


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

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Make ideas real





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Wi-Fi
the wireless power horse at
home & offices

The HISTORY and FUTURE of Wi-Fi



WaveLAN, the starting point for Wi-Fi development, was used for wirelessly connecting cashing machines.

802.11 b
Higher speed physical layer extension in the 2.4 GHz band

Channel bandwidth	20 MHz
Channel bandwidth	22 MHz
Modulation type	QPSK
Channel bandwidth	20 MHz
Channel bandwidth	22 MHz
Modulation type	QPSK
Channel bandwidth	20 MHz
Channel bandwidth	22 MHz
Modulation type	QPSK

CSMA/SSS

802.11 g
High speed physical layer in the 5 GHz band

Channel bandwidth	20 MHz
Channel bandwidth	22 MHz
Modulation type	64QAM
Channel bandwidth	20 MHz
Channel bandwidth	22 MHz
Modulation type	64QAM
Channel bandwidth	20 MHz
Channel bandwidth	22 MHz
Modulation type	64QAM

CSMA/OFDM

Need for faster speed and better distance coverage.

The ability to connect to the internet via mobile devices and the rising number of smartphones on the market required the introduction of features like MIMO.

802.11 n
Further higher data rate extension

Channel bandwidth	20 MHz
Channel bandwidth	22 MHz
Modulation type	64QAM
Channel bandwidth	20 MHz
Channel bandwidth	22 MHz
Modulation type	64QAM
Channel bandwidth	20 MHz
Channel bandwidth	22 MHz
Modulation type	64QAM

CSMA/OFDM

Designed for in-room/desk network applications requiring very high data rates such as for HD video streaming.

More and more people wanted Wi-Fi at home and at work. High speed Wi-Fi was therefore required in the 5 GHz spectrum to relieve the overcrowded 2.4 GHz spectrum.



802.11 ac
Directional multi-gigabit (DMG) in the 60 GHz band

Channel bandwidth	20 MHz
Channel bandwidth	22 MHz
Modulation type	64QAM
Channel bandwidth	20 MHz
Channel bandwidth	22 MHz
Modulation type	64QAM
Channel bandwidth	20 MHz
Channel bandwidth	22 MHz
Modulation type	64QAM

CSMA/SSS

Achieves up to 20 Gbit/s throughput and enables extended distances for enlarged application space.



802.11 ay
Enhanced DMG (EDMG) in bands above 45 GHz

Channel bandwidth	8.94 MHz
Channel bandwidth	16 MHz
Modulation type	64QAM
Channel bandwidth	8.94 MHz
Channel bandwidth	16 MHz
Modulation type	64QAM
Channel bandwidth	8.94 MHz
Channel bandwidth	16 MHz
Modulation type	64QAM

CSMA/OFDM

Enables use of the sub GHz spectrum for IoT and remote internet applications.

802.11 p
Enhancements for higher throughput (HT)

Channel bandwidth	10 MHz
Channel bandwidth	11 MHz
Modulation type	64QAM
Channel bandwidth	10 MHz
Channel bandwidth	11 MHz
Modulation type	64QAM
Channel bandwidth	10 MHz
Channel bandwidth	11 MHz
Modulation type	64QAM

CSMA/OFDM

802.11 bc
Enhancements for very high throughput (VHT)

Channel bandwidth	160 MHz
Channel bandwidth	180 MHz
Modulation type	256QAM
Channel bandwidth	160 MHz
Channel bandwidth	180 MHz
Modulation type	256QAM
Channel bandwidth	160 MHz
Channel bandwidth	180 MHz
Modulation type	256QAM

CSMA/OFDM

The heavy use of Wi-Fi meant that a new approach was required. OFDMA allows multiple devices to communicate simultaneously.

802.11 ah
Reverse very high throughput (RVHT)

Channel bandwidth	10 MHz
Channel bandwidth	11 MHz
Modulation type	256QAM
Channel bandwidth	10 MHz
Channel bandwidth	11 MHz
Modulation type	256QAM
Channel bandwidth	10 MHz
Channel bandwidth	11 MHz
Modulation type	256QAM

CSMA/OFDM

802.11 ah
Sub 1 GHz

Channel bandwidth	1.7, 2, 4, 8 MHz
Channel bandwidth	16 MHz
Modulation type	256QAM
Channel bandwidth	1.7, 2, 4, 8 MHz
Channel bandwidth	16 MHz
Modulation type	256QAM
Channel bandwidth	1.7, 2, 4, 8 MHz
Channel bandwidth	16 MHz
Modulation type	256QAM

CSMA/OFDM

802.11 ax
Enhancement for high efficiency (HE) Wi-Fi

Channel bandwidth	160 MHz
Channel bandwidth	180 MHz
Modulation type	1024QAM
Channel bandwidth	160 MHz
Channel bandwidth	180 MHz
Modulation type	1024QAM
Channel bandwidth	160 MHz
Channel bandwidth	180 MHz
Modulation type	1024QAM

CSMA/OFDM/OFDMA



802.11 be
Enhancements for extreme high throughput (EHT)

Channel bandwidth	160 MHz
Channel bandwidth	180 MHz
Modulation type	4096QAM
Channel bandwidth	160 MHz
Channel bandwidth	180 MHz
Modulation type	4096QAM
Channel bandwidth	160 MHz
Channel bandwidth	180 MHz
Modulation type	4096QAM

CSMA/OFDM/OFDMA

The advent of home office and schooling as well as industrial applications require improved data throughput, reduced latency and efficiency.

Provide Wi-Fi based car-to-car communications to enable emerging intelligent traffic services.

802.11 p
Wireless access in vehicular environments

Channel bandwidth	10 MHz
Channel bandwidth	11 MHz
Modulation type	64QAM
Channel bandwidth	10 MHz
Channel bandwidth	11 MHz
Modulation type	64QAM
Channel bandwidth	10 MHz
Channel bandwidth	11 MHz
Modulation type	64QAM

CSMA/OFDM

Meet today's and tomorrow's rising demands on V2X communications on the way to fully autonomous vehicles.

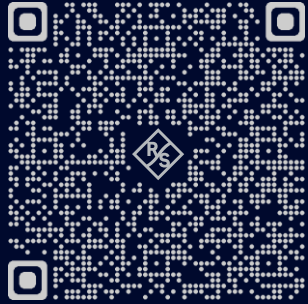


802.11 bd
Enhancements for next generation vehicular (NGV)

Channel bandwidth	10, 20 MHz
Channel bandwidth	18, 20 MHz
Modulation type	256QAM
Channel bandwidth	10, 20 MHz
Channel bandwidth	18, 20 MHz
Modulation type	256QAM
Channel bandwidth	10, 20 MHz
Channel bandwidth	18, 20 MHz
Modulation type	256QAM

CSMA/OFDM

Poster available at rohde-schwarz.com



Rohde & Schwarz

R&S
RF generator

Work in the class of Wi-Fi modulation

R&S
RF signal and spectrum analyzer

Setting standards in innovation

R&S
RF signal and spectrum analyzer

The right choice for Wi-Fi E

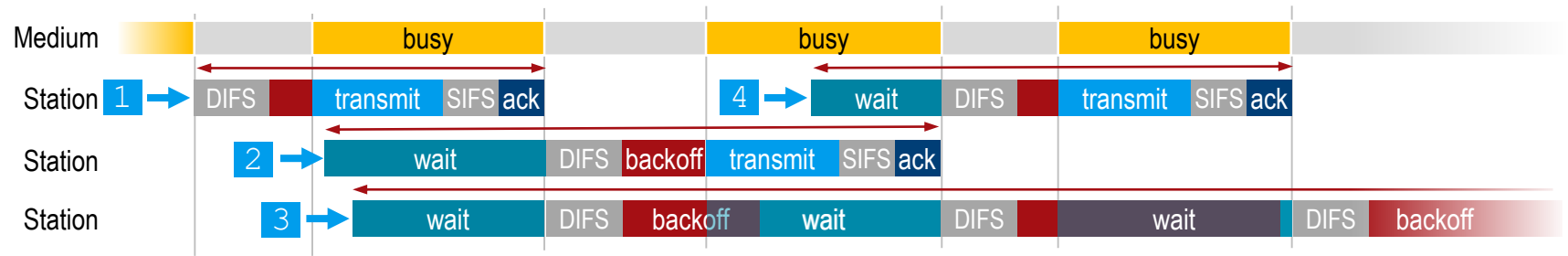
R&S
RF regulatory test system for wireless devices

Techn

R&S
RF diagnostic chamber

Access scheme based on CSMA/CA has some limitations

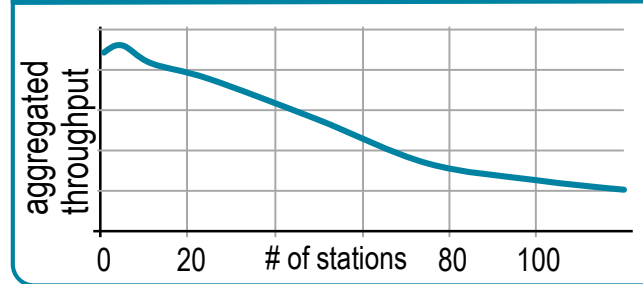
Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)



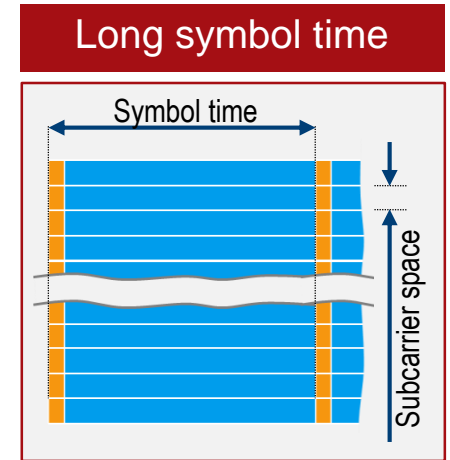
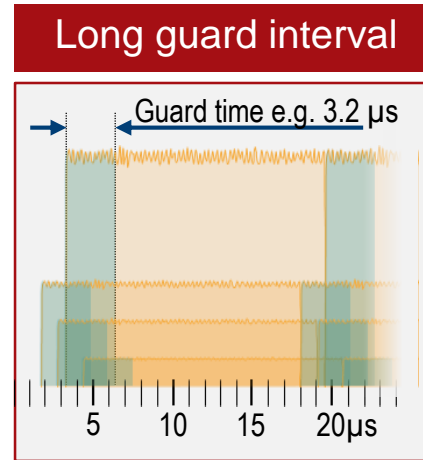
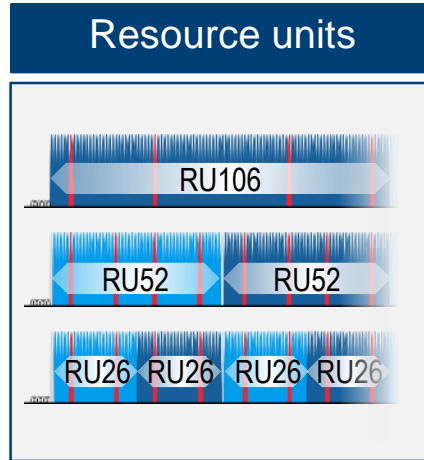
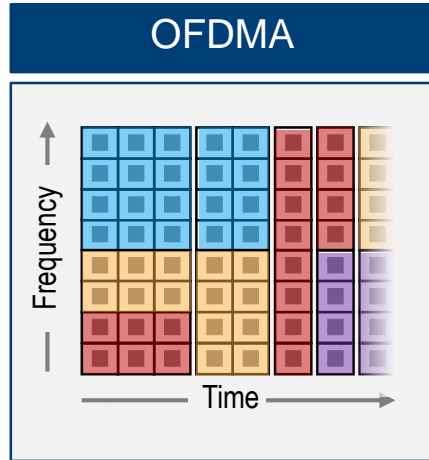
Works well for small # of clients ..., but fails in traffic jam



Throughput depend on # of stations



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



- ◆ 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) <i>High Throughput (HT)</i>	Wi-Fi 5 (802.11ac) <i>Very High Throughput (VHT)</i>	Wi-Fi 6 (802.11ax) <i>High Efficiency (HE)</i>
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 μ s, 0.8 μ s	0.4 μ s, 0.8 μ s	0.8 μ s, 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*

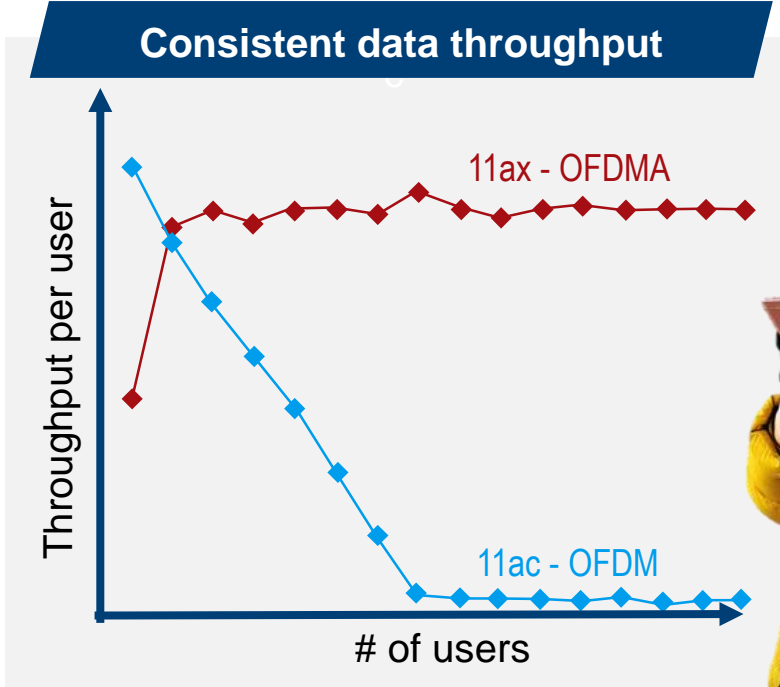
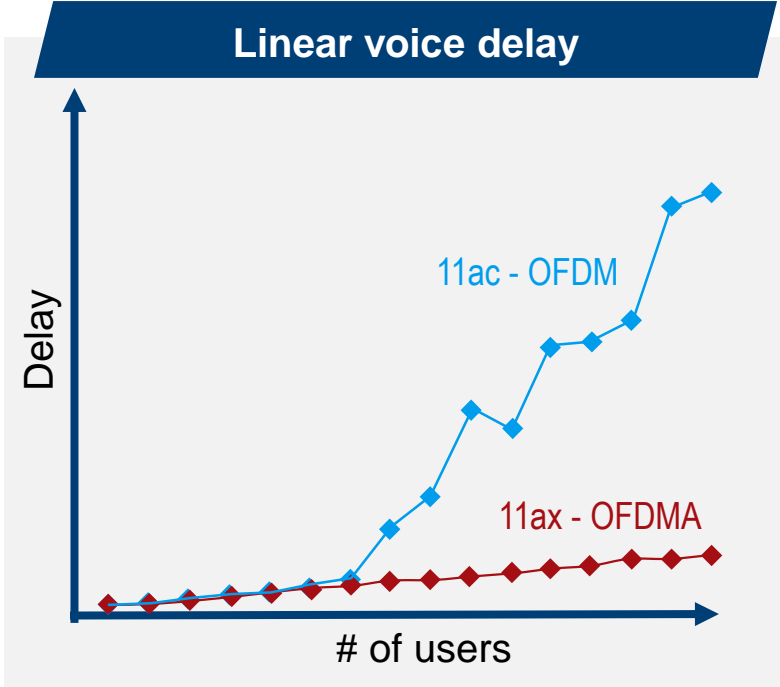
x13

x1.4

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



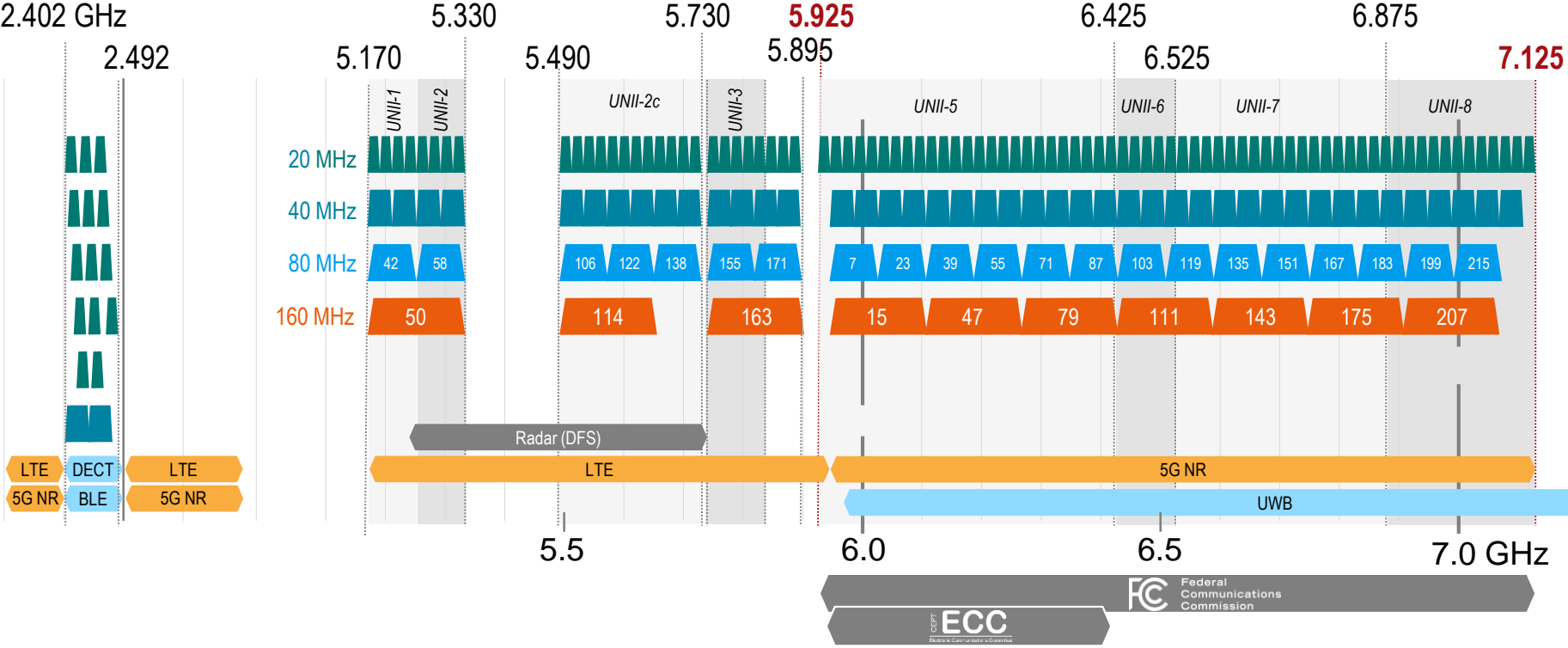
OFDMA (802.11ax) makes Wi-Fi carrier-grade and attractive for related services like VoWiFi or Wi-Fi offload



Source: Cisco and Cisco sponsored research



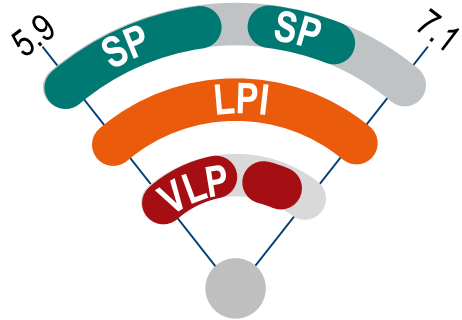
New spectrum allocation allows more wide channels in a (still) less congested 6 GHz band



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

FC 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

Very Low Power

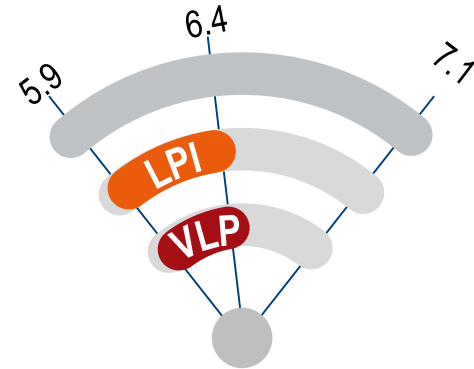
EIRP: 14 dBm
(geofenced VLP AP)

Low Power Indoor

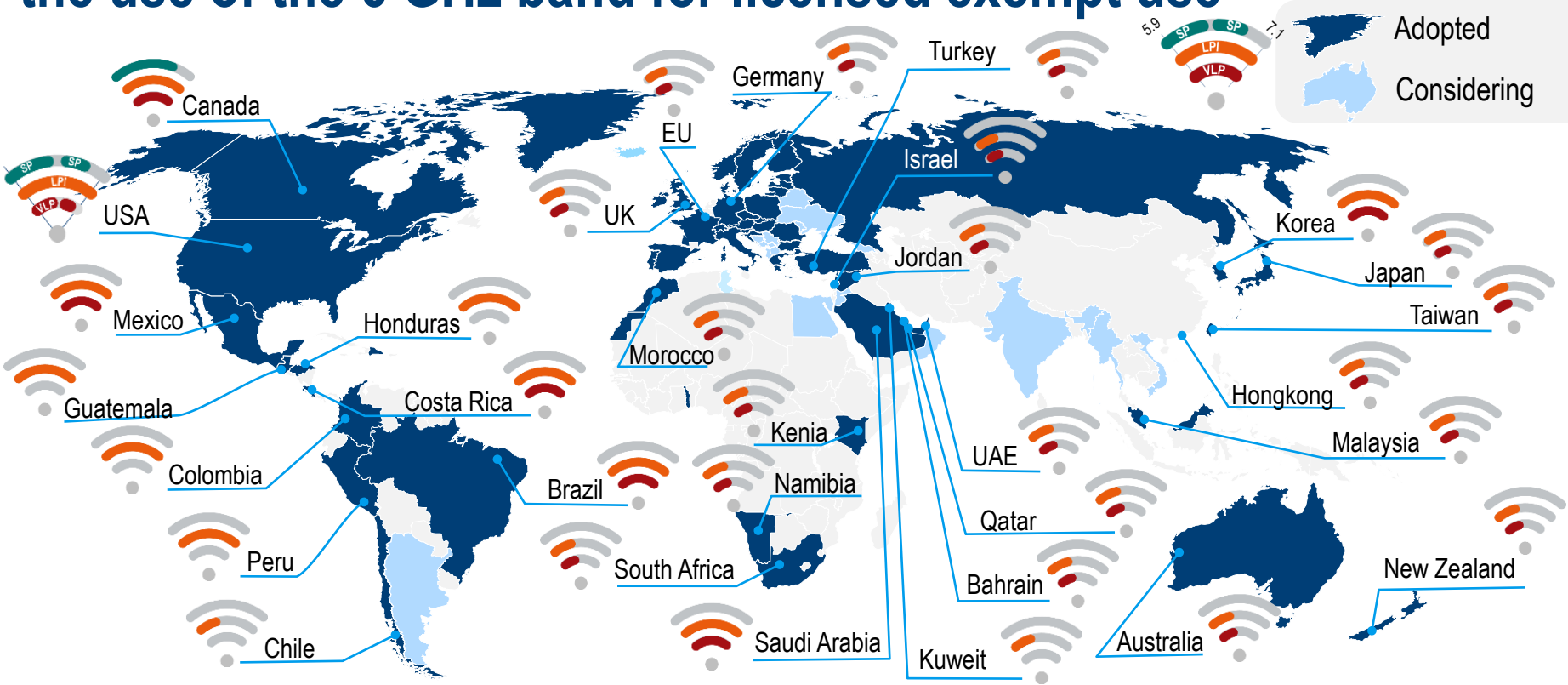
AP: EIRP: 23 dBm
UE: EIRP: 23 dBm

Very Low Power

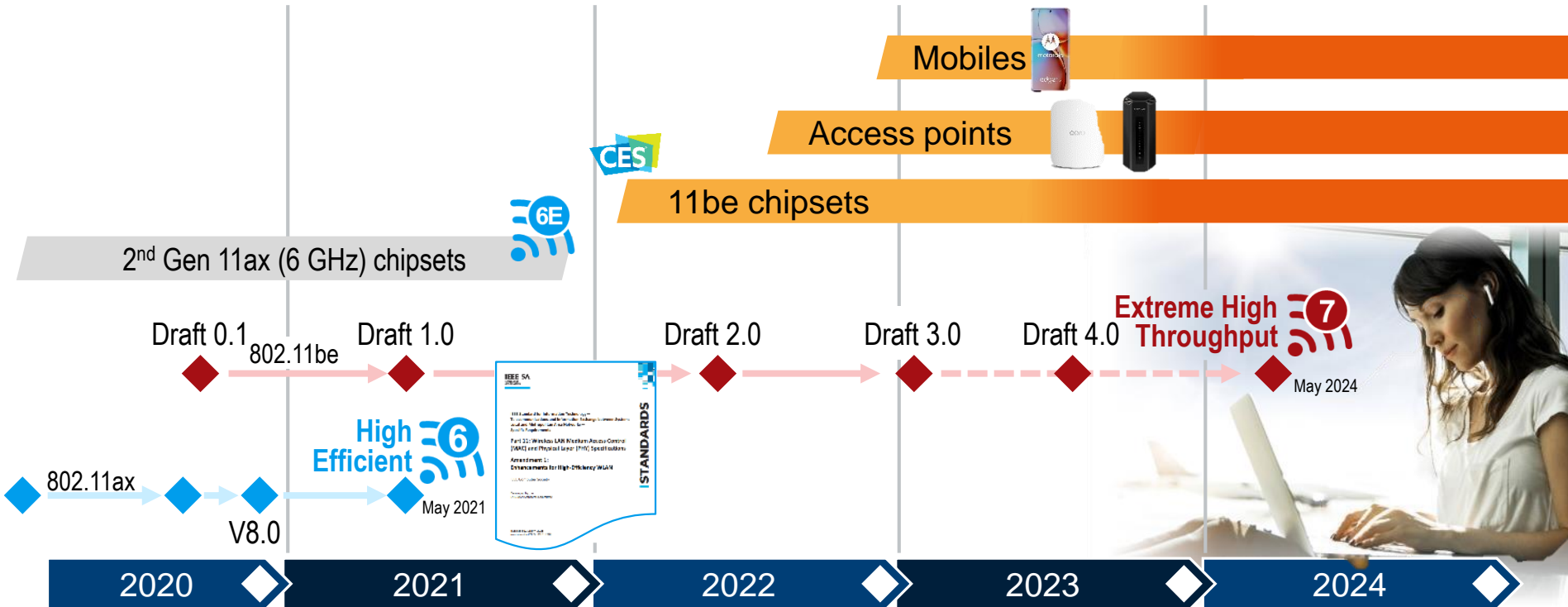
EIRP: 14 dBm



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

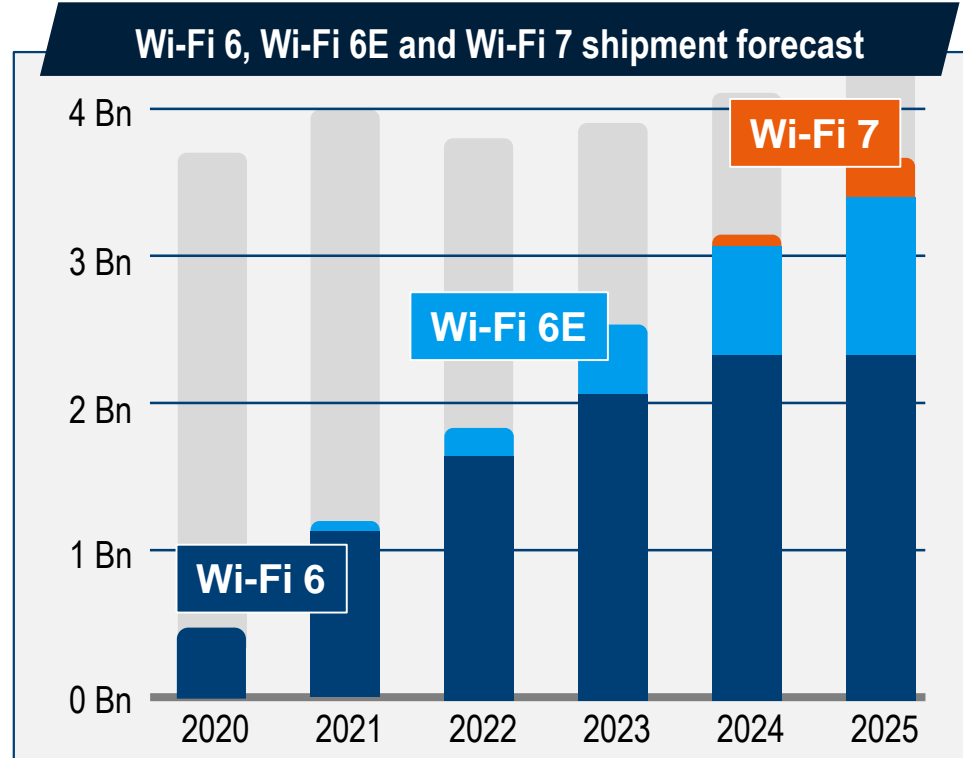


Extreme high throughput WLAN (EHT – IEEE 802.11be – Wi-Fi7) is entering the market with amazing speed



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

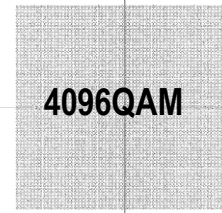


Source: IDC/ Wi-Fi alliance 2023

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



modulated bits



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

Code rate

Symbol time

of data carriers



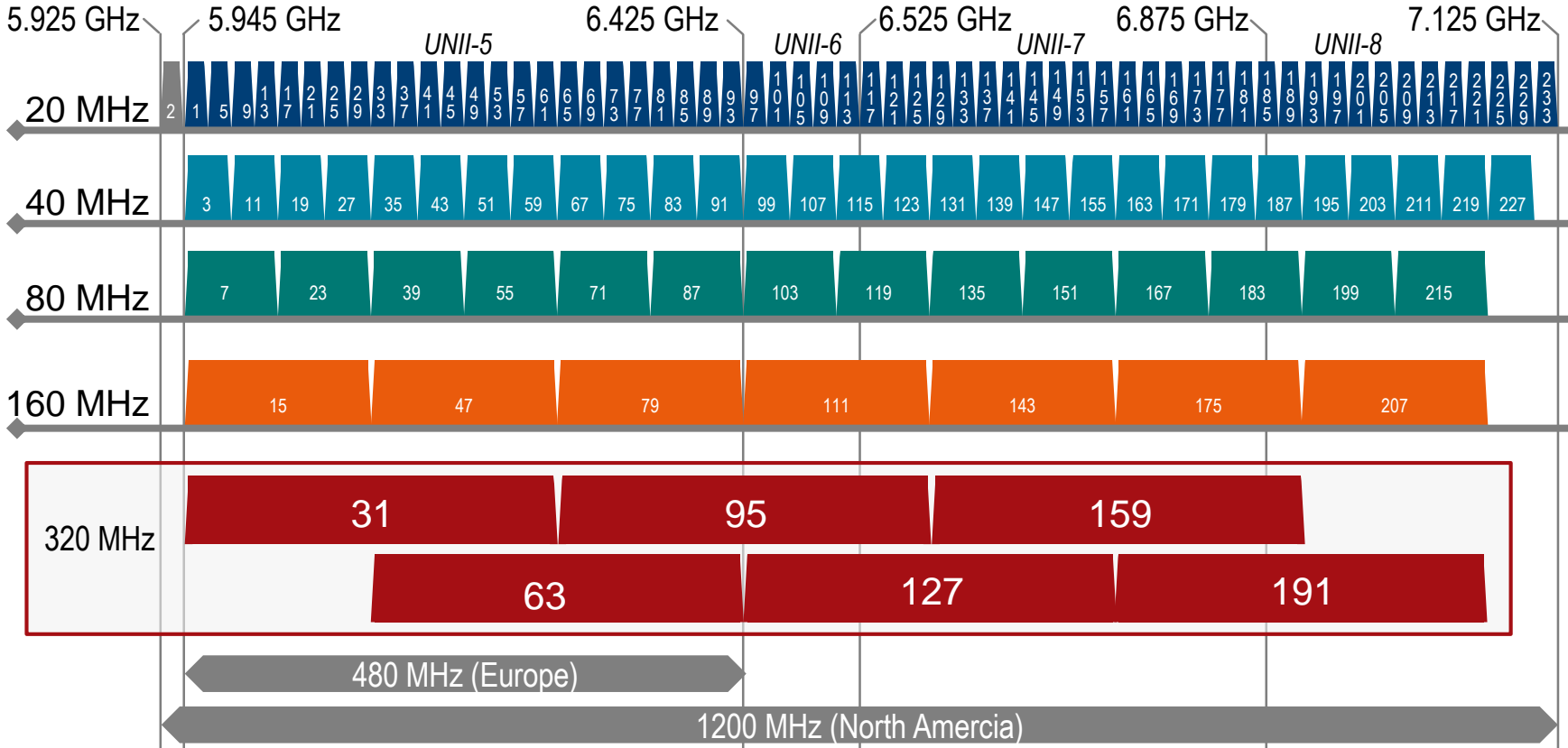
≤ 320 MHz

spatial streams



16x16

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

Error Vector Magnitude

802.11ac

256QAM
(8 bit)

Reference constellation point

Measured point

EVM: $\leq 3.16\%$
 $\leq -30\text{dB}$

802.11ax

1024QAM
(10 bit)

EVM: $\leq 1.78\%$
 $\leq -35\text{dB}$

802.11be

4096QAM
(12 bit)

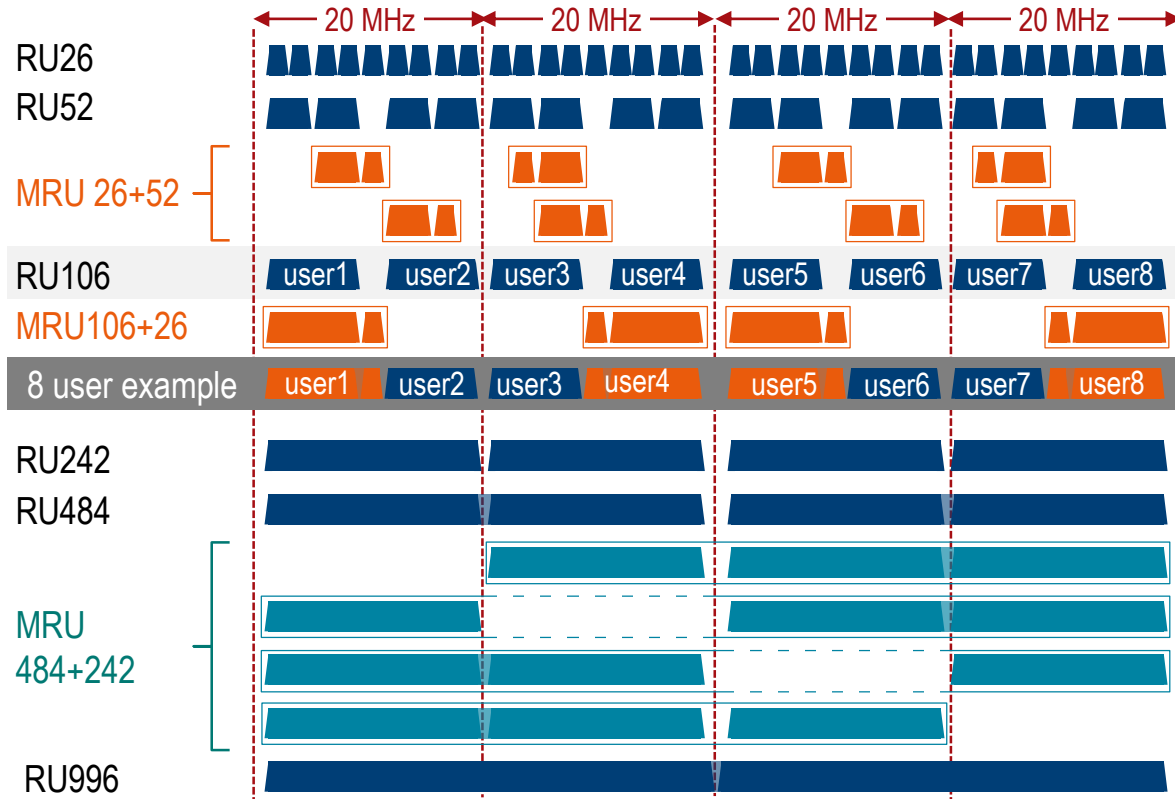
EVM: $\leq 1.26\%$
 $\leq -38\text{dB}$



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

	Wi-Fi 5 (802.11ac) <i>Very High Throughput (VHT)</i>	Wi-Fi 6E (802.11ax) <i>High Efficiency (HE)</i>	Wi-Fi 7 (802.11be) <i>Extreme High Throughput (EHT)</i>
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 μ s, 0.8 μ s	0.8 μ s, 1.6 μ s, 3.2 μ s	0.8 μ s, 1.6 μ s, 3.2 μ s
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-OFDMA¹⁾ 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
160 MHz	in 80 MHz
320 MHz	sub blocks

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”

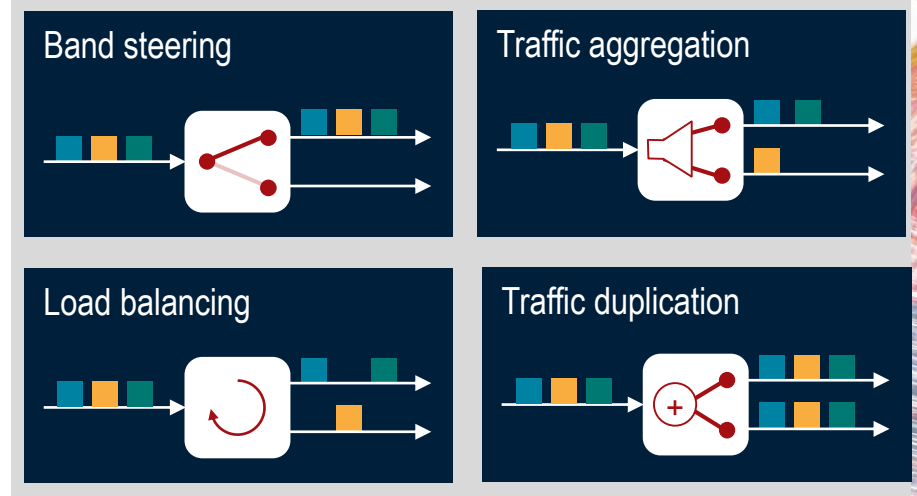
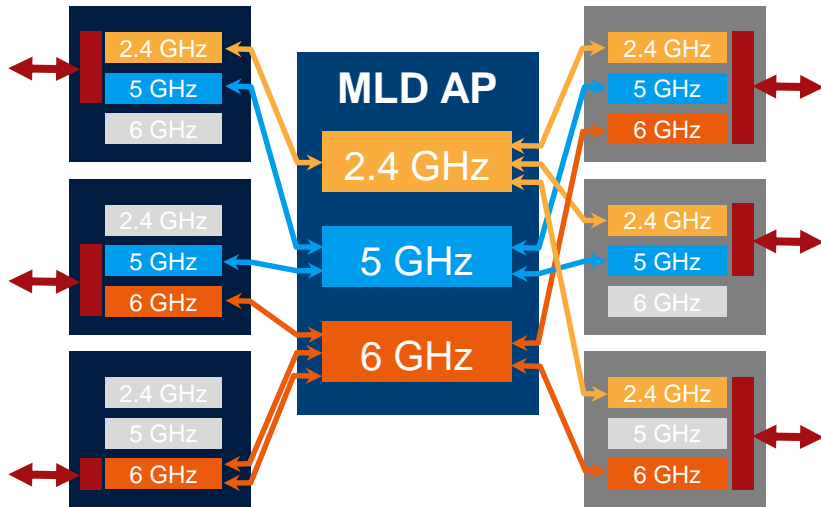
“The MLO mechanism helps Wi-Fi 7 to triple throughput comparing to Wi-Fi 6 in an ideal environment”

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

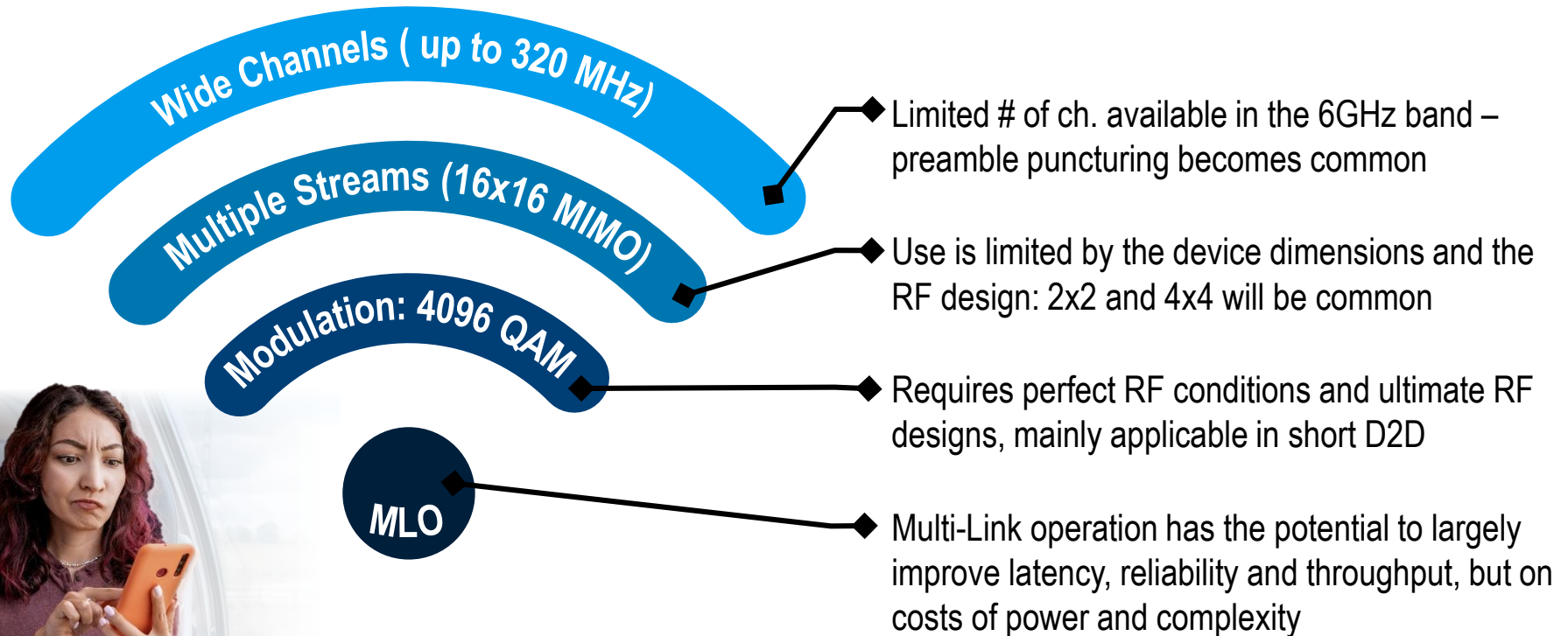
“MLO achieves lower latency and serves a higher number of XR users ...”



Wi-Fi 7 will allow multi-link operation



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



Wi-Fi test solutions for today and tomorrow

Conformance



R&S®TS8997

RF performance



R&S®CMW500/270



R&S®CMX500 OBT



R&S®CMP180



R&S®CMW100



R&S®TS7124



Make ideas real



R&S®ZNA



R&S®FSW



R&S®SMM100A



R&S®VSE

RF design and compliance



R&S®NGU



R&S®RTP

Embedded design & power



A person wearing a blue long-sleeved shirt is shown from the side, looking at a smartwatch on their left wrist. The watch has a rectangular screen displaying some data. The background is a blurred outdoor scene with a body of water and buildings.

Bluetooth

gets ready for the
future

ROHDE & SCHWARZ

Make ideas real

Bluetooth most attractive applications today & tomorrow

AUDIO STREAMING



DATA TRANSFER



LOCATION SERVICE



HOME NETWORKS



AUDIO BROADCAST



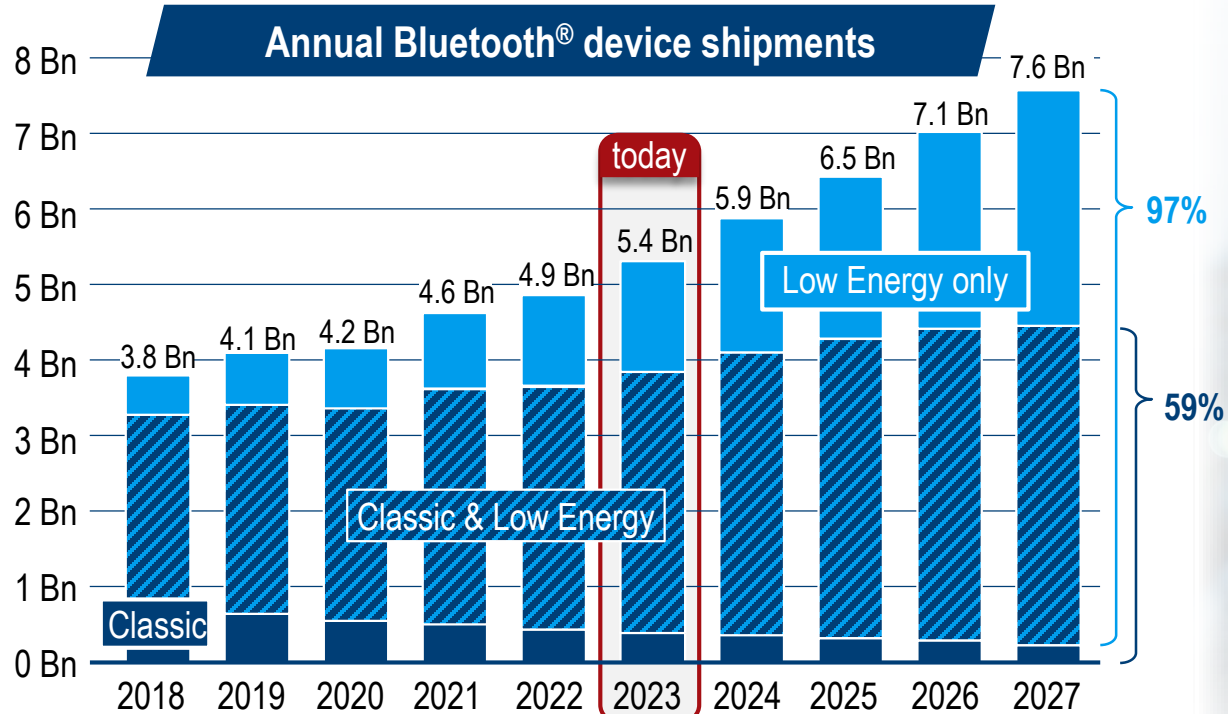
SECURE ACCESS



MASSIVE IOT



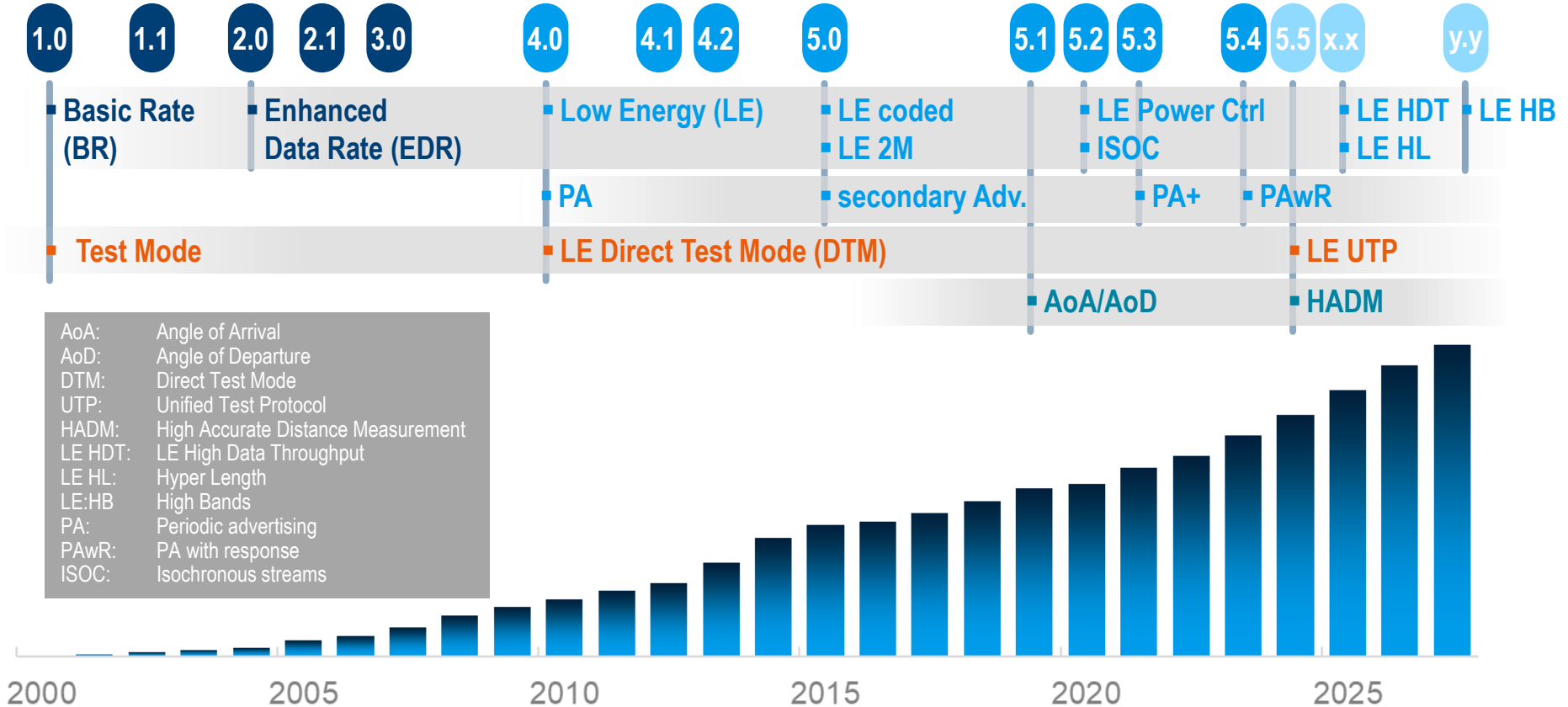
Continuous growth (9% CAGR) and move from Bluetooth® *Classic* to *Low Energy* expected for the next years



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



Bluetooth evolution (selected features over time)

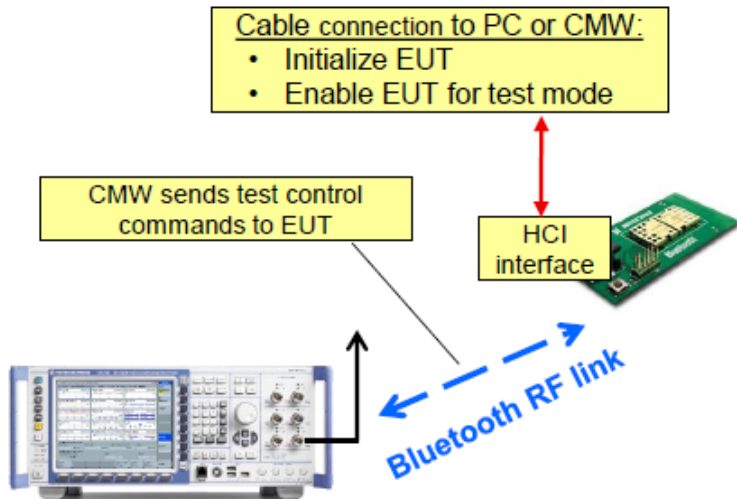


AoA: Angle of Arrival
 AoD: Angle of Departure
 DTM: Direct Test Mode
 UTP: Unified Test Protocol
 HADM: High Accurate Distance Measurement
 LE HDT: LE High Data Throughput
 LE HL: Hyper Length
 LE:HB High Bands
 PA: Periodic advertising
 PAwR: PA with response
 ISOC: Isochronous streams

Bluetooth Test Modes for RF Testing

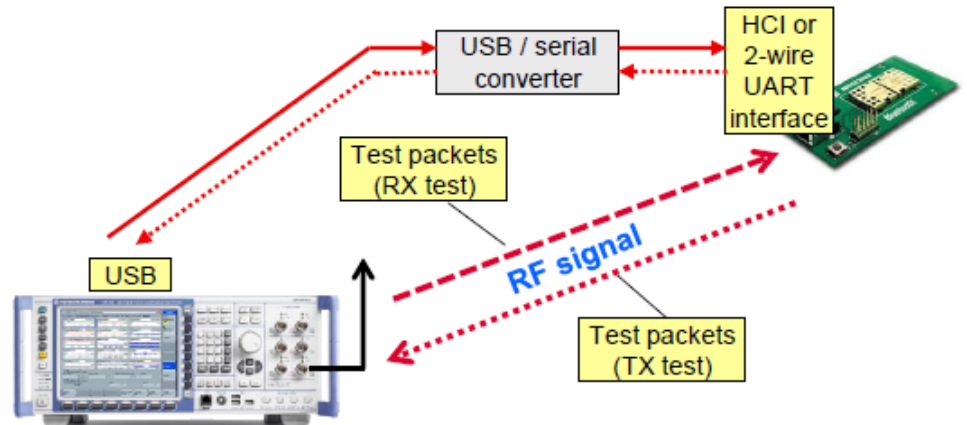
Bluetooth Classic (BR/EDR) Test Mode

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

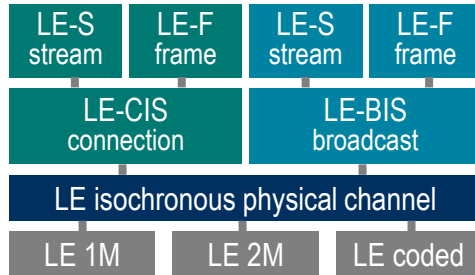


Bluetooth® 5.2: Native Bluetooth® LE audio support for several applications ...

LE isochronous channels

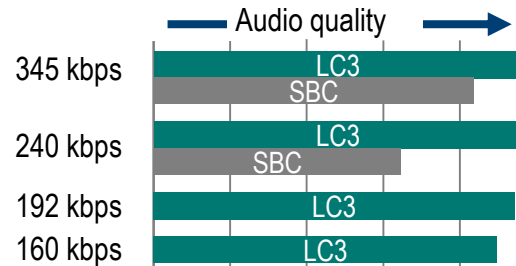
Allows communication of time-bound data to one or more devices for time-synchronized processing.

- Multi-channel audio streaming incl. hearing aids
- Audio broadcasting



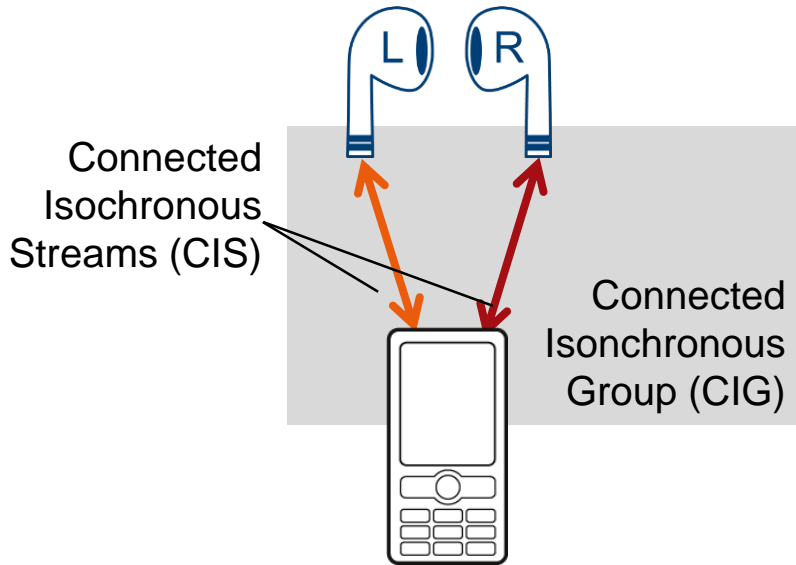
LC3 audio codec

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.

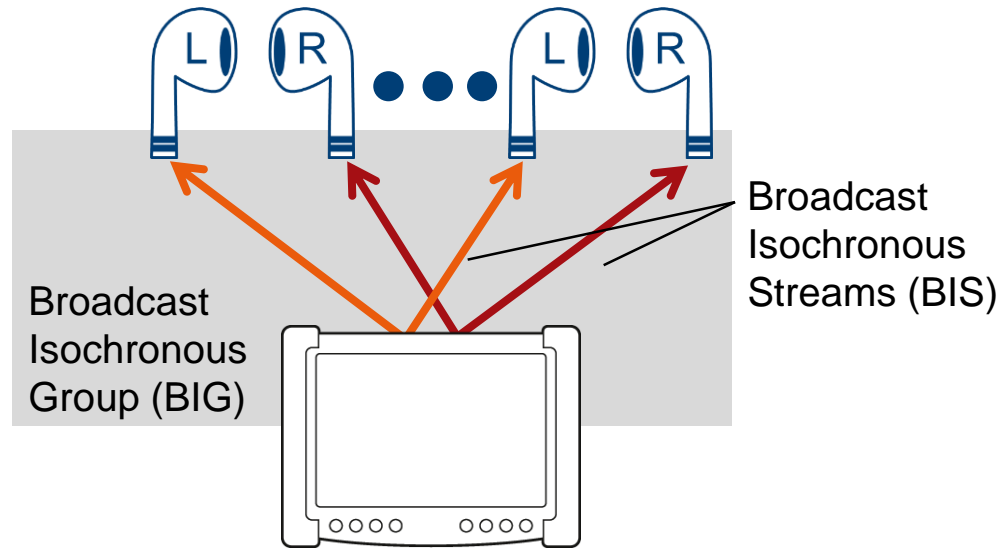


Bluetooth® 5.2: Multi-Stream Audio and Broadcast Audio Sharing

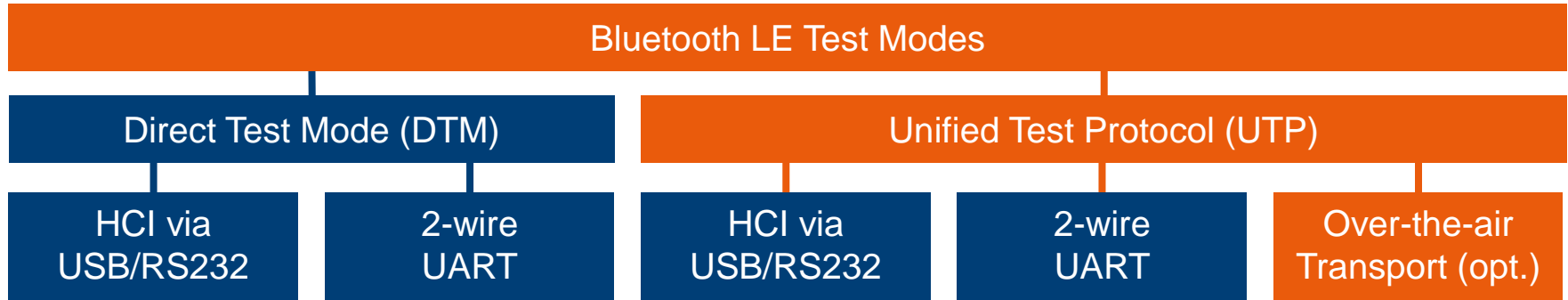
**Audio streams
to/from stereo clients**



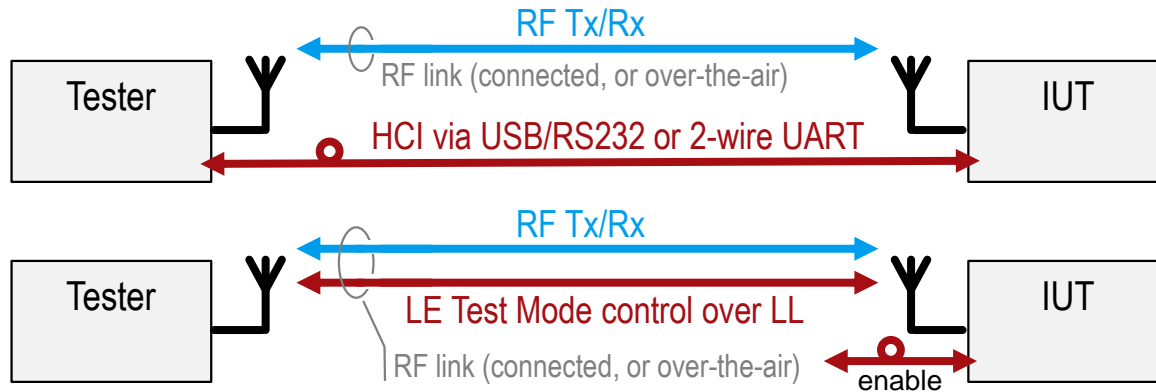
**Broadcast-oriented audio streams
to several stereo clients**



The unified test protocol as enhanced alternative to the DTM

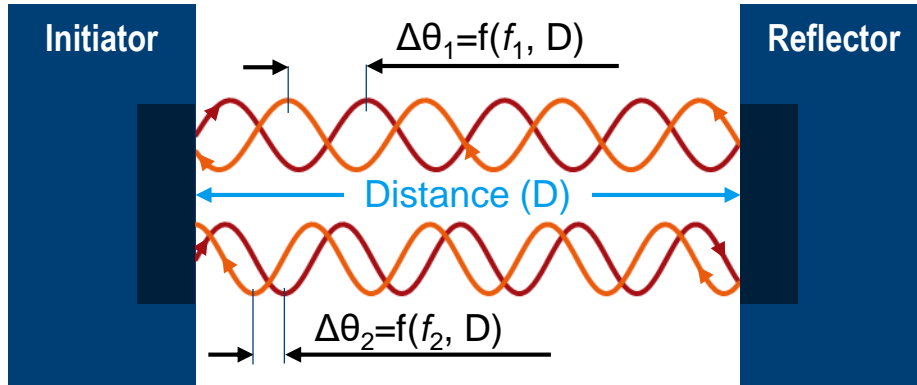


Unified Test Protocol



For OTA transport an ACL connection and LL protocol is used to exchange control messages
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 ($\Delta\theta$) 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 $\Delta\theta$

$$D_{max} = \frac{1}{2} \frac{c}{\Delta f} \left| \Delta f_{min} = 1 \text{ MHz} \right.$$

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

Bluetooth® test solutions for the product life cycle

Conformance



RF performance/Qualification



Production



RF design and compliance



Embedded design & power





THANK YOU

VERY MUCH

ROHDE & SCHWARZ

Make ideas real

