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Federal Department of the Environment, Transport, Energy and Communication DETEC

Federal Office of Communications OFCOM

Equipment and Frequency Management International
Radio Technology Section

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WLAN Factsheet

Wireless Local Area Networks

Summary

WLANs are wireless local area networks. They enable easy wireless internet access within a building or in the garden. In buildings with WLANs, distances of several tens of metres are typically bridged, depending on the data rate.

Since as early as 1997, thanks to the IEEE 802.11 (Institute of Electrical and Electronics Engineers) standards, there have been standardised air interfaces for these local wireless networks. These first systems allowed a maximum gross data rate of 1 or 2 Mbit/s. On this basis, the standards have been constantly extended, mainly to increase the data transfer rate. Today, with IEEE standard 802.11ac, hypothetical gross data rates of up to 6.9 Gbit/s can be achieved; commercially, however, only equipment up to 1.7 Gbit/s is usually encountered. In practice, under real environmental conditions, 800 Mbit/s will typically be achieved.

The development of WLANs is set to continue for some time to come. The use of multiple antennas (e.g. beamforming) is a promising approach to further increasing capacity. The IEEE 802.11ax standard, for example, which uses multi-user MIMO in the uplink and downlink, enables data rates of up to 9.6 Gbit/s gross.

Five public-domain frequency bands are currently available for WLANs. The most-used ranges are 2.4 GHz and 5 GHz. Since 2021, the 6 GHz frequency range has been available. This enables higher data rates, and simultaneous data streams from multiple devices in the uplink and downlink over the same radio channel. In addition, there are the 60 GHz frequency ranges (for very high data rates over short line-of-sight distances up to approximately 10 metres) and 900 MHz (for relatively low data rates and relatively large distances of up to several hundred metres outdoors).

This factsheet concentrates on the technical aspects of WLANs. The legal basis can be found at: https://www.bakom.admin.ch/bakom/en/homepage/equipments-and-installations/particular-equipment/wlan-rlan.html.

FAQs about WLANs can be found at: WLAN (admin.ch)

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1 Introduction

This WLAN factsheet provides an introduction to and an overview of wireless networks for the interested public.

2 What is meant by a WLAN?

Nowadays, personal computers (PCs) in offices are generally networked. In most cases this networking is achieved by means of a cable which connects the PC with the network connection socket in the vicinity of the PC. Depending on the network and controller used, data transmission rates of 10 Mbit/s, 100 Mbit/s and up few Gbit/s can be achieved.

For some time, there has been a desire to liberate users from this cable. The advantages are obvious: no costly cabling work is needed in offices, and a PC or laptop can be used anywhere in the office building. As a result of the possibilities of information technology and constant progress in semiconductor integration, it has now become possible to realise this desire. Wireless networks are now available to everyone at affordable prices.

The terms Radio Local Area Network (RLAN) and Wireless Local Area Network (WLAN) mean the same thing.

3 Principle of a WLAN

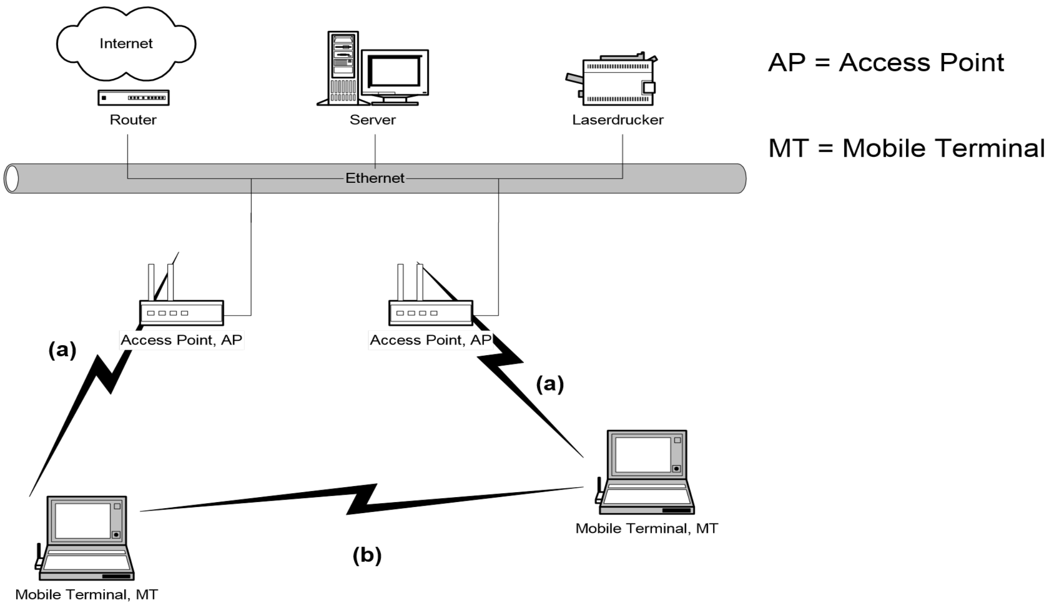

Figure 1: WLAN network

By means of WLANs, connections can be established between the Mobile Terminal and the Access Point (a). This makes the Mobile Terminal part of the Ethernet, and allows it to access all connected devices, such as printers, servers, internet access, etc.

If no infrastructure exists, direct connections for data exchange (b) can be set up between multiple Mobile Terminals.

In this context, the range of the wireless link depends of several factors, such as:

- transmitting power
- interference (with other users, can be optimised by network design)
- data transmission rate (type of modulation)

- the environment (inside or outside the house, line-of-sight link).

The following conditions apply:

- the higher the data transmission rate, the shorter the range
- the more obstacles between the wireless users and the Access Points, the shorter the range
- the more simultaneously active users, the lower the data transmission rate

This explains why the data transmission rate drops at greater distances, or when there is reciprocal interference.

The data transmission rate, moreover, refers to the maximum data transmission rate in both directions. This data transmission rate is split between the individual users using this channel. The more users on this channel, the lower the data transmission rate for each individual user. In addition, overhead and access losses must be taken into consideration, which lead to a reduced effective data transmission rate.

3.1 Access Point (AP)

The Access Point is the switching point in the WLAN. The wireless users are connected via the Access Point to the world of fixed networks, i.e. the Access Point is normally connected to the Ethernet.

In many cases, other functions are integrated in the Access Point, e.g.:

- ADSL / cable modem
- 10/100 MHz LAN link
- Router
- Print server

Additional software functions may also be provided by the Access Point, such as:

- Firewall
- Access control
- Password protection
- Encryption.

3.2 Mobile Terminal (MT)

Users with laptops used to be connected by a PCMCIA card and those with a PC by a separate PCI card or a PCI holder card, which in turn can take a PCMCIA card. Nowadays WLAN interfaces are integrated into PCs, notebooks and smartphones.

The subscriber connection communicates across the air interface with the Access Point, from where connections with the wirebound Ethernet are established.

Ad hoc functions generally also provide the possibility of exchanging data directly, without an Access Point.

The Mobile Terminal is actually 'only' a portable terminal, since the systems are not designed for mobile operation. However, all of the various standards permit handover from one radio cell to the next.

3.3 Services

It is not possible to speak of actual services in the case of wireless LANs. Commercially available systems are used for wireless connection of PCs to the Ethernet. For users, these systems are fully transparent, i.e. it makes no difference whether they are connected to the network via a cable or a wireless link. All applications and services (file transfer, access to printers, the internet, etc.) which are available on the network are therefore available without limitation (subject to the restricted data transmission rate).

Current offerings are limited to LAN applications and internet access, with all its facilities.

4 Security

4.1 Confidentiality

In the case of WLANs, security is an issue since access to the air interface is entirely possible without on-site access. The range is approx. 100 metres, or approx. 300 metres maximum. However, it has recently been shown that the encryption can be broken – given appropriate effort. Software tools already exist to permit hacking into the encryption procedure.

The encryption techniques work on individual or multiple layers of the OSI model, using different methods. There is a wide range of such methods.

The formerly widely used WEP (Wired Equivalent Privacy) encryption method, which uses the RC-4 algorithm, proved to be insecure. The method uses a constant WEP key and a variable initialisation vector (IV) transmitted on the radio channel in clear text. This vector is only 24 bits long and is generated randomly. Consequently, the same effective key occurs relatively frequently for different packets. Long-term monitoring and observation make it possible to determine the constant WEP key. Cracking tools exploit precisely this weakness.

A further development of WEP, known as WEP2, uses a 128-bit initialisation vector and periodic renewal of the previously constant WEP key. This extension is considered to be not much more secure and has therefore already been rejected.

WEPplus is a new, more secure but proprietary development. This encryption method is more robust in that a key generation algorithm is used which avoids weak keys. It is therefore more difficult to crack the key by monitoring the radio channel. Nonetheless, it is only a matter of time until a corresponding software tool becomes available. WEPplus is fully backward-compatible with earlier WEP-WLANs.

Fast Packet Keying works on a similar principle and was developed by RC4's inventors, RSA Data Security. For each data packet, this algorithm generates a 104-bit packet key and a 24-bit initialisation vector. This avoids the repeated use of a key with the same initialisation vector, one of the principal problems with WEP. Fast Packet Keying is also designed for compatibility with existing WLAN hardware and can be retrofitted using driver and firmware upgrades.

The WLAN encryption WPA2 (Wi-Fi Protected Access) introduced in 2004 is currently the proven standard and will continue to offer a high level of security in the future. The most current encryption protocol is WPA3. Introduced in 2018, WPA3 uses the modern encryption method SAE (Simultaneous Authentication of Equals) and offers, among other things, increased security against so-called 'dictionary attacks' and thus effectively prevents the automated trying out of passwords.

However, an encryption protocol is not necessarily activated by the operator in the WLAN Access Points.

The radio signals of a WLAN can be received up to a distance of several hundred metres, i.e. not only by the immediate neighbour. To protect data reliably, it is best to use an additional 'end-to-end' security solution. One of the most promising solutions currently is IPSec. IPSec is an encrypted TCP/IP protocol and requires data traffic on the network to use the IP protocol exclusively. In most cases this is not a problem, since TCP/IP is omnipresent because of the spread of the internet. IPSec is one of the most secure methods of encryption for WLANs, but requires careful and quite complex configuration. Unfortunately, of all the techniques, IPSec involves the greatest increase in overhead and consequently a reduction in data transmission rate.

The HTTPS protocol (Hypertext Transfer Protocol Secure) also offers an 'end-to-end' transport encryption that is considered secure. Without transport encryption, such as with HTTP, the data transmitted over the internet can be read in plain text by anyone who has access to the network in question. When using open (i.e. unencrypted) WLANs, it is even more important to use HTTPS because it allows content to be encrypted independently of the network.

At network access level, in addition to the encryption algorithms, the customary security mechanisms such as logon with user name and password, computer account (identification of a PC by its MAC address) and domain security features are active. No security system offers 100% protection, whether individually or combined.

4.2 Electromagnetic compatibility and the environment

The Ordinance on Protection against Non-Ionising Radiation (NIRO)[1] is in principle also applicable to wireless networks. Transmission equipment with an equivalent radiating power (ERP) of less than 6 W is exempted from this regulation. WLANs have an ERP of less than 6 W and are therefore not affected by the Ordinance on Protection against Non-Ionising Radiation.

5 Applied standards

5.1 DECT-based WLAN

One simple solution is the application of the DECT standard to link wireless users. DECT is a standard which has proved itself over some years; it is very robust and powerful. It additionally supports handover between base stations, in so far as these are connected by a cable.

The DPRS (DECT Packet Radio Service) protocol permits data rates per time slot of up to 76.8 kbit/s (gross) with robust modulation and up to 460.8 kbit/s (gross) with high-grade modulation. Up to 11 time slots per direction of transmission can be combined, resulting in maximum data rates of 844.8 kbit/s (gross) with simple modulation and up to 5.07 Mbit/s (gross) with high-grade modulation.

5.2 WLAN according to IEEE 802.11

The IEEE established the IEEE 802.11 standard in 1997. It permits a data transmission rate of 1 or 2 Mbit/s and works in the ISM frequency band of 2.4 GHz. In this frequency range (2400 – 2483.5 MHz) 79 channels, each with 1 MHz bandwidth, are available.

These channels are each occupied briefly (for a few ms) using the Frequency-Hopping-Spread-Spectrum System (FHSS); communication then takes place on a different channel. To achieve this, the transmitter and receiver must occupy the channels synchronously according to a pre-set table.

The same standard also describes a method with a spread of signal bandwidth by a factor of 11. This Direct Sequence Spread Spectrum (DSSS) method distributes the energy used for the transmission of information over 22 MHz. Multiple connections can then take place simultaneously on the same channel. For this type of technique, there are 13 carrier frequencies channels with a 5 MHz channel arrangement available in the 2400 – 2483.5 MHz frequency range.

In order to ensure trouble-free operation of different WLANs on the same site, e.g. only channels 1, 7 and 13 should be occupied; otherwise the channels overlap.

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[1] https://www.fedlex.admin.ch/eli/cc/2000/38/de

5.3 WLAN according to IEEE 802.11b

In 1999 the data transmission rate was increased to 5.5 or 11 Mbit/sec by modifying the type of modulation. These WLANS also work only in the 2.4 GHz band. The increase in data transmission rate is achieved by the use of CCK spread codes (Complementary Code Keying), a class of sophisticated spread codes. It is accompanied by a reduction in range. The data transmission rates defined in the IEEE 802.11 standard are also supported.

The IEEE 802.11b standard works at the higher data transmission rates exclusively with DSSS.

5.4 WLAN according to IEEE 802.11g

An extension of the 802.11b standard was produced under this designation. With this standard, a maximum of 54 Mbit/s in the 2.4 GHz ISM band is achieved.

The higher data rates are achieved by extending the air interface (PHY) by two modulations/coding types. The extension bears the name Extended Rate PHY (ERP). The following are the new modulations/coding types:

- ERP-PBCC: the user data are coded with the aid of a convolution coder with 256 states and then modulated using 8PSK. In addition, the preamble and header are abbreviated in time, producing gross bit rates of 22 and 33 Mbit/s in this mode.
- DSSS-OFDM: this type of modulation is a hybrid of DSSS and OFDM. A shortened preamble and header are modulated and spread as in standard IEEE802.11b BPSK. The user data are modulated by OFDM on 48 sub-carriers. Depending on the data rate, the sub-carriers BPSK, QPSK, 16QAM or 64QAM are modulated. Varying the sub-carrier modulation type and the code rate (1/2, 2/3 or 3/4) produces gross bitrates of 6, 9, 12, 18, 24, 36, 48 or 54 Mbit/s (see also Section 9.3).

The IEEE 802.11g standard is compatible with equipment to IEEE802.11 and IEEE 802.11b. In addition, the OFDM parameters are adapted to those of WLAN systems in the 5 GHz band; this allows the manufacture of WLAN chipsets which support the 2.4 and 5 GHz band.

5.5 Bluetooth

The IEEE 802.15.1 standard is behind the name Bluetooth. Bluetooth is designed for bridging short distances (up to 10 metres at 0 dBm EIRP and up to 100 metres at 20 dBm EIRP) with data transmission rates up to 1 Mbit/s. There are three power classes of devices: 0, 4 and 20 dBm (1, 2.5 and 100 mW). Bluetooth devices are expected to be used typically in a Wireless Personal Area Network (WPAN). A WPAN embraces all the wirelessly connected devices (mobile telephone, organiser, laptop, printer, camera, multimedia projector, etc.) in close proximity to a person. The goal is to simplify the connection of the above-mentioned devices.

Bluetooth connections are powerful and robust point-to-point links, with the possibility of operating several connections simultaneously. One possibility is even multi-hop connections, which extend the local spread of a PAN, using intermediate devices as repeaters.

Unlike WLAN, which allows roaming access to the intranet or the internet, Bluetooth is designed as a universal wireless adapter (e.g. serial interface). The wirebound counterpart would be the USB interface. The first products were wireless headsets for mobile phones, plus printer and video camera connections to PCs and laptops.

Bluetooth is especially optimised for low energy consumption. Since Bluetooth, like IEEE802.11 / IEEE802.11b, works in the 2.4 GHz ISM band, the systems may cause reciprocal interference. Capacity reduces as traffic increases. This is a disadvantage which must be taken into consideration in bands which are not subject to licensing.

5.6 WLAN according to IEEE 802.11a

WLANs according to IEEE 802.11a work in the 5 GHz band. They offer data transmission rates of 6 Mbit/s to 24 Mbit/s and optionally up to 54 20 Mbit/s. The channel arrangement is 20 MHz. The standard provides for two frequency bands in the 5 GHz band with different transmitting powers (see also Section 6).

To enable WLAN Access Points in Europe to use the entire 5 GHz band, they must detect the signals of other radio systems in this frequency band and work around these by means of a frequency change. To this end, functions for dynamic frequency selection (DFS) and transmit power control (TPC) must be implemented in the WLAN access point. The transmit power can also be halved as an alternative to TPC.

Unfortunately, WLANs according to IEEE 802.11a lack these two features. However, the use of systems to IEEE 802.11a is possible in Europe with certain restrictions. More detailed information is available from OFCOM.[2]

In the case of WLANs according to the IEEE 802.11h standard (see the following section), this deficiency has finally been rectified.

5.7 WLAN according to IEEE 802.11h

The standard corresponds as closely as possible to IEEE 802.11a (see Section 5.6) and operates in the 5 GHz band. The DFS and TPC functions are implemented here. The standard may therefore be used in Europe.

5.8 WLAN according to IEEE 802.11n

This standard is used both in the 2.4 GHz band and in the 5 GHz band. Most inexpensive devices, however, are intended to support only the 2.4 GHz band. The DFS and TPC functions are implemented in the 5 GHz band and there is therefore no obstacle to the use of this standard in Europe.

The standard covers WLANs with a gross bit rate of up to 600 Mbit/s, which is achieved by the use of 4 x 4 MIMO (Multiple Input Multiple Output), 64-QAM modulation and a bandwidth of 40 MHz (see also Section 9.3 in the Annex). Given a good radio link, in net terms in practice only about half of this will be achieved.

As the name suggests, in the case of MIMO multiple antennas are used both at the access point and at the mobile terminal. In the case of a 4 x 4 MIMO this involves 4 antennas at the transmitter and 4 antennas at the receiver. Using individual antennas, different data streams can be transferred on the same frequency and for the same link. On the reception side, the signals can be decoded again with the aid of complex algorithms. When the number of antennas is doubled on both sides of a radio link, the data rate can therefore theoretically be doubled, without additional frequency resources and without additional transmitting power.

As a result of the use of MIMO in IEEE 802.11h, there is an additional dimension on top of frequency and time: the spatial dimension. In this context, one therefore also speaks of spatial multiplexing.

Alternatively, in a MIMO system, instead of increasing the data rate, the signal-to-noise ratio, and hence the quality of radio communication, can be improved. By sending the same coded transmission via several antennas, the quality of the signal at the periphery of the cell – for the same total transmitting power of all antennas together – can be improved substantially (diversity gain), but without an increase in the data rate. As a result, the range is increased.

With MIMO there is a third possibility: so-called beamforming. The transmit power is bundled in the direction towards the receiver and vice versa. Consequently, the range is also increased and interference from other users is reduced.

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[2] Market access of radiocommunications equipment (admin.ch)

5.9 WLAN according to IEEE 802.11ac

IEEE 802.11ac is a further development of IEEE 802.11n. MIMO techniques (only in the downlink) up to 8 x 8 are possible with this standard and modulation has been extended to 256-QAM. The maximum bandwidth is 160 MHz.

This standard can operate in the 5 GHz band. Gross bit rates of up to 6,933 Mbit/s are theoretically possible (see Annex 9.3). This is achieved by the use by 8 x 8 MIMO, 256-QAM modulation and in a bandwidth of 160 MHz. Given a good radio link, probably only a fraction of this could actually be used in practice.

WLANs conforming to IEEE 802.11ac unfortunately usually lack the DFS and TPC functions which are prescribed throughout Europe (see Section 5.6). These systems in Europe are therefore operated in the 5 GHz band only on certain channels. More detailed information is available from OFCOM[3].

5.10 WLAN according to IEEE 802.11ax

IEEE 802.11ax is a further development of IEEE 802.11ac. OFDMA (orthogonal frequency-division multiple access) and MIMO techniques (uplink and downlink) up to 8 x 8 are possible with this standard and modulation has been extended to 1024-QAM. The maximum bandwidth is 160 MHz.

In addition to the 2.4 GHz and 5 GHz bands, this standard can also operate in the 6 GHz band. Gross bit rates of up to 9,607 Mbit/s are theoretically possible.[4] The main feature of 802.11ax is OFDMA technology, which combines TDMA and FDMA in a similar manner as 4G and 5G mobile networks. Other improvements in spectrum use include better power control methods to avoid interference with neighbouring networks, 1024-QAM modulation, MIMO in both directions (uplink and downlink) and MU-MIMO to further increase throughput.

5.11 WLAN according to IEEE 802.11ad

IEEE 802.11ad is known as Wireless Gigabit – WiGig for short – and enables fast point-to-point connections. WLANs according to IEEE 802.11ad are operated in the frequency range around 60 GHz. Because of the high transmit frequency, the signals on the radio interface are greatly attenuated. Therefore, and because of the relatively low transmitting power, the range with this standard is only approximately 10 m. Additionally, there must be visual contact between transmitter and receiver. At greater distances, the connection switches automatically to a standard with a reduced data rate in the 2.4 or 5 GHz range.

On one of the four radio channels approximately 2 GHz wide, depending on the distance, gross data rates from 385 to 4,620 Mbit/s (single carrier mode) or from 693 to 6,757 Mbit/s (OFDM) are possible.

Efficient beamforming is supported by the standard. The high frequencies used in this case are highly appropriate, as many antennas can be used over a small area. Consequently the transmit power can be specifically matched to the corresponding receiver and interference in neighbouring systems is minimised (see also Section 5.8).

5.12 WLAN according to IEEE 802.11ah

The IEEE 802.11ah standard is designed for IoT (Internet of Things) applications and is therefore designed for low power consumption, a relatively long range and low bandwidth (low data transfer rates). With this new standard, it would be possible to network devices which are, for example, battery-powered, which do not continuously send data and which do not need a high transmission rate. This technology is therefore in competition with technologies like Bluetooth or Zigbee. The WiFi Alliance has adopted the IEEE 802.11ah standard and named it 'HaLow'.

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[3] https://www.bakom.admin.ch/bakom/en/homepage/equipments-and-installations/particular-equipment/wlan-rlan.html

[4] https://ieeexplore.ieee.org/document/9442429

In Europe HaLow works in the 863 – 870 MHz frequency range. The standard envisages transmission bandwidths of 1 and 2 MHz. As an option, 4, 8 and 16 MHz can also be used; as a result of available bandwidths in the public-domain bands, the 8 und 16 MHz bandwidths can be used only in the USA and in China. On the uplink and downlink, the data rate is 150 kbit/s to 346.6 Mbit/s. Outside buildings, ranges of up to 1 km are possible.

5.13 LTE

The LTE mobile radio standard is constantly being expanded, so devices to this standard can also be used, in addition to mobile data communication in licensed bands, for data communication over short distances in public-domain bands. An LTE mobile radio device can therefore, if necessary, switch automatically to WLAN transmission or connect to WLAN transmission, without adversely affecting instantaneous data transmission. With this evolution of the LTE standard within the 3GPP committee, LTE has been and is being enhanced with the following functions:

- LTE license assisted access (LTE-LAA): this technology takes advantage of the feature of LTE which permits distributing data communication simultaneously over different frequency bands. Thus data traffic is always transferred via a primary and a secondary radio cell. The primary radio cell works in the licensed frequency range, whilst the secondary cell uses the public-domain 5 GHz frequency range with a maximum transmission bandwidth of 20 MHz. A distinction is made between 'supplemental downlink' mode, where only the capacity of the downlink is increased and 'carrier aggregation', where the capacity of the uplink and downlink is increased by using the 5 GHz spectrum. The parameters of the air interface for the primary and secondary radio cell are identical in principle, apart from the transmit power. Additional capabilities are required only for the air interface of the secondary radio cell, to ensure compatibility with the existing systems in the 5 GHz band. Thus the secondary cell transmitter, as with all other WLANs, may send radio signals only if it is guaranteed that the radio link is not already occupied by another system.
- LTE WLAN aggregation (LTE-LWA) is a specification which, like LTE-LAA, uses frequencies from the unlicensed 5 GHz band for data transmission, in addition to the frequencies in licensed bands. In this case the mobile radio equipment uses 5 GHz WLAN access point signals. In the future, with the completion of 3GPP rel 14, LTE devices are to be specified so that signals from the 60-GHz band can be used in addition to signals in the 5 GHz band. As in the case of LTE-LAA, for LTE-LWA, at the same time as a connection via the secondary cell a connection is also required via a primary radio cell, i.e. in a licensed frequency band.

In addition to LTE extensions for operation in unlicensed bands, manufacturers are driving development for LTE-based systems in unlicensed bands. MultiFire is a corresponding standard for LTE-based systems which works in unlicensed frequency bands without requiring a connection via a primary LTE radio cell in a licensed band.

6 Standards, frequencies and transmit powers for WLANs in Switzerland

In Switzerland only wireless networks which meet the following standards may be operated:

- DECT
- In the 24 GHz band, all equipment which meets the EN 300 328-2 standard, including IEEE 802.11, IEEE 802.11b and IEEE 802.11g

- In the 5 GHz band, all equipment which meets the EN 301 893 standard and which falls within the framework of ERC/DEC(04)08[5] (see Decides 1 – 6). This includes IEEE 802.11h and IEEE 802.11n, and with specific measures also IEEE 802.11a and IEEE 802.11ac.
- In the 6 GHz band, all equipment which meets the EN 303 687 standard[6] and falls within the framework of ECC Decision (20)01.[7] This includes IEEE 802.11ax.
- Bluetooth

The public-domain frequency ranges released for WLAN systems are in the 800 MHz, 2.4 GHz, 5 GHz and 60 GHz frequency band. There is no protection from interference in these bands. The following frequency ranges and transmit powers are available in Switzerland for WLAN systems:

Frequency band	Frequency range	max. EIRP [mW]
2.4 GHz band (ISM band)	2400 – 2483.5 MHz	100
5 GHz band	5150 – 5350 MHz [a)]	200
5 GHz band	5470 – 5725 MHz	1,000
6 GHz band	5945 – 6425 MHz	200 (Low Power Indoor) 25 (Very Low Power)
60 GHz band	57 – 66 GHz	20/MHz, max 10,000
800 MHz band	863 – 868 MHz	25

a) WLANs to standard EN 301 893 and restricted to indoor use.

The technical interface requirements define one of the conditions for the market access of radio equipment. They describe the frequency characteristics and the radio parameters, as well as the permissible measuring procedures. For WLANs, technical interface requirements[8] are legally binding.

Directional antennas for WLANs are available on the market or in some cases are independently manufactured. Such antennas can serve to reduce reciprocal interference of different systems or adjoining cells, increasing the range or data throughput. The operation of equipment with such an antenna is, however, permissible only if the maximum transmitting power EIRP does not exceed that indicated in the above table. The user of the equipment is responsible for compliance with the regulations in force (EIRP, indoors for 5 GHz, etc.). In practice this means that the transmit power must be reduced if a directional antenna is used.

6.1 ERC/DEC(04)08 at a glance

The following table contains the requirements for WLAN equipment covered by European decision ERC/DEC (04)08.

5 https://docdb.cept.org/document/415

6 EN 303 687 - V1.0.0 - 6 GHz WAS/RLAN; Harmonised Standard for access to radio spectrum (etsi.org)

7 https://docdb.cept.org/document/16737

8 https://www.bakom.admin.ch/bakom/en/homepage/equipments-and-installations/particular-equipment/wlan-rlan.html

Frequency range	5150 – 5250 MHz	5250 – 5350 MHz	5470 – 5725 MHz
Indoor or Outdoor use	Indoor only	Indoor only	Indoor and Outdoor
Max. mean e.i.r.p	200 mW	200 mW	1000 mW
Max. mean e.i.r.p. density	10 mW in any 1 MHz	10 mW in any 1MHz	50 mW in any 1 MHz
Required standard compliance	EN 301 893	EN 301 893	EN 301 893
TPC or 3 dB power reduction required	no	yes	yes
DFS complying with ITU-R M.1652 Annex 1	no	yes	yes
Uniform random channel selection	yes	yes	yes

6.2 ECC Decision (20)01 at a glance

The following tables contain the requirements for WLAN equipment covered by European decision ECC (20)01.

Low Power Indoor (LPI) devices

Parameter	Technical conditions
Permissible operation	Restricted to indoor use only (including trains where metal coated windows (note 1) are fitted and aircraft) Outdoor use (including in road vehicles) is not permitted.
Category of device	An LPI access point or bridge that is supplied power from a wired connection, has an integrated antenna and is not battery powered. An LPI client device is a device that is connected to an LPI access point or another LPI client device and may or may not be battery powered.
Frequency band	5945 – 6425 MHz
Channel access and occupation rules	An adequate spectrum sharing mechanism shall be implemented.
Maximum mean e.i.r.p. for in-band emissions (note 2)	23 dBm
Maximum mean e.i.r.p. density for in-band emissions (note 2)	10 dBm/MHz
Maximum mean e.i.r.p. density for out-of-band emissions below 5935 MHz (note 2)	-22 dBm/MHz
Note 1: Or similar structures made of material with comparable attenuation characteristics. Note 2: The 'mean e.i.r.p.' refers to the e.i.r.p. during the transmission burst, which corresponds to the highest power, if power control is implemented.	

Very Low Power (VLP) devices

Parameter	Technical conditions
Permissible operation	Indoors and outdoors Use on drones is prohibited
Category of device	The VLP device is a portable device
Frequency band	5945 – 6425 MHz
Channel access and occupation rules	An adequate spectrum sharing mechanism shall be implemented.
Maximum mean e.i.r.p. for in-band emissions (note 1)	14 dBm
Maximum mean e.i.r.p. density for in-band emissions (note 1)	1 dBm/MHz
Narrowband usage maximum mean e.i.r.p. density for in-band emissions (note 1) (note 2)	10 dBm/MHz
Maximum mean e.i.r.p. density for out-of-band emissions below 5935 MHz (note 1)	-45 dBm/MHz (note 3)
Note 1: The 'mean e.i.r.p.' refers to the e.i.r.p. during the transmission burst, which corresponds to the highest power, if power control is implemented. Note 2: Narrowband (NB) devices are devices that operate in channels bandwidths below 20 MHz. Narrowband devices also require a frequency hopping mechanism based on at least 15 hop channels to operate at a PSD value above 1 dBm/MHz. Note 3: ECC will study the appropriateness of this level of OOBE by 31/12/2024. In absence of justified evidence, a value of -37 dBm/MHz will be adopted from 1 January 2025.	

7 WLAN air interfaces

The following table gives an overview of the air interfaces of WLAN systems.

Standard	Frequency range (GHz)	Number of channels	Bandwidth (MHz)	PHY Datarate (/s)	Modulation	Spreading	Channel access	max. Transmit power (mW EiRP)	Range (m)
DECT	1.88 - 1.90	10	0.864 (3dB)	0.8448 (GFSK) ⋮ 5.07 (64-QAM)	GFSK (B·T=0.5) π/2-DBPSK π/4-DQPSK ⋮ 16-QAM 64-QAM	no spreading	TDMA/FDM	250	300
Bluetooth	2.4 - 2.4835	79	1	1	GFSK	FHSS	TDD/FH	1 / 2.5 / 100	2 - 100
IEEE 802.11	2.4 - 2.4835	79	1	1	2-level GFSK	FHSS	CSMA/CA	100	20 - 100
			1	2	4-level GFSK				
		13	22	1	DBPSK	DSSS			
			22	2	DQPSK				
IEEE 802.11b	2.4 - 2.4835	13	22	1	DBPSK	DSSS	CSMA/CA	100	40 - 100
			22	2	DQPSK				
			22	5.5, 11	DBPSK / CCK / PBCC	DSSS	CSMA/CA	100	
IEEE 802.11g	2.4 - 2.4835	13	22	1	DBPSK	DSSS	CSMA/CA	100	40 - 140
			22	2	DQPSK				
			22	5.5, 11	DQPSK / CCK / PBCC				
			22	22, 33	8-PSK / ER-PBCC				
		3 / 7[d)]	22	6, 9	BPSK	DSSS / OFDM			

Standard	Frequency range (GHz)	Number of channels	Bandwidth (MHz)	PHY Datarate (/s)	Modulation	Spreading	Channel access	max. Transmit power (mW EiRP)	Range (m)
			22	12, 18	QPSK				
			22	24, 36	16-QAM				
			22	48, 54	64-QAM				
IEEE 802.11a	5.15 - 5.25 a) 5.25 - 5.35 a) c)	4 a)	20	same as IEEE 802.11h	same as IEEE 802.11h	OFDM 64 subcarriers (Δf = 312.5 kHz)	CSMA/CA / TDMA/TDD	Indoors 200	40 - 120
	5.47 - 5.725 c)	15 c)						1000	
IEEE 802.11h	5.15 - 5.35 a)	8 a)	20	6, 9 b)	BPSK	OFDM 64 subcarriers (Δf = 312.5 kHz)	CSMA/CA / TDMA/TDD	Indoors 200	40 - 120
				12, 18 b)	QPSK				
				24, 36 b)	16-QAM				
				48 b), 54 b)	64-QAM b)				
	5.47 - 5.725	11		6, 9 b)	BPSK			1000	
				12, 18 b)	QPSK				
				24, 36 b)	16-QAM				
				48b), 54b)	64-QAM b)				
IEEE 802.11n	2.4 - 2.4835	8 x 20 MHz 4 x 40 MHz	20 40	150 (1 stream) 300 (2 streams) 450 (3 streams) 600 (4 streams)	BPSK QPSK ⋮ 64-QAM	4 x 4 MIMO OFDM 128 subcarriers (Δf = 312.5 kHz)	CSMA/CA / TDMA/TDD	100	70 - 250
	5.15 - 5.35 a)	19 x 20 MHz 9 x 40 MHz						Indoors 200	
	5.47 - 5.725							1000	
IEEE 802.11ac (Gigabit WLAN)	5.15 - 5.25 a) 5.25 - 5.35 a) c)	2 x 80 MHz 1 x 160 MHz	20 40 80 160 (optional)	867 (1 stream) 1,733 (2 streams) 2,600 (3 streams) 3,467 (4 streams) 6,933 (8 streams)	BPSK QPSK ⋮ 256-QAM	8 x 8 MIMO OFDM 512 subcarriers (Δf = 312.5 kHz)	CSMA/CA / TDMA/TDD	Indoors 200	40 - 120
	5.47 - 5.725 c)							1000	
IEEE 802.11ax	2.4 - 2.4835	8 x 20 MHz 4 x 40 MHz	20 40 80 160	1,201 (1 stream) 2,402 (2 streams) 3,603 (3 streams) 4,803 (4 streams) 6,005 (5 streams) 7,205 (6 streams) 8,406 (7 streams)	BPSK QPSK ⋮ 1024-QAM	8 x 8 MIMO UL/DL OFDM 2048 subcarriers (Δf = 78.125 kHz)	OFDMA	100	40 - 120
	5.15 - 5.25 a) 5.25 - 5.35 a) c)	2 x 80 MHz 1 x 160 MHz						Indoors 200	
	5.47 - 5.725 c)							1000	
	5.945-6.425	24 x 20 MHz						25	

Standard	Frequency range (GHz)	Number of channels	Bandwidth (MHz)	PHY Datarate (/s)	Modulation	Spreading	Channel access	max. Transmit power (mW EiRP)	Range (m)
		12 x 40 MHz 6 x 80 MHz 3 x 160 MHz		9,607 (8 streams)				Indoors 200	
IEEE 802.11ad (Wigig)	57 - 66	4	1’830.5	385 - 4’620 (SC) 693 - 6’757 (OFDM)	SC: π/4-BPSK π/4-QPSK π/4-16-QAM Spread QPSK OFDM: QPSK 16-QAM 64-QAM	SC: 1’760 Msym/s OFDM: 355 act. subcarrier (Δf = 5.15625 MHz)	TDMA/LBT	1000	10
IEEE 802.11ah (HaLow)	863 - 868 MHz	5 (1 MHz) 2 (2 MHz)	1 2	up to 8’670	BPSK QPSK ⋮ 256-QAM	OFDM 64 subcarrier (Δf = 31.25 kHz)	CSMA/CA/ TDMA/TD	25 e.r.p.	<1000
LTE-LAA	5.15 - 5.35 5.47 - 5.725	10 x 20 MHz 12 x 20 MHz	20 20	max. 100.8	QPSK 16 QAM 64 QAM	OFDM (Δf=15kHz)	TDD / LBT	200	40-120

a) Indoors only permitted

b) Optional

c) *not permitted throughout Europe because of absence of TPC and DFS mitigation techniques (acc. to ERC/DEC(04)08, Decides 1– 6 and EN 301 893)*

d) overlapping

8 Registration obligation for WLAN operators

The question of compulsory registration is often posed by users of a public WLAN hotspot.

The Telecommunications Act does not provide for any obligation to notify or register users of the means of communication. The telecommunications service provider (TSP) registered with OFCOM or known WLAN access providers are usually contacted by FDJP agencies (Federal Department of Justice and Police) to ensure monitoring of postal and telecommunications services. OFCOM cannot provide any information on this; you are therefore requested to contact the competent authorities. You can find more information on this at: www.li.admin.ch

In relation to WLAN hotspots it should be noted here that the predominant proportion of such internet accesses does not constitute a telecommunications service under the telecommunications legislation, since these are limited to transmission to one or an adjacent property. The actual internet access telecommunications service is provided in this case by a TSP from the property and the associated network access point. This corresponds by analogy to the rating for telephone equipment of restaurants or businesses in the past.

As soon as a company provides communication services to third parties across multiple properties which do not serve internal company communication, a telecommunications service must be assumed. It must be noted that the mere cession or granting of an access to a service of a registered TSP does not constitute an active offering; it would have to constitute an independent service to a customer in order to constitute the basis for registration. This is accepted, for example, if restaurants first conflate the communication services included in the offering for guests within the group (e.g. a hotel chain) via their own (virtual) infrastructures brought together and only transfer centrally to another TSP at a remote location.

Since 2021, OFCOM has only registered and published TSPs which use certain resources under national administration in Switzerland for the services, e.g. within the framework of a radiocommunications licence.

The permissible radio frequencies for WLAN do not require a licence. If telecommunications services are provided by means of WLAN, this does not require standard registration and publication as a TSP with OFCOM. TSPs registered for other reasons must identify telecommunication services via WLAN as 'Local RAN'.

Further answers to questions on TSP registration and publication can be found in our factsheet on the subject, available online here:

https://www.bakom.admin.ch/bakom/en/homepage/telecommunication/telecommunication-services-providers/registration-and-publication-as-a-tsp.html

9 Annex

9.1 Other sources of information

IEEE 802 LAN/MAN Standards Committee	http://www.ieee802.org
ETSI, EP BRAN	http://www.etsi.org, http://pda.etsi.org/pda/queryform.as
OFCOM	https://www.bakom.ad-min.ch/bakom/en/homepage.html
Elektronik Kompendium	http://www.elektronik-kompen-dium.de/sites/net/0610051.htm

9.2 Abbreviations

3GPP	3rd Generation Partnership Project
ADSL	Asymmetrical Digital Subscriber Line
AP	Access Point
ARQ	Automatic repeat request
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CCK	Complementary Code Keying
CDMA [a)]	Code Division Multiple Access
CEPT	European Conference of Postal and Telecommunications Administrations
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CSMA/CD	Carrier Sense Multiple Access with Collision Detection
dB	Decibel
dBc	Decibel relative to the carrier
dBm	Decibel relative to one milliwatt
DBPSK	Differential Binary Phase Shift Keying
DECT	Digital Enhanced Cordless Telecommunications
DES	Data Encryption Standard
DFS	Dynamic frequency selection
DPRS	DECT Packet Radio Service
DQPSK	Differential Quadrature Phase Shift Keying
DS	Direct Sequence
DSSS	Direct sequence spread spectrum
EIRP	Equivalent Isotropic Radiated Power
ERP	Effective radiated power
ER-PBCC	Extended Packet Binary Convolutional Coding
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDD	Frequency division duplex
FDMA [b)]	Frequency Division Multiple Access
FEC	Forward error correction
FH	Frequency hopping

FHSS	Frequency hopping spread spectrum
FSK	Frequency shift keying (4FSK = 4 level FSK)
FTP	File Transfer Protocol
GFSK	Gaussian Frequency Shift Keying
GMSK	Gaussian Minimum Shift Keying
GSM	Global System for Mobile Communication
HF	High Frequency
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISM	Industrial, Scientific and Medical
ITU	International Telecommunication Union
LAN	Local area network
LTE	Long Term Evolution (3rd generation mobile radio)
LTE-LAA	LTE-License Assisted Access
LTE-LWA	LTE-WLAN Aggregation
MAC	Media Access Control (OSI Layer 2)
MAN	Metropolitan Area Network
Mbit/s	Megabits (10^6 bit) per second
MIMO	Multiple Input Multiple Output (multiple antennas)
m-PSK	Phase Shift Keying with m-phase states
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA [d)]	Orthogonal Frequency Division Multiple Access
OSI	Open Systems Interconnection
PAN	Private Area Network
PBCC	Packet Binary Convolutional Coding
PC	Personal Computer
PHY	Physical air interface (OSI Layer 1)
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RLAN	Radio local area network
SAE	Simultaneous Authentication of Equals
SC	Single Carrier
SHA	Secure Hash Algorithm
TCP/IP	Transmission Control Protocol / Internet Protocol
TDD	Time Division Duplex
TDMA [c)]	Time Division Multiple Access
TSP	Telecommunications service provider
TPC	Transmit power control

UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
WAN	Wide Area Network
WEP	Wired Equivalent Privacy
WiFi	Wireless Fidelity
WLAN	Wireless Local Area Network
WPAN	Wireless Private Area Network
WPA	Wi-Fi Protected Access

a) Code division multiple access (CDMA): in this procedure, codes are assigned to the individual subscribers. The signal to be transmitted is spread and transmitted with this code. In the receiver, the signal is re-assembled using the same code and the original signal is recovered in this way. The bandwidth of the signal to be transmitted can be selected by allocation of corresponding codes. In this procedure, central stations and user stations transmit continuously; the transmitted signal is kept just above the absolutely essential minimum.

b) Frequency-division multiple access (FDMA): in this procedure, the individual connections are transmitted on separate frequencies. The range of the individual connections can be adapted dynamically depending on volumes of traffic. In this procedure, the central station and the user station transmit continuously for the duration of the connection.

c) Time-division multiple access (TDMA): in this procedure time slots are made available to the individual users; they transmit their data during these slots. Multiple time slots can be combined for higher data rates. In this procedure, the central station normally transmits continuously; the user station transmits in the cycle of its assigned time slots.

d) Combined frequency and time division multiplexing (OFDMA): in this procedure, the resources in the time-frequency space are allocated to the individual subscribers, which enables the simultaneous data transmission of several users.

In addition to the above-mentioned access procedures, combinations exist, such as, for example, CDMA with TDMA.

9.3 Derivation of bit rates (gross) of some OFDM systems

Standard IEEE					802.11g	802.11a	802.11n				802.11ac							
Band					2.4 GHz	5 GHz	2.4 GHz / 5 GHz				5 GHz							
Bandwidth [MHz]					20	20	20		40		20		40		80		160	
Subcarrier total					64	64	64	64	128	128	64	64	128	128	256	256	512	512
Subcarrier spacing [kHz]					312.5	312.5	312.5	312.5	312.5	312.5	312.5	312.5	312.5	312.5	312.5	312.5	312.5	312.5
Pilot subcarrier					4	4	4	4	6	6	4	4	6	6	8	8	16	16
Null subcarrier					12	12	8	8	14	14	8	8	14	14	14	14	28	28
Data subcarrier					48	48	52	52	108	108	52	52	108	108	234	234	468	468
Symbol time [µs]					3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Guard interval [µs]					0.8	0.8	0.8	0.4	0.8	0.4	0.8	0.4	0.8	0.4	0.8	0.4	0.8	0.4
Block time [µs]					4.0	4.0	4.0	3.6	4.0	3.6	4.0	3.6	4.0	3.6	4.0	3.6	4.0	3.6
PHY overhead					45%	45%	39%	30%	36%	27%	39%	30%	36%	27%	29%	20%	29%	20%
Symbol rate [MSym/s]					**12**	**12**	**13.0**	**14.44**	**27.0**	**30.0**	**13.0**	**14.44**	**27.0**	**30.0**	**58.5**	**65.0**	**117.0**	**130.0**
MIMO	Streams	Modulation [1]	Coderate	Bits/Symbol	Bitrate [MBit/s]	Bitrate [MBit/s]	Bitrate [MBit/s]		Bittrate [MBit/s]		Bitrate [MBit/s]		Bitrate [MBit/s]		Bitrate [MBit/s]		Bitrate [MBit/s]	
	1	1	1/2	0.5	6	6	6.50	7.22	13.5	15.0	6.50	7.22	13.50	15.00	29.3	32.5	58.5	65.0
	1	1	3/4	0.75	9	9	9.75	10.83	20.3	22.5	9.75	10.83	20.25	22.50	43.9	48.8	87.8	97.5
	1	2	1/2	1	12	12	13.00	14.44	27.0	30.0	13.00	14.44	27.00	30.00	58.5	65.0	117.0	130.0
	1	2	3/4	1.5	18	18	19.50	21.67	40.5	45.0	19.50	21.67	40.50	45.00	87.8	97.5	175.5	195.0
	1	4	1/2	2	24	24	26.00	28.89	54.0	60.0	26.00	28.89	54.00	60.00	117.0	130.0	234.0	260.0
	1	4	3/4	3	36	36	39.00	43.33	81.0	90.0	39.00	43.33	81.00	90.00	175.5	195.0	351.0	390.0
	1	6	2/3	4	48	48	52.00	57.78	108.0	120.0	52.00	57.78	108.00	120.00	234.0	260.0	468.0	520.0
	1	6	3/4	4.5	**54**	**54**	58.50	65.00	121.5	135.0	58.50	65.00	121.50	135.00	263.3	292.5	526.5	585.0
1 x 1 (non-MIMO)	1	6	5/6	5			65.00	**72.22**	135.0	**150.0**	65.00	72.22	135.00	150.00	292.5	325.0	585.0	650.0
	1	8	3/4	6							78.00	86.67	162.00	180.00	351.0	390.0	702.0	780.0
	1	8	5/6	6.67							86.67	**96.30**	180.00	**200.00**	390.0	**433.3**	780.0	**866.7**
	2	1	1/2	1			13.00	14.44	27.0	30.0	13.00	14.44	27.00	30.00	58.5	65.0	117.0	130.0
	2	2	1/2	2			26.00	28.89	54.0	60.0	26.00	28.89	54.00	60.00	117.0	130.0	234.0	260.0
	2	2	3/4	3			39.00	43.33	81.0	90.0	39.00	43.33	81.00	90.00	175.5	195.0	351.0	390.0
	2	4	1/2	4			52.00	57.78	108.0	120.0	52.00	57.78	108.00	120.00	234.0	260.0	468.0	520.0
	2	4	3/4	6			78.00	86.67	162.0	180.0	78.00	86.67	162.00	180.00	351.0	390.0	702.0	780.0
	2	6	2/3	8			104.00	115.56	216.0	240.0	104.00	115.56	216.00	240.00	468.0	520.0	936.0	1'040.0
2 x 2	2	6	3/4	9			117.00	130.00	243.0	270.0	117.00	130.00	243.00	270.00	526.5	585.0	1'053.0	1'170.0
	2	6	5/6	10			130.00	**144.44**	270.0	**300.0**	130.00	144.44	270.00	300.00	585.0	650.0	1'170.0	1'300.0
	2	8	3/4	12							156.00	173.33	324.00	360.00	702.0	780.0	1'404.0	1'560.0
	2	8	5/6	13.33							173.33	**192.59**	360.00	**400.00**	780.0	**866.7**	1'560.0	**1'733.3**
	3	1	1/2	1.5			19.50	21.67	40.5	45.0	19.50	21.67	40.50	45.00	87.8	97.5	175.5	195.0
	3	2	1/2	3			39.00	43.33	81.0	90.0	39.00	43.33	81.00	90.00	175.5	195.0	351.0	390.0
	3	2	3/4	4.5			58.50	65.00	121.5	135.0	58.50	65.00	121.50	135.00	263.3	292.5	526.5	585.0
	3	4	1/2	6			78.00	86.67	162.0	180.0	78.00	86.67	162.00	180.00	351.0	390.0	702.0	780.0
	3	4	3/4	9			117.00	130.00	243.0	270.0	117.00	130.00	243.00	270.00	526.5	585.0	1'053.0	1'170.0
	3	6	2/3	12			156.00	173.33	324.0	360.0	156.00	173.33	324.00	360.00	702.0	780.0	1'404.0	1'560.0
3 x 3	3	6	3/4	13.5			175.50	195.00	364.5	405.0	175.50	195.00	364.50	405.00	789.8	877.5	1'579.5	1'755.0
	3	6	5/6	15			195.00	**216.67**	405.0	**450.0**	195.00	216.67	405.00	450.00	877.5	975.0	1'755.0	1'950.0
	3	8	3/4	18							234.00	260.00	486.00	540.00	1'053.0	1'170.0	2'106.0	2'340.0
	3	8	5/6	20							260.00	**288.89**	540.00	**600.00**	1'170.0	**1'300.0**	2'340.0	**2'600.0**
	4	1	1/2	2			26.00	28.89	54.0	60.0	26.00	28.89	54.00	60.00	117.0	130.0	234.0	260.0
	4	2	1/2	4			52.00	57.78	108.0	120.0	52.00	57.78	108.00	120.00	234.0	260.0	468.0	520.0
	4	2	3/4	6			78.00	86.67	162.0	180.0	78.00	86.67	162.00	180.00	351.0	390.0	702.0	780.0
	4	4	1/2	8			104.00	115.56	216.0	240.0	104.00	115.56	216.00	240.00	468.0	520.0	936.0	1'040.0
	4	4	3/4	12			156.00	173.33	324.0	360.0	156.00	173.33	324.00	360.00	702.0	780.0	1'404.0	1'560.0
	4	6	2/3	16			208.00	231.11	432.0	480.0	208.00	231.11	432.00	480.00	936.0	1'040.0	1'872.0	2'080.0
4 x 4	4	6	3/4	18			234.00	260.00	486.0	540.0	234.00	260.00	486.00	540.00	1'053.0	1'170.0	2'106.0	2'340.0
	4	6	5/6	20			260.00	**288.89**	540.0	**600.0**	260.00	288.89	540.00	600.00	1'170.0	1'300.0	2'340.0	2'600.0
	4	8	3/4	24							312.00	346.67	648.00	720.00	1'404.0	1'560.0	2'808.0	3'120.0
	4	8	5/6	26.67							346.67	**385.19**	720.00	**800.00**	1'560.0	**1'733.3**	3'120.0	**3'466.7**
	8	2	1/2	8.00							104.0	115.56	216.00	240.00	468.0	520.0	936.0	1'040.0
	⋮	⋮	⋮	⋮							⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
8 x 8	8	8	5/6	53.33							693.3	**770.37**	1'440.0	**1'600.0**	3'120.0	**3'466.7**	6'240.0	**6'933.3**

1) 1: BPSK
2: QPSK
4: 16-QAM
6: 64-QAM
8: 256-QAM

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