The Future of Wi-Fi: Embracing mmWave with multi-AP FTTR

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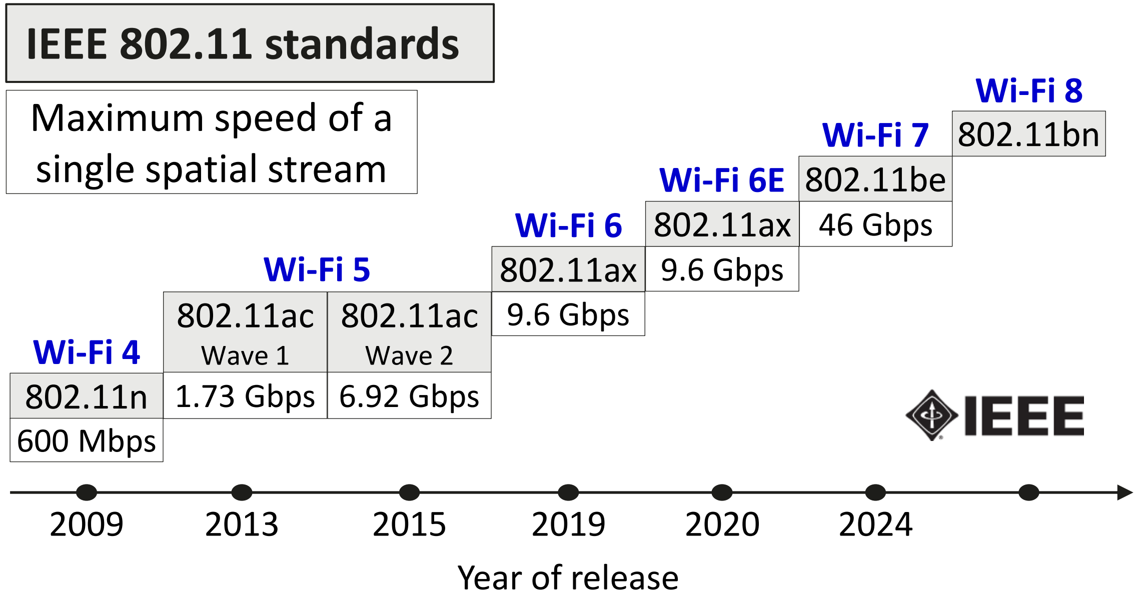
Introduction

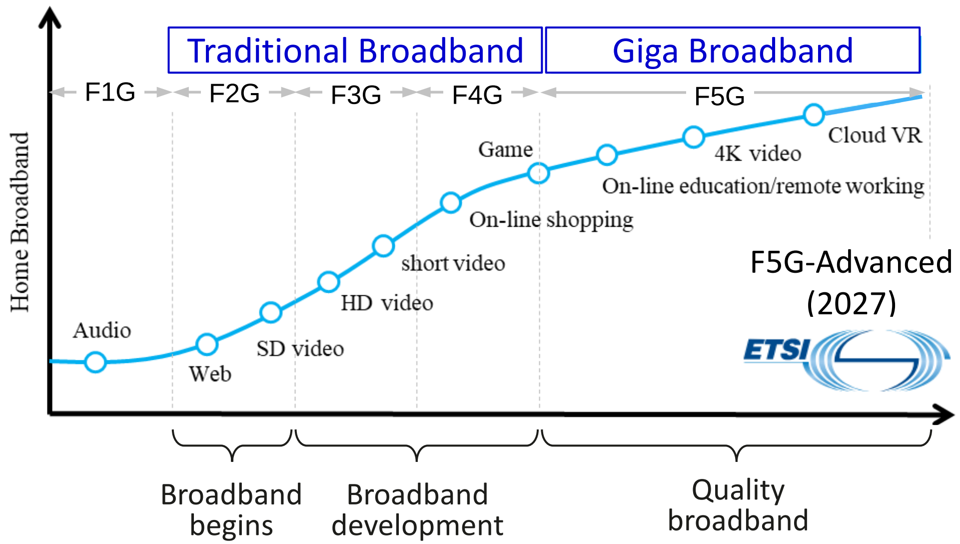
- Wi-Fi is a key technology for data communications indoors, both for residential premises and enterprises.
- As one of the top global vendors of **consumer**[1] and **enterprise**[2] **Wi-Fi equipment**, Huawei makes significant contributions to the development of Wi-Fi standards.
- Huawei is also a vendor of **4G/5G solutions**[3] for indoor data communications delivered with the highest quality of user experience.
- Here we address the current **status of Wi-Fi** and examine where we see the technology and its deployment going forward in the **next 5-10 years** to support potential new demands.

1 See https://e.huawei.com/en/products/wlan for further information on our enterprise products.
2 See https://consumer.huawei.com/en/routers/ for further information on our consumer products.

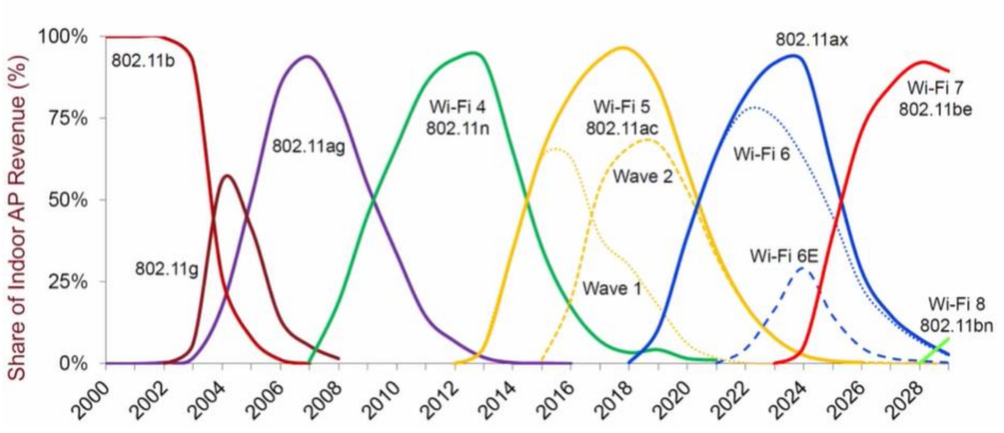
Home broadband: past and future



ETSI ISG: Fifth generation fixed network (F5G)



WLAN manufacturer's revenue by Wi-Fi generation

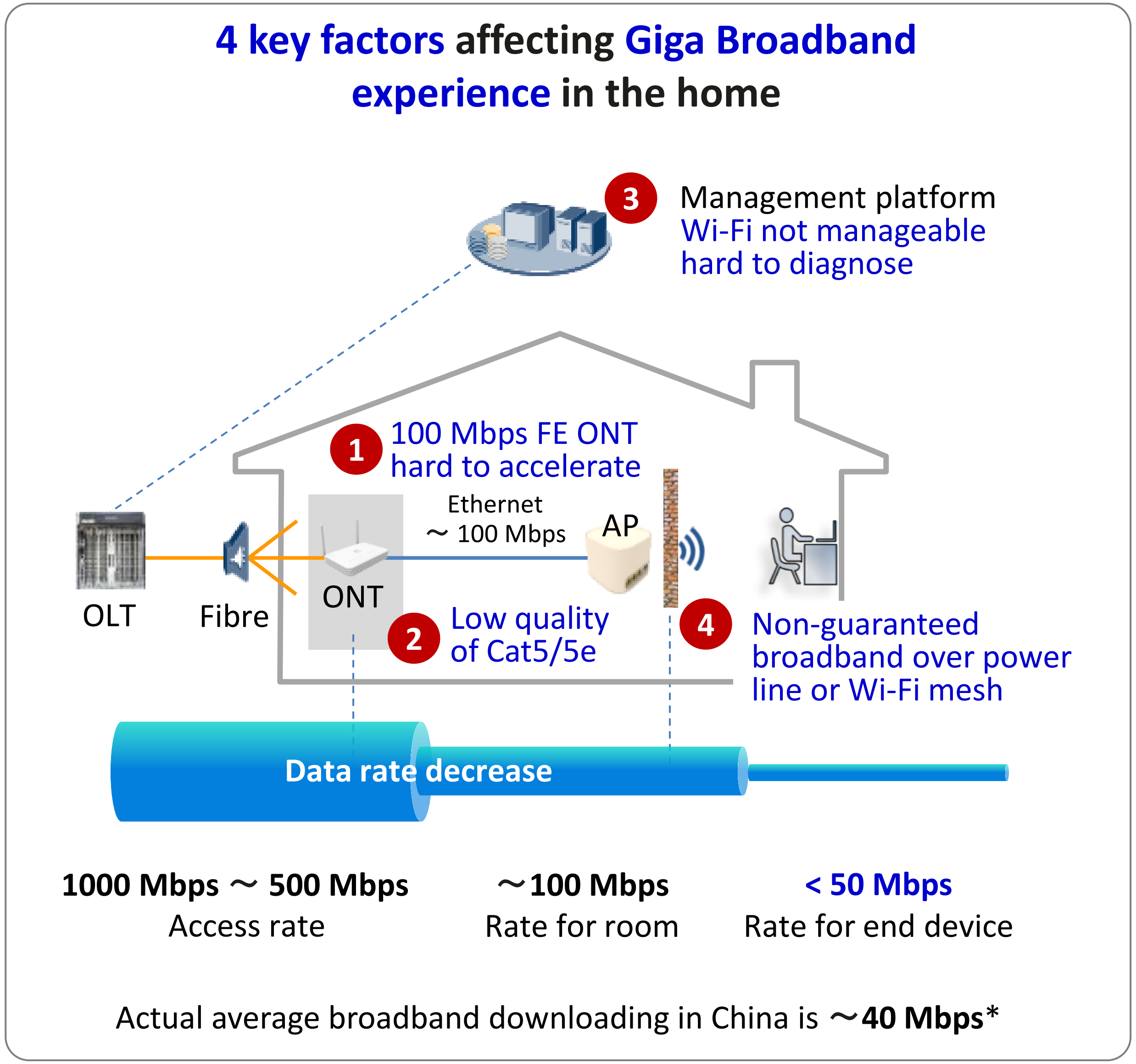


Dell'Oro Group report at Wi-Fi Now, Geneva, 2025

G-PON to XGS-PON: service, network and technology

	Past		Future
	Service: web, HD video **Network:** 100 Mbps, high latency **Technology:** GPON, Wi-Fi 5/6		**Service**: gaming, streaming, VR **Network:** Gigabit, guaranteed QoE **Technology:** 10G/50G-PON, Wi-Fi 7/8
	G-PON	**FTTR**	**XGS-PON**
Downstream:	1480～1500 nm (2.5 Gbps)	1480～1500 nm (2.5 Gbps)	1575～1580 nm (10 Gbps)
Upstream:	1290～1330 nm (1.25 Gbps)	1290～1330 nm (2.5 Gbps)	1260～1280 nm (10 Gbps)

Home broadband: pain points



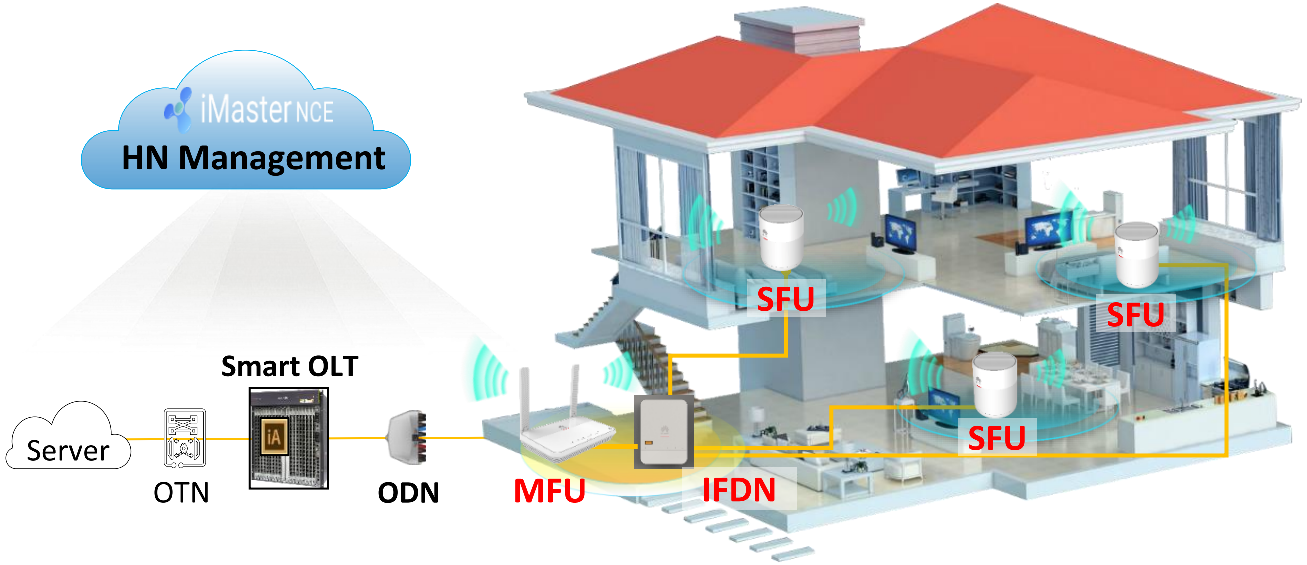
G-PON: Gigabyte Passive Optical Network
OLT: Optical Line Terminal
ONT: Optical Network Termination
AP: Wi-Fi Access Point

* Report of Broadband Development Alliance, 2020.

Enhanced Gigabit experience: FTTR (Fiber-to-the-Room)

FTTR supports **enhanced gigabit experience** in home networks

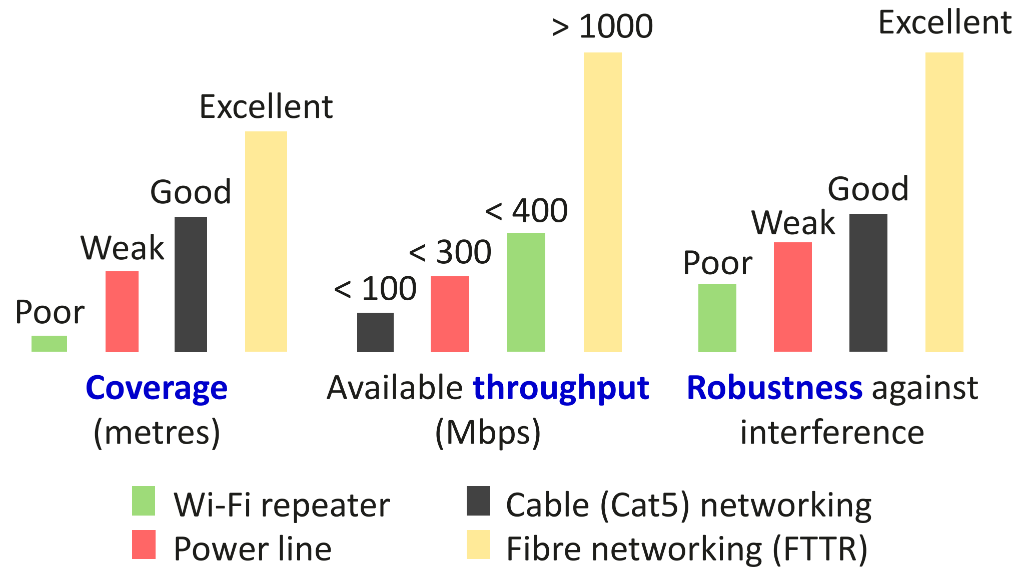
100% Wi-Fi Coverage | **> 1000 Mbps** Speed rate | **< 20 ms** Roaming | **P2MP + Passive splitter** easy-to-extend in each floor



- FTTR use cases and architecture defined in **ITU-T/SG15Q3**.
- FTTR is rapidly taking up. (**30m FTTR users** in China, **120k** FTTR units shipped outside China).
- **MFU**: Main FTTR AP, **smart** channel assignments and power management for SFUs.
- **SFUs**: Sub FTTR AP, **simpler** and less expensive than traditional APs.

Analysys Mason, "What opportunities does FTTR bring to telecoms operators?" Dec 2024.
GSMA Intelligence, "Fibre to the room (FTTR): revolutionising home and business connectivity," May 2025.

Key advantages for FTTR



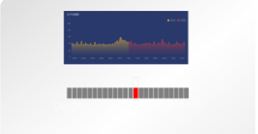
Smart home platform

200+ IoT connections

Agile deployment

20 mins installation/room

Home network management



Minute-level fault locating

FTTR for Home and **FTTR for SME** dedicated products, fibre, and architectures.

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Comtel field tests: Wi-Fi capacity

Objective:

- Assess performance of latest Wi-Fi products in the **2.4 GHz**, **5 GHz**, and **Lower 6 GHz** bands.

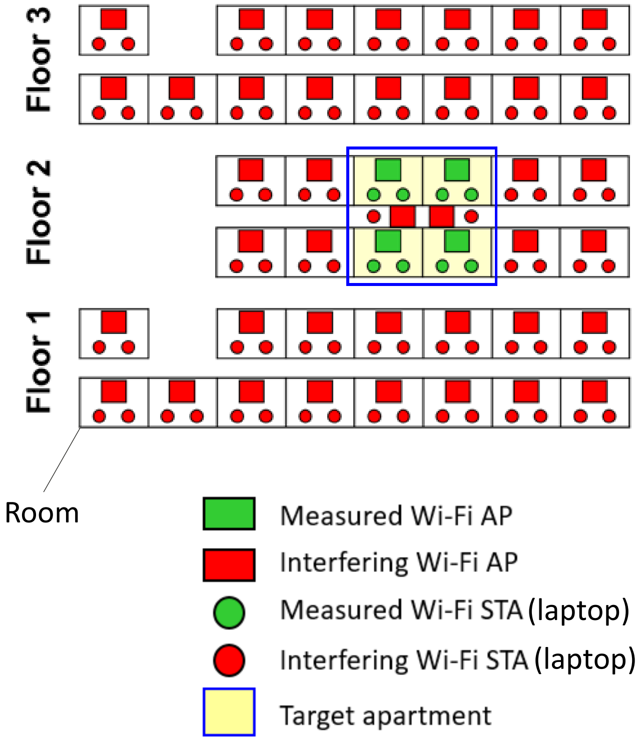
Approach:

- Tests with **42 Wi-Fi APs** and **84 clients** (laptops) across **3 floors** of a hotel.
- Replicate **isolated dwelling** and **dense urban apartment** scenarios.
- Removed any **bottlenecks** in the **fixed broadband** network behind the Wi-Fi APs.
- Generate sufficient traffic to/from each Wi-Fi laptop using all available capacity of the APs.
- Generate interference from a **high density** of **Wi-Fi APs**.

See here for summary and full report.

	5 GHz band (4 x 80 MHz) + **L6 GHz** band (3 x 160 MHz)	**Total throughput in 4-room apartment**
4-room "apartment" and **no interference** from outside the apartment	**1 AP** in a room, 2 laptops in the same room	**1.5 Gbit/s**
	4 APs (1 in each of 4 rooms), 8 laptops (2 in each of 4 rooms)	**6.3 Gbit/s**
4-room "apartment" **with interference** from 38 APs and 76 laptops in 38 other rooms	**2 APs** (1 in each of 2 rooms), 8 laptops (2 in each of 4 rooms)	**1.7 Gbit/s**
	4 APs (1 in each of 4 rooms), 8 laptops (2 in each of 4 rooms)	**4.5 Gbit/s**

NOTE: Multi-AP deployment without enhancements from FTTR.



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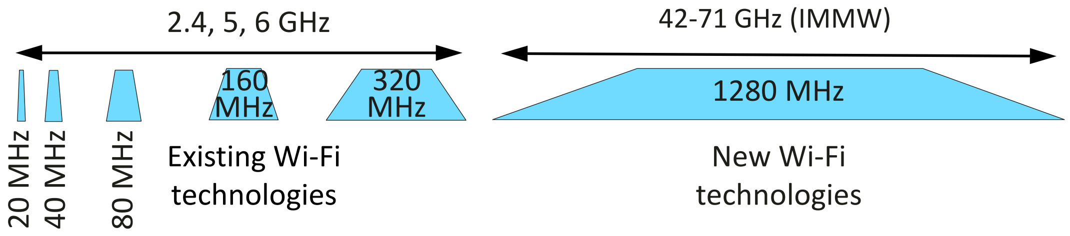
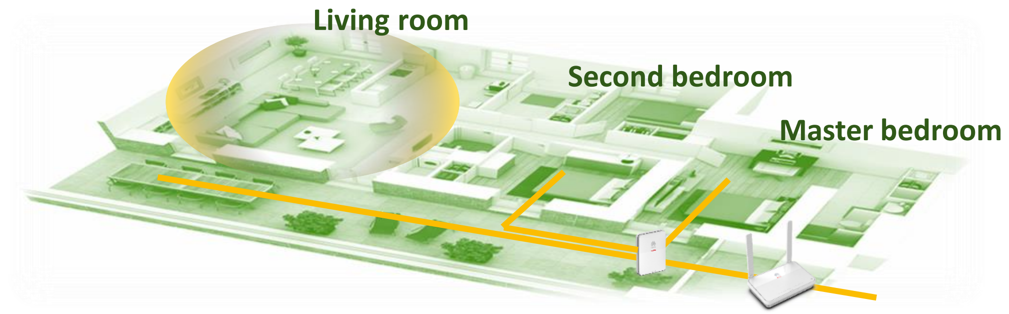
Enhancing FTTR with complementary mmW Wi-Fi

Ultra-large bandwidth: The **mmW** spectrum resources allow for a **large number** of very **wide channels**. Enabling high throughput and low latency.

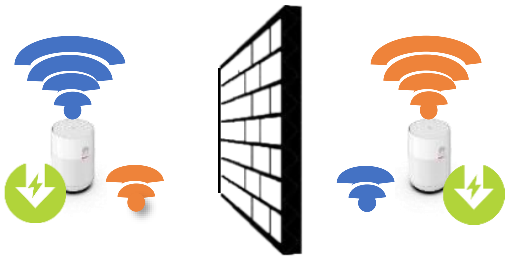




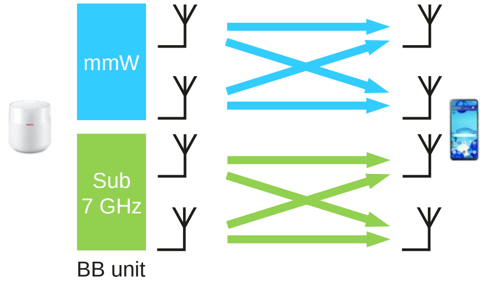
Low interference between rooms: mmW **higher wall penetration** losses are exploited to manage **spectrum-sharing** between APs in different rooms, ensuring higher privacy too.

Low latency/low congestion: wide channels minimize latency dependency on number of users. Directional antennas and full-spatial multiplexing reduce risk of collisions and interference to provide consistent **sub-ms-level latency**.

Low power consumption: when **added to FTTR,** coverage can be confined within individual rooms (LOS) allowing for **lower transmit power**, while the higher propagation loss is compensated with **higher antenna gain.**



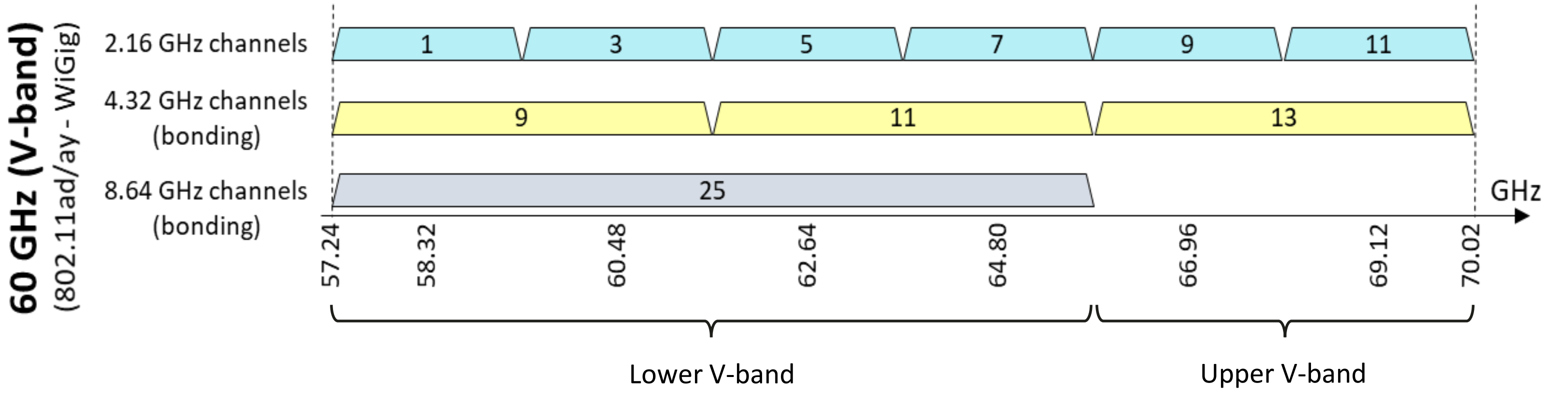
mmW Wi-Fi **reuses sub-7 GHz PHY processing capability** in a flexible way, to address mmW challenges (e.g. mobility, blockage, costs).



Wi-Fi mmWave 57-71 GHz (V-band)

Higher frequencies can play a role in addressing the increasing connectivity demand by exploiting the **larger bandwidth** availability and the **better frequency reuse**, especially for applications and use cases with limited or no mobility.

The oxygen absorption peak that happens around the 60 GHz leads to higher attenuation than in other mmWave bands. This has the effect of **limiting** the **reach** of the wanted signal, but also **reduces interference** therefore increasing the potential for spectral reuse increasing spectrum utilization. The 60 GHz millimeter wave signal cannot typically penetrate walls but can propagate by reflection from walls, ceilings.

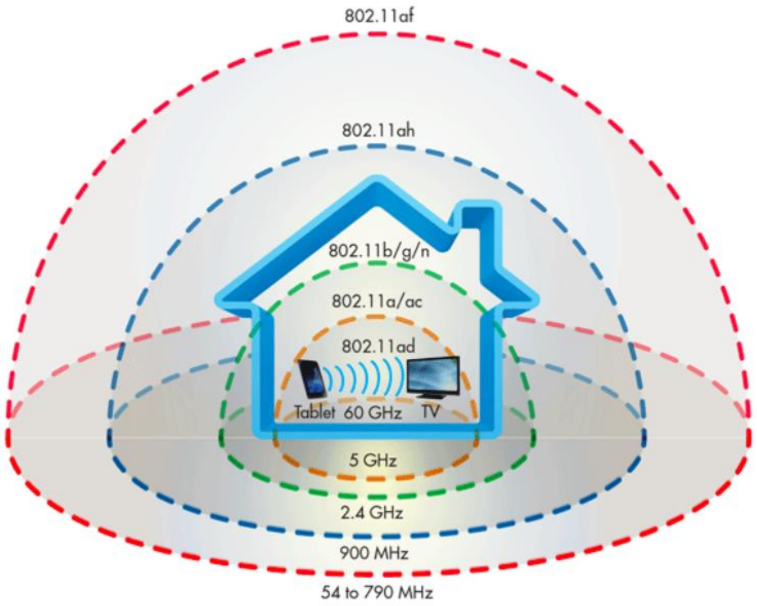


ETSI channel plan for Multiple Gigabit Wireless Systems (MGWS) at 57 - 71 GHz.

Source: ETSI TR 103 583 V1.1.1 (2019-08) "System Reference document (SRdoc);
Technical characteristics of Multiple Gigabit Wireless Systems (MGWS) in radio spectrum between 57 and 71 GHz".

IEEE 802.11ad (WiGig, 2013)

The **Wireless Gigabit** (WiGig) Alliance was formed to promote the adoption of **IEEE 802.11ad** standard addressing mmW spectrum and the 60 GHz band (**57-66 GHz**) in particular in Europe. The "ad" products are certified by Wi-Fi Alliance. IEEE 802.11ad was the first 60 GHz Wi-Fi standard introduced in **2013**. It was developed to provide a **Multiple Gigabit Wireless System** (MGWS) which leveraged on up to **six** frequency channels of **2160 MHz** bandwidth) to support multi-gigabit (up to **~7 Gbit/s** nominal speed) **short range** (1 to 10 m) wireless transmission of audio and UHD video content within offices or homes (**cable replacement**). When roaming away from 60 GHz coverage, the 802.11ad protocol can switch to make use of the other, lower bands, which can propagate through walls (with a lower data rate).

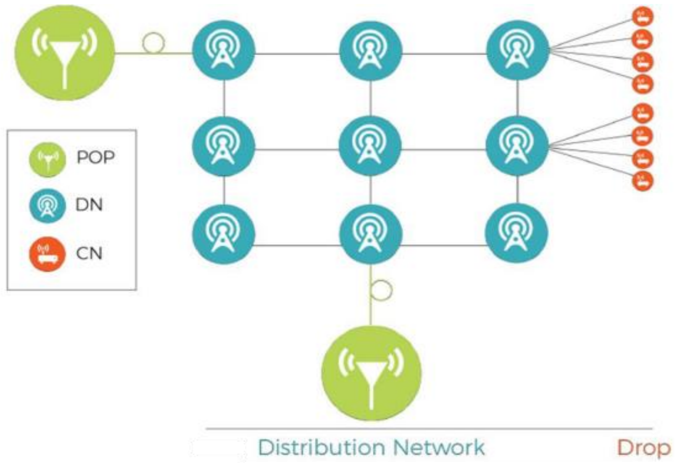


The IEEE 802.11ad target use case (source: www.60ghz-wireless.com).

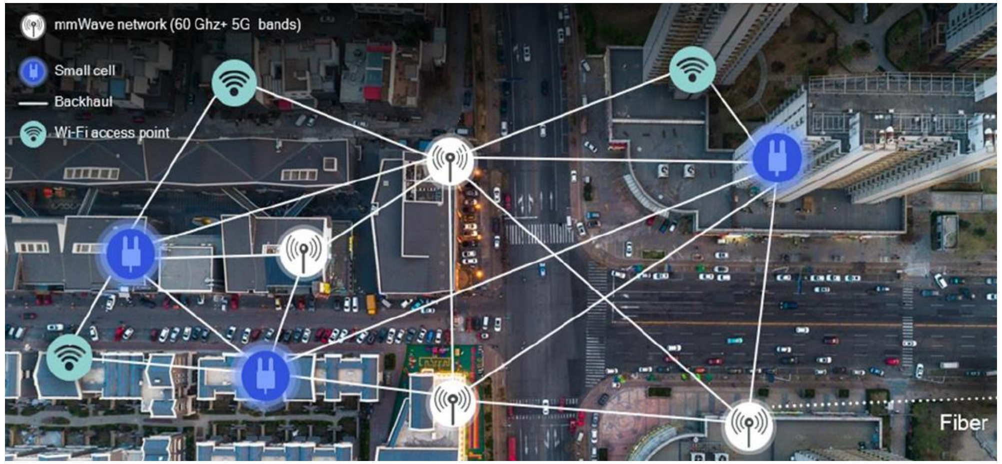
"Is 802.11ad the Ultimate Cable Replacement?". Broadband Technology Report (BTR).

IEEE 802.11ay (2021)

The **IEEE 802.11ay** standard was introduced in 2021 **superseding** the **IEEE 802.11ad** by adding a number of **new features** and capabilities. Leveraging on the same 60 GHz band, 802.11ay introduced **four times** the channel bandwidth (**8.64 GHz**), added support for phased array antennas allowing for up to **8 MIMO streams** and beamforming, added **256 QAM modulation**, changed the medium access scheme from **CSMA** to **TDMA** (deterministic channel access reducing latency and jitter), and introduced enhancements to the mesh architecture. 802.11ay operates in line of sight **LOS** conditions and uses a **mesh architecture** in which distribution nodes (DNs) are connected to each other and eventually to a fiber PoP, creating a redundant and **self-healing mesh network**. In turn, DNs connect to client nodes (CNs) which act as the customer premises equipment (CPE) in an 802.11ay network. One of the implementations of 802.11ay is **Terragraph**.



Terragraph architecture (source: TIP)



Wi-Fi and small cells backhaul with Terragraph (source: Qualcomm)

Differently from WiGig, Terragraph is **not an access technology** but a transport technology to connect homes and businesses (**FWA**), and to provide **backhaul** for small cells, Wi-Fi access points, IoT networks, and smart-city infrastructure.

IEEE 802.11bq – a new approach

The **IEEE 802.11ad** and **802.11ay** standards are **not aligned** with the other **IEEE 802.11** standards addressing the **sub-7 GHz** frequencies leading to significantly more **complex deployments**. The IEEE community is currently **re-thinking** its approach to the mmW frequencies targeting the **Multi-Link Operation (MLO)** of spectrum within the **42-71 GHz** range (focus on the license-exempt portion only) with **sub-7 GHz** frequencies.
The work on the detailed specifications has just started.

IEEE 802.11bq project was approved by IEEE in **December 2024** targeting **non-standalone Wi-Fi** operation within the **42-71 GHz** range using single-user (SU) OFDM based transmissions. The amendment requires that devices also support **at least one** of the **2.4 to 7.25 GHz** unlicensed bands to improve **NLOS operation** and connection **robustness**. 802.11bq expands the multi-link operation defined in the sub-7.25 GHz band specifications to support non-standalone operation in the unlicensed bands between 42-71 GHz. This new standard aims at addressing the more stringent requirements emerging to meet the demands of new applications (e.g. augmented and virtual reality, proximity ranging and sensing) both in terms of throughput, latency bounds and accuracy at the lowest cost to improve the QoS of Wi-Fi in the mmW bands.

2025			
May 11-16	Warsaw Presidential Hotel, Warsaw, Poland Registration open	211	Interim*
July 27 - August 1	Melia Castilla Madrid, Madrid, Spain Registration open	212	Plenary
September 14-19	Hilton Waikoloa Village, Waikoloa, Hawaii, USA	213	Interim*
November 9-14	Marriott Marquis Queen's Park, Bangkok, Thailand	214	Plenary
2026			
January 11-16	Victoria Conference Centre and Fairmont Empress, Victoria, British Columbia, Canada	215	Interim*
March 8-13	Hyatt Regency Vancouver, Vancouver, Canada	216	Plenary
May 10-15	Hilton Antwerp Old Town, Antwerp, Belgium	217	Interim*
July 12-17	Le Centre Sheraton Montreal, Montreal, Canada	218	Plenary
September 13-18	Hilton Waikoloa Village, Waikoloa, Hawaii, USA	219	Interim*
November 8-13	Marriott Marquis Queen's Park, Bangkok Thailand	220	Plenary

Agenda for the upcoming IEEE 802 sessions

https://www.ieee802.org/11/Meetings/Meeting_Plan.html

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Takeaways: Wi-Fi in the short, medium, and long term (before and after 2030)

STEP 1

- **Wi-Fi spectrum availability to meet the EU Digital Decade Policy Programme 2030 connectivity objectives for end users at a fixed location.**
  - **At least 1 Gbps delivery** within residential apartments (provided that sufficient fixed broadband capacity is delivered to the APs).
  - More efforts are needed to **extend high-capacity fibre availability** for residential users and businesses.

STEP 2

- **In the mid-term, Wi-Fi performance will be coverage-limited rather than capacity-limited. This can be effectivity addressed through installation of additional APs within residential premises, apartments and offices, facilitated by FTTR.**
  - Multi-AP coordination techniques at MAC/PHY being discussed now at **IEEE 802.11bn**.

STEP 3

- **In the long term, once additional APs are installed, new Wi-Fi 8 technologies will have the opportunity to exploit higher frequency bands to meet new demands for capacity:**
  - High bands will provide **interference-free** very high capacity within rooms.
  - Candidates are **42-71 GHz** (being discussed now at **IEEE 802.11bq**).

ANNEX

IEEE 802.11bq / ay / ad: different mmW Wi-Fi approaches

	802.11ad (WiGig)	802.11ay	802.11bq (ongoing work)
Standard ratification	2013	2021	2028? (work just started)
Frequency band	57 – 71 GHz	57 – 71 GHz	42 – 71 GHz
Channel BW	2.16 GHz	2.16 GHz, 4.32 GHz, 6.48 GHz, 8.64 GHz	TBC
Nominal speed	Up to 8 Gbit/s	Up to 30 Gbps per stream (up to 8 spatial streams)	TBC
Target use case	Access technology: multi-gigabit short range wireless transmission of audio and UHD video content within offices or homes (wireline replacement).	Transport technology: connecting homes and businesses (FWA), providing backhaul for small cells, Wi-Fi access points, IoT networks, and smart-city infrastructure	Access technology for home network residential and enterprises users. Short range applications with high performance in terms of throughput, latency, accuracy and reliability (e.g. AR, XR, proximity ranging and sensing, up to 8K video mirroring).
Range	Short range: 1 – 10 m.	Long range: 300 – 500 m.	TBC
Mesh/backhaul support	No	Yes	Yes
MIMO, beamforming support	Single streams. Beamforming.	SU-MIMO, MU-MIMO (8 streams), phased array antennas, full beam tracking.	SU OFDM based transmissions. Simple beam tracking (TBC).
Modulation	SC/OFDM and 64 QAM.	SC/OFDM and 64 QAM.	OFDM/TBC.
Access Mode	TDMA + CSMA/CA	TDMA-based+OFDMA: deterministic channel access (reducing latency and jitter) and up stream beam alignment.	Contention-based (Enhanced Distributed Channel Access) and / or TDMA (TBC).
Multi-band operation	Band switching for handoffs between 2.4, 5, 60 GHz.	Standalone: mmW only.	Non-standalone: devices to support at least one Sub-7 GHz unlicensed bands. Multi Link Operation involving both Sub-7 GHz and mmW.
Backward compatibility	Not backward compatible to 11ac and 11n.	Not backward compatible to 11ac and 11n. Enhancement of 802.11ad.	Similar to 802.11ac, ax, be, bn, etc. Reusing baseband.
Complexity	Low	Higher	Simpler: simple beam tracking (TBC), reusing the Sub-7 GHz baseband and IF, reduced output power

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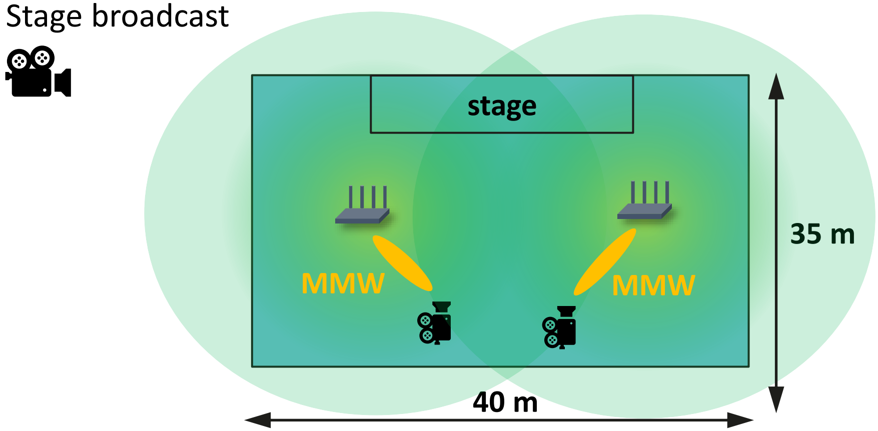
Use cases enabled by mmW Wi-Fi

Interactive VR (8K*8K)

Smooth experience without jitter

Requirements: throughout > 2.35 Gbps, delay jitter < 10 ms

Stage broadcast

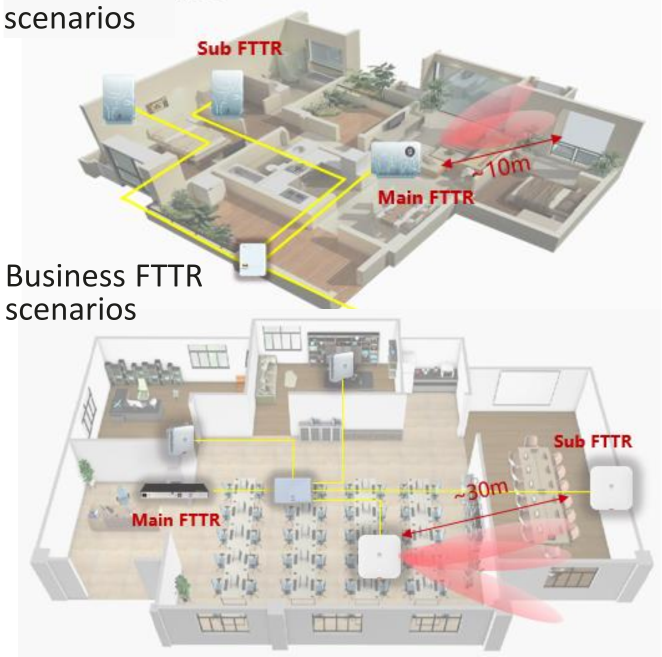


Dense spatial reuse

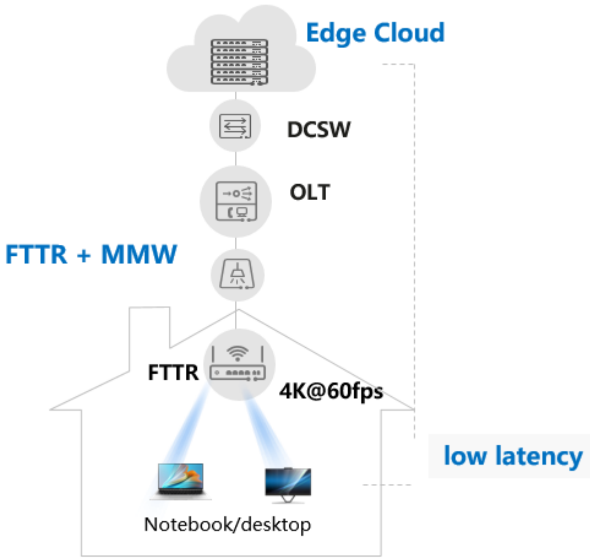
Requirements: throughput > 200 Mbps, delay jitter < 20 ms

Home FTTR scenarios

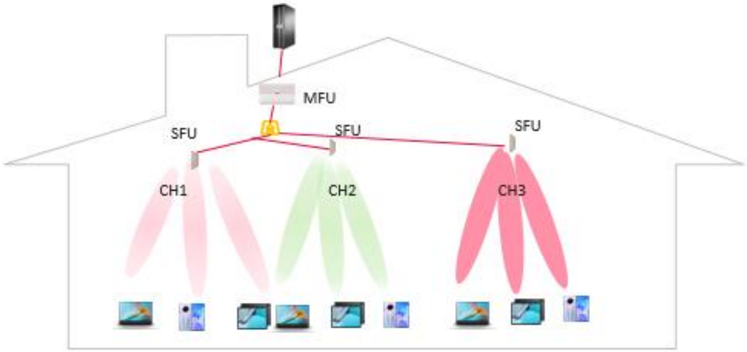
Business FTTR scenarios



Higher number of array elements and antenna gain



Ultra-high-speed GPU Cloud Desktop



Different APs use different channels to prevent EMI (even in the same room).

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