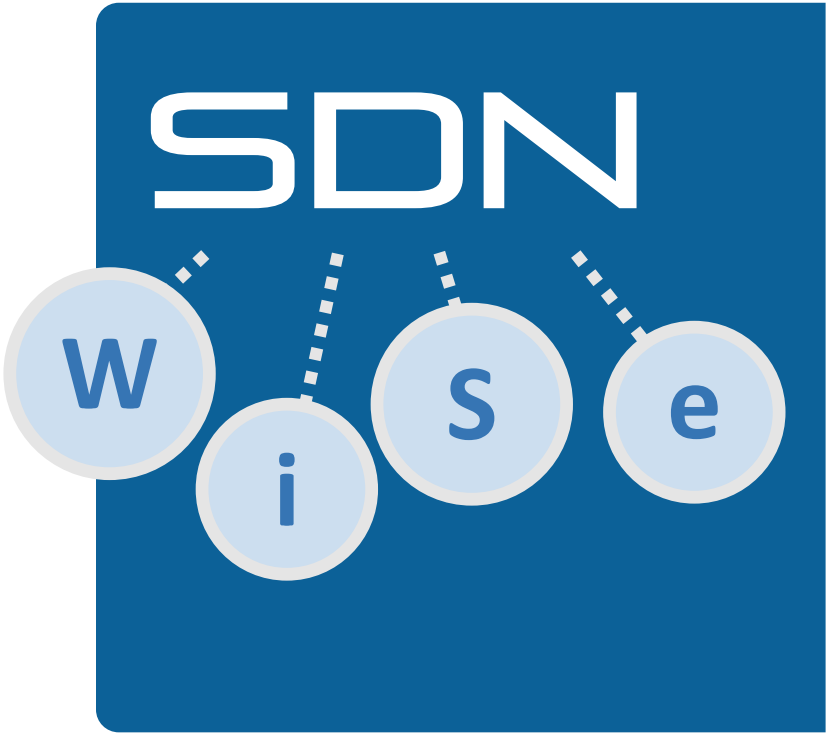


Wireless Software Defined Networks

Giacomo Morabito

University of Catania

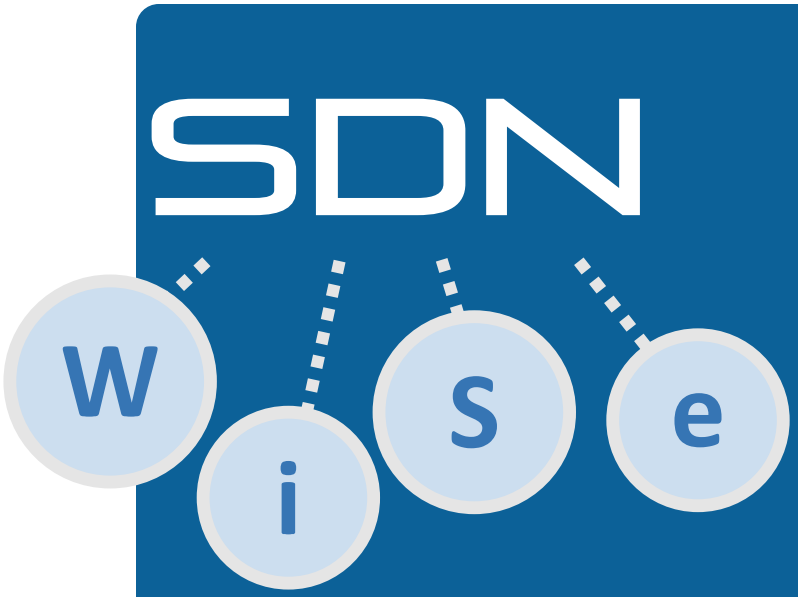
International Conference on Information Networking – 2018
January 10th, 2018 - Chiang Mai, Thailand

Acknowledgements

- The following are the results of the work carried out with many colleagues and reported in the following papers:
  - S. Costanzo, L. Galluccio, G. Morabito, S. Palazzo. "Software Defined Wireless Networks: Unbridling SDN". **EWSDN 2012,** September 2012.
  - L. Galluccio, S. Milardo, G. Morabito and S. Palazzo. "*SDN-WISE: Design, prototyping and experimentation of a stateful SDN solution for WIreless Networks*". **IEEE Infocom**. April 2015
  - -- "*Reprogramming Wireless Sensor Networks by Using SDN-WISE: a Hands-On Demo*". **IEEE Infocom -- Demo**. April 2015
  - C. Buratti, A. Stajkic, G. Gardasevic, S. Milardo, M. D. Abrignani, S. Mijovic, G. Morabito, and R. Verdone. "*Testing Protocols for the Internet of Things on the EuWIn Platform*", **IEEE Internet of Things Journal. 2015**
  - A.C. Anadiotis, G. Morabito, and S. Palazzo. An SDN-assisted Framework for Optimal Deployment of MapReduce Functions in WSNs. **IEEE Transactions on Mobile Computing**. 2015
  - A.C. Anadiotis, L. Galluccio, S. Milardo, G. Morabito, and S. Palazzo. Towards a Software-Defined Network Operating System for the IoT. Proc. of **IEEE World Forum on Internet of Things**. December 2015

Outline

- Introdution
- Part I: SDN in infrastructured wireless networks
- Part II: SDN in infrastructureless wireless networks
- Conclusions

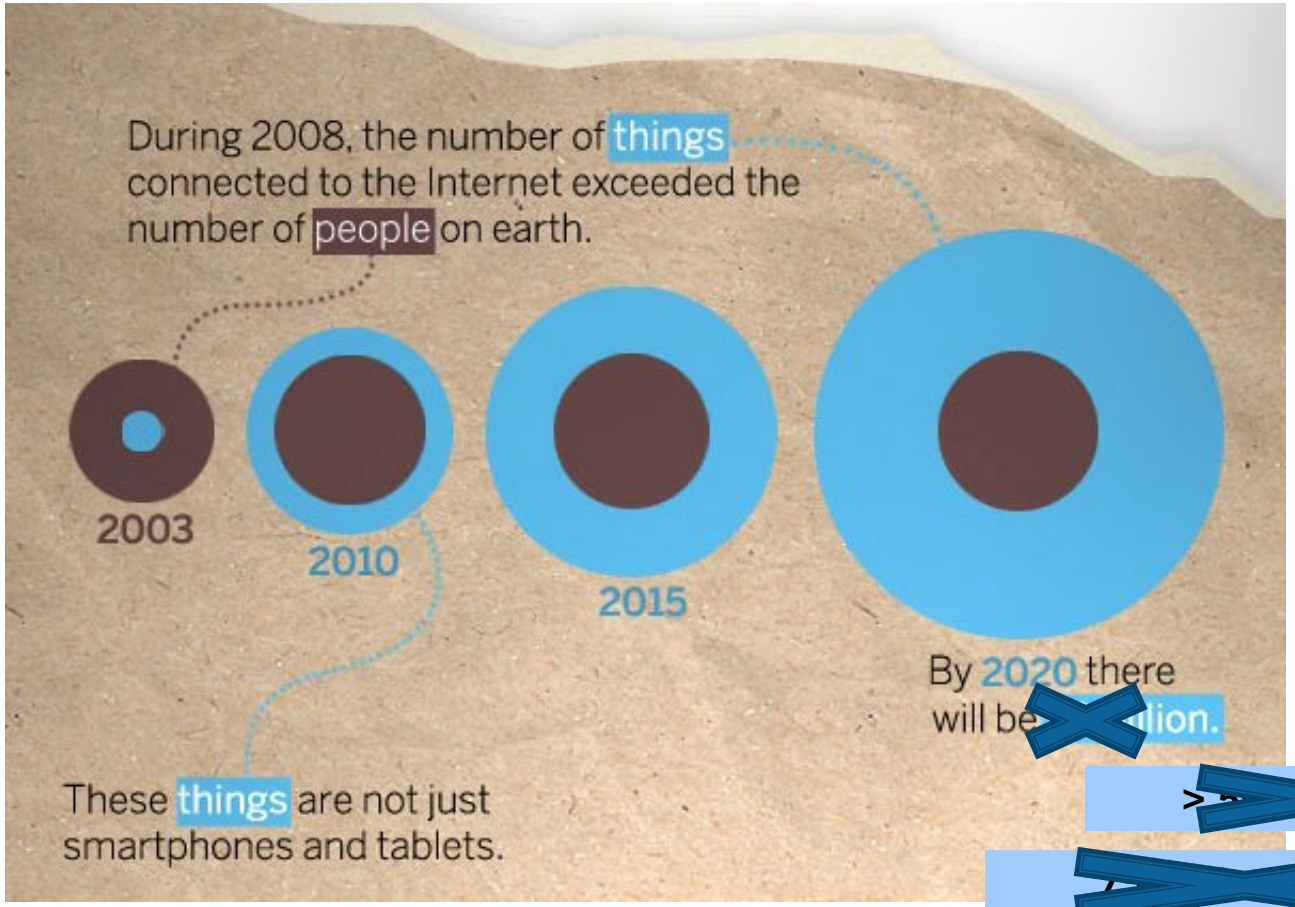


Introduction

Assumptions

- You know what is SDN
  - No? You have been a bad student
- You believe that IoT is important
  - No? You have bitten the wrong apple 10 years ago and you woke up in Chiang Mai 20 minutes ago

Internet of Things: Where it starts?



> ricsson)

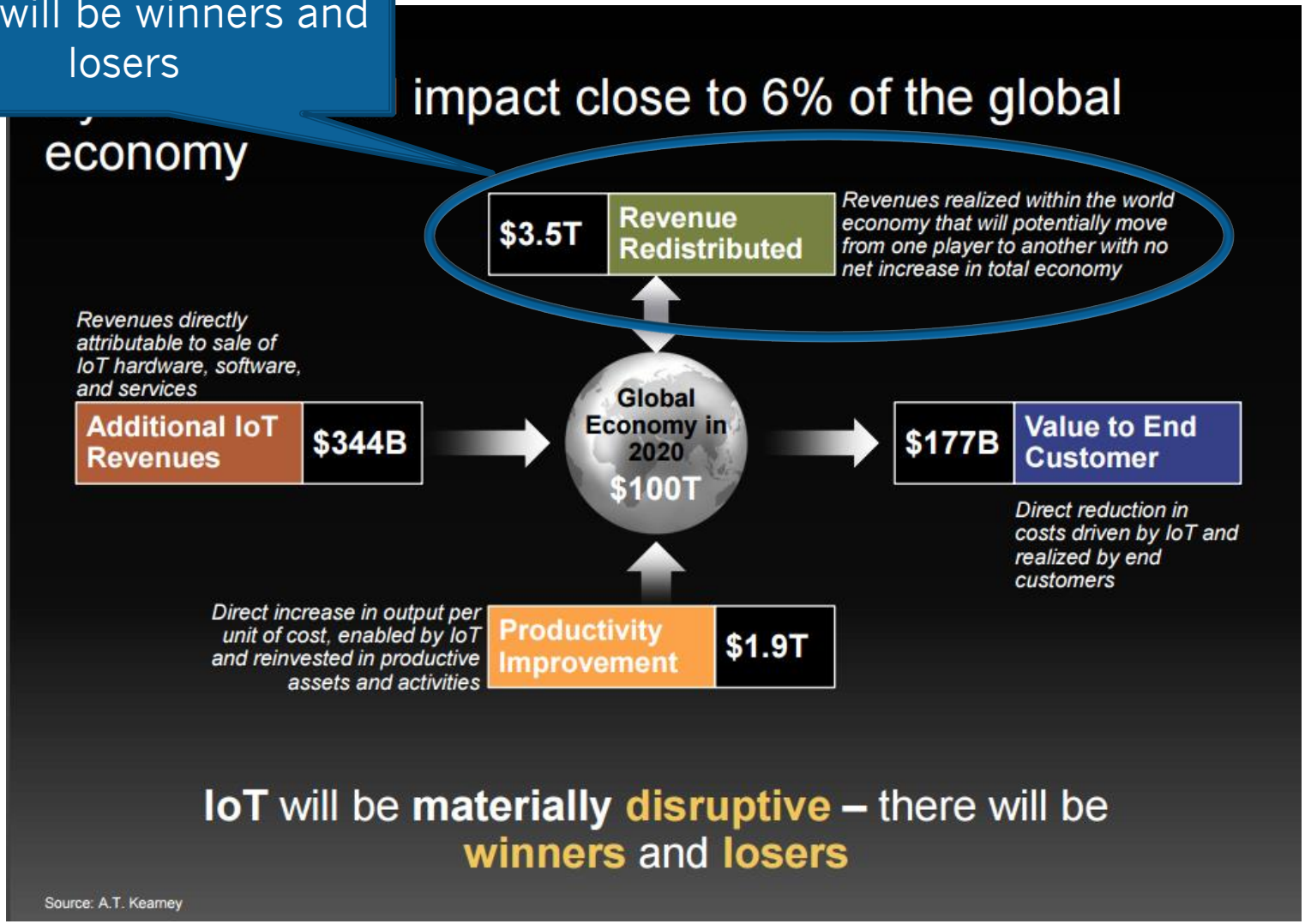
an Stanley)

200 Billion (Intel)

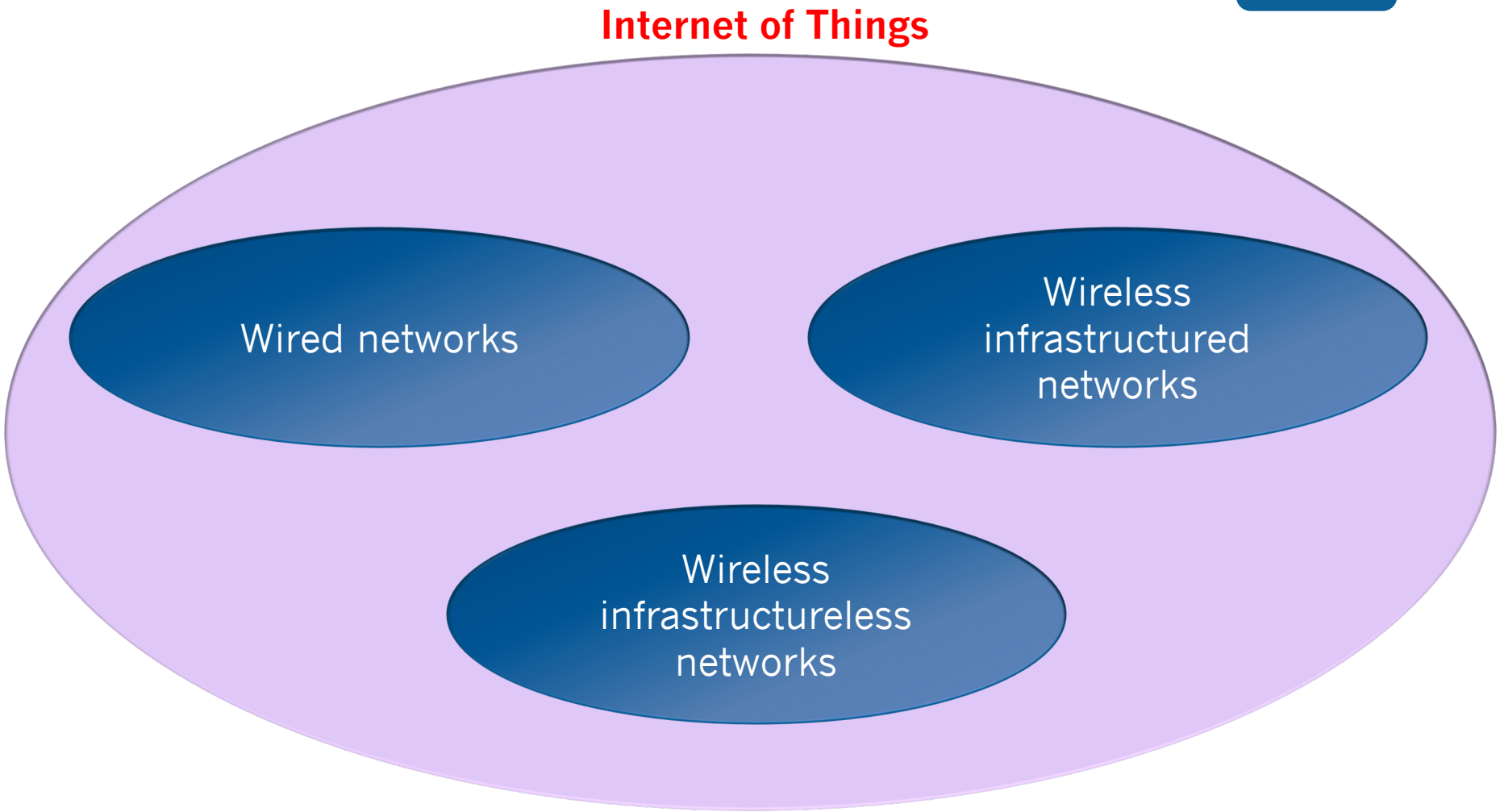
Source: Cisco IBSG, Jim Cicconi, AT&T, Steve Leibson, Computer History Museum, CNN, University of Michigan, Fraunhofer. Available at:
http://readwrite.com/2011/07/17/cisco_50_billion_things_on_the_internet_by_2020

Economic impact

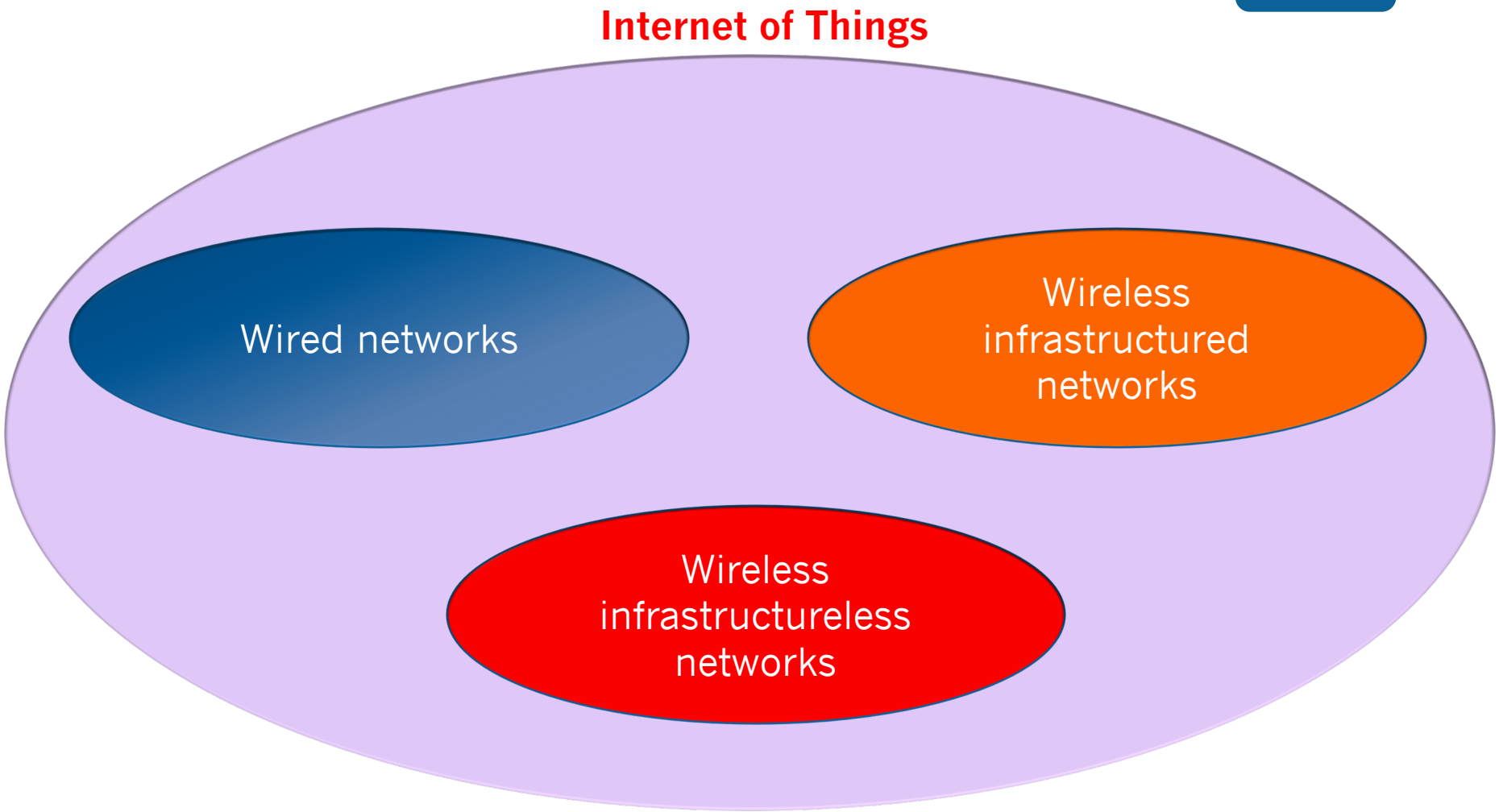
There will be winners and losers

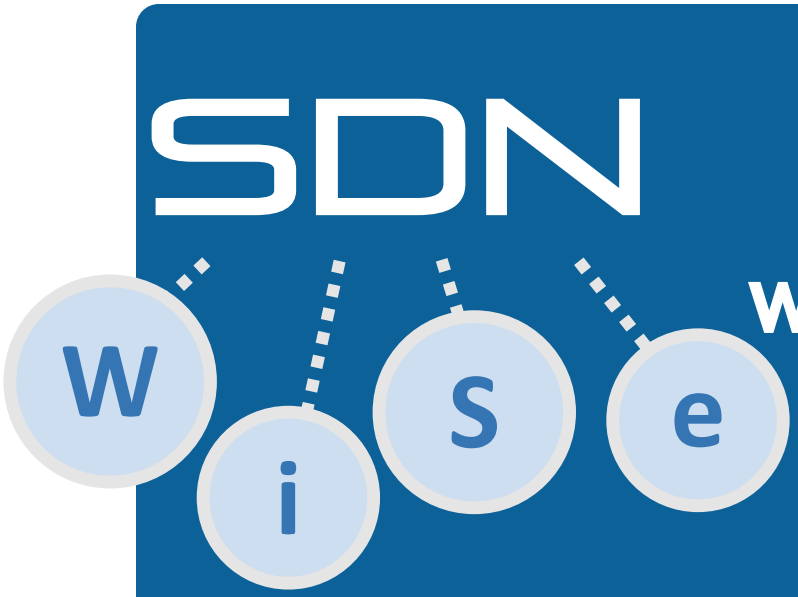


IoT: a melting pot of networks



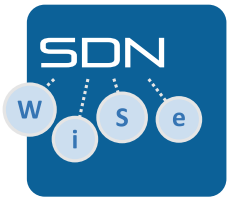
IoT: a melting pot of networks





Part I: SDN in infrastructured wireless networks

Why is SDN different in wireless networks?



Wired networks

Wireless networks

Current wireless networks are

- Difficult to scale
  - Static over-provisioned networks cannot cope with the rise of users demand (think to video)
- Difficult to manage
  - Heterogeneous technologies
  - Manually intensive, prone to errors, lengthy delays in provisioning and troubleshooting
- Inflexible
  - Given the above it takes weeks to months to introduce new services. Multi-tenancy and isolation limited to VLANs and tunnels. No (or limited) policy management mechanisms
- Too costly
  - Inefficient and inflexible use of resources and increasing complexity → CapEx and (especially) OpEx are rapidly increasing

Open Networking Foundation, "*OpenFlow-Enabled Mobile and Wireless Networks*". White paper. 2013.

Benefits of using SDN

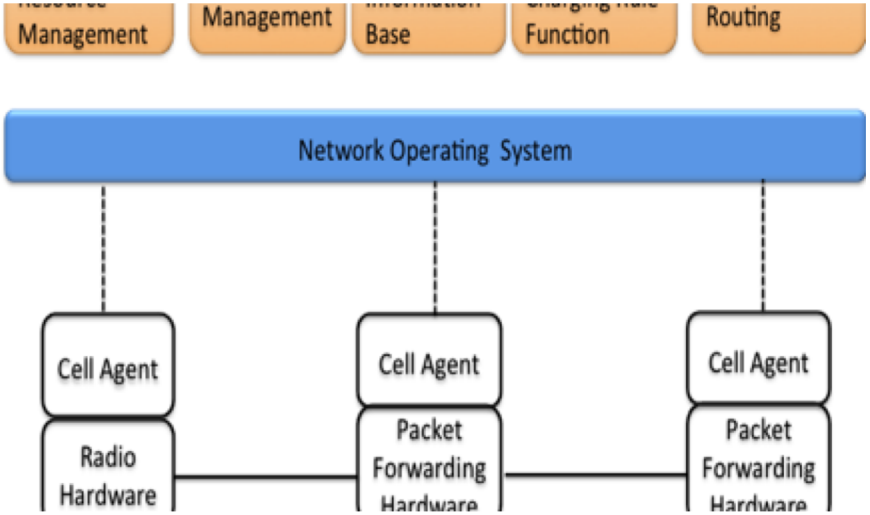
- The flow paradigm well suites the need to establish communication services across several technologies
- Logically centralized control makes it easier to introduce new solutions
- Simple path management is beneficial when users change their location frequently
- Network virtualization enables slicing and customized policies to be implemented in each slice

Open Networking Foundation, "*OpenFlow-Enabled Mobile and Wireless Networks*". White paper. 2013.

CellSDN

- One of the earliest solutions
- **Four main innovations**

1. controller applications should be able to express policy in terms of subscriber attributes, rather than IP addresses or physical locations
   - The Controller should maintain a Subscriber Information Base
2. to improve control-plane scalability, each switch should run a local control agent that performs simple actions
3. switches should support more flexible data-plane functionality, such as deep packet inspection and header compression
4. base stations should support remote control of virtualized wireless resources to enable flexible cell management.

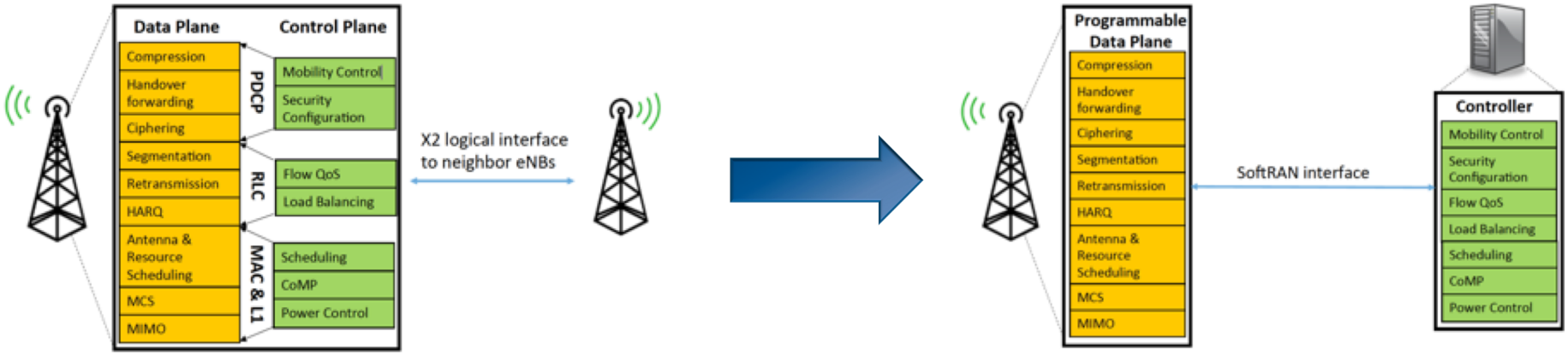


Major limitation: only embryonic ideas no concrete solutions to several specific issues

L. E. Li, Z. M. Mao, and J. Rexford. Toward Software-Defined Cellular Networks. EWSDN 2012.

Soft-RAN

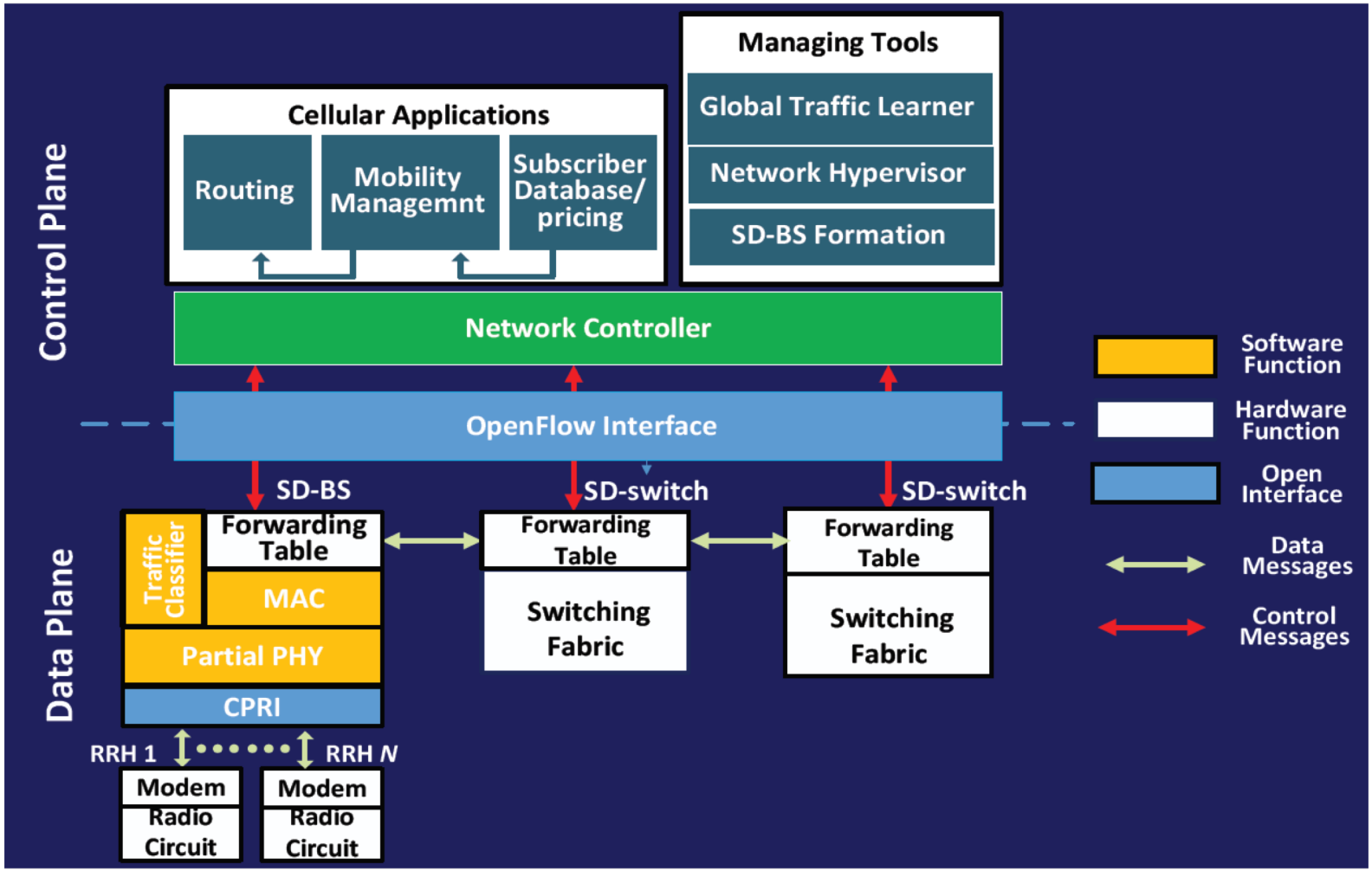
- Decouples the data plane and control plane for the RAN
- Control plane that programs the radio resource usage in a macro sector in an unified fashion
- Very low latency (<1ms RTT) control transport latency
- Data plane that leverages low cost of transport using whatever is available
  - Does not require low latency



Major limitation: no complete support of NFV

A. Gudipati, D. Perry, L. E. Li, and S. Katti. SoftRAN: software defined radio access network. ACM *HotSDN*'13.

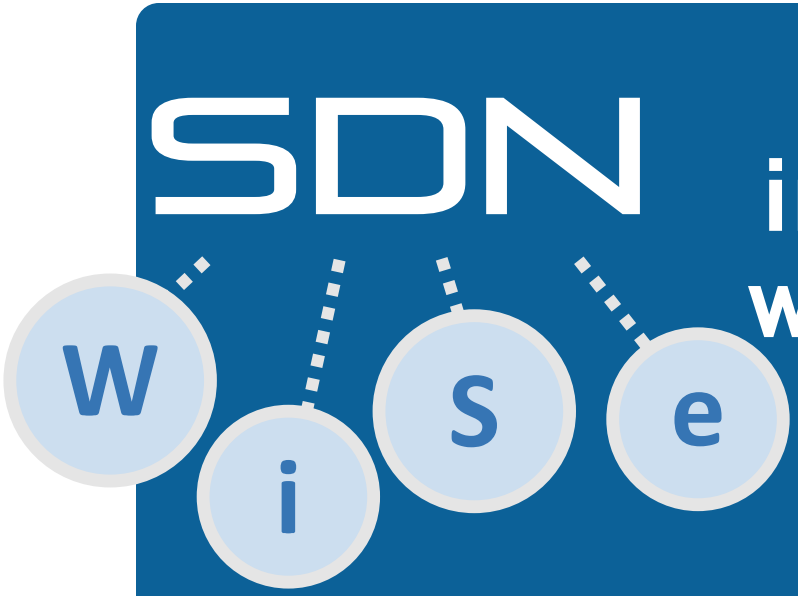
SoftAir



I. F. Akyildiz, P. Wang, S. C. Lin. SoftAir: A software defined networking architecture for 5G wireless systems. Computer Networks. 2015.

… the above are just the tip of a huge mountain

- Lots of papers
- Lots of research project
  - A simple query to Cordis database: 23 active research projects in the domain
- Lot of interest from the industry…



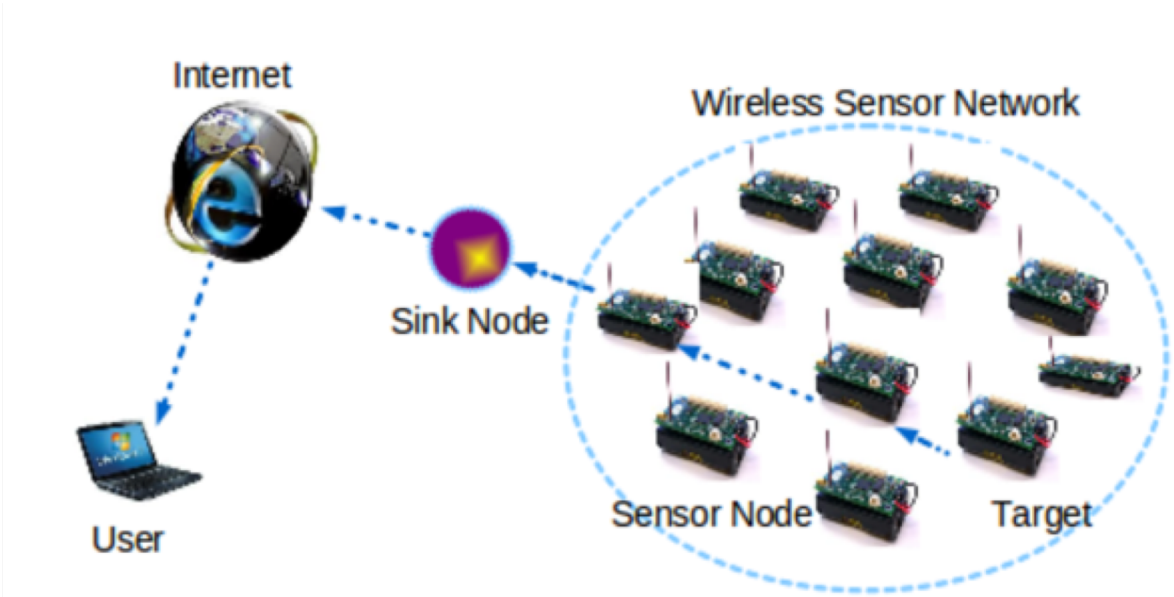
Part II: SDN in infrastructureless wireless networks

A tale of the last 5 years of my (research) life

End of 2011 - The search for a new research topic…

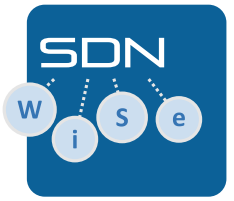
- What I had been doing…
  - MAC & routing for WSNs (not excited anymore)
  - Opportunistic networks (never excited about it)
  - Internet of Things
    - Social Internet of Things (too easy…)
- What next? Browsing the literature… couple of topics selected
  - Query your oracles…
- Find the niche…
  - Wireless obviously…
  - No cellular networks, WSN instead…

Wireless sensor networks



- Multihop wireless communications
- Mostly many-to-one and one-to-many communications
- Energy limitations
- Processing limitations
- Storage limitation
- Link unreliability
- Prone to failures
- Vulnerable to (physical) attacks

A few facts about wireless sensor networks



- Mature technology since early 2000s
- Challenging communication & networking environment
- Requirements extremely application specific

The bottom-line...

There is nothing like a one-fits-all solution

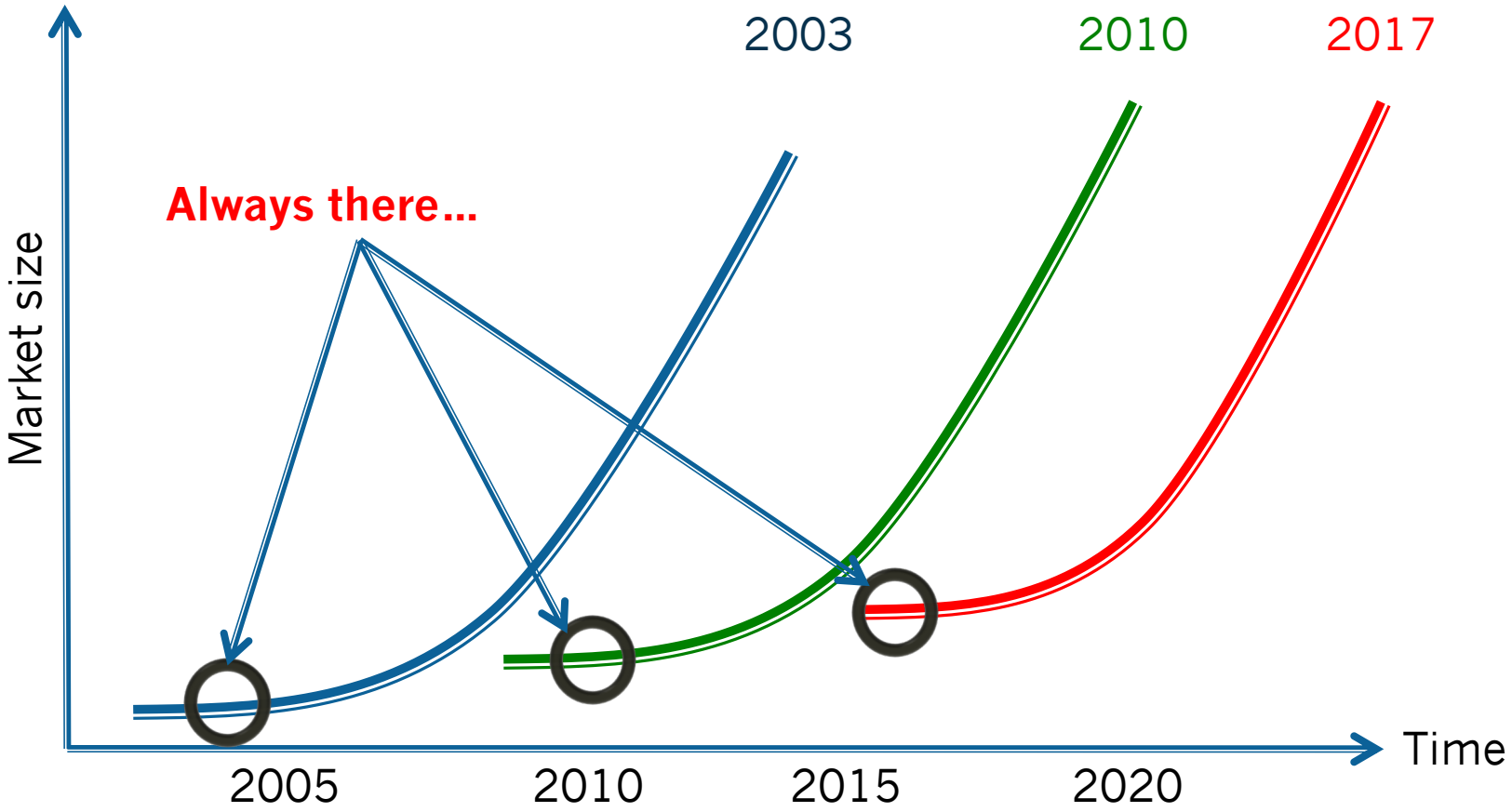
Upsides:

- Large number of solutions proposed
- Deep understanding of the WSN domain
- Zillions of papers, citations, academic promotions, projects

Downsides:

- High solution specialization
- Market fragmentation
- Burden on application developers
- Low reusability

The consequence…



It's not taking off!

Vision

2 months
WSN project

Reject!

Our goal

2 weeks
WSN project

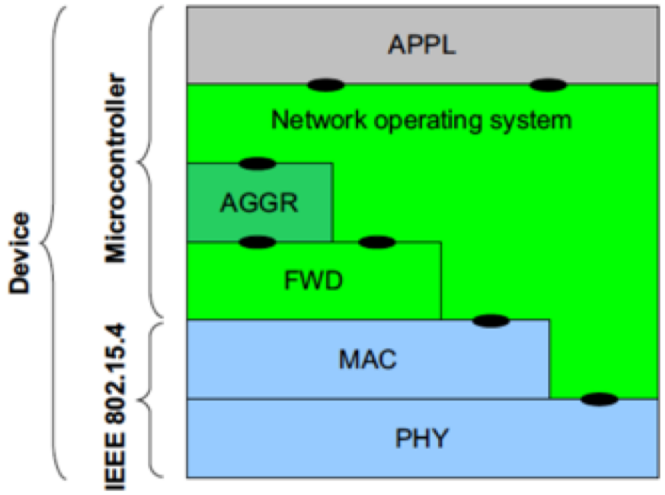
Accept!

Previous work

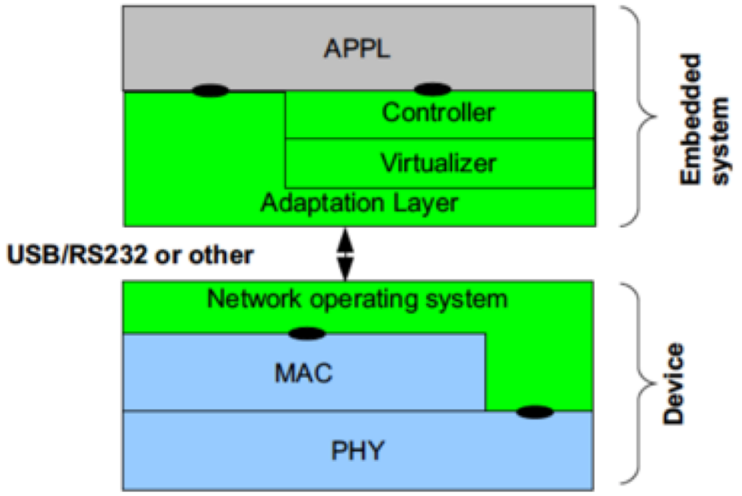
(New) requirements

- Support duty cycles
- Support data aggregation
- Support (more) flexible definition of rules
- Robust to (frequent) topology changes
- Robust to packet losses
- Robust to node failures

Architecture, Flow Table, and packet format



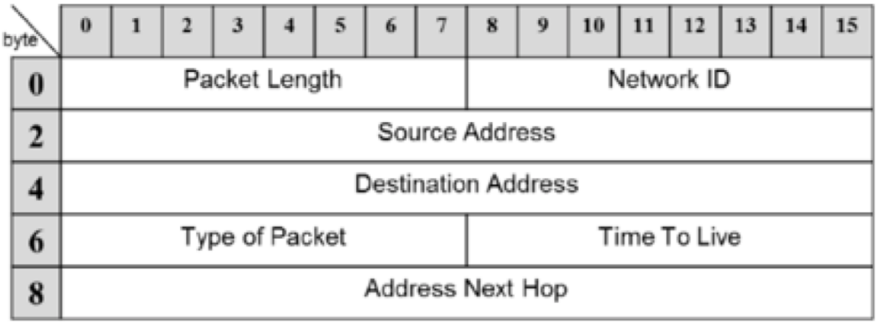
Generic node



Sink

Window I				Window II				...	Action		Stats
Size	*Op*	*Addr*	*Value*	*Size*	*Op*	*Addr*	*Value*	...	*Type*	*Value*	*Count*
2	=	2	170.24	2	≠	4	170.11	..	Forward	170.23	17
2	=	2	170.16	1	=	1	3	..	Drop	1	3
2	≠	2	170.24	1	=	7	25	..	Modify	7/26	3
2	=	2	170.17	0	=	0	0	..	Forward	170.21	11

Flow table



Packet header

S. Costanzo, L. Galluccio, G. Morabito, S. Palazzo. *Software Defined Wireless Networks: Unbridling SDNs*. EWSDN 2012. October 2012.

Vision

2 months
WSN project

Reject!

Our goal

2 weeks
WSN project

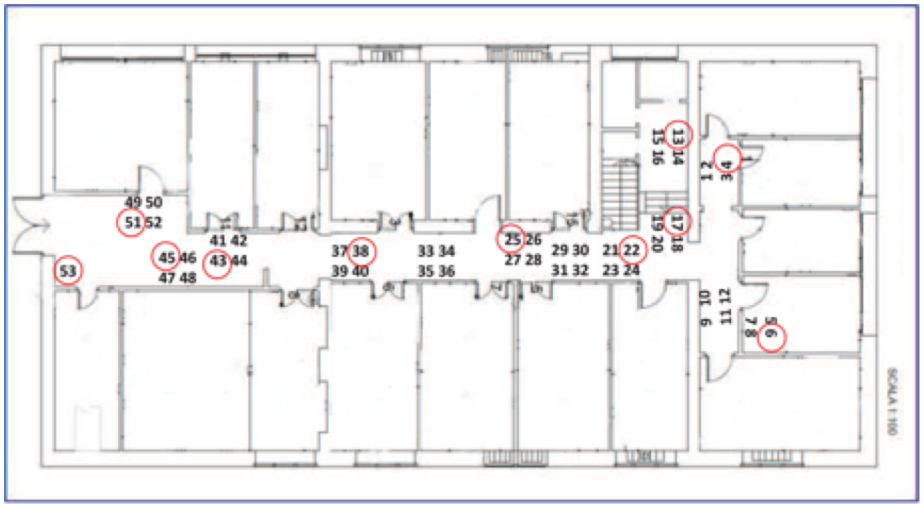
Accept!

Empirical demonstration

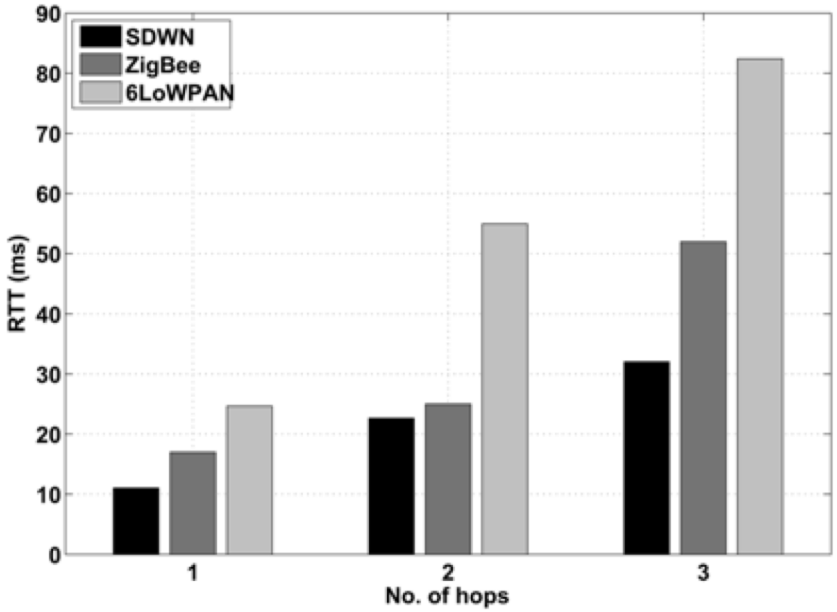
- A group of three *good* students
  - second year, MS program in TLC Engineering, BS in Computer networks engineering
- **The deal:**
  - I give you a programmer manual (5 pages)
  - You implement a routing such that:
    - If the value stored in the payload of the packet is larger than *k* the packet the path must contain node *A*
    - Otherwise it must NOT contain *A*
  - If you can do it in less than 24 hours I give you maximum score without any further examination
- I received the email with the code after **12 hours**

Experimentation in the EuWIN platform (University of Bologna)

- Measures performed by colleagues at CNIT Bologna
- We provided implementation of SDWN for their devices (TI CC2530)



Results



Protocol	Unicast 20 bytes	Unicast 30 bytes	Multicast 20 bytes	Multicast 30 bytes
SDWN	0.53	0.8	1.06	1.59
ZigBee	0.53	0.8	1.05	1.57
6LoWPAN	0.53	0.8	0.97	1.43

Protocol	RTT (ms): static	RTT (ms): quasi-static
SDWN	44	49
ZigBee	51	76
Protocol	PLR (%): static	PLR (%): quasi-static
SDWN	1.5	2
ZigBee	13	21.5

Protocol	RTT (ms)	PLR (%)
SDWN	40	96
ZigBee	61	33.5

Buratti, Stajkic, Gardasevic, Milardo, Abrignani, Mijovic, Morabito, Verdone. *Testing Protocols for the Internet of Things on the EuWIn Platform*. IEEE IoT Journal. Feb. 2016.

Afterthoughts

Right

- Topic and niche
- Title
- Timing

Wrong

- Venue…. nobody giving a $#§√ about it
- Not the *best* paper ever not even in the top 20

Lessons learnt and/or shared thoughts

- Crazy community, aka, the *conference-journal* ***dilemma***:
  - Journal: long processing time → paper are published when they are old → too late for impact
  - Conference: short processing time → fresh and timely ideas → good impact
- Your previous work becomes literature and you must prove to go well beyond it in the future → **one idea, one ~~paper~~ conference, one (very) good journal**
  - Exceptions for project dissemination activities only

From SDWN to SDN-WISE

- During the implementation phase we found several little problems
- Success of SDWN paper: missed opportunity of having a good paper on the subject
- New talented PhD student on the topic →
- Go beyond: SDN-WISE

Galluccio, Milardo, Morabito, Palazzo. *SDN-WISE:* Design, prototyping and Experimentation of a stateful SDN solution for WIreless SEnsor networks. IEEE Infocom 2015. April. 2015.

--. *Reprogramming Wireless Sensor Networks by Using SDN-WISE: a Hands-On Demo.* IEEE Infocom 2015. April 2015.

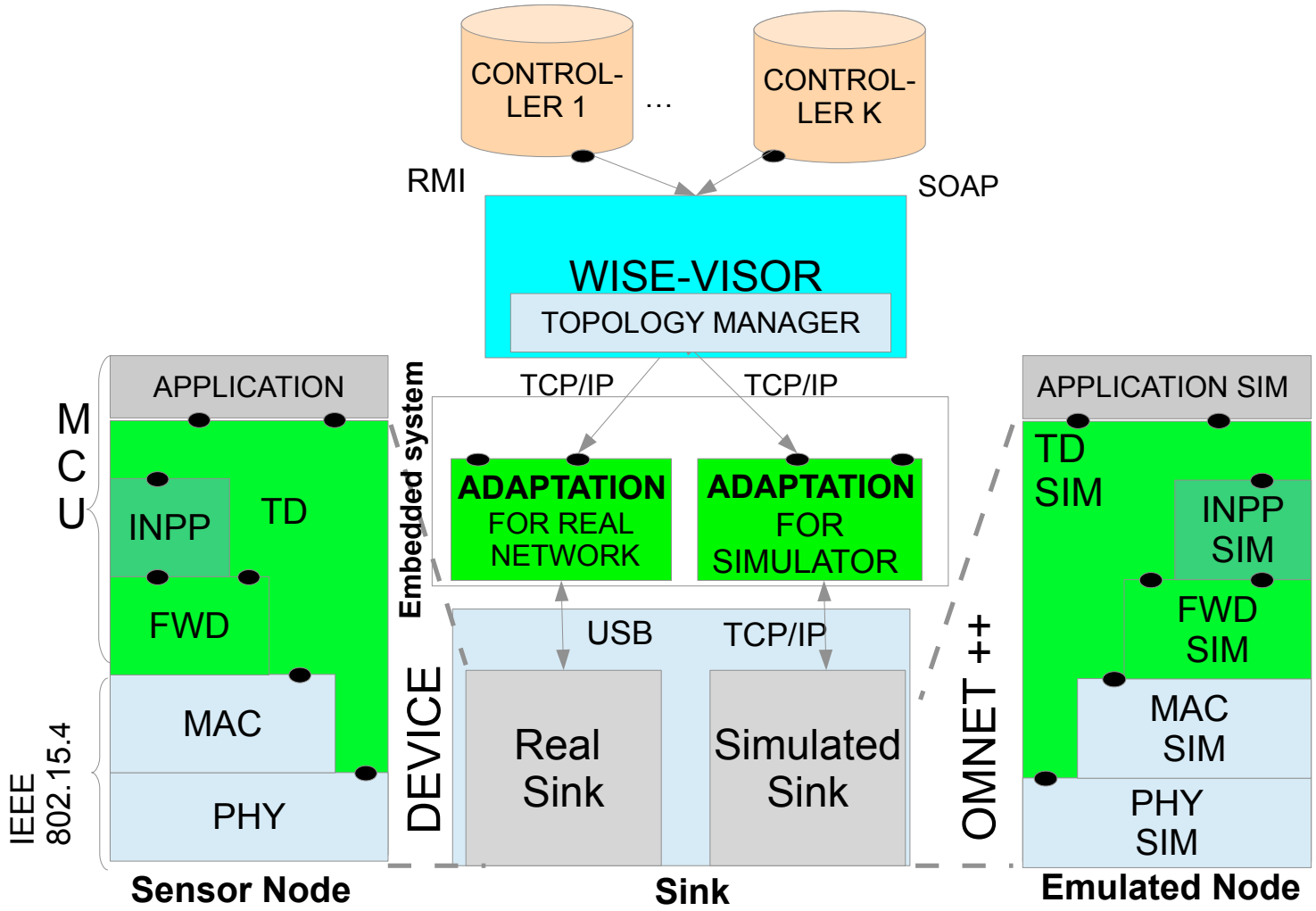
Major features (compared to OpenFlow)

1. Statefulness
2. Flexible definition of rules (not just “=“ and “!=“)
3. Support of duty cycles
4. Support of multitenancy (beyond *slicing*)
5. Lots of deployment options and programming languages
6. Integration with simulation environments (OMNET++ & OPNET)

WISE Table

Matching Rule					Matching Rule					Matching Rule					Action					Statistics	
Op.	Size	S	Offset	Value	Op.	Size	S	Offset	Value	Op.	Size	S	Offset	Value	Type	M	S	Offset	Value	TTL	Counter
=	2	0	2	B	>	2	0	10	x_{Thr}	=	1	1	0	0	Modify	1	1	0	1	122	23
=	2	0	2	B	≤	2	0	10	x_{Thr}	=	1	1	0	1	Modify	1	1	0	0	122	120
=	2	0	2	B	-	0	-	-	-	-	0	-	-	-	Forward	0	0	0	D	122	143
=	2	0	2	A	=	1	1	0	0	-	0	-	-	-	Drop	0	0	-	-	100	42
=	2	0	2	A	=	1	1	0	1	-	0	-	-	-	Forward	0	0	0	D	100	32

SDN-WISE Architecture



Multitenancy (beyond *slicing*)

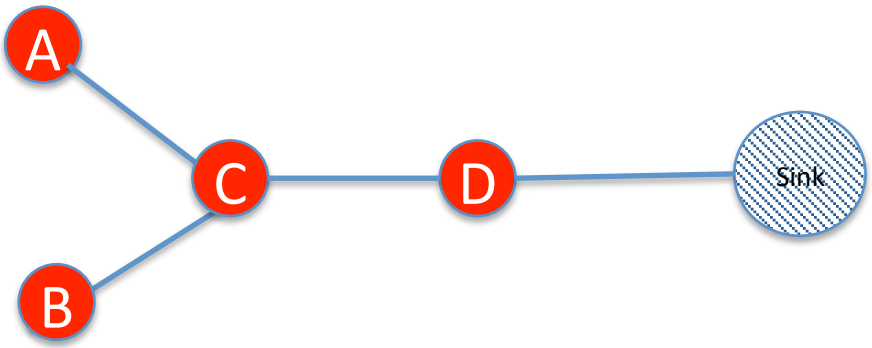
- Slicing assigns each packet to **only** one tenant
- In WSN the same piece of data can be of interest of several applications
- **WISE-Visor** a new layer which abstracts the real network and creates (different) views for different tenants
- At each node a packet belongs to all tenants that agree on its treatment
- When there is a disagreement, a new copy of the packet is created

Statefulness

- Inspired by OpenState
- SDN-WISE is stateful: a buffer of memory is reserved for state information
  - Rules can use state info to classify packets in flows
  - Actions can modify state info
- **Why?** Reduce the number of interactions with the Controller if local policies must be applied
- 3 exemplary uses of the state...

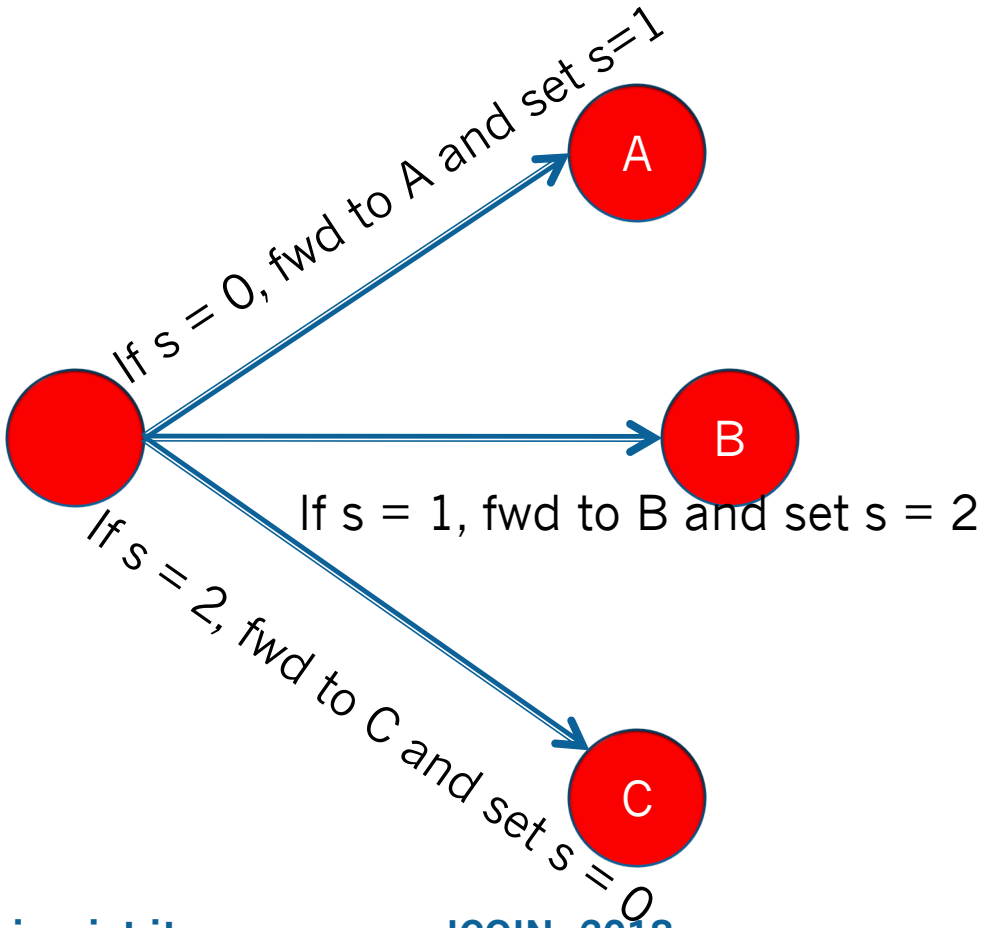
Exemplary use of the state (1)

- Conditional forwarding:
  - C must forward packets from A only, if the values coming from B are higher than a threshold



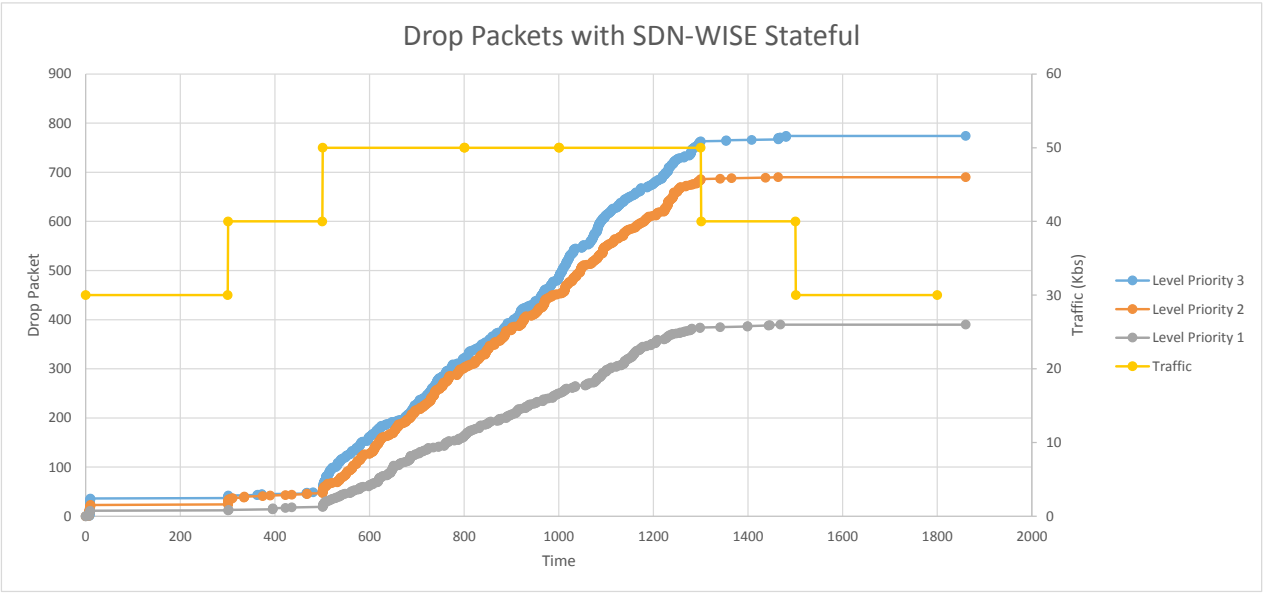
Exemplary use of the state (3)

- Multipath routing



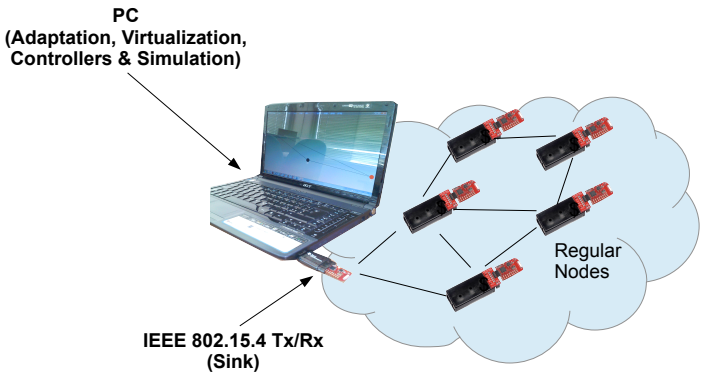
Exemplary use of the state (2)

- Support of QoS:
  - A congested node must give different priorities to different flows
  - Level of congestion stored as state information
  - Different drop probabilities given to different flows in the WISE-table in case of congestion

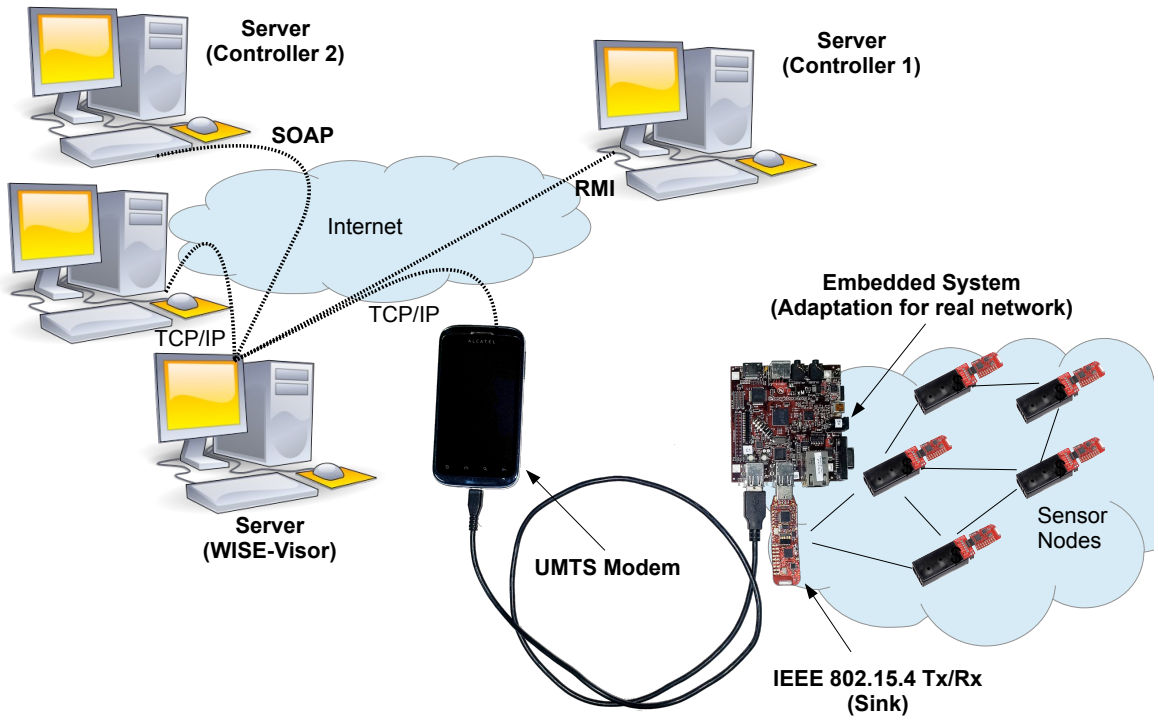


Lots of deployment options and programming languages

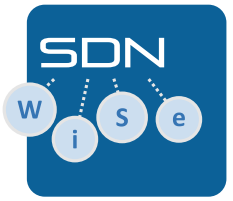
Simple



Complex



Afterthoughts



Right

- Nice paper
- PR campaign

Wrong

- Attitude… I got Infocom paper why bothering for a journal?

Lessons learnt and/or shared thoughts

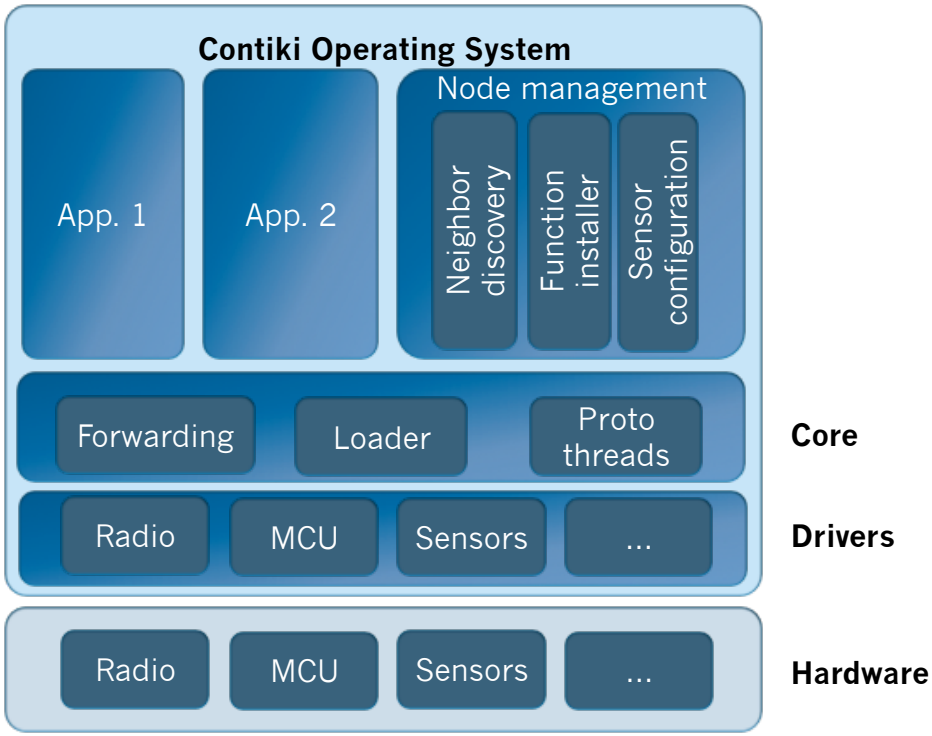
- Taking a research idea (paper) to the *next step* takes time and resources
  - How can a small research group pursue ambitious goals?
  - People much much **much MUCH** more important than resources
  - Why?

Two problems, one solution…

- The two problems:
  - SDN-WISE requires platform-dependent implementations → not sustainable
  - The “stateful” approach takes a lot of table entries to perform even simple solutions
- … and the solution is…

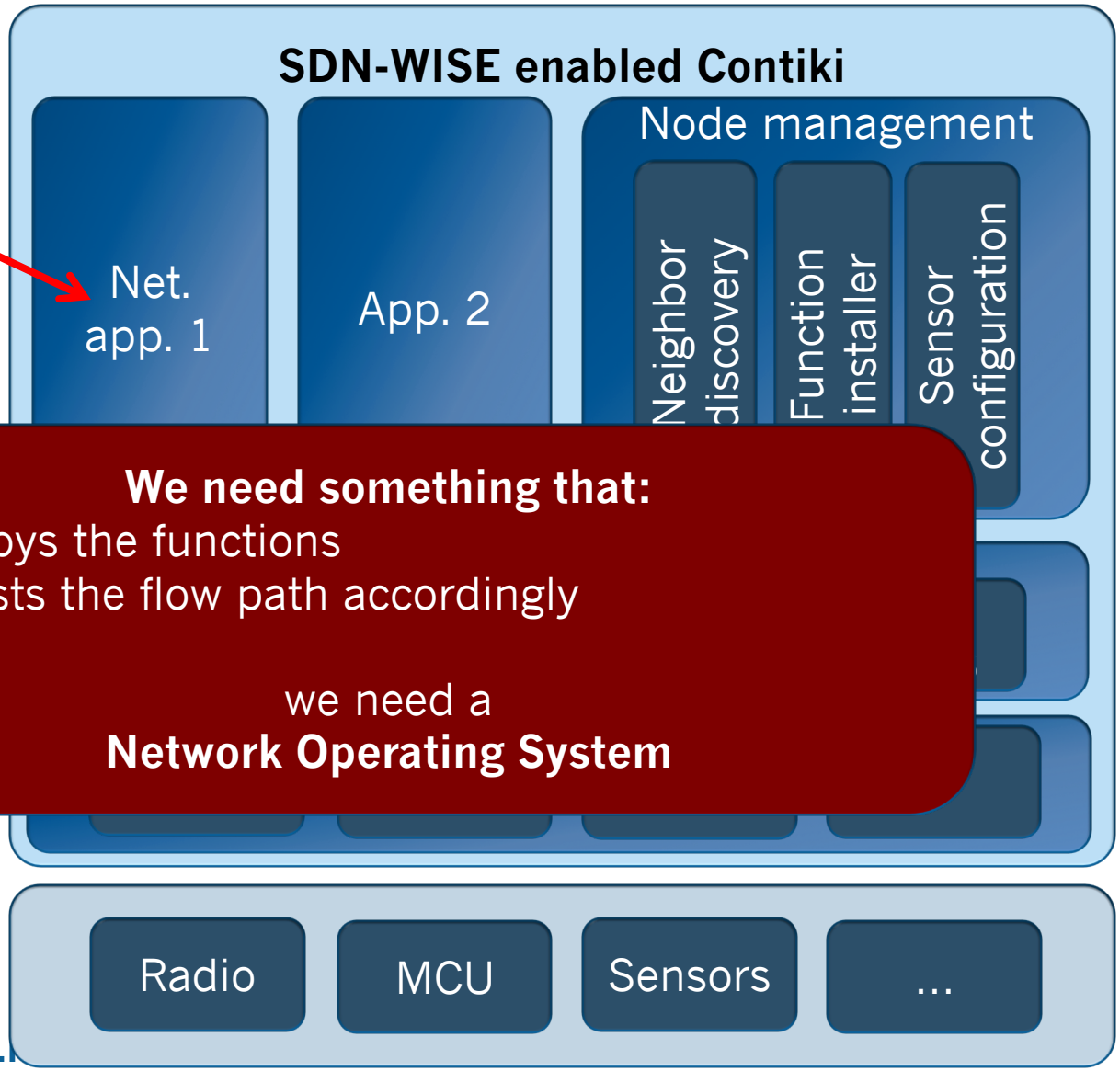
An Operating System

- A few popular open source solutions
  - Contiki
  - RIOT
- Large number of hardware platforms supported (TI, STM, FreeScale, Infineon)
- Support:
  - IPv6 and IPv4
  - 6LOWPAN
  - RPL
  - CoAP
- Active communities
- Industrial interest
- Network simulator: Cooja (for Contiki)



SDN-WISE enabled Contiki

- 6LowPAN
- CoAP
- Geographic routing
- Data aggregation
- **Data analytics**



We need something that:

- Deploys the functions
- Adjusts the flow path accordingly

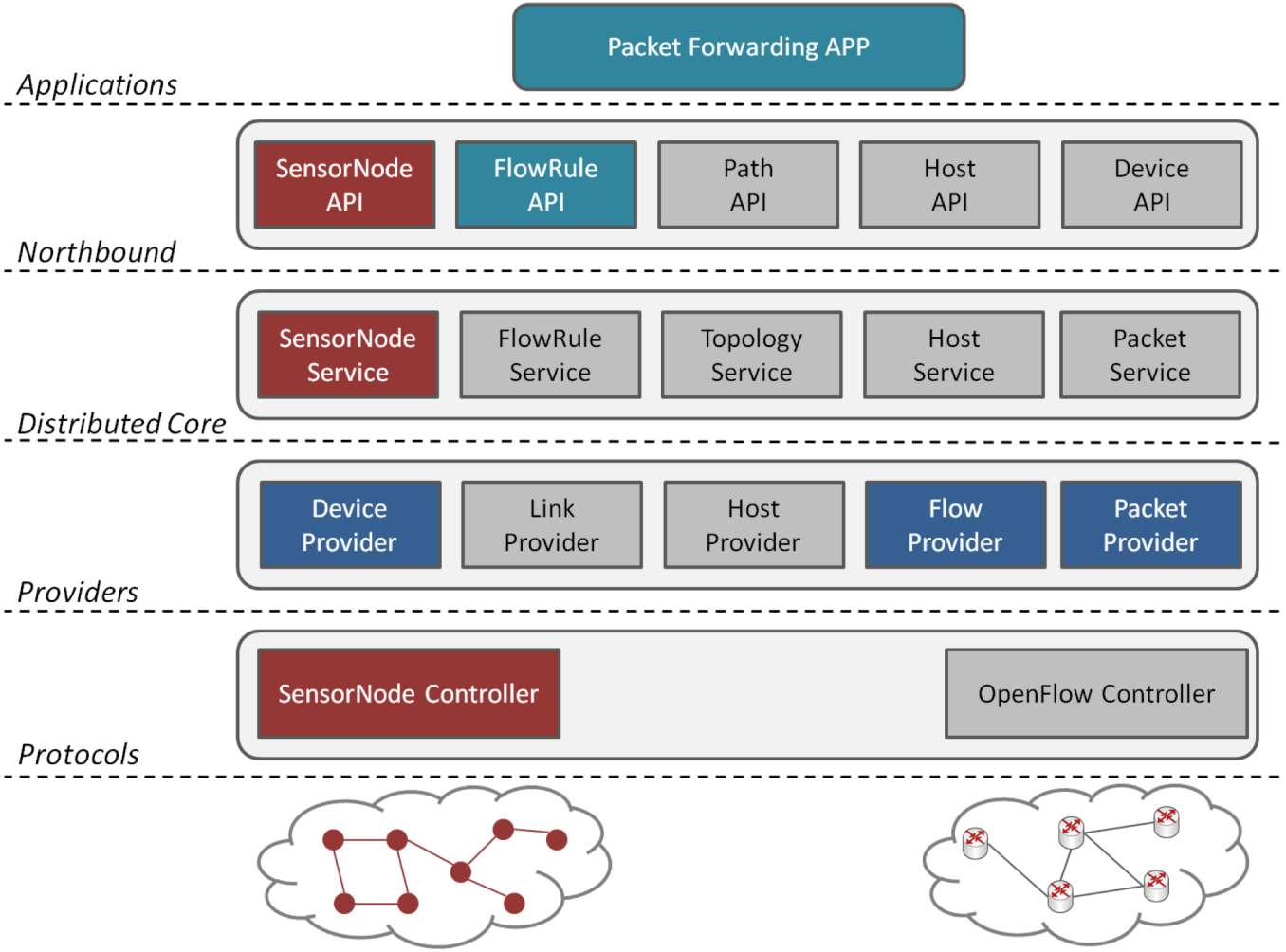
we need a
Network Operating System

Core

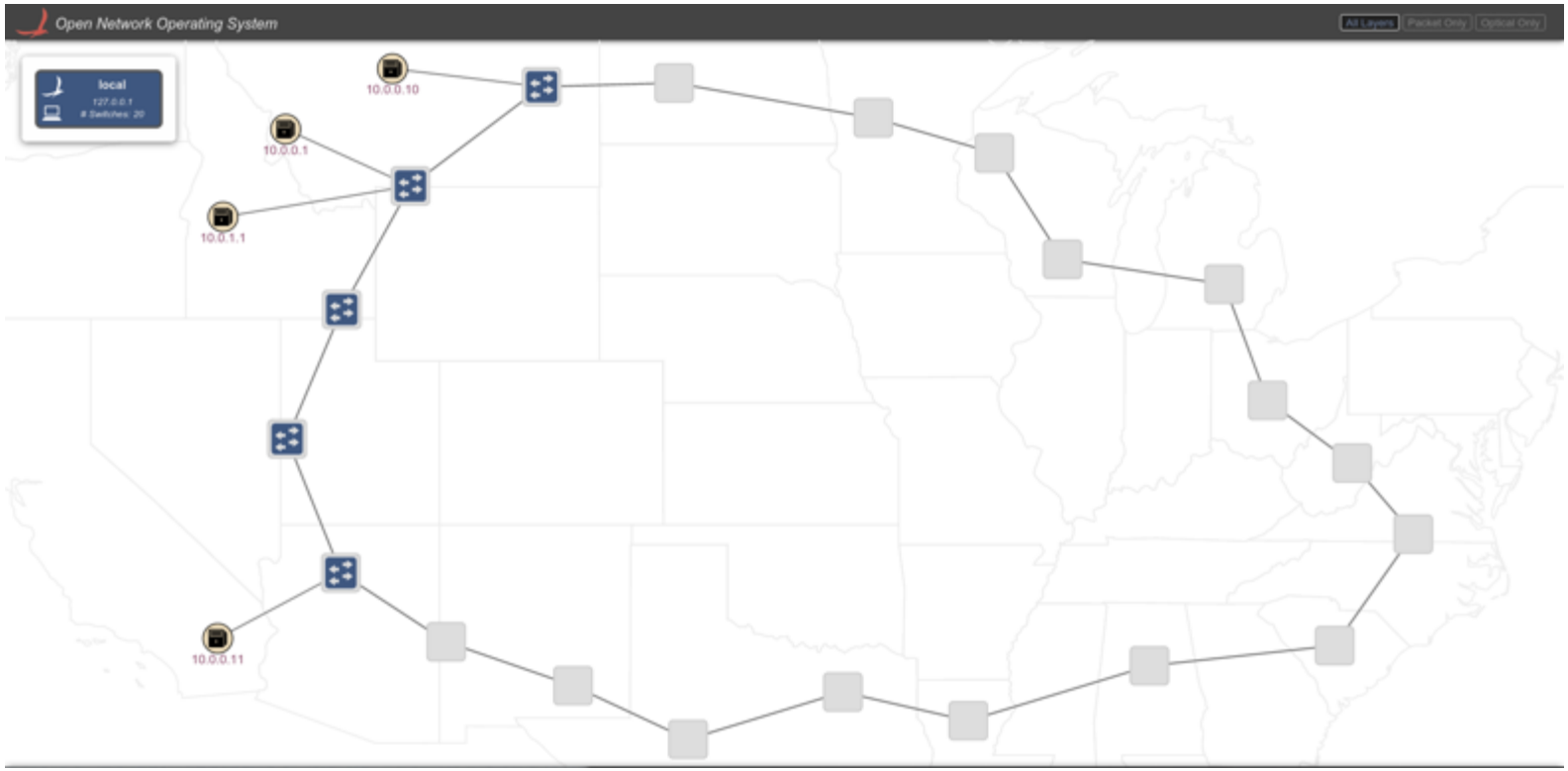
Driv

Hard

ONOS extension



Success!



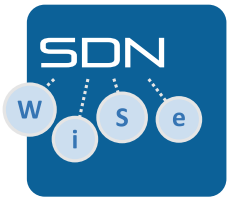
Anadiotis, Galluccio, Milardo, Morabito, Palazzo. *Towards a Software-Defined Network Operating System for the IoT*. IEEE World Forum on IoT. December 2015.

In network data analytics

- Too much data produced by sensors → not sustainable model
- Process data inside WSN
- Exploit the SDN paradigm and the Contiki OS to support MapReduce *in* WSN
- Problems addressed:
  - Select the nodes that will process data (NP hard problem)
  - Adjust the routing accordingly

Anadiotis, Morabito, and Palazzo. An SDN-assisted Framework for Optimal Deployment of MapReduce Functions in WSNs. IEEE Trans. on Mobile Computing. 2015.

Afterthoughts



Right

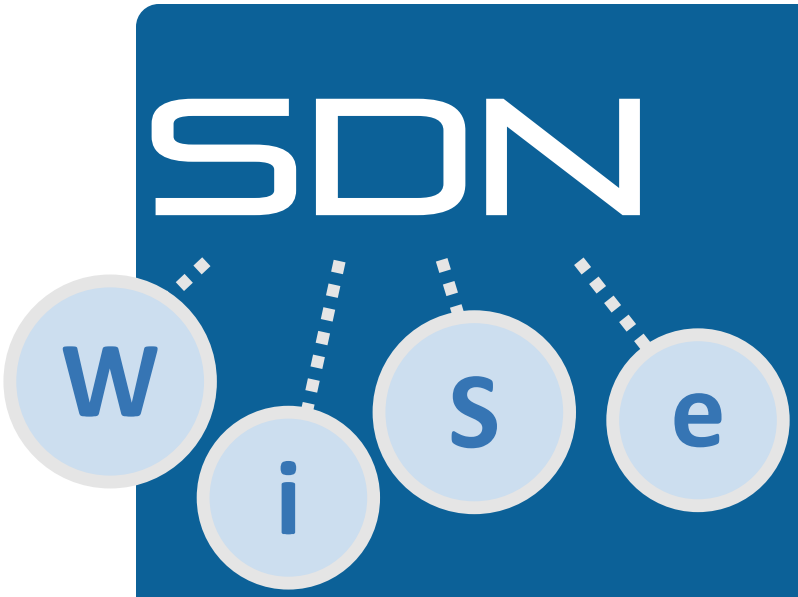
- Start from existing platforms (Contiki and ONOS), rather than implementing our own
- Invest in our platform
- PR campaign

Wrong

- Scarce effort in the development of a community
- Scarce effort in the tentative of introducing our solutions in ONOS and Contiki distributions

Lessons learnt and/or shared thoughts

- We started in 2013, 2-3 years earlier than (almost) anybody else
- We have lost most of the advantage and now there is a large number of (mostly bad) papers → Difficult to provide further original contributions
  - Partially inevitable
  - Partially our fault → Not enough tension in publishing
- However, we still have our platform which is unique and is our strength



Conclusions

Open issues

- Security
  - Dilemma: security vs. efficiency
- Scalability
  - ONOS crashes if network has > 40000 nodes
  - IoT: network > 50 billion nodes
- Original IoT vision vs. real IoT implementations
  - Original vision: “World wide network of uniquely addressable objects based on standard communication protocols”
  - Real implementations based on the “channel” model
- In the infrastructureless segment of the IoT nodes are both sources/sinks and switching/forwarding elements → Ask the NOS to take care of non networking issues
  - Example: control the sampling rate of the sensor

Conclusions

- In the last 5 years we have developed a software platform that integrates SDN/NFV in the WSN ecosystem
- Everything is open source and you are welcome to use our work and to improve it
- SDN-WISE → SD-WISE
  - More than just a SD *Network*
- New exciting capabilities will be available soon:
  - Library that allows interaction with ONOS-enabled WSN using MATLAB
  - …

Q&A

http://sdn-wise.dieei.unict.it