Q1) **What are the different 802.11 PHY layer standards? Compare their characteristics?**

The IEEE 802.11 standards define the PHY (Physical) layer specifications for wireless local area networks (WLANs). Below is a comparison of the key 802.11 PHY layer standards and their characteristics:

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| --- | --- | --- | --- | --- | --- | --- | --- |
| Standard | Release Year | Frequency Band | Maximum Data Rate | Modulation Scheme | Channel Bandwidth | Range (Indoor) | Key Features |
| 802.11 | 1997 | 2.4 GHz | 2 Mbps | DSSS, FHSS | 20 MHz | ~20 meters | Original standard, now obsolete. |
| 802.11a | 1999 | 5 GHz | 54 Mbps | OFDM | 20 MHz | ~35 meters | Higher speed, less interference, but shorter range than 802.11b. |
| 802.11b | 1999 | 2.4 GHz | 11 Mbps | DSSS | 20 MHz | ~35 meters | Improved range over 802.11a, but slower and more prone to interference. |
| 802.11g | 2003 | 2.4 GHz | 54 Mbps | OFDM | 20 MHz | ~38 meters | Combines speed of 802.11a with backward compatibility to 802.11b. |
| 802.11n | 2009 | 2.4/5 GHz | 600 Mbps | OFDM (MIMO) | 20/40 MHz | ~70 meters | Introduced MIMO, higher throughput, and better range. |
| 802.11ac | 2013 | 5 GHz | 6.9 Gbps | OFDM (MU-MIMO) | 80/160 MHz | ~35 meters | Wider channels, MU-MIMO, higher efficiency for high-density environments. |
| 802.11ax | 2019 (Wi-Fi 6) | 2.4/5 GHz | 9.6 Gbps | OFDMA | 20/40/80/160 MHz | ~30 meters | OFDMA, improved MU-MIMO, better performance in crowded areas. |
| 802.11be | Expected 2024 (Wi-Fi 7) | 2.4/5/6 GHz | 46 Gbps | OFDMA (Multi-Link) | Up to 320 MHz | ~30 meters | Multi-link operation, higher throughput, lower latency for advanced applications. |

* **Frequency Band**: Earlier standards (802.11, 802.11b/g) used 2.4 GHz, while later ones (802.11a/ac/ax/be) added 5 GHz and 6 GHz for less interference and higher bandwidth.
* **Data Rates**: Evolved from 2 Mbps (802.11) to multi-gigabit speeds (802.11ax/be).
* **Modulation**: Transitioned from DSSS/FHSS to OFDM and OFDMA for better spectral efficiency.
* **MIMO**: Introduced in 802.11n, enhanced with MU-MIMO in 802.11ac/ax.
* **Channel Bandwidth**: Expanded from 20 MHz to 320 MHz in Wi-Fi 7 for greater throughput.
* **Use Cases**: Later standards focus on high-density environments (e.g., 802.11ax for IoT, smart homes) and ultra-low latency (802.11be for AR/VR, 8K streaming).