Mininet-WiFi: Emulation Platform for Software-Defined Wireless Networks

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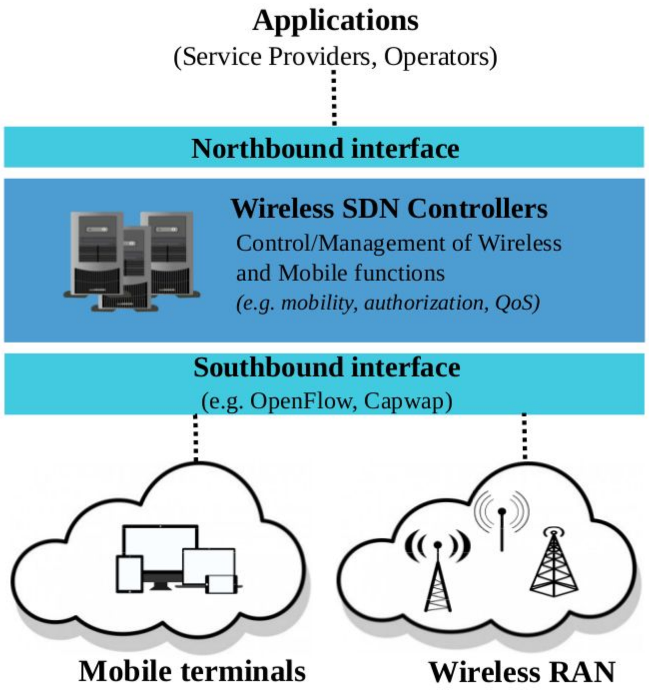
Outline

1. Introduction
2. Mininet-WiFi
3. Emulation Fidelity and Scalability
4. Use Cases Scenarios
5. Contributions
6. Final Considerations/Future Work

1 Introduction

① Introduction

Software-Defined Wireless Networks



- Based on a programmatic **separation** of the **control plane** (aka. *Network OS*) from the **data plane** (aka. *forwarding*)
- The **OpenFlow** protocol [4] is the **most popular southbound interface** but not the only one, CAPWAP [14], FORCES [15], or NETCONF [16] are also candidate protocols in scope.
- **SDWN Proposals.** OpenRoads [23], Odin [24], OpenRF [25], Ethanol [26], CloudMac [27], Chandelle [28], etc.

① Introduction

Why SDN for Wireless Networks?

There are many opportunities for researching SDN in wireless networks:

- Enabling interconnections among heterogeneous networks
- **Operators to provide services by requiring**, managing and operating virtual networks sharing the same substrate physical networks
- **Deployment of innovative and flexibly technologies** by programming through open APIs and customized services
- **Improvements on the resource utilization** and save the costs by globally optimizing and resource sharing, such as energy and device utilizing cost

1 Introduction

SDN for Wireless Networks

- The need to support **exponentially increasing mobile traffic** and the fact that **spectrum is limited**
- Wireless networks are very **sensitive** to **policy changes**, **hard to manage**, **tightly coupling with specific hardware** (often proprietary solutions) and **lack of flexible control interfaces**.
- There is **no clear architecture**, neither experimental platform able to fill all the gaps towards the concept of SDN applied to wireless networks
- A **couple of alternatives** that allow to experiment with WiFi and OpenFlow together are available, but they **have some drawbacks**

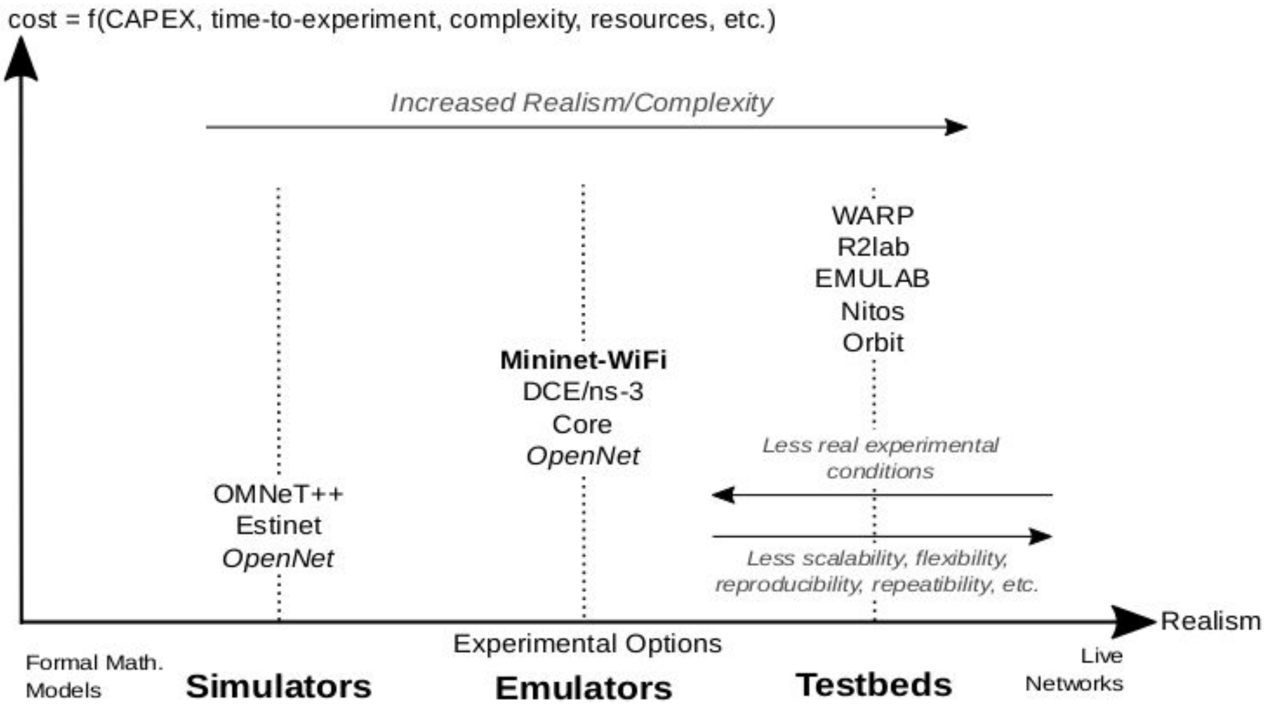
① Introduction

Motivation

- Software-Defined Wireless Networks/OpenFlow x Wireless Networks
- Efforts conducted by Open Networking Foundation (ONF)
- *Limited experimental platforms*
- OpenWrt: the only realistic way to do research with Wi-Fi and OpenFlow
- Success story (fast prototyping and reproducible research) of Mininet in support of wired SDN

① Introduction

Related work and trade-offs of different wireless experimental platforms



① Introduction

Background - Mininet-WiFi x DCE/ns-3

	Mininet-WiFi (v2.1)	**DCE/ns-3** (v1.8)
sysctl, ifconfig, route	✓	✗
IPv6 address config.	✓	✗
full *POSIX*	✓	✗
poll implementation	✓	✗
Quagga routing stack	✓	✓
extensive test	✓	✗
real time scheduler	✗	✓
mobility models	●●○	●●●
propagation models	●●○	●●●
supported technologies	WiFi	LTE/WiFi

① Introduction

Background - Mininet-WiFi x DCE/ns-3

"Despite the fact that the ns-3 already has a module that supports simulations with OpenFlow switches, it is possible to note that the available implementation provides a very outdated OpenFlow protocol (version 0.8.9, from 2008)"

Source: (2016) *http://www.lrc.ic.unicamp.br/ofswitch13/*

Does not support:
auxiliary connections
multiple controllers
openFlow channel encryption
in-band control

① Introduction

Why an Emulator for Software-Defined Wireless Networks?

- The most appropriate research tool approach comes always along with trade-offs
- Network emulation provides a balanced approach compared to simulators and physical testbeds
- Mininet emulator: The most popular tool used by the SDN research community

1

Introduction

Methodology

- **Wireless Medium**
- **Propagation Models**
- **Mobility Models**

① Introduction

Methodology

Re<u>produce</u>

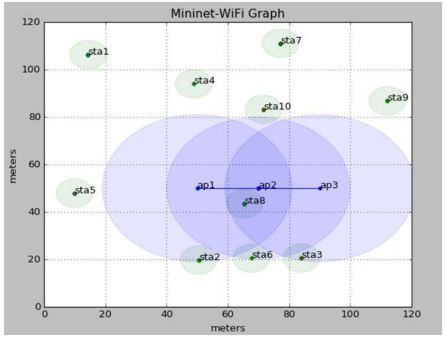
2

Mininet-WiFi

② Mininet-WiFi

Main Goal

Aims at providing high fidelity emulation of wireless networks enabling real network analysis in fully controlled environments in support of research on Wireless and SDWN.



② **Mininet-WiFi**

Requirements

Functional Requirements:

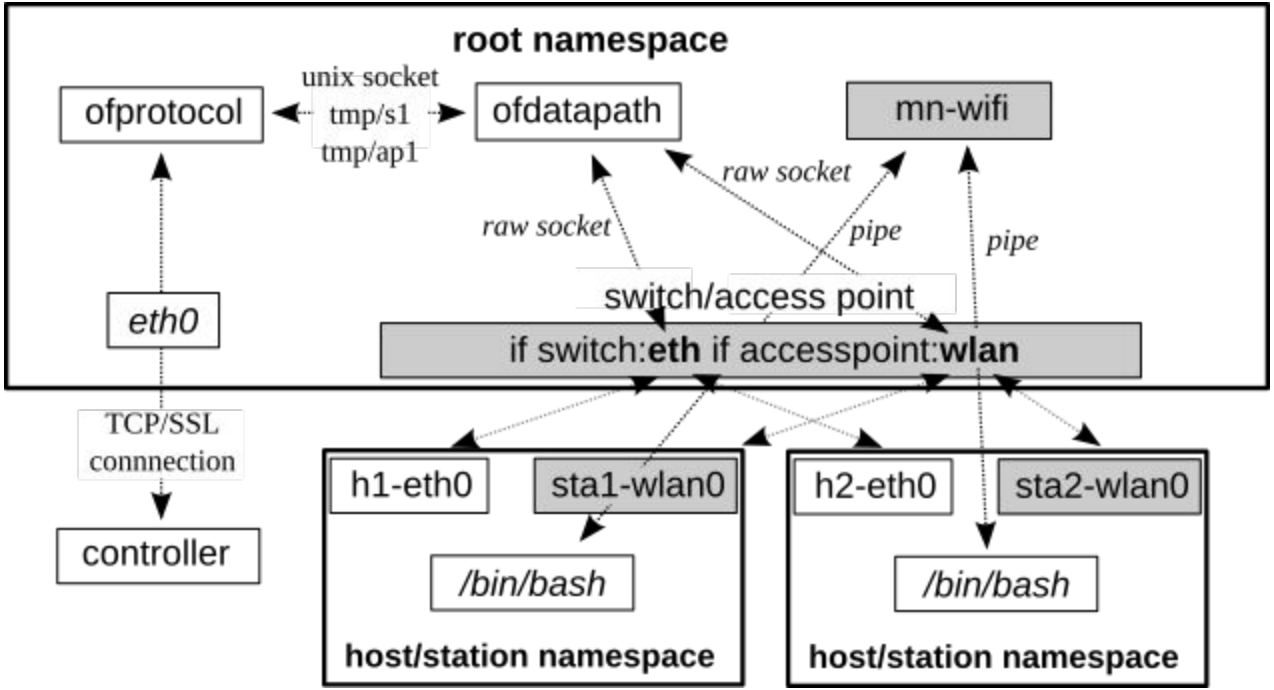
- easy experimentation
- mixed topology
- channel fidelity

Non-Functional Requirements:

- Open Source
- interoperability

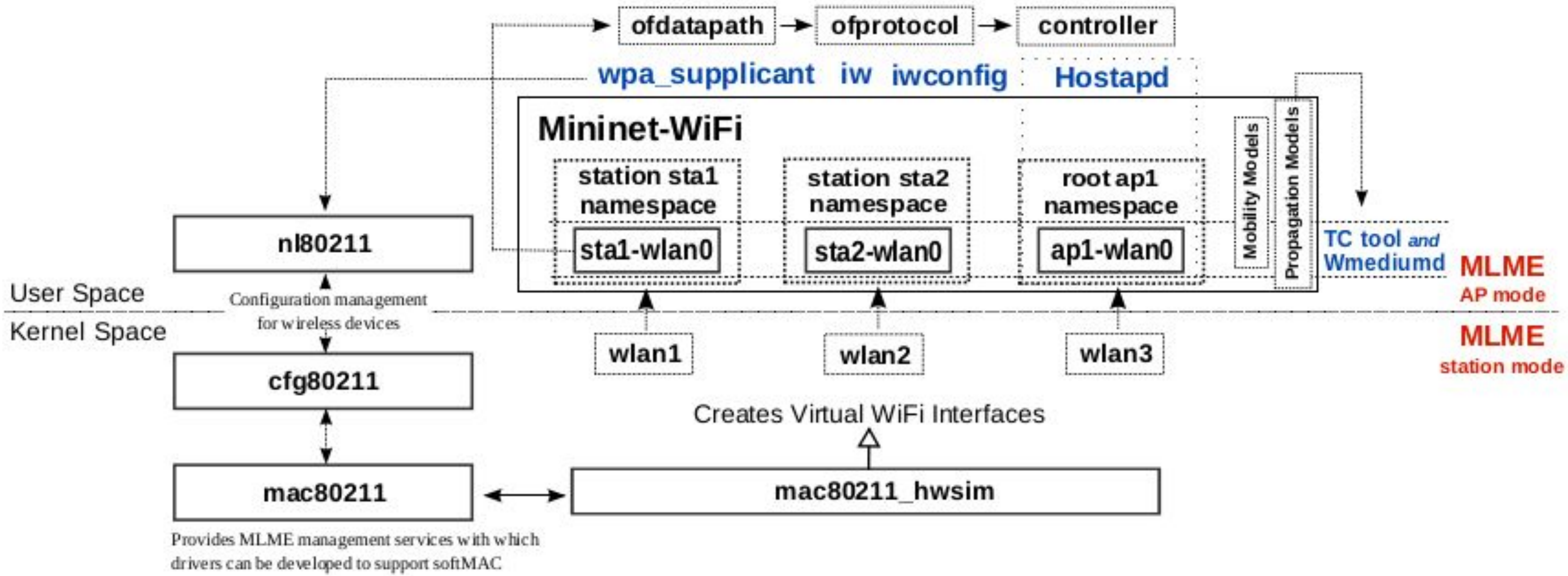
② **Mininet-WiFi**

Architecture



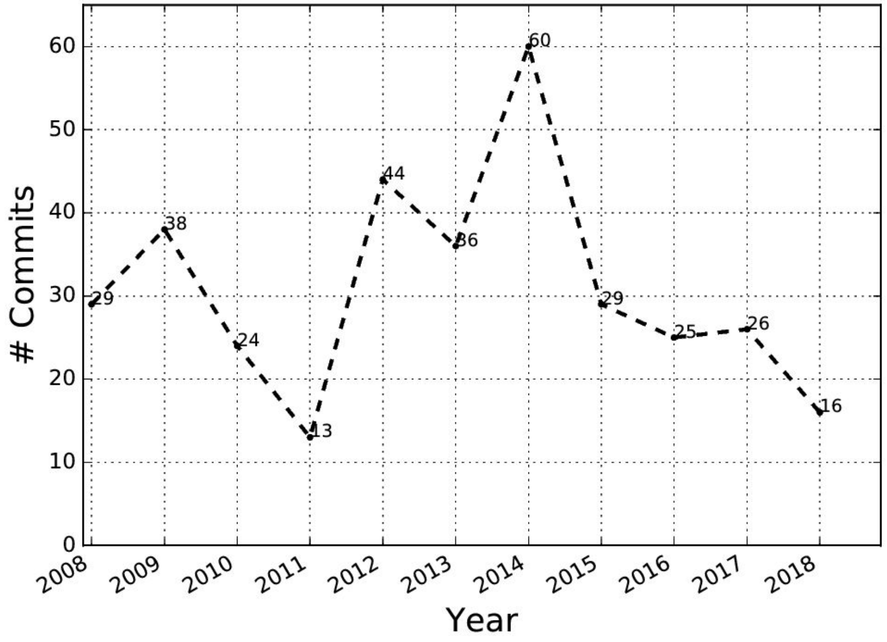
② # Mininet-WiFi

Components



② Mininet-WiFi

Statistics from mac80211_hwsim



② # Mininet-WiFi

Working with

mininet-wifi>

Network

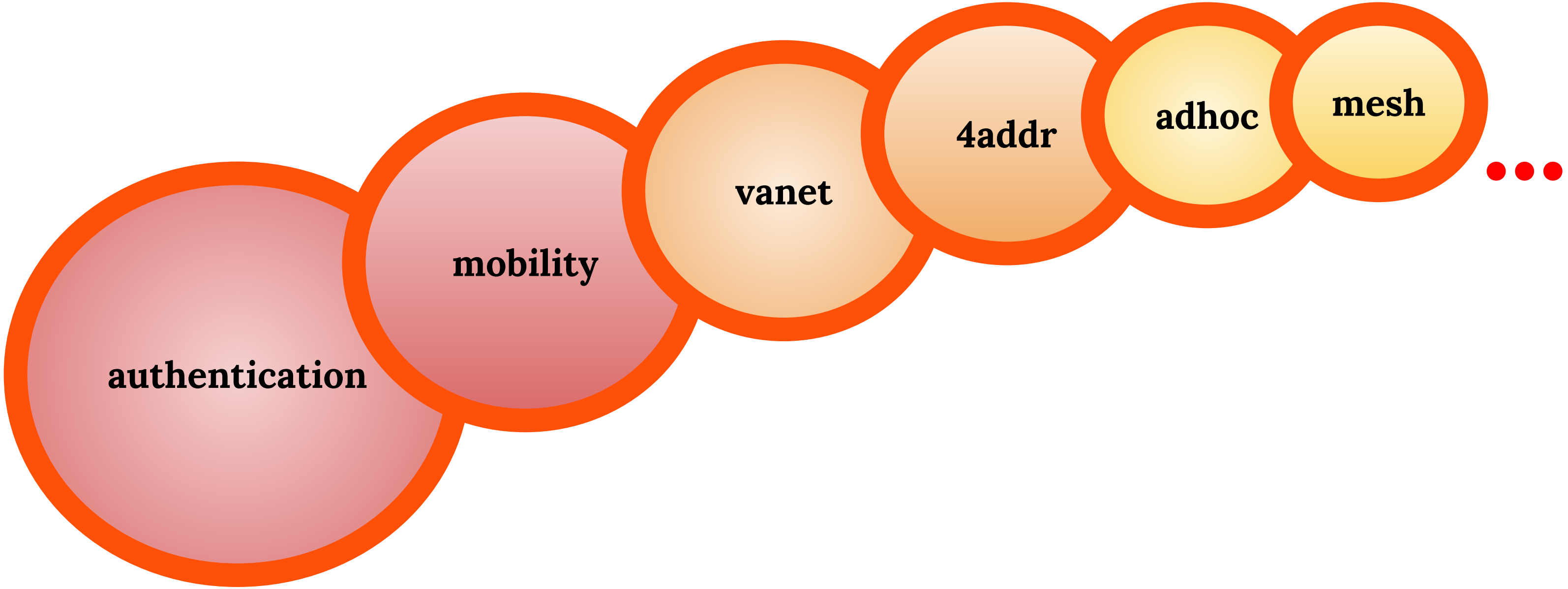
Ping	Iperf	iw
sta1 ping sta2	sta1 iperf -c 10.0.0.1	sta1 iw dev sta1-wlan0 scan

Queries

Position	Distance
py sta1.params[‘position’]	distance sta1 sta2

② **Mininet-WiFi**

Sample Files



② **Mininet-WiFi**

Supported Features

- All the features supported by hostapd/wpa_supplicant
- Vast number of IEEE 802.11 Protocols
- Hybrid Physical-Virtual Environment
- Replaying Traces

② # Mininet-WiFi

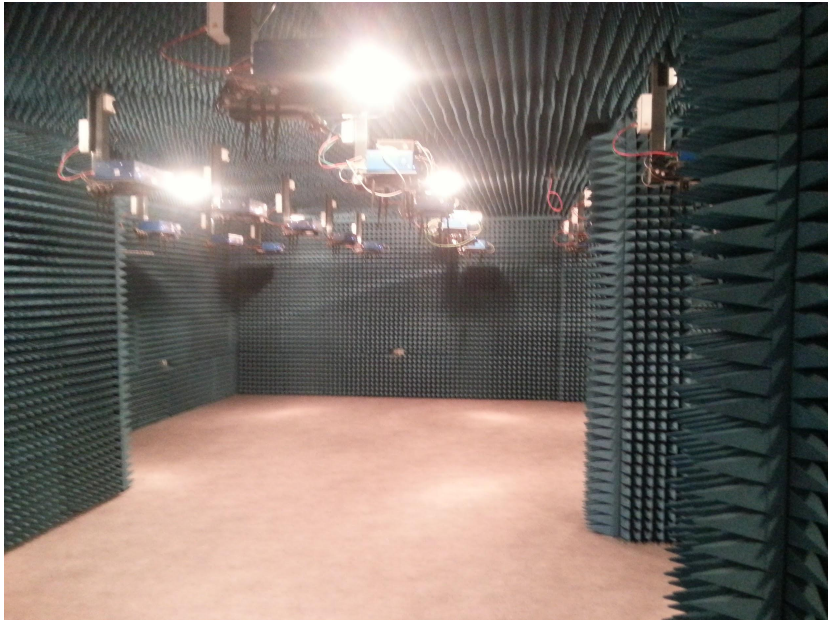
Limitations

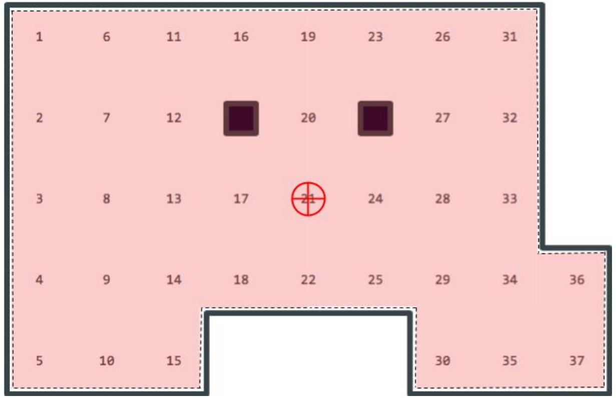
- Running on a single system is convenient, but it imposes resource limits: if the host has 3 GHz of CPU and can switch about 10 Gbps of simulated traffic, those **resources** will need to be **balanced and shared among the virtual nodes**;
- Although you can attach VMs to Mininet-WiFi, it uses a **single Linux kernel** for all virtual hosts;
- Unlike a simulator, Mininet-WiFi **does not have a strong notion of virtual time**; this means that timing measurements will be based on real time, and that faster-than-realtime results (e.g. 100 Gbps networks) cannot easily be emulated;
- It is not recommended to run **more than 1000 APs**, because the system **might be not responsive and it might return non-accurate results**.

3 Fidelity and Scalability

③ **Fidelity**

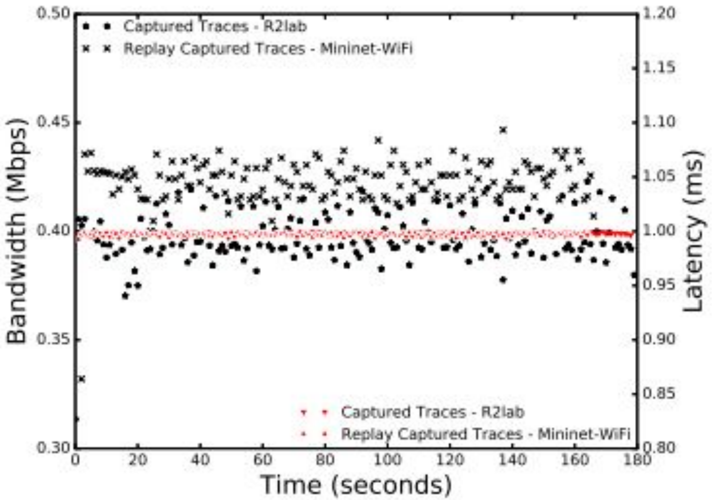
R2lab



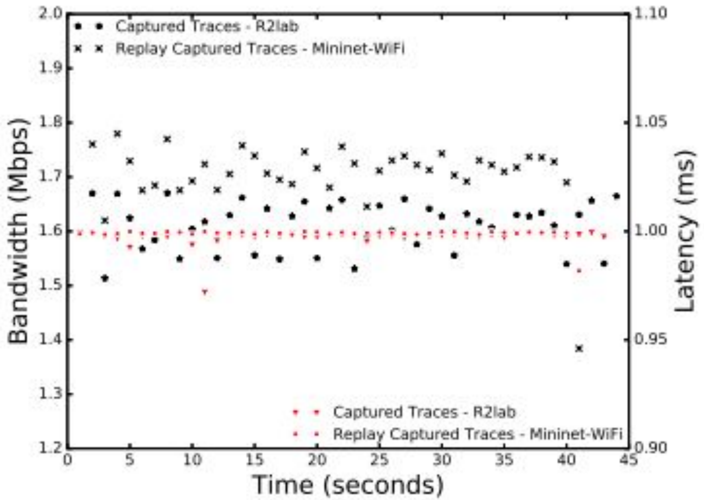


③ Fidelity

Replaying Traces



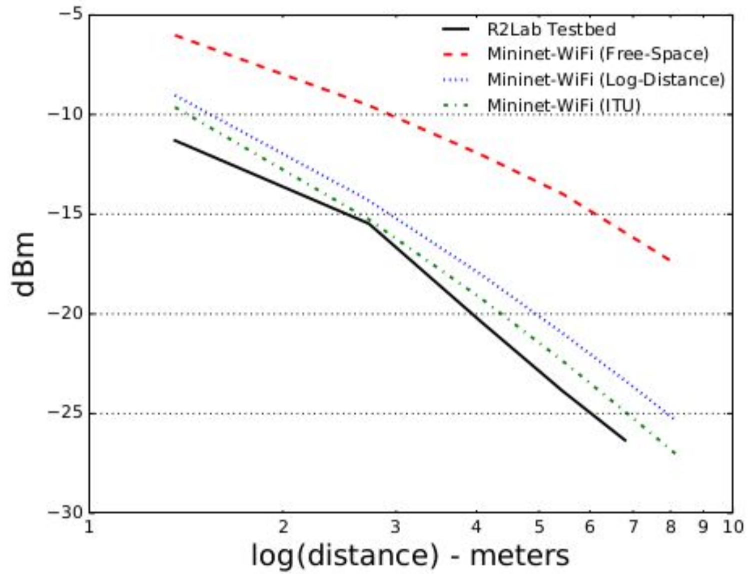
(a) *IEEE 802.11b*

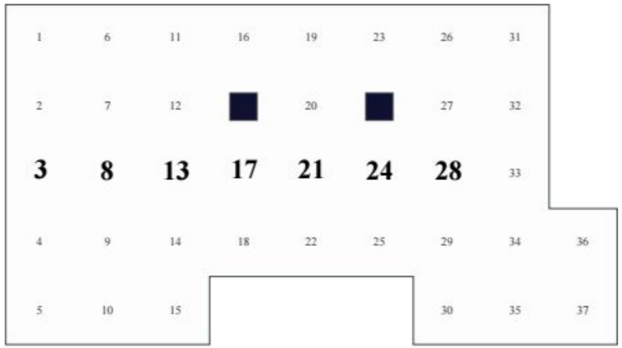


(b) *IEEE 802.11g*

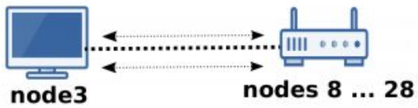
③ Fidelity

Realism on the wireless channel





(a) *Overview of R2lab's chamber*



(b) *Sample Topology*

③ Scalability Tests

- Memory
- Execution Time
- Latency
- Throughput

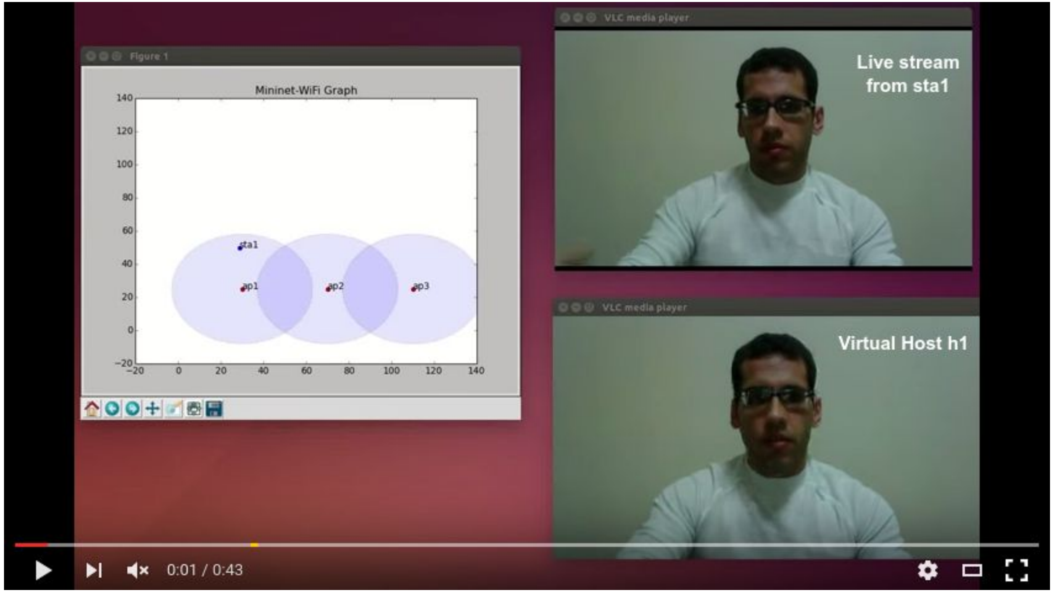
4 Case Studies

④ Case Studies

- Using all wireless network around us
- Multipath TCP (MP-TCP)
- SSID-based flow abstraction
- Simple file transfer
- VANETs
- Hybrid Physical-Virtual SDWN Research
- Security
- Network Slicing

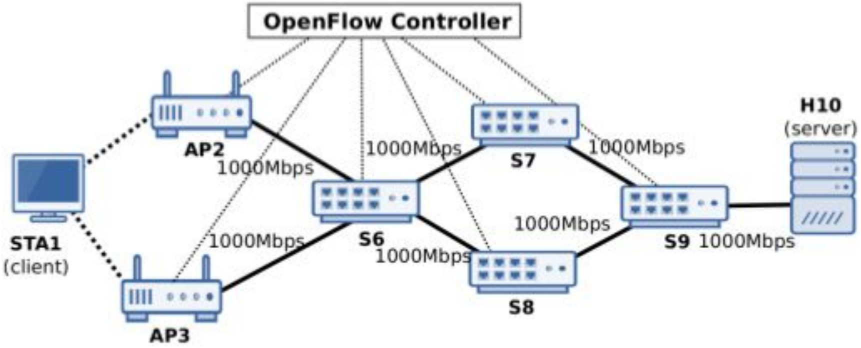
④ Case Studies

Using all the wireless networks around us



④ Case Studies

MPTCP



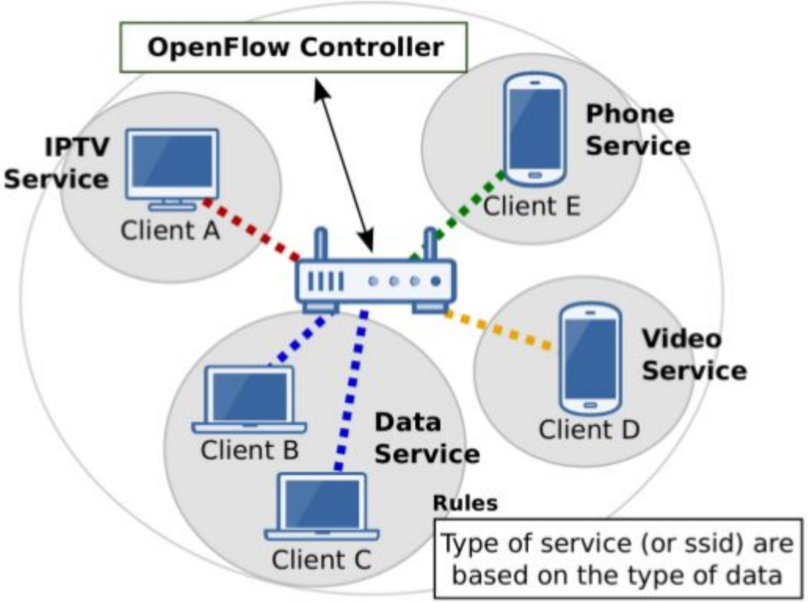
(a) *Topology setup*

Client				Server	
mininet-wifi> sta1 ifstat				mininet-wifi> h10 ifstat	
sta1-wlan0		sta1-wlan1		h10-eth0	
KB/s in	KB/s out	KB/s in	KB/s out	KB/s in	KB/s out
246.04	5047.28	632.20	25951.69	30592.15	886.37
245.37	5045.90	624.49	25949.27	30592.50	872.26
246.96	5045.91	625.94	25950.82	30594.53	870.65
245.09	5047.38	624.06	25949.16	30590.97	870.02
245.19	5047.35	624.34	25950.53	30594.11	870.48
247.08	5045.96	625.22	25949.61	30592.60	869.30
245.21	5047.43	625.50	25950.95	30593.90	868.02
246.84	5046.30	624.95	25948.97	30591.12	869.98
244.79	5047.37	625.49	25950.64	30594.98	871.94
246.59	5045.86	624.63	25950.56	30590.90	867.48

(b) *Results*

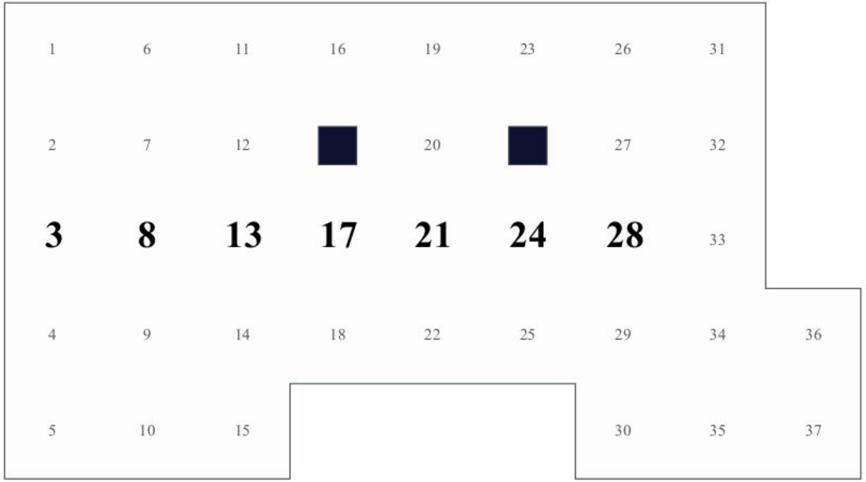
④ Case Studies

SSID-based flow abstraction



④ Case Studies

Simple file transfer



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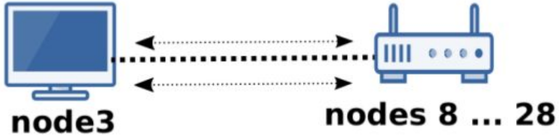
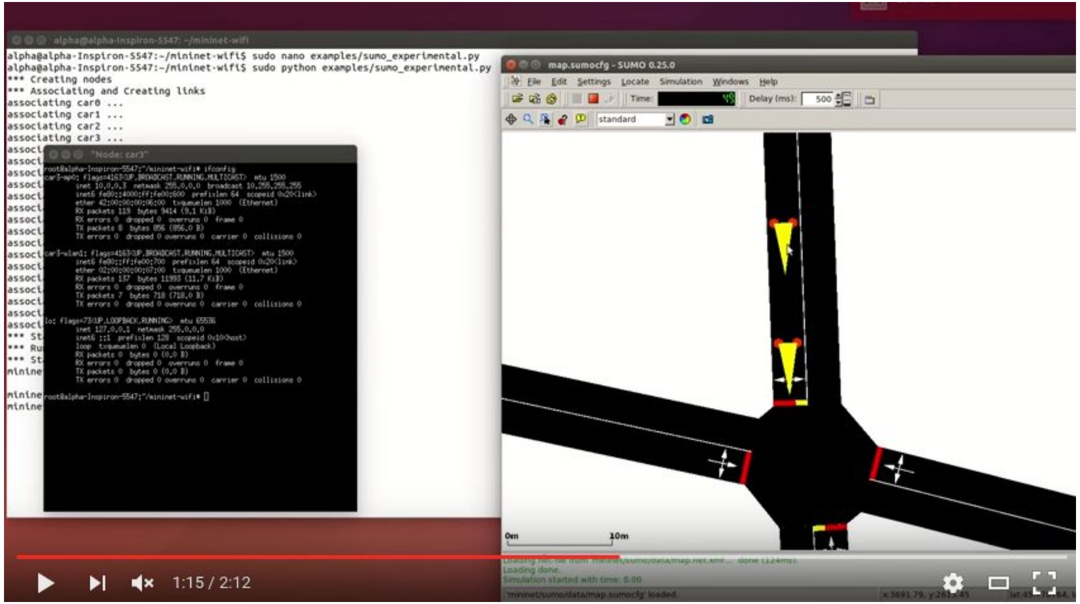


(b) Sample Topology

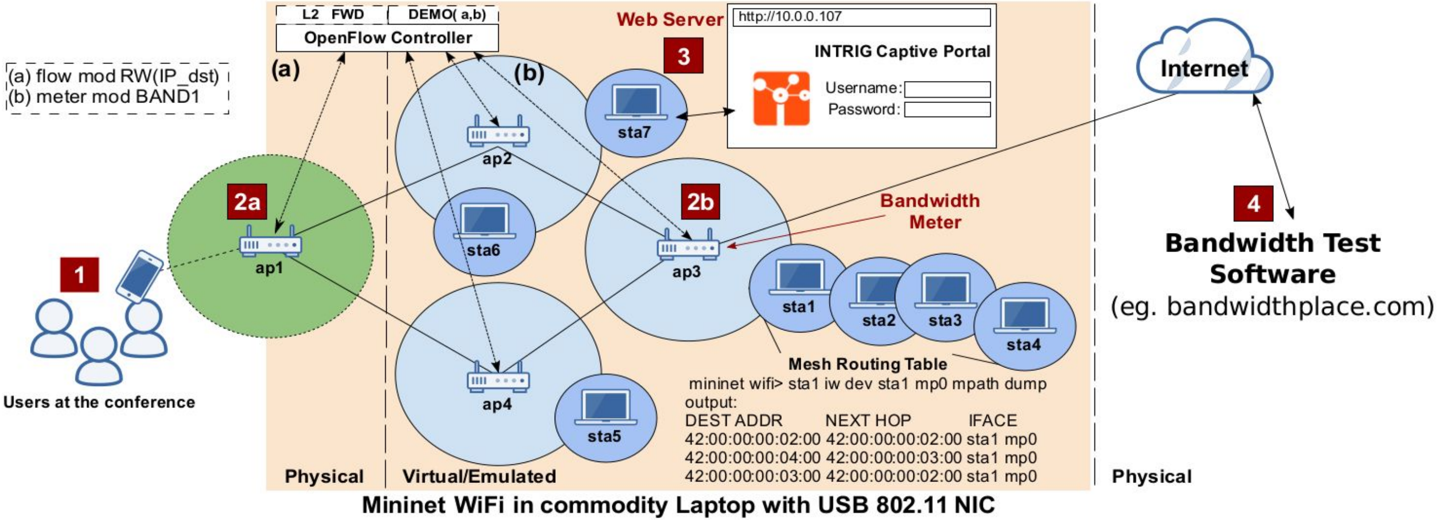
④ Case Studies

VANETs



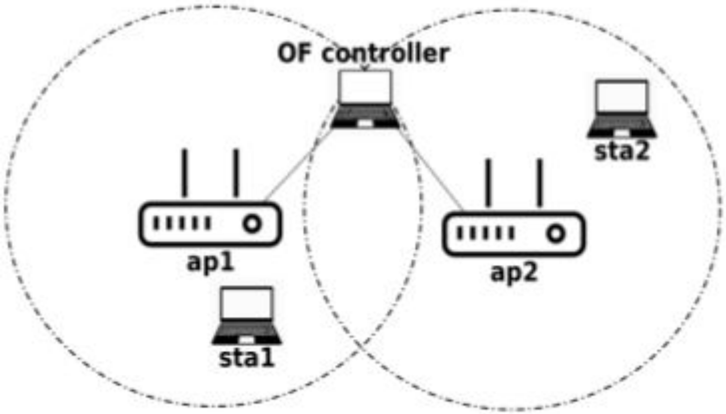
④ Case Studies

Hybrid Environment

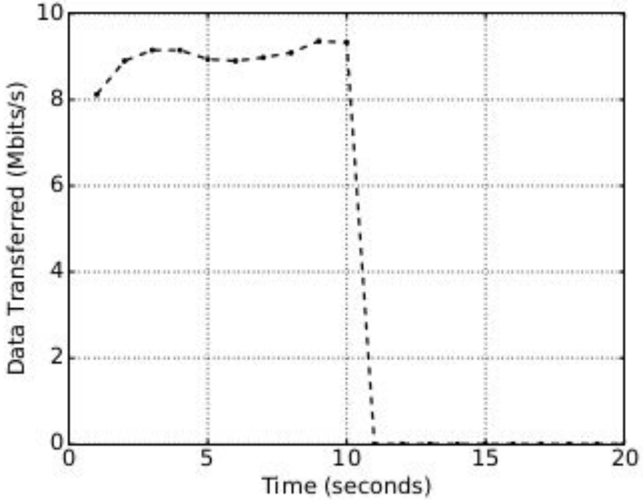


④ # Case Studies

Security (Krack Attack)



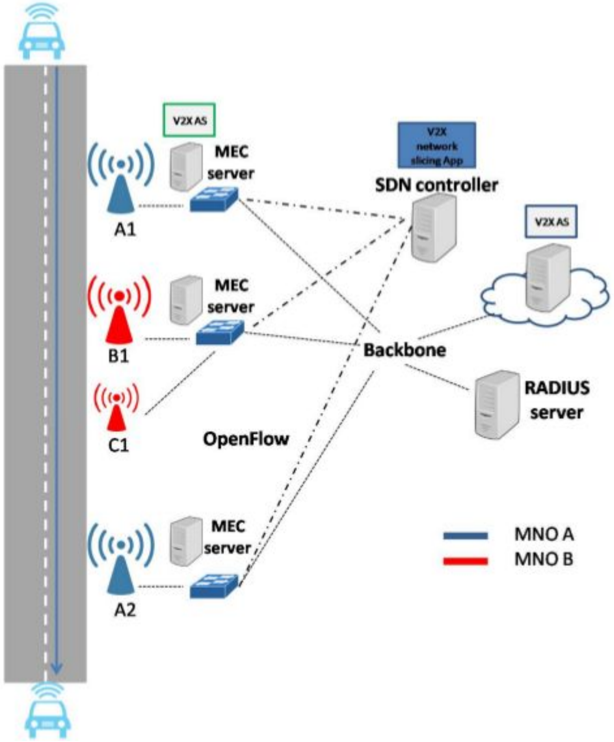
(a) *Sample Topology*



(b) *Data Transferred between sta1 and sta2*

④ Case Studies

Network Slicing



5 Contributions

⑤ Contributions

Reproducibility Experiences

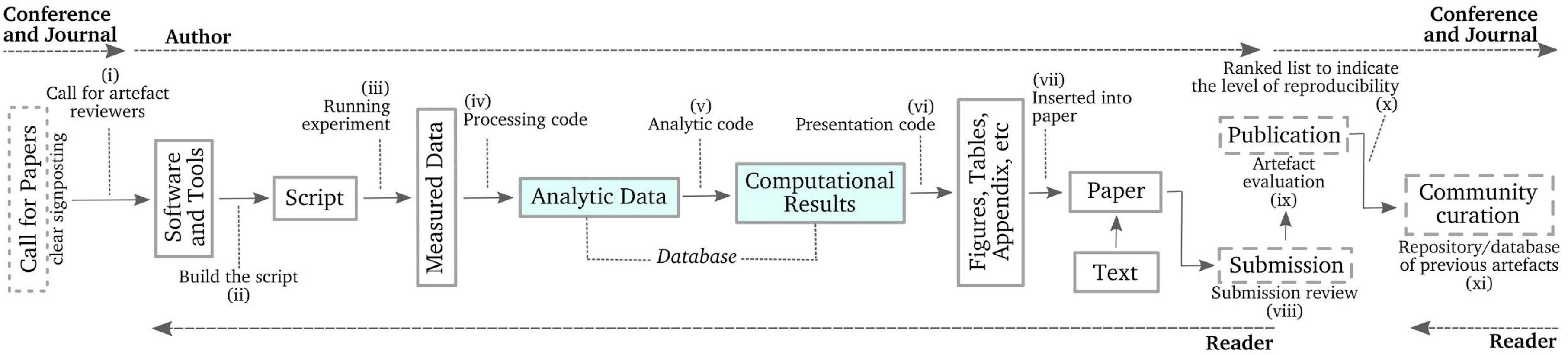
Reproduce

⑤ Contributions

“Reproducible Research”
The essence behind the development of Mininet-WiFi

⑤ Contributions

Workflow towards reproducible research purposes



⑤ Contributions

Publications

- 1. Fontes, R. R. and Rothenberg, C. E. **Towards an Emulator for Software Defined Wireless Networks**. In: SwitchOn 2015, Sao Paulo, SP, Brazil. October, 2015.
- 2. (Best Paper Award) Fontes, Ramon R., Afzal, Samira, Brito, Samuel H. B., Santos, Mateus A. S. and Rothenberg, Christian Esteve. **Mininet-WiFi: Emulating Software-defined Wireless Networks**. Proceedings of the 2015 11th International Conference on Network and Service Management (CNSM). Doi: 10.1109/CNSM.2015.7367387, IEEE Computer Society. Washington, DC, USA. November, 2015.
- 3. Ramon Fontes and Christian Esteve Rothenberg. **Mininet-WiFi: Emulação de Redes Sem Fio Definidas por Software com suporte a Mobilidade**. In Simpósio Brasileiro de Redes de Computadores e Sistemas Distribuídos (SBRC 2016) - Salão de Ferramentas, Salvador, BA, Brazil. June, 2016.
- 4. Fontes, Ramon dos Reis and Rothenberg, Christian Esteve. **Mininet-WiFi: A Platform for Hybrid Physical-Virtual Software-Defined Wireless Networking Research**. Proceedings of the 2016 Conference on ACM SIGCOMM 2016 Conference. Doi: 10.1145/2934872.2959070. ACM, Florianopolis, Brazil. August, 2016.

⑤ Contributions

Publications

- 5. Ramon Dos Reis Fontes, Claudia Campolo, Christian Esteve Rothenberg and Antonella Molinaro. **From Theory to Experimental Evaluation: Resource Management in Software-Defined Vehicular Networks**. Doi: 10.1109/access.2017.2671030. Journal: IEEE Access, 2017.
- 6. Ramon dos Reis Fontes, Mohamed Mahfoudi, Walid Dabbous, Thierry Turletti and Christian Rothenberg. **How Far Can We Go? Towards Realistic Software-Defined Wireless Networking Experiments.** Doi: 10.1093/comjnl/bxx023. Oxford University Press. Journal: The Computer Journal, 2017.
- 7. Jafar Badarneh, Yaser Jararweh, Mahmoud Al-Ayyoub, Mohammad Al-Smadi and Ramon Fontes. **Software Defined Storage for Cooperative Mobile Edge Computing System**. International Conference on Software Defined Systems (SDS). Valencia, Spain, 2017.
- 8. Ramon dos Reis Fontes and Christian Esteve Rothenberg. **On the Krack Attack: Reproducing Vulnerability and a Software-Defined Mitigation Approach**. IEEE Wireless Communications and Networking Conference (WCNC). Barcelona, Spain, 2018.

⑤ Contributions

Publications

- 9. Claudia Campolo, Ramon R. Fontes, Antonio Iera, Christian E. Rothenberg and Antonella Molinaro. **Towards 5G Network Slicing for the V2X Ecosystem**. Workshop on Advances in Slicing for Softwarized Infrastructures (S4SI). IEEE Conference on Network Softwarization (NETSOFT). Montreal, Canada, 2018.

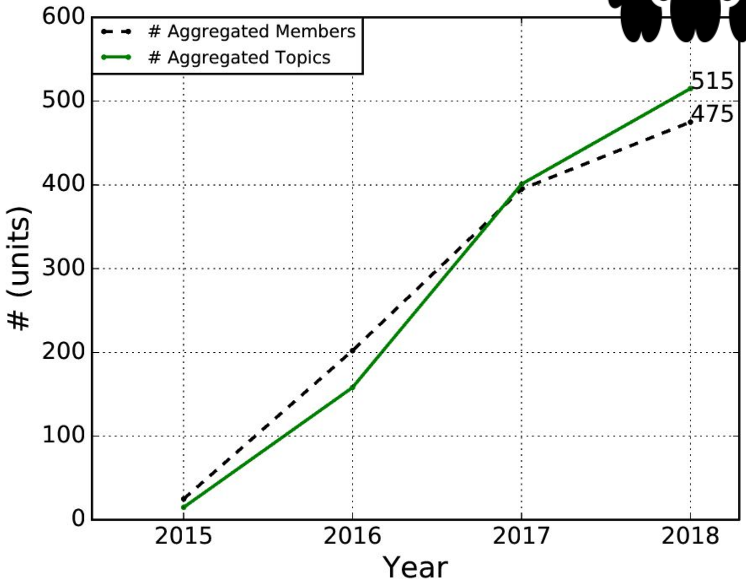
- 10. (*accepted for publication*) Jafar Al-Badarneh, Yaser Jararweh, Mahmoud Al- Ayyoub, Ramon Fontes, Mohammad Al-Smadi and Christian Rothenberg. **Cooperative Mobile Edge Computing System for VANET-Based Software Defined Content Delivery.** Elsevier Computers and Electrical Engineering, 2018.

⑤ Contributions

Citations and Community building

Use Cases Catalogue

- **80+** Research Papers
- **19** Dissertations and Thesis
- **3** Technical Reports
- **1** Book



⑤ Contributions

Educational

- Undergrad Course (EA080) Laboratory of Network Computing. Unicamp, 2017-2018.
- Grad Course (IA376) Advanced Topics in Networking: Laboratório de Redes Softwarizadas / Network Softwarization Lab. Unicamp, 2017-2018
- Extension Course (INF556) Software-Defined Networking. Unicamp, 2016-2017-2018.
- High School Course. IFBA, 2017-2018.
- Software-Defined Wireless Networking (SDWN): From Theory to Practice with Mininet-WiFi. International Summer School on Latency Control for Internet of Services. 26 June - 30, June 2017, Karlstad, Sweden.
- Hackaton - Memphis; etc.

⑤ Contributions

Further Contributions

- Reproducibility Experiences
- Support to SUMO/Sflow
- Filter and process beacons with OpenFlow Controller
- Improvements on Wmediumd
- NDN-WiFi

6 Conclusions and Future Work

⑥ Conclusions

- Mininet-WiFi can Provide High-Fidelity
- Open Source Software (OSS)
- User Community

⑥ Future Work

- Improvements of the supported features
- Collaborate with the Linux Network Community
- Support to other Wireless Technologies

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Mailing list mininet-wifi-discuss@googlegroups.com

Source https://github.com/intrig-unicamp/mininet-wifi

Docker https://hub.docker.com/r/ramonfontes/mininet-wifi/

Videos https://goo.gl/4P02YB

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Thanks!

Any *questions* ?

Ramon Fontes - ramonrf@dca.fee.unicamp.br

Mailing list: mininet-wifi-discuss@googlegroups.com

WebSite: http://www.intrig.dca.fee.unicamp.br/

Source Code: https://github.com/intrig-unicamp/mininet-wifi

Docker: https://hub.docker.com/r/ramonfontes/mininet-wifi/

Videos: https://goo.gl/4P02YB

7 References

7 References

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BACKUP

① # Introduction

Background - Related tools

Software	Last Activity	Availability	Programming Language	Supported Protocols
Simulators				
OMNeT++ (VARGA; HORNIG, 2008)	2018	Open	C++, Java	IEEE 802.11, etc
Estinet (WANG *et al.*, 2013)	2015	Proprietary	?	IEEE 802.3, 802.11, etc
Emulators				
Mininet-WiFi (FONTES *et al.*, 2015)	2018	Open	Python	Any (L3 - L7) IEEE 802.11, 802.3, etc.*
DCE/ns-3 (MANCINI *et al.*, 2014)	2018	Open	C++, Python	IEEE 802.11, LTE, etc
Core (AHRENHOLZ *et al.*, 2008)	2018	Open	several different languages	IEEE 802.2, 802.11, etc
Simulators-Emulators Hybrid				
OpenNet (CHAN *et al.*, 2014b)	2017	Open	C++, Python	IEEE 802.11, LTE, etc
Testbeds				
WARP (WARP, 2018)	2018	Public	-	IEEE 802.11, etc
R2lab (TESTBEDS, 2016)	2018	Public	-	IEEE 802.11, LTE, etc
EMULAB (WHITE *et al.*, 2002)	2018	Public	-	IEEE 802.11, etc.
Nitos (PECHLIVANIDOU *et al.*, 2014)	2017	Public	-	IEEE 802.11, WiMAX, LTE, etc
Orbit (RAYCHAUDHURI, 2003)	2017	Public	-	IEEE 802.11, WiMAX, LTE, Bluetooth, ZigBee, etc.

**6LoWPAN is being supported by fakelb kernel module. It is still under initial development process.*

① Introduction

Ranking of Simulators, Emulators and Testbeds

Characteristic	Simulators	Emulators	Testbeds
Total Cost	●○○	●○○	●●●
Overall Fidelity	●○○	●●○	●●●
Replay Real Traces	●●○	●●○	●●●
Real Applications	●○○	●●●	●●●
Traffic Realism	●○○	●●●	●●●
Timing Realism	●●●	●●○	●●●
Scalability	●●●	●●○	●○○
Maintainability	●●●	●●●	●○○
Flexibility	●●●	●●●	●○○
Replication	●●●	●●●	●○○
Isolation	●●●	●●○	●●●

Future Work *(qualification)*

- Implementation of a new class which represents a new node towards to SDN-based Vehicular Ad hoc Network (VANET) ✓
- Implementation of Interference ✓
- Including information regarding RSSI in the packet header ✓
- Executing scalability tests ✓
- keep adding features and support of scenarios as requested by the increasing user community via the mailing list and the public code repository ✓
- Validating new features through use cases ✓