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Home IEEE 802.1AE-2018/Cor 1-2020 Language: English Available Formats Options Availability Priced From (in USD) PDF Immediate download Free Download Log in to download Free Download Log in to download Customers Who Bought IEEE 802.1Qbf-2011 Priced From \$99.00 IEEE 802.1CF-2019 Priced From \$190.00 Replace Figure 9-4 with Figure 9-4 from IEEE Std 802.1AE-2006. This standard will facilitate secure communication over publicly accessible LAN/MAN media for which security has not already widespread and supported by multiple vendors, in additional applications. Corrigendum Standard - Active. How all or part of a network can be secured transparently to peer protocol entities that use the MAC Service provided by IEEE 802(R) LANs to communicate is specified in this standard. AC security (MACsec) provides connectionless user data confidentiality, data frame integrity, and data origin authenticity. IEEE GET program at Published: 07/21/2020 ISBN(s): 9781504468220 Number of Pages: 12 File Size: 1 file , 480 KB Product Code(s): STDGT24249 Note: This product is unavailable in Belarus, Russia Adding Item to Cart... Specifications for Wi-Fi wireless networks This Linksys WRT54GS Wi-Fi router operates on the 2.4 GHz "g" standard, capable of transmitting 54 Mbit/s. For comparison, this Netgear dual-band router from 2013 uses the "ac" standard, capable of transmitting 1900 Mbit/s (combined). IEEE 802 set of local area network (LAN) technical standards, and specifies the set of media access control (MAC) and physical layer (PHY) protocols for implementing wireless local area network (WLAN) computer communication. The standard and amendments provide the basis for wireless network products using the Wi-Fi brand and are the world's most widely used wireless computer networking standards. IEEE 802.11 is used in most home and office networks to allow laptops, printers, smartphones, and other devices to communicate with each other and access the Internet without connecting wires. The standards are created and maintained by the Institute of Electrical and Electronics Engineers (IEEE) LAN/MAN Standards Committee (IEEE 802). The base version of the standard was released in 1997 and has had subsequent amendments. While each amendment is officially revoked when it is incorporated in the latest version of the standard, the corporate world tends to market to the revisions because they concisely denote the capabilities of their products. As a result, in the marketplace, each revision tends to become its own standard. IEEE 802.11 uses various frequencies including, but not limited to, 2.4 GHz, 5 GHz, 6 GHz, and 60 GHz frequency bands. Although IEEE 802.11 specifications list channels that might be used, the radio frequency spectrum availability allowed varies significantly by regulatory domain. The protocols are typically used in conjunction with IEEE 802.2, and are designed to interwork seamlessly with Ethernet, and are very often used to carry Internet Protocol traffic. General description The 802.11 family consists of a series of half-duplex over-the-air modulation techniques that use the same basic protocol. The 802.11 protocol family employs carrier-sense multiple access with collision avoidance whereby equipment listens to a channel for other users (including non 802.11 users) before transmitting each frame (some use the term "packet", which may be ambiguous: "frame" is more technically correct). 802.11-1997 was the first wireless networking standard in the family, but 802.11b was the first widely accepted one, followed by 802.11a, 802.11g, 802.11n, and 802.11ac. Other standards in the family (c-f, h, j) are service amendments that are used to extend the current scope of the existing standard, which amendments may also include corrections to a previous specification.[1] 802.11b and 802.11g use the 2.4-GHz ISM band, operating in the United States under Part 15 of the U.S. Federal Communications Commission Rules and Regulations. 802.11n can also use that 2.4-GHz band. Because of this choice of frequency band, 802.11b/g/n equipment may occasionally suffer interference in the 2.4-GHz band from microwave ovens, cordless telephones, and Bluetooth devices. 802.11b and 802.11g control their interference and susceptibility to interference by using direct-sequence spread spectrum (DSSS) and orthogonal frequency-division multiplexing (OFDM) signaling methods, respectively. 802.11a uses the 5 GHz U-NII band which, for much of the world, offers at least 23 non-overlapping, 20-MHz-wide channels. This is an advantage over the 2.4-GHz, ISM-frequency band, which offers only three non-overlapping, 20-MHzwide channels where other adjacent channels overlap (see: list of WLAN channels). Better or worse performance with higher or lower frequencies (channels) may be realized, depending on the environment. 802.11n can use either the 2.4 GHz or 5 GHz band; 802.11ac uses only the 5 GHz band. The segment of the radio frequency spectrum used by 802.11 varies between countries. In the US, 802.11a and 802.11g devices may be operated without a license, as allowed in Part 15 of the FCC Rules and Regulations. Frequencies used by channels one through six of 802.11b and 802.11g fall within the 2.4 GHz amateur radio band. Licensed amateur radio operators may operate 802.11b/g devices under Part 97 of the FCC Rules and Regulations, allowing increased power output but not commercial content or encryption.[2] Generations Wi-Fi Generations Wi-Fi Generations Wi-Fi Generations (GHz)[3] Wi-Fi 7 802.11be 40000 TBA 2.4/5/6 Wi-Fi 6E 802.11ax 600 to 9608 2020 2.4/5/6 Wi-Fi 6 2019 2.4/5 Wi-Fi 5 802.11ac 433 to 6933 2014 5 Wi-Fi 4 802.11n 72 to 600 2008 2.4/5 (Wi-Fi 3\*) 802.11g 6 to 54 2003 2.4 (Wi-Fi 2\*) 802.11a 6 to 54 1999 5 (Wi-Fi 1\*) 802.11 1 to 2 1997 2.4 \*: (Wi-Fi 0, 1, 2, 3, are unbranded common usage.[4][5]) In 2018, the Wi-Fi Alliance began using a consumer-friendly generation numbering scheme for the publicly used 802.11 protocols. Wi-Fi generations 1-6 refer to the 802.11b, 802.11a, 8 1991 NCR Corporation/AT&T (now Nokia Labs and LSI Corporation) invented a precursor to 802.11 in Nieuwegein, the Netherlands. The inventors initially intended to use the technology for cashier systems. The first wireless products were brought to the market under the name WaveLAN with raw data rates of 1 Mbit/s and 2 Mbit/s. Vic Hayes, who held the chair of IEEE 802.11 for 10 years, and has been called the "father of Wi-Fi", was involved in designing the initial 802.11b and 802.11b and 802.11b and 802.11b and 802.11a standards within the IEEE.[9] He, along with Bell Labs Engineer Bruce Tuch, approached IEEE to create a standard.[10] In 1999, the Wi-Fi Alliance was formed as a trade association to hold the Wi-Fi trademark under which most products are sold.[11] The major commercial breakthrough came with Apple's adopting Wi-Fi for their iBook series of laptops in 1999. It was the first mass consumer product to offer Wi-Fi network connectivity, which was then branded by Apple as AirPort.[12][13][14] One year later IBM followed with its ThinkPad 1300 series in 2000.[15] Protocol vteIEEE 802.11 network PHY standards Frequencyrange, or type PHY Protocol Release date[16] Frequency Bandwidth Stream data rate[17] AllowableMIMO streams Modulation Approximate range[citation needed] Indoor Outdoor (GHz) (MHz) (Mbit/s) 1–6 GHz DSSS/FHSS[18] 802.11-1997 Jun 1997 2.4 22 1, 2 — DSSS, FHSS 20 m (66 ft) 100 m (330 ft) HR-DSSS[18] 802.11b Sep 1999 2.4 22 1, 2, 5.5, 11 - DSSS 35 m (115 ft) 140 m (460 ft) OFDM 802.11a Sep 1999 5 5/10/20 6, 9, 12, 18, 24, 36, 48, 54(for 20 MHz bandwidth, divide by 2 and 4 for 10 and 5 MHz) - OFDM 35 m (115 ft) 120 m (390 ft) 802.11j Nov 2004 4.9/5.0[D][19][failed verification]? 802.11p Jul 2010 5.9 ? 1,000 m (3,300 ft)[20] 802.11y Nov 2008 3.7[A] ? 5,000 m (16,000 ft)[A] ERP-OFDM 802.11g Jun 2003 2.4 38 m (125 ft) 140 m (460 ft) HT-OFDM[21] 802.11n(Wi-Fi 4) Oct 2009 2.4/5 20 Up to 288.8[B] 4 MIMO-OFDM 70 m (230 ft) 250 m (820 ft)[22][failed verification] 40 Up to 600[B] VHT-OFDM[21] 802.11ac(Wi-Fi 5) Dec 2013 5 20 Up to 346.8[B] 8 MIMO-OFDM 70 m (15 ft)[23] ? 40 Up to 800[B] 80 Up to 1733.2[B] 160 Up to 3466.8[B] HE-OFDMA 802.11ax(Wi-Fi 6) Feb 2021 2.4/5/6 20 Up to 1147[F] 8 MIMO-OFDM 30 m (98 ft) 120 m (390 ft) [G] 40 Up to 2294[F] 80 Up to 2294 OFDM, single carrier, low-power single carrier 3.3 m (11 ft)[26] ? 802.11aj Apr 2018 45/60[C] 540/1,080[27] Up to 15,000[28](15 Gbit/s) 4[29] OFDM, single carrier 10 m (33 ft) 100 m (328 ft) Sub-1 GHz IoT TVHT[32] 802.11af Feb 2014 0.054-licensed 3.7 GHz band. Increased power limits allow a range up to 5,000 m. As of 2009[update], it is only being licensed in the United States by the FCC. B1 B2 B3 B4 B5 B6 Based on short guard interval; standard guard interval is ~10% slower. Rates vary widely based on distance, obstructions, and interference. C1 For Chinese regulation. D1 For Japanese regulation. E1 Wake-up Radio (WUR) Operation. F1 F2 F3 F4 For single-user cases only, based on default guard interval which is 0.8 micro seconds. Since multi-user via OFDMA has become available for 802.11ax, these may decrease. Also, these theoretical values depend on the link distance, whether the link is line-of-sight or not, interferences and the multi-path components in the environment. G1 The default guard interval is 0.8 micro seconds. However, 802.11ax extended the maximum available guard interval to 3.2 micro seconds, in order to support Outdoor communications, where the maximum possible propagation delay is larger compared to Indoor environments. 802.11-1997 (802.11 legacy) Main article: IEEE 802.11 (legacy mode) The original version of the standard IEEE 802.11 was released in 1997 and clarified in 1999, but is now obsolete. It specified two net bit rates of 1 or 2 megabits per second (Mbit/s), plus forward error correction code. It specified three alternative physical layer technologies: diffuse infrared operating at 1 Mbit/s; frequency-hopping
spread spectrum operating at 1 Mbit/s; and direct-sequence spread spectrum operating at 1 Mbit/s; and direct-sequence spread spectrum operating at 1 Mbit/s; and direct-sequence spread spectrum operating at 1 Mbit/s; frequency-hopping spread spectrum operating at 1 Mbit/s; and direct-sequence spectrum operating lower frequencies, such as the U.S. 900 MHz ISM band. Legacy 802.11 with direct-sequence spread spectrum was rapidly supplanted and popularized by 802.11a. 1999 802.11a, published in 1999, uses the same data link layer protocol and frame format as the original standard, but an OFDM based air interface (physical layer) was added. It operates in the 5 GHz band with a maximum net data rate of 54 Mbit/s, plus error correction code, which yields realistic net achievable throughput in the mid-20 Mbit/s.[35] It has seen widespread worldwide implementation, particularly within the corporate workspace. Since the 2.4 GHz band is heavily used to the point of being crowded, using the relatively unused 5 GHz band gives 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11b/g. In theory, 802.11a is less than that of 802.11a is less than the solid objects in their solid objects in the solid objects in path due to their smaller wavelength, and, as a result, cannot penetrate as far as those of 802.11b. In practice, 802.11b typically has a higher range at low signal strengths). 802.11a also suffers from interference, [36] but locally there may be fewer signals to interfere with, resulting in less interference and better throughput. 802.11b Main article: IEEE 802.11b-1999 The 802.11b standard has a maximum raw data rate of 11 Mbit/s (Megabits per second) and uses the same media access method defined in the original standard. 802.11b products appeared on the market in early 2000, since 802.11b is a direct extension of the modulation technique defined in the original standard. The dramatic increase in throughput of 802.11b (compared to the original standard) along with simultaneous substantial price reductions led to the rapid acceptance of 802.11b as the definitive wireless LAN technology. Devices using 802.11b experience interference from other products operating in the 2.4 GHz band. Devices operating in the 2.4 GHz range include microwave ovens, Bluetooth devices, baby monitors, cordless telephones, and some amateur radio equipment. As unlicensed intentional radiators in this ISM band, they must not interfere with and must tolerate interference from primary or secondary allocations (users) of this band, such as amateur radio. 802.11g Main article: IEEE 802.11g-2003 In June 2003, a third modulation standard was ratified: 802.11g. This works in the 2.4 GHz band (like 802.11b), but uses the same OFDM based transmission scheme as 802.11a. It operates at a maximum physical layer bit rate of 54 Mbit/s exclusive of forward error correction codes, or about 22 Mbit/s average throughput.[37] 802.11g hardware is fully backward compatible with 802.11b hardware, and therefore is encumbered with legacy issues that reduce throughput by ~21% when compared to 802.11a.[38] The then-proposed 802.11g standard was rapidly adopted in the market starting in January 2003, well before ratification, due to the desire for higher data rates as well as reductions in manufacturing costs.[citation needed] By summer 2003, most dual-band/tri-mode, supporting a and b/g in a single mobile adapter card or access point. Details of making b and g work well together occupied much of the lingering technical process; in an 802.11g network, however, the activity of an 802.11b participant will reduce the data rate of the overall 802.11g network. Like 802.11b, 802.11g network. Like 802.11b, 802.11g network. Like 802.11b, 802.11g network. Like 802.11b, 802.11g network are of the overall 802.11g network. Like 802.11b, 802.11g network are of the overall 802.11g network. Like 802.11b, 802.11g network are of the overall 802.11g network. Like 802.11b, 802.11g network are of the overall 802.11g network. Like 802.11b, 802.11g network are of the overall 802.11g network are of the overall 802.11g network. Like 802.11b, 802.11g network are of the overall 802.11g network. Like 802.11b, 802.11g network are of the overall 802.1 of the amendments to the 1999 version of the 802.11 standard. REVma or 802.11ma, as it was called, created a single document that merged 8 amendments (802.11a, b, d, e, g, h, i, j) with the base standard. Upon approval on 8 March 2007, 802.11REVma was renamed to the then-current base standard. IEEE 802.11n-2009 802.11n is an amendment that improves upon the previous 802.11 standards; its first draft of certification was published in 2006. The 802.11n standard was retroactively labelled as Wi-Fi Alliance.[40][41] The standard added support for multiple-output antennas (MIMO). 802.11n operates on both the 2.4 GHz and the 5 GHz bands. Support for 5 GHz bands is optional. Its net data rate ranges from 54 Mbit/s to 600 Mbit/s. The IEEE has approved the amendment, and it was published in October 2009.[42][43] Prior to the final ratification, enterprises were already migrating to 802.11n networks based on the Wi-Fi Alliance's certification of products conforming to a 2007 draft of the 802.11n proposal. 802.11n proposal. 802.11k, r, y, n, w, p, z, v, u, s) with the 2007 base standard. In addition much cleanup was done, including a reordering of many of the clauses.[45] Upon publication on 29 March 2012, the new standard was referred to as IEEE 802.11ac Main article: IEE 802.11ac standard was retroactively labelled as Wi-Fi 5 by the Wi-Fi Alliance.[40][41] Changes compared to 802.11n include wider channels (80 or 160 MHz) in the 5 GHz band, more spatial streams (up to eight versus four), higher-order modulation (up to 256-QAM vs. 64-QAM), and the addition of Multi-user MIMO (MU-MIMO). The Wi-Fi Alliance separated the introduction of ac wireless products into two phases ("waves"), named "Wave 1" and "Wave 2".[47][48] From mid-2013, the alliance started certifying Wave 1 802.11ac Draft 3.0 (the IEEE standard was not finalized until later that year).[49] In 2016 Wi-Fi Alliance introduced the Wave 2 certification, to provide higher bandwidth and capacity than Wave 1 products. Wave 2 products include additional features like MU-MIMO, 160 MHz channel width support, support for more 5 GHz channels, and four spatial streams (with four antennas; compared to three in Wave 1 and 802.11n, and eight in IEEE's 802.11ax specification).[50][51] 802.11ad This section needs to be updated. Please help update this article to reflect recent events or newly available information. (November 2013) Main article: IEEE 802.11ad IEEE 802.11ad is an amendment that defines a new physical layer for 802.11 ad This section needs to be updated. This frequency band has significantly different propagation characteristics than the 2.4 GHz and 5 GHz bands where Wi-Fi networks operate. Products implementing the 802.11ad standard are being brought to market under the WiGig brand name. The certification program is now being developed by the Wi-Fi Alliance instead of the now defunct Wireless Gigabit Alliance.[52] The peak transmission rate of 802.11ad is 7 Gbit/s.[53] IEEE 802.11ad is a protocol used for very high data rates (about 1-10 meters).[54] TP-Link announced the world's first 802.11ad router in January 2016.[55] The WiGig standard is not too well known, although it was announced in 2009 and added to the IEEE 802.11 family in December 2012. 802.11 af Main article: IEEE 802.11 af Main article: IEEE 802.11 af IEEE 802.11 [58] It uses cognitive radio technology to transmit on unused TV channels, with the standard taking measures to limit interference for primary users, such as analog TV, digital TV, and wireless microphones.[58] Access points and stations determine their position using a satellite positioning system such as GPS, and use the Internet to query a geolocation database (GDB) provided by a regional regulatory agency to discover what frequency channels are available for use at a given time and position.[58] The physical layer uses OFDM and is based on 802.11ac.[59] The propagation path loss as well as the attenuation by materials such as brick and concrete is lower in the UHF and VHF bands than in the 2.4 GHz and 5 GHz bands, which increases the possible range.[58] The frequency channels are 6 to 8 MHz wide, depending on the regulatory domain.[58] Up to four channels may be bonded in either one or two contiguous blocks.[58] MIMO operation is possible with up to four streams used for either space-time block code (STBC) or multi-user (MU) operation.[58] The achievable data rate per spatial stream is 26.7 Mbit/s for 6 and 7 MHz channels.[33] With four spatial streams and four bonded channels.[33] With four spatial stre which was known as IEEE 802.11 REVmc, [60] is a revision based on IEEE 802.11-2012, incorporating 5 amendments (11ae, 11ad, 11ac, 11af). In addition, existing MAC and PHY functions have been renumbered. [61] 802.11ah Main article: IEEE 802.11ah IEEE 802.11ah IEEE 802.11ah, published in 2017,[62] defines a WLAN system operating at sub-1 GHz license-exempt bands. Due to the favorable propagation characteristics of the low frequency spectra, 802.11ah can provide improved transmission range
compared with the conventional 802.11 WLANs operating in the 2.4 GHz and 5 GHz bands. 802.11ah can be used for various purposes including large scale sensor networks, [63] extended range hotspot, and outdoor Wi-Fi for cellular traffic offloading, whereas the available bandwidth is relatively narrow. The protocol intends consumption to be competitive with low power Bluetooth, at a much wider range. [64] 802.11ai Main article: IEEE 802.11ai IEEE 802.11ai is an amendment to the 802.11 standard that added new mechanisms for a faster initial link setup time.[65] 802.11aj IEEE 802.11aj is a derivative of 802.11aj is network.[65] 802.11-2020 IEEE 802.11-2020, which was known as IEEE 802.11 REVmd,[66] is a revision based on IEEE 802.11-2016 incorporating 5 amendments (11ai, 11ah, 11aj, 11ak, 11aq). In addition, existing MAC and PHY functions have been enhanced and obsolete features were removed or marked for removal. Some clauses and annexes have been added.[67] 802.11ax Main article: IEEE 802.11ax is the successor to 802.11ac, marketed as Wi-Fi 6 (2.4 GHz and 5 GHz)[68] and Wi-Fi 6 (2.4 GHz and 5 GHz)[68] and Wi-Fi 6 (2.4 GHz and 5 GHz)[69] by the Wi-Fi Alliance. It is also known as High Efficiency Wi-Fi, for the overall improvements to Wi-Fi 6 (2.4 GHz and 5 GHz)[68] and Wi-Fi 6 (2.4 GHz maximum improvement in data rate (PHY speed) against the predecessor (802.11ac) is only 39%[a] (for comparison, this improvement was nearly 500%[b] for the predecessors).[c] Yet, even with this comparatively minor 39% figure, the goal was to provide 4 times the throughput-per-area[d] of 802.11ac (hence High Efficiency). The motivation behind this goal was the deployment of WLAN in dense environments such as corporate offices, shopping malls and dense residential apartments.[70] This is achieved by means of a technique called OFDMA, which is basically multiplexing in the frequency domain (as opposed to spatial multiplexing, as in 802.11ac). This is equivalent to cellular technology applied into Wi-Fi.[70]:qt The IEEE 802.11ax-2021 standard was approved on February 9, 2021.[73][74] 802.11ay Main article: IEEE 802.11ay This section needs to be updated. Please help update this article to reflect recent events or newly available information. (March 2015) IEEE 802.11ay This section needs to be updated. Please help update this article to reflect recent events or newly available information. (March 2015) IEEE 802.11ay This section needs to be updated. Please help update this article to reflect recent events or newly available information. Enhanced Directional MultiGigabit PHY. It is an amendment that defines a new physical layer for 802.11 networks to operate in the 60 GHz millimeter wave spectrum. It will be an extension of the existing 11ad, aimed to extend the throughput, range, and use-cases. The main use-cases include indoor operation and short-range communications due to atmospheric oxygen absorption and inability to penetrate walls. The peak transmission rate of 802.11ay is 40 Gbit/s.[75] The main extensions include: channel bonding (2, 3 and 4), MIMO (up to 4 streams) and higher modulation schemes. The expected range is 300-500 m.[76] 802.11ba IEEE 802.11ba Wake-up Radio (WUR) Operation is an amendment to the IEEE 802.11 standard that enables energy efficient operation for data reception without increasing latency.[77] The target active power consumption to receive a WUR packet is less than 1 milliwatt and supports data rates of 62.5 kbit/s and 250 kbit/s. The WUR PHY uses MC-OOK (multicarrier OOK) to achieve extremely low power consumption.[78] 802.11be Main article: IEEE 802.11be IEEE 802.11be Extremely High Throughput (EHT) is the potential next amendment to the 802.11 IEEE standard,[79] and will likely be designated as Wi-Fi 7.[80][81] It will build upon 802.11ax, focusing on WLAN indoor and outdoor operation with stationary and pedestrian speeds in the 2.4 GHz, 5 GHz, and 6 GHz frequency bands. Common misunderstandings about achievable throughput Graphical representation of Wi-Fi applications of 802.11, maximum achievable throughputs are given either based on measurements unde ideal conditions or in the layer-2 data rates. However, this does not apply to typical deployments in which data is being transferred between two endpoint is connected to an infrastructure via a wireless link. Graphical representation of Wi-Fi application specific (UDP) performance envelope 2.4 GHz band, with 802.11n with 40MHz This means that, typically, data frames pass an 802.11 (WLAN) medium and are being converted to 802.3 (Ethernet) or vice versa. Due to the difference in the frame (header) lengths of these two media, the application's packet size determines the speed of the data transfer. This means applications that use small packets (e.g., VoIP) create dataflows with high-overhead traffic (i.e., a low goodput). Other factors that contribute to the overall application data rate are the speed with which the application data rate are the speed with which the application transmits the packets (i.e., the data rate) and, of course, the energy with which the wireless signal is received. The latter is determined by distance and by the configured output power of the communicating devices.[82][83] The same references apply to the attached graphs that show measurements of UDP throughput. Each represents an average (UDP) throughput the attached graphs that show measurements of UDP throughput the attached graphs that show measurements of UDP throughput (please note that the error bars are there but barely visible due to the small variation) of 25 measurements of UDP throughput. measurements. Each is with a specific packet size (small or large) and with a specific data rate (10 kbit/s). Markers for traffic profiles of common applications are included as well. These figures assume there are no packet errors, which, if occurring, will lower the transmission rate further. Channels and frequencies See also: List of WLAN channels 802.11b, 802.11g, and 802.11n-2.4 utilize the 2.400-2.500 GHz spectrum, one of the ISM bands. 802.11a, 802 frequency and bandwidth, analogous to how radio and TV broadcast bands are sub-divided. The 2.4 GHz band is divided into 14 channels have additional restrictions or are unavailable for use in some regulatory domains. Graphical representation of Wi-Fi channels in the 2.4 GHz band The channel numbering of the 5.725-5.875 GHz spectrum is less intuitive due to the differences in regulations between countries. These are discussed in greater detail on the list of WLAN channels. Channel spacing within the 2.4 GHz band In addition to specifying the channel center frequency, 802.11 also specifies (in Clause 17) a spectral mask defining the permitted power distribution across each channel. The mask requires the signal to be attenuated a minimum of 20 dB from its peak amplitude at ±11 MHz from the center frequency, the point at which a channel is effectively 22 MHz wide. One consequence is that stations can use only every fourth or fifth channel without overlap. Availability of channels is regulated by country, constrained in part by how each country allocates radio spectrum to various services. At one extreme, Japan permits the use of all 14 channels for 802.11g/n-2.4. Other countries such as Spain initially allowed only channels 10 and 11, and France allowed only 10, 11, 12, and 13; however, Europe now allow channels 1 through 13.[84][85] North America and some Central and South America and some Central and South America and some Central masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for 802.11g channels 1–14 in the 2.4 GHz band Since the spectral masks for to be attenuated by -50 dBr, it is often assumed that the energy of the channel extends no further than these limits. It is more correct to say that the overlapping signal on any other channels. Due to the near-far problem a transmitter can impact (desensitize) a receiver on a "non-overlapping" channel, but only if it is close to the victim receiver (within a meter) or operating above allowed power levels. Conversely, a sufficiently distant transmitter on an overlapping channel can have little to no significant effect. Confusion often arises over the amount of channel separation required
between transmitting devices. 802.11b was based on direct-sequence spread spectrum (DSSS) modulation and utilized a channel bandwidth of 20 MHz. This occasionally leads to the belief that four "non-overlapping" channels (1, 5, 9, and 13) exist under 802.11g. However, this is not the case as per 17.4.6.3 Channel Numbering of operating channels (1, 5, 9, and 13) exist under 802.11g. However, this is not the case as per 17.4.6.3 Channel Numbering of operating channels (1, 5, 9, and 13) exist under 802.11g. However, this is not the case as per 17.4.6.3 Channel Numbering of operating channels (1, 5, 9, and 13) exist under 802.11g. However, this is not the case as per 17.4.6.3 Channel Numbering of operating channels (1, 5, 9, and 13) exist under 802.11g. However, this is not the case as per 17.4.6.3 Channel Numbering of operating channels (1, 5, 9, and 13) exist under 802.11g. 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However, this is not the case as per 17.4.6.3 Channel Numbering of operating channels (1, 5, 9, and 13) exist under 802.11g. However, this is not the case as per 17.4.6.3 Channel Numbering of operating channels (1, 5, 9, and 13) exist under 802.11g. However, this is not the case as per 17.4.6.3 Channel Numbering (1, 5, 9, and 13) exist interference if the distance between the center frequencies is at least 25 MHz."[86] and section 18.3.9.3 and Figure 18-13. This does not mean that the technical overlapping channels recommends the non-use of overlapping channels. The amount of inter-channel interference seen on a configuration using channels 1, 5, 9, and 13 (which is permitted in Europe, but not in North America) is barely different from a three-channel configuration, but with an entire extra channel.[87][88] 802.11 non-overlapping channels for 2.4GHz. Covers 802.11b,g,n However, overlap between channel.[87][88] 802.11 non-overlapping channels with more narrow spacing (e.g. 1, 4, 7, 11 in North America) may cause unacceptable degradation of signal quality and throughput, particularly when users transmit near the boundaries of AP cells.[89] Regulatory domains and legal compliance IEEE uses the phrase regdomain to refer to a legal regulatory domains and legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal compliance IEEE uses the phrase regdomain to refer to a legal complex. Domain codes are specified for the United States, Canada, ETSI (Europe), Spain, France, Japan, and China. Most Wi-Fi certified devices default to regdomain 0, which means least common denominator settings, i.e., the device will not transmit at a power above the allowable power in any nation, nor will it use frequencies that are not permitted in any nation.[citation needed] The regulatory agencies such as the United States' Federal Communications Commission.[citation needed] Layer 2 - Datagrams The datagrams are called frames. Current 802.11 standards specify frame types for use in the transmission of data as well as management and control of wireless links. Frames are divided into very specific and standardized sections. Each frame consists of a MAC header, payload, and frame check sequence (FCS). Some frames may not have a payload. Field Frame control Duration, id. Address 1 Address 3 Sequence control Address 4 QoS control HT control Frame body Frame check sequence Length (Bytes) 2 2 6 6 6 0, or 2 6 0, or 2 6 0, or 2 6 0, or 2 0, or 4 Variable 4 The first two bytes of the MAC header form and function of the frame. This frame control field is subdivided into the following sub-fields: Protocol Version: Two bits representing the protocol version. The currently used protocol version is zero. Other values are reserved for future use. Type: Two bits identifying the type of WLAN frame. Control, Data, and Management are various frame types defined in IEEE 802.11. Subtype: Four bits providing additional discrimination between frames. Type and Subtype are used together to identify the exact frame. ToDS and FromDS: Each is one bit in size. They indicate whether a data frame is headed for a distribution system. Control and management frames set these bits set. However, communication within an independent basic service set (IBSS) network always sets these bits set. to zero. More Fragments: The More Fragments bit is set when a packet is divided into multiple frames for transmission. Every frame except the last frame of a packet will have this bit set. Retry: Sometimes frames require retransmission, and for this, there is a Retry bit that is set to one when a frame is resent. This aids in the elimination of duplicate frames. Power Management: This bit indicates the power management state of the sender after the completion of a frame exchange. Access point uses this bit to facilitate stations in power-saver mode. It indicates that at least one frame is available and addresses all stations connected Access (WPA), or Wi-Fi Protected Access (WPA), or Wi-Fi Protected Access II stations connected. (WPA2). Order: This bit is set only when the "strict ordering" delivery method is employed. Frames and fragments are not always sent in order as it causes a transmission performance penalty. The next two bytes are reserved for the Duration ID field, indicating how long the field's transmission will take so other devices know when the channel will be available again. This field can take one of three forms: Duration, Contention-Free Period (CFP), and Association ID (AID). An 802.11 frame can have up to four address 1 is the receiver, Address 1 is the receiver. is only present in data frames transmitted between access points in an Extended Service Set or between intermediate nodes in a mesh network. The remaining fields of the header are: The Sequence Control field is a two-byte section used to identify message order and eliminate duplicate frames. The first 4 bits are used for the fragmentation number and the last 12 bits are the sequence number. An optional two-byte Quality of Service control field, present in QoS Data frames; it was added with 802.11e. The payload or frame body field is variable in size, from 0 to 2304 bytes plus any overhead from security encapsulation, and contains information from higher layers. The Frame Check Sequence (FCS) is the last four bytes in the standard 802.11 frame. Often referred to as the Cyclic Redundancy Check (CRC), it allows for integrity checks of retrieved frames. As frames are about to be sent, the FCS is calculated and appended. When a station receives a frame, it can calculate the FCS of the frame and compare it to the one received. If they match, it is assumed that the frame was not discorted during transmission.[91] Management frames are not always authentication frame: 802.11 authentication frame: 802.11 authentication frame: 802.11 authentication frames are not always authenticated, and allow for the maintenance, or discontinuance, or discontinuance frames are not always authenticated. card (WNIC) sending an authentication frame to the access point containing its identity. When open system authentication is being used, the WNIC sends only a single authentication frame, and the access point responds with an authentication frame of its own indicating acceptance or rejection. When shared key authentication is being used, the WNIC sends an initial authentication request, and the access point responds with an authentication frame containing the encrypted version of the challenge text to the access point. The access point responds with an authentication frame containing the encrypted version of the challenge text to the access point. own key. The result of this process determines the WNIC's authentication status. Association request frame: Sent from a station, it enables the access point to allocate resources and synchronize. The frame carries information about the WNIC, including supported data rates and the SSID of the network the station wishes to associate with. If the request is accepted, the acceptance or rejection to a station containing the acceptance or rejection to an association ID
for the WNIC. Association request. If it is an acceptance, the frame will contain information such as an association ID and supported data rates. Beacon frame: Sent periodically from an access point to announce its presence and provide the SSID, and other parameters for WNICs within range. Deauthentication frame: Sent from a station wishing to terminate connection. It is an elegant way to allow the access point to relinquish memory allocation and remove the WNIC from the association table. Probe request frame: Sent from a station when it requires information, supported data rates, etc., after receiving a probe request frame. Reassociation request frame: A WNIC sends a reassociation request when it drops from the currently associated access point range and finds another access point coordinates the forwarding of any information that may still be contained in the buffer of the previous access point. Reassociation response frame: Sent from an access point containing the acceptance or rejection to a WNIC reassociation required for association such as the association such as the association required for association such as the association required for association such as the associat Transition, etc. These frames are sent by a station when it needs to tell its peer for a certain action to be taken. For example, a station can tell another station frame. The other station would then respond with an ADDBA Response action frame. The body of a management frame consists of frame-subtype-dependent fixed fields follows: Field Type Length Data Length 1 1–252 Control frames facilitate the exchange of data frames between stations. Some common 802.11 control frames include: Acknowledgement (ACK) frame: After receiving a data frame, the receiving station will send an ACK frame to the sending station doesn't receive an ACK frame to the sending station doesn't receive an ACK frame to the sending station approvide an optional collision reduction scheme for access points with hidden stations. A station sends an RTS frame as the first step in a two-way handshake required before sending data frames. Clear to Send (CTS) frame. It provides clearance for the requesting station to send a data frame. The CTS provides collision control management by including a time value for which all other stations are to hold off transmission while the requesting station transmits. Data frames Dat a Subnetwork Access Protocol (SNAP) header if the DSAP is hex AA, with the organizationally unique identifier (OUI) and protocol ID (FID) field is an EtherType value.[93] Almost all 802.11 data frames use 802.2 and SNAP headers, and most use an OUI of 00:00:00 and an EtherType value. Similar to TCP congestion control on the internet, frame loss is built into the operation of 802.11. To select the correct transmission speed or Modulation and Coding Scheme, a rate control algorithm may test different speeds. The actual packet loss rate of Access points varies widely for different link conditions. There are variations in the loss rate experienced on production Access points, between 10% and 80%, with 30% being a common average.[94] It is important to be aware that the link layer should recover these lost frames. If the sender does not receive an Acknowledgement (ACK) frame, then it will be resent. Standards and amendments Within the IEEE 802.11 Working Group, [57] the following IEEE Standards Association Standard and Amendments exist: IEEE 802.11-1997: The WLAN standard (1997), all the others listed below are Amendments to this standard, except for Recommended Practices 802.11F and 802.11T. IEEE 802.11a: 54 Mbit/s, 5 GHz standard (1999, shipping products in 2001) IEEE 802.11b: 5.5 Mbit/s and 11 Mbit/s, 2.4 GHz standard (1999) IEEE 802.11c: Bridge operation procedures; included in the IEEE 802.11d: International (country-to-country) roaming extensions (2001) IEEE 802.11b: 5.5 Mbit/s and 11 Mbit/s, 2.4 GHz standard (1999) IEEE 802.11c: Bridge operation procedures; included in the IEEE 802.11d: International (country-to-country) roaming extensions (2001) IEEE 802.11b: 5.5 Mbit/s and 11 Mbit/s, 2.4 GHz standard (1999) IEEE 802.11c: Bridge operation procedures; included in the IEEE 802.11c: Bridge operation procedures; included bursting (2005) IEEE 802.11F: Inter-Access Point Protocol (2003) Withdrawn February 2006 IEEE 802.11g: 54 Mbit/s, 2.4 GHz standard (backwards compatible with b) (2003) IEEE 802.11h: Spectrum Managed 802.11a (5 GHz) for European compatibility (2004) IEEE 802.11i: Enhanced security (2004) IEEE 802.11j: Extensions for Japan (4.9-5.0 GHz) (2004) IEEE 802.11-2007: A new release of the standard that includes amendments a, b, d, e, g, h, i, and j. (July 2007) IEEE 802.11n: Higher Throughput WLAN at 2.4 and 5 GHz; 20 and 40 MHz channels; introduces MIMO to Wi-Fi (September 2009) IEEE 802.11p: WAVE-Wireless Access for the Vehicular Environment (such as ambulances and passenger cars) (July 2010) IEEE 802.11r: Fast BSS transition (FT) (2008) IEEE 802.11r: Fast BSS transition (WPP)—test methods and metrics Recommendation cancelled IEEE 802.11u: Improvements related to HotSpots and 3rd-party authorization of clients, e.g., cellular network offload (February 2011) IEEE 802.11v: Wireless network management Frames (September 2009) IEEE 802.11v: Wireless network management (February 2011) IEEE 802.11v: Wireless network management Frames (September 2009) IEEE 802.11v: Wireless network management Frames (September 2009) IEEE 802.11v: Wireless network management (February 2011) IEEE 802.11v: Wireless network management (Feb Setup (DLS) (September 2010) IEEE 802.11-2012: A new release of the standard that includes amendments k, n, p, r, s, u, v, w, y, and z (March 2012) - see Stream Reservation Protocol IEEE 802.11ac: Very High Throughput WLAN at 5 GHz[e]; wider channels (80 and 160 MHz); Multi-user MIMO (down-link only)[95] (December 2013) IEEE 802.11ad: Very High Throughput 60 GHz (December 2012) — see WiGig IEEE 802.11af: TV Whitespace (February 2014) IEEE 802.11-2016: A new release of the standard that includes amendments aa, ac, ad ae, and af (December 2016) IEEE 802.11ah: Sub-1 GHz license exempt operation (e.g., sensor network, smart metering) (December 2016) IEEE 802.11ai: Fast Initial Link Setup (Dece Discovery (July 2018) IEEE 802.11-2020: A new release of the standard that includes amendments ah, ai, aj, ak, and aq (December 2020) IEEE 802.11ax: High Efficiency WLAN at 2.4, 5 and 6 GHz;[f] introduces OFDMA to Wi-Fi[70] (February 2021) IEEE 802.11ay: Enhancements for Ultra High Throughput in and around the 60 GHz Band (March 2021) IEEE 802.11ba: Wake Up Radio (March 2021) In process IEEE 802.11bb: Enhanced Broadcast Service IEEE 802.11bb: Light Communications[97] IEEE 802.11bb: Light Comm WLAN Sensing IEEE 802.11bh: Randomized and Changing MAC Addresses IEEE 802.11me: 802.11 Accumulated Maintenance Changes IEEE 802.11bi: Enhanced Data Privacy 802.11F and 802.11T are recommended practices rather than standards and are capitalized as such. 802.11mis used for standard maintenance. 802.11-2007, 802.11mb for 802.11-2012, 802.11mc for 802.11-2016, and 802.11-2020. Standards (98] As far as the IEEE Standards Association is concerned, there is only one current standard; it is denoted by IEEE 802.11 followed by the date published. IEEE 802.11-2020 is the only version currently in publication, superseding previous releases. The standard is updated by means of amendments are created by task groups (TG). Both the task groups (TG). for example, IEEE 802.11a or IEEE 802.11ax. Updating 802.11 is the responsibility of task group m. In order to create a new version, TGm also provides clarification and interpretation to industry on published documents. New versions of the IEEE 802.11 were published in 1999, 2007, 2012, 2016, and 2020.[99] Nomenclature Various terms in 802.11 are used to specify aspects of wireless local-area networking operation and may be unfamiliar to some readers. For example, Time Unit (usually abbreviated TU) is used to indicate a unit of time equal to 1024 microseconds. Numerous time constants are defined in terms of TU (rather than the nearly equal millisecond). Also, the term "Portal" is used to describe an entity that is similar to an 802.11 LAN STAs. Security In 2001, a group from the University of California, Berkeley presented a paper describing weaknesses in the 802.11 Wired Equivalent Privacy (WEP) security mechanism defined in the original standard; they were followed by Fluhrer, Mantin, and Shamir's paper titled "Weaknesses in the Key Scheduling Algorithm of RC4". Not long after, Adam Stubblefield and AT&T publicly announced the first verification of the attack, they were able to intercept transmissions and gain unauthorized access to wireless networks.[citation needed] The IEEE set up a dedicated task group to create a replacement security solution, 802.11e effort to enhance the MAC layer). The Wi-Fi Alliance announced an interim specification called Wi-Fi Protected Access (WPA) based on a subset of the then-current IEEE 802.11i draft. These started to appear in products in mid-2003. IEEE 802.11i (also known as WPA2) itself was ratified in June 2004, and uses the Advanced Encryption Standard (AES), instead of RC4, which was used in WEP. The modern recommended encryption for the home/consumer space is WPA2 (AES Pre-Shared Key), and for the enterprise space is WPA2 along with a RADIUS authentication server (or another type of authentication needed] In January 2005, the IEEE set up yet another task group "w" to protect management and broadcast frames, which previously were sent unsecured. Its standard was published in 2009.[100] In December 2011, a security flaw was revealed that affects some wireless routers with a specific implementation of the optional Wi-Fi Protected Setup (WPS) feature. While WPS is not a part of 802.11, the flaw allows an attacker within the range of the wireless routers to recover the WPS. PIN and, with it, the
router's 802.11i password in a few hours.[101][102] In late 2014, Apple announced that its iOS 8 mobile operating system would scramble MAC addresses[103] during the pre-association stage to thwart retail footfall tracking made possible by the regular transmission of uniquely identifiable probe requests.[citation needed] Wi-Fi users may be subjected to a Wi-Fi deauthentication attack to eavesdrop, attack passwords, or force the use of another, usually more expensive access point.[citation needed] See also 802.11 Frame Types Comparison of the IEEE 802.11 standards LTE-WLAN Aggregation OFDM system comparison table TU (time unit) TV White Spaces (radio) Wi-Fi operating system support Wibree or Bluetooth low energy WiGig Wireless USB – another wireless protocol primarily designed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit/signed for shorter-range applications Notes ^ 802.11ax with 2402 Mbit (MCS Index 11, 2 spatial streams, 160 MHz); versus 802.11ac with 1733.3 Mbit/s (MCS Index 9, 2 spatial streams, 160 MHz); versus 802.11ac with 1733.3 Mbit/s (MCS Index 9, 2 spatial streams, 160 MHz); versus 802.11ac with 1733.3 Mbit/s (MCS Index 9, 2 spatial streams, 160 MHz); versus 802.11ac with 1733.3 Mbit/s (MCS Index 9, 2 spatial streams, 160 MHz); versus 802.11ac with 1733.3 Mbit/s (MCS Index 9, 2 spatial streams, 160 MHz); versus 802.11ac with 1733.3 Mbit/s (MCS Index 9, 2 spatial streams, 160 MHz); versus 802.11ac with 1733.3 Mbit/s (MCS Index 9, 2 spatial streams, 160 MHz); versus 802.11ac with 1733.3 Mbit/s (MCS Index 9, 2 spatial streams, 160 MHz); versus 802.11ac with 1733.3 Mbit/s (MCS Index 9, 2 spatial streams, 160 MHz); versus 802.11ac with 1733.3 Mbit/s (MCS Index 9, 2 spatial streams, 160 MHz); versus 802.11ac with 1733.3 Mbit/s (MCS Index 9, 2 spatial streams, 160 MHz); versus 802.11ac with 1733.3 Mbit/s (MCS Index 9, 2 spatial streams, 160 MHz); versus 802.11ac with 1733.3 Mbit/s (MCS Index 9, 2 spatial streams, 160 MHz); 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