Sharing is caring: a cooperation scheme for RPL network resilience and efficiency

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Outline

Internet of Things (IoT)

Set of constrained objects interconnected with the Internet via wireless communications

Constraints

- Computation power
- Memory storage
- Battery $\rightarrow$ limited energy

New usages, new standards

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

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

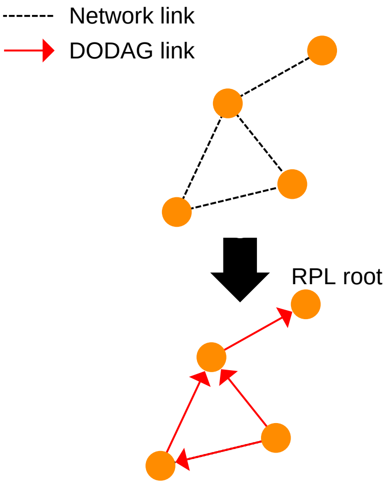


Figure 1: Physical and logical topology

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

RPL inherent issues

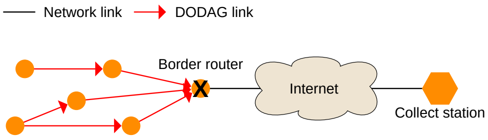


Figure 2: Border router failure

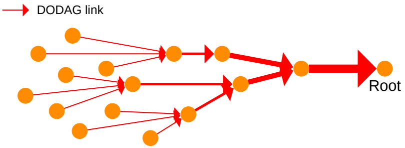


Figure 3: Funneling effect [WEC05]

Solution = border router redundancy

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

[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

Related work

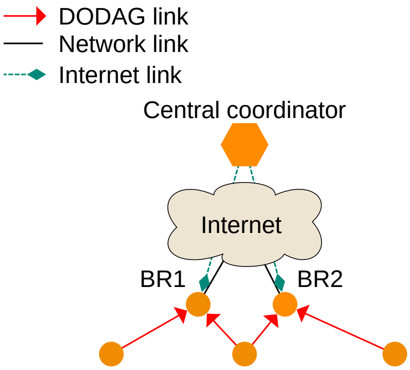


Figure 4: Central coordination [NMM16]

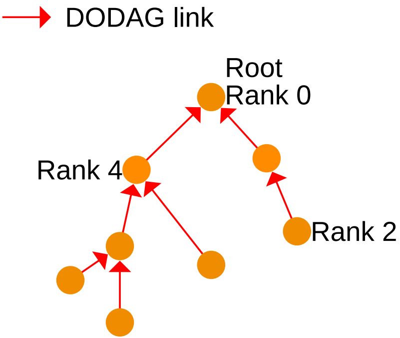


Figure 5: Local load balancing [KKP17]

[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

[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

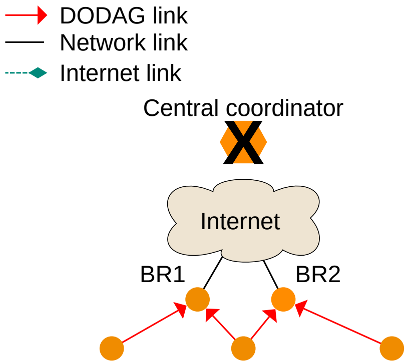
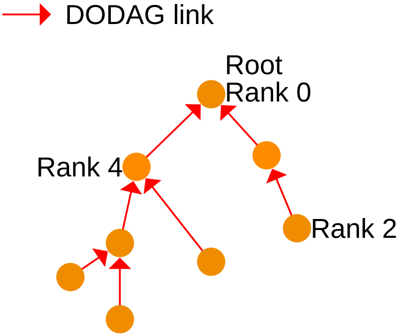


Figure 4: Single point of failure [NMM16]



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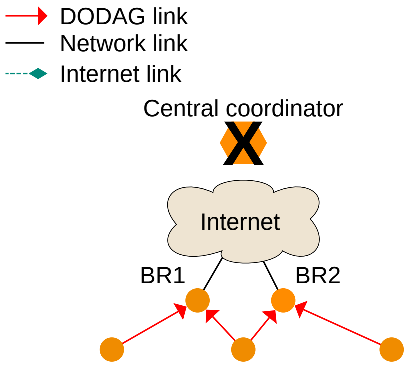

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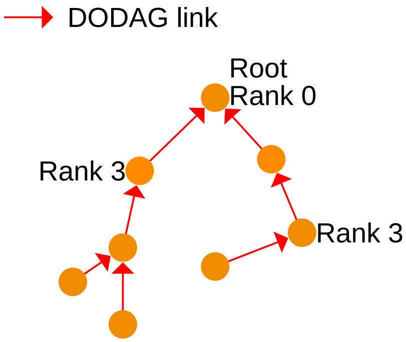

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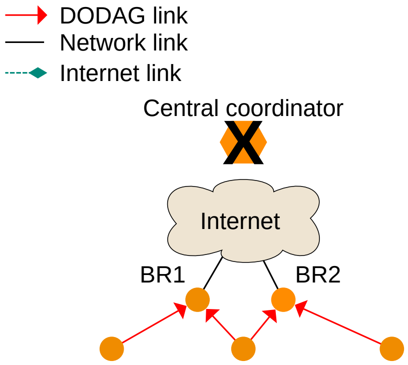

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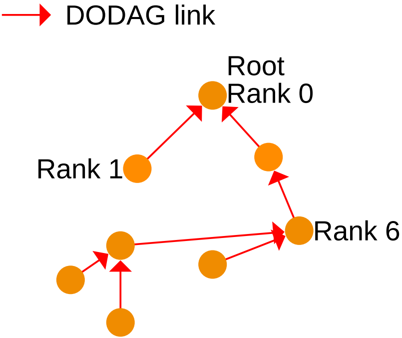

Figure 5: Network instability [KKP17]

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Outline

Considered scenario

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

Figure 6: Smart cities (from [IEE18])

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

Multiple border routers

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

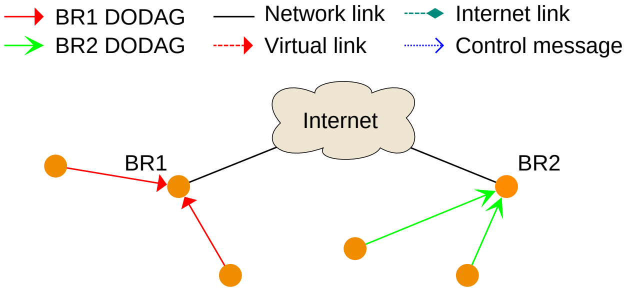

Figure 7: Border router discovering and inter-connexion

[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

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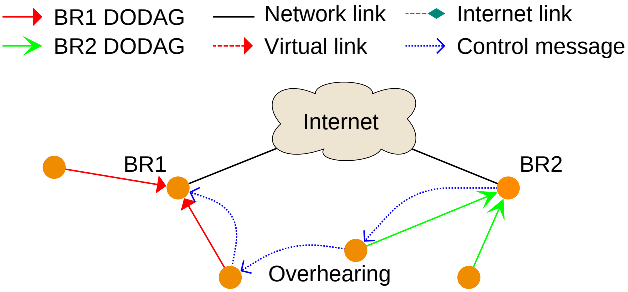

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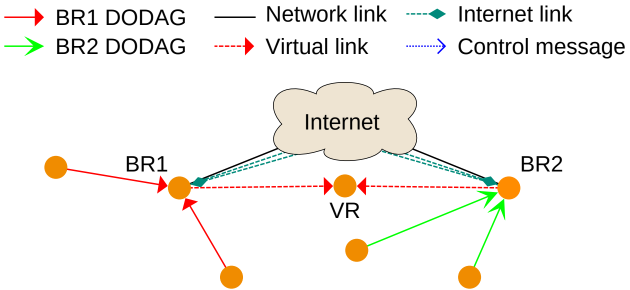

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Load balancing

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)

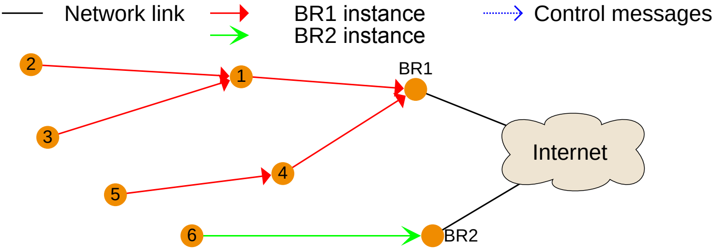

Figure 8: Redirection of node 4 from BR1 to BR2

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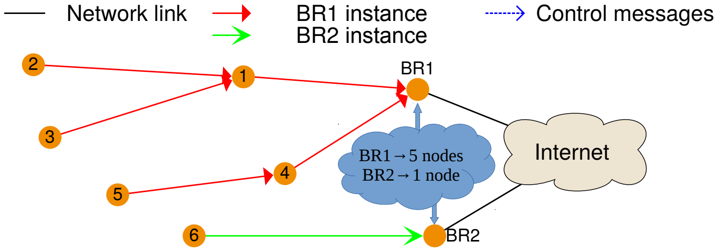

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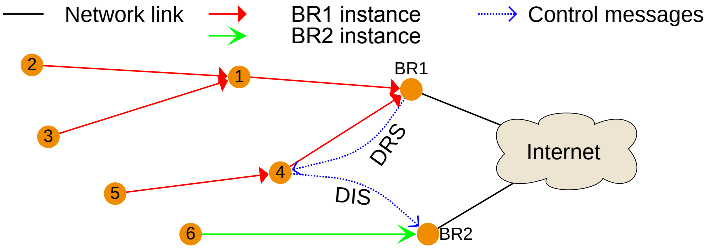

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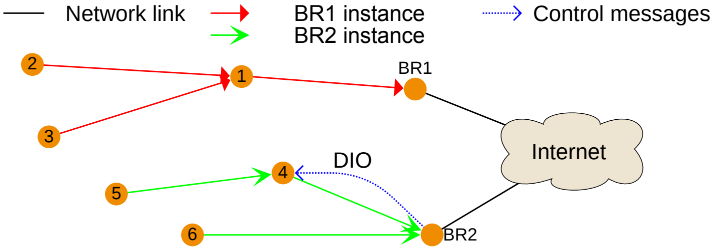

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Considered scenario → multiple distinct IPv6 prefixes
⇒ RPL + IPv6 Network Prefix Translation (NPT) [WB11]
⇒ Prefixes sharing → backup routes → multi-homing

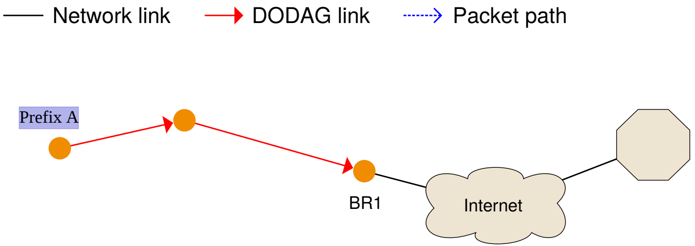

Figure 9: Address translation upon border router packet forwarding

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

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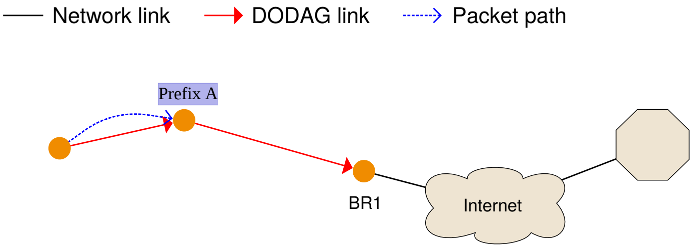

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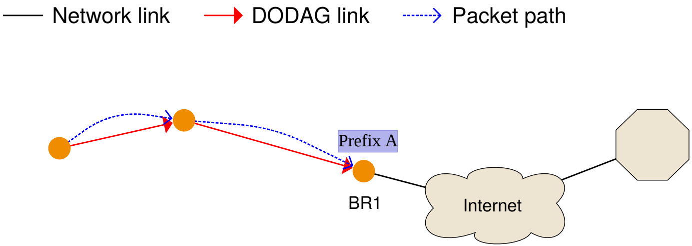

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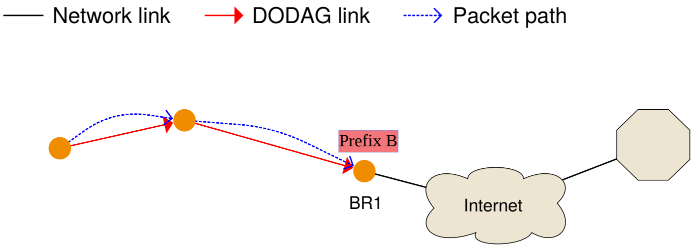

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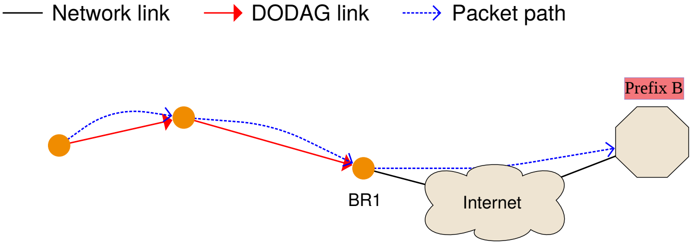

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Outline

Experimental setup

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

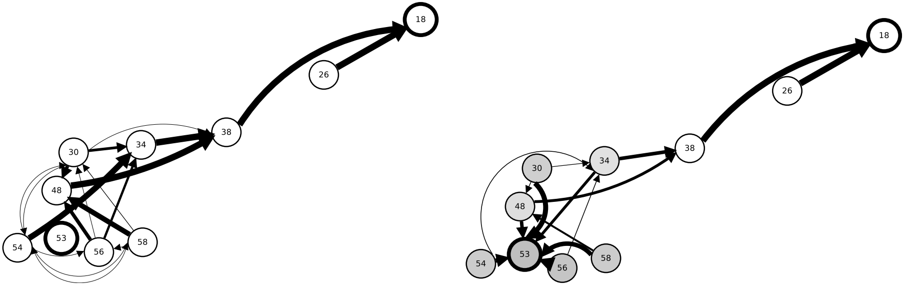
Parameters

- IEEE 802.15.4 CSMA/CA
- no radio duty cycle mecanism
- 1 UDP packet per second
- sub-DODAG size threshold as congestion trigger

Scenario

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

Topologies



(a) RPL topology

(b) RPL-NPT-LB topology

Figure 10: Cumulative final DODAGs from all experiments (the thicker a link is, the more frequently it appears)

Bandwidth repartition

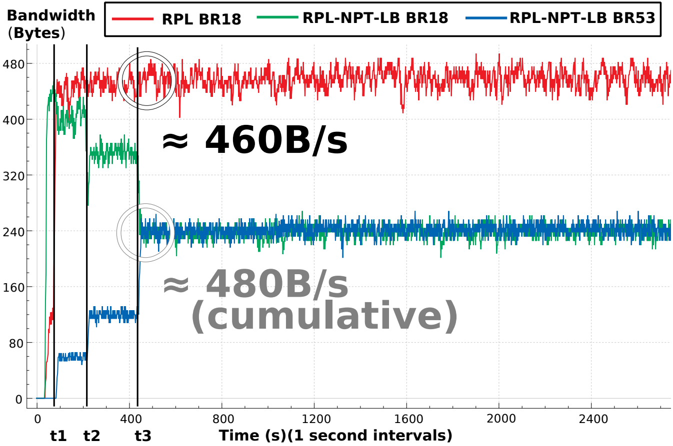


Figure 11: Better division of the traffic load between border routers

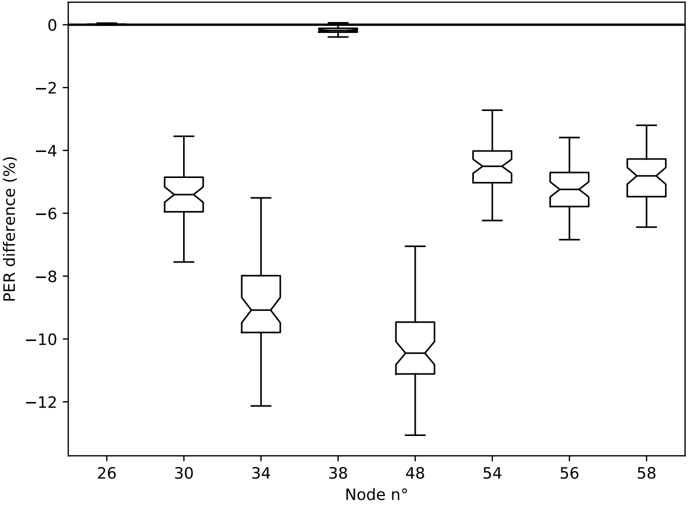


Figure 12: End-to-end losses difference between RPL-NPT-LB and RPL (lower is better)

Number of one-hop transmissions

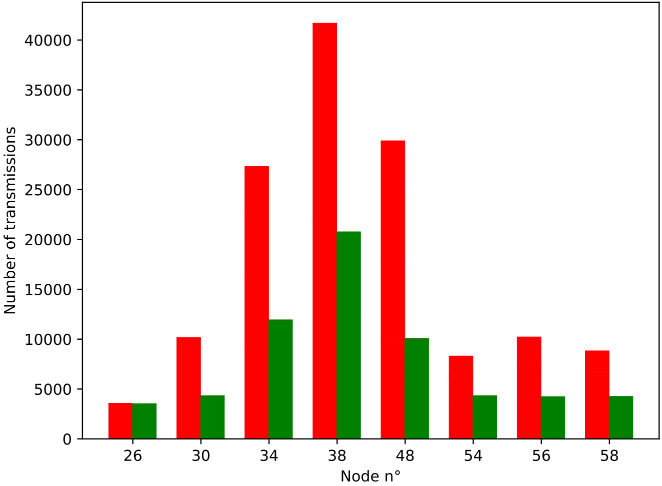


Figure 13: Number of transmissions (red is RPL — green is RPL-NPT-LB)

Energy consumption

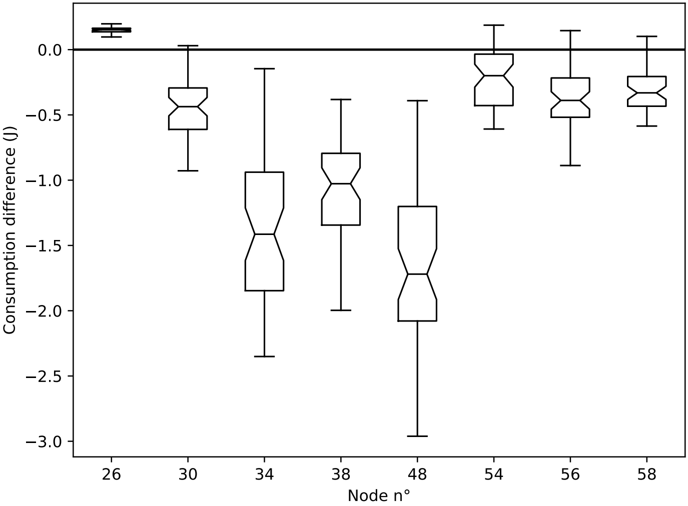


Figure 14: Energy consumption difference between RPL-NPT-LB and RPL (lower is better)

Outline

Conclusion

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

Conclusion

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

Future work

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

Thank you for your attention! Questions?

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Control messages

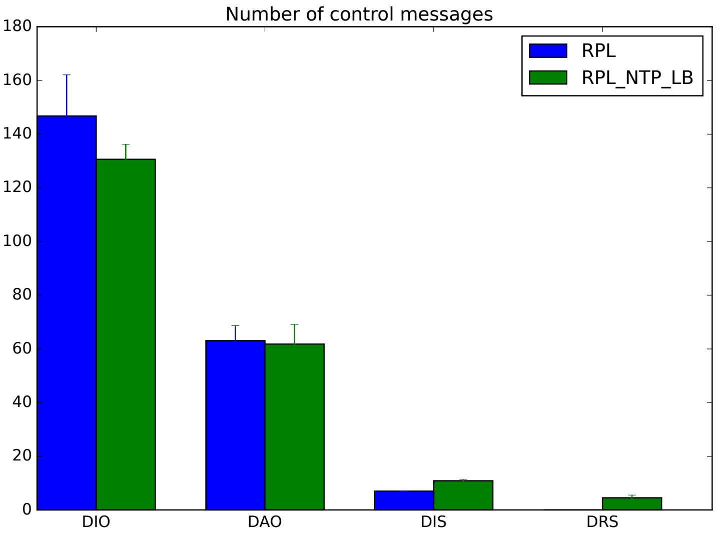

Figure 15: Transmission number of control messages

Experimental parameters

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

Repartition of transmission state

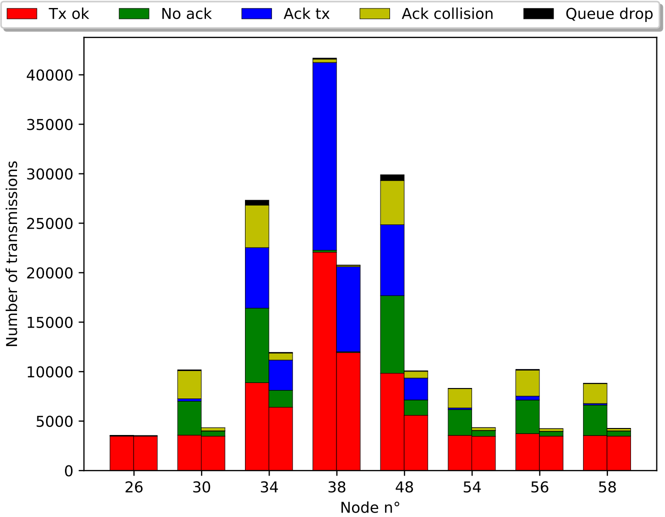

Figure 16: Repartition of transmission state (left RPL — right RPL-NPT-LB)