AN ANALYSIS OF THE INFLUENCE OF THE PHYSICAL LAYER TYPE ON THE IEEE 802.11 NETWORK PERFORMANCE

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ABSTRACT

This paper presents a simulation analysis of influence of the physical layer type on the IEEE 802.11 network performance. The throughput and the mean frame delay as functions of offered load for three types of physical layers for different number of stations were studied. This investigation allows us to compare the IEEE 802.11 network performance when using DSSS, FHSS and IR layers.

1 INTRODUCTION

Wireless local area communications is one of the most dynamically developing fields of telecommunications. In addition to the mobility that becomes possible with wireless LANs (WLANs), these systems can also be used in environments where the cable installation is expensive or impossible. They play a very important role in the network architecture as a provider of easy and unconstrained access to wired infrastructures.

Currently, there are two standards that describe WLANs, namely IEEE 802.11 [7] and HIPERLAN [6]. One expects that IEEE 802.11 will play a very similar role to that of Ethernet in wired networks. In this paper we focus our attention on IEEE 802.11 networks. The medium access protocol for IEEE 802.11 wireless networks incorporates two access methods. The first method is mandatory and based on the CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance) protocol. It is called the Distributed Coordination Function (DCF). The second one, PCF (Point Coordination Function), is optional and only used in the infrastructure mode to provide time-bounded services.

The IEEE 802.11 standard permits to use three types of physical layer: two radio units, both operating in the 2400-2500 MHz band - DSSS (Direct Sequence Spread Spectrum) and FHSS (Frequency Hopping Spread Spectrum), and one baseband unit - IR (Infrared). This paper presents the realized throughput and the mean frame delay as functions of offered load for three types of physical layers and different number of stations. The obtained results allow us to compare the network performance when using DSSS, FHSS and IR layers. This research shows that the physical layer dependent parameters have substantial influence on the efficiency of the IEEE 802.11 MAC protocol.

2 DCF FUNCTION

The IEEE 802.11 standard supports two access methods: the Distributed Coordination Function (DCF) method (mandatory) which is available in both ad hoc and infrastructure configurations, and the Point-Coordinated Function (PCF) which is optional and available in certain infrastructure environments. PCF enable us to provide time-bounded services.

DCF is the fundamental access method used to support asynchronous data transfer on the best effort basis. All the stations must support DCF. DCF employs the carrier sensing (CS) mechanism that check whether the signal energy in the occupied band does not exceed a given threshold to determine whether the medium is free and available for transmission. In order to minimize the probability of collisions a random backoff mechanism is used to randomize moments at which medium is tried to be accessed [2], [4], [5], [8], [9].

The DCF protocol is enhanced further by provision of a virtual CS indication called Net Allocation Vector (NAV), which is based on duration of information transferred in special RTS/CTS frames before the data exchange. It allows stations to avoid transmission in time intervals in which the medium is surely busy.

When using DCF, a station, before initiating a transmission, senses the channel to determine if another station is transmitting. The station proceeds with its transmission if the medium is determined to be idle for an interval that exceeds the Distributed Inter Frame Space (DIFS) (see Figure 1). In the case when the medium is busy, the transmission is deferred until the end of ongoing transmission. A random interval (backoff interval) is then selected and used to initialize the backoff timer. The backoff timer is decremented only when the medium is idle. It is frozen when the medium is busy. After a busy period the decrementing of the backoff timer resumes only after the medium has been free longer then DIFS. A station initiates a transmission when the backoff timer reaches zero. To reduce the probability of collision, after each unsuccessful transmission attempt the expected value of the random backoff interval is increased exponentially up to the predetermined maximum.

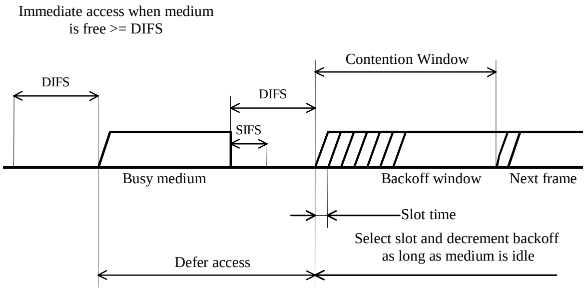

Figure 1. Basic access method.

Immediate positive acknowledgements are employed to determine the successful reception of each data frame. The receiver initiates the transmission of an acknowledgement frame after a time interval called Short Inter Frame Space (SIFS). This time is less then DIFS. In the case when an acknowledgment is not received, the data frame is presumed lost and the transmitter schedules a retransmission.

3 PHYSICAL LAYERS

The DSSS and FHSS layers use 2.4 GHz band designed for ISM applications. The DSSS system uses baseband modulations of DBPSK (Differential Binary Phase Shift Keying) and DQPSK (Differential Quadrature Phase Shift Keying) to provide the 1 and 2 Mbps data rates, respectively. The FHSS system uses two or four-level GFSK (Gaussian Frequency Shift Keying) with a nominal bandwidth bit-period (BT)=0.5 for 1 and 2 Mbps data rates. The physical layer for an infrared system uses near-visible light in the 850 nm to 950 nm range for signaling. This is similar to the spectral usage of both common consumer devices such as infrared remote controls, as well as IrDA (Infrared Data Association) devices.

The IEEE 802.11 protocol parameters can be divided into two groups. Some of them is independent from the physical layer type, whereas the others take values characteristic for the specific physical layer. Table 1 presents the selected values characteristic for the physical layers.

Table 1. The selected protocol parameter values characteristic for physical layers.

Parameter \ Physical layer type	**IR**	**DSSS**	**FHSS**
DIFS	23 µs	50 µs	128 µs
PIFS	15 µs	30 µs	78 µs
SIFS	7 µs	10 µs	28 µs
Slot time	8 µs	20 µs	50 µs
Length of physical layer preamble	16 µs (1 Mbit/s) 20 µs (2 Mbit/s)	144 bits	96 µs
Minimum number of slots – CWmin	63	31	15
Maximum number of slots – CWmax	1023	1023	1023
Rx/Tx turnaround time	0 µs	≤ 5 µs	20 µs

Each physical layer adds a physical preamble of different length to each packet. DSSS adds 144 bits, FHSS 96 µs and IR 16 µs for 1 Mbps and 20 µs for 2 Mbps. It is interesting to compare the interframe spaces (xIFS). The smallest values are defined for the IR layer. The longest times are proposed for the FHSS layer. Each slot in the backoff window has the length of 8 µs (IR), 20 µs (DSSS) or 50 µs (FHSS). The standard specifies separately the values CWmin and CWmax for every kind of physical layer. For FHSS the recommended values are following: CWmin=15, CWmax=1023. For DSSS we have: CWmin=31 and CWmax=1023. For IR the values are as follows: CWmin=63, CWmax=1023. The Rx/Tx turnaround time varies from 0 µs for IR, less then 5 µs for DSSS to 20 µs for FHSS. From this comparison it is clear that the performance is highly dependent on the type of applied layer.

4 SIMULATION RESULTS

In order to investigate these phenomena intensive simulations were performed. Obtained simulations allowed to determine the realized throughput and the mean frame delay as functions of offered load while transmitting 1000 bytes frames for different number of stations (5, 25 and 100). The frame arrivals were realized according to the Poisson distribution. Several assumptions were made to reduce the complexity of the simulation model:

- The effects of propagation delay were neglected. This is very realistic assumption if the transmission distances are of tens meters between stations.
- The channel was error-free that means that each frame that was transmitted by the sender was successfully and correctly received by the receiver.
- There were no stations operating in the power-saving mode. All stations were “awake” all the time and then transmitted frames were received immediately by the destination station.
- The stations were able to hear each other – the hidden station scenario was not considered.
- There was no interference from nearby Basic Service Sets (BSSs).

The DATA + ACK mode of transmission was used. The network was configured to 2 Mbps medium capacity. All parameters were taken from the standard specification. The assumed parameters typical for DSSS, FHSS and IR layers are presented in Table 1. The remaining parameters used throughout all simulations are displayed in Table 2.

Table 2. Parameters used throughout all simulations.

Parameter	**Value**	**Parameter**	**Value**
Length of RTS	20 octets	Buffer size	10 frames
Length of CTS	14 octets	T3 timer	300 µs
Length of ACK	14 octets	Number of stations	5, 25, 100
Length of DATA header	32 octets	Number of retransmission of DATA frames	4
Length of DATA frame	1000 octets	Medium capacity	2 Mbps

The results of obtained simulations are presented in some figures. The plots are divided in two groups. The realized throughput as a function of offered load for different physical layers and number of stations (Figs. 2 – 4) is the first group. The mean frame delay as a function of offered load for different physical layers and number of stations (Figs. 5 – 7) is the second group.

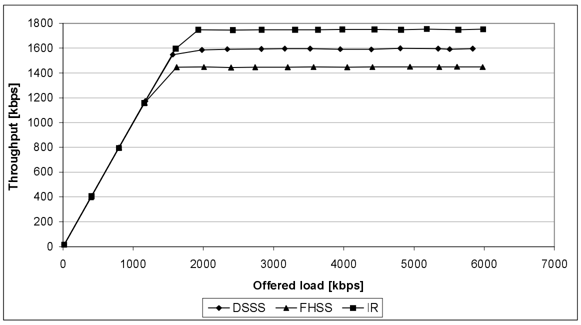

Figure 2. Throughput versus offered load for 5 stations for DSSS, FHSS and IR layer.

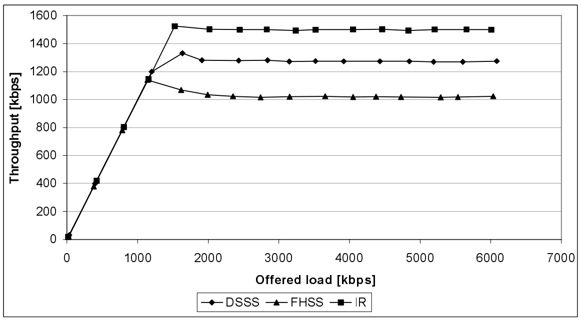

Figure 3. Throughput versus offered load for 25 stations for DSSS, FHSS and IR layer.

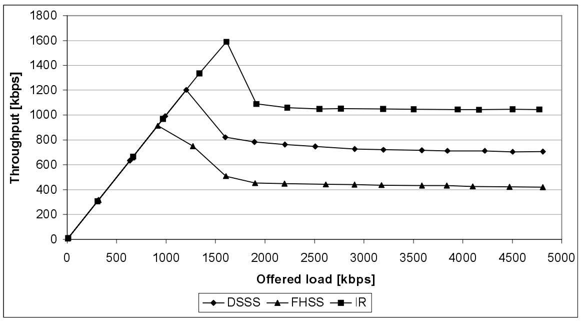

Figure 4. Throughput versus offered load for 100 stations for DSSS, FHSS and IR layer.

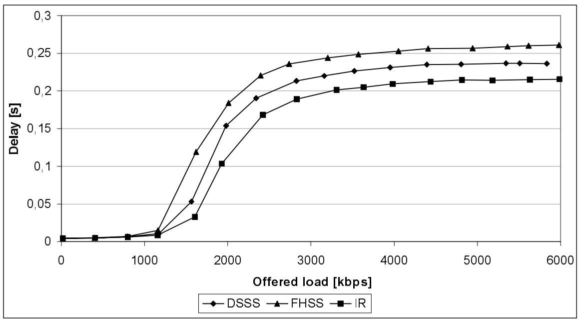

Figure 5. Mean frame delay versus offered load for 5 stations for DSSS, FHSS and IR layer.

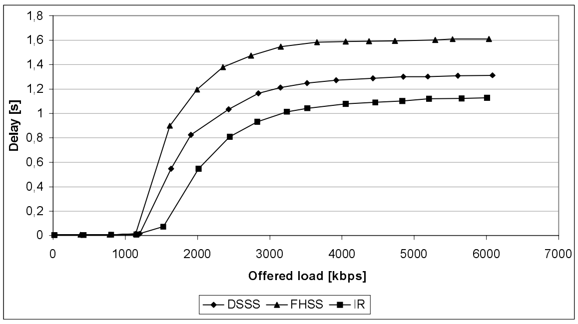

Figure 6. Mean frame delay versus offered load for 25 stations for DSSS, FHSS and IR layer.

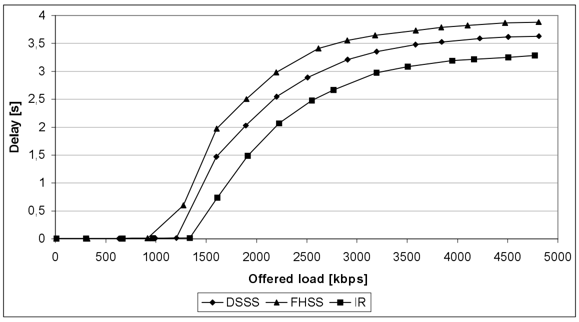

Figure 7. Mean frame delay versus offered load for 100 stations for DSSS, FHSS and IR layer.

An analysis of the presented results allows us to draw a number of interesting conclusions. A linear growth of the realized throughput for small values of offered load can be observed. The reduction of the maximum of realized throughput with the increased number of contending stations is very characteristic. The very interesting phenomena of local maximum appearance of the realized throughput for large number of stations can be observed [8]. A higher level of offered load brings a large number of collisions. The lack of the RTS/CTS mechanism causes a high level of losses that arises from a large number of collisions of relative large data frames. The growth of offered load above the nominal capacity of the network does not brings the degradation of the realized throughput as in some others wireless networks like Aloha, Slotted Aloha, CSMA. The DCF function of IEEE 802.11 protocol is much more stable. Independently of the number of stations the network attains the maximum throughput using IR layer. The worst results are achieved when IEEE 802.11 protocol uses FHSS layer. The throughput saturated on the level of 1750 kbps (IR), 1600 kbps (DSSS), 1470 kbps (FHSS) for 5 stations. It is degraded to 1500 kbps (IR), 1270 kbps (DSSS), 1020 (FHSS) for 25 stations. The smallest values of throughput are attained for 100 stations: 1050 kbps (IR), 700 kbps (DSSS) and 420 kbps (FHSS).

The mean frame delays as a function of offered load are presented in Figs. 5 – 7. A very low increase of the mean delay for low offered network load can be observed. The mean frame delay is of some tens of milliseconds. The number of stations has a little influence on the shape of the obtained characteristics but large on the transmission delay. The growth of mean frame delay is relatively small after a certain value of offered load. The smallest values of delays are observed for IR, whereas the biggest for FHSS layer. The maximum level of delay amount 0,21 s (IR), 0,23 s (DSSS), 0,26 s (FHSS) for 5 stations. The growth of delay for 25 stations is observed: 1,1 s (IR), 1,3 s (DSSS), 1,6 s (FHSS). The largest values of mean delay are obtained for 100 stations: 3,3 s (IR), 3,6 s (DSSS) and 3,9 s (FHSS).

5 CONCLUSIONS

This research shows that the choice of physical layer has the significant influence on the efficiency of the IEEE 802.11 protocol. From the presented results and considerations, one can draw a number of interesting conclusions presented below.

1. The network efficiency is highly dependent on the physical layer type. The best results are achieved for IR, while the worst for FHSS.
2. The minimization of the length of interframe spaces, slot times and the physical layer preamble has the positive influence on the network efficiency.
3. The proper choice of CWmin size has a large influence on the network efficiency. Using too small values of CWmin at large number of stations brings a large number of collisions and degradation of network performance (like in case of FHSS - CWmin=15 slots and 100 contending stations).

REFERENCES

[1] V. Bharghavan, A. Demers, S. Shenker, L. Zhang, “MACAW: A Media Access Protocol for Wireless LAN’s”, ACM Sigcomm 1994.

[2] H. S. Chaya, “Performance evaluation of the IEEE 802.11 MAC Protocol for wireless LANs”, M. Sc. Thesis, Chicago, Illinois Institute of Technology, May 1996.

[3] Chen Kwang-Cheng, “Medium Access Control of Wireless LANs for Mobile Computing”, IEEE Network, September/October 1994.

[4] B. Crow, I. Widjaja, G. J. Kim, P. T. Sakai, “IEEE 802.11 Wireless Local Area Networks”,

IEEE Communications Magazine, September 1997.

[5] W. Diepstraten, G. Ennis, P. Belanger, “DFWMAC - Distributed Foundation Wireless Medium Access Control”, IEEE 802.11 Working Group paper IEEE 802.11-93/190, Nov. 1993.

[6] HIPERLAN - High Performance Radio Local Area Network; Functional Specification. Draft ver. 1.1 ETSI January 1995.

[7] IEEE 802.11 Standard for Wireless LAN: Medium Access Control (MAC) and Physical Layer (PHY) Specification. New York, IEEE Inc. 1997.

[8] M. Natkaniec, A. R. Pach., “Analysis of Backoff mechanism in IEEE 802.11 standard” – ISCC’2000 – IEEE Symposium on Computers and Communications, Antibes – Juans les Pins, France 3-6 July 2000.

[9] A. R. Pach., S. Palazzo, D. Panno, “On the Behaviour of the MAC Protocol for 802.11 Wireless Networks”, Proceeding of the Regional International Teletraffic Conference, Pretoria, South Africa 1995.