Can experiments lead to scientific results?

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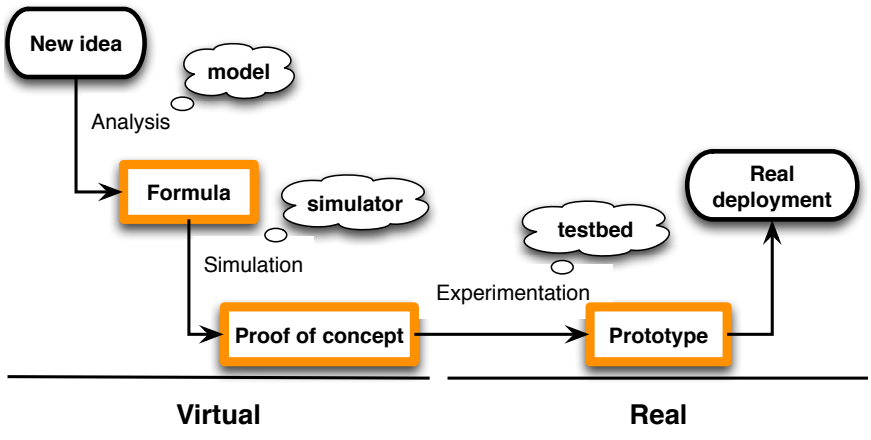
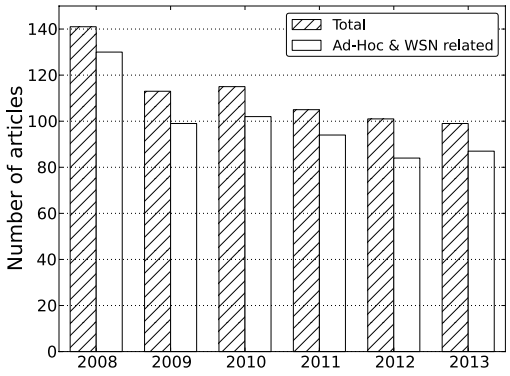
Testing before deploying (in real-world)?



[1] I. Stojmenovic, "Simulations in Wireless Sensor and Ad Hoc Networks: Matching and Advancing Models, Metrics, and Solutions," IEEE Communications Magazine, 2008.

Current tendency of the validation methods

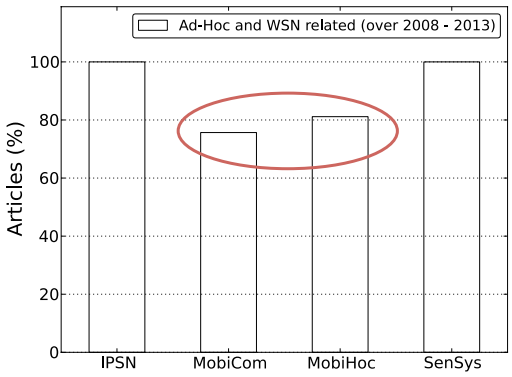
of published articles per year



- ACM/IEEE IPSN, ACM MobiCom, ACM MobiHoc and ACM SenSys from 2008 to 2013
- We studied 674 articles in total, out of which 596 are related to Ad Hoc & WSN [2]

[2] G. Z. Papadopoulos, K. Kritsis, A. Gallais, P. Chatzimisios and T. Noel, "Performance Evaluation Methods in Ad-Hoc and Wireless Sensor Networks: A Literature Study," *to appear* IEEE Communication Magazine, 2015.

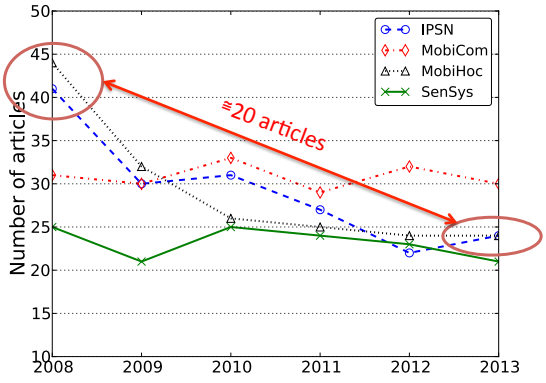
Appropriateness of our conference sample



- 78 articles on other wireless technologies (e.g., WiFi, WiMAX)
- Published in MobiCom and MobiHoc conference

[2] G. Z. Papadopoulos, K. Kritsis, A. Gallais, P. Chatzimisios and T. Noel, "Performance Evaluation Methods in Ad-Hoc and Wireless Sensor Networks: A Literature Study," *to appear* IEEE Communication Magazine, 2015.

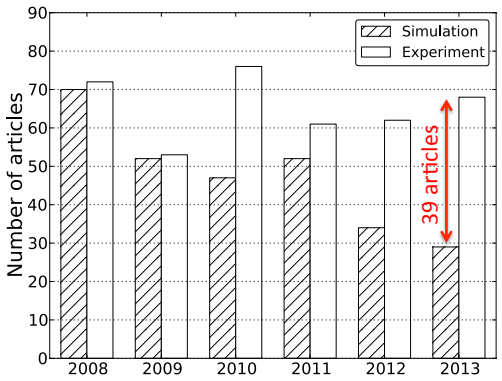
Publication flows



- "Decreasing" tendency of published articles in the proceedings

[2] G. Z. Papadopoulos, K. Kritsis, A. Gallais, P. Chatzimisios and T. Noel, "Performance Evaluation Methods in Ad-Hoc and Wireless Sensor Networks: A Literature Study," *to appear* IEEE Communication Magazine, 2015.

Simulations vs. experiments



- Simulations is decreasing every year (except in 2011)
- Experiments present at a relatively stable rate.

[2] G. Z. Papadopoulos, K. Kritsis, A. Gallais, P. Chatzimisios and T. Noel, "Performance Evaluation Methods in Ad-Hoc and Wireless Sensor Networks: A Literature Study," *to appear* IEEE Communication Magazine, 2015.

Simulations

Simulators / emulators [3, 4]

I. OMNeT++, ns-2, etc.
- Retain or simplify **many** assumptions
- Provide "unlimited" memory and computation resources

II. TOSSIM, COOJA, etc.
- Retain or simplify **some** assumptions
- **Bridge the gap** between simulations and experiments
- Rely on the same code for both emulation and experimental campaigns

[3] A. Dwivedi and O. Vyas, "An Exploratory Study of Experimental Tools for Wireless Sensor Networks," Wireless Sensor Network, 2011.
[4] E. Egea-Lopez, J. Vales-Alonso, A. S. Martınez-Sala, P. Pavon-Marino, and J. Garcıa-Haro, "Elder Care Based on Cognitive Sensor Network," Summer Simulation Multiconference - SPECTS, 2005.

Advantages and limitations

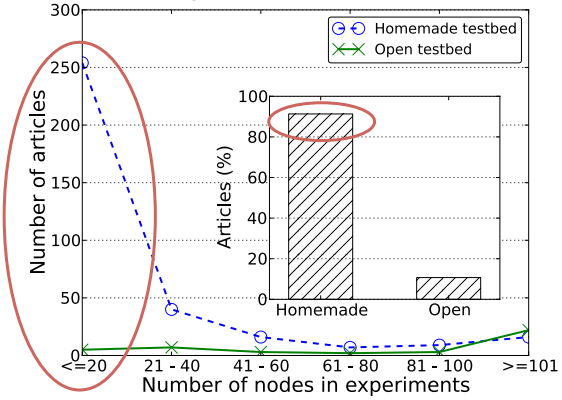
I. Better control of the scenario
- Start from "any" assumption
  - Simplified assumptions
  - Localization (e.g., mobility, geographic routing)
- Allow to build large-scale networks
- Reproducible results

II. But …
- Not necessarily realistic
  - No weather impacts (e.g., temperature [5])
- Do not take into account the *node failure* or *network disconnection* [6, 7]
- Imperfect radio models

[5] C. A. Boano, J. Brown, Z. He, U. Roedig, and T. Voigt, "Lowpower radio communication in industrial outdoor deployments: The impact of weather conditions and atex-compliance," Sensor Applications, Experimentation, and Logistics, 2010.
[6] G. Barrenetxea, F. Ingelrest, G. Schaefer, and M. Vetterli, "The hitchhiker's guide to successful wireless sensor network deployments," in Proc. of ACM SenSys, 2008.
[7] K. Langendoen, A. Baggio, and O. Visser, "Murphy loves potatoes: experiences from a pilot sensor network deployment in precision agriculture," in Proc. of IEEE IPDPS, 2006.

Experiments

Testbed usage & scales of experimented networks



- 91.3% choose to set up their own testbeds
- For small-scale networks, researchers choose homemade testbeds

[2] G. Z. Papadopoulos, K. Kritsis, A. Gallais, P. Chatzimisios and T. Noel, "Performance Evaluation Methods in Ad-Hoc and Wireless Sensor Networks: A Literature Study," *to appear* IEEE Communication Magazine, 2015.

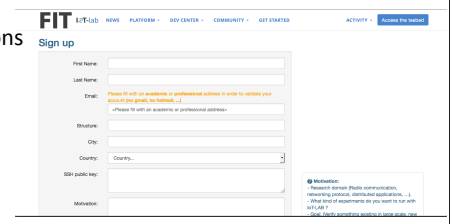
Facilities for IoT and WSN experimentation [8, 9]

I. Open testbeds

- MoteLAB (USA: in 2005), TWIST (Germany: in 2006), SensLAB – FIT IoT-LAB (France: in 2008) WISEBED (Europe: in 2008), INDRIYA (Singapore: in 2011) …

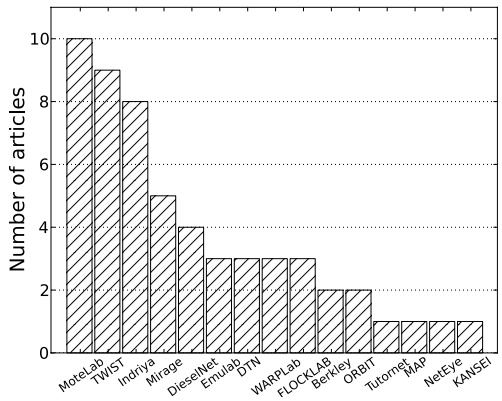
II. Allow to construct pertinent networks

- Tens or even hundreds of nodes
- Real (or close) real world conditions
- Creating an account (i.e., no cost)



[8] A. Gluhak, S. Krco, M. Nati, D. Pfisterer, N. Mitton, and T. Razafindralambo, "A Survey on Facilities for Experimental Internet of Things Research," IEEE Communications Magazine, 2011.
[9] A.-S. Tonneau, N. Mitton, and J. Vandaele, "A Survey on (mobile) Wireless Sensor Network Experimentation Testbeds," in Proc. IEEE DCOSS, 2014.

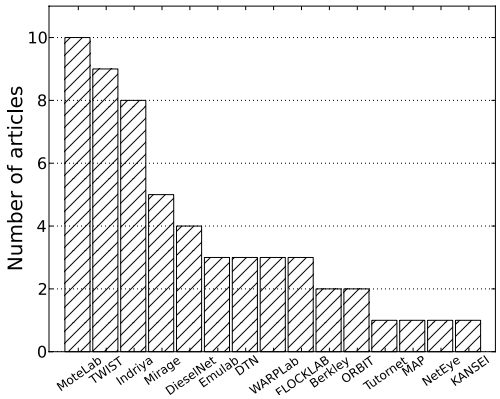
Popularity of open testbeds



- MoteLab and TWIST were among the very first to provide such a service
- They consist consist in widespread hardware (Telosb for Indriya)

[2] G. Z. Papadopoulos, K. Kritsis, A. Gallais, P. Chatzimisios and T. Noel, "Performance Evaluation Methods in Ad-Hoc and Wireless Sensor Networks: A Literature Study," *to appear* IEEE Communication Magazine, 2015.

Popularity of open testbeds



- FIT IoT-LAB is still a "young" testbed
- Articles are published in other venues (e.g., IEEE DCOSS, MASS, Globecom)

[2] G. Z. Papadopoulos, K. Kritsis, A. Gallais, P. Chatzimisios and T. Noel, "Performance Evaluation Methods in Ad-Hoc and Wireless Sensor Networks: A Literature Study," *to appear* IEEE Communication Magazine, 2015.

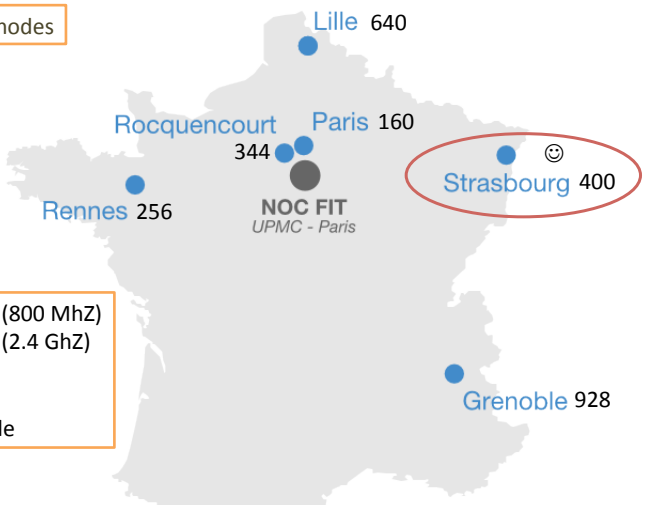
FIT IoT-LAB

FIT EQUIPEX Future Internet (of Things) - FRANCE

FIT IoT-lab

FIT IoT-LAB [10]

2728 wireless nodes



WSN430 node (800 MhZ)
WSN430 node (2.4 GhZ)
M3 node
A8 node
Open Host node

[10] C. Adjih, E. Baccelli, E. Fleury, G. Harter, N. Mitton, T. Noel, R. Pissard-Gibollet, F. Saint-Marcel, G. Schreiner, J. Vandaele, T. Watteyne, "FIT IoT-LAB: A Large Scale Open Experimental IoT Testbed," *to appear* in Proc. IEEE WF-IoT, 2015.

FIT EQUIPEX Future Internet (of Things) - FRANCE

FIT IoT-lab

ICube platform [11]

I. 400 nodes
- Total 120 M3
- Total 24 A8
- Total 256 WSN430

II. 318 fixed nodes
- 64 M3 and 14 A8 (AT86RF231)
  - 2 layers of 38 (1x1x2 meter spacing)
- 240 WSN430 (CC1101)
  - 3 layers of 80 (1x1x1 meter spacing)

III. 45 mobile nodes
- 35 M3,
- 10 WSN430

[11] G. Z. Papadopoulos, J. Beaudaux, A. Gallais, T. Noel, and G. Schreiner, "Adding value to WSN simulation using the IoT-LAB experimental platform," in Proc. IEEE WiMob, 2013.

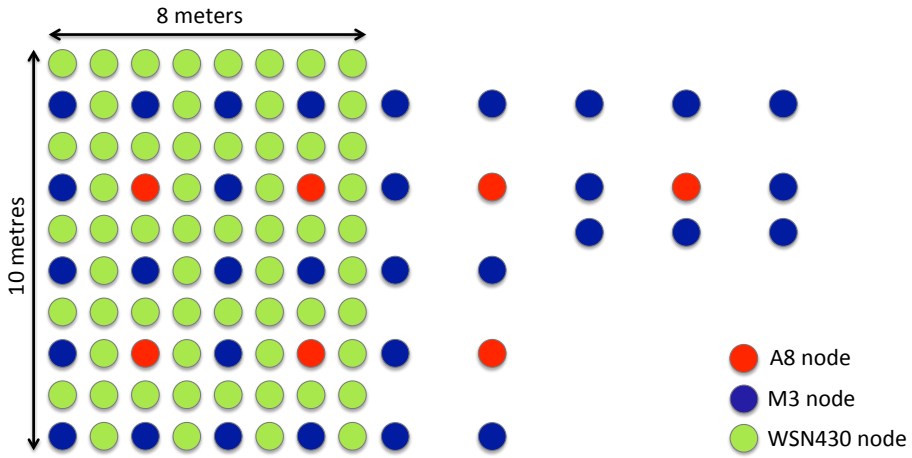
Advantages and limitations

I. Many advantages
- Remote administration
  - Accessibility from any place (i.e., internet connection)
- Building a network is less complex (and time-consuming)
- Results are closer to real-world deployments
  - e.g., humidity, temperature, noise etc.
- Enlarges the potentials of academic institutes
  - e.g., more "qualitative" articles, collaborations

II. But … there are limitations (or challenges) as well

"Large-scale" networks ?

"Large-scale" networks ?



ICube platform (10m x 8m x 3m): 240 WSN430 nodes distributed in 3 layers of 80 (1x1x1)

Examples from real-world deployments

http://postscapes.com/internet-of-things-examples/

Link stability & symmetry

Bursty traffic

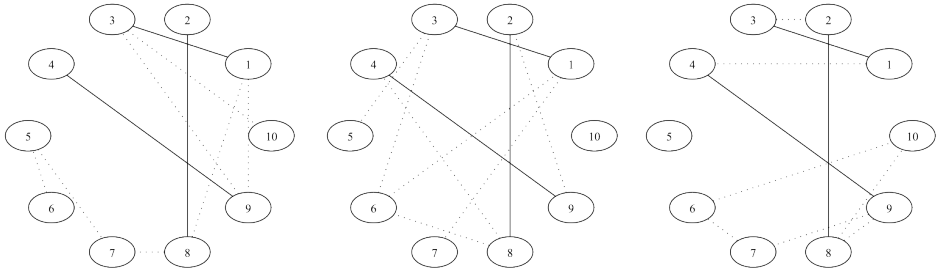
I. Wildlife monitoring, biotelemetry etc.
- Bursty data transmissions may occur [12, 13]

II. Link quality fluctuation
- Has a negative impact on successful packet delivery [14]

III. Repeated retransmission of lost packets increases:
- Latency at all levels of communication
- But also the energy consumption

[12] G. Z. Papadopoulos, J. Beaudaux, A. Gallais and T. Noel, "T-AAD: Lightweight Traffic Auto-ADaptations for Low-power MAC Protocols," in Proc. IFIP/IEEE Med-Hoc-Net, 2014.
[13] G. Z. Papadopoulos, V. Kotsiou, A. Gallais, P. Chatzimisios and T. Noel, "Wireless Medium Access Control under Mobility and Bursty Traffic Assumptions in WSN," in Springer Mobile Networks and Applications, 2015.
[14] Z. Ansar, J. Wen an E. Debebe Ayele and W. Dargie, "An efficient burst transmission scheme for wireless sensor networks," in Proc. ACM MSWiM, 2015.

Link stability & symmetry [11]



(a) Wednesday (Night) (b) Thursday (Morning) (c) Thursday (Night)

# of neighbors in average (per node):

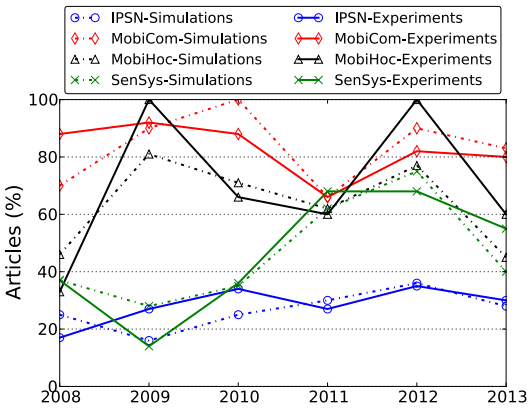
13.95 (2.16) **13.38** (1.9) **15.34** (1.94)

This link fluctuations impact the MAC layer protocols

[11] G. Z. Papadopoulos, J. Beaudaux, A. Gallais, T. Noel, and G. Schreiner, "Adding value to WSN simulation using the IoT-LAB experimental platform," in Proc. IEEE WiMob, 2013.

Assigning and planning trajectories for mobile robots

Mobility scenarios



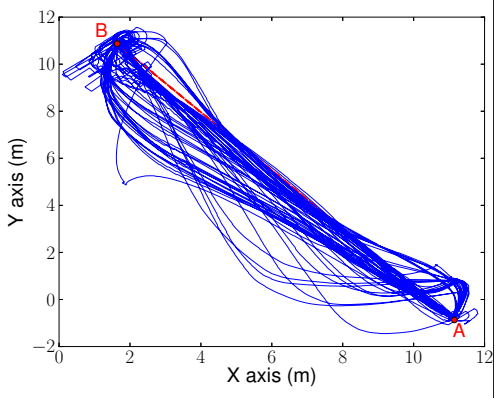
- 52.1% (148 out of 284 articles) simulated mobile scenarios
- 51.2% (201 out of 392 articles) experimented mobile scenarios

[2] G. Z. Papadopoulos, K. Kritsis, A. Gallais, P. Chatzimisios and T. Noel, "Performance Evaluation Methods in Ad-Hoc and Wireless Sensor Networks: A Literature Study," *to appear* IEEE Communication Magazine, 2015.

Trajectories

I. Robots replay,
- Line trajectory: drift of 0.57 m

Line trajectory



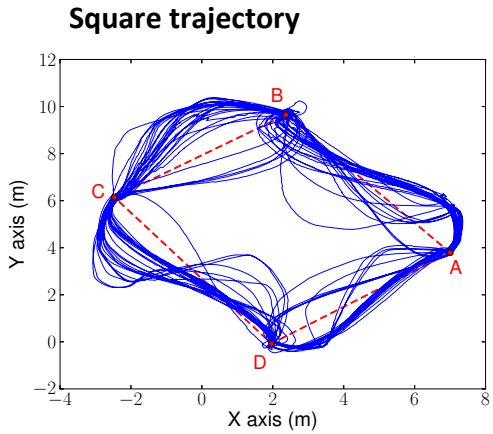
[15] G. Z. Papadopoulos, "Improving Medium Access for Dynamic Wireless Sensor Networks," *to appear* Ph.D. Thesis, 2015.

Trajectories

I. Robots replay,
- Line trajectory: drift of 0.57 m
- Square circuit: drift of 0.46 m

II. Miscalculation of AMCL module

III. The 3D camera lacks in open-space & large-scale environments



Raising the question of cost versus accuracy versus quantity of robots in our community [15]

[15] G. Z. Papadopoulos, "Improving Medium Access for Dynamic Wireless Sensor Networks," *to appear* Ph.D. Thesis, 2015.

Management

Management

I. Nodes reservation conflict

II. Learning phase
- Collecting and parsing the log files
- Scripting

III. Debug procedure is time-consuming and (tedious?)

IV. Unexpected node (or nodes) crashes
- Resume the experiment → time consuming

Discussion

Discussion

I. Due to the real-world unexpected (or expected) issues
- Link fluctuations
- Weather conditions
- Unexpected node (or nodes) crashes

II. Experiments are hard to get repeatable setups for reproducible results

III. Affects the performance of the MAC or routing layer solutions

IV. The obtained (experimental) results are scientific or proof-of-concept?

References

[1] I. Stojmenovic, "Simulations in Wireless Sensor and Ad Hoc Networks: Matching and Advancing Models, Metrics, and Solutions," IEEE Communications Magazine, 2008.

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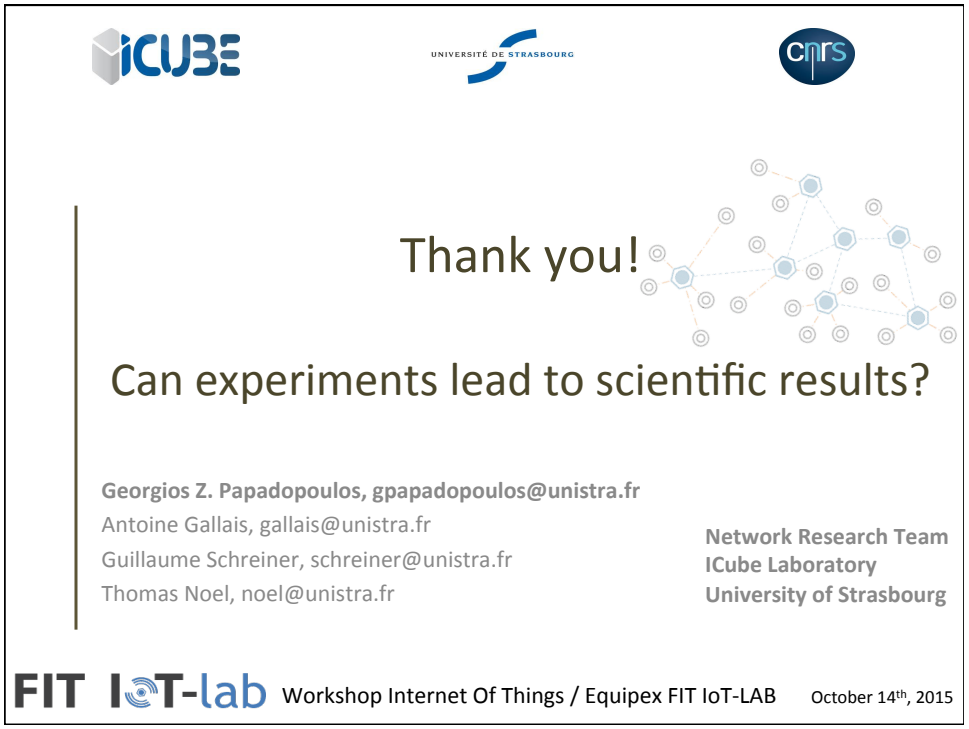
Thank you!
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