THE SMART WAY TO TEST WI-FI 7

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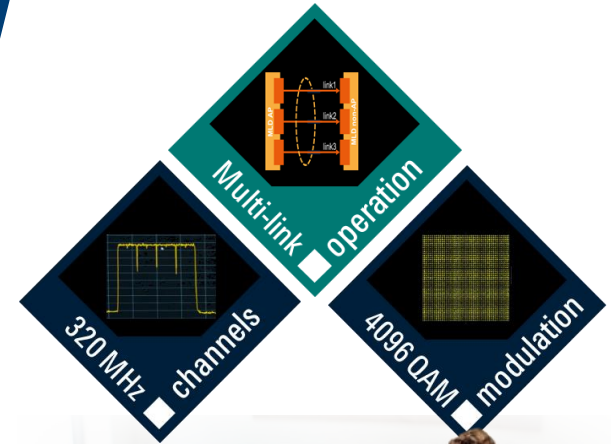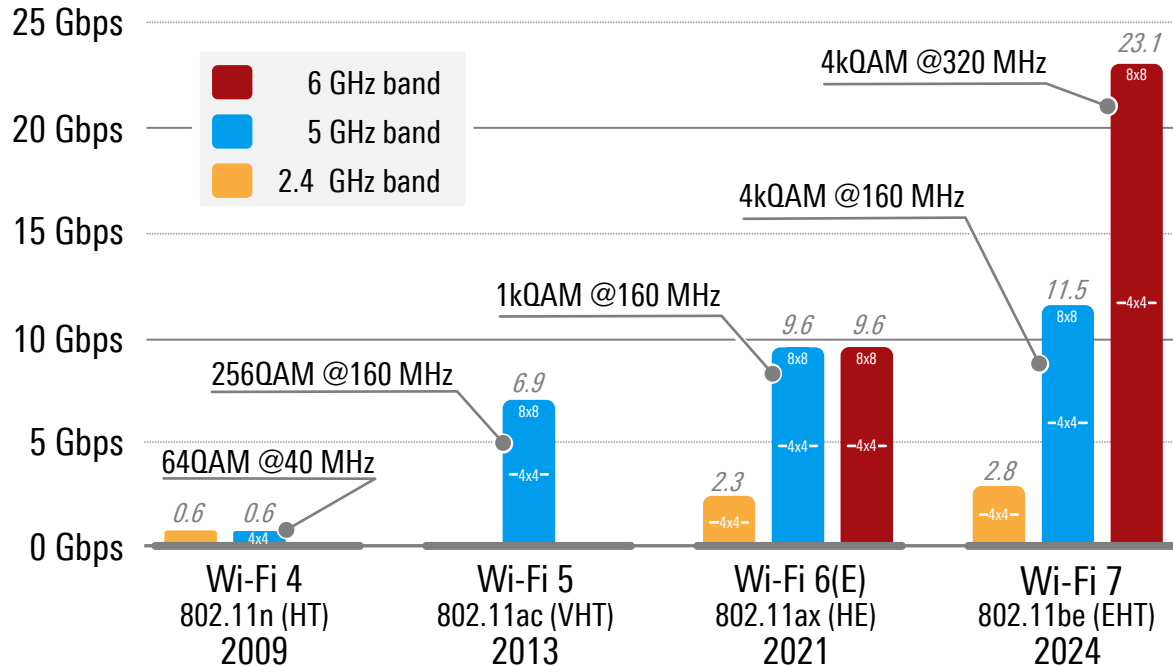
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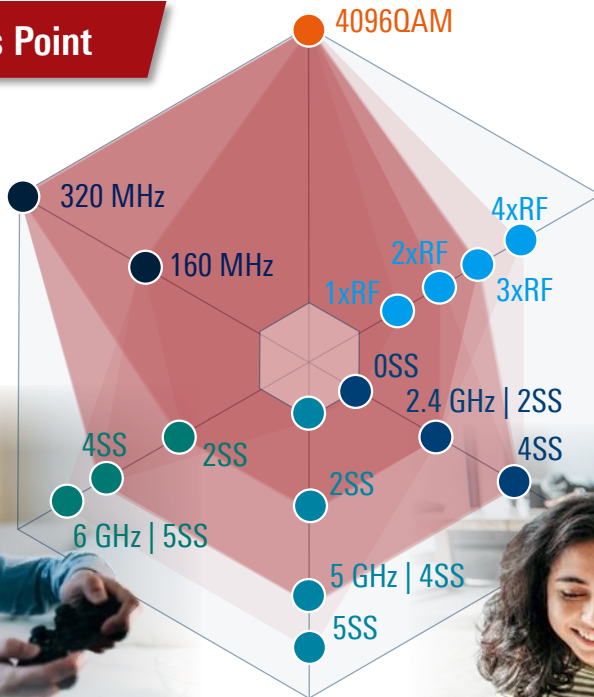Make ideas real

On the way to achieve extreme high throughput (EHT) with Wi-Fi 7

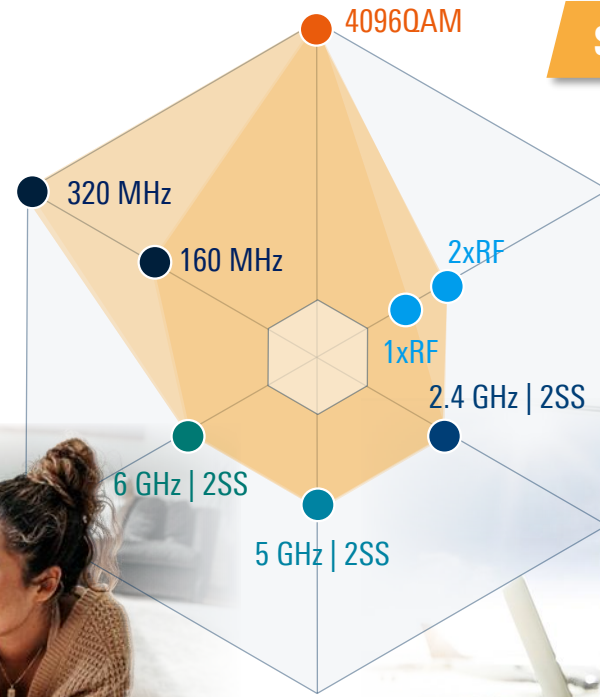Evolution of maximum achievable throughput per single link in all bands

Legend:
- 6 GHz band
- 5 GHz band
- 2.4 GHz band

Chart data:

	Wi-Fi 4 802.11n (HT) 2009	Wi-Fi 5 802.11ac (VHT) 2013	Wi-Fi 6(E) 802.11ax (HE) 2021	Wi-Fi 7 802.11be (EHT) 2024
2.4 GHz band	0.6 (4x4)		2.3 (4x4)	2.8 (4x4)
5 GHz band	0.6 (4x4)	6.9 (8x8, 4x4)	9.6 (8x8, 4x4)	11.5 (8x8, 4x4)
6 GHz band			9.6 (8x8, 4x4)	23.1 (8x8, 4x4)

Annotations:
- 64QAM @40 MHz
- 256QAM @160 MHz
- 1kQAM @160 MHz
- 4kQAM @160 MHz
- 4kQAM @320 MHz

Feature diamonds:
- Multi-link operation (link1, link2, link3)
- 320 MHz channels
- 4096 QAM modulation

What can you get today? – a kind of Wi-Fi 7 chipset survey

Home is where
Wi-Fi connects automatically
FAST ◆ RELIABLE ◆ SECURE

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Conformance ◆ Compliance ◆ Acceptance
A collection of test requirements for Wi-Fi STAs and APs

Standard conformance	Wi-Fi interoperability	Wi-Fi mobile converged devices	Wi-Fi AP operator acceptance	Regulatory compliance
Based on requirements defined in IEEE 802.11 like: • Spectrum mask • Spectral flatness • Transmitter modulation accuracy (EVM) • Receiver minimum input sensitivity • …..	Validate interoperability with other Wi-Fi CERTIFIED equipment operating in the same frequency band. Examples are Wi-Fi certified 6 (incl. 6E) or Wi-Fi EasyMesh.	RF perform. evaluation of Wi-Fi mobile converged devices. The scope of testing includes for example handhelds, or access points, that support Wi-Fi as well as cellular technologies.	Test cases for RF performance, coverage, capacity and bandwidth, and stability / robustness defined in TR-398: Wi-Fi Residential & SOHO Performance Testing.	Based on national laws covering: • Interference • Efficient use of RF resource • Coexistence ETSI EN 300 328, EN 301 893, EN 303 687 FCC 15.407, FCC15.247

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Receiver and transmitter test requirement based on IEEE 802.11be standard
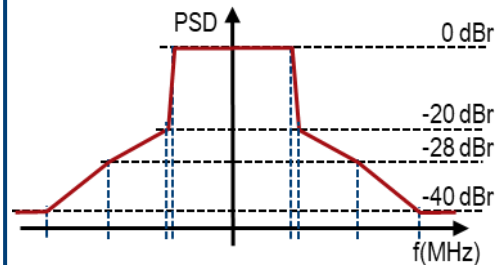
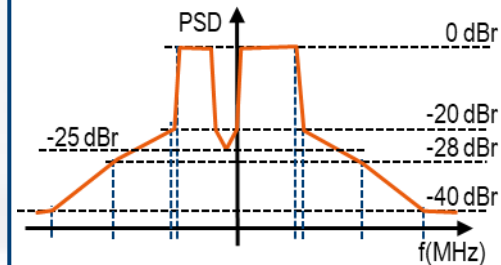Spectral flatness

Center frequ. leakage

Min. input sensitivity

Channel rejection

Maximum input level

320 MHz spectrum mask NEW

Punctured spectrum mask ADD

MRU unused tone error NEW
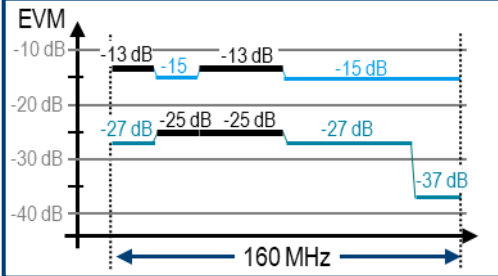
Transmitter constellation error NEW

MCS	Mod.	Coding	Error Vector Magnitude of		
			EHT MU PDDU	EHT TB PDDU	
				P > MCS7	P ≤ MCS7
12	4096 QAM	3/4	-38 dB	-38 dB	- 38 dB
13		5/6	-38 dB	-38 dB	-38 dB

Absolut power accuracy

Relative power accuracy

RSSI meas. accuracy

Carrier frequency offset

Accurate start time

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Wi-Fi residential & SOHO performance testing

TR-398 provides a set of performance test cases with pass/fail requirements for 802.11n/ac/ax implementations, to assist operators in the selection of Wi-Fi capable devices.

RF capability
Provides a simplified receiver's sensitivity measurement related to the point at which the connection degrades (MSC)

Baseline performance
Several performance parameters like max. #connections, airtime fairness, dual-band throughput, latency, bidirectional throughput, …

Coverage
Measuring range vs. rate, spatial consistency, and peak performance

Parameter accuracies
Check the accuracy of parameters (receive channel power indicator, channel utilization, f noise levels) reported by the DUT

Multiple STA performance
Multiple STAs performance and multiple association/ disassociation stability measures, MU-MIMO performance

Stability/Robustness
Stability performance of Wi-Fi device under stress, AP coexistence test, automatic channel selection test

Mesh/Extender
Measuring throughput performance of a mesh Wi-Fi system, w/ and w/o 2-node Wi-Fi extender and roaming time test

DUT   STA(s)

IP gen/anl   IP gen/anl
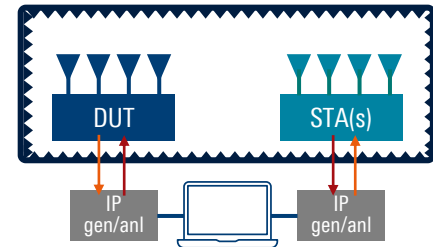
# Test plan for RF performance evaluation of Wi-Fi mobile converged devices

RF performance evaluation of Wi-Fi mobile converged devices (incl. handheld, self-contained Wi-Fi/Mobile module, access point, notebook and tablet devices) that support Wi-Fi as well as cellular technologies.

Conducted RF tests

Measure basic RF performance such as sensitivity and transmit power.
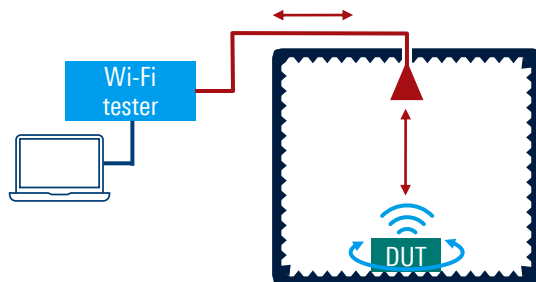
- Output power (dBm)
- Receiver sensitivity (dBm)
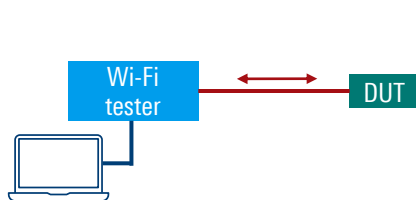
Radiated RF tests

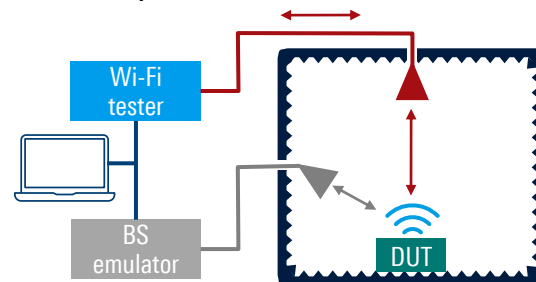Measuring radiated power and isotopic sensitivity in an over the air setup based on CTIA OTA spec.

- Total Radiated Power (TRP)
- Total Isotropic Sensitivity (TIS)

Desensitization tests

Desensitization tests measure the impact of cellular radio upon Wi-Fi reception and vice-versa

- Desensitization (dB)
- Max. provided EIS in case of complete failure (dBm)

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Wi-Fi Alliance®:
Wi-Fi CERTIFIED 7™ Test Plan

Testbed for execution of Wi-Fi Certified 7 test plan
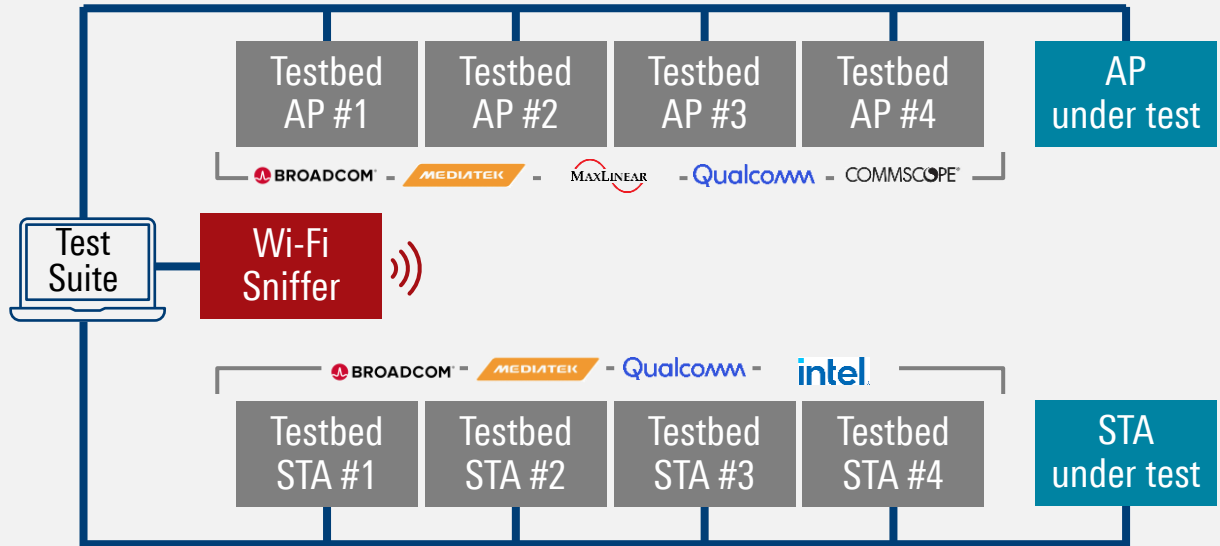
A Wi-Fi CERTIFIED 7 APUT and Wi-Fi CERTIIFIED 7 STAUT device shall implement and pass the following Wi-Fi Alliance certifications as a **prerequisite**:

- Wi-Fi CERTIFIED WPA3™
- Wi-Fi Enhanced Open™
- Wi-Fi CERTIFIED™ 6
- Wi-Fi CERTIFIED™ n
- Wi-Fi CERTIFIED™ ac
- Wi-Fi CERTIFIED Agile Multiband™
- WMM® (Wi-Fi Multimedia™)
- Security Vulnerability Detection
- Protected Management Frames

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Wi-Fi device related regulatory test requirements for CE RED & FCC compliance

CE

Test results are part of 'technical documentation':
- Prepared before placing product on the market
- Made available to surveillance authorities
- Kept for 10 years from placed on the market

FCC

Testing is performed by an FCC-recognized accredited testing laboratory.

Health & Safety
Art 3.1a

Directive 2014/35/EU
CENELEC - EN 50360
Specific absorption rate

EMC
Art 3.1b

EN 301 489-1 Common
EN 301 489-17 WLAN

47CFR §15.247/15.407

C63.10 American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices

2.4 GHz:	KDB 558074
5 GHz:	KDB 789033/KDB 905462
6 GHz:	KDB 987594

Specific Topics
Art 3.3

Guideline 2019/320 (E112)
Emergency service

Radio Spectrum
Art 3.2

EN 300 328	**WLAN 2.4 GHz**
EN 301 893	**WLAN 5 GHz**
EN 303 687	**WLAN 6 GHz**

6 GHz band regulation around the globe:
Standard power w/ AFC, low power indoor and very low power

EIRP limits	
FCC	CEPT ECC — Electronic Communications Committee
Standard Power (SP) w/ AFC	
AP: 36 dBm UE: 30 dBm	n.a.
Low Power Indoor (LPI)	
AP: 30 dBm UE: 24 dBm	AP: 23 dBm UE: 23 dBm
Very Low Power (VLP)	
UE: 14 dBm	UE: 14 dBm

Map labels: Canada, USA, Mexico, Honduras, Guatemala, Costa Rica, Colombia, Peru, Chile, Brazil, Germany, EU, UK, Turkey, Israel, Jordan, Morocco, Kenia, Namibia, South Africa, Saudi Arabia, Kuwait, Bahrain, Qatar, UAE, Korea, Japan, Taiwan, Hongkong, Malaysia, Australia, New Zealand

Legend: Adopted / Considering

The different ways of testing performance of Wi-Fi devices

Non-Signaling Test `PHY`

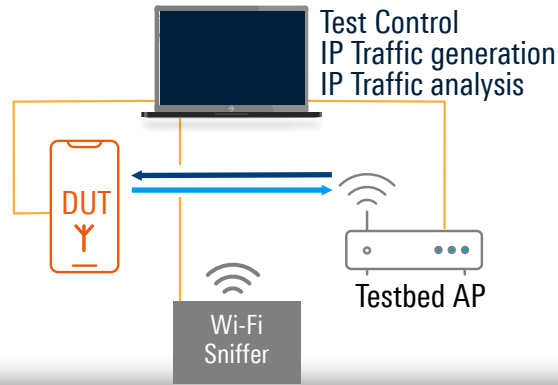Device/chip specific test interfaces allow DUT control of testing used from early R&D to manufacturing

Instrument & DUT control
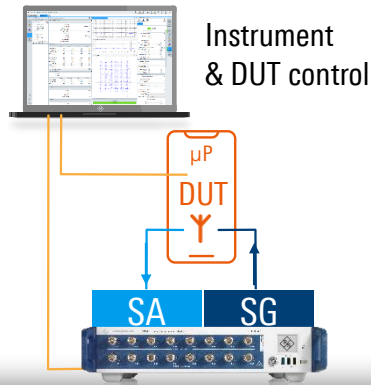
▶ **Fast & reliable RF performance, compliance testing and calibration**

Reference STA/AP `PHY/MAC`

Relying of the availability of reference devices (AP/STA) and required control interfaces to run testing

Test Control
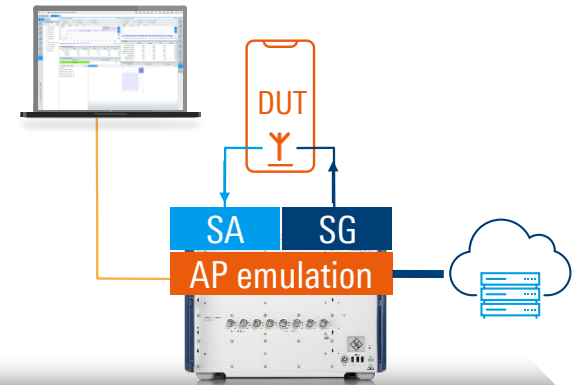IP Traffic generation
IP Traffic analysis

Testbed AP

Wi-Fi Sniffer

▶ **Testing against reference devices with limited test control/flexibility**
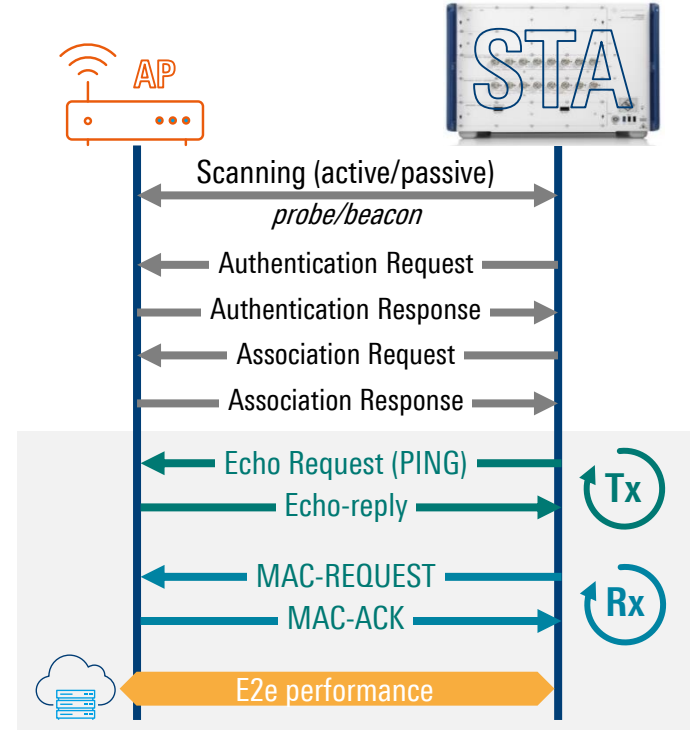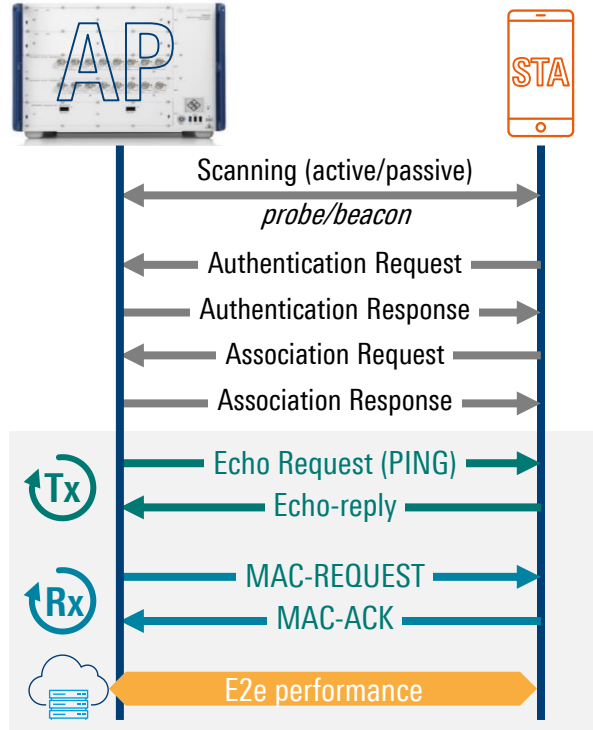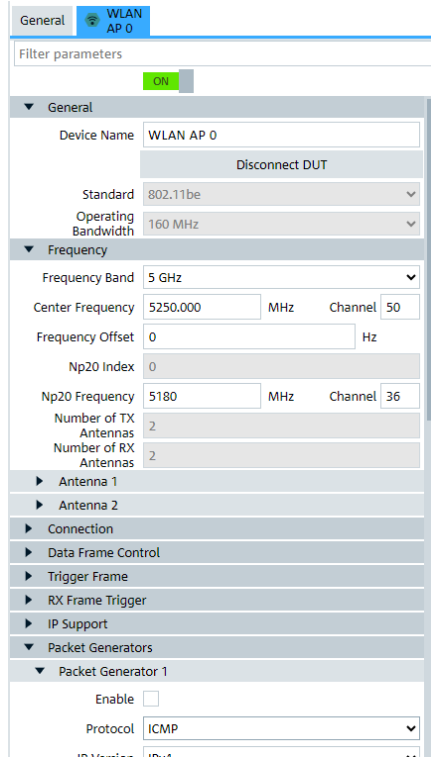
Signaling Test `PHY/MAC`

Emulating an AP/STA allows testing under well defined network conditions Without limitations (e.g. regulation)

AP emulation

▶ **Full power of device testing with full control and maximum flexibility**

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The principle of Wi-Fi performance testing w/ a signaling tester

Rohde & Schwarz Wi-Fi/WLAN signaling test solutions

THE WIRELESS CONNECTIVITY TESTER

R&S®CMW270

- WLAN 11a/b/g/n/ac/ax SISO and MIMO
- Wi-Fi 6E extension for 6 GHz Band
- Bluetooth Low Energy, Basic Rate and EDR

THE WIDEBAND RADIOCOM TESTER

R&S®CMW500

- Bluetooth and WLAN capability same as R&S®CMW270
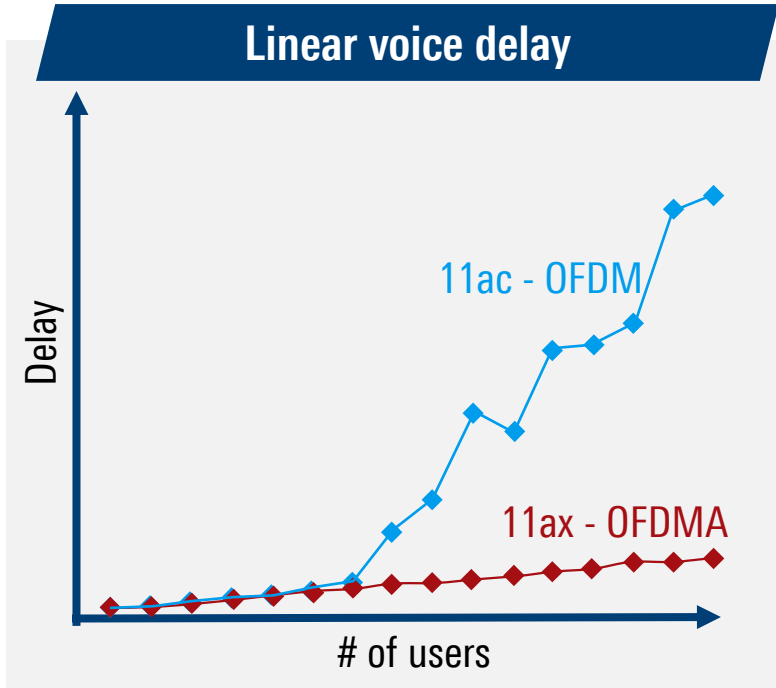- 2G (GSM...) 3G (WCDMA, c2k,...) 4G (LTE, LTE-A)
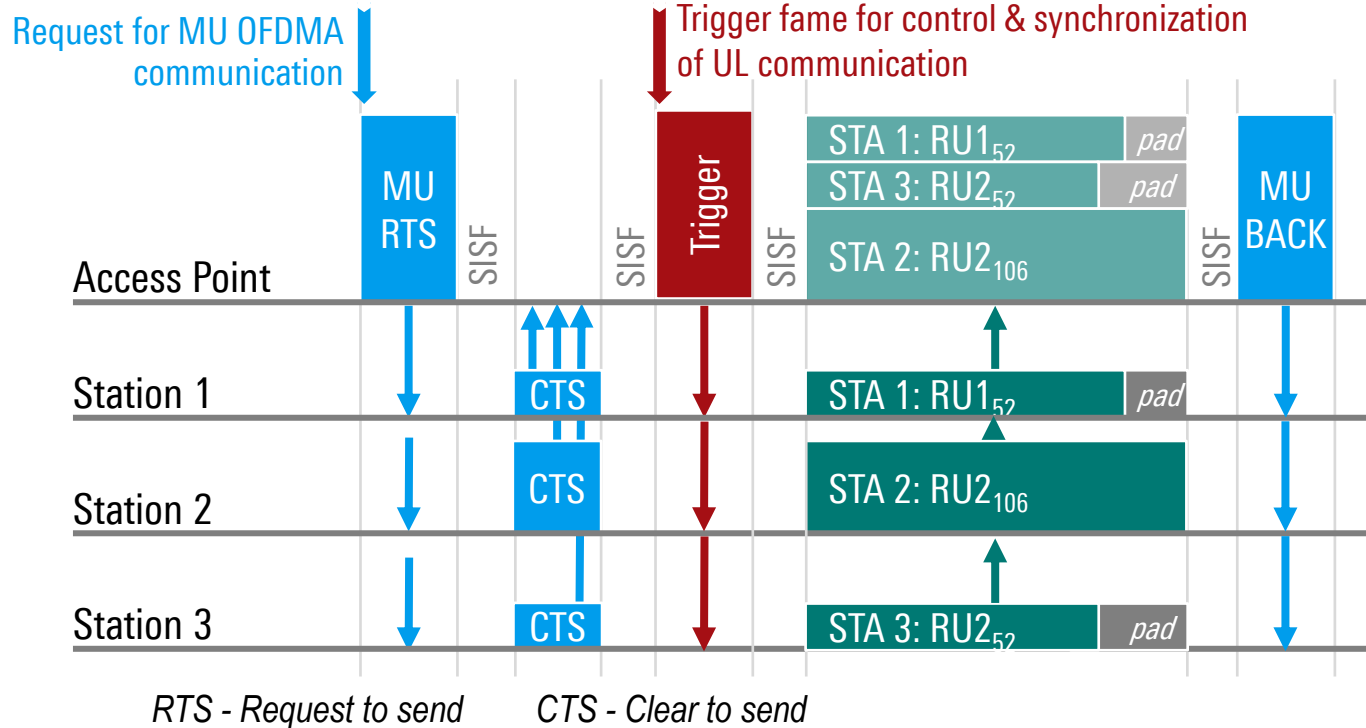
THE ALL-IN-ONE BOX SIGNALING TESTER

R&S®CMX500

- 4G (LTE, LTE-A), 5G FR1/FR2 and WLAN
- Frequency range up to 8 GHz
- WLAN 11a/b/g/n/ac/ax/be SISO and MIMO

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The value of **OFDMA** to make Wi-Fi carrier-grade – introduced with **IEEE 802.11ax** – Wi-Fi 6

Linear voice delay

Delay

11ac - OFDM

11ax - OFDMA

# of users

Consistent data throughput

Throughput per user

11ax - OFDMA

11ac - OFDM

# of users

Source: Cisco and Cisco sponsored research

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The principle of trigger-based OFDMA communication
Frames should arrive at the AP on same time, power & duration

Request for MU OFDMA communication

Trigger fame for control & synchronization of UL communication

| Access Point | MU RTS | SISF | SISF | Trigger | SISF | STA 1: RU1$_{52}$ *pad* \n STA 3: RU2$_{52}$ *pad* \n STA 2: RU2$_{106}$ | SISF | MU BACK |

Station 1 — CTS — STA 1: RU1$_{52}$ *pad*

Station 2 — CTS — STA 2: RU2$_{106}$

Station 3 — CTS — STA 3: RU2$_{52}$ *pad*

RTS - Request to send   *CTS - Clear to send*

1. AP collects buffer status information from all stations

2. AP calculates RU/MCS map and starts with MU-RTS request

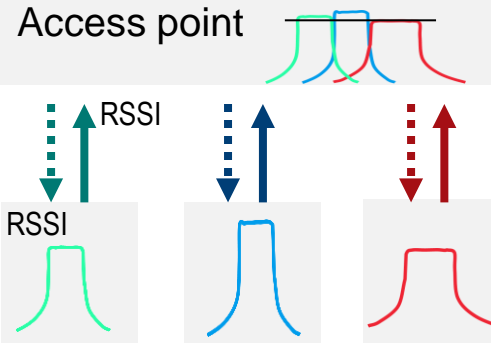3. Stations send HE_TRIG in RU with defined MCS, power and duration

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Tests should ensure stable trigger-based communication „Trigger based PPDU precorrection"

Accurate start time and CFO

$\pm$ 400 ns

SISF (16 µs)

Trigger

AP

STA 1
STA 2
STA 3

STA1 — HE_TRIG

STA2 — HE_TRIG

STA3 — HE_TRIG
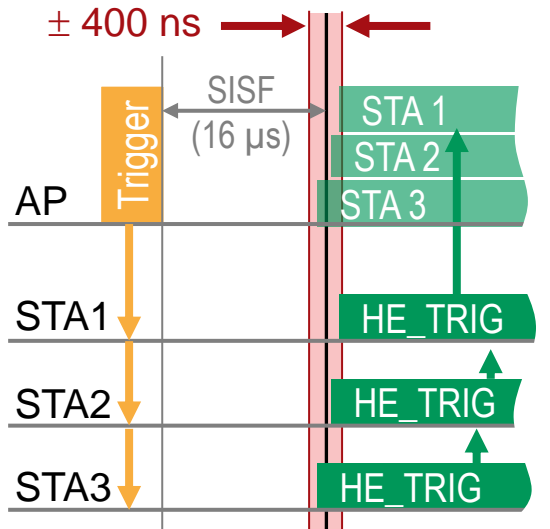
Residual CFO error: < 350 Hz

Accurate power control

Access point

RSSI

RSSI

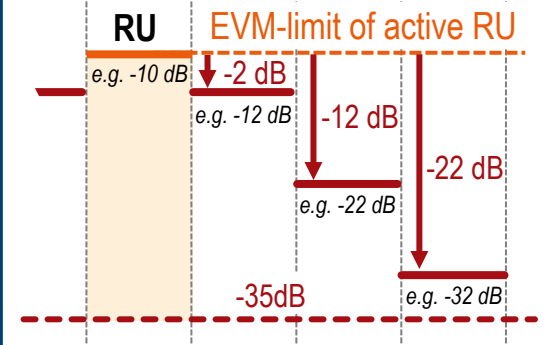**STA RSSI measurement accuracy:**
class A: $\pm$ 3 dB   class B: $\pm$ 5 dB

STA transmit power accuracy:
class A: $\pm$ 3 dB   class B: $\pm$ 9 dB

Adjacent RU interference

RU   EVM-limit of active RU

e.g. -10 dB   -2 dB
e.g. -12 dB   -12 dB
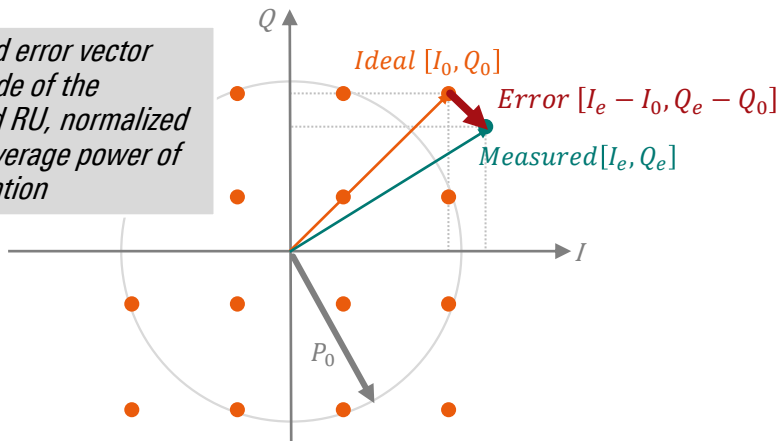e.g. -22 dB   -22 dB

-35dB   e.g. -32 dB

Ensure RU transmit modulation accuracy for the unused tones to avoid interference:
Unused Tone Error

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Resource unit (RU) transmit error vs. unused tone error

(used tone) Error Vector Magnitude

Averaged error vector magnitude of the occupied RU, normalized by the average power of constellation

$Ideal\ [I_0, Q_0]$

$Error\ [I_e - I_0, Q_e - Q_0]$

$Measured\ [I_e, Q_e]$

P_0

$$Error_{RMS} = \frac{1}{N_f} \sum_{i_f}^{N_f} \sqrt{\frac{1}{P_0} \frac{1}{N_{SYM}} \frac{1}{N_{SS}} \frac{1}{N_{SD}} \sum_{i_s}^{N_{SYM}} \sum_{i_{ss}}^{N_{SS}} \sum_{i_{sc}}^{N_{SD}} (I_e - I_0)^2 + (Q_e - Q_0)^2}$$

P_0	average power of constellation	N_{SS}	number of spatial streams
N_f	number of frames	N_{SYM}	number of data OFDM symbols
N_{SD}	number of data tones of RU		

Unused Tone Error (vector magnitude)

Unused SC power, averaged over 26 tones and normalized by the average power per SC of the occupied RU

$Measured\ [I_u, Q_u]$

$Ideal\ [0,0]$

P_S
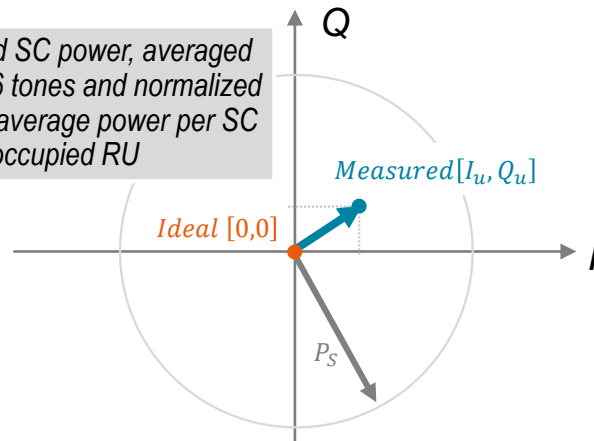
$$UnusedToneError_{RMS} = \frac{1}{N_f} \sum_{i_f}^{N_f} \sqrt{\frac{1}{P_S} \frac{1}{N_{SYM}} \frac{1}{26} \sum_{i_s}^{N_{SYM}} \sum_{i_{sc}}^{26} I_u^2 + Q_u^2}$$

P_s	average data SC power of the <u>occupied</u> RU		
N_f	number of frames		
N_{SYM}	number of data OFDM symbols		

Reference model for multi-link operation (MLO) of multi-link devices (MLD) to improve latency, throughput and reliability

Multi-link operation (MLO) enables a non-AP multi-link device (MLD) to discover, authenticate, associate, and set up one or more links with an AP MLD.
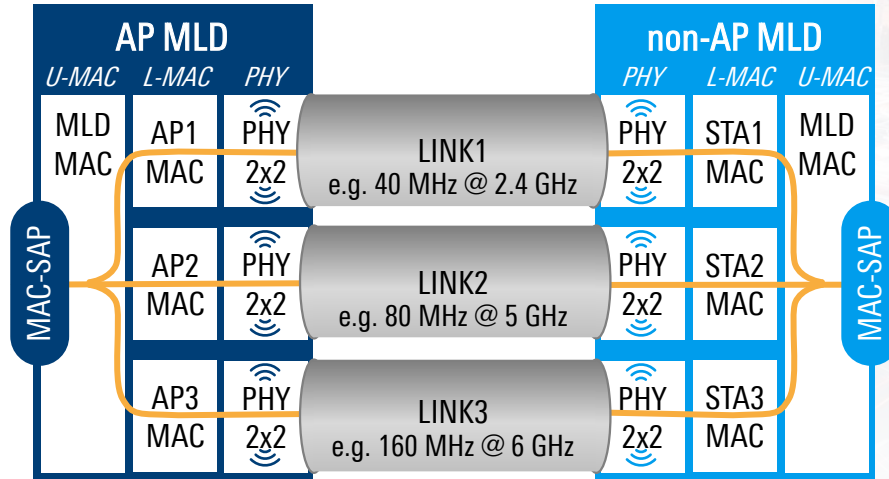

Each link enables **channel access** and **frame exchanges** between the non-AP MLD and the AP MLD based on the supported capabilities exchanged during the association.

Multi-link element (MLE) information is used to setup and manage MLO – added to beacons, probe request and reconfiguration

Element ID	Length	Element ID extension	Multi-link control	Common info	Link info

Simultaneous transmit & receive (STR) on multi-radio devices
Low latency and high throughput due to simultaneous operation
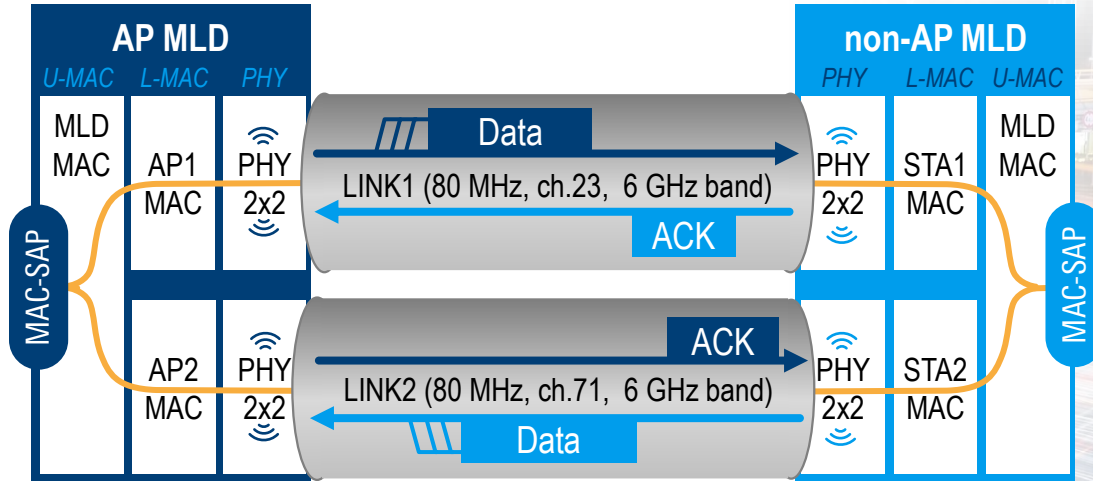

Simultaneous and independent operation of the links between multi-link devices
MLO devices with two or more radios can transmit and receive on different links at the same time,
called simultaneous transmit and receive (STR).

▷ To avoid in-device interference problems the non-AP MLD indicates in the MLD capability and operations
subfield the recommended minimum frequency gap (nx 80 MHz) between two links of an STR pair
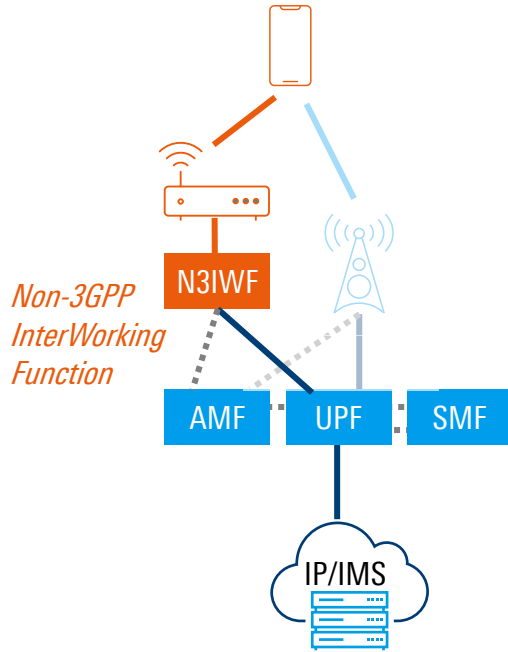
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Enhanced multi-link single-radio (EMLSR) operation

Mobile non-AP devices are supporting typically single radio implementations across all three bands with a low number of spatial streams (e.g. 2x2 MIMO). For this kind of devices EHT specifies an enhanced MLO mode (enhanced multi-link single-radio) for devices which support multiple receives chains allowing to listen on two radio links simultaneously.
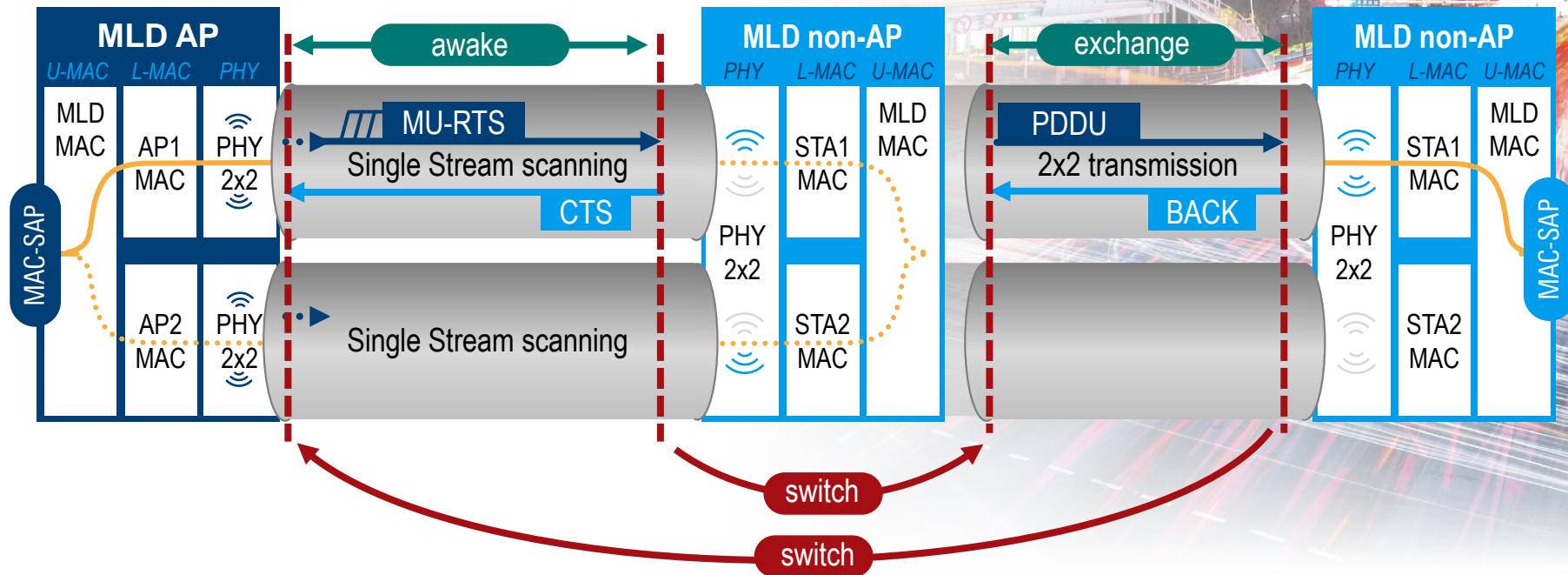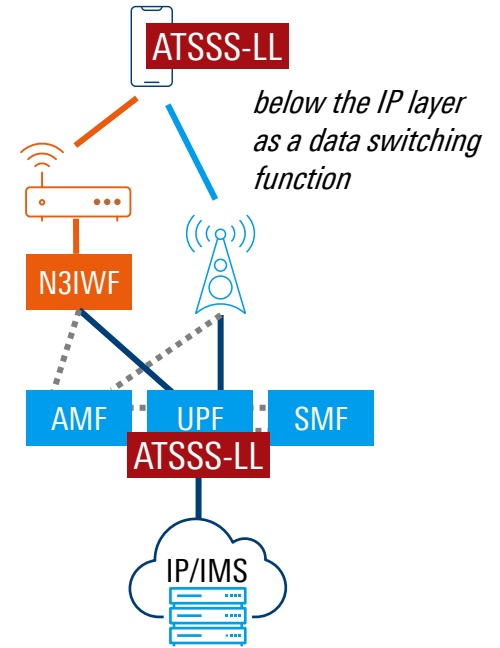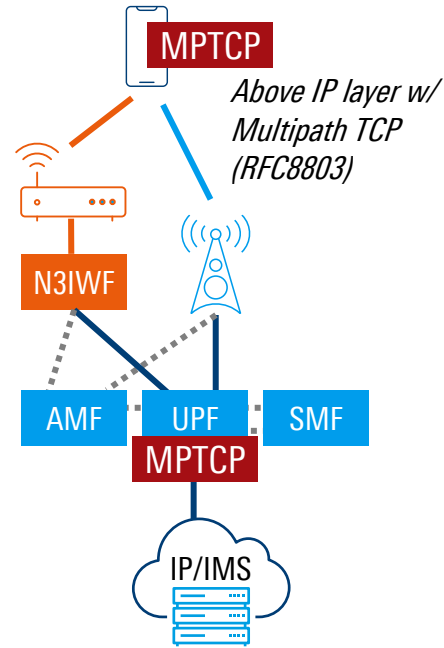
The different flavors of non-3GPP access (Wi-Fi) to 5G NR core

3GPP Wi-Fi offload

Access Traffic steering switching and splitting

N3IWF

Non-3GPP InterWorking Function

AMF UPF SMF

IP/IMS

MPTCP

Above IP layer w/ Multipath TCP (RFC8803)

N3IWF

AMF UPF SMF

MPTCP

IP/IMS

ATSSS-LL

below the IP layer as a data switching function

N3IWF

AMF UPF SMF

ATSSS-LL

IP/IMS

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Wi-Fi test solutions for today and tomorrow

Conformance

R&S®TS8997

RF performance

R&S®CMW500/270

R&S®CMX500 OBT

Production

R&S®CMP180

R&S®CMW100

R&S®TS7124

Make ideas real

RF design and compliance

R&S®ZNA

R&S®FSW

R&S®SMM100A

R&S®VSE

Embedded design & power

R&S®NGU

R&S®RTP

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