

SIMULATION ANALYSIS OF SERVICE INTEGRATION IN IEEE 802.11 NETWORKS

Marek Natkaniec, Andrzej R. Pach

Department of Telecommunications, The University of Mining and Metallurgy

Al. Mickiewicza 30, 30-059 Krakow, Poland

natkanie@kt.agh.edu.pl.; pach@kt.agh.edu.pl

1. Introduction

This paper presents a simulation analysis of the MAC protocol (DFWMAC -Distribution Foundation Wireless Medium Access Protocol) described in the IEEE 802.11 standard in order to verify the possibility of integrated services provision. This standard specifies a wireless local computer network (WLAN). The key issue is to design a WLAN in such a way to secure the effective transmission for the existing applications and those which appear in near future like e.g. HDTV, videoconferencing or video on demand. It seems that multimedia applications which include various types of information (video, pictures, sounds, text) will be the most attractive in the near future. They possess different characteristics and network requirements.

An intensive simulation of DFWMAC was carried out to test the network efficiency. The network was configured to 1 and 2 Mbits medium capacities. Various network configurations working at different modes were simulated. The simulations were performed in some stages. The DCF (*Distributed Coordination Function*) efficiency tests were made in the first stage. Connections between DCF and PCF (*Point Coordination Function*) were checked in the second. Implementation possibility of integrated services was examined in the third. Telephony, video-telephony, high quality audio CD transmission and video-conference as isochronous services were considered. Other services like HDTV or MPEG video transmission have not been implemented because the total medium capacity of the IEEE 802.11 network is too low. All others services were of asynchronous type.

A large volume of data was gathered which has allowed us to determine the quality of service and number of acceptable services (in terms of the throughput and delay). The paper presents these results and key conclusions which give some hints how to integrate asynchronous and isochronous services in the IEEE 802.11 network. The simulations results determined the average delay for asynchronous traffic. Basing on the obtained

results of these a number of conclusions was also on the network behaviour at very variable, sometimes extreme situations.

2. DFWMAC Protocol

The medium access protocol for IEEE 802.11 wireless networks is called DFWMAC and incorporates two access methods. The first method is mandatory and based on the CSMA/CA protocol. It is called the Distributed Coordination Function (DCF). The second one, the Point Coordination Function (PCF), is optional and used for provision of time bounded services.

DCF employs the carrier sensing (CS) mechanism that check whether the signal energy in occupied band does not exceed a given threshold so as to determine the medium is free and available for transmission. In order to minimise the probability of collisions a random backoff mechanism is used to randomise moments at which medium is tried to be accessed.

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

3. Service Characterisation

We mean by service integration simultaneous provision of different kinds of services including isochronous and asynchronous ones. Content of every data stream may be a combination of time bounded (real time or non real time) or unbounded (asynchronous) services. The time bounded services include audio and video distribution and require synchronisation between different information elements to be transferred. The time unbounded services include, for example, transfer of images, graphics or text.

Service characterisation should include communication requirements [2] on bandwidth, delay and transmission errors. The bandwidth is the most important quantity since it immediately tells us whether the service can be provided or not. The total required bandwidth in a wireless LAN depends on:

- type of service
- number of active users
- number of stations participating in each service (point-to-point or multipoint)
- type of connection (symmetric or asymmetric)

The total required bandwidth is the sum of bandwidths of different combinations of basic services.

The mean delay of data transfer is another key performance measure. It has a substantial influence on the quality of isochronous services provided. Beside this, an important role plays the availability of service for all users connected to the network.

In order to characterise timed information to be delivered in real time, two measures are defined, namely the total delay and delay fluctuation. The total delay is very important

for real time applications like videoconference or telephony since the reaction of recipient is expected in some short period of time. Such short response time guarantees natural conversation. The delay fluctuation is the variance of total delay, measured between consecutive packets of the same information stream. If the bandwidth is enough to satisfy the users' needs then the delay fluctuation should not appear. The delay fluctuation should be limited for timed information since information is transferred at a given throughput. The total delay is a key measure for timeless information or non real time services which should be less than the response time required for the service.

In the wireless LAN environment, the main source of errors stems from the characteristics of this environment, i.e. different kind of unpredictable errors.

4. Discussion of Simulation Results

The knowledge of tradeoffs between DCF and PCF functions allow us to determine the network capability of isochronous service transfer necessary for full implementation of integrated services. In order to assess this information, simulations were carried out using the simulator having the following properties:

- one BSS with a limited number of stations
- modes of transmission: DATA, DATA + ACK, RTS/CTS + DATA + ACK, RTS/CTS + DATA
- Poisson arrivals
- packet delivery to a give station or stations including broadcast
- asynchronous and synchronous frame transmissions
- normal or adaptive backoff
- pointing hidden stations

Different network configurations were examined. Simulations were carried out in three phases. In the first phase performance evaluation of DCF was done. In the second phase tradeoffs between DCF and PCF were studied. In the third phase network capabilities for integrated service provision were evaluated.

4.1 Phase 1 – Performance evaluation of DCF protocol

In this phase, the total achieved bandwidth and the mean packet delay as functions of offered traffic were investigated. Some parameters were fixed during all simulations runs. These parameters included all ones necessary to reflect the behaviour of a real network or having a minor influence on this. Since any IEEE 802.11 practical implementations have not been reported in the literature as yet, a number of network parameters has been set using hints from the standard or published papers on IEEE 802.11 performance evaluation [8].

4.2 Phase 2 – Tradeoff between DCF and PCF functions

In this phase, the total achieved bandwidth and the mean frame delay as functions of the data field length were investigated for different number of services. Implementation of isochronous services in an IEEE 802.11 network is ensured by use of the intelligent MAC protocol and the management station. In dependence on the number of services to be controlled by the management station, the proper bandwidth is reserved. However, this is limited by the network parameters mainly by the tradeoff between the superframe

length and CFP period. The MAC protocol is based on polling of stations being on the list of isochronous services. So, one can expect that the throughput achieved by the isochronous service will depend on the number of granted access cycles to the medium from the management station. In turn, when the station will obtain the access then the throughput will depend on the number of data octets. This was the reason that the tradeoffs between the throughput obtained by a service and the length of CFP period in superframe or data field length were investigated. Simulations were carried out for the medium capacity equal 1 and 2 Mbit/s. The length of superframe was fixed to 25 ms. The length of CFP period varied from 5 to 25 ms. The number of stations was 10 and this did not limit the number of implemented isochronous services. Each time, 1, 2, 5 or 10 full duplex services (2, 4, 10 or 20 simplex services – half duplex data transmission was considered as 2 simplex services and one full duplex service) were examined. Some parameters were fixed for all simulations runs.

4.3 Phase 3 – Implementation of services in an IEEE 802.11 network

In this phase, the attention was laid on the following issues:

- direct reflection of isochronous services in parameters used in simulations
- definition of network capacity in terms of the number of implemented services and their types
- examination of isochronous services behaviour in an IEEE 802.11 network and their coexistence with asynchronous ones.

The following isochronous services were considered:

- telephony – 2×32 kbit/s (full duplex service after ADPCM compression)
- videotelephony (minimum capacity) – 2×64 kbit/s (full duplex service)
- broadcast of hi-fi audio (CD) – 256 kbit/s
- videoconference – $p \times 32$ kbit/s (sound – simplex service – ADPCM compression) + asynchronous bandwidth for transmission of images, graphics and text.

Other isochronous services like HDTV or transmission of MPEG streams were not considered due to small network capacity (up to 2 Mbit/s).

All isochronous services require delivery of consecutive frames in proper time gaps. This is caused by the necessity of transmission fluency and synchronisation. During simulation two values of delays occurring in the realisation of isochronous services were assumed. The first one was 25 ms. This is rather small delay – number of simultaneous services is small. The second value was 150 ms. This value is accepted as an upper limit for telephone conversation. Taking these remarks in mind, the proper network parameters were been searching. The following goals attained the maximum attention:

- ensuring sufficient bandwidth and delay below a given threshold for isochronous services
- minimalization of CFP period (or maximalization of remaining bandwidth for asynchronous services)
- maximalization of data field length used in isochronous services (in order to reduce the number of cycles necessary to obtain the access to the medium).

The parameters used throughout all simulations are displayed in Table 1.

Table 1. Parameters used throughout all simulations

Parameter	Value
SIFS	3 μ s
PIFS	7 μ s
DIFS	32 μ s
Length of RTS	20 octets
Length of CTS	14 octets
Length of ACK	14 octets
DATA header	32 octets
Physical layer preamble	10 octets
Length of Beacon	32 octets
Maximum number of slots	32000
Initial size of window CW	32
Length of slot	4 μ s
Size of buffer for frames	50
Number of retransmission of DATA frames	4
Number of retransmission of RTS frames	4
Timer 1	10 ms
Timer 3	10 ms
Beacon is transmitted every	5 ms
Superframe lasts for	25 ms
Length of asynchronous data field	random in range 64 - 1518 octets
Threshold to use RTS/CTS procedure	300 octets
Medium capacity	1 or 2 Mbit/s
Contention Free Period	5, 10, 15, 20, 25 ms – chosen in such a way to maximise capacity for asynchronous service
Length of asynchronous data field	chosen in such a way to maximise capacity for asynchronous service

The number of services possible to implement with the assumed quality was rather not large (especially for 1 Mbit/s medium capacity). Table 2 presents the maximum numbers of isochronous services realised simultaneously in a network of fixed capacity and at the maximum delay.

Table 2. Numbers of services possible to implement as functions of assumed capacity and delay

Service	1Mbit/s	2Mbit/s	1Mbit/s	2Mbit/s,
	Delay of 25ms	Delay of 25ms	Delay of 150ms	Delay of 150ms
Audio-CD	2 simplex	4 simplex	2 simplex	4 simplex
Videotelephony	3 duplex	7 duplex	3 duplex	9 duplex
Videoconference	9 simplex	20 simplex	14 simplex	36 simplex
ADPCM telephony	5 duplex	10 duplex	7 duplex	18 duplex

Performed simulations allowed us to determine the amount of bandwidth for asynchronous service. Thus this enabled us to add some asynchronous services to the existing isochronous ones. Simulation runs also allowed us to determine the average delays (measured from the arrival of a call to the moment of proper ACK reception) arising in asynchronous transmission. Plots and comets are presented in the following. In this article plots obtained for the fixed delay of 150 ms are only presented.

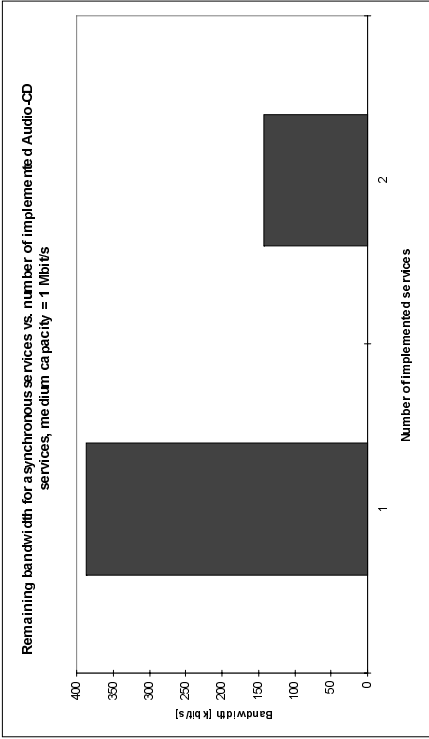


Fig. 1a

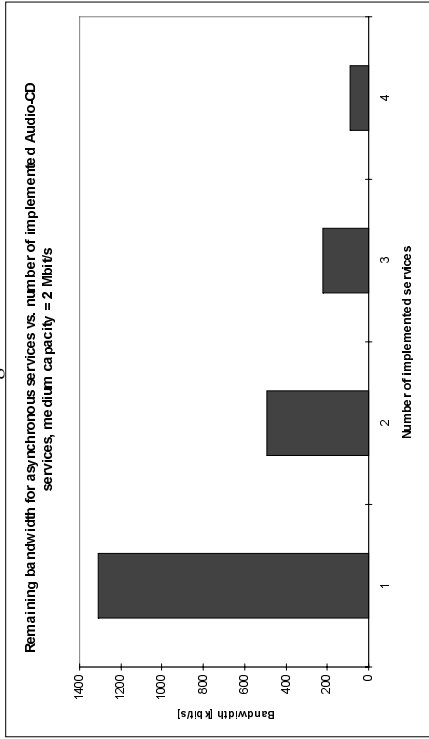


Fig. 2a

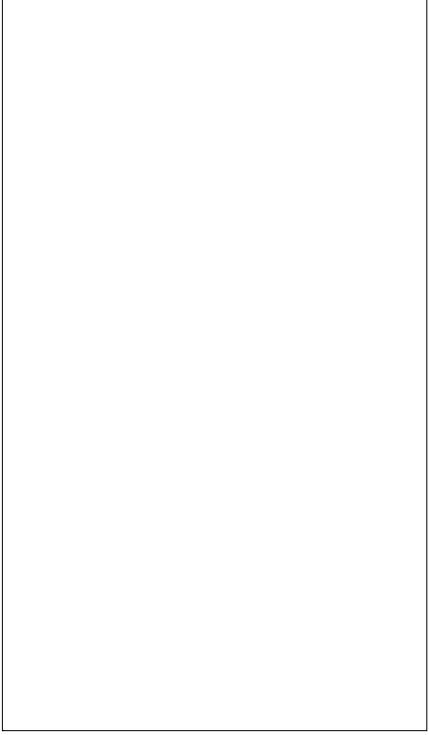


Fig. 1b

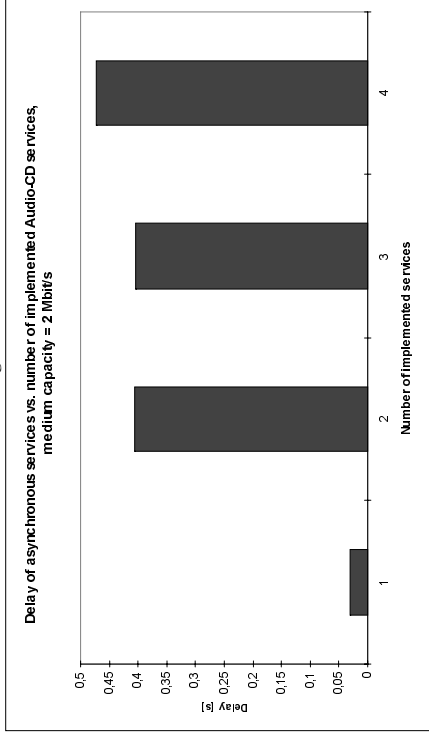


Fig. 2b

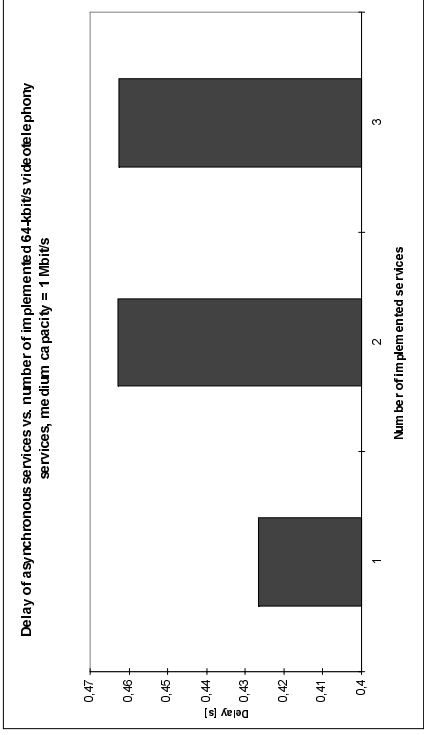
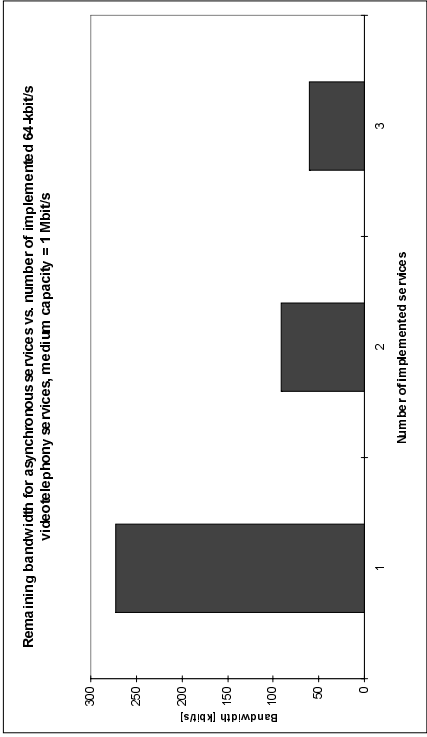


Fig. 3a

Fig. 3b

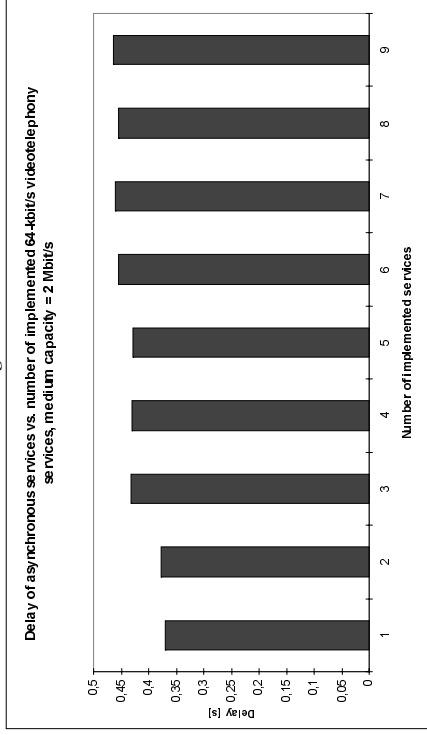
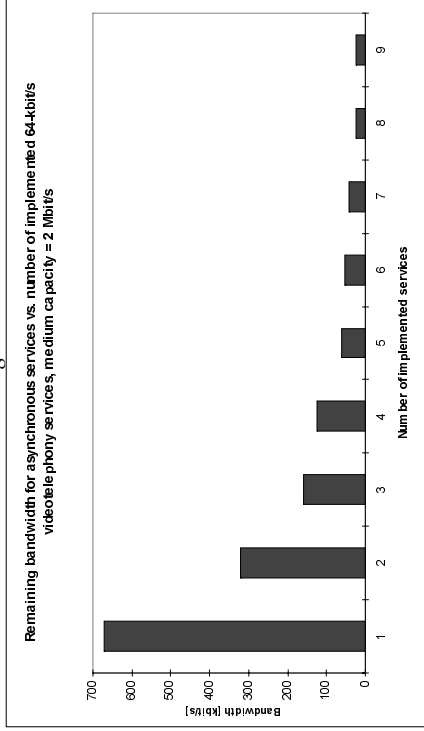


Fig. 4a

Fig. 4b

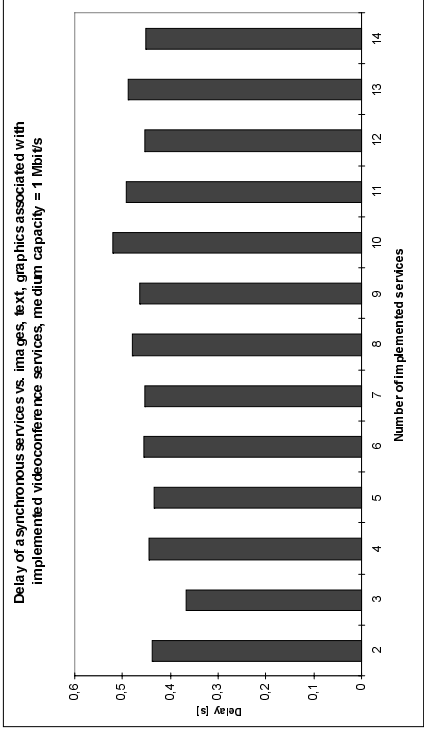
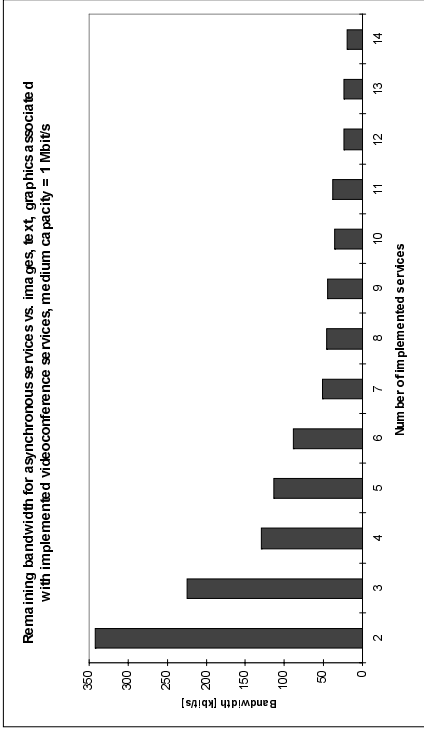


Fig. 5a

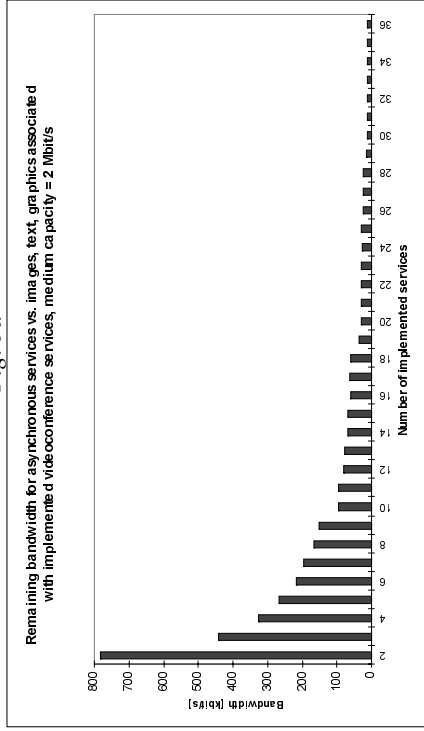


Fig. 5b

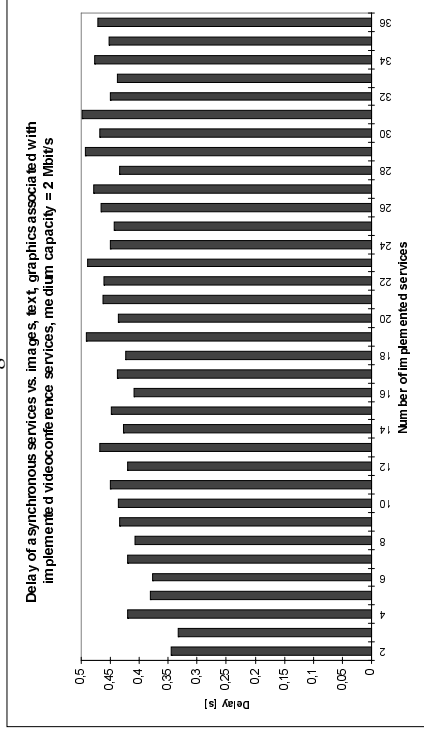


Fig. 6a

Fig. 6b

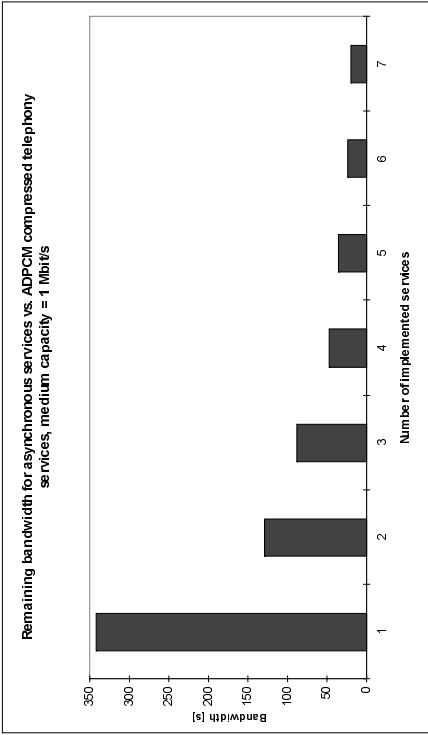


Fig. 7a

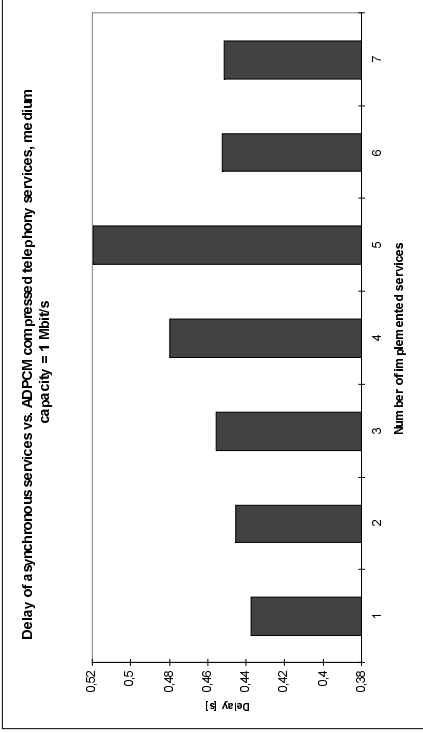


Fig. 7b

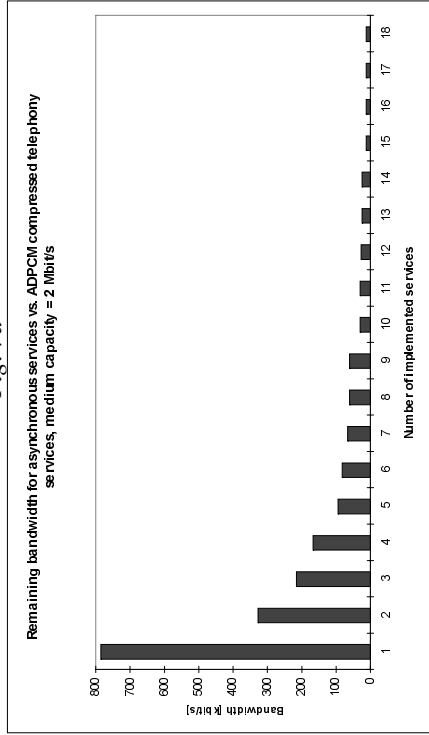


Fig. 8a

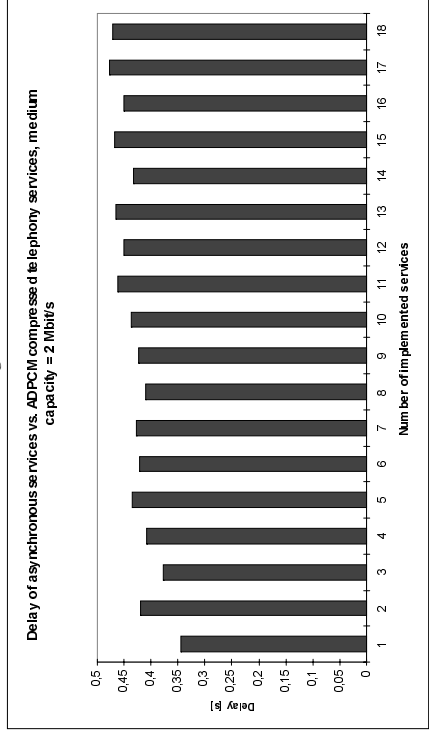


Fig. 8b

The results presented in the figures presented above allow us to draw the following remarks.

1. When the number of any kind services increases then the remaining channel capacity decreases, independently it is a simplex or duplex one (series "a" of plots).
2. Delay incurred by an asynchronous service increases when the number of services increases, however, for all cases it exhibits saturation at level of 0.4 – 0.6 s (series "b" of plots).
3. The network is scalable when considering capacity for asynchronous services. However, doubling the nominal network capacity does not mean doubling the remaining capacity. Scalability may also be observed in the maximal number of realised isochronous services for both capacities equal 1 and 2 Mbit/s (see e.g. Figs. 1a and 2a, and so on).
4. In the case of isochronous services implementation, independently on the CPF length in superframe, better results are achieved for shorter packets used for these services provision.
5. For both assumed isochronous delays (25 and 150 ms), the network given type and number of implemented services, at a given nominal medium capacity, leaves the bandwidth for asynchronous traffic of same magnitude.
6. Further increase of isochronous delay (above 150 ms) does not implicate further increase of the number simultaneous isochronous services provided, since we reach then the nominal capacity of the network.
7. When implementing different isochronous services then some bandwidth remains for use to provide asynchronous services. This allow us to integrate asynchronous and synchronous services. In the presented figures, the remaining capacities to be used at each simplex channel for Audio-CD. service (Figs. 1a, 2a) and videoconference (Figs. 5a, 6a) are shown. The remaining capacities to be used by each communicating party in duplex services like videotelephony (Figs.3a, 4a) or compressed ADPCM telephony (Figs. 7a, 8a) are also showed.
8. One can put some asynchronous services in the remaining asynchronous bandwidth. These service may include data, graphics, text transmission, WWW, FTP, Telnet and so on.
9. If the remaining capacity is not always sufficient to immediate realisation of desired asynchronous service (neglecting access time) then the time of asynchronous service realisation lengthens.

5. Conclusions

The objective of this paper was to analyse an IEEE 802.11 network in terms of provision of integrated services. Basing ourselves on simulation we defined which types of services can be implemented at a given level of quality. The presented analysis led us to some important conclusions briefly presented below.

1. An IEEE 802.11 network is able to provide integrated services, however, achievable throughput do not let implement services of any kind.

2. The maximum throughputs are achieved for asynchronous services. Implementation of isochronous services causes a substantial reduction of asynchronous throughput.
3. There is a possibility of integration voice, sound with both moving and still images. This allows for provision of telephony, videotelephony and videoconference.
4. The proper choice of parameters for isochronous services is the key issue since it allows us to achieve maximum throughputs. These parameters include the length of superframe, CFP period, length of data fields in frames.
5. Parameters like the length of transmitted frames, number of accessing stations, number of hidden terminals, threshold for starting the RTS/CTS mechanism, type of backoff plays the role for asynchronous services.
6. The network is scalable when providing asynchronous services, Scalability refers also to isochronous services but proportions are non-linear.

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