*International Journal of Computational and Experimental Science and ENgineering*
*(IJCESEN)*

*Vol. 11-No.3 (2025) pp. 4642-4654*
*http://www.ijcesen.com*

*Copyright © IJCESEN*

***ISSN: 2149-9144***

**Research Article**

# A new approach of wireless communication system using quality of service requirements system satisfaction

**Maha Abdulameer Kadhim***

Middle Technical University (MTU) professor, Baghdad, Iraq
*** Corresponding Author Email**: Maha.abd@mtu.edu.iq- **ORCID:** 0000-0002-6459-5862

**Article Info:**

**DOI:** 10.22399/ijcesen.2869
**Received :** 21 April 2025
**Accepted :** 19 June 2025

**Keywords**

Wireless networks
Nodes
Transferred data
Modulation
Citizen network

**Abstract:**

During our autopsy, we studied and identified the main components of local wireless networks and presented some of the work of the scientific community on these same networks. Nevertheless, and despite the ambition of the MANET group, it is clear that all contributions on wireless networks is focused on the management of physical layers, access methods, mobility, routing. This is partly due to the complexity inherent in the layered construction of these networks. There has been no disruption of usage related to the proliferation of wireless networks: on the contrary, these networks are today mainly used as a local network for individuals to distribute access to the Internet. However, examples of new uses mentioned in MANET, such as mesh networks, are almost non-existent in current use; the few initiatives are the work of research groups, wishing to experiment the behavior of protocols on localized or groups of voluntary users, who take advantage of the possibilities of certain embedded hardware, such as some routers using Linux as an operating system to integrate routing functions into an 802.11 access point, and thus creating a community network, like the Citizen network in Belgium[1]. However, from the very confession of the users, these networks are rather inefficient, and pose problems ranging from the setting up of new nodes, addressing, routing, naming, reaction times, security transferred data.

## 1. Introduction

The purpose of this standard is to "provide wireless connectivity to automatic machines, equipment, or stations that require rapid deployment, that can be portable or even hand, or mounted in mobile vehicles in an area However, this is more than that, in fact it is a question of meeting a need for wireless connectivity, in a constrained environment, with flexible regulation [1].As a result, local wireless networks are very promising. These networks have the immense advantage over other types of wireless networks of being multirole. Indeed, due to the speeds and the ranges considered, they assume perfectly connectivity at all the levels, that it is personal (radio link of computer computer-to-computer), local (replacement of traditional Ethernet networks), metropolitan (access to the Internet through a network of metropolitan terminals forming a single operator network or a city) or global (access to a hotspot).Nevertheless, the main problem lies in their design and integration into operating systems, deeply rooted in a local network vision. Local wireless networks, such as IEEE 802.11 or WiFi, are intrinsically an ad hoc replacement for wired Ethernet networks. As such, they include many of these concepts: CSMA / CD based CSMA / CA access method, physical layer architecture (PHY) and MAC recovery, use of a state machine to reproduce the connected / disconnected state of a cable connection, and of course support for the TCP / IP protocol layer.

## 2. The Physical Layer

IEEE 802.11 relies mainly on radio waves for the transmission of information. The sequences of bits to be transmitted (for example, packets following the TCP / IP protocol) are not transmitted as such in the air; indeed, the transmitted binary signal directly (so-called baseband transmission) would not be suitable for the wireless communication channel. In order to facilitate the propagation, the signal is modulated around a carrier frequency. Because the IEEE 802.11 network is designed for unlicensed use[2], designers move quickly to free frequency bands, including the

2.4 GHz Industrial, Scientific and Medical (ISM) bands and then the 5 GHz N-II bands. These frequencies belong to the frequency domain of microwaves whose wavelength is reduced, which facilitates the use of small size antennas and adapted for integration into mobile equipment. Finally, at this frequency, and for low power (between 10 and 100 mW), the range of the radio signal reaches 500 meters, which covers the spectrum of uses planned for IEEE 802.11. In order to improve the efficiency of the transmission, the bits are encoded in form of symbols, thanks to a modulation operation. IEEE 802.11 offers several modulation techniques.

### 2.1. Different Modulation Techniques

The modulation is generally performed in the electromagnetic field by changing the amplitude, frequency, or phase of the transmitted signal. IEEE 802.11 uses almost exclusively phase and amplitude modulations. The set of modulations used by IEEE 802.11 is based on an I (In phase) / Q (Quadrature) modulator, illustrated in (Figure. 1), composed of two multipliers, a carrier signal (here, either 2.4 GHz or 5 GHz), and a summoned. The advantage of this modulator is to transmit two information (I and Q) on a single carrier and using the bandwidth of a single component, I or Q.The principle is to represent in the I / Q plane the bits to be transmitted which constitute a symbol, then using an analog-digital converter, to constitute a signal I and a signal Q to be transmitted.

The main modulations used by IEEE 802.11 are:

- BPSK: 1 bit is transmitted by symbol;

- QPSK: 2 bits are transmitted by symbol;

- QAM: 4 or 6 bits are transmitted by symbol;

(Figure 2) illustrates the 4-bit coding forming a unique 16-state symbol in the I / Q plane.However, the transmission of these symbols on the public band may be impaired by other interference signals; in order to improve the resistance, IEEE 802.11 uses two techniques: spectrum broadening, and OFDM.

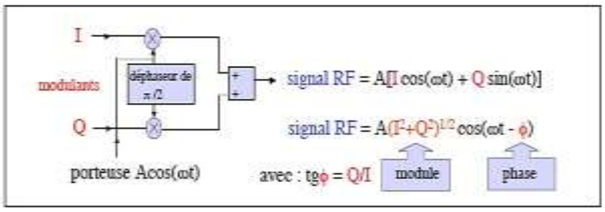


***Figure 1.*** *I / Q Modulator: Used for modulations in 802.11. (Excerpt from Gérard Couturier's course, IUT Bordeaux)*

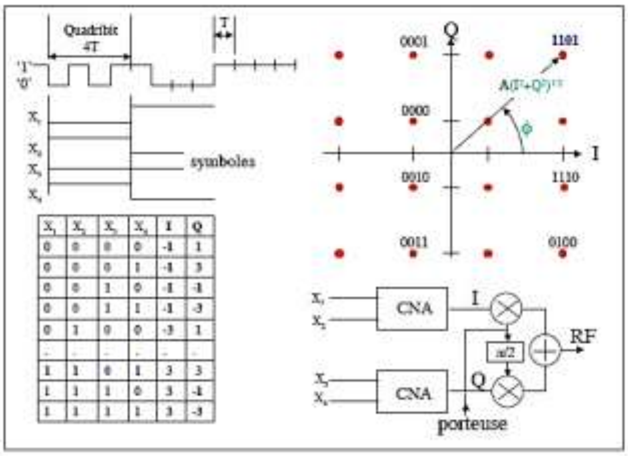


***Figure 2.*** *Principle of symbol coding for QAM modulation16. (Excerpt from Gérard Couturier's course, IUT Bordeaux)*

## 3. Family with Spectrum Broadening DSSS

This technique is based on broadening the band used by the useful signal so as to make it more resistant. To this end, the I / Q signals resulting from the setting of the symbol are multiplied by a pseudo-random sequence (Pseudo Random, P / R) called chipping, which, if it is known to the transmitter and receiver, allows the reception of the original signal. The sequence must have equilibrium property (there are as many as 0 and 1) and its cross-correlation by itself must allow the immediate detection of symbols.In the case of 802.11, the chipping sequence is called a barker (see Figure .3), and is composed of 11 bits (called chips). To obtain the nominal bit rate of 802.11, namely 1Mbits / s, it is therefore necessary to have an encoding rate of 1MSymbols / s. In order to maintain this rate, the sequence is encoded at 11 MHz. To receive all Elements of the sequence, it is necessary to have a sufficient sampling frequency: The Shannon theorem guarantees us that this one must be double of the maximum frequency of the signal to be sampled, i.e. here 22 MHz The 802.11 signals therefore occupy a frequency of 22 MHz on the frequency band.

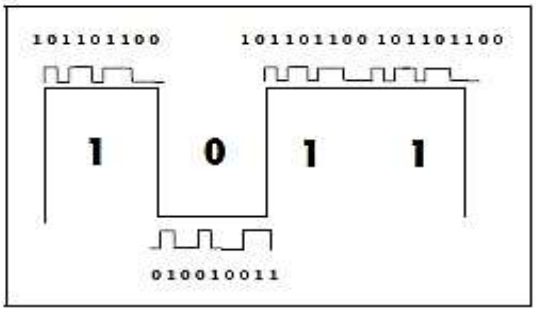


***Figure 3.*** *Barker Sequence: Chips used in 802.11 for 1 and 2Mbits / s data rates.*

In order to allow the simultaneous use of multiple 802.11 networks, the initial standard [3] provides that the frequency bands are split into channels on the 2.4 GHz frequency bands. The ISM 2.4GHz band is broken down into channels spaced at 5 MHz, and distributed between 2.400-2.4835 GHz, shown in the tables in Appendix A.1. The 5 MHz spacing for 22 MHz channel width means that adjacent channels are scrambled in between, so there are only 3 independent channels on the 2.4GHz ISM band. Nevertheless, the use of spread spectrum by chipping allows the coexistence of networks on adjacent channels, but the efficiency this cohabitation should be put into perspective considering the access method retained for 802.11, as we will see in the following section, dedicated to the study of the MAC layer.

### 3.1. CCK Family

Designers want to improve the spreading method to increase flow rates. In amendment 802.11b [4], the standard suggests an increase in bit rates by modifying the initial modulation: the modulation uses complementary multiphase codes (Polyphone Complementary Code). The code has the same autocorrelation properties as the barker sequence, except that this time is complex symbols instead of a binary sequence. The modulator encodes in successive bit blocks: 2 bits are used to describe the rotation of the code in the complex plane as shown in figure (4), and then the remaining bits are used for the polynomial code, either on 2 bits (4 codes available) or on 6 bits (64 bits). Available codes).

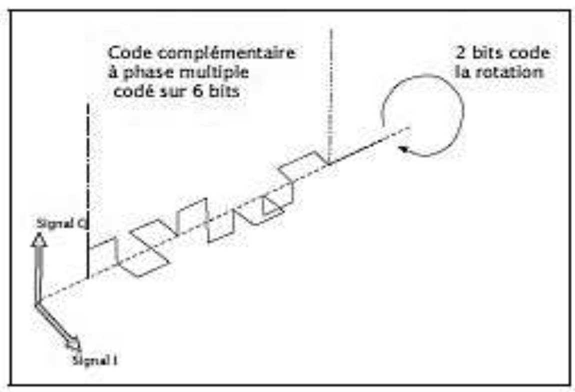


***Figure 4.*** *CCK Sequence: Complex chips used for 5.5 and 11 Mbps data rates.*

The theoretical rates provided for in Amendment 802.11b are then summarized in Figure 1. These flows constituted a first level in the theoretical flows. However, the search for higher speeds will lead the IEEE 802.11 group to take inspiration from new modulation techniques derived from modem transmissions. The Orthogonal Frequency Division Multiplexing (OFDM).

***Table 1.*** *Modulations used for the IEEE 802.11a standard and corresponding bit rates.*

| Modulation | BPSK | QPSK | DQPSK | DQPSK |
|---|---|---|---|---|
| Bits by symbols | 1 | 2 | 4 | 8 |
| Type of spreading | Barker | Barker | CCk | CCk |
| Chip size (bits) | 11 | 11 | 8 | 8 |
| Chipping speed | 11 | 11 | 11 | 11 |
| Bitrates (Mbps) | 1 | 2 | 5.5 | 11 |

### 3.2. OFDM Family

In modem transmissions, the goal was to significantly increase bandwidth; the first modems used modulations that maximized the number of bits transmitted in the bandwidth of the voice (i.e. 4 KHz). Flow rates were therefore quickly limited (standard modems reached speeds of 28.8 and then 56 Kbps). The idea was therefore to use frequencies different from that of the voice but the channel used (copper wire) was very selective in frequency: the spread of the delays is large in front of the transmission time of a symbol. The principle of OFDM is therefore to transmit the symbols under several carriers (called sub-carriers); it is therefore possible to transmit longer symbols, insensitive to delays, but in greater numbers, which leads to maintain the same rate as a traditional single-carrier modulation. OFDM is therefore a dual version of time-division multiplexing used on single-frequency modulations: multiplexing is here frequency. The spectral efficiency will characterize the modulations by subcarrier: it is about the bit rate per unit of frequency. The choice of subcarriers and their spacing will therefore influence the spectral efficiency. In order to maximize the spectral efficiency, the subcarriers must be closest to each other, while ensuring that the receiver is able to distinguish between them and is able to recover the transmitted symbols. This is true if the spectrum of a subcarrier is zero for the frequencies of another subcarrier as shown in figure (5): it is called orthogonal subcarrier, hence the term OFDM [5]. The carrier modulated signal with the use of a rectangular waveform (a binary signal consisting of a sequence of 0 and 1) has a spectrum defined by a cardinal sinus; It vanishes at given intervals. If Ts is the duration of a symbol, and the subcarriers are separated by an interval of 1 / Ts, we can obtain a superposition of subcarrier spectra guaranteeing the

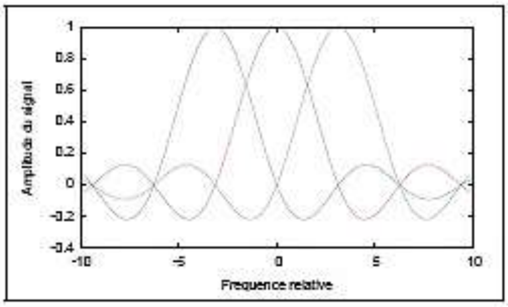


***Figure 5.*** *Superposition of the spectrum of 3 orthogonal subcarriers.*

recovery of each subcarrier as shown in Figure.5. The realization of an OFDM modulator can seem complex: indeed, it is necessary to have a set of orthogonal subcarriers. However, an OFDM symbol decomposes as a sum of components, which identifies with the inverse Fourier transform. From the formalism related to the Fourier transform, it is therefore entirely possible to carry out the inverse Fourier transformation of a continuous signal I or Q (derived from an I / Q modulator for example) into a component sum (Figure.6); to the transmission of this one, then to the reception of the components which allow by Fourier transform to find the initial continuous signal (Figure.7).

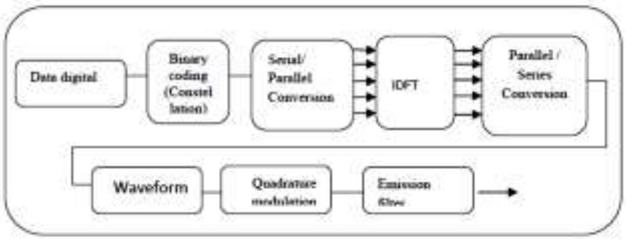


***Figure 6.*** *OFDM Transmitter by discrete inverse transform.*

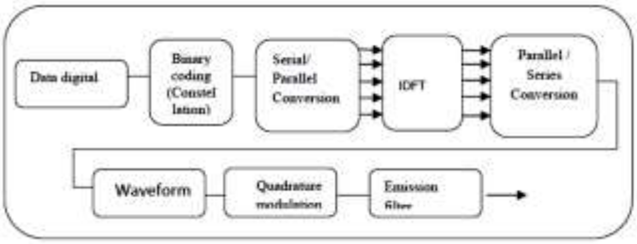


***Figure 7.*** *OFDM Receiver by discrete transform.*

In the context of IEEE 802.11, the OFDM was introduced by amendment 802.11a [6], on the 5GHz frequency band, in particular on the public band called NII, and introduced for this purpose by Apple by a petition in 1995. We detail the channels offered on this frequency range in the tables in Annex A.2, A.3, and A.4. The channel spacing ensures interference-free operation between 802.11 networks using adjacent channels [7]. IEEE 802.11a therefore uses the constellation coding techniques in the I / Q plan introduced by the previous amendments. Given the high data rates, the standard introduces Forward Error Correction (FEC) error correction codes. These codes consist of a redundancy of information to find corrupted data. This redundancy is expressed by encoding rates, which indicate the proportion of unique information on the sum of total information transmitted: 1/2 means that 2 bits are transmitted for 1 bit of unique information. Thus IEEE 802.11a uses 52 OFDM subcarriers, 48 of which are used for data transport, and 4 for channel calibration (called pilots). Each subcarrier uses the same type of modulation as the previous 802.11 amendments, namely BPSK, QPSK, 16- Quadrature Amplitude Modulation (16-QAM) or 64-QAM. The duration of a symbol is 4 µs.

***Table 2.*** *Modulations used for the IEEE 802.11a standard and corresponding bit rates.*

| Modulation | BPSK | BPSK | QPSK | QPSK |
|---|---|---|---|---|
| Bits per subcarrier | 1 | 1 | 2 | 2 |
| FEC code | 1/2 | 3/4 | 1/2 | 3/4 |
| Number of useful bits per symbol | 24 | 36 | 48 | 72 |
| Speeds | 6 | 9 | 12 | 18 |
| Modulation | QAM16 | QAM16 | QAM64 | QAM64 |
| Bits per subcarrier | 4 | 4 | 6 | 6 |
| FEC code | 1/2 | 3/4 | 2/3 | 3/4 |
| Number of useful bits per symbol | 96 | 144 | 192 | 216 |
| Speeds Mbps | 24 | 36 | 48 | 54 |

These modulations were subsequently reported on the ISM 2.4GHz band in the 802.11g amendment [8]. The gradual improvement of modulation techniques has resulted in a full range of flow rates.Therefore, these multiple modulations allow the maintenance of connectivity over a large area, to the detriment of the flow that will decrease with distance.802.11 do not propose a particular algorithm for the management of these different modulations. In the 802.11b amendment, the manufacturers mainly adopted the Auto Rate Fallback ARF algorithm implemented on the Waveland-II cards [9]: if too many losses are recorded with a modulation, the card uses a more resistant modulation (therefore, at a lower rate) in the modulations that are allowed in the 802.11 network considered.However, the use of these multiple rates on the same band involves the use of techniques allowing compatibility, even minimal. 802.11 propose two entities to solve this problem: the PLCP and the PMD.

### 3.3. An Effort for Compatibility: PLCP and PMD

From its conception, 802.11 have included the need to coexist several technologies on the same basis. For coexistence with 802.11 technologies, the standard offers an abstraction between data transmission and the different modulation standards: the Physical Layer Convergence Protocol (PLCP) and the Physical Medium Dependent (PMD).PLCP provides primitives to the medium access control layer (MAC layer - Medium Access Control). This is mainly to offer an abstraction to the MAC layer with respect to physical modulations that are managed by the PMD. PLCP provides a PLCP radio header to perform functions.PLCP proposes the following primitives:

**Determining the state of the channel:** This is done by two sub-functions: the Carrier Sense (CS) and the Clear Channel Assessment (CCA). The CS is used for reception: an 802.11 radio interface constantly polls the medium to decode the PLCP header, indicating that a transmission is taking place. The CCA is used when the medium access layer wishes to transmit a packet: if the channel is free, availability is indicated to the MAC layer; otherwise, an occupation is transmitted to it.

**Reception:** During a successful CS, the decoded PLCP header makes it possible to recover the PMD, which will be decoded by specific physical demodulation. The result of this operation is transmitted to the upper layers.

**Transmission:** If the CCA has indicated a free channel, then the data to be transmitted is encoded by the PMD and is preceded by a PLCP header. The interface transmits a PLCP header consisting of a preamble. The header introduced by the PLCP protocol is composed of several parts: it consists first of a preamble allowing the synchronization of the receiving stations and to identify the beginning of a transmission. This is distinct depending on the modulation family used.

## 4. Reflections on the Management of Multiple Flows

The adaptation of the rate (or rate control) has been the subject of many publications, mentioned by Lacage in [4]. The first algorithm proposed and adopted by most manufacturers, ARF was introduced in WaveLAN cards, the ancestors of IEEE 802.11 cards [9]. With ARF, transmitters choose higher rate modulation from a number of successful consecutive transmissions (10 for example), and switch to lower rate modulations in two consecutive failures. In a given time window. The transmission following the transmission after increase or decrease is called probe (or Probing) and must succeed immediately otherwise the flow returns to the initial value and the retry counter is reset.The problem of such a method is the unsuitability for rapid changes in the channel, for example during a mobile host or during ad hoc connection; from one package to another, the situation may change; from then on, the optimal throughput changes from packet to packet. The packet interval that gives rise to a reaction (2 packets for a low rate, 10 for a higher rate) is too large compared to the variability of the system. Paradoxically, ARF is also too responsive: in the context of a desktop use of the wireless network, the user does not move; there is therefore a relative stability of its transmissions. However, transmissions are often altered in consecutive groups in such an environment. ARF is therefore too reactive in this case, since 2 consecutive transmissions are enough to switch to a lower modulation. This instability is the consequence of the fact that the same regulation mechanism is used to manage short-term and long-term disturbances.In order to improve the reactivity of ARF, several solutions have been proposed. AARF [5] propose to dynamically modify ARF reactivity thresholds. In AARF, the evolution is controlled by a Binary Exponential Back off algorithm, similar to the one used in the contention window management algorithm in 802.11, which we will study in the section devoted to the MAC layer. Thus, when the probe packet is not acknowledged, the modulation is downgraded to a lower value, but the successful transmission interval is doubled before it can be switched to higher modulation. The immediate effect is that AARF stabilizes the connection by creating less transmission failure, since probe packets are further apart. The authors studied the possibilities of implementations, and identified 802.11 cards at low and high latency; AARF is under implementation called AMRR on high latency cards, at the cost of poorer responsiveness.

## 5. The MAC Layer

The Medium Access Control (MAC) layer manages access to the channel. As part of 802.11, as in the context of packet radio networks seen earlier in this script, several hosts compete to use the bandwidth offered by the radio channel used. In an almost perfect medium, such as the Ethernet copper pair, it is easy to identify whether a transmission is occurring or not; indeed, the electrical signals are easily detectable. In the context of a radio transmission, this exercise is not easy. Indeed, the complexity of the radio transmissions makes that a transmission is not necessarily acquired; electromagnetic disturbances may affect the quality of the received signal, the signal-to-noise ratio, which contributes to misinterpretation; a signal more powerful than another can totally hide the latter, it is the capture effect. In Ethernet, a collision between two emissions is detectable; on a radio link, the collision is not detectable because the situation at the receiver is unknown, the conditions are not necessarily the same. As we saw in the previous section, the 802.11 standard uses a set of primitives (CS, CCA) provided by PLCP to evaluate the availability of the channel during a transmission or to detect a transmission as part of a reception

## 6. Distributed Model, DCF

The medium access layer used primarily by IEEE 802.11 is the Distributed Coordination Function; it allows the automatic sharing of the medium between several hosts through the use of CSMA / CA and a random back off following a busy state of the channel. All direct traffic uses acknowledgments (ACK) in which case any retransmission is initiated if the ACK is not received by the transmitting station. The CSMA / CA protocol is designed to reduce the probability of collisions when multiple stations access the medium. CSMA / CA is a derivative of the access method used in ALOHA networks [6]. ALOHA is based on the following principle: a host wishing to transmit data sends them immediately, and if there is a collision, then the packet is simply sent back.The analysis of the effectiveness of this method shows that it does not make it possible to use a major part of the available channel. If one considers the arrival of the packets according to a process of fish of rate λ during the interval [0, t], then the number of transmitted packets X (t) is given by the following probability:

$$P\ (X\ (t) = k) = ((\lambda t)^{k} e^{-\lambda t}) / k \qquad (1)$$

In the case of an original ALOHA network, packets that precede a broadcast or are broadcast during a broadcast are collisions. In this case, the bandwidth is defined by

$$S = G * p\ (aucunecollision) \qquad (2)$$

Where G is the load, that is $G = \lambda * \tau = \lambda * N / R$ where N is the number of bits per packet and R the flow rate of the channel. The probability of having no collision during the emission of a user during [0, τ] is therefore the probability that no transmission intervenes during [-τ, τ], i.e.:

$$P\ (X\ (t = 2\tau) = 0) = e^{-2\lambda\tau} \qquad (3)$$

An effective bandwidth of:

$$S = G\ e^{-2G} \qquad (4)$$

The maximum bandwidth in this case is reached for G = 0.5, i.e. S = 0.18. In other words, the bitrate is only 18% of what one would have a single user, which is very low. The inefficiency is explained by the fact that in ALOHA, the absence of synchronization leads users to transmit on each other. By synchronizing the users so that the transmissions are time-aligned, the partial transmission overlays can be avoided. This is what Slotted ALOHA [8] proposes by dividing time in time slot of size τ. Thus, there is no partial recovery, and therefore a packet transmitted during the period [0, τ] is received correctly if no other packet is transmitted, which corresponds to the probability calculation with t = τ:

$$P\ (X\ (t = 2\tau) = 0) = e^{-\lambda\tau} \qquad (5)$$

An effective bandwidth:

$$S = G\ e^{-G} \qquad (6)$$

The efficiency here reaches 36% of the bandwidth for G = 1. Thus, Slotted ALOHA has a maximum bandwidth twice that of ALOHA, at the cost of a necessary synchronization. However, collisions can still occur if two hosts are transmitting during the same slot. To reduce the impact of collisions, the method of access can use the Carrier-Sense [7]. The principle is to listen to the channel and wait before transmitting if the channel is busy. Carrier Sense Medium Access may be p-persistent or non-persistent:In p-persistent mode, when the channel is empty, the host transmits with probability p; it differs its emission with the probability 1-p and repeats the same procedure. If the channel is busy, the host waits for availability to resume the same procedure.In non-persistent mode, when the channel is empty the host transmits the data; if the channel is busy, it chooses a random time interval before retrying a show.If the channel is free at this time, it transmits; otherwise it chooses a new random value waiting. Choosing a random time eliminates most of the collisions that result from simultaneous transmission at the busy / free transition.

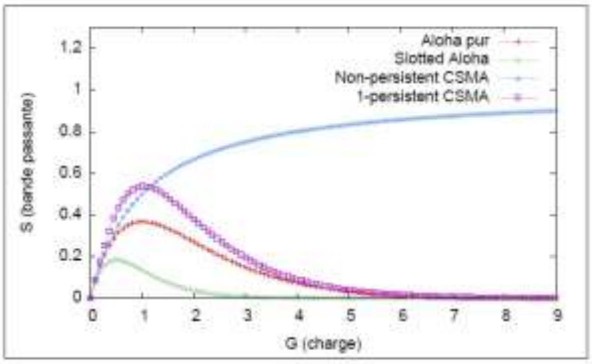


***Figure 8.*** *Comparative Efficacy of ALOHA, slotted ALOHA and CSMA.*

The effectiveness of the different methods is compared in Figure.8. In summary, methods based on ALOHA or slotted ALOHA do not allow maximum use of the channel. For low traffic levels, p-persistent CSMA offers the best bandwidth; for large volumes, non-persistent CSMAs offer the higher flows. The search for an optimum p can lead to interesting performances in the case of p-persistent CSMA; however, the performances of Slotted no persist CSMA are interesting in that the method does not require a search for the optimum: this is the method that was chosen for 802.11 DCF. 802.11 use time sharing as a slot. The slot has duration of 20 µs in the initial version of the standard; for amendment 802.11a and 802.11g, this duration is reduced to 9 µs.In 802.11, the Carrier-Sense (CS) step required by CSMA is performed through physical and virtual mechanisms. The physical mechanism is done through the PLCP, detailed in the previous section. The virtual mechanism is carried out meanwhile through a booking operation of the channel announcing the use of the medium to other stations. A Ready-To-Send (RTS) and Clear-To-Send (CTS) frame exchange is performed before sending the data.The RTS / CTS frames contain an 802.11 header indicating the Duration and Identification which defines the period of time for which the medium is to be reserved, which corresponds to the sending of the data and the receipt of the acknowledgment. All stations that are within reception range of the transmitting station (which sends the RTS) or the receiving station (which sends the CTS) can thus obtain information on the use of the channel. In this case, the stations update a Network Allocation Vector (NAV) that keeps track of the prediction of future traffic on the network. The RTS / CTS exchange is detailed in Figure.9. This exchange is however optional, and the choice of its use is left to the discretion of the users. The intervals between 802.11 frames are called Interface Space (IFS). A station therefore uses the channel status with the Carrier Sense during a dedicated interval. Four different intervals are used: SIFS, interface short space, PIFS, space interface PCF, DIFS, and space interface CFS, and extended interface space EIFS. Figure 10 shows the relationships between the different types of intervals.

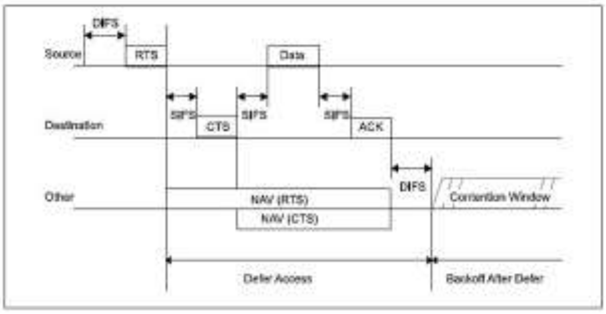


***Figure 9.*** *Virtual Carrier Sense Mechanism: RTS / CTS. (From IEEE specifications)*

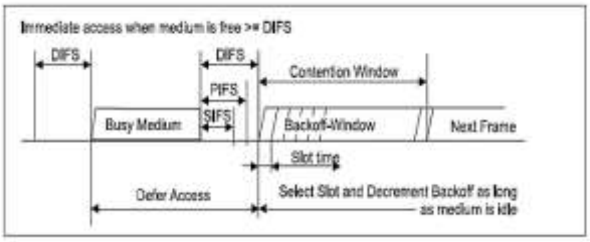


***Figure 10.*** *Relationship between the different IFS time units. (Extracted from IEEE specifications)*

The interval between a transmission and its acknowledgment is fixed at SIFS, whose value is fixed at 10 µs for 802.11-802.11b, and 16 µs for 802.11a. In the case of a compatibility mode for 802.11g, SIFS is set to 10 µs. EIFS is the interval corresponding to an expiration indicating a transmission error following the non-receipt of an acknowledgment; this value is calculated from the following formula:

$$EIFS=SIFS+(8*ACK\ Size)+Preamble+PLCP\ Header+DIFS$$

The silence interval to respect before a transmission attempt is set to DIFS. DIFS is calculated from the duration of a slot and SIFS. Thus for 802.11 / 802.11b, DIFS = 2 * slot + SIFS = 2 * 20 + 10 = 50µs; For 802.11a, DIFS = 2 * 9 + 16 = 34µs. Thus, after a DIFS interval (or EIFS if the last frame was wrong) the station must generate a random back off to perform an additional wait, using a back off count. This one consists of a random number of slots, calculated according to:

$$Backoff = Random\ () * Slot\ Time$$

Where Random () is a uniform draw function of an integer between the interval [0, CW [. CW being an integer representing the window of contention (or

Contention Window) varying between [CWmin, CWmax], two parameters function of the number of theoretical machines admitted in contention. The backoff mechanism is detailed in Figure 11. The evolution of the contention window (CW) follows a Binary Exponential Backoff (BEB) algorithm, that is to say that its value is doubled each aborted sending attempt following a busy channel. When CW reaches CWmax, the value remains maximum until the process is reset by successfully sending a frame. In 802.11 / 802.11b, CWmin is set to 31 slots, in 802.11a / g CWmin is set to 15 slots. The maximum backoff value is set to CWmax = 1024 slots. The evolution of CW values is shown in Figure.12.

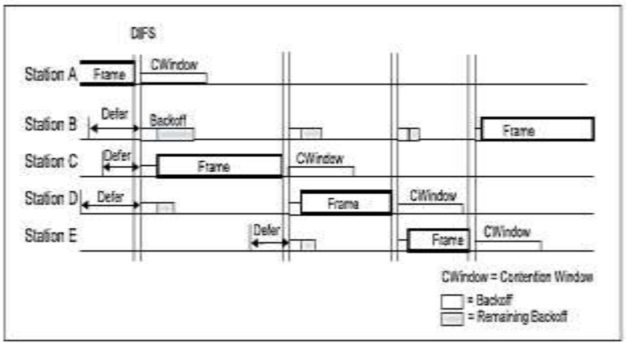


***Figure 11.*** *Backoff mechanism. (Extracted from IEEE specifications)*

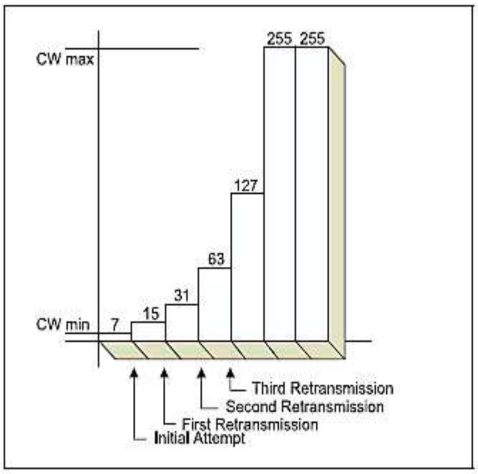


***Figure 12.*** *Evolution of CW Window Contention according to Binary Exponential Backoff. (Extracted from IEEE specifications)*

The minimal operation of DCF is summarized in Figure 13. It therefore offers a distributed and automatic medium sharing mechanism through the CSMA access method, and collision avoidance (CA) techniques. The Sense Carrier, both physical (provided by the PLCP) and virtual (provided by the headers of the RTS / CTS exchange) allows to determine the occupation of the channel (NAV positioning).

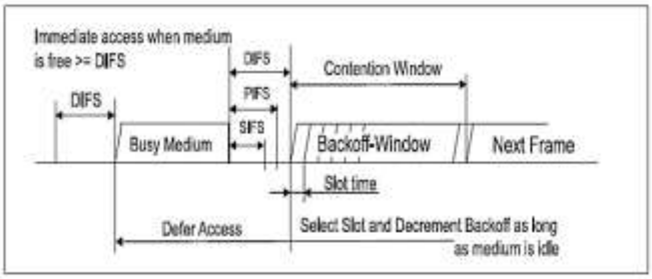


***Figure 13.*** *Operation of DCF. (Extracted from IEEE specifications)*

## 7. Calculation of Theoretical Flows

Knowing the physical characteristics of the transmissions, as well as the access method used for IEEE 802.11 networks, and the characteristics of the 802.11 protocol, it is easy for us to theoretically evaluate the average rates offered by saturated 802.11 networks for a single station. . The method consists in establishing a temporal report on a given transmission: each transmission on the channel is characterized by an inter-frame time (DIFS, SIFS ...), by a possible contention (random draw of a number of slots among CWmin), a PLCP header transmitted at a constant speed, then an 802.11 packet with a header of a certain size (depending on its nature: data packet, acknowledgment ...).

A UDP stream transmitted by a station can be defined as follows:

$$T_{UDP} = T_{DIFS} + T_{Contention} + T_{DATA} + T_{SIFS} + T_{ACK}$$

Where $T_{DIFS}$ and $T_{SIFS}$ are constant for a given 802.11 technology. The other times are calculated according to:

$$T_{DATA} = T_{PLCP} + T_{802.11} + T_{Ethernet}$$

$$T_{ACK} = T_{PLCP} + T_{802.11\text{-}ACK}$$

For contention, we consider the average value of a draw, knowing that there is no collision, the station being alone. Since then:

$$T_{Contention} = \frac{CW\ min}{2} * T_{slot} \qquad (7)$$

Where $T_{slot}$ is the duration of a slot. The durations $T_{802.11}$, $T_{802.11\text{-}ACK}$, $TE_{\mathbf{thernet}}$ correspond to the quantity of bytes transmitted at the speed considered. So, in general: T = Data /Speed. TPLCP times are based on 802.11 technologies, but remain constant so that all stations in range can decode the header and can position the NAV allocation vector to block their concurrent broadcast [8]. After calculation, we obtain the flow tables in Appendix D which we summarize the numerical results for 802.11b (2.3), 802.11a (2.4), 802.11g (2.5) and compatibility mode 802.11b / g We also reported the percentage of the broadcast time spent in contention ($T_{Contention}$) [9]. The analysis of these results provides some insights into the actual performance of 802.11 wireless networks. As part of these calculations, our working hypotheses are optimistic: a single host on the network, emitting UDP traffic[10].

***Table 3.*** *- Comparison between modulation used and expected theoretical throughput for 802.11b*

| | | | | |
|---|---|---|---|---|
| $T_{Contention}$ | 2.5% | 4.7% | 12% | 18.2% |
| Modulation | 1Mbits/s | 2Mbits/s | 5.5Mbits/s | 11Mbits/s |
| 802.11 Throughput | 0.92Mbits/s | 1.77Mbits/s | 4.24Mbits/s | 7.02Mbits/s |
| Protocol efficiency | 93% | 89% | 78% | 64% |

***Table.4.*** *- Comparison between modulation used and expected theoretical rate for 802.11a*

| | | | | |
|---|---|---|---|---|
| $T_{Contention}$ | 4% | 4.5% | 5.7% | 7.8% |
| Modulation | 6Mbits/s | 9Mbits/s | 12Mbits/s | 18Mbits/s |
| 802.11 Throughput | 5.42Mbits/s | 7.82Mbits/s | 10.04Mbits/s | 14.03Mbits/s |
| Protocol efficiency | 91% | 87% | 84% | 78% |
| $T_{Contention}$ | 9.9% | 13.5% | 16.3% | 17.5% |
| Modulation | 24Mbits/s | 36Mbits/s | 48Mbits/s | 54Mbits/s |
| 802.11 Throughput | 17.50Mbits/s | 23.91Mbits/s | 28.78Mbits/s | 30.88Mbits/s |
| Protocol efficiency | 73% | 67% | 58% | 58% |

***Table 5.*** *- Comparison between modulation used and expected theoretical throughput, for 802.11g*

| | | | | |
|---|---|---|---|---|
| $T_{Contention}$ | 4% | 4.4% | 5.8% | 9% |
| Modulation | 6Mbits/s | 9Mbits/s | 12Mbits/s | 18Mbits/s |
| 802.11 Throughput | 5.45Mbits/s | 7.88Mbits/s | 10.14Mbits/s | 14.23Mbits/s |
| Protocol efficiency | 91% | 88% | 85% | 78% |
| $T_{Contention}$ | 11% | 14.7% | 17.6% | 18.9% |
| Modulation | 24Mbits/s | 36Mbits/s | 48Mbits/s | 54Mbits/s |
| 802.11 Throughput | 17.81Mbits/s | 24.50Mbits/s | 29.64Mbits/s | 31.86Mbits/s |
| Protocol efficiency | 75% | 69% | 62% | 58% |

***Table .6*** *- Comparison between modulation used and expected theoretical throughput, for 802.11b / g compatibility mode*

| | | | | |
|---|---|---|---|---|
| $T_{Contention}$ | 2.9% | 3.8% | 4.8% | 6.6% |
| Modulation | 6Mbits/s | 9Mbits/s | 12Mbits/s | 18Mbits/s |
| 802.11 Throughput | 5.02Mbits/s | 7.01Mbits/s | 8.75Mbits/s | 11.63Mbits/s |
| Protocol efficiency | 84% | 78% | 73% | 65% |
| $T_{Contention}$ | 7.9% | 9.9% | 11.3% | 11.9% |
| Modulation | 24Mbits/s | 36Mbits/s | 48Mbits/s | 54Mbits/s |
| 802.11 Throughput | 14.15Mbits/s | 17.70Mbits/s | 20.24Mbits/s | 21.25Mbits/s |
| Protocol efficiency | 59% | 49% | 42% | 39% |

To another host. In addition, the restraint chosen is an average value, which does not take into account possible randomness problems that artificially increase the drawdown of certain values. Yet already, we observe that the protocol cost of the set PLCP and 802.11 is a brake on efficiency. But more importantly [11], it's the legacy of successive standards, as well as maintaining backward compatibility (the ability of an 802.11g access point to allow 802.11b host connectivity) that is an important part of protocol overhead (especially visible in compatibility mode, where the use of 54Mbits / s modulation translates into 39% of the bit rate that the user might expect). However, this short study also shows the weight of the choice of the access method in the flow rates obtained, notably the influence of the time spent in contention ($T_{Contention}$). The ability to improve the access method is therefore essential for future wireless networks [12].

## 8. Reflections on The Uses of 802.11

The different modes of operation offer attractive features. For example, the infrastructure mode, when used in the presence of multiple access points, offers the prospect of mobile use of network access. The ad hoc mode, it opens the door to routing problems, especially under the MANET vision.

### 8.1. Mobility in 802.11 Networks

Station mobility has been a widely studied problem. Indeed, rid of wired connectivity, users aspire to the same functionality with a mobile phone: namely the maintenance of connectivity during the trip. In the context of 802.11, this is mainly to maintain the connectivity of the 802.11 interface of a mobile terminal.There are several types of mobility, studied in particular in several theses, including [13]. From the point of view of the user, the criterion is the connection to a new network or subnet, which involves performing operations at 802.11, as well as at the higher level (requesting an address by DHCP, getting a new IP address etc. ...), or the connection to the same subnet (conservation of IP parameters in particular). In the case of a network change, we speak of macro mobility; in the case of mobility in the same sub-network, we speak of micro mobility. We will focus mainly on micro-mobility within the framework of the IEEE 802.11 protocol, or more exactly what the authors of [11] called the level 2 handover. Indeed, the fact of maintaining a connection between two points of access from the same IEEE 802.11 subnet will involve time requirements in order to maintain business continuity above the 802.11 layer, typically IP, UDP, and TCP. Buffering techniques help prevent data loss, but some types of traffic, such as Voice over IP (VoIP), cannot tolerate the presence additional delay when traveling. When switching (handoff) from one access point to another in the mode infrastructure, access points form an Extended Service Set (ESS) composed of independent Basic Service Set (BSS). However, since the 802.11 standard has not defined the distribution system generically, the 802.11 handoff consists in the current implementations of the stations in the following operations, as described by Mishra.

- Assessment of the signal-to-noise ratio of the current network beacons, decrease notification;

- Launch a scan of other tags indicating the presence of other access points; this operation can be either active or passive; if it is active, probe packets are sent by the station to interrogate the different channels; in this case, the operation may result in packet loss because the channel change is not instantaneous.- Re-authentication: the station authenticates again according to a priority list of APs. Re-authentication can be accomplished through the transfer of credential information by a dedicated protocol, such as the Inter Access Point Protocol (IAPP). Figure 18 illustrates the Hand-off process used in 802.11 networks.Mishra et al. empirically studied handover in 802.11 networks and evaluated the time duration of all these operations. The authors noted a large disparity in transition times - between 200 and 1000 ms. Knowing that a real-time stream carrying a telephone conversation cannot support an offset of more than 200ms, several authors sound the alarm, notably the team of Henning Schulzrinne , inventor of the SIP protocol dedicated to the management of real-time multimedia streaming sessions.

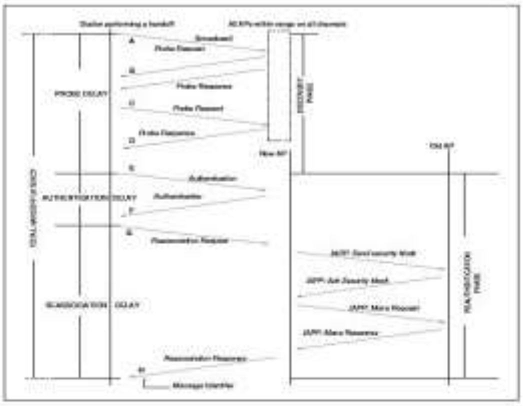

***Figure 18.*** *Handoff procedure used in 802.11 implementations (from the IAPP proposal).*

Lay), which causes an exchange of 3 to 7 frames; the authentication delay consists of an exchange of 3 to 4 frames; finally, the association time is also composed of 3 to 4 frames 802.11. The authors also mention the so-called Bridging delay, corresponding to the refresh of the ARP tables of the access points used in the Handoff procedure. For the authors, the probe delay (Probe request) is the essential (90%) of the loss of time spent by the card to perform his handoff. Other experiments confirm the same origin of the delay during the handoff: the detection and search phases take too much time.The 802.11 protocol thus exerts a too much overhead during the handoff between access points, in particular because of the phases of detection. Several authors have proposed solutions.Mishra and Al. propose a reduction in delay by reducing the time to wait for a response to a probe frame and heuristics to use a minimum of active detection phases to increase the response time. The authors then propose to use

Neighbor Graphs in and proposed a modification of IAPP accordingly. This change includes a proactive cache system: it uses neighborhood information to proactively send the context to the neighbor. Thus, it dissociates the context of the process of association, which allows a drastic reduction of the handoff deadlines. Subsequently, this suggested change was retained in the final version of IAPP. Later, the authors extended the concept of graph to authentication by proposing a distributed authentication model on the various access points of the network, as proposed in figure 19. The authors also propose to take advantage of the adjacent character of the channels and perform a total scan of the channels to build a mask that will be used during the following handoffs (figure.20). These proposals are effective only when the network density is sufficient, and reduce the responsiveness of customers to the appearance of a new access point. Vlahos and Al. have a different approach: they propose a modification of the behavior of the 802.11 cards by triggering the phase of sounding as soon as the loss of packets in the absence of collision is identified. The authors demonstrate that the scan phase can be triggered as soon as 3 consecutive packets are lost in the absence of a collision, which reduces for authors the handoff delay from 900 ms to 3 ms (in the absence of authentication), in the presence of traffic by the station; in the absence of traffic, the authors advocate a shortening of the retransmission time beacons by the access point to 60ms (while it is usually set at 100 ms). Thus the detection times are obviously reduced in the presence and absence of traffic from the mobile station. Trusted because here it is rather to improve the performance of the client in the presence of multiple

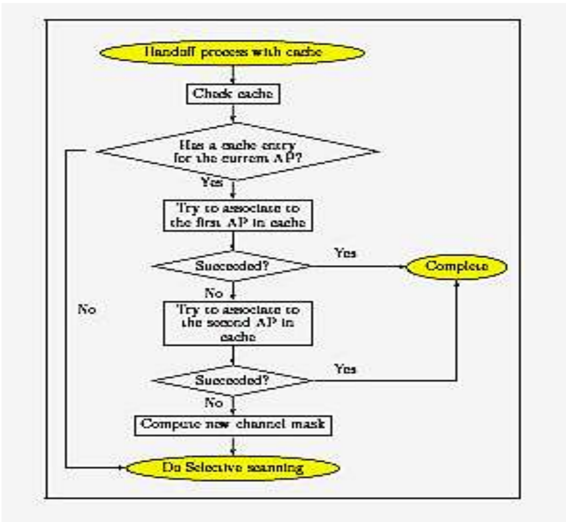


***Figure 19.*** *Handoff proposal based on a cache of previous polls. (Excerpt from "Context Caching Using Neighbor Graphics for Fast Handoffs in a Wireless Network", Mishra et al.)*

access points of the same subnet. The authors then propose and evaluate a series of triggers on the received signal values to trigger an access point change. Thus, they evaluate a beacon detection algorithm, a threshold algorithm, and then based on hysteresis, and finally an algorithm analyzing trends. In the end, the handoff delays obtained on their experimental platform indicate a long delay (between 530 and 860 ms) for the threshold-based algorithms.

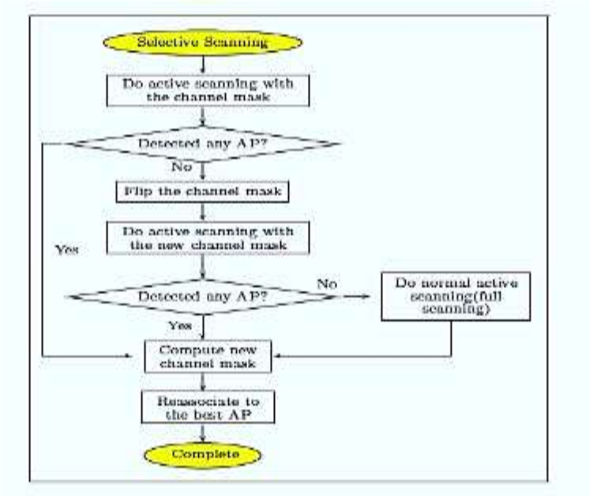


***Figure 20.*** *Handoff proposal based on a scan channel mask (from "Context Caching Using Neighbor Graphs for Fast Handoffs in a Wireless Network", Mishra et al.)*

Placement of the mobile to provide network traces exploitable by simulators. But these mobility models can also be used to anticipate the user's movements out of the coverage of an access point or other mobile nodes.However, even if mobility models are proposed, to our knowledge there is no proposal to improve the 802.11 handoff benefiting from a decision taken by the network itself, as in cellular networks for example. However, the 802.11 networks represent an interesting opportunity for the study of the mechanisms of micro-mobility: indeed, the taking into account of the physical characters, as the level of the signal, or the presence of beacons allows substantial improvements of the micro-mobility. We will come back later on the problem of mobility and the contribution of taking into account the lower layers, especially through our contributions.

## 9. Conclusions

Wireless networks to 802.11 or WiFi are the result of a complex and progressive construction, resulting from the success of layered structures that are global networks of Internet or local type as Ethernet. In fact, the layered design, which is independent but regulated by the 802.11 standard, has enabled the development of new physical layers while retaining its original MAC layer as well as the 802.11 protocol. Thus, the modulations progressed during the successive amendments 802.11b, 802.11a and 802.11g: the manufacturers have only to modify the components dedicated to the radio frequency part and keeping the logic of the MAC layer and, if necessary, the device drivers.However, the technique has reached its limits. As we have seen, each layer inherently has limitations: the physical layer must be able to handle multiple modulations; the mac layer must be able to maximize the usable capacity; finally, mesh networks radically change the uses of 802.11.However, layered architecture has reached its limits here. Most of the work of the scientific community on these issues inherently involves closer co-operation of the layers: for example, multiple flow management is directly related to the performance anomaly. Therefore, it is inconceivable to dissociate physical layer and mac layer. Therefore, any improvement in performance can only happen through solutions involving multiple layers.The latest developments in 802.11 are a striking example: the 802.11n standard, still in the process of being ratified, is one of the first amendments to propose simultaneous changes to the physical layers, MAC, or the 802.11 protocol. First, the standard exploits the new capabilities of MIMO technologies that use a multiple number of antennas and therefore physical flows to increase throughput; add to this a modification of the MAC layer, aimed at improving the capacity of the channel, by focusing on aggregation techniques, proposed in particular to solve the capacity problems of 802.11 networks. In addition, delayed acknowledgment mechanisms will significantly improve channel utilization by reducing protocol overhead of 802.11, as our calculations have shown.As a result, 802.11 hardware vendors migrated from a strict layer model to a more flexible model with changes across all layers. However, these changes are only intended to improve the performance of the current modes of operation, especially in an access point scenario. The 802.11e amendment, aimed at providing quality of service, was mainly designed in a conventional approach to an access point: it implements 4 classes of traffic, best-effort, background, voice and video, so the MAC settings are significantly different (CWmin distinct, possibility to send packets burst). The stated goal is clearly an improvement in quality when multiple access points are used by multiple clients. Yet an amendment being ratified tries to introduce the concept of mesh: it is 802.11s. It tries to standardize a hybrid routing protocol, allowing all vendors to use either an AODV or OLSR type protocol. The first implementations (OLPC and then its generalization open802.11s1.) Take over the existing layers to simply add new 802.11 messages and add the routing, traditionally at level 3 of the TCP / IP model, in the 802.11 layers. It is therefore natural that wireless networks are moving towards an inter-layer architecture: however, to date, the traditional architecture of operating systems seems to limit this evolution. It must therefore go beyond its theoretical model to offer new perspectives.

## Author Statements:


- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.


## References


[1] V Cerf et R Kahn. (2021). A Protocol for Packet Network Intercommunication. *IEEE Transactions on Communications*, 22(5):637– 648.

[2] A Mishra, M Shin et W Arbaugh. (2013). An empirical analysis of the IEEE 802.11 MAC layer handoff process. *ACM SIGCOMM Computer Communication Review*, 33(2):93–102.

[3] R Draves, J Padhye et B Zill. (2014). Routing in multi-radio, multi-hop wireless mesh networks. *Proceedings of the 10th Annual International Conference on Mobile Computing and Networking*, 114–128.

[4] Z Haas. (1997). A new routing protocol for the reconfigurable wireless networks. *IEEE 6th International Conference on Universal Personal Communications Record*, 2:562 – 566 vol.2.

[5] G Holland, N Vaidya et P Bahl. (2021). A rate-adaptive MAC protocol for multi-Hop wireless networks. *Proceedings of the 7th Annual International Conference on Mobile Computing and Networking*, 236–251.

[6] M Fiore, J Haerri, F Filali et C Bonnet. (2017). Vehicular Mobility Simulation for VANETs. *40th Annual Simulation Symposium (ANSS'07)*, 301–309.

[7] D Johnson, D Maltz et J Broch. (2011). DSR: The Dynamic Source Routing Protocol for Multi-Hop Wireless Ad Hoc Networks. *Ad Hoc Networking by Charles E. Perkins*, 5.

[8] S Shin, G Forte, A Rawat et H Schulzrinne, (2014). Reducing MAC layer handoff latency in IEEE 802.11 wireless LANs. *Proceedings of the Second International Workshop on Mobility Management & Wireless Access Protocols*, 19–26.

[9] A Kochut, A Vasan, A Shankar et A Agrawala, (2014). Sniffing out the correct physical layer capture model in 802.11 b. *Proceedings of the 12th IEEE International Conference on Network Protocols ICNP 2004*., 252–261.

[10] Y Ko et N Vaidya. (2020). Location Aided Routing (LAR) in mobile ad hoc networks. *Wireless Networks*, 6:307–321.

[11] F Guillemin, P Robert et B Zwart. (2018). AIMD algorithms and exponential functionals. *The Annals of Applied Probability*, 14(1):90–117.

[12] F Calì, M Conti et E Gregori. (2019). IEEE 802.11 Protocol: Design and Performance Evaluation of an Adaptive Backoff Mechanism. *IEEE Journal on Selected Areas on Communications*, 18(9):1774–1786.

[13] H Ma, X Li, H Li, P Zhang, S Luo et C Yuan. (2019). *Dynamic optimization of IEEE 802.11 CSMA/CA based on the number of competing.*