Wi-Fi6/6E/7 and Bluetooth 5.x

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Wi-Fi
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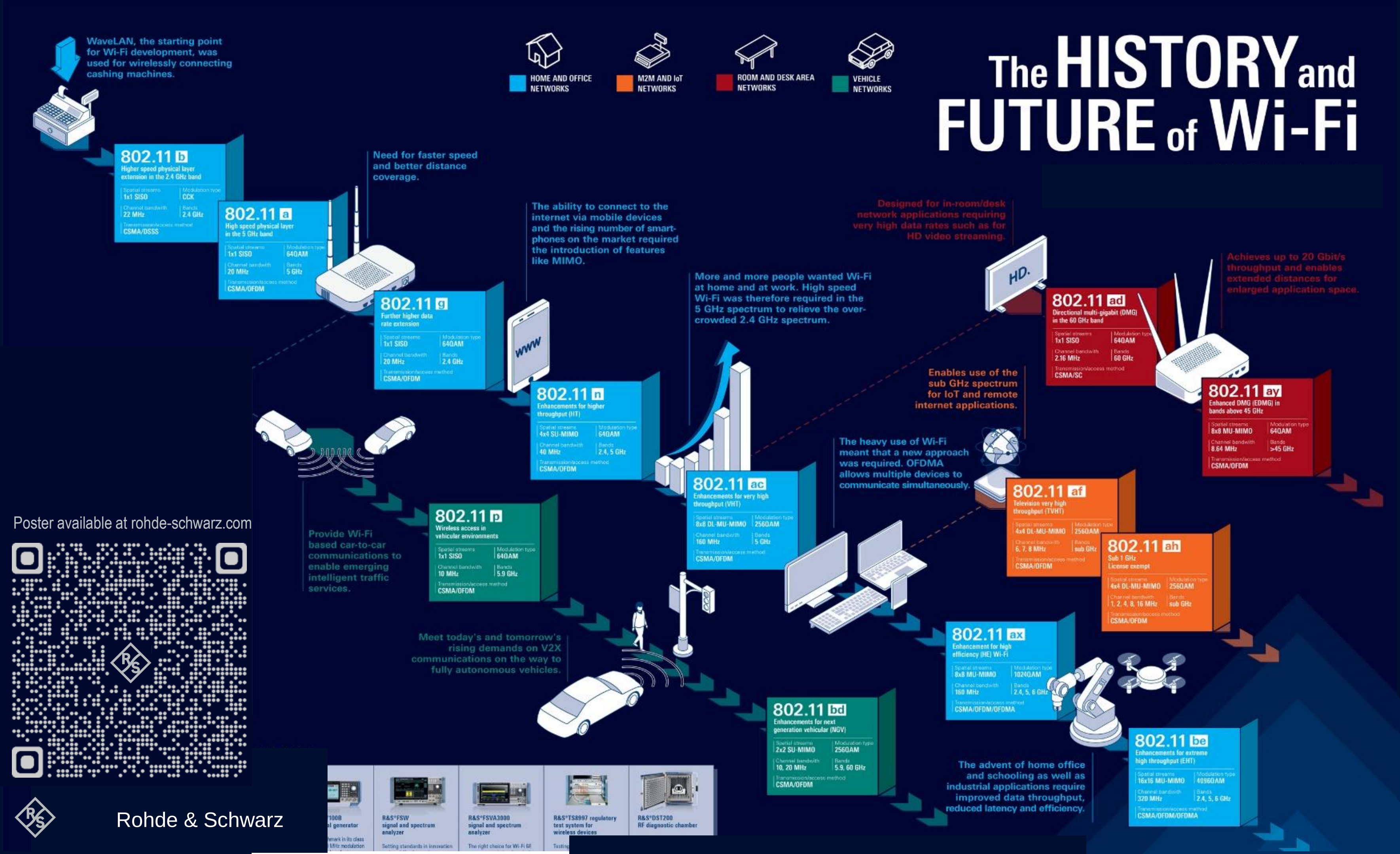

Poster available at rohde-schwarz.com

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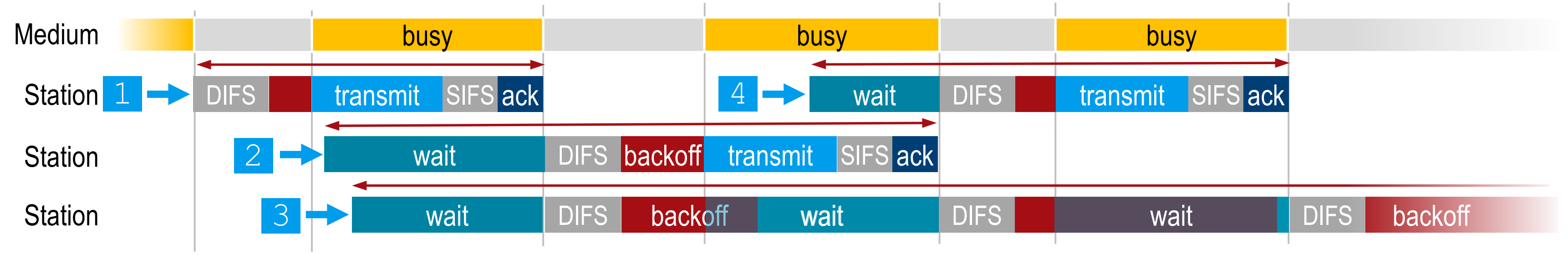
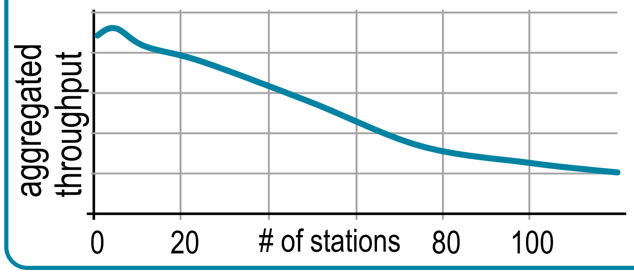
Access scheme based on CSMA/CA has some limitations

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)



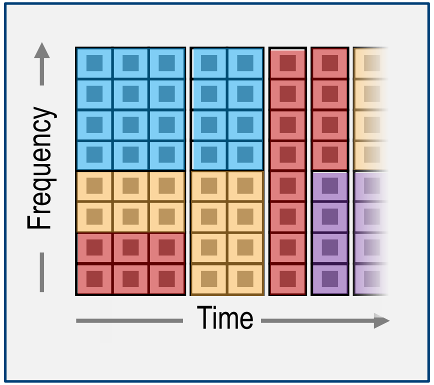
Works well for small # of clients …, but fails in traffic jam

Throughput depend on # of stations

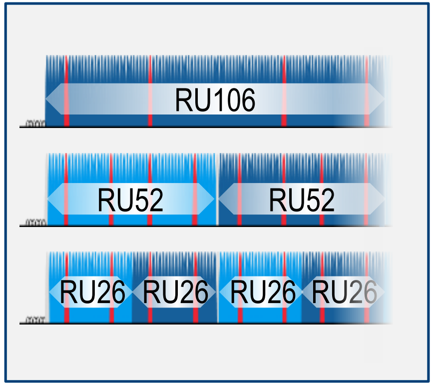


A short recap:
Technology cornerstones of the Wi-Fi 6 (802.11ax) revolution

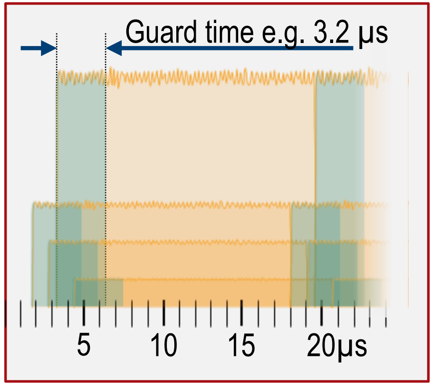
OFDMA



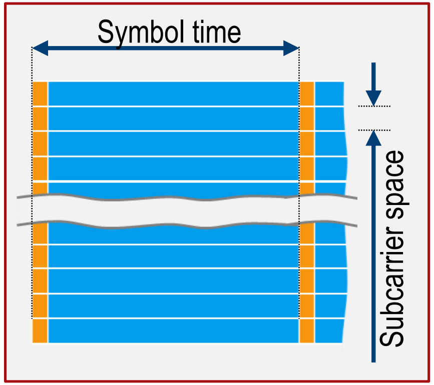
Resource units



Long guard interval



Long symbol time



- Efficient use of available spectrum
- Multi-user operation and latency reduction

- Avoiding inter-symbol interferences
- More efficient use of available resources

What was new in Wi-Fi6?

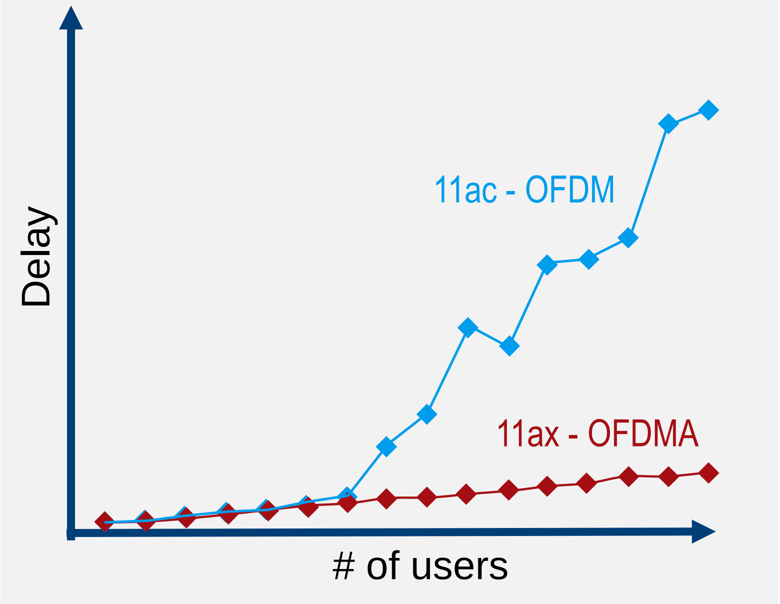
	Wi-Fi 4 (802.11n) *High Throughput (HT)*	Wi-Fi 5 (802.11ac) *Very High Throughput (VHT)*	Wi-Fi 6 (802.11ax) *High Efficiency (HE)*
Supported bands	2 GHz, 5 GHz	5 GHz	2 GHz, 5 GHz
Channel bandwidth (MHz)	20, 40	20, 40, 80, 80+80, 160	20, 40, 80, 80+80, 160
Transmission scheme	OFDM	OFDM	OFDM, **OFDMA**
Subcarrier spacing	312.5 kHz	312.5 kHz	**78.125 kHz**
Guard interval	0.4 µs, 0.8 µs	0.4 µs, 0.8 µs	0.8 µs, **1.6 µs, 3.2 µs**
Spatial streams	4x4 (SU-MIMO only)	8x8 (incl. DL-MU-MIMO)	8x8 (incl. MU-MIMO)
Modulation (highest)	64QAM	256QAM	**1024QAM**
Max. data rate*	*540 Mbps**	*6 934 Mbps**	*9 765 Mbps**

x13 (Wi-Fi 4 → Wi-Fi 5), x1.4 (Wi-Fi 5 → Wi-Fi 6)

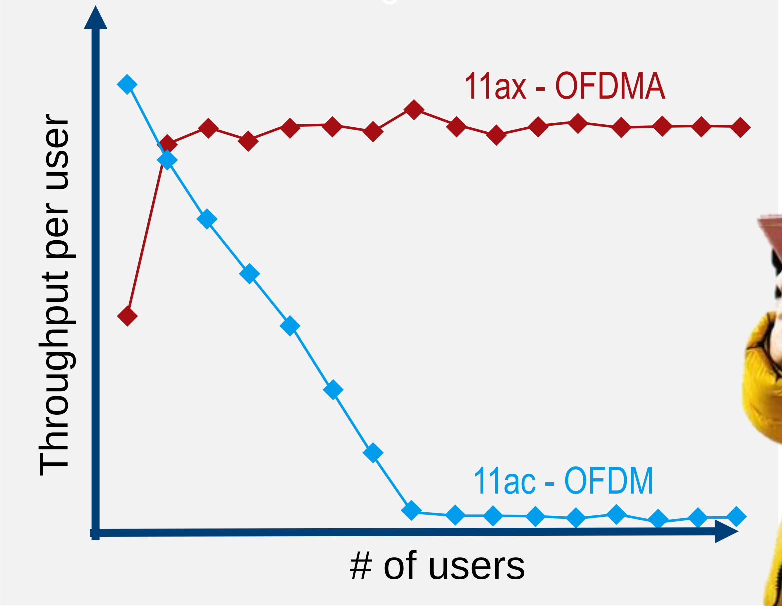
** dependent on configuration (GI) and incl. signaling overhead*

OFDMA (802.11ax) makes Wi-Fi carrier-grade and attractive for related services like VoWiFi or Wi-Fi offload

Linear voice delay

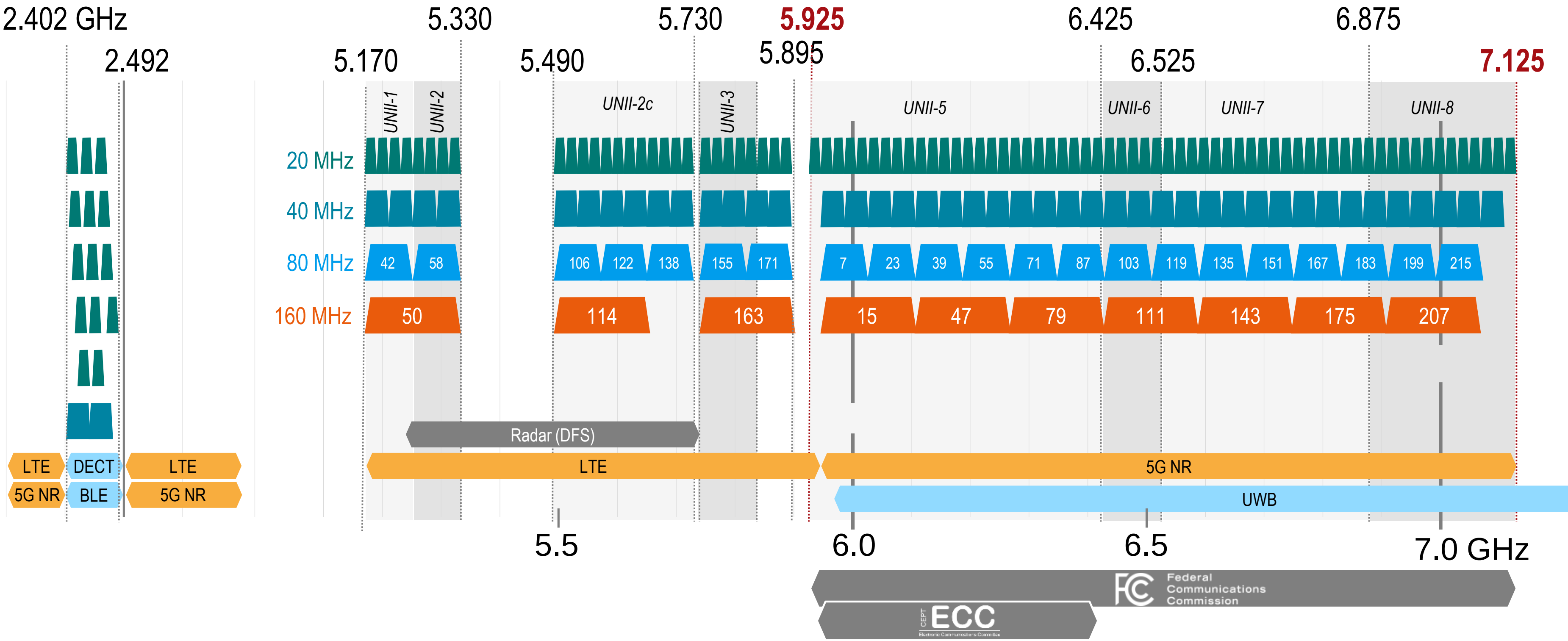


Consistent data throughput

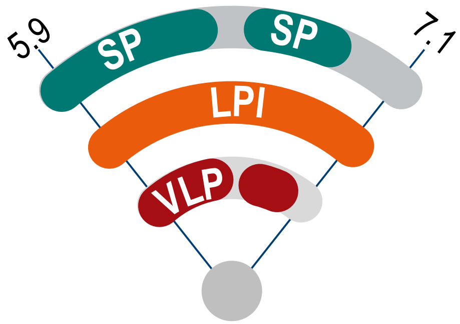


Source: Cisco and Cisco sponsored research

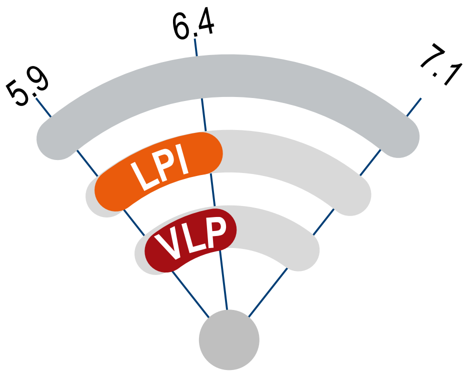
New spectrum allocation allows more wide channels in a (still) less congested 6 GHz band



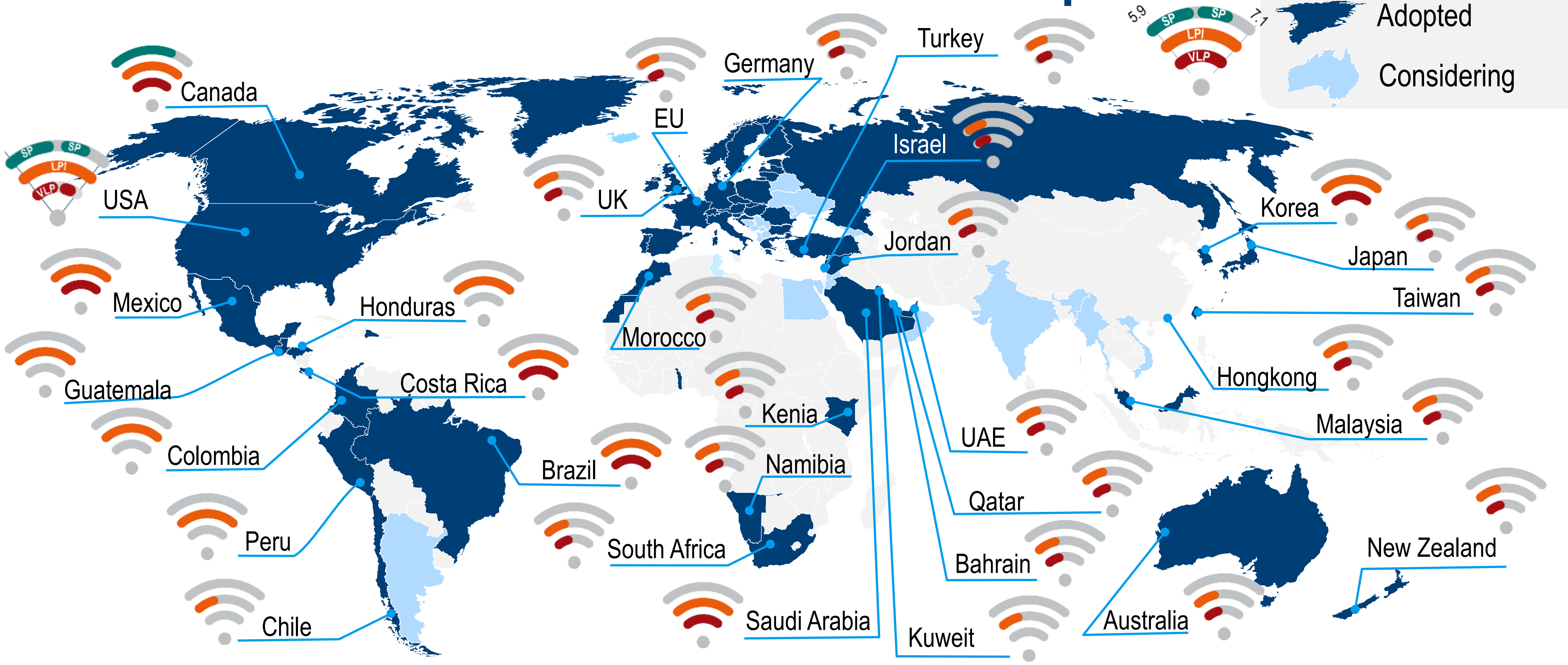
A common approach for 6 GHz band indoor operation with lower power, but …



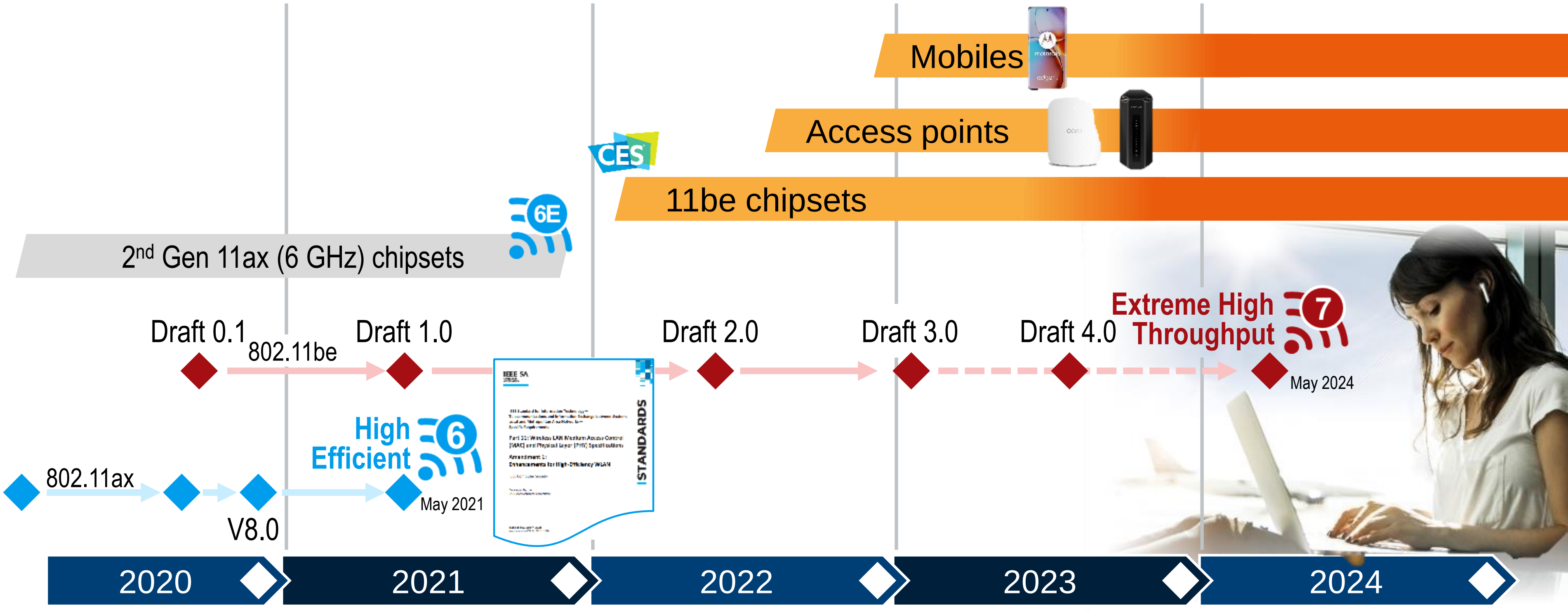
Federal Communications Commission	CEPT ECC Electronic Communications Committee
Standard Power AP: EIRP: 36 dBm (AFC) UE: EIRP: 30 dBm	
Low Power Indoor AP: EIRP: 30 dBm UE: EIRP: 24 dBm	**Low Power Indoor** AP: EIRP: 23 dBm UE: EIRP: 23 dBm
Very Low Power EIRP: 14 dBm (geofenced VLP AP)	**Very Low Power** EIRP: 14 dBm



More and more countries allow or consider to allow the use of the 6 GHz band for licensed exempt use

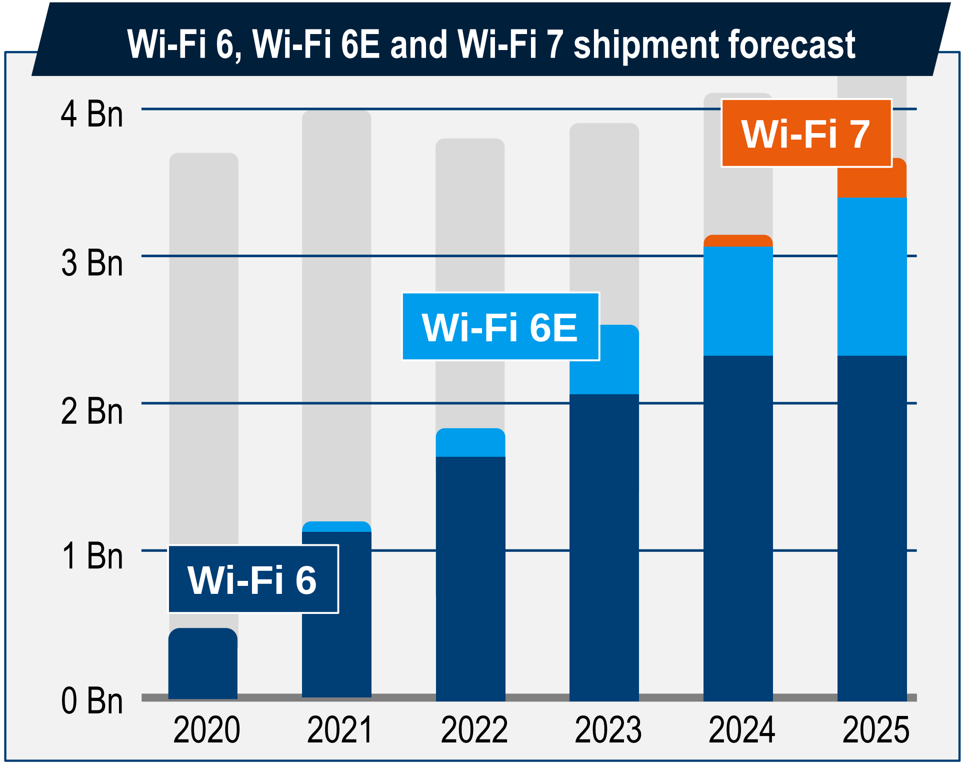


Extreme high throughput WLAN (EHT – IEEE 802.11be – Wi-Fi7) is entering the market with amazing speed



Wi-Fi 6 enters the market and Wi-Fi 7 will approach fast

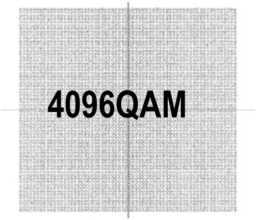
- 19.5 Bn Wi-Fi devices in use (2023)
- 3.9 Bn Wi-Fi devices forecasted to ship
- 18% of all Wi-Fi 6 device shipments in 2023 support 6 GHz band operation



Source: IDC/ Wi-Fi alliance 2023

How to achieve extreme high throughput with Wi-Fi 7?

modulated bits



Code rate

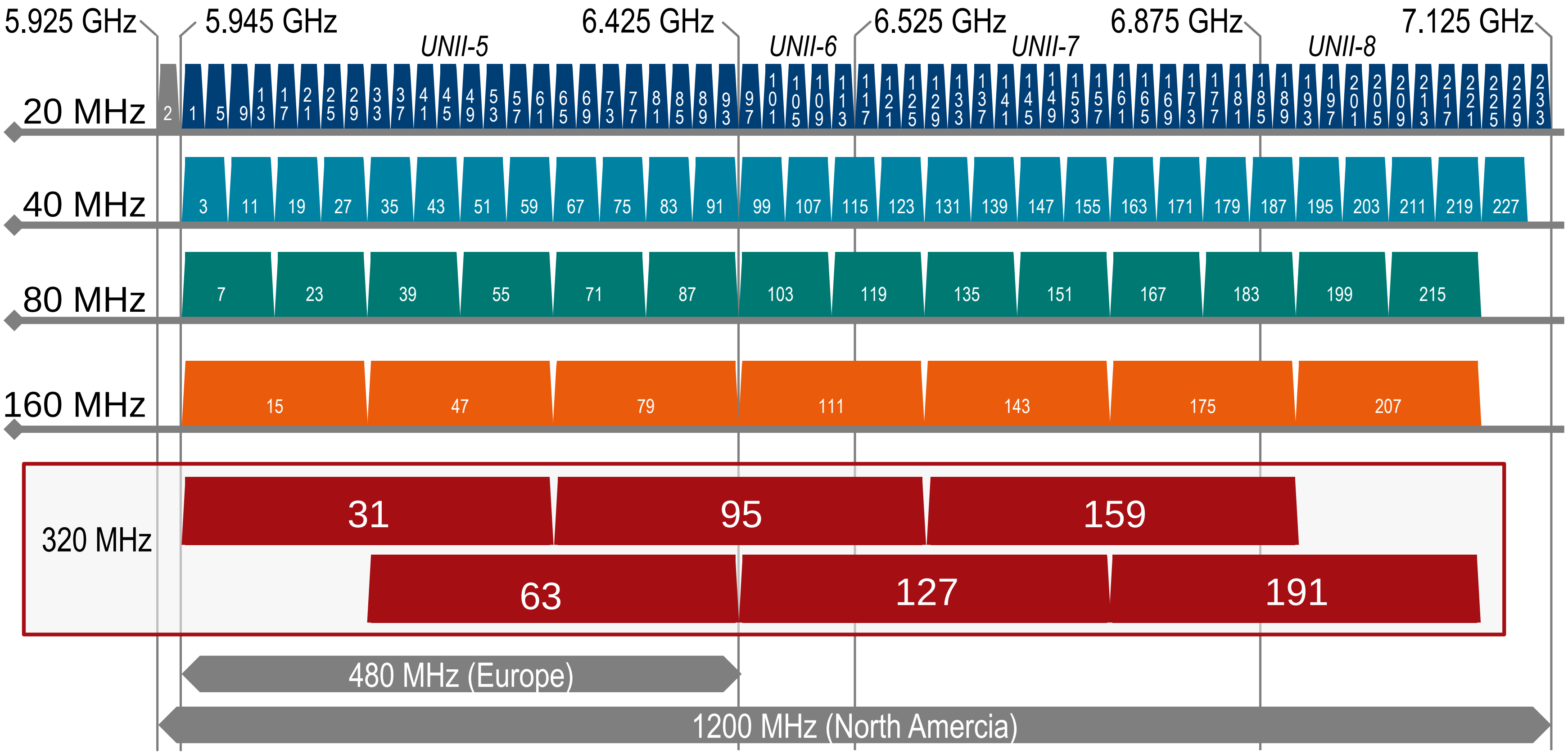
$$Max.\,phy\,data\,rate = N_{SD}\,\frac{N_{CBPS} \cdot R}{T_{SYM}}\,N_{SS}$$

Symbol time

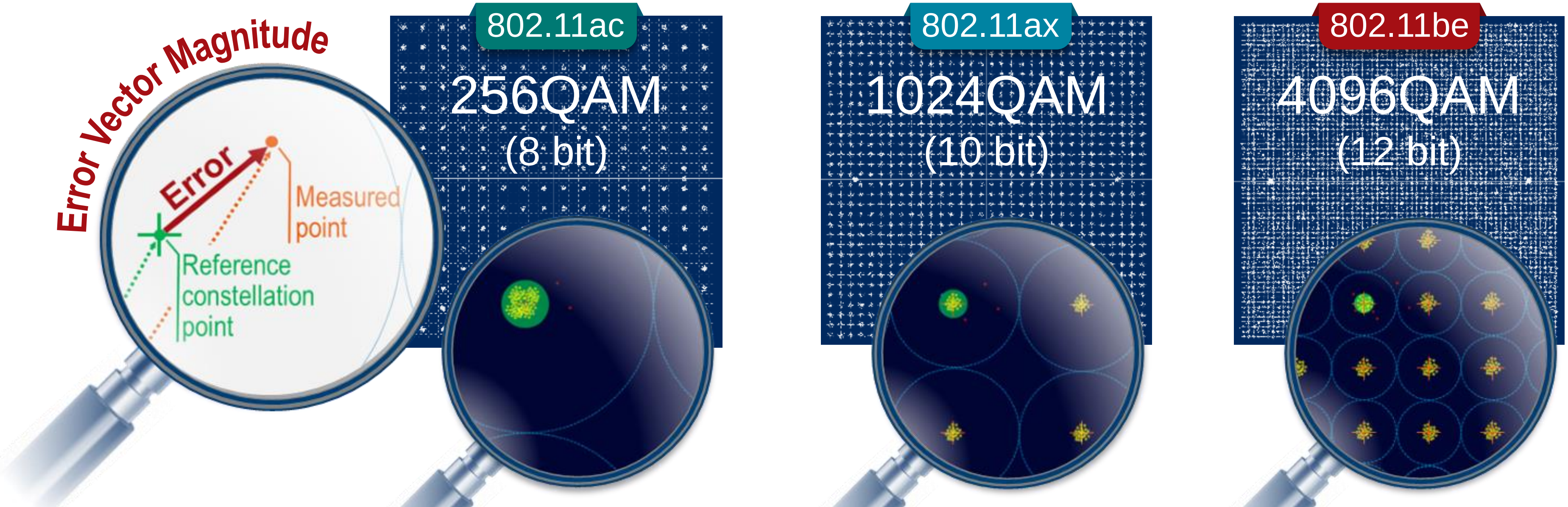
# of data carriers

spatial streams

A few overlapping 320 MHz channels in the 6 GHz band



Wi-Fi 7 pushes RF performance requirements and test equipment quality to the next level



EVM:≤ 3.16%
≤ -30dB

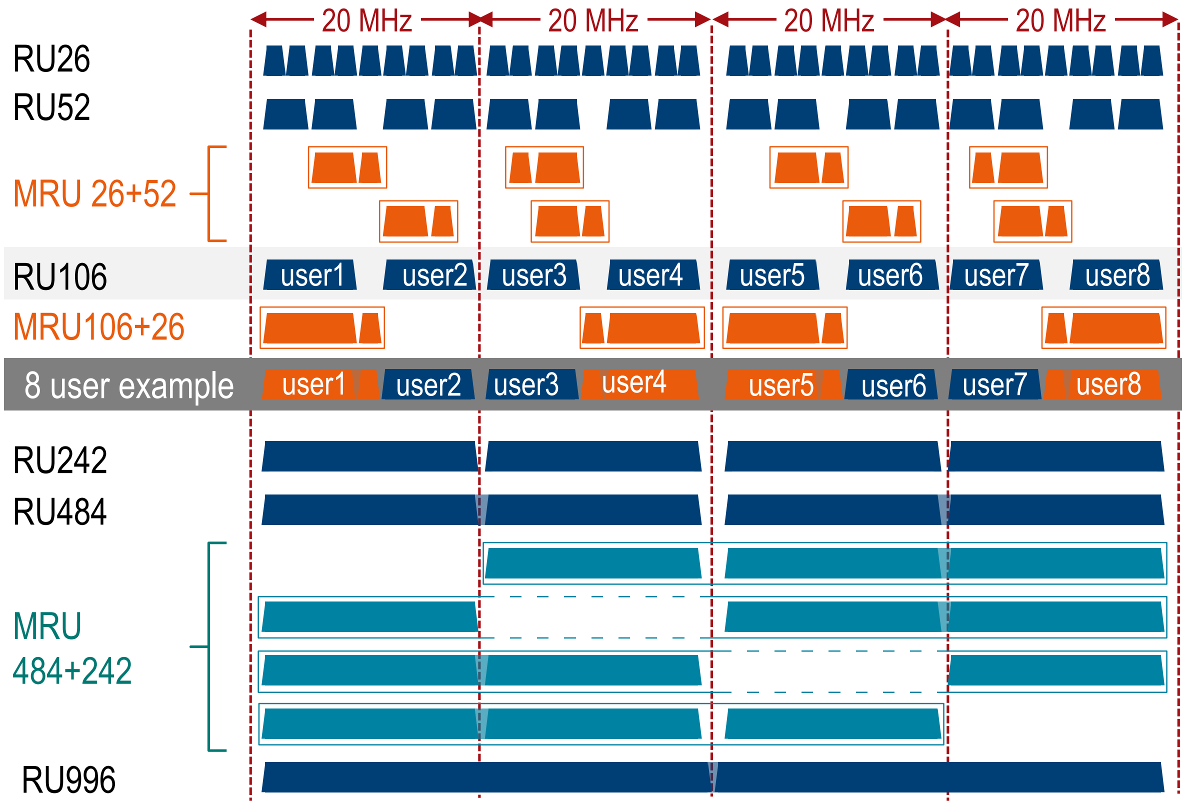
EVM:≤ 1.78%
≤ -35dB

EVM:≤ 1.26%
≤ -38dB

Over two generations a six-fold increase of max. throughput

	Wi-Fi 5 (802.11ac) *Very High Throughput (VHT)*	Wi-Fi 6E (802.11ax) *High Efficiency (HE)*	Wi-Fi 7 (802.11be) *Extreme High Throughput (EHT)*
Supported bands	5 GHz	2 GHz, 5 GHz, **6 GHz**	2 GHz, 5 GHz, 6 GHz
Channel bandwidth (MHz)	20, 40, 80, 80+80, 160	20, 40, 80, 80+80, 160	20, 40, 80, 160, **320**
Transmission scheme	OFDM	OFDM, OFDMA	OFDM, OFDMA
Subcarrier spacing	312.5 kHz	78.125 kHz	78.125 kHz
Guard interval	0.4 µs, 0.8 µs	0.8 µs, 1.6 µs, 3.2 µs	0.8 µs, 1.6 µs, 3.2 µs
Spatial streams	8x8 (incl. DL-MU-MIMO)	8x8 (incl. MU-MIMO)	**16x16** (incl. MU-MIMO)
Modulation (highest)	256QAM (8 bit)	1024QAM (10 bit)	**4096QAM (12 bit)**

Multiple Resource Units (MRU) per user for efficiency



A **small size MRU** (i.e. 26, 52, 106 tone) can only be combined for **efficiency** with another small size RU to form an MRU. RUs in the MRU need to be contiguous and within a 20 MHz channel boundary

The permitted **large size MRU** combinations (i.e. 242, 484, 996 tone) allow additional aggregated bandwidth options (e.g. 60 MHz) per user that don't need to be continuous.

Extended use of preamble puncturing in 802.11be defined for EHT MU PDDU (UL/DL) and EHT TB PPDU (UL)

Non-OFDMA[1] preamble puncturing

80 MHz	20 MHz
160 MHz	20 or 40 MHz
320 MHz	40 and/or 80 MHz

[1] An EHT PPDU that is transmitted using a single RU or MRU that occupies all the non-punctured 20 MHz channels within the PPDU bandwidth.

80 MHz: 484+242-tone MRU 2

160 MHz: 996+484-tone MRU 2

160 MHz: 996+484+242-tone MRU 4

320 MHz: 3x 996-tone MRU 2

320 MHz: 2x 996+484-tone MRU 3

OFDMA preamble puncturing

80 MHz	0..4 20 MHz in 80 MHz sub blocks
160 MHz	
320 MHz	

80 MHz: 484-tone RU + 242-tone RU

160 MHz: 3x 242-tone RUs + 484-tone RU

160 MHz: 2x 242-tone RUs + 484+242-tone MRU

320 MHz: 2x 969-tone RUs + 2x 484-tone RUs

320 MHz: 2x 484+242-tone MRUs +242-tone RU + 2x 484-tone RUs

Multi-Link Operation (MLO): The key to Wi-Fi 7 performance?

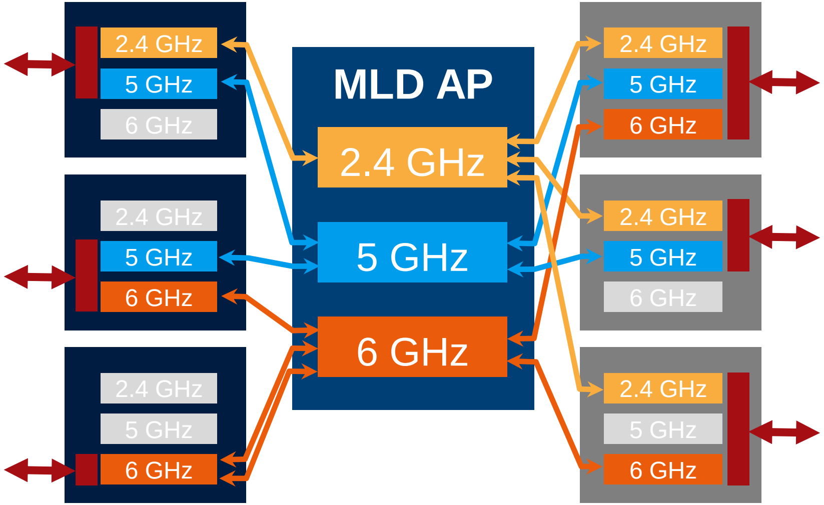
“MLO is bringing ultra-low latency to Wi-Fi 7”

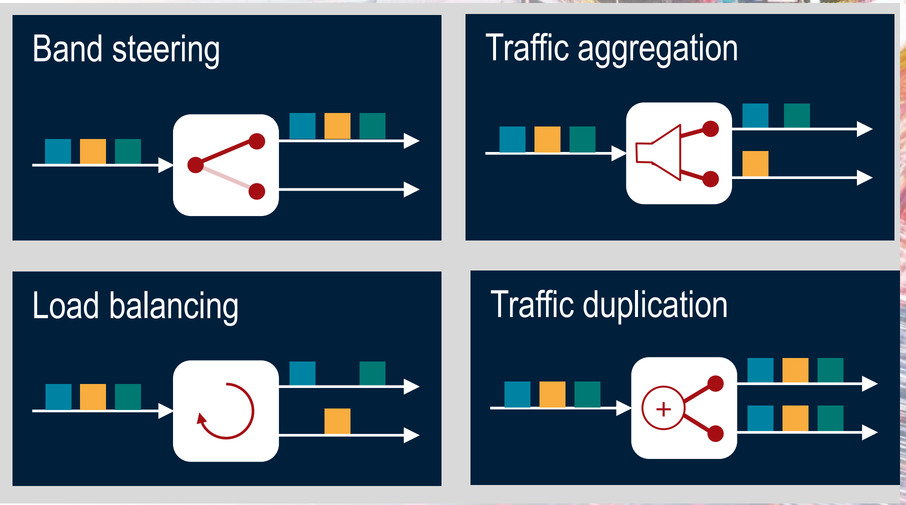
“The MLO mechanism helps Wi-Fi 7 to triple throughput comparing to Wi-Fi 6 in an ideal environment”

“MLO gives WiFi 7 routers and devices an undeniable advantage over last-gen tech”

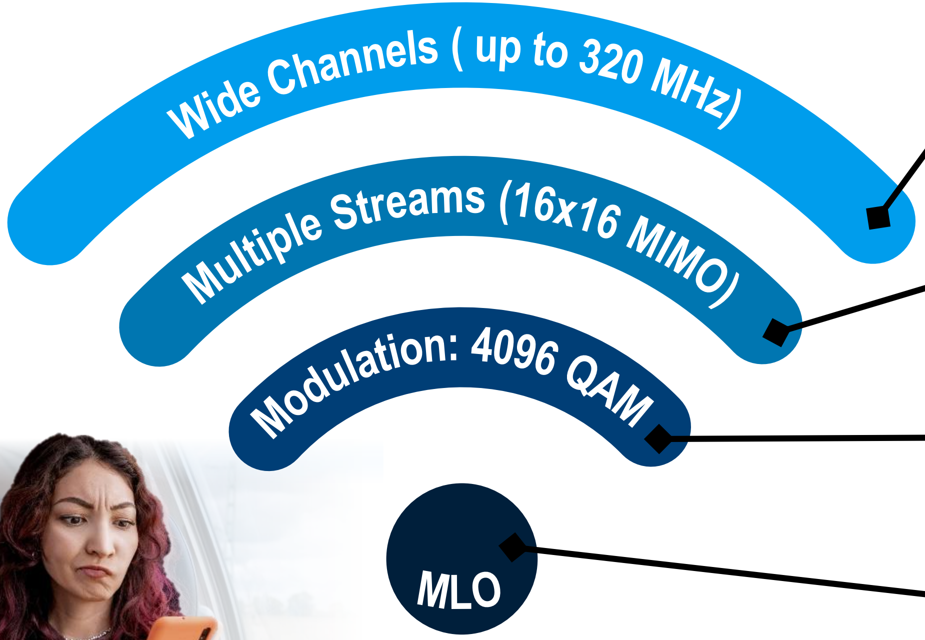
“MLO achieves lower latency and serves a higher number of XR users …”

Wi-Fi 7 will allow multi-link operation





Lets make the reality check, what is Wi-Fi7 about?



- Limited # of ch. available in the 6GHz band – preamble puncturing becomes common
- Use is limited by the device dimensions and the RF design: 2x2 and 4x4 will be common
- Requires perfect RF conditions and ultimate RF designs, mainly applicable in short D2D
- Multi-Link operation has the potential to largely improve latency, reliability and throughput, but on costs of power and complexity

Wi-Fi test solutions for today and tomorrow


Bluetooth
gets ready for the
future
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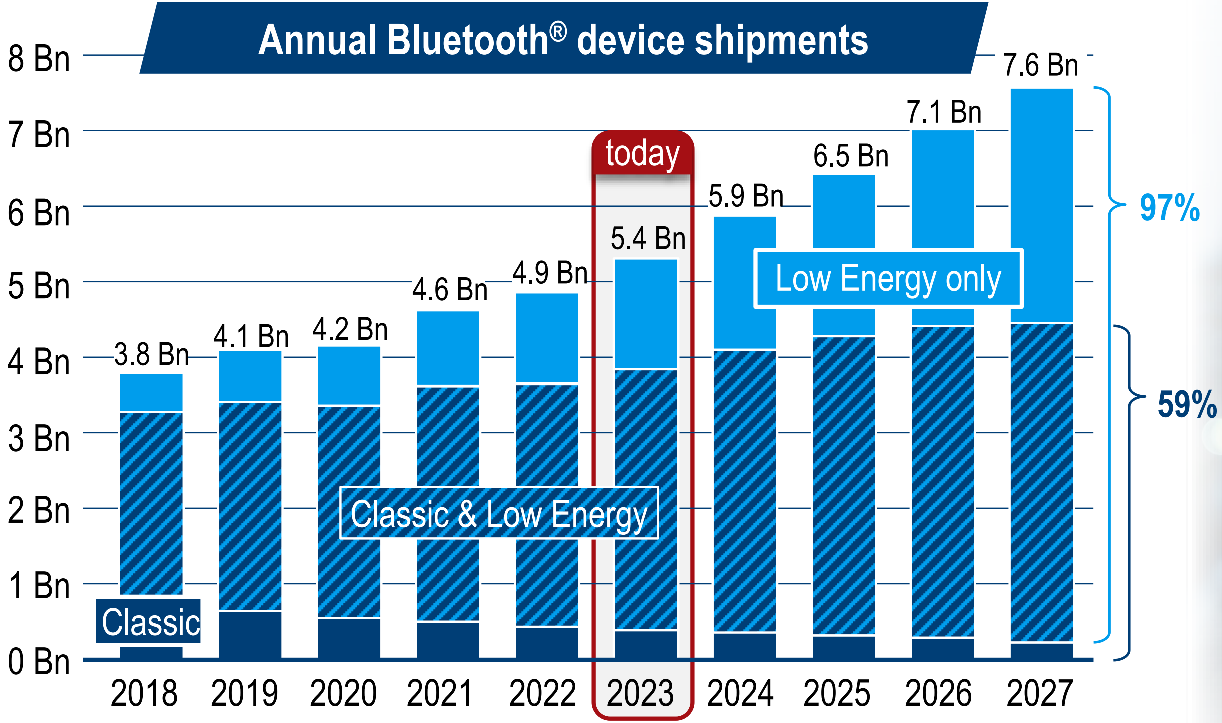
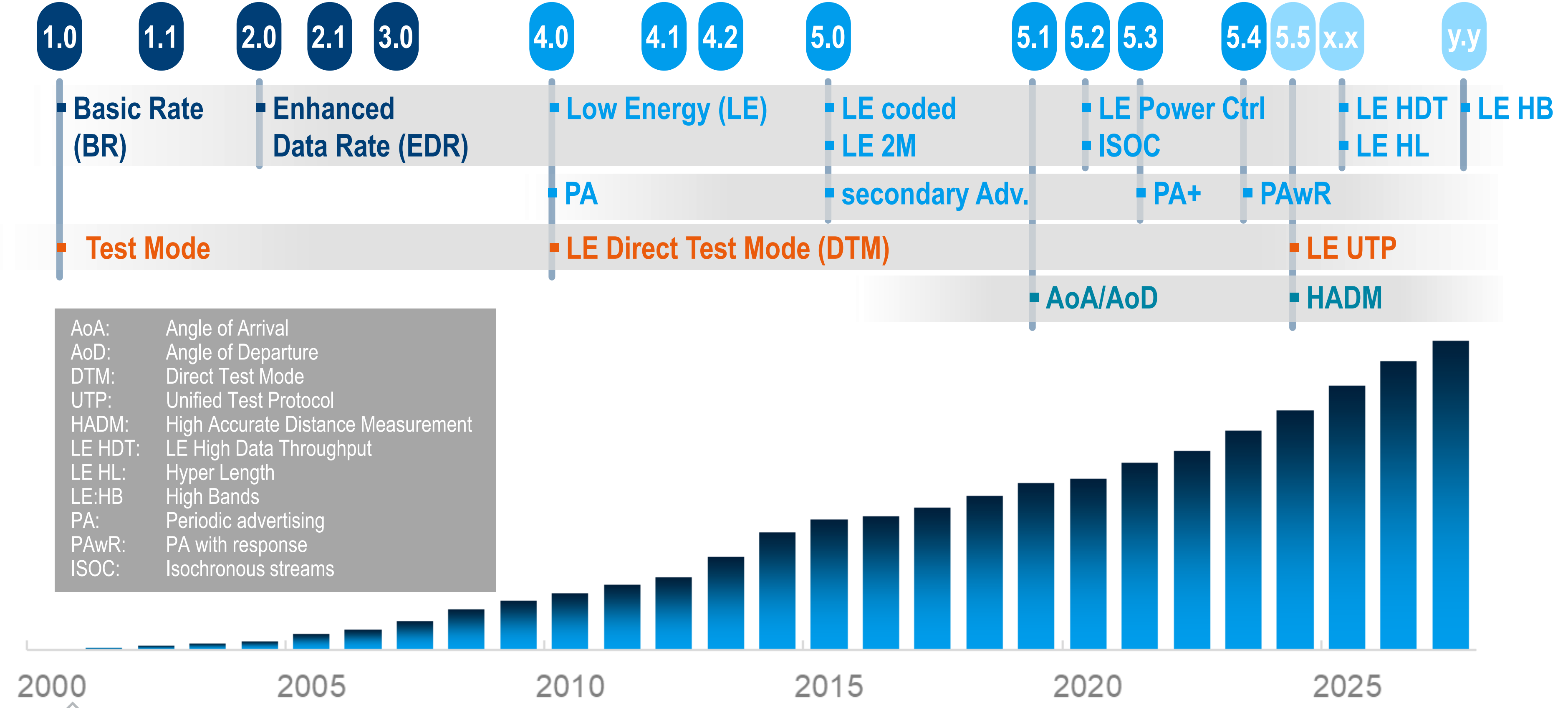
Bluetooth most attractive applications today & tomorrow

Continuous growth (9% CAGR) and move from Bluetooth® *Classic* to *Low Energy* expected for the next years



Source: Bluetooth SIG, April 2023, https://www.bluetooth.com/2023-market-update/

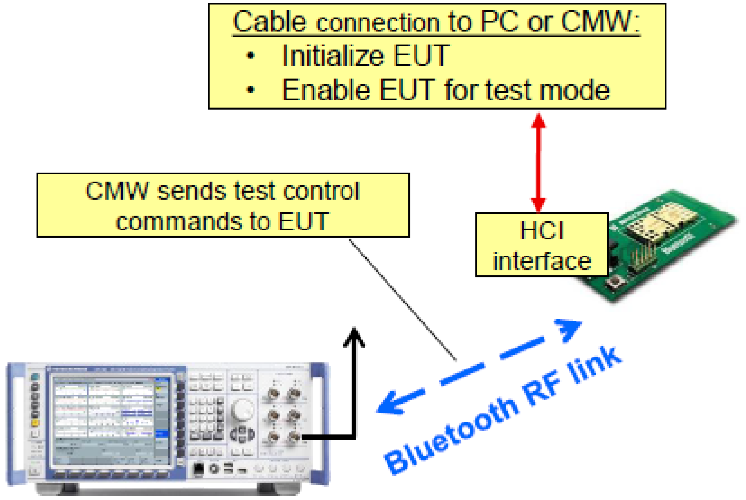
Bluetooth evolution (selected features over time)



Bluetooth Test Modes for RF Testing

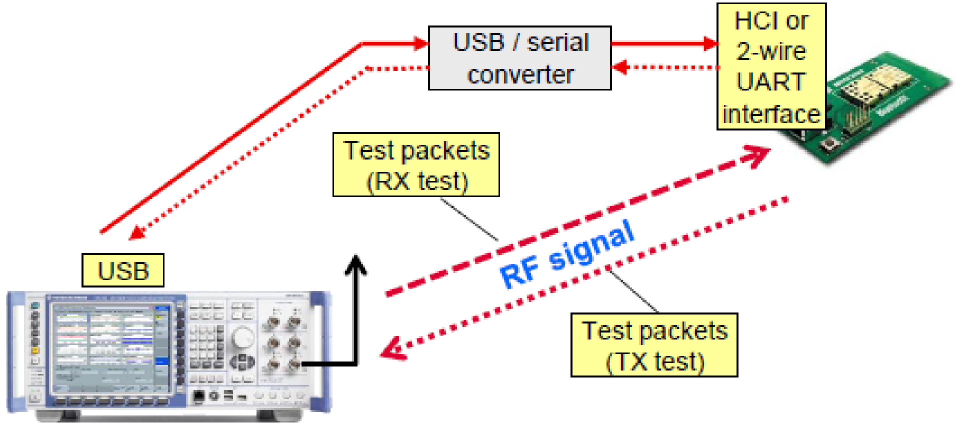
Bluetooth Classic (BR/EDR) Test Mode

EUT is controlled via Bluetooth RF link
Measurements in signaling mode



Bluetooth Low Energy Direct Test Mode

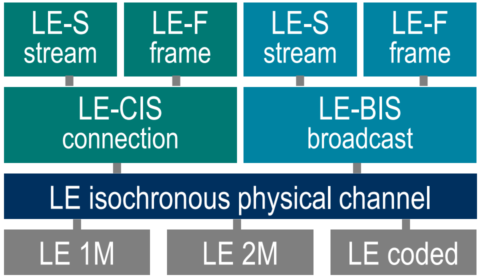
EUT is controlled via cable
Measurements in non-signaling mode



Bluetooth® 5.2: Native Bluetooth® LE audio support for several applications …

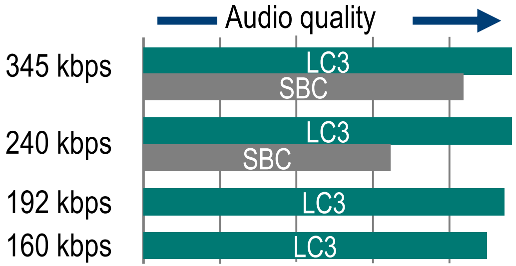
LE isochronous channels

Allows communication of time-bound data to one or more devices for time-synchronized processing.
- Multi-channel audio streaming incl. hearing aids
- Audio broadcasting



LC3 audio codec

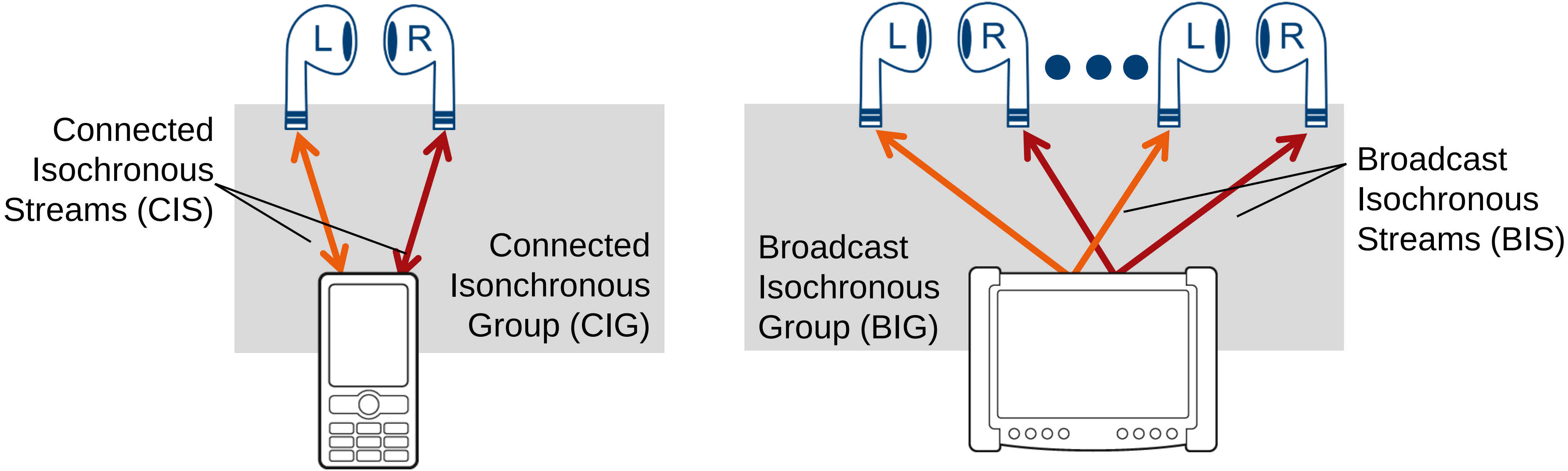
The new low complexity codec developed by Fraunhofer IIS is optimized for high-resolution music streaming operating at low latency, low computational complexity and low memory footprint.



Bluetooth® 5.2:
Multi-Stream Audio and Broadcast Audio Sharing

Audio streams to/from stereo clients

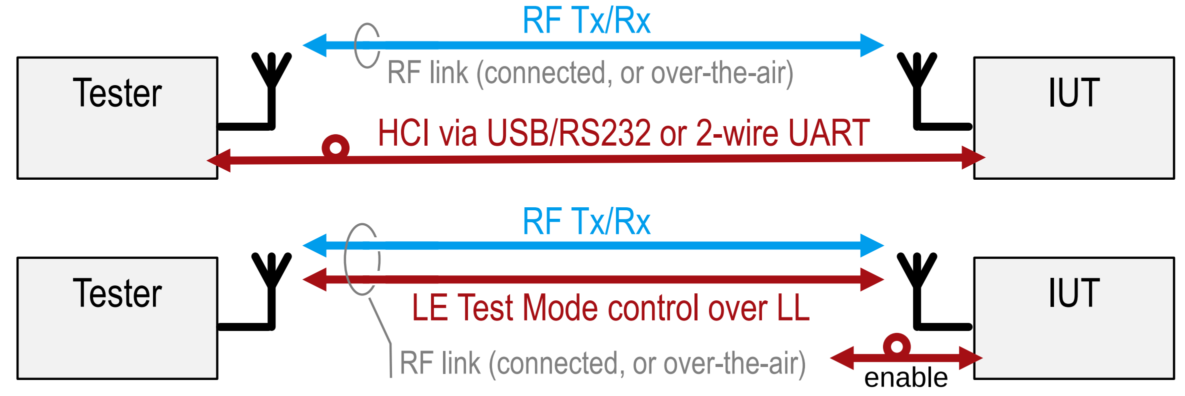
Broadcast-oriented audio streams to several stereo clients



The unified test protocol as enhanced alternative to the DTM

- Bluetooth LE Test Modes
  - Direct Test Mode (DTM)
    - HCI via USB/RS232
    - 2-wire UART
  - Unified Test Protocol (UTP)
    - HCI via USB/RS232
    - 2-wire UART
    - Over-the-air Transport (opt.)

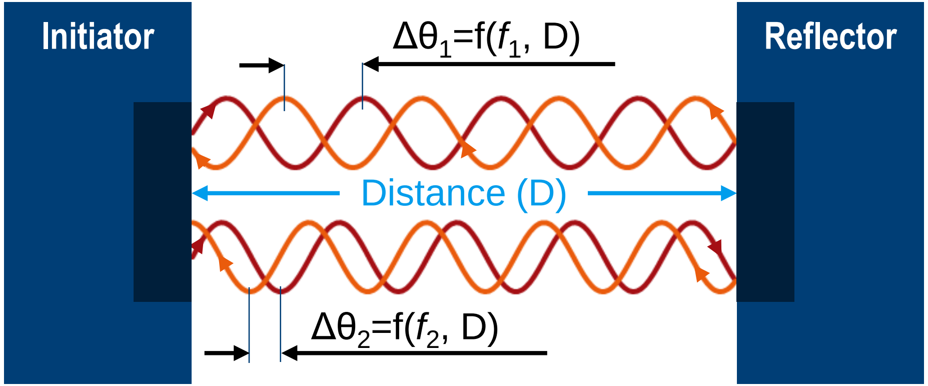
Unified Test Protocol



For OTA transport an ACL connection and LL protocol is used to exchange control messsages

Test mode need to be enabled via new command (HCI_LE_Enable_Test_Mode)

Channel sounding applying phase ranging principle for high accurate distance measurements (HADM)



Calculating the distance (D) by measuring the phase difference (Δθ) between multiple carriers with different frequencies (f_i) supported by RTT measurements.

Requires capabilities to accurately measure and generate stable frequencies and phases

Total phase change over distance D

$$\Delta\theta_i = 2\pi \frac{2Df_i}{c}$$

$$\frac{\Delta\theta}{\Delta f} = 2\pi \frac{2D}{c}$$

$$D = \frac{1}{2}\frac{c}{2\pi\,\Delta f}\Delta\theta$$

$$\Delta\theta = \Delta\theta_1 - \Delta\theta_2$$

$$\Delta f = f_1 - f_2 = 1\text{ MHz}$$

Periodicity of phase difference Δθ

$$D_{max} = \frac{1}{2}\frac{c}{\Delta f}\bigg|_{\Delta f_{min} = 1\,MHz}$$

$$D_{max} \approx 150\text{ m}$$

Bluetooth® test solutions for the product life cycle


THANK YOU
VERY MUCH
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