What's the Difference between IEEE 802.11af and 802.11ah?

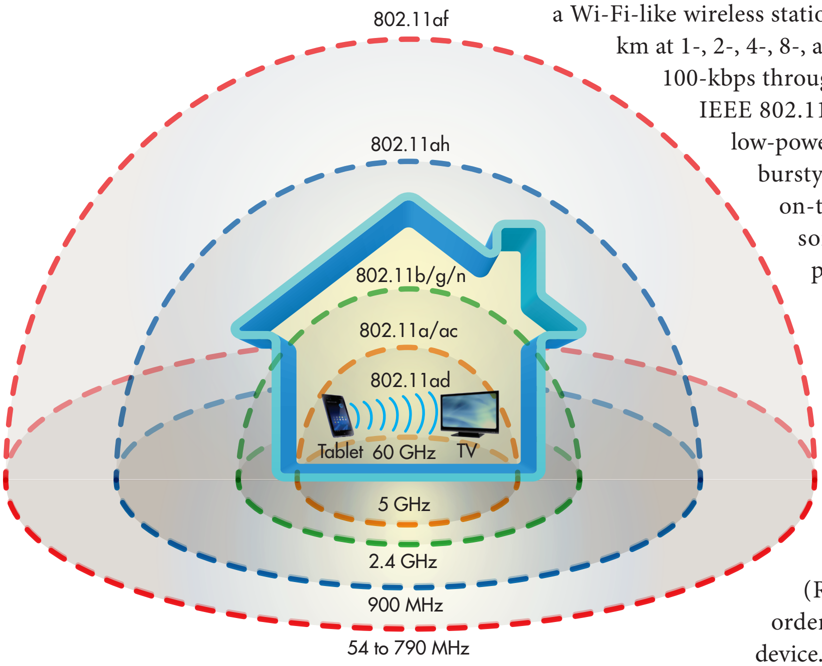
Although IEEE 802.11af and 802.11ah are both sub-1-GHz standards, they are designed to fill different niches in upcoming IoT and wireless-backhaul applications.

THE EMERGING INTERNET OF THINGS (IOT) and machine-to-machine (M2M) communication markets demand wireless networking standards that operate in the sub-1 GHz spectrum, providing long-range and low-power operation. There also is a need to offload the data demands of smartphones and portable electronics from the cellular network. The IEEE 802.11af and 802.11ah standards aim to solve these challenges by offering a Wi-Fi-like experience with reasonable data rates up to and beyond a kilometer. To do so, they occupy different parts of the 1-GHz spectrum and exhibit numerous other differences *(Fig. 1 and Table 1)*.

WHAT IS IEEE 802.11AH?

Making use of the 900-MHz licensed exempt bands could enable long-range and low-power wireless sensor networks (WSNs) and other massive, multiple-node wireless networks based on stations and relays. With IEEE 802.11ah, the concept of a Wi-Fi-like wireless station can be realized. It promises range to 1 km at 1-, 2-, 4-, 8-, and 16-MHz channels with a minimum of 100-kbps throughput *(Fig. 2)*. Maximum throughput for IEEE 802.11ah may reach as high as 40 Mbps. This low-power and low-throughput mode enables short bursty data packets, which enable a very short on-time for remote or battery-powered sensors. The medium-access-control (MAC) protocols of the upcoming standard also enable smaller-frame formats, beaconless paging modes, and sensor traffic priority for lower-power applications.

It is likely that IEEE 802.11ah will use a downsampled version of the IEEE 802.11a/g specifications to service the 26 channels around 900 MHz *(Fig. 3)*. Set to be finalized in early 2016, IEEE 802.11ah makes use of relay access points (RAPs) and network stations (STAs) in order to communicate frames from device to device. This relay function enables intelligent and low-power networking schemes that limit power use through an expansive network. In addition, the modulation and coding scheme (MCS) level



1. As a function of propagation characteristics at different RF and microwave frequencies, the various IEEE 802.11 standards exhibit different range and data-rate features.

can be adjusted based on the quantity of data that needs to be transmitted. To limit energy consumption due to the overhead of relays and hopping, bi-directional hopping will be limited to two exchanges.

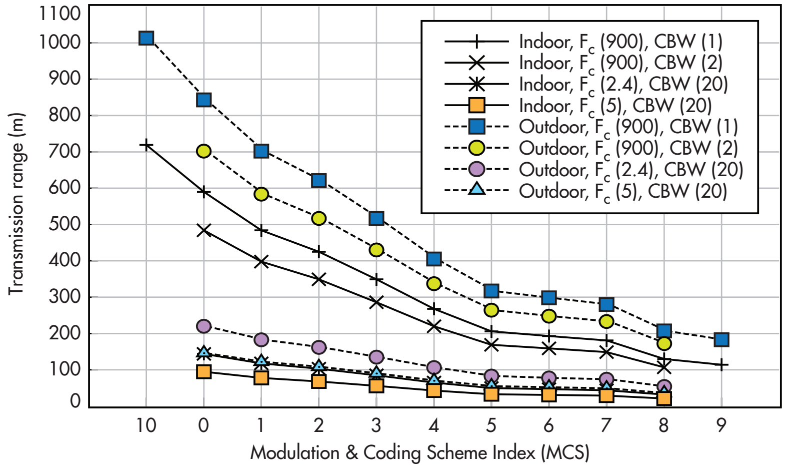
To increase energy efficiency and power savings, the target-wake-time (TWT) function in IEEE 802.11ah permits a routine and scheduled sleep time for each access point and station. The access points are grouped within a basic service set (BSS) along with restricted channel access to a designated group. The goal of this type of partitioning is to prevent multiple transmissions from networks that are unable to see each other. Sectorization can be implemented with electronically controlled antenna beams or a diversified set of antennas.

In the United States, up to 26 MHz of spectrum is available at 900 MHz, enabling up to 16 MHz of bandwidth for the standard. This increased bandwidth enables even higher-data-rate applications if necessary. Additionally, the MAC protocol is designed to account for a massive amount of nodes in an environment with the timing, paging, and sectorization protocols. Given these factors, IEEE 802.11ah can provide an IP-based Wi-Fi-like system for M2M applications with much longer range and better material penetrating frequencies over earlier versions of Wi-Fi. IEEE 802.11ah is now included as part of an amendment to the 802.11REVmc standard with working group approval planned for January 2016.

WHAT IS 802.11AF?

The IEEE 802.11 working group has already formed standards targeting the television white space (TVWS) in the very-high-frequency (VHF) band and lower end of the ultra-high-frequency (UHF) band from 54 to 790 MHz. In February 2014, the IEEE Std 802.11af -2013 amendment was approved, enabling wireless-local-area-network (WLAN) operation in TVWS *(Fig. 4)*. As a product of the legacy analog TV, digital TV, and wireless microphone, this standard requires cognitive-radio functions that limit interference for these "primary" users.

In addition, IEEE 802.11af uses many of the recent operational enhancement techniques adopted by the most recent IEEE 802.11 standards, such as multiple-input multiple-output (MIMO), orthogonal frequency division multiplexing (OFDM), and channel bonding. Specifically, IEEE 802.11af offers the ability to bond up to four of the 6-to-8-MHz-wide



2. More complex modulation and coding schemes can increase throughput while sacrificing range. The lower-frequency IEEE 802.11 standards benefit from better propagation characteristics, although they have less available bandwidth to increase data rates.

TABLE 1: IEEE 802.11 COMMON WIFI STANDARDS BREAKDOWN

Standard	Frequency Band	Bandwidth	Modulation Scheme	Channel Arch.	Maximum Data Rate	Range	Max Transmit Power
802.11	2.4 GHz	20 MHz	BPSK to 256-QAM	DSSS, FHSS	2 Mbps	20 m	100 mW
b	2.4 GHz	21 MHz	BPSK to 256-QAM	CCK, DSSS	11 Mbps	35 m	100 mW
a	5 GHz	22 MHz	BPSK to 256-QAM	OFDM	54 Mbps	35 m	100 mW
g	2.4 GHz	23 MHz	BPSK to 256-QAM	DSSS, OFDM	54 Mbps	70 m	100 mW
n	2.4 GHz, 5 GHz	24 MHz and 40 MHz	BPSK to 256-QAM	OFDM	600 Mbps	70 m	100 mW
ac	5 GHz	20, 40, 80, 80+80= 160 MHz	BPSK to 256-QAM	OFDM	6.93 Gbps	35 m	160 mW
ad	60 GHz	2.16 GHz	BPSK to 64-QAM	SC, OFDM	6.76 Gbps	10 m	10 mW
af	54-790 MHz	6, 7, and 8 MHz	BPSK to 256-QAM	SC, OFDM	26.7 Mbps	>1km ?	100 mW
ah	900 MHz	1, 2, 4, 8, and 16 MHz	BPSK to 256-QAM	SC, OFDM	40 Mbps	1 km	100 mW

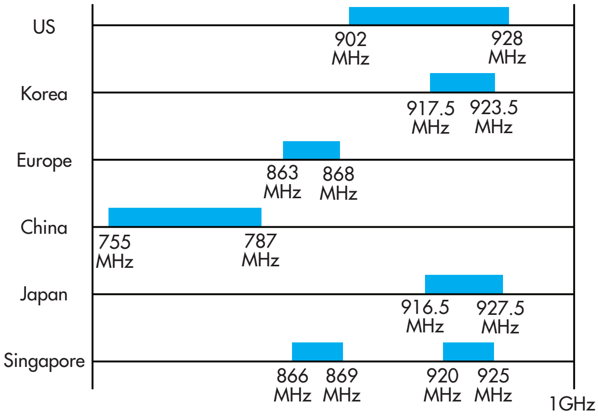
channels (the channel bandwidth depends upon the regulatory domain), which can be blocked into either one or two contiguous blocks *(Table 2)*. Up to four MIMO streams can be implemented in either multi-user (MU-MIMO) or space-time-block-code (STBC) operation.

In terms of data rates, the maximum available data rate per spatial stream for IEEE 802.11af is 35.6 Mbps at an 8-MHz channel bandwidth. The 6- and 7-MHz channel bandwidths are limited to 26.7 Mbps per spatial stream. Each additional spatial stream and bonded channel can theoretically compound-increase the data rate. The 6- and 7-MHz mode—operating with four channels and four MIMO streams—can potentially reach speeds of 426.7 Mbps. Under the same conditions, the 8-MHz mode reaches 568.9 Mbps.

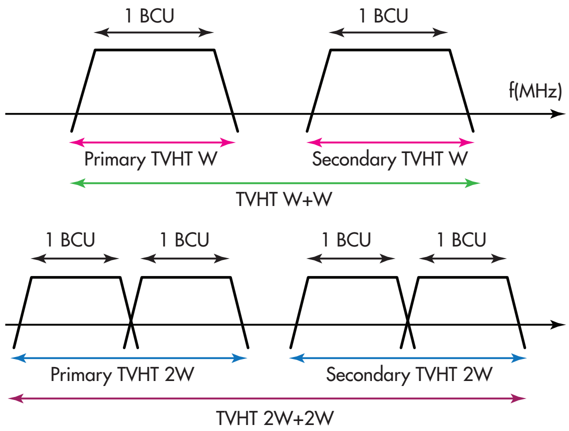
Because IEEE 802.11af channels operate over a wide frequency range, propagation characteristics differ for the various channels. IEEE 802.11af may reach up to 1 km in range at maximum power with a single stream and channel and a lower data rate. This new VHF/UHF standard may be able to offer a reasonable Wi-Fi experience in ranges reaching several hundred meters.

In the United States, only 6-MHz channel bandwidths are permitted in TV channels 2, 5, 6, 14-35, and 38-51 for a maximum of 48 hours of continuous use *(Table 3)*. The U.S. also requires a GPS geolocation query through the Internet, which will update the unit on any regional regulations that are in effect. These features enable IEEE 802.11af to operate in the licensed TVWS bands, although different countries and regions have their own specific regulations.

IEEE 802.11af is being processed for an additional standard revision in the IEEE 802.11 working group letter ballots. This move is part of a revision to IEEE Std P802.11REVmc, which is predicted to gain approval in November 2015.



3. According to the spectrum regulations of individual countries, the exact band occupied by the IEEE 802.11ah standard is adjusted.



4. IEEE 802.11af operates within the old TV white space (TVWS) bands with TV high-throughput (TVHT) physical-layer applications. They combine many TVWS channels for increased data rate over a long range.

TABLE 2: IEEE 802.11AF SINGLE SPATIAL STREAM THEORETICAL THROUGHPUT (IN MBIT/S)

			6 and 7 MHz channels		8 MHz channels	
MCS Index	Modulation	Rate	6 µs GI	3 µs GI	4.5 µs GI	2.25 µs GI
0	BPSK	2-Jan	1.8	2	2.4	2.7
1	QPSK	2-Jan	3.6	4	4.8	5.3
2	QPSK	4-Mar	5.4	6	7.2	8
3	16-QAM	2-Jan	7.2	8	9.6	10.7
4	16-QAM	4-Mar	10.8	12	14.4	16
5	64-QAM	3-Feb	14.4	16	19.2	21.3
6	64-QAM	4-Mar	16.2	18	21.6	24
7	64-QAM	6-May	18	20	24	26.7
8	256-QAM	4-Mar	21.6	24	28.8	32
9	256-QAM	6-May	24	26.7	32	35.6

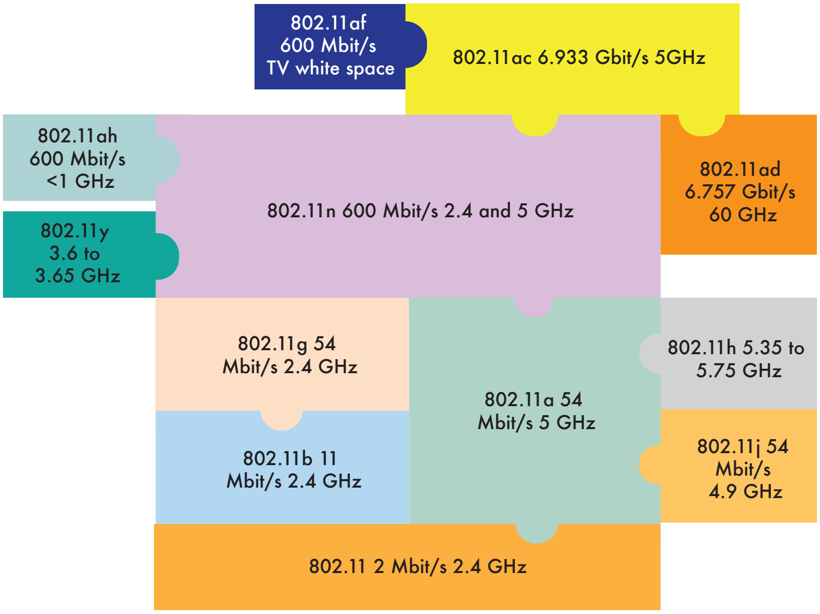
IEEE 802.11AF VS. IEEE 802.1AH

When it comes to the MAC and physical layer (PHY) for IEEE 802.11af and 802.11ah, the most significant differences are derived from a divergence in functional intent and spectrum. IEEE 802.11ah occupies a contiguous block of spectrum in the 900-MHz licensed exempt band. In contrast, IEEE 802.11af occupies many various channels of TVWS in pre-licensed bands. Its operation is limited based on potential regional interference.

IEEE 802.11af is designed to operate more like a traditional Wi-Fi network. Using many of the latest developments, it is able to increase bandwidth over a long-range wireless local-area network (WLAN). In contrast, IEEE 802.11ah is better suited for M2M and IoT applications. It is designed for low-power communication between a wireless network's APs and station nodes.

In terms of transmit power, the new standards will be limited according to the same regulation of 100mW maximum.

Generally, however, IEEE 802.11af will have a longer operating range—especially when operating in the low VHF band. In most regions, IEEE 802.11ah should demonstrate considerably higher throughput in a single stream than IEEE 802.11af. Yet this will not hold true in the United States, where IEEE 802.11af bandwidths can reach 8 MHz. Although single-stream throughput should be higher for IEEE 802.11ah, MIMO and channel-bonding aspects of IEEE 802.11af could enable it to outperform IEEE 802.11ah when multiple antenna or channels are available.



The various IEEE 802.11 standards have evolved over time adopting techniques, technologies, and protocols from the previous standards.

IEEE 802.11AH GLOBAL FREQUENCY RANGE

Country	Frequency
US	902 to 928 MHz
Korea	917.5 to 923.5 MHz
Europe	863 to 868 MHz
China	755 to 787 MHz
Japan	916.5 to 927.5 MHz
Singapore	866-869 MHz, 920-925 MHz

With the different MAC and PHY designs, the IEEE 802.11ah hardware should operate with higher power efficiencies than IEEE 802.11af—even at higher frequencies. In terms of power efficiency, remote and battery-operated applications may benefit more from IEEE 802.11ah than IEEE 802.11af. After all, IEEE 802.11ah can operate in bursty packet nodes and within a field of wireless nodes. Here, data sent by a node will only have to travel to the nearest node, limiting power consumption per bit. The IEEE 802.11ah standard also boasts sectorization, bi-directional transmit opportunity (TXOP), restricted access window, and target wake times, which will help to enable lower-power M2M and IoT WSN applications. Conversely, IEEE 802.11af is optimized to exchange data in a more Wi-Fi-like manner. Its access points send and receive data from remote portable devices, instead of taking IEEE 802.11ah's approach and using other APs and nodes. **mw**

TABLE 3: IEEE 802.11AF FREQUENCIES AND TV WHITE-SPACE CHANNELS

TV White Space Channel	Lower Frequency	Upper Frequency	Channel Width	Spectrum
2	54 MHz	60 MHz	6 MHz	VHF Low-Band
5	76 MHz	82 MHz	6 MHz	VHF Low-Band
6	82 MHz	88 MHz	6 MHz	VHF Low-Band
14 - 35	470 - 596 MHz	476 - 602 MHz	6 MHz	UHF
38 - 51	614 - 692 MHz	620 - 698 MHz	6 MHz	UHF

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