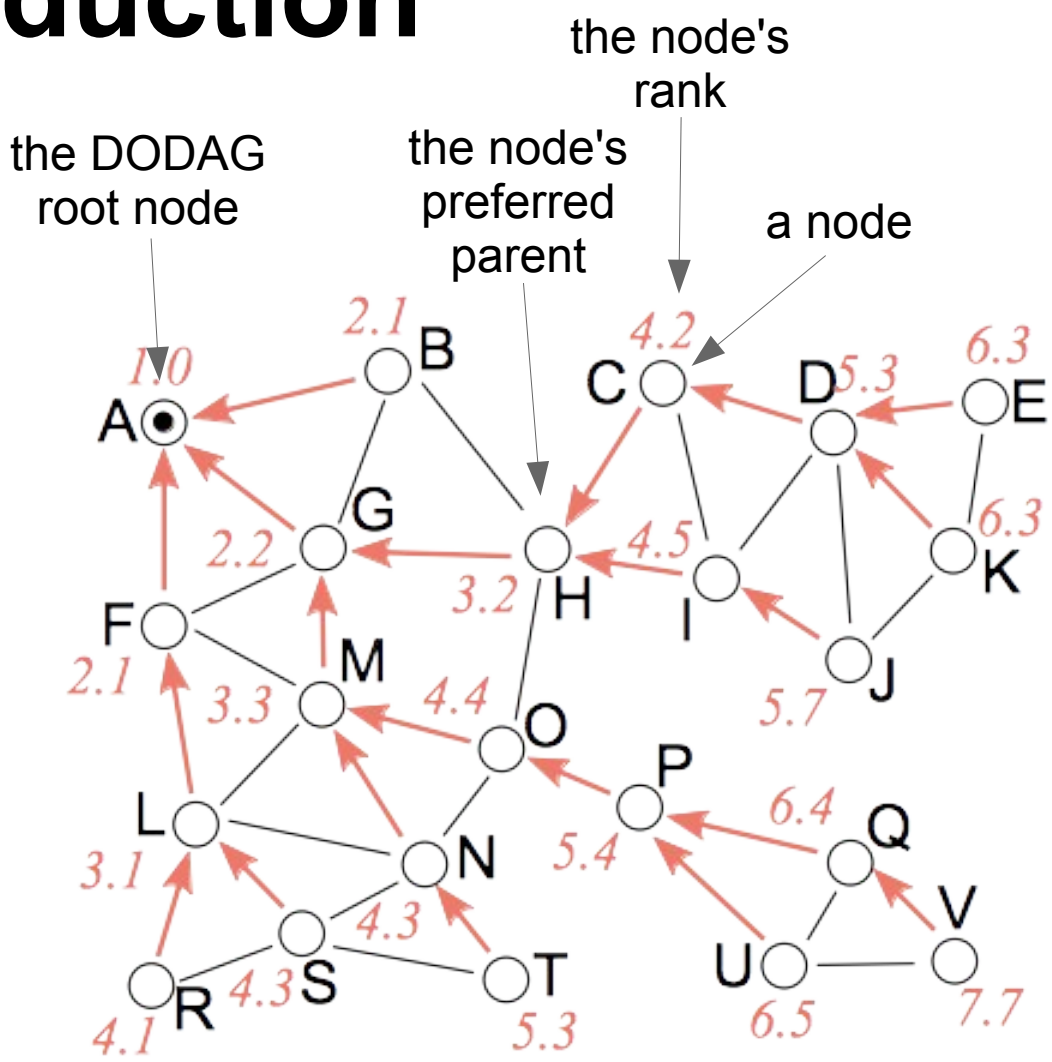

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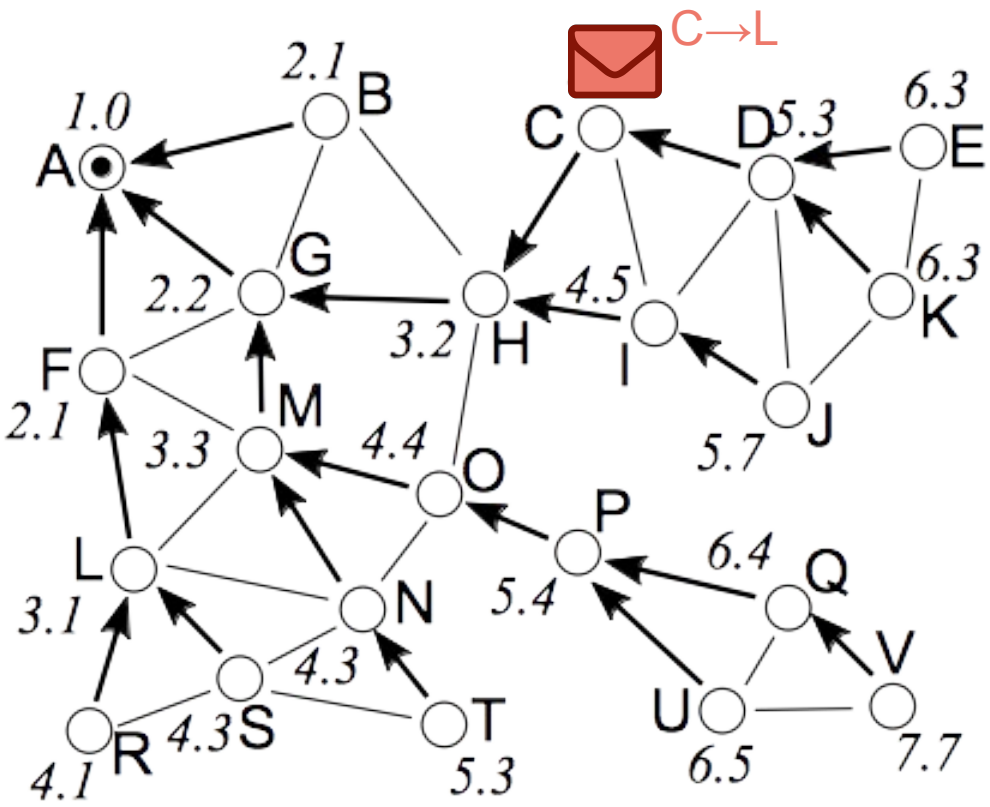

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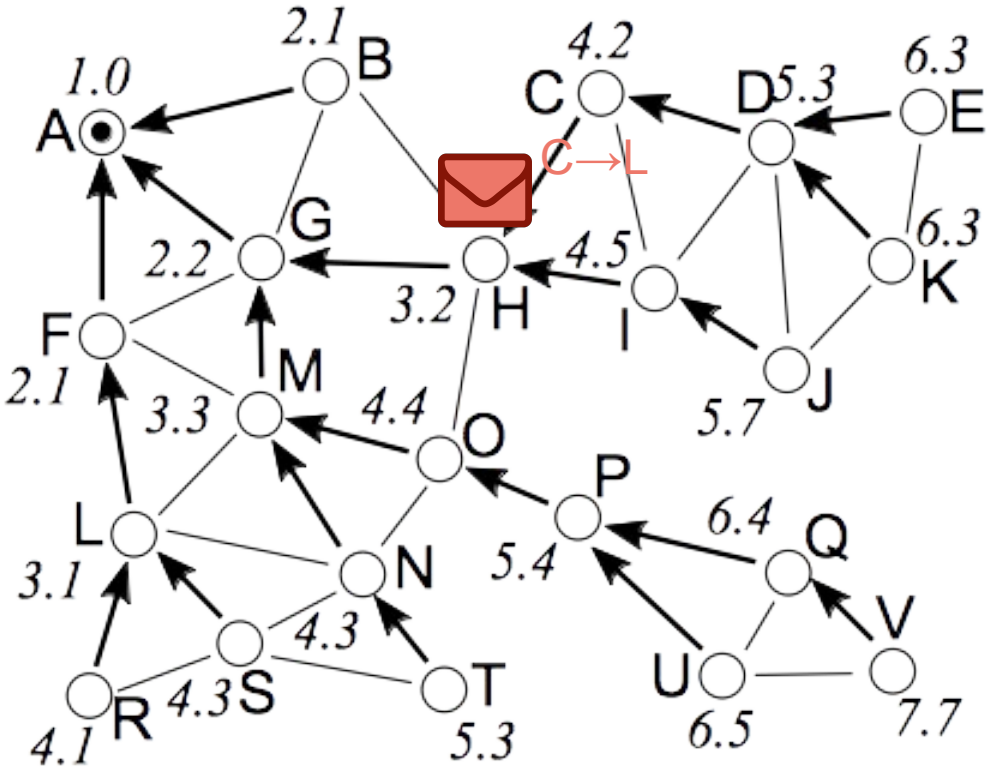

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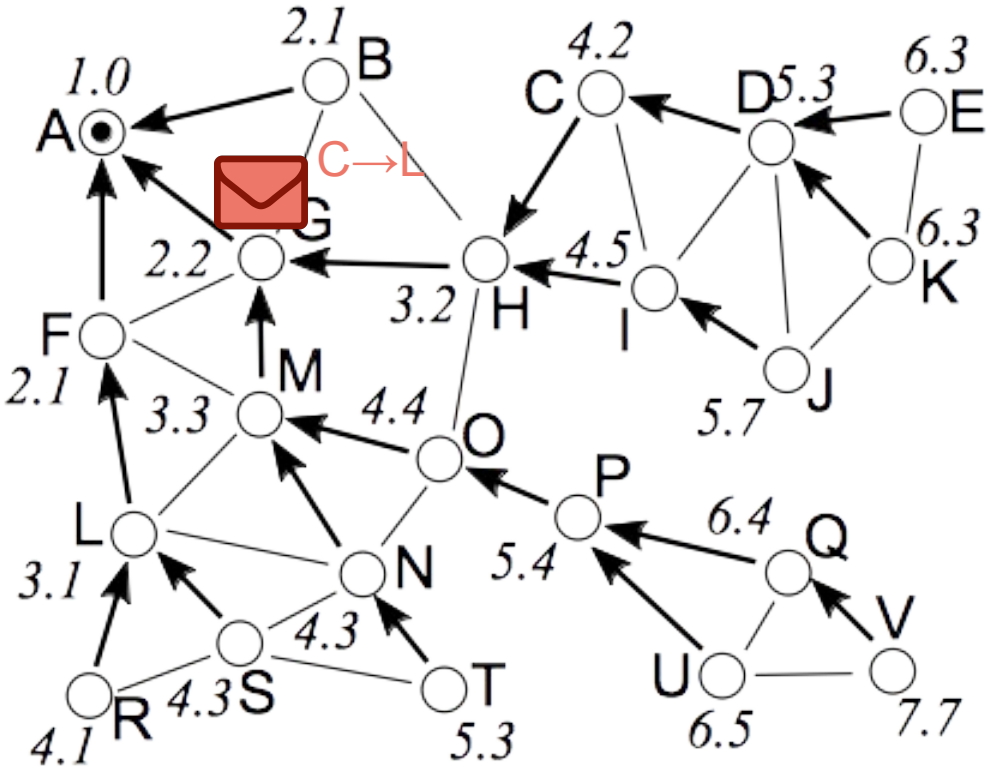

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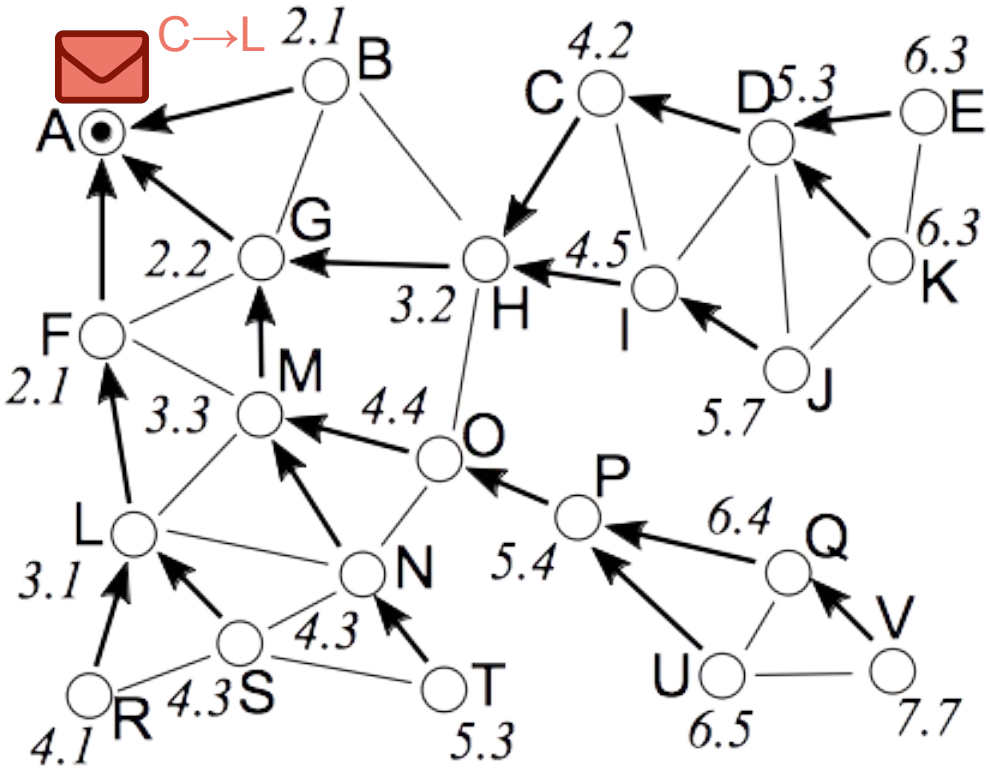

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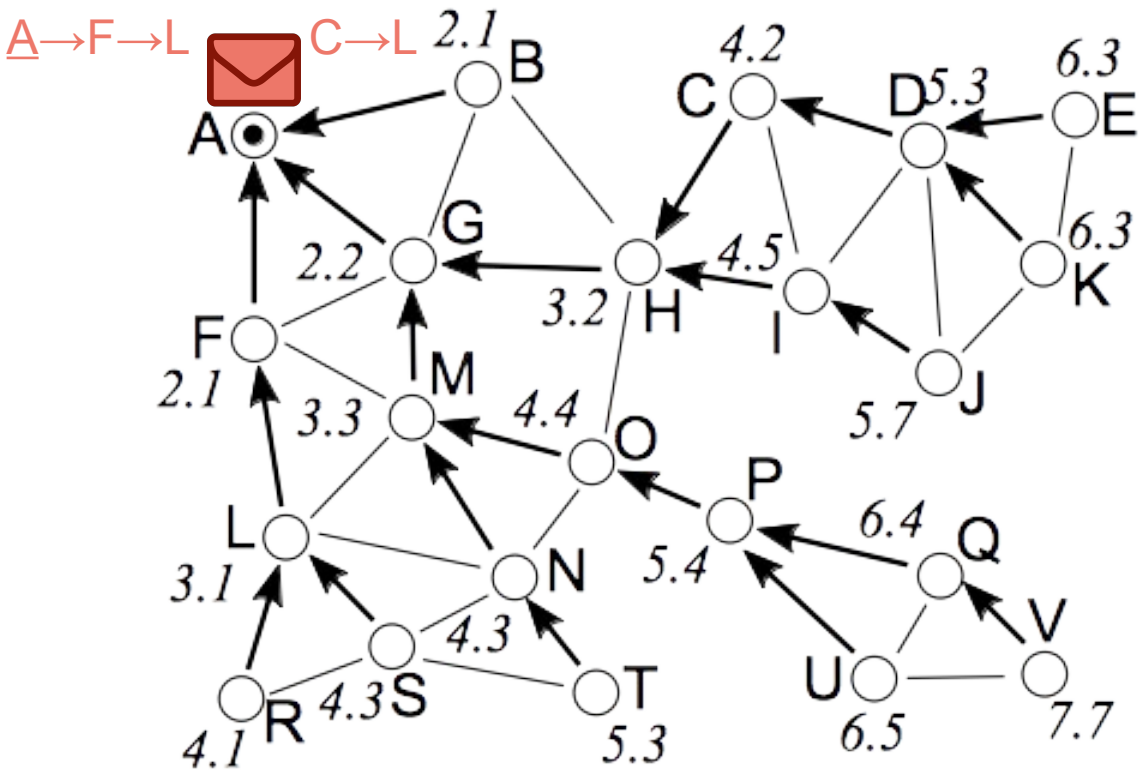

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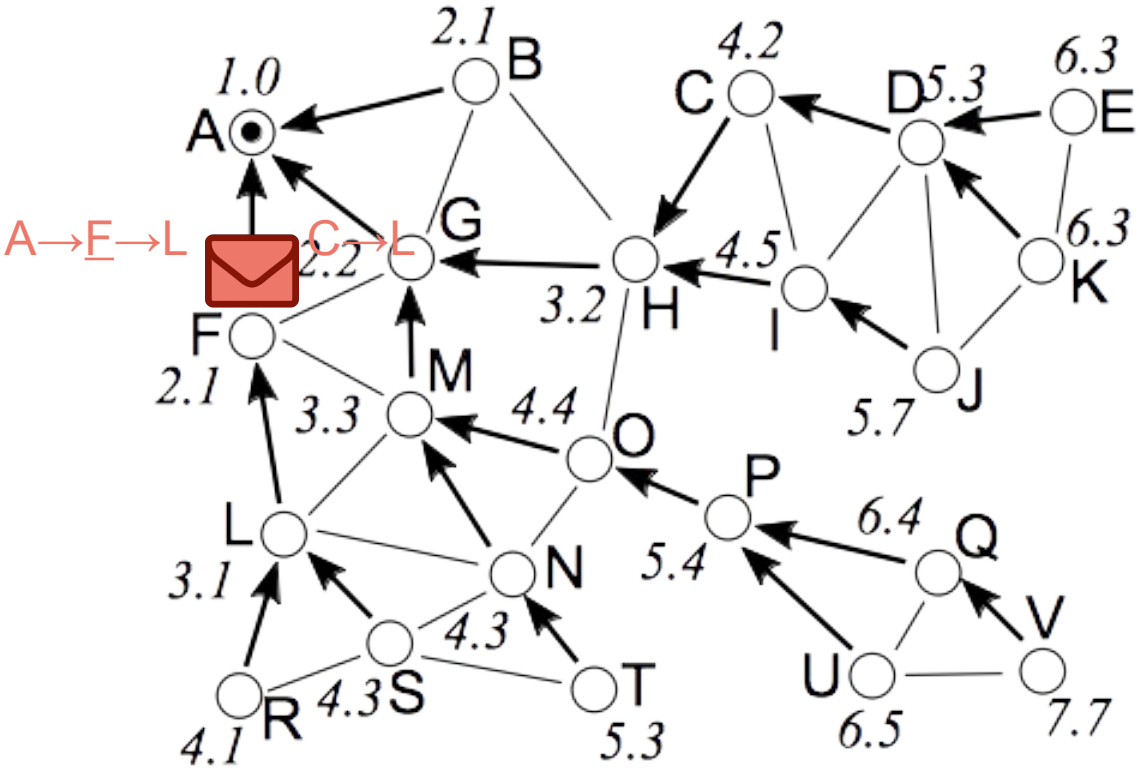

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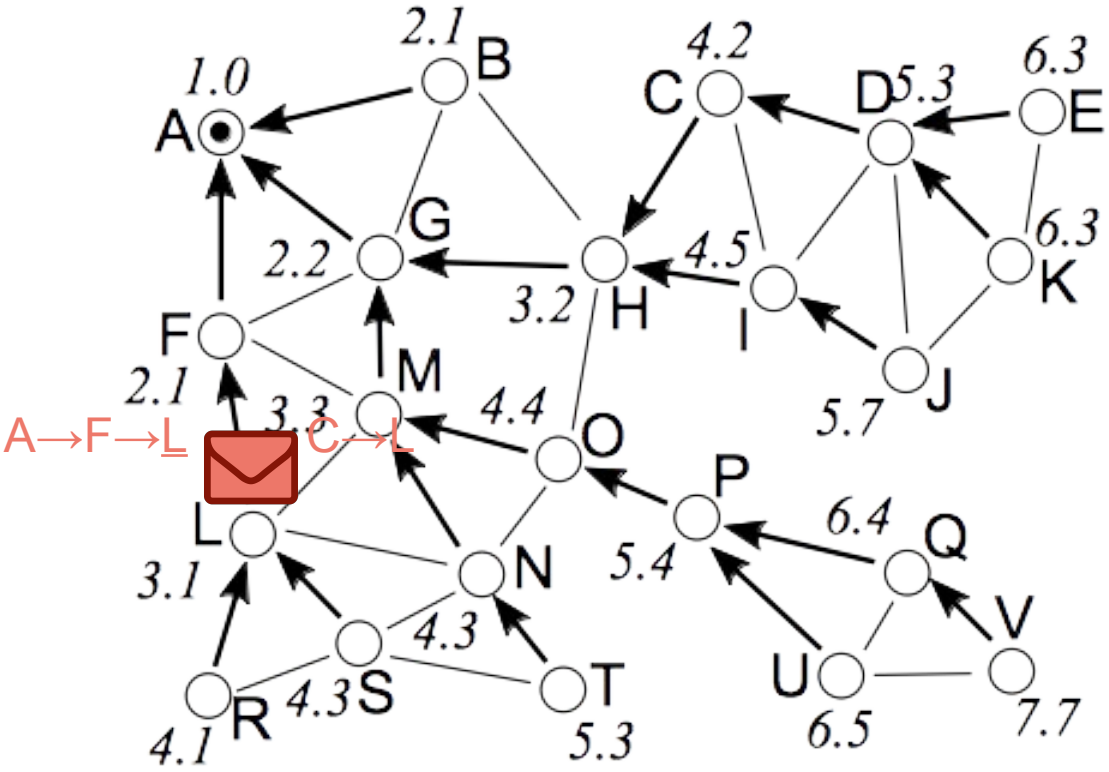

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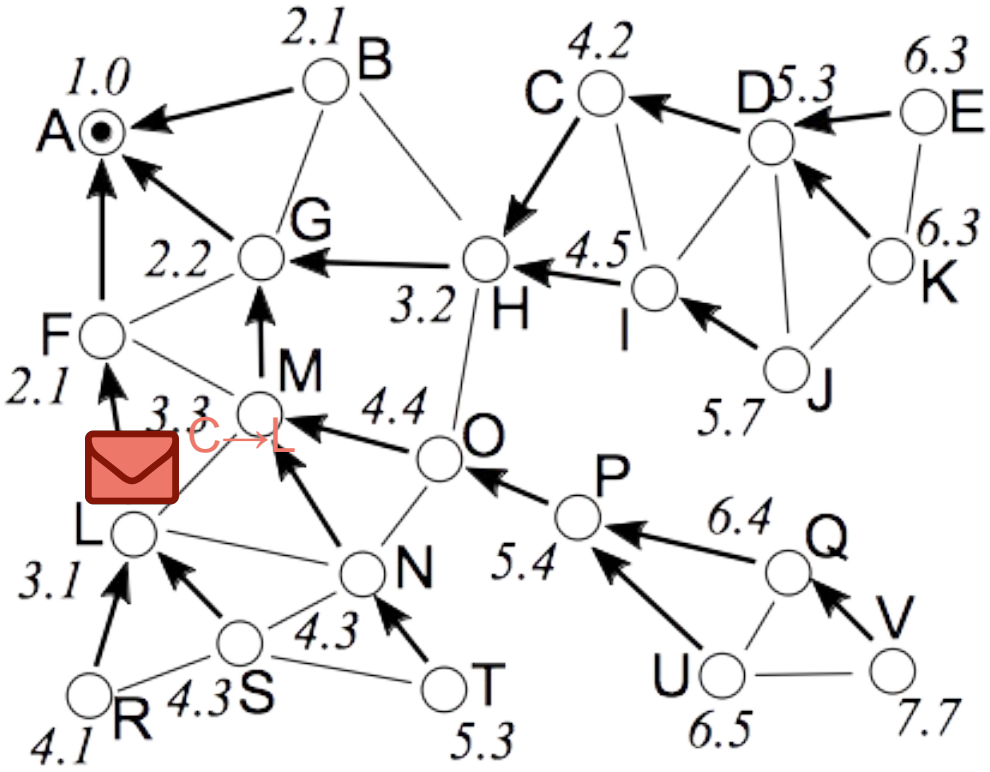

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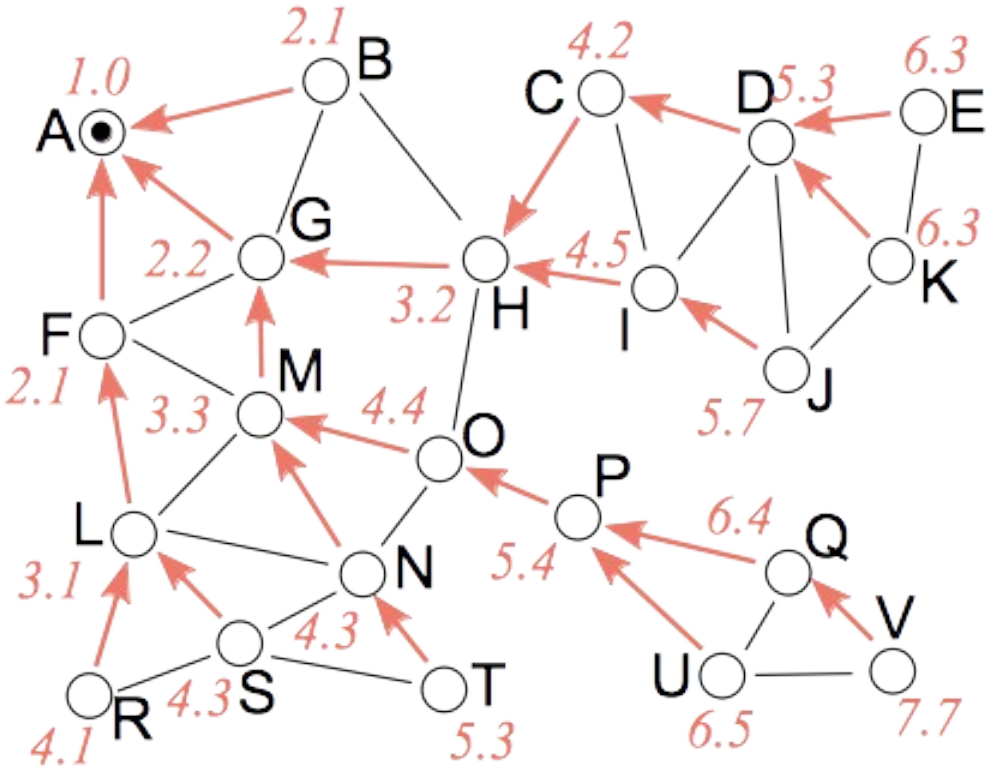
- The maintenance of the DODAG is RPL's major task:



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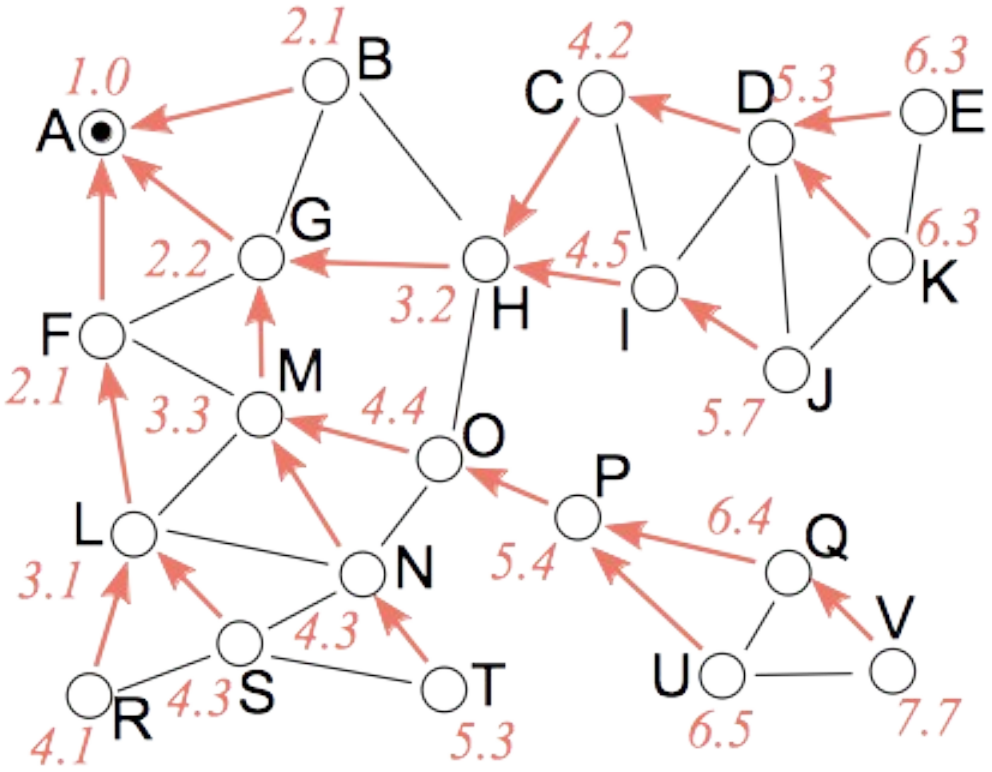

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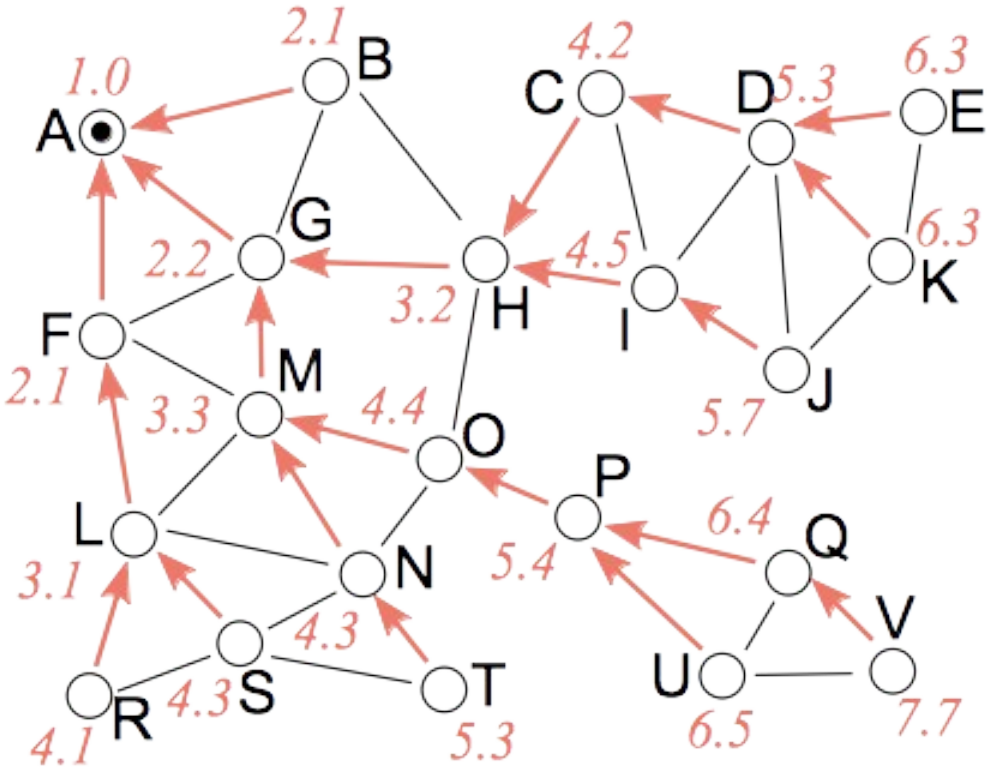

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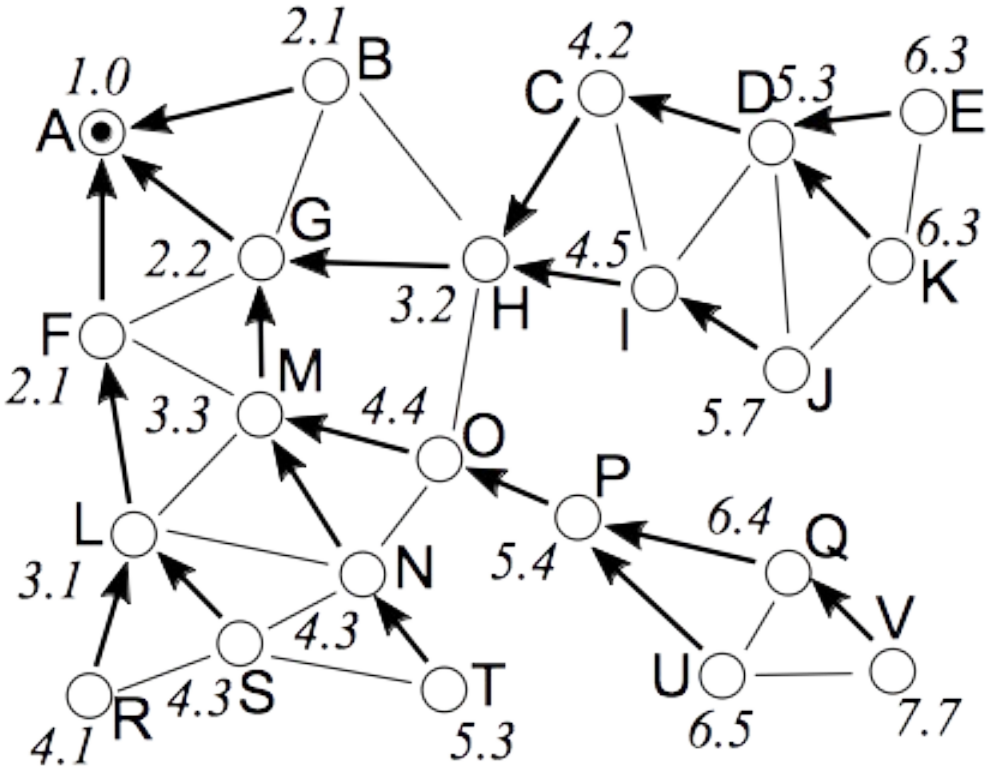
- RPL routes in a so-called **DODAG**.
- The maintenance of the DODAG is RPL's major task:
  - The quality of the links changes continuously.
  - Nodes may fail and recover.
- We are concerned with hard-to-handle failures: **network partitions**.

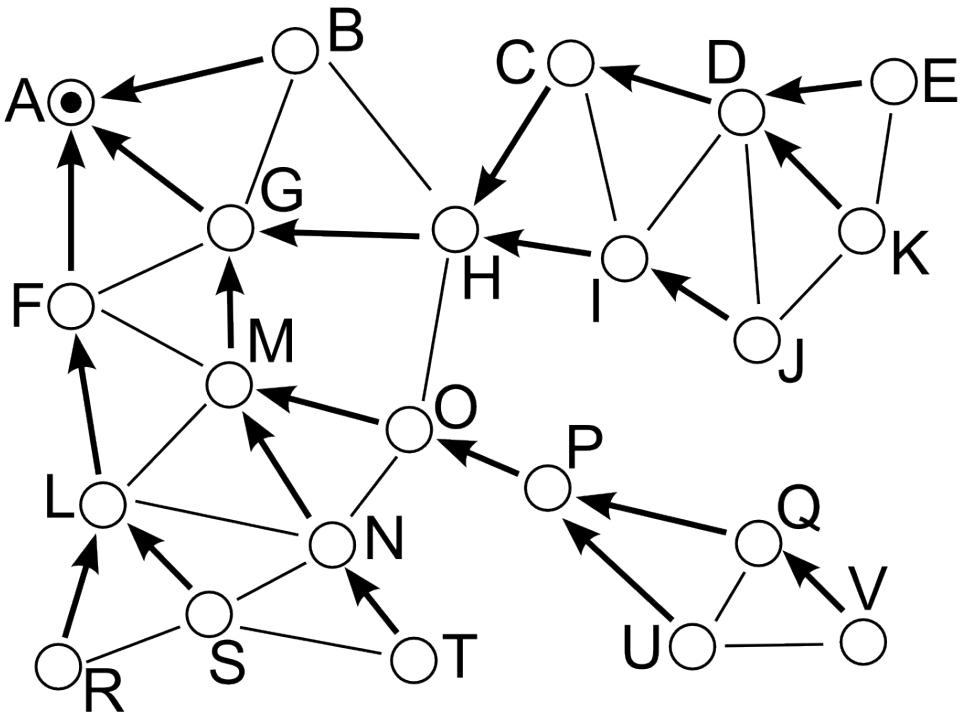


Problem

A network is **partitioned** / **split** / **disconnected** if and only if it contains two working nodes between which no path exists via the DODAG root.

Problem

A connected network.



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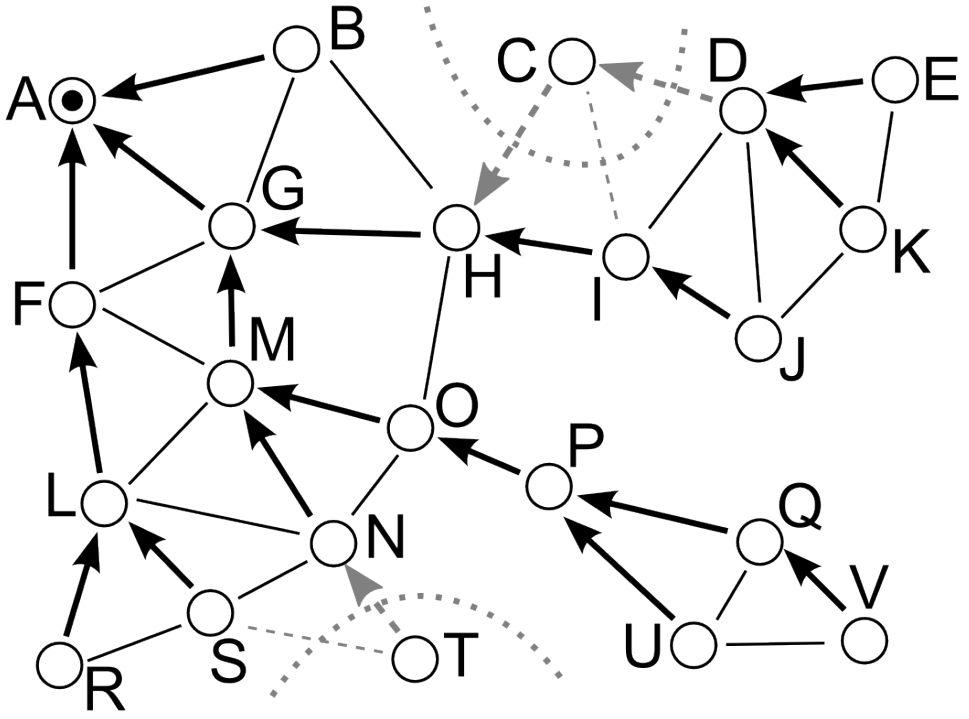
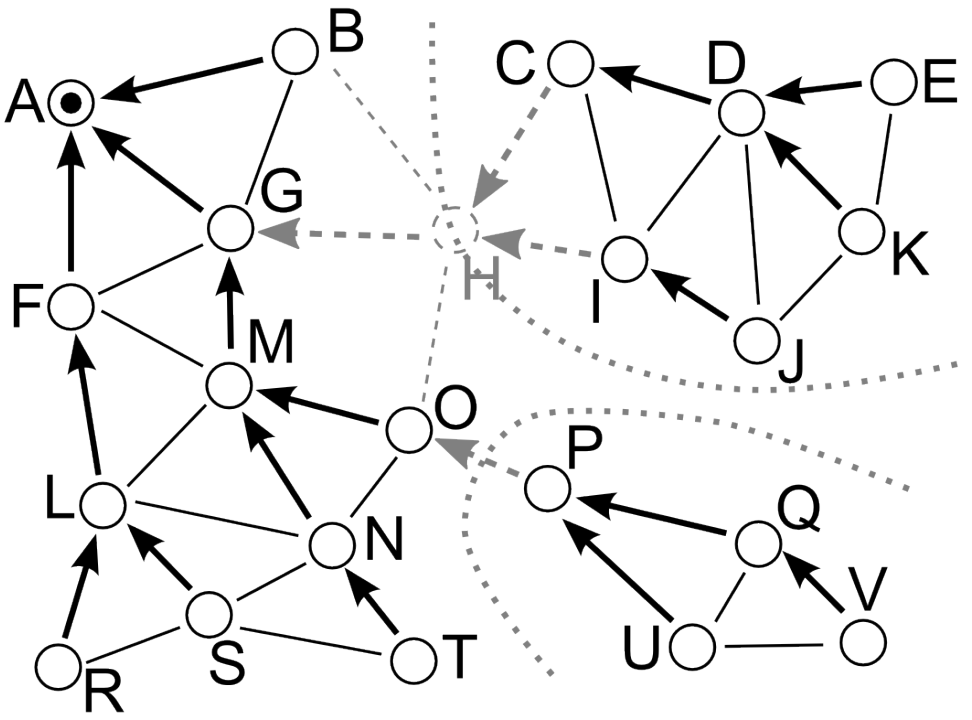


Isolated nodes.

Problem

Multi-node partitions.



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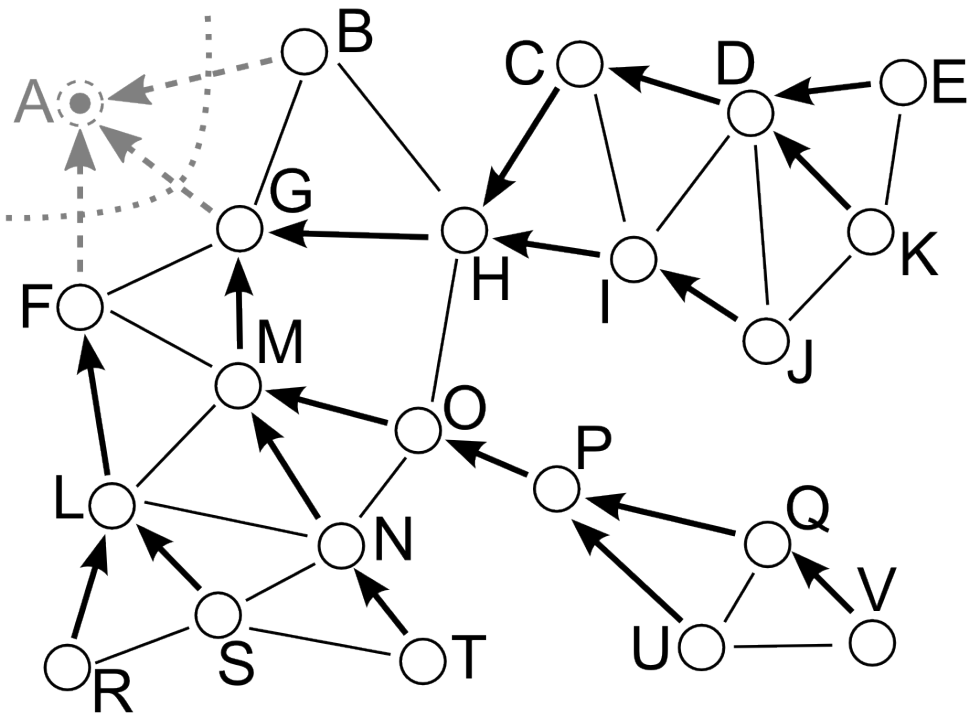


The DODAG root's crash.

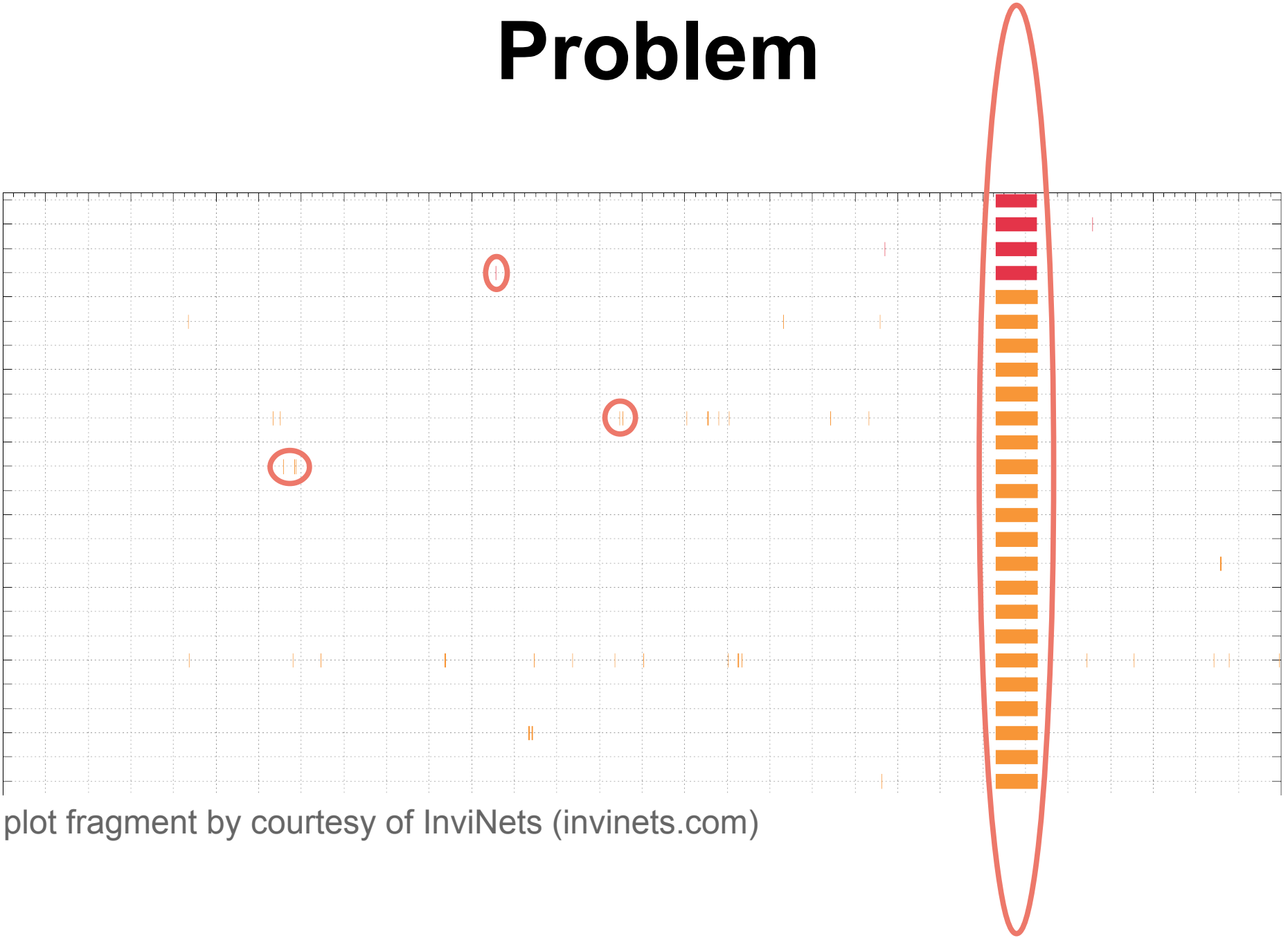
Problem

How relevant is the problem?

Problem

photos by courtesy of InviNets (invinets.com)

Problem



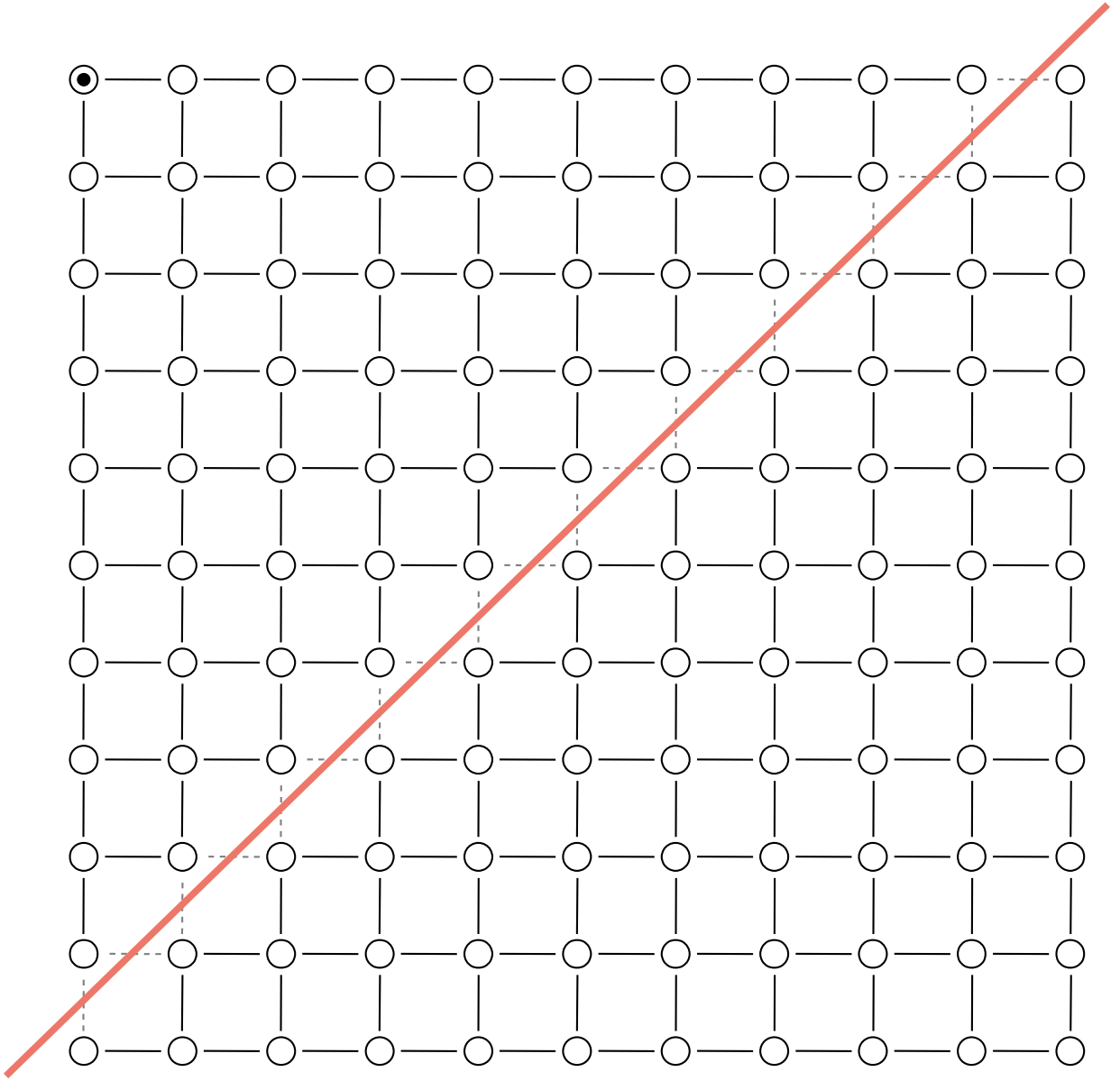
plot fragment by courtesy of InviNets (invinets.com)

RPL Implementations & Partitions

Let us illustrate the behavior of RPL's two popular implementations:

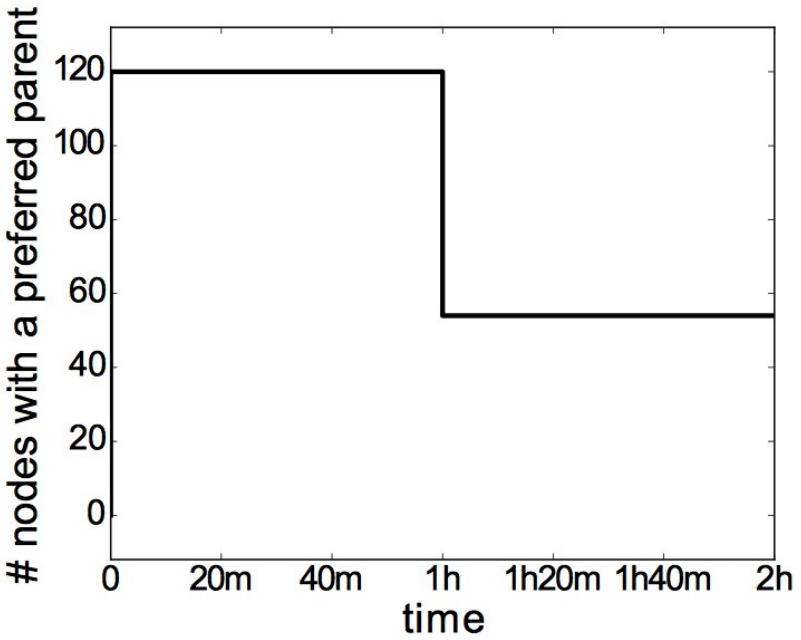
- ContikiRPL
- TinyRPL

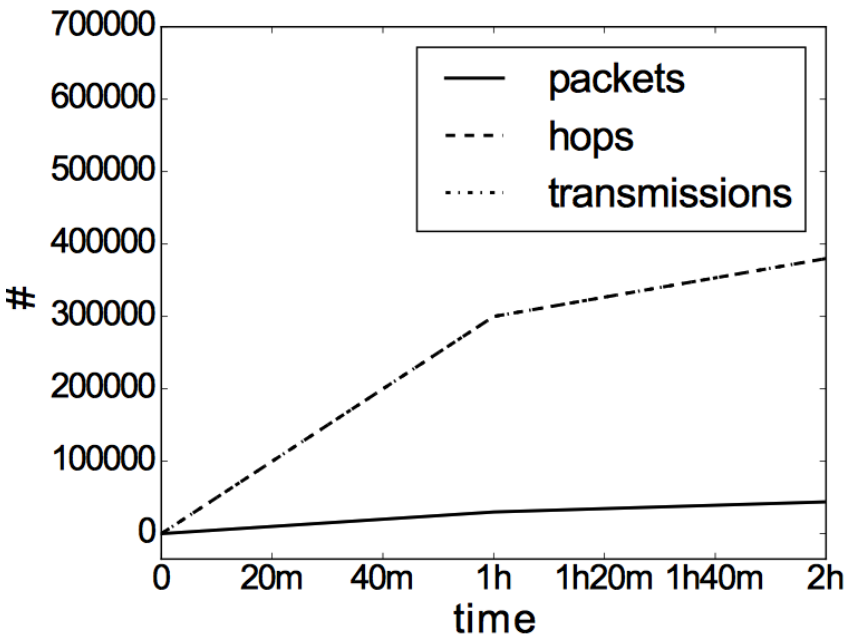
in a sample simulated network partition scenario.



RPL Implementations & Partitions

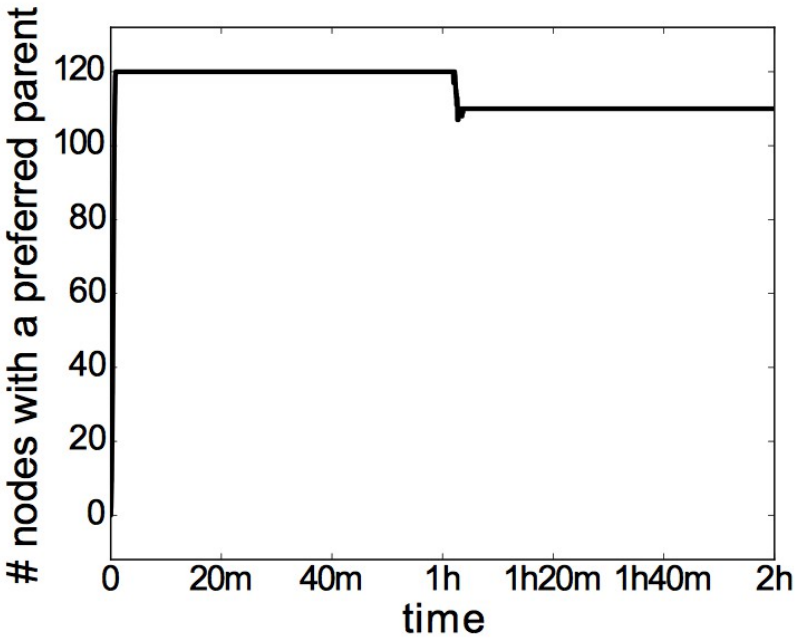
Expected behavior

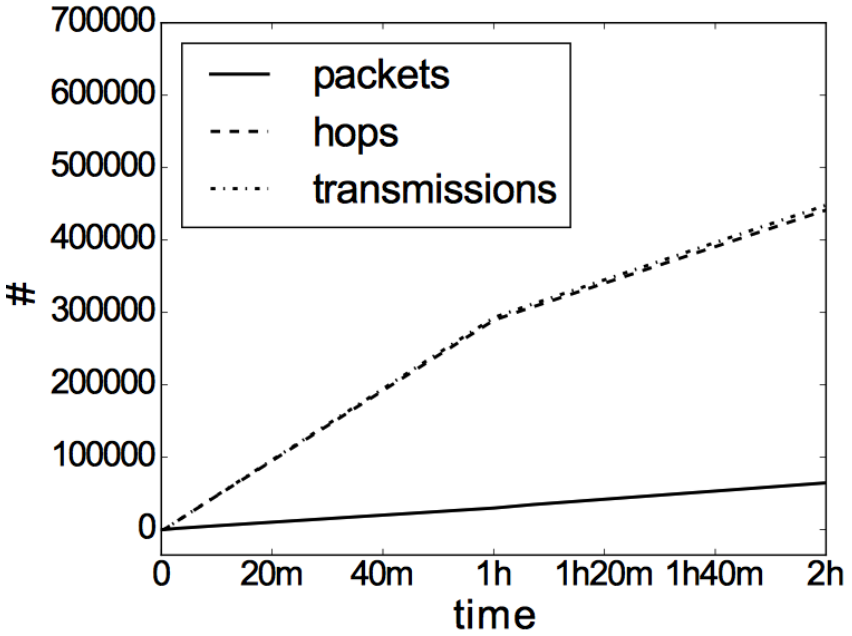




RPL Implementations & Partitions

ContikiRPL's behavior





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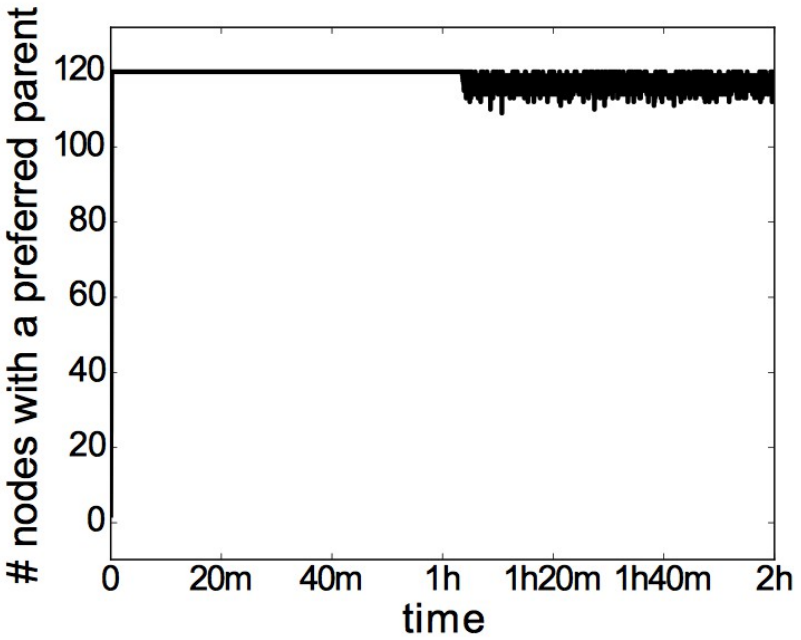
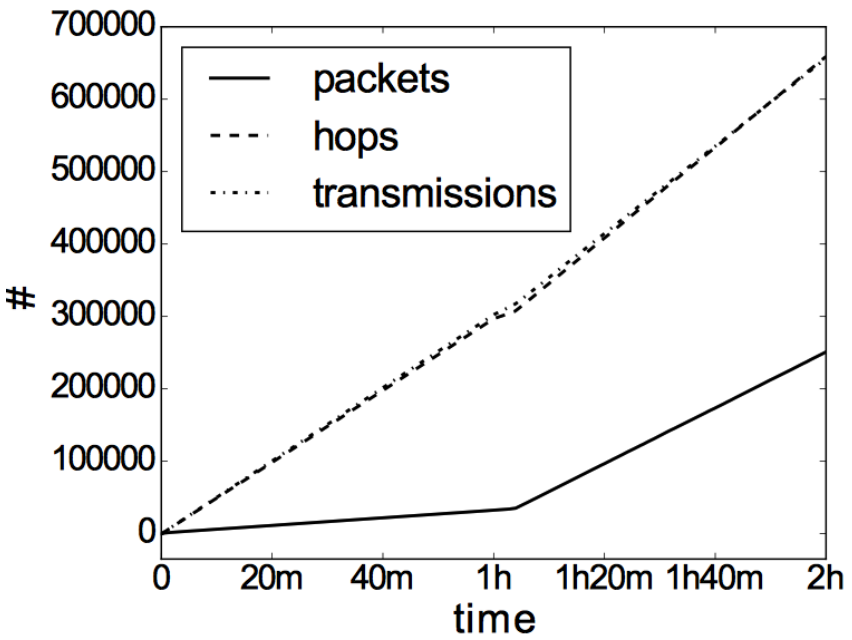
TinyRPL's behavior





RPL Implementations & Partitions

Is this behavior of RPL's implementations due to:

- bugs in those implementations *OR*
- some features or RPL's design itself?

Analyzing RPL

- We developed a model:
  - using a LTL-like formalism;
  - based on RPL's specification;
  - in abstraction from the issues the specification leaves open to implementations;
  - captures RPL's dynamic behavior.
- Using the model we formulated a hypothesis that RPL is able to handle network partitions.
- We subsequently attempted to prove the hypothesis.

Analyzing RPL

Property examples:

RA1: Always, if a node's *NeighborSet* changes (i.e., entries are added or removed, or their fields are modified), then the node will eventually reselect its *PreferredParent* and *Rank*.

RA3: If a node's neighbor is eventually always non-adjacent, then an entry, *n*, with this neighbor's identifier as *n.Id* will eventually always either be absent from the node's *NeighborSet* or have its *n.Reachable* field set to *False*.

OF2: A node's *MinRank* is always equal to the minimal value of the node's *Rank* so far.

DIO2: If a node's neighbor is always eventually adjacent, then the node will always eventually receive a DIO message from this neighbor.

Analyzing RPL

Main hypothesis:

Hypothesis 1: If an always-eventually-live node is eventually always partitioned from the DODAG root, then eventually always, whenever the node is live, its *PreferredParent* and *Rank* will be equal to *Null* and *Infinity*, respectively.

Analyzing RPL

Proof scheme:

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3. Show that, from some moment in time, the aforementioned minimum will repeatedly increase (Lemma 3).
4. Show that a node's rank cannot increase infinitely (Lemma 4).

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RPL's implementations fail to handle partitions.

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We analyzed the two implementations for the violations of our properties.

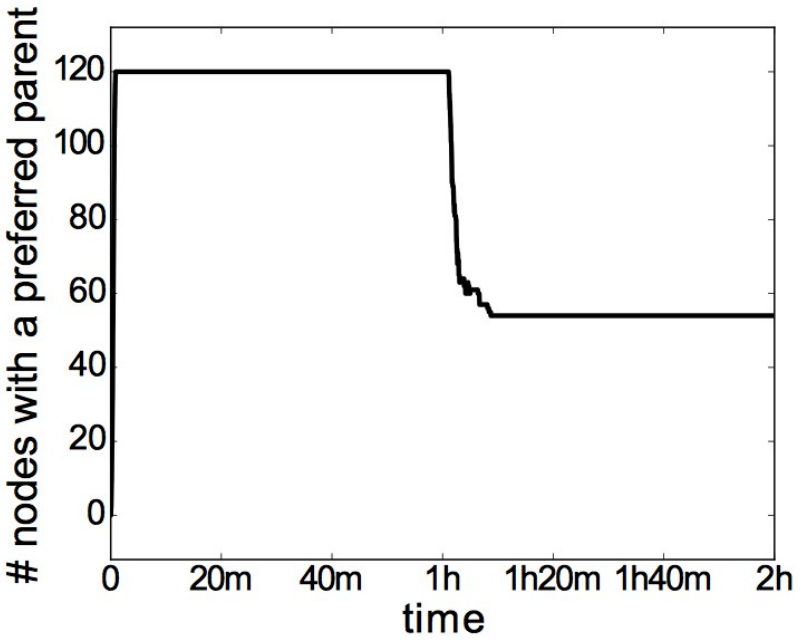
Application of the Results

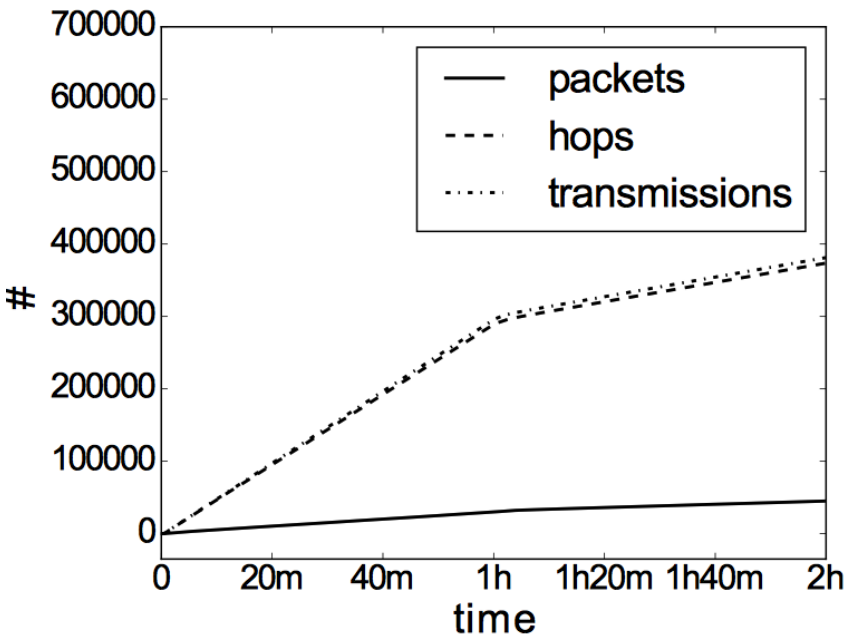
Property	Is property not violated in the source code?	
	ContikiRPL	TinyRPL
RA1	yes	NO
RA2	yes	yes
RA3	NO	yes
OF1	yes	yes
OF2	NO	NO
OF3	yes	yes
OF4	yes	yes
OF5	yes	yes
DIO1	yes	yes
DIO2	yes	NO
DIO3	yes	yes

We patched these bugs.

RPL's Behavior after the Fixes

ContikiRPL's behavior





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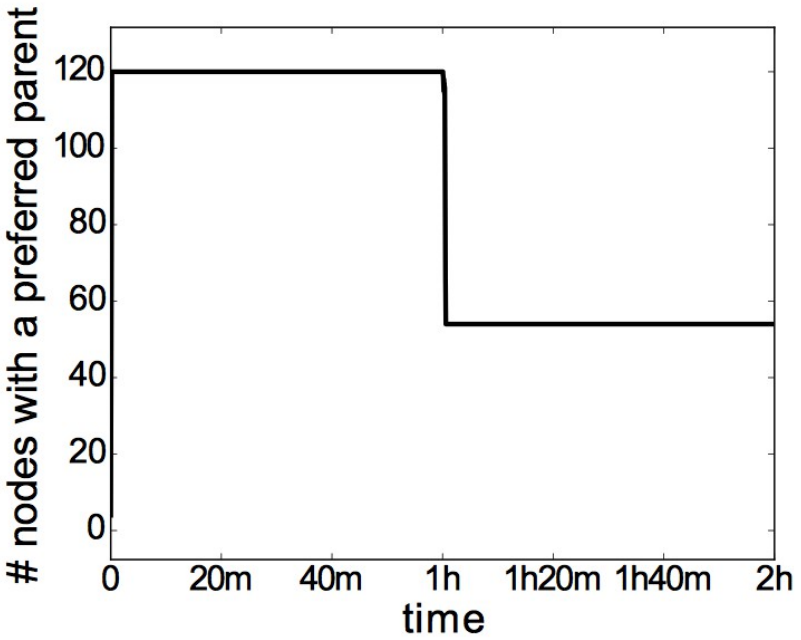
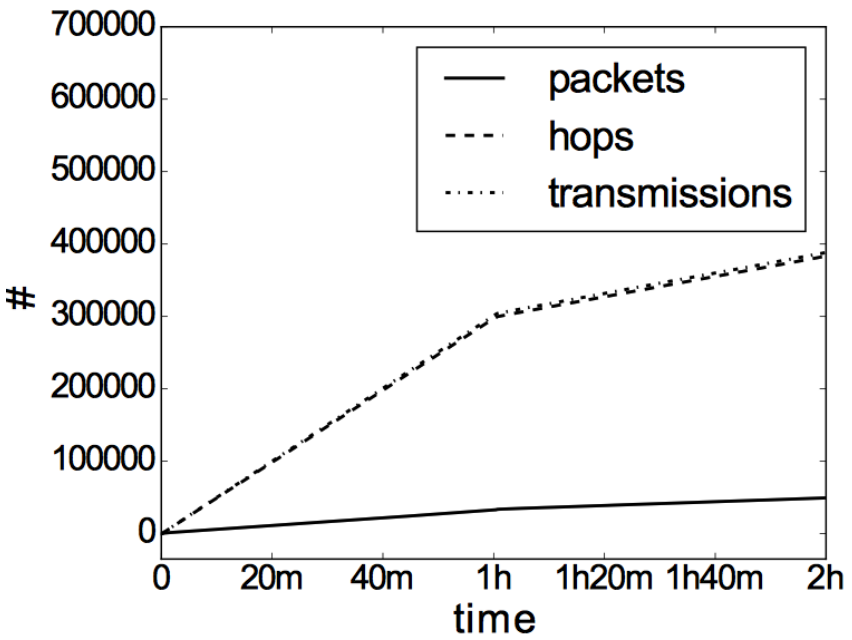
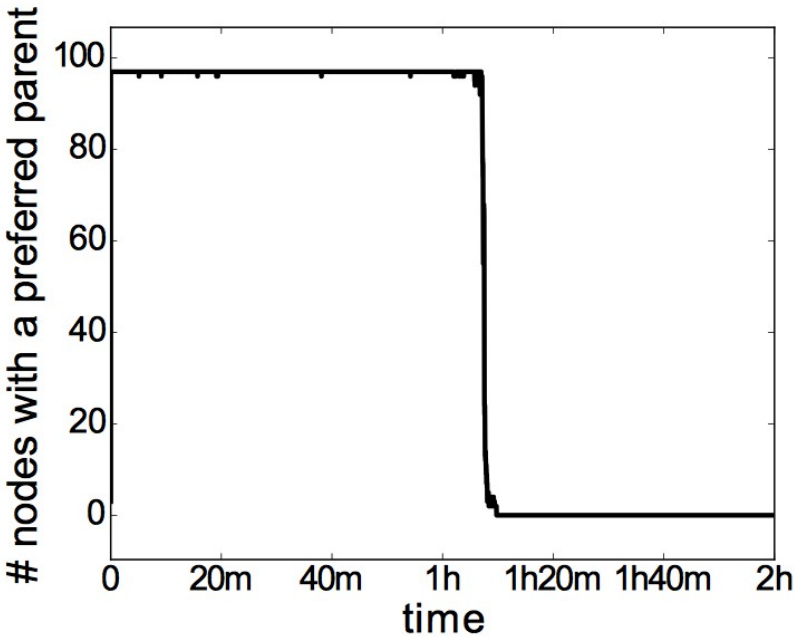
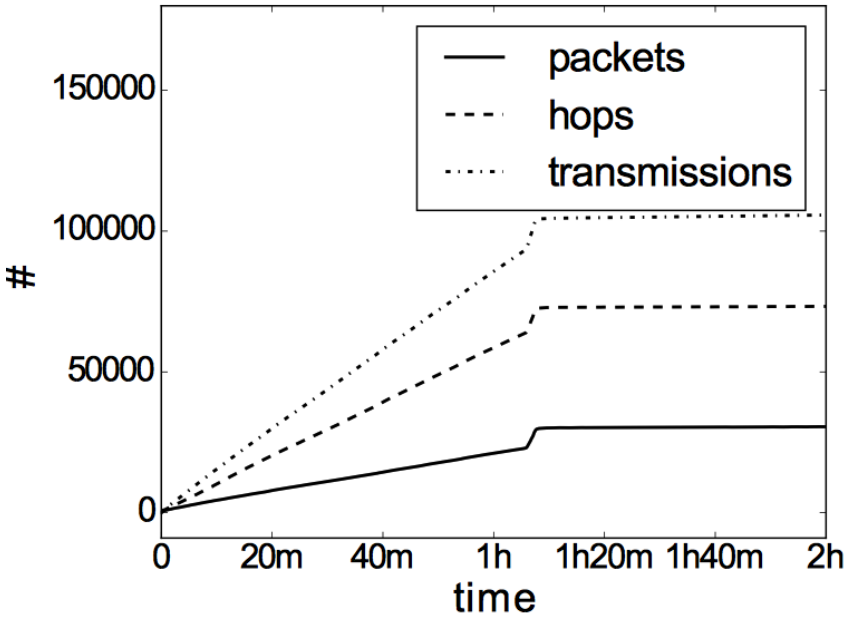




RPL's Behavior after the Fixes

TinyRPL on Indryia with the DODAG root's crash





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  - Others concerned issues that are left open in RPL's spec.
- The overall conclusion is that despite the seeming maturity of RPL's implementations, their reliability leaves room for improvement.

Thank you

Questions?

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The National Centre
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