Model Train'ing like a Pro: Performance Evaluation of a Wireless SDN

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Preposition

"A mesh is a network topology
following no predefined structure or pattern"

-- Unknown author

"Software Defined Networking (SDN; RFC 7246) is a paradigm focusing on a programmable forwarding plane. That is separating control from forwarding functionality."

Agenda

- Part 1: Getting a master's degree by playing with an old Playmobile toy train
- Part 2: How this could be relevant for Wireless Community Mesh Networks.

ETCS balises Lutherstadt Wittenberg, bigbug21, CC-BY-SA 25

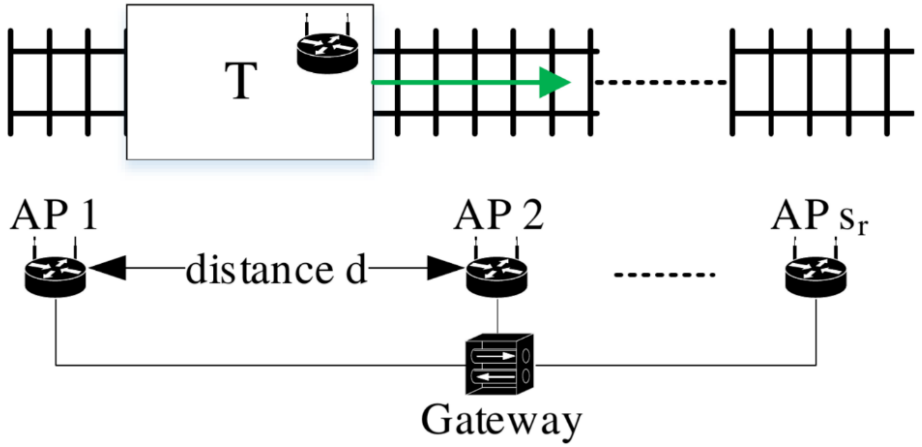
Part 1: Getting a master‘s degree

By playing with an old Playmobile toy train

1. Hypothesis

"Seamless horizontal soft handovers in an SDN-based IEEE 802.11 train-to-ground backhaul provide capacity and latency suitable for internet provisioning inside a running train."

- Train passes Base Stations / Access Points (AP)
  - Link is handed over, i.e. switching
  - make-before-break ("soft-handover")
  - IEEE 802.11: Lacks soft-handover capabilities



- IEEE 802.11 train-to-ground network feasible?
  - Early experiments: IEEE 802.11g (~ 10 - 25 Mbit/s UDP) [YSS+10]
  - Commercial Reality: Broadcast MAC for train control: [FBKS17, FBKS18]
    Avoids handovers by broadcasting
  - Reuse existing Control Plane (i.e. SDN): Research subject regarding wireless

2.1 Related Work: Handover for Highspeed Trains

- Adaptations to WIMAX / LTE:
  Mobility Model, Environment, Soft Handovers, Internet Provisioning ./. Train Control
- January 29th 2020, Google Scholar: 6470 publications → Classification by surveys [ZA14]:
  Position based, Dual radio, Moving Cell / single frequency, radio over fiber, leaky cable, satellite

Work	Metrics	Evaluation	Result
[HH11]	Execution time	Mathematical model	Scanning for 802.16 base stations can be avoided
[KLW12]	Handover latency Handover failure rate Throughput Delay	Simulation	Seamless handover for LTE on-board femtocell
[AJA+12]	Throughput End-to-end delay Jitter Packet error rate WiMAX delay Handover delay	Simulation	General performance gain by reducing 802.16 scanning delay
[FF12]	Handover success rate Handover delay Handover frequencies	Mathematical model Simulation	Two schemes for LTE-A: 1) Reduce handover delay, 2) Avoid unnecessary handovers
[CFL12]	Received signal strength Handover probability Handover success rate	Mathematical model Simulation	Beamforming can improve handovers for LTE

Table 1: Position based schemes

Work	Metrics	Evaluation	Result
[DLML12]	Interruption time Call dropping rate	Simulation	Interruption time reduced by 50 %, call dropping rate below 1 %
[LCCS14]	Latency Satisfaction Packet loss Signalling traffic	Simulation Mathematical model	Low signalling traffic due to group handover
[TZL+11] [TLH+12]	Handover & failure probability Throughput Interruption time	Simulation Mathematical model	Non-interrupted communication, reduced delay, reduced signalling
[YLDF10]	Handover probability Capacity Throughput	Simulation	No omission or downtime on combined link
[LYW14]	Failure probability	Simulation Mathematical model	Reduced failure probability
[LZF12]	Outage & success probability	Simulation Mathematical model	Dual-antenna achieves soft-handover
[LCCS14]	Packet loss Success probability Signaling traffic Handover latency	Simulation Mathematical model	Bicasting can be avoided

Table 2: Dual radio schemes

Client mobility

- Non-SDN clients in Campus networks
- Wired Access Points
- **But: Complexity**

Work	Type	Metrics	Evaluation	Result
[SSZM+12]	Distributed VAP	HTTP goodput	Physical experiment	Seamless handover using a custom agent
[DVK+12]	Cloud VAP	TCP throughput Round-trip-times Packet loss	Physical experiment	Cloud based energy efficiency
[ZZX14]	Split-MAC	TCP throughput UDP throughput	Simulation	Improved performance by split MAC approach
[SS15]	Split-MAC	TCP throughput UDP throughput	Simulation	Reduced load compared to [ZZX14]

Wireless Mesh Topology changes

- SDN-capable mesh nodes, for wireless ISP
- MANET based [BTD06], **hence too slow to adapt**

Work	Discovery	Metrics wrt topology changes	Evaluation	Result
[DKB11]	OLSR	Outage duration	Physical experiment	Practical feasibility of OpenFlow and IEEE 802.11 wrt mobility — 200 ms outage for hard-handover.
[CGA+12] [CGA+13]	802.11s	None	Physical experiment	Characterizes QoE in static backhaul
[DPSBM13]	OLSR	None	Emulation	OpenFlow can be used for traffic engineering conventional WMN
[YGH+14]	batman-adv	None	Physical experiment	OpenFlow can be used for traffic engineering conventional WMN
[HLGZ15]	(static)	None	Simulation	Frequency allocation can be optimized
[NAK+15] [KHB+12]	(custom)	None	Various	Mature architecture for providing real world internet connectivity
[YCF15]	static	None	Phyiscal experiment	OpenFlow can be used for traffic engineering conventional WMN
[Pat16]	OpenFlow (ext)	Controller Switch reconnection latency	Emulation	OpenFlow based topology discovery and routing implementation for WMN
[LBF16]	Custom	None	Simulation	OpenFlow surpasses mesh protocols in terms of overhead, convergence time and packet loss
[BQCM+16]	OpenFlow (ext)	None	Physical experiment	OpenFlow allows load-balancing wrt. cpu and channel load

2.3 IEEE 802.11 SDN in train-to-ground networks

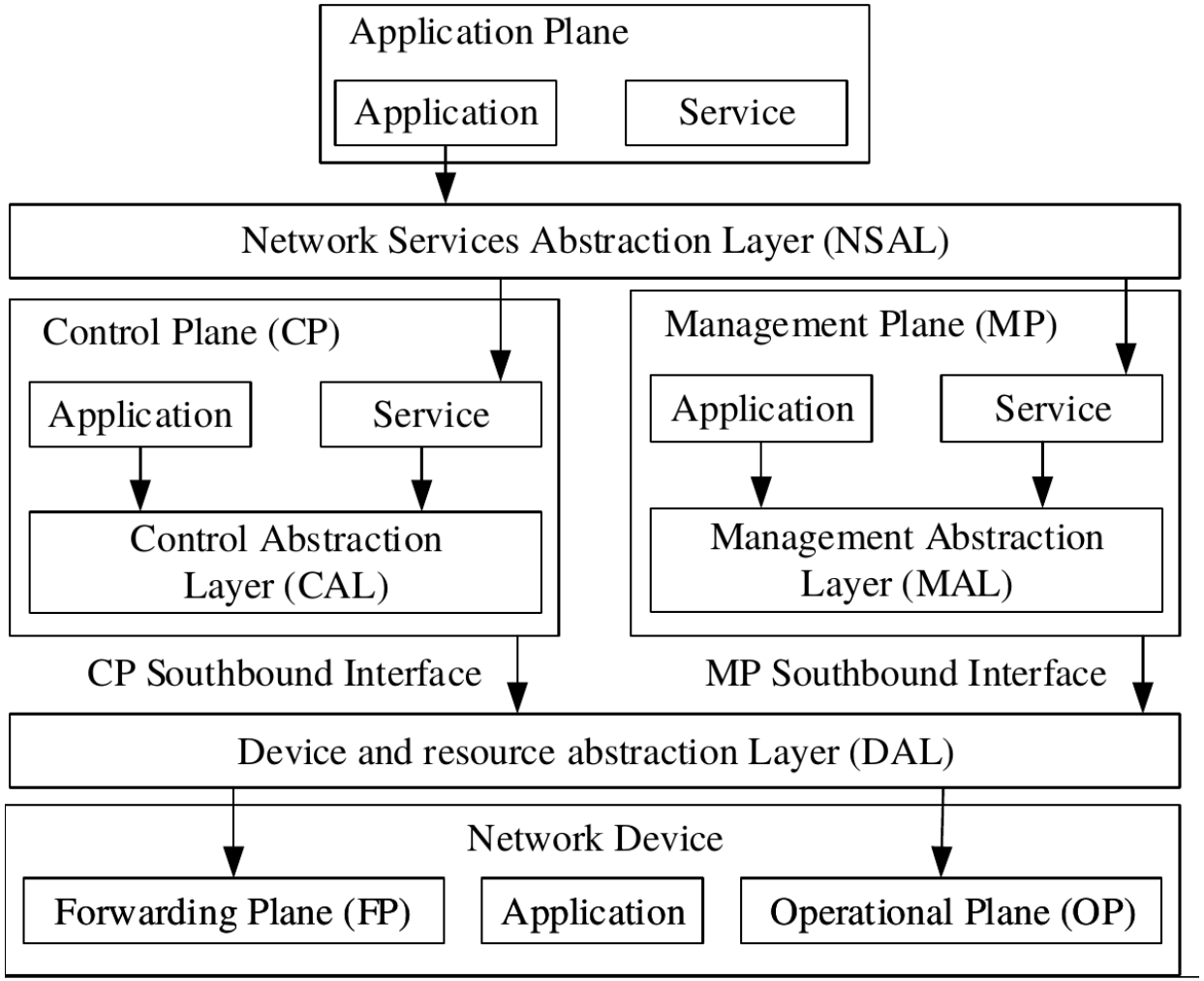
- Only two works – 2019
  - [FAT19] Franco, Aguado, Toledo.
    An Adaptable Train-to-Ground Communication: Architecture Based on the 5G Technological Enabler SDN. Electronics 8.6 (2019): 660.
    But: Train Control System, Duplicates Packets, TCP only (MPTCP)
  - [SSK19] Sen, Krishna, Sivalingam, Narayanan
    Persistent WiFi connectivity during Train journey: An SDN based approach.
    2019 IFIP/IEEE Symposium on Integrated Network and Service Management.
    But: No IPv6, Custom protocols, NAT, Tunneling (overhead), Excludes certain trains, only averaged performance values

Work	Metrics	Evaluation	Result
[FAT19]	Multipath TCP throughput MQTT application level delay	Emulation	Delay below 60 ms, mature design
[SSK19]	TCP delay & throughput UDP delay & throughput	Simulation	Feasibility of an IEEE 802.11 based SDN for the use-case subject to this thesis

3. System Design: What is SDN?

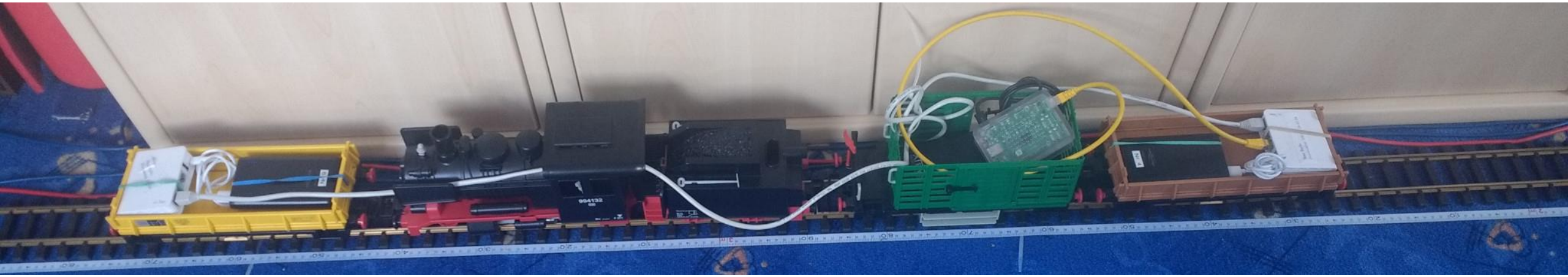
Taxonomy Regarding RFC 7246

- **Application Plane**
  Handover application written in Python
- **Control Plane**
  SDN-Controller: Ryu, OpenFlow
  Southbound: OpenFlow
- **Forwarding Plane**
  OpenFlow / Open vSwitch
- **Management Plane**
  Static inventory (i.e. JSON files)
  Southbound: MQTT, files
- **Operational Plane**
  Local Agent (Python), Linux CLI utilities
- **Outside of RFC 7246**
  ETCS-Positioning (mock): MQTT / JSON

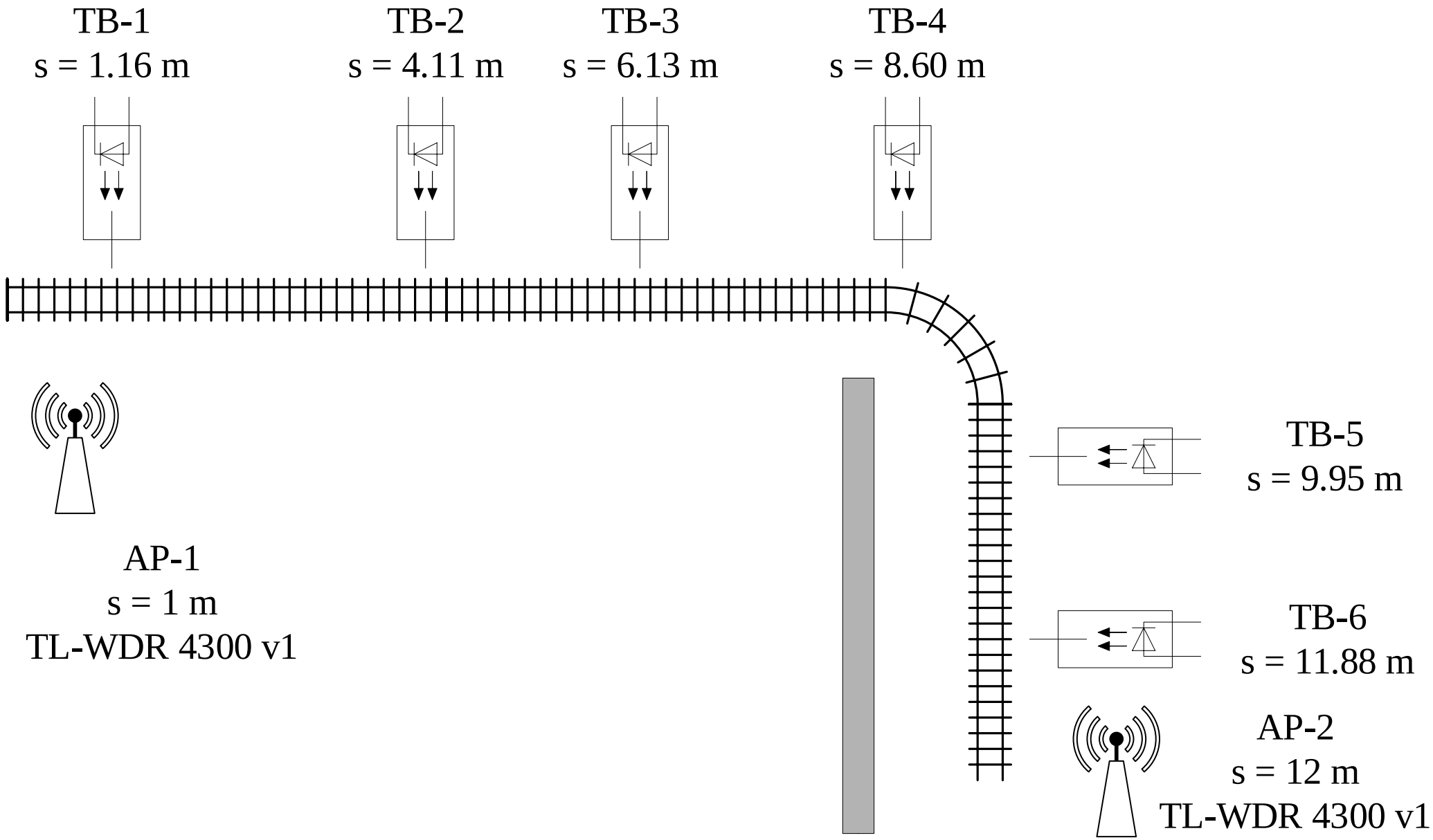


Location Based Scheme / hard-handover: MP / OP sufficient - i.e. CP, hence no SDN
SDN (i.e. OP / FP) functionality steers traffic when two links are existing (soft-handover)

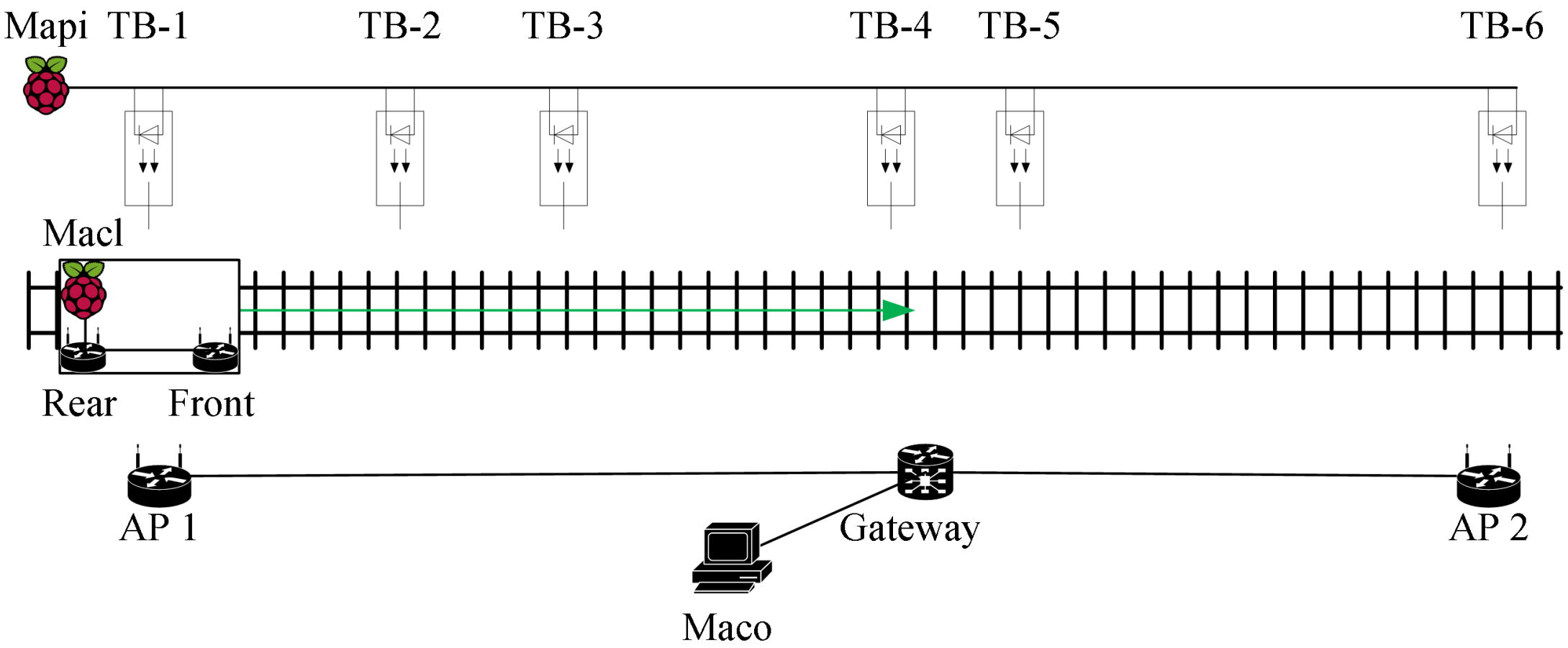
4.1 Train



4.2 Track


TB-1
s = 1.16 m
TB-2
s = 4.11 m
TB-3
s = 6.13 m
TB-4
s = 8.60 m
AP-1
s = 1 m
TL-WDR 4300 v1
TB-5
s = 9.95 m
TB-6
s = 11.88 m
AP-2
s = 12 m
TL-WDR 4300 v1

4.3 Network Model



4.4 Watch it running

- Code: https://git.fslab.de/jluehr_ext/trainmesh
- Video: https://www.youtube.com/channel/UCOrOHTunRA2dtMWBWdDsdwQ

Part 2: How it could be relevant

For Wireless Community Mesh Networks

5. Software Defined Wireless Mesh Networks

- Centralized Controllers: Challenging Assumption
  - Distributed ./. Non-Distributed
  - “The OLSR.ORG story“ (Elektra)
  - Mesh ≠ Mobile Ad-Hoc Network (MANET)

Fraunhofer FIT

Fraunhofer-Institut für Angewandte Informationstechnik FIT

- WiBACK: Wireless Backhaul
  - Mesh, comprised of directed, IEEE 802.11-based links
  - *“Connecting the unconnected”*
  - Closed Source ☹

https://www.fit.fraunhofer.de/de/fb/cscw/projects/wiback.html

- How could OpenFlow & Open vSwitch help?
  - Load-Balancing
  - Fast-Failover
  - Prototyping of Mesh Protocols (original purpose of OpenFlow)
  - More general: adaptation to local environment (i.e. exploit structures and patterns)

6. Research on SDN and Wireless Mesh Networks compositions

- Challenges
  - Wireless Interfaces
  - Control plane connection and topology discovery
  - Routing and load-balancing
  - Modulation and Coding
  - Client handling

OF	Wirel. int.	Ctl-Conn.	Topo.-Disc.	M&C	Routing	Clients	Focus
Yes	Static but custom monitoring	Out-of-band (SSID segregation)	OLSR	No	Client distribution	Active	Hybrid architecture with custom monitoring
Yes	Static	Out-of-band (add. NIC)	802.11 s	No	Chain	Wired	Experiments: WMN protocols vs. OF
Yes	Static	Out-of-Band (add. NIC)	802.11 s	No	Chain	Wired	Experiments: 802.11 s vs. OF
Yes	Static	In-band	OLSR	No	Gateway selection	Passive	Hybrid architecture and distribution of flows among gateways
Yes	Static	In-band (VPN)	B.A.T.M. A.N.	No	Generic link conditions	N/A	Hybrid architecture with dynamic load-balancing
Yes	Extended-OF	Out-of-band (SDR)	Static	No	Policies	Passive	Control- and data-channel resource optimization via spectrum division (SDR)
No	Custom	In-band	Custom	Yes	MPLS	Passive	WBN solution with custom SDN protocol
Yes	Static	Out-of-band (add. NIC)	No	No	Manual	Wired	Experiments: simple flow redirection
Yes	Static	In-band	Extended-OF	No	Shortest path	Passive	Shortest path routing with bootstrapping architecture
Yes	Static	Out-of-band (add. WNIC)	OLSR	No	Assisted OLSR	No	Study on hybrid routing strategies
Yes	Static but extended-OF monitoring	In-band	Extended-OF	No	Interference, Link-Load, CPU	No	Dynamic load-balancing process due to extended-OF monitoring

Software-Defined Wireless Mesh Networking: Current Status and Challenges, Rademacher et al, 2017

7. Conclusion

- It‘s fun setting up a simple SDN using a model train
- OpenWRT is “batteries included” (Open vSwitch, etc.), Ryu is easy to use
- OpenFlow based switching: Exploit local structure or pattern in addition to mesh protocols
- Do not control a full Freifunk Mesh by an almighty Admin-Team running an SDN controller
- … challenging subject. There’ll be dragons ☺

Thanks for your time

Questions?

https://www.youtube.com/channel/UCOrOHTunRA2dtMWBWdDsdwQ