Polymorphical wireless communication for connected agriculture

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Focus & Outline

Cooperation between multiple RPL networks
with Julien Montavont (University of Strasbourg)

1. Scientific context
   - Internet of Things
   - RPL: routing in the IoT
   - Inherent issues in RPL
2. State of the art
3. Contribution
4. Experimentation
5. Conclusion

Internet of Things (IoT)

Set of constrained objects interconnected with the Internet via wireless communications

Many constraints

- Size & weight
- Computation power
- Memory storage
- Battery → limited energy
- Plus application dependant constraints...

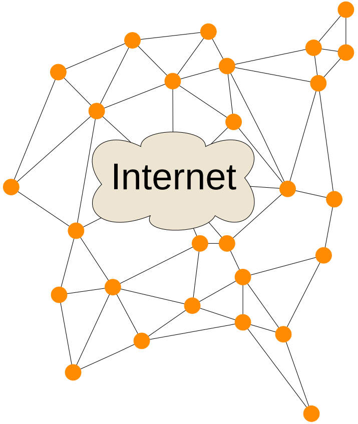

Figure 1: IoT network

IoT Stack

New usages, new standards

- Classic IP protocols not efficient with IoT devices
- Specialized standards from the IEEE and the IETF

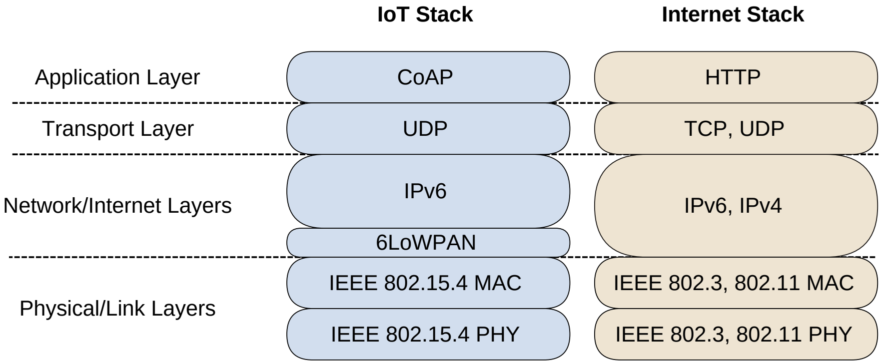

Figure 2: New IoT network procotol stack

RPL: routing in the IoT [WTB12]

- Proactive intra-domain distance-vector routing protocol
- Destination Oriented Directed Acyclic Graph (DODAG)
- Metrics: Hop count, Expected Transmission Count (ETX)...
- Traffic patterns: multi-point to point, point to multi-point, point to point

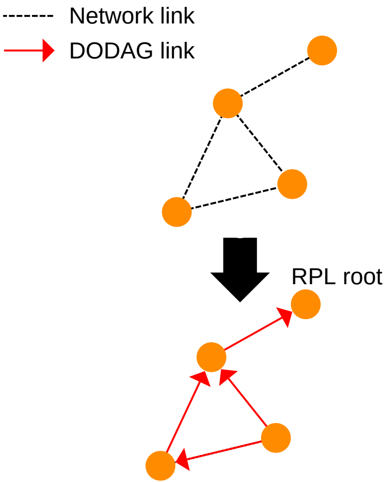

Figure 3: Physical and logical topology

[WTB12] T. Winter et al. *RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks.* RFC 6550. Mar. 2012

RPL inherent issues

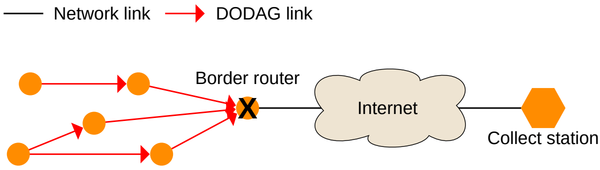

Figure 4: Border router failure

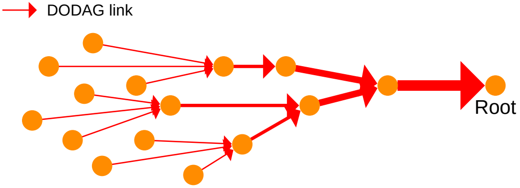

Figure 5: Funneling effect [WEC05]

[WEC05] Chieh-Yih Wan et al. "Siphon: Overload Traffic Management Using Multi-radio Virtual Sinks in Sensor Networks". In: *Proceedings of the 3rd International Conference on Embedded Networked Sensor Systems*. ACM, 2005

Border router redundancy

Common solution to both border router failure and funneling effect

- *Orphan nodes redirect traffic to another border router*
- *Multiple exit points → traffic shared between multiple paths*

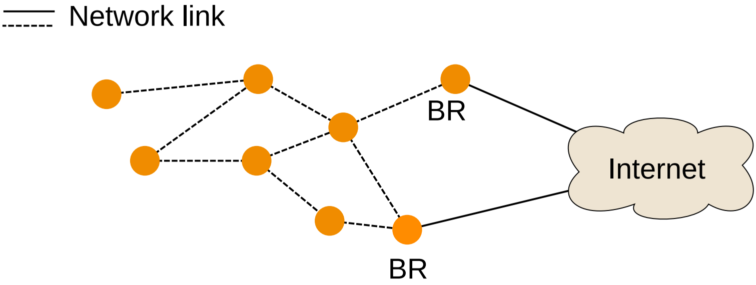

Figure 6: Border router redundancy

Outline

Virtual DODAG root

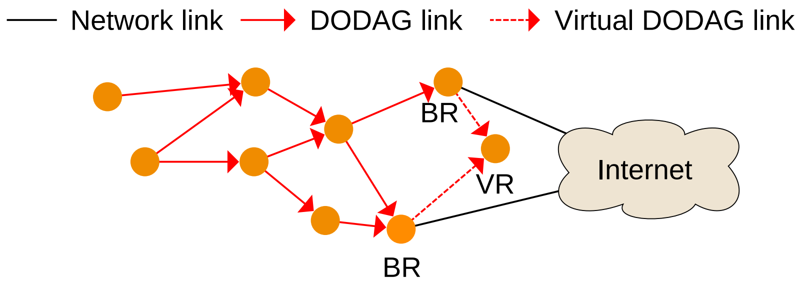

Figure 7: Virtual DODAG root example

- Multiple DODAG roots coordinated to act and appear as a single root
- No full specification → open question

Multiple sinks in literature

- Virtual root proposals in [GZL15; DDO14; CDP14; NMM16]
- Border router failure resilience & load balancing

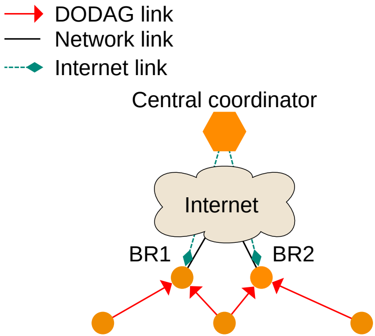

Figure 8: Central coordination

[GZL15] Wei Ge et al. "Implementation of multiple border routers for 6LoWPAN with ContikiOS". In: *2015 International Conference on Information and Communications Technologies (ICT 2015)*. Apr. 2015, pp. 1–6

[DDO14] Laurent Deru et al. "Redundant Border Routers for Mission-Critical 6LoWPAN Networks". In: *Real-World Wireless Sensor Networks*. Ed. by Koen Langendoen et al. Springer International Publishing, 2014. ISBN: 978-3-319-03071-5

[CDP14] David Carels et al. "Support of multiple sinks via a virtual root for the RPL routing protocol". In: *EURASIP Journal on Wireless Communications and Networking* 2014.1 (June 2014), p. 91. ISSN: 1687-1499

[NMM16] Quang-Duy Nguyen et al. "RPL Border Router Redundancy in the Internet of Things". In: *Ad-hoc, Mobile, and Wireless Networks*. Ed. by Nathalie Mitton, Valeria Loscri, and Alexandre Mouradian. Springer International Publishing, 2016. ISBN: 978-3-319-40509-4

Multiple sinks in literature

- Virtual root proposals in [GZL15; DDO14; CDP14; NMM16]
- Border router failure resilience & load balancing

- Unique point of coordination → single point of failure shifted
- No dynamic (*i.e.* adaptative) load balancing

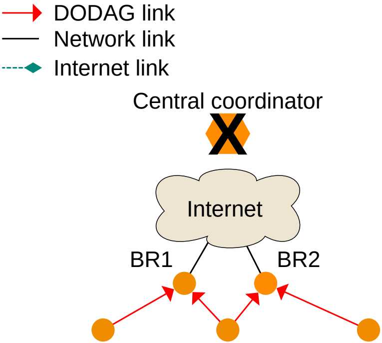

Figure 8: Single point of failure

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Load balancing in literature

- Load metric
  (*e.g.* queue load [KKP17])
- Local decision

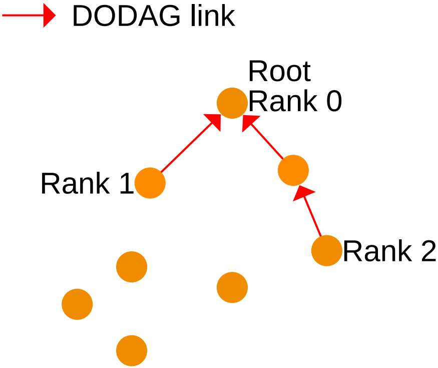

Figure 9: Choosing less loaded path

[KKP17] H. S. Kim et al. "Load Balancing Under Heavy Traffic in RPL Routing Protocol for Low Power and Lossy Networks". In: *IEEE Transactions on Mobile Computing* 16.4 (Apr. 2017), pp. 964–979. ISSN: 1536-1233

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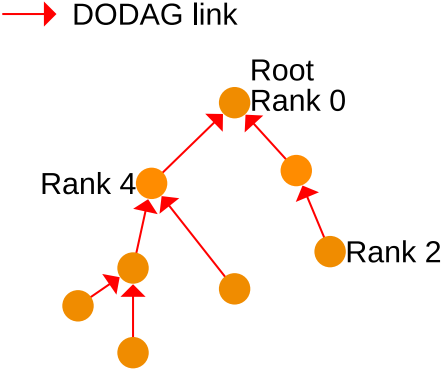

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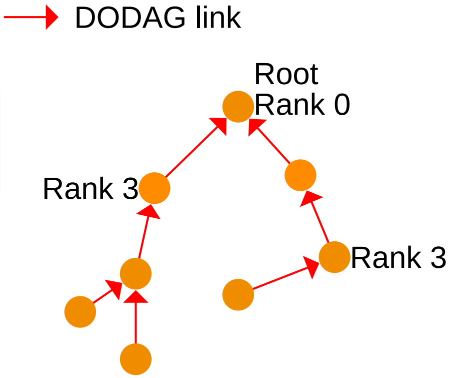

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- Load metric
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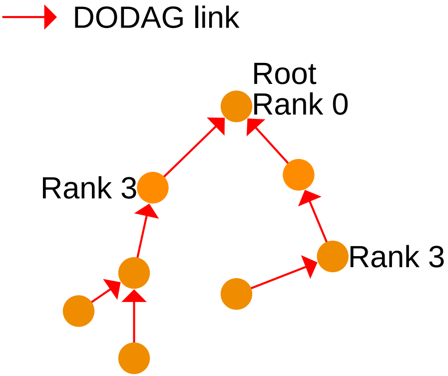
- Local decision

- Uncoordinated decision
  → sub-optimal redirection
  → network instability



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Outline

Considered scenario

- Smart cities: smart street lights, smart health, smart parking, *etc.* → colocated networks
- Different Internet service providers
- Different IPv6 prefixes
- Same IoT stack

Figure 10: Smart cities (from [IEE18])

[IEE18] *IEEE smart cities*. URL: https://beyondstandards.ieee.org/smart-cities/smart-smart-cities/ (visited on 08/20/2018)

Redundancy → failure resilience & load sharing between exit points
⇒ RPL + distributed virtual DODAG root
⇒ Initialization using discovering (*e.g.* [KLR16])

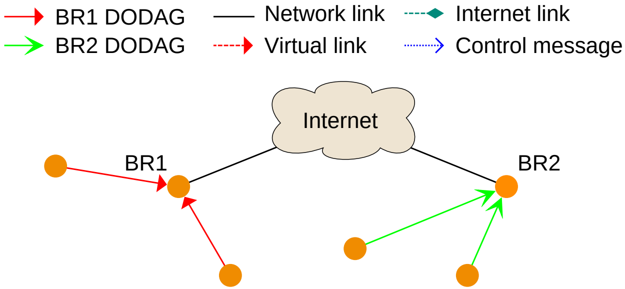

Figure 11: Border router discovering and inter-connexion

[KLR16] M. M. Khan et al. "A multi-sink coordination framework for low power and lossy networks". In: *2016 International Conference on Industrial Informatics and Computer Systems (CIICS)*. Mar. 2016, pp. 1–5

Multiple border routers

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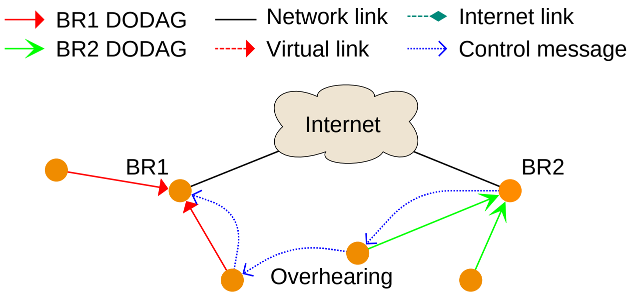

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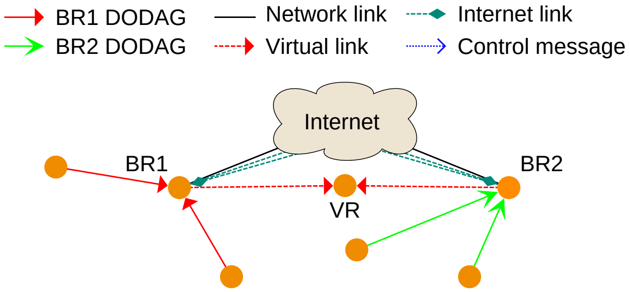

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Multiple IPv6 prefixes

Considered scenario → multiple distinct IPv6 prefixes
⇒ RPL + IPv6 Network Address Translation (NAT) [WB11]
⇒ Prefixes sharing → backup routes → multi-homing

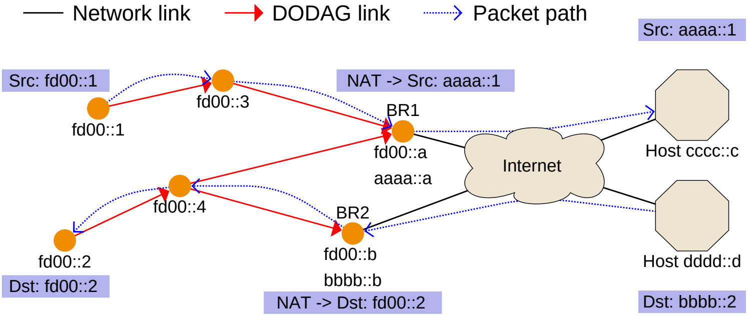

Figure 12: Address translation upon border router packet forwarding

[WB11] M. Wasserman and F. Baker. *IPv6-to-IPv6 Network Prefix Translation*. RFC 6296. June 2011

Load balancing

Border router redundancy → static (*i.e.* non-adaptative) load balancing
⇒ RPL + explicit redirection:

- Multiple RPL instances → border router differentiation
- Colocated networks → nodes set "redirectable" flag
- Congested border router → DODAG Redirection Solicitation (DRS)

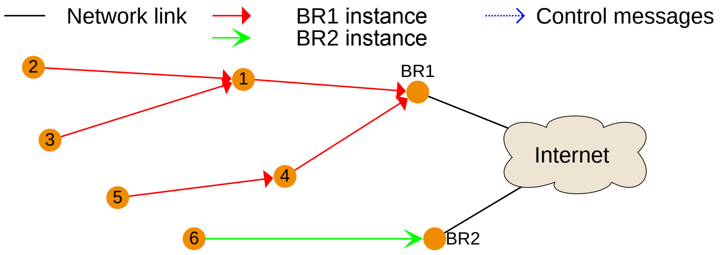

Figure 13: Redirection of node 4 from BR1 to BR2

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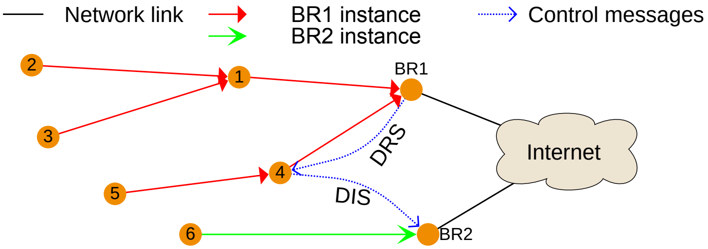

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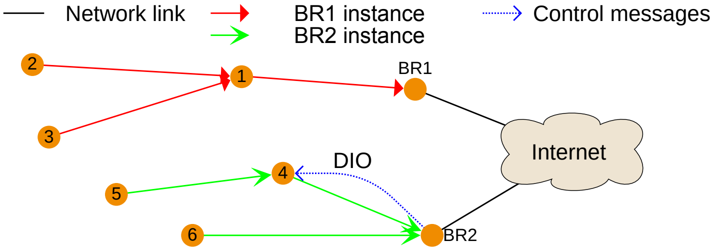

Figure 13: Redirection of node 4 from BR1 to BR2

Outline

Experimental setup

- Contiki OS 3.x → Contiki RPL
- FIT/IoT-LAB: testbed with real hardware

MAC layer	IEEE 802.15.4 CSMA/CA
MAC acknowledgments	Enabled
MAC Tx queue size	1 packet
RDC mechanism	No RDC (NULLRDC)
Traffic type	UDP packets
Traffic rate	1 packet per second
Tx power	3 dBm
Rx power threshold	-60 dBm
Motes used	10 M3 open node
RPL mode	Non-storing
RPL OF	MRHOF ETX
Congested mode trigger	Sub-DODAG size threshold

Scenario and network layout

- 2 border routers & 8 traffic generating nodes
- Border router 53 wakes up 60s after border router 18
- 100 experiments of 1h each

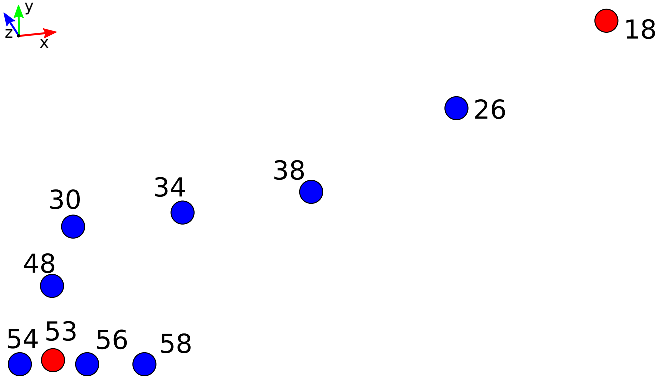

Figure 14: Testbed layout (red border routers, blue traffic generating nodes)

Topologies

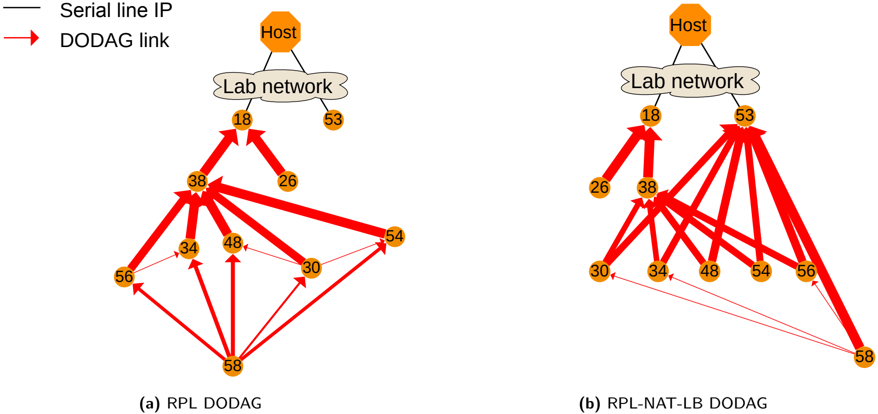

Figure 15: Cumulative final DODAGs from all experiments
(the thicker a link is, the more frequently it appears)

Bandwidth repartition

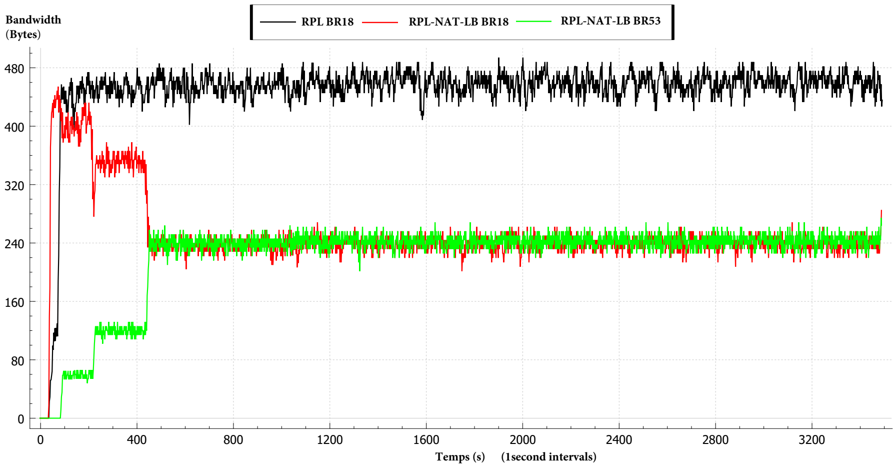

Figure 16: Better division of the traffic load between border routers

Bandwidth repartition

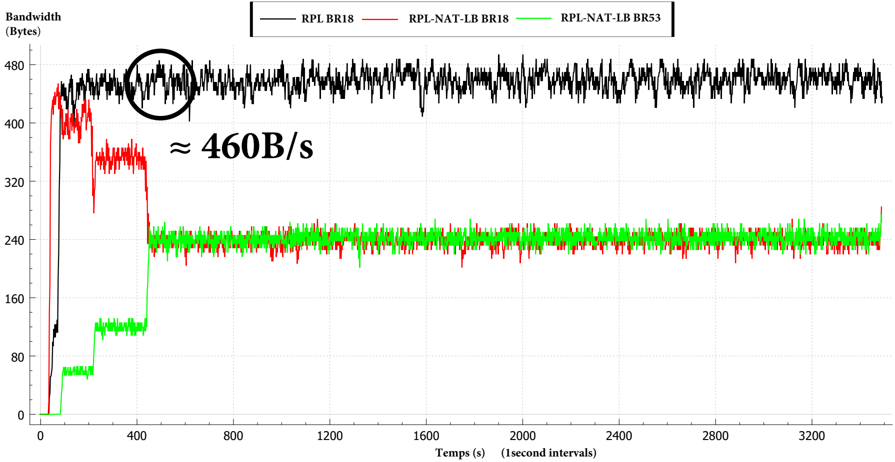

Figure 16: Better division of the traffic load between border routers

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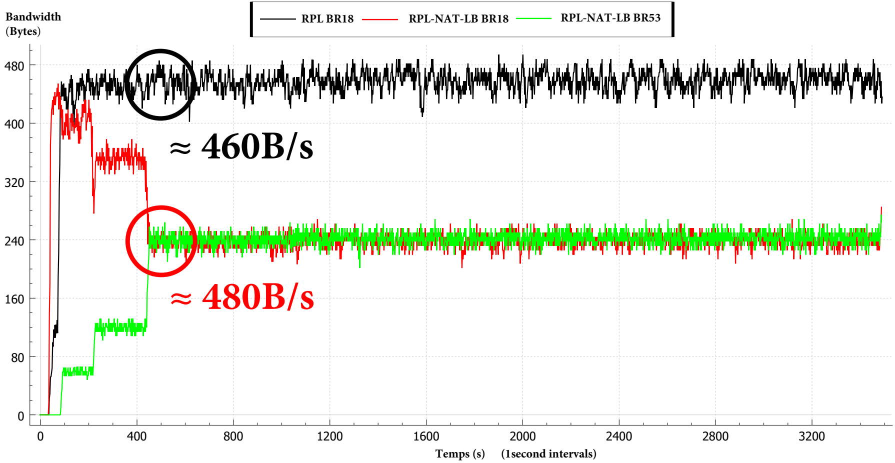

Figure 16: Better division of the traffic load between border routers

End-to-end and link packet error rate

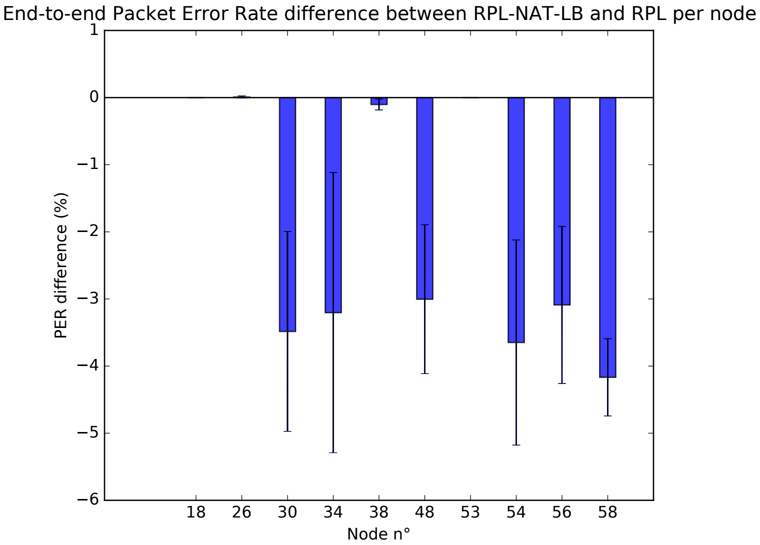

Figure 17: Decrease of overall proportion of end-to-end losses with RPL-NAT-LB

Link packet error rate

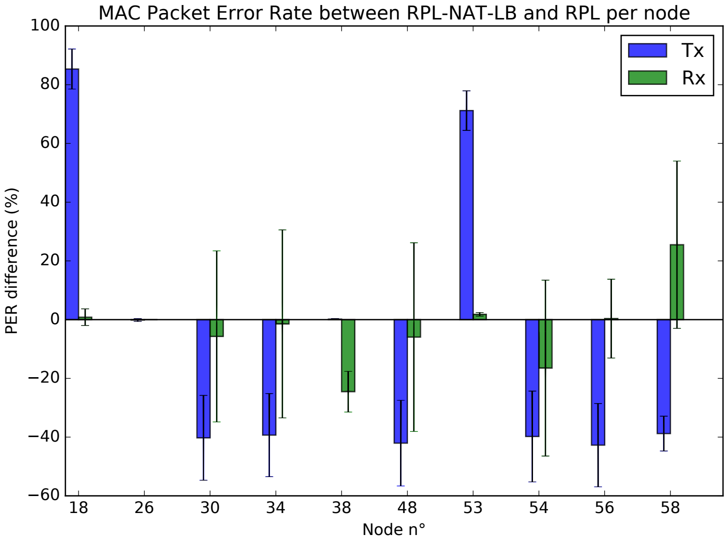

Figure 18: Decrease of overall proportion of link errors with RPL-NAT-LB

Outline

Conclusion

- IoT and RPL $\rightarrow$ single point of failure (border router)
- Colocated networks $\rightarrow$ cooperation for redundancy

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Border router redundancy for

- Failure resilience
- Multi-homing
- Load sharing

Conclusion

- IoT and RPL → single point of failure (border router)
- Colocated networks → cooperation for redundancy

Border router redundancy for

- Failure resilience
- Multi-homing
- Load sharing

- Experiments with only one network layout
- Only one congested mode trigger: sub-DODAG size
- Simple conditions for redirectable node → weak links

Conclusion

Future work

- Experiment with larger and random network layouts
- Different congested mode triggers
- Precise assessment before redirection (*e.g.* link quality)
- In depth study of energy consumption

Conclusion

Future work

- Experiment with larger and random network layouts
- Different congested mode triggers
- Precise assessment before redirection (*e.g.* link quality)
- In depth study of energy consumption

PhD

- Ongoing PhD with Nathalie Mitton (Inria) and Sencrop
- Polymorphical wireless communication for connected agriculture
- Innovative solution for data collection from field wireless sensors
- Combination of wireless communication technologies

Thank you for your attention! Questions?

Polymorphical wireless communication for connected agriculture

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Link layer transmission status

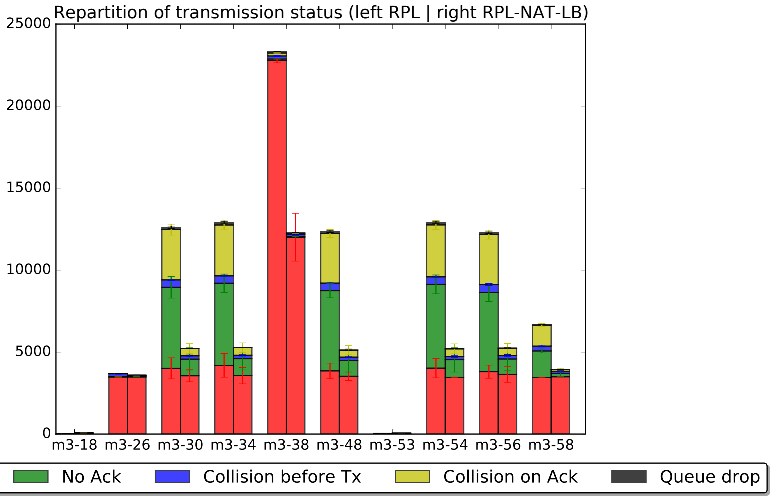

Figure 19: Decrease of overall number of link errors with RPL-NAT-LB

RPL CONTROL MESSAGES

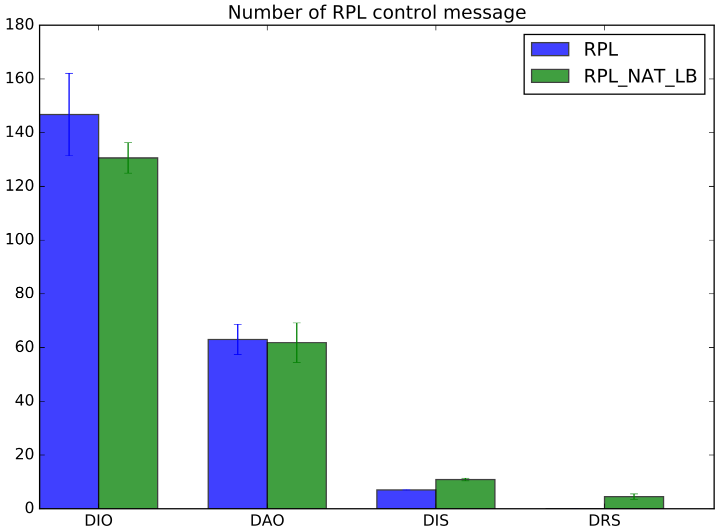

Figure 20: Commensurate overall number of control messages transmission

Energy depletion

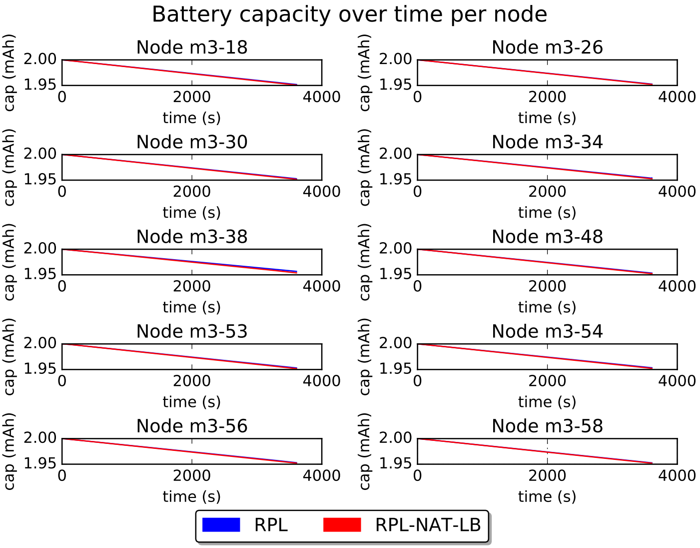

Figure 21: Slight increase in overall energy consumption with RPL-NAT-LB