PERFORMANCE ANALYSIS OF INTERCONNECTIONS OF IEEE 802.11 NETWORKS WITH OTHER NETWORKS

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ABSTRACT

Wireless LANs coming into existence about 10 years ago and up to this time the number of total wireless devices grows up to 1 million. IEEE 802.11 is the new wireless networks standard that was finished and standardized in 1997. The physical layer and MAC described in standard allow us to achieve wireless connectivity between moving, portables and fixed stations within a certain area called BSA (Basic Service Area). These areas through access points and some logical objects (portals) can communicate with any wired networks. 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 (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 used only in infrastructure mode. In this paper the efficiency of DCF function while transmitting frames of different length was investigated. The total achieved bandwidth and the mean frame delay as functions of the offered load were investigated for different number of stations (2, 5, 10, and 20).

INTRODUCTION

Wireless local area networks are one from younger and most dynamically being developed fields of telecommunication. First WLANs appeared about 10 of years ago. Up to this time the number of total wireless devices grows up to 1 million. A WLANs permit on large free choice of architecture. They can be used as an extension of existing already wired networks. They can also be installed in places that are very difficult to wire for example trading floors, manufacturing facilities, warehouses and historical buildings. The new possibilities of WLANs will permit on realization inaccessible (with comparison of wired networks) services. Lastly, that network may be temporary and operational for a very short period of time, making installation of wired network impractical. Wireless local area networks will assure easy and free access to existing infrastructures of networks: LAN, MAN and WAN. The main receivers can so be industrial institutions, schools, offices, departments, financial or commercial firms, military institutions, conference registration centers etc. These networks can also be attractive over completely new users, assured wireless access to databases in magazines, stores, hospitals, airfields, museums etc. Market of wireless LANs is evolutionary. Marketing investigations inform that United States market before 2000 year will bring income of over milliard of dollars a year. Usage of WLANs brings following advantages:

- Access to information in real time from every place in given organization - mobility of stations is a feature that can’t be obtainment in wired networks.
- Fast and easy installation procedures - all problems connected with location and set of wired infrastructures are eliminated.
- Installation of network in places, where cable installation is impossible.
- Lower cost of installation and maintenance - especially when architecture has to be dynamically changed. First cost of equipment

of WLANs can be however higher than required equipment of wired network.

- Better scalability - number of users can change quickly from a dozen or so in case of Ad Hoc topology to several thousands in case of infrastructure network.

The range of today's, wired computer networks (LAN, MAN and WAN) stretches on many areas, sometimes separated and considerably from oneself distant. Local area networks include with one's own range nodes of distant up to several of kilometers. Typical installations are located in offices, industrial halls, campus centers etc. Attained throughput will reach up to 1 Gbps. It is remarkable that LANs are very quick. Wide area networks spread out over an area of all world. Obtained throughputs are much lower compared with LANs, attaining values of tens kbps. Metropolitan area networks create an indirect solution among LANs and WANs. Attained distances will reach up to 50 km, so they can spread out over an area of city. They can deliver services above 1 Mbps: voice transmission, data and video transmission. The most popular networks are Ethernet, Token Bus, Token Ring, DQDB, FDDI and ATM. Specifications of mentioned networks are described by suitable standards. These networks are completely different in respect of architecture, physical layer and medium access control layer. One of characteristic feature is placed in frame size definition. Some networks transfer frames about constant of length. The other group transfer variable size frames.

Final version of standard IEEE 802.11 was standardized in 1997. This standardization projects begun in 1990. Through 8 years many of unapproved drafts was published. The physical layer and MAC described in standard allow us to achieve wireless connectivity between moving, portables and fixed stations within a certain area called BSA (Basic Service Area). These areas through access points and some logical objects (portals) can communicate with any wired networks (IEEE 802.x). 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 (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 used only in infrastructure mode to provide time-bounded services.

In this paper the efficiency of DCF function while transmitting frames of different length (that come from other types of networks) was investigated. Research has been done using simulation techniques. The overall throughput and mean packet delay of transmission were analyzed. Introduced results allow us to answer the question: is it profitable to use frames fragmentation or de-fragmentation before the data exchange? The simulation results show that the performance of network degrade when the packet size decreases.

ARCHITECTURE

The IEEE 802.11 standard is a part of family of standards for local and metropolitan area networks (IEEE 802.3 – IEEE 802.12). This family deals with the physical and data link layers as defined by the ISO/IEC (International Organization for Standardization / International Electrotechnical Commission) Open System Interconnection Basic Reference Model.

Wireless networks have fundamental characteristics that make them significantly different from traditional wired LANs. In wired LANs, an address is equivalent to a physical location. In IEEE 802.11, the addressable unit is a station (STA). The STA is a message destination, but not a fixed location. The IEEE 802.11 architecture consists of several components. The most basic block of an IEEE 802.11 LAN is called Basic Service Set (BSS) and may consist of only two stations. The stations within the same BSS can communicate directly. This type of operation is often referred to an ad-hoc network (Figure 1) [Chen94].

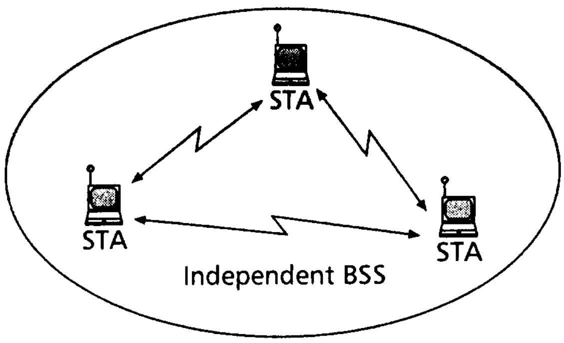

Figure 1. Ad-Hoc network

The association between a STA and a BSS is dynamic. The BSS may also be a component of an extended form of network. The architectural component used to interconnect BSSs is called Distribution System (DS). The station that provides access to the DS is Access Point (AP). It provides DS services in addition to acting as a STA. The transmitted data move between a BSS and the DS via an AP (Figure 2). AP is analogous to the base station in a cellular communications network. The Access Point fulfill the network management functions:

- Authentication and association all mobile stations with the correct BSS.
- Power management – AP should remember which stations are in power-saving mode and keep in buffer all destinations.
- Synchronization all stations to common timer.

Because of limitations on wireless PHY ranges, wireless LANs intended to cover reasonable geographic distance may be built from basic coverage building blocks. The DS and BSSs allow IEEE 802.11 to create a wireless network of arbitrary size and complexity. IEEE refers to this type of network as the Extended Service Set (ESS) network. The key concept lies in the same LLC layer. Stations within an ESS may communicate and mobile stations may move from one BSS to another transparently to LLC. In generally:

- The BSS may be partially overlap.
- The BSS could be physically disjointed (there is no limit to the distance between BSS);
- The BSS may be physically collocated (to provide redundancy).

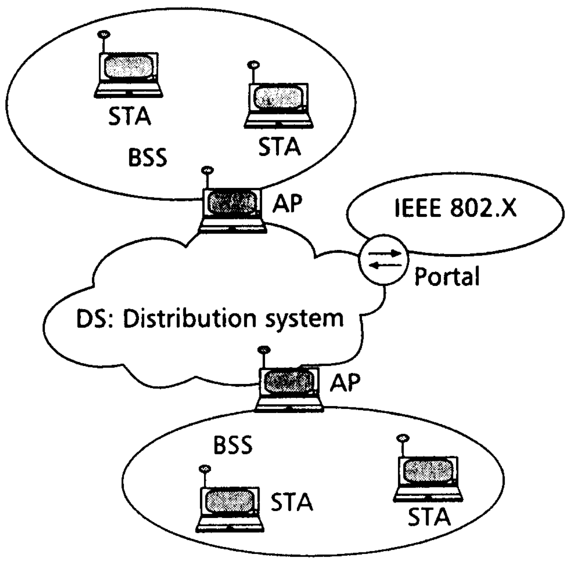

Figure 2. Infrastructure network - distribution systems, access point and portal

In order to integrate the IEEE 802.11 with a traditional wired LAN, a new logical component has been introduced and named as the portal (see Figure 2). It is a point at which MSDUs from an integrated non-IEEE wireless LAN enter the IEEE 802.11 DS. The portal provides logical integration between the IEEE 802.11 architecture and existing wired LANs. It is possible for one device to offer both the functions: an AP and a portal. The DS, as specified by IEEE 802.11, is implementation independent. Therefore, the DS could be a wire IEEE 802.3 Ethernet, IEEE 802.4 token bus, IEEE 802.5 token ring, fiber distributed data interface (FDDI) metropolitan area network, or another IEEE 802.11 wireless medium. DS could physically be the same transmission medium as the BSS, but they are logically different, because the DS is solely used as a transport backbone to transfer packets between different BSSs in the ESS. The standard defines the services that DS must realized. There are two categories of services: Station Services and Distribution System Services. The first category comprises: MSDU frames transport between the stations within BSS, authentication and deauthentication stations to the network, privacy. The second category includes association and disassociation, distribution, integration and reassociation.

DCF ACCESS PROCEDURE

The IEEE 802.11 standard supports two access methods: a mandatory distributed coordination function method which is available in both ad hoc and infrastructure configurations, and an optional point-coordinated function which is available within certain infrastructure environments and which can be provide time-bounded services [Crow97], [Natk99], [Wein95].

The DCF is the fundamental access method used to support asynchronous data transfer on best effort basis. All the stations must support DCF. The 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 [Diep93] , [Pach95], [Puig94].

The DCF 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 before the data exchange. It allows stations to avoid transmission in time intervals in which the medium is surely busy.

When using the 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 InterFrame Space (DIFS). In the case the medium is busy the transmission is deferred until the end of ongoing transmission. A random interval (backoff interval) is then selected and is 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 probability of collision, after each unsuccessful transmission attempt the expected value of the random backoff interval is increased exponentially up to predetermined maximum (see Figure 3).

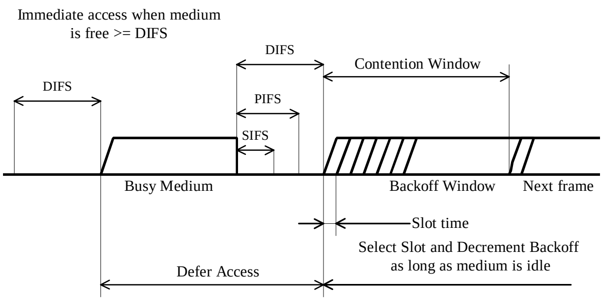

Figure 3. Basic access method

Immediate positive acknowledgements are employed to determine the successful reception of each data frame. This is accomplished by the receiver initiating the transmission of an acknowledgement frame after a time interval called Short InterFrame Space (SIFS). This time is less then DIFS. Acknowledgement is transmitted without the receiver sensing the state of the channel. In the case when an acknowledgment is not received the data frame is presumed lost and the transmitter schedules a retransmission.

Since a source station in a BSS cannot hear its own transmission, when a collision occurs, the source continues transmitting the complete MPDU. If MPDU is large (e.g., 2000 octets), a lot of channel bandwidth is wasted due to a corrupt MPDU. Request To Send (RTS) and Clear To Send (CTS) control frames can be used by station to reserve channel bandwidth prior to the transmission of an MPDU and to minimize the amount of bandwidth wasted when collision occur. The rules for the transmission of an RTS frame are the same as those for a data frame under basic access. The transmitter sends an RTS frame after the channel has been idle for a time interval exceeding DIFS. On receiving an RTS frame the receiver responds witch a CTS frame, which can be transmitted after the channel has been idle for a time interval exceeding SIFS. After a successful exchange of RTS and CTS frames the data frame can be sent by the transmitter after waiting for a time interval SIFS. In the case when a CTS frame is not received within a predetermined time interval, the RTS is retransmitted following the backoff rules as specified in basic access.

The RTS and CTS frames contain a duration field that indicates the period the channel is to be reserved for transmission of the actual data frame. This information is used by stations that can hear either the transmitter and/or the receiver to update their Net Allocation Vector (NAV) – a timer that is always decreasing if its value is non-zero. A station is not allowed to initiate a transmission if its NAV is non-zero. The use of NAV to determine the busy/idle status of the channel is referred to as the Virtual Carrier sense mechanism. Since stations that can hear either the transmitter or the receiver resist from transmitting during the transmission of the data frame under consideration the probability of its success is increased. However, this increase the probability of successful delivery is achieved at the expense of the increased overhead involved with the exchange of RTS and CTS frames, which can be significant for short data frames. The detailed protocol description can be found in [IEEE96], [Chay96].

SIZE OF FRAMES

The most popular networks are Ethernet (IEEE 802.3), Token Ring (IEEE 802.5), Token Bus (IEEE 802.4), FDDI and ATM. We can find some of them in offices, flats, etc. (LANs); other ones assure connectivity in campus centers, buildings located in the area of city (MANs); the last one group allow to connect the cities or countries. Some networks transfer constant length frames. The other group transfer variable size frames of different length. In Ethernet network the data field length can change from 46 to 1500 bytes; in Token Bus 0 – 8182 bytes; in Token Ring it could amount 8000 bytes for 16 Mbps medium capacity and 4500 bytes for 4 Mbps medium capacity; FDDI support frames of 4500 bytes size; in ALOHA it can grows up to 40 and 80 bytes; in

ATM networks it is constant 53 bytes frame called ATM cell.

IEEE 802.11 network allows transmitting up to 2312 bytes data frames. It is indispensable to use frames fragmentation to provide transmission from FDDI, Token Ring etc. networks, where much longer frames are used. There is a need of making de-fragmentation of very short frames to provide efficient transmission in IEEE 802.11 networks. This conclusion can be draw leaning on simulation results. The detailed IEEE 802.11 frame size is presented on Figure 4.

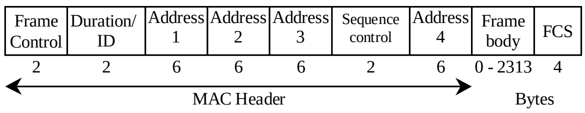

Figure 4. The IEEE 802.11 detailed frame size.

We check the possibility of transmission frames of following sizes:

- 53 byte frame (ATM frame size);
- 432 byte frame (average packet size of the Ethernet trace-file taken from the Bellcore Morristown Research Institute);
- 1500 byte frame (maximum Ethernet frame size);
- 2250 byte frame (almost maximum of IEEE 802.11 frame size, can be taken from fragmentation of much longer frames that are transmitted from other networks like FDDI, Token Ring, etc.).

SIMULATION RESULTS

Simulations were carried out for DCF function while transmitting frames of different length. The total achieved bandwidth and the mean frame delay as functions of the offered load were investigated for different number of stations (2, 5, 10, and 20). Several assumptions have been made to reduce the complexity of the simulation models:

- The effects of propagation delay are neglected. This is very realistic assumption if the transmission distances are tens meters between stations.
- Channel was error free that means that each packet that was transmitted by the sender was successfully and correctly received by the receiver (no collision was occurred).
- The “hidden stations” problem is not addressed in simulation model.
- No stations operate in the “power-saving” mode. All stations should be “awake” at all time, then transmitted MPDUs can be received immediately by the destination station.
- A finite transmit buffer (30 frames) is maintained for each station.
- There is no interference from nearby BSSs.

The DATA+ACK mode of transmission was chosen. The network was configured to 2 Mbps medium capacity. The parameters used throughout all simulations are displayed in Table 1.

Table 1. Fixed parameters used throughout all simulations

Parameter	Value
SIFS	28 µs
PIFS	70 µs
DIFS	130 µs
Length of RTS	20 octets
Length of CTS	14 octets
Length of ACK	14 octets
DATA header	32 octets
Physical layer preamble	10 octets
Maximum number of slots	32000
Initial size of window CW	32
Length of slot	50 µs
Size of buffer for frames	30 frames
Number of retransmission of DATA frames	4
Number of retransmission of RTS frames	4
Timer 1	300 µs
Timer 3	300 µs
Length of asynchronous data field	53, 432, 1500, 2250 octets
Number of stations	2, 5, 10, 20

The results of obtained simulations are presented on two series of plots presented on figures 5 - 12:

- Dependence of throughput for asynchronous services (for all assumed lengths of asynchronous data field) as a function of offered load for 2, 5, 10 and 20 stations.
- Dependence of mean packet delay for asynchronous services (for all assumed lengths of asynchronous data field) as a function of offered load for 2, 5, 10 and 20 stations.

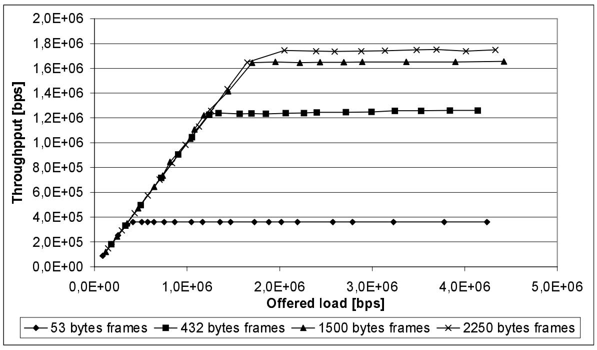

Figure 5. Throughput versus offered load for different packet sizes for 2 stations

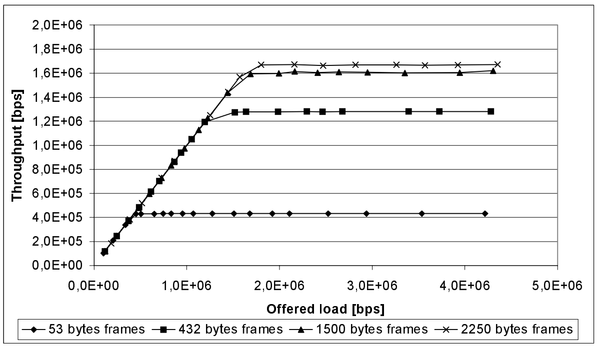

Figure 6. Throughput versus offered load for different packet sizes for 5 stations

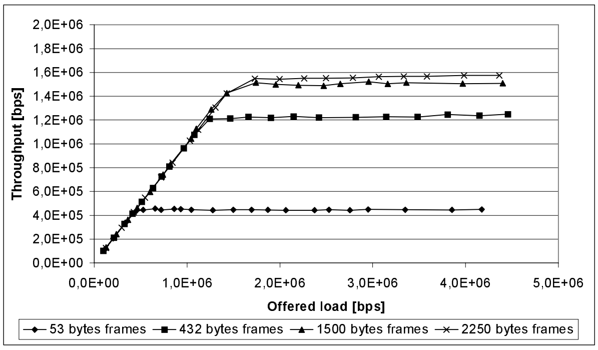

Figure 7. Throughput versus offered load for different packet sizes for 10 stations

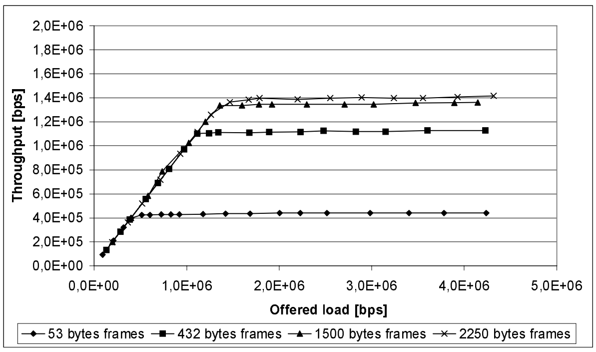

Figure 8. Throughput versus offered load for different packet sizes for 20 stations

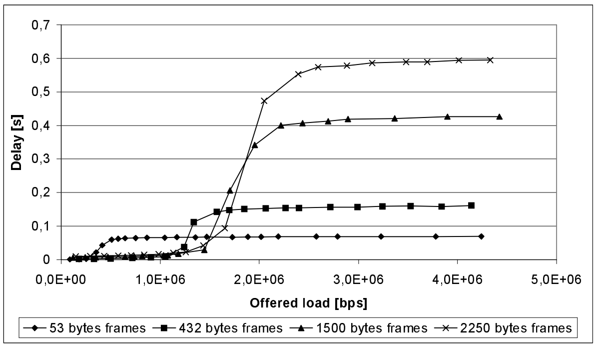

Figure 9. Delay versus offered load for different packet sizes for 2 stations

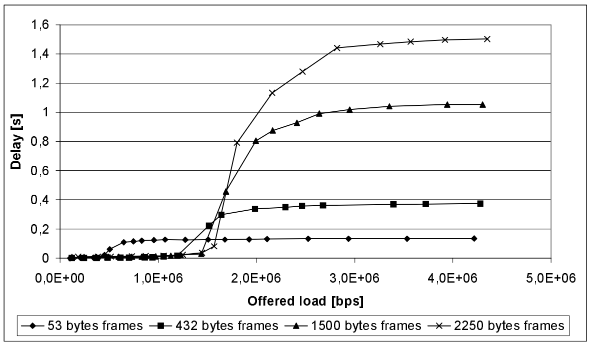

Figure 10. Delay versus offered load for different packet sizes for 5 stations

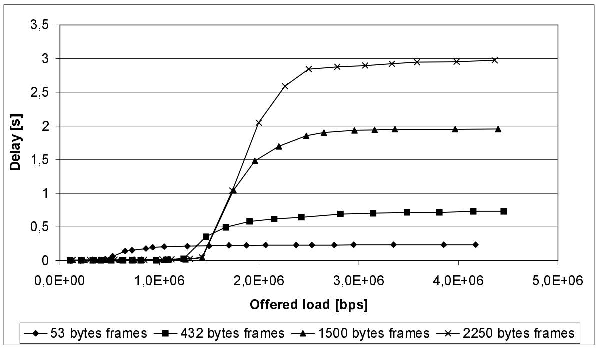

Figure 11. Delay versus offered load for different packet sizes for 10 stations

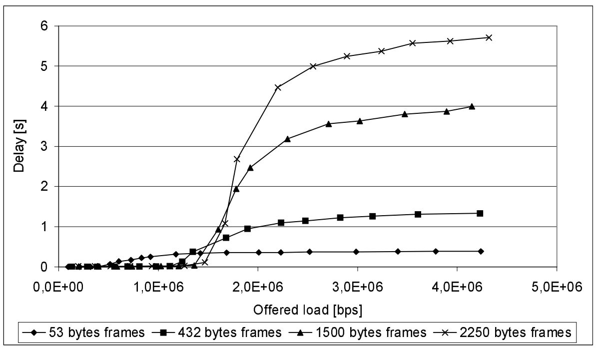

Figure 12. Delay versus offered load for different packet sizes for 20 stations

Introduced graphs are divided on two groups. First group presents dependence of throughput for asynchronous services (for all assumed lengths of asynchronous data field) as a function of offered load for 2, 5, 10 and 20 stations (Fig. 5, Fig. 6, Fig. 7 and Fig. 8). The second group - dependence of mean packet delay for asynchronous services (for all assumed lengths of asynchronous data field) as a function of offered load for 2, 5, 10 and 20 stations (Fig. 9, Fig. 10, Fig. 11 and Fig. 12).

Detailed analysis of presented figures allows us to draw out several interesting conclusions. The performance of network degrades while transmitting short ATM frames. It is the effect of the large payload (preamble, FCS, addresses, control sequence etc. – see Figure 4). Another reason lies in the number of times in which medium is accessed by the stations. While transmitting very small frames the cost of accessing the medium is huge. The realized throughput as a function of offered load for all frame sizes grows linear up to certain limit. After then the realized throughput saturate on certain level and it is independent from offered load. In case of 53 byte frames the network efficiency is independent from number of stations participating in transmission and saturates the level 400 kbps of realized throughput. The realized throughput degrades as a number of participating stations grows for longer frame sizes. In case of 2250 bytes frames for 2 stations it attain 1750 kbps, for 5 stations – 1680 kbps, for 10 stations – 1580 kbps, for 20 stations – 1400 kbps. Characteristic is also the fact of non-linear influence of packet length on efficiency of realized throughput. In case of 1500 bytes frames we must reconcile with fall of efficiency about 5%. It is possible to increase the throughput while transmitting maximum size frames. Then the DATA+ACK+RTS+CTS mode of transmission should be used to minimize the probability of collisions (usage these additional frames can also dissolves problems resulting from existences of hidden stations). The control information transferred in RTS / CTS frames guarantees that all stations within range of either sender or receiver have knowledge of the transmission as of the duration of it. The RTS /CTS mechanism increases bandwidth efficiency since if collision occur they do not occur with the long data packets but with the relative small control packets. We must remember that using RTS / CTS mechanism the bandwidth decreases while transmitting short frames because probability of collision is small and the introducing overhead is relative large. Due to mentioned trade-offs, the IEEE 802.11 standard allows RTS /CTS usage but doesn't demand it. Usage policy is set on help of a object RTS_Threshold that indicates the payload length under which the data frames should be sent without the RTS / CTS prefix.

The next series of plots presents dependence of mean packet delay for four frame sizes as a function of offered load for 2, 5, 10 and 20 stations. Low increase of mean delay for low offered network load is observed. It is on the level of some milliseconds. The mean packet delay grows faster for lower values of offered load, more quickly attaining the maximum levels of delay in case of short frames transmission. Number of stations participating in transmission has comparatively low influence on shape of obtained characteristics. We can observe that mean packet delay significantly increases while transmitting frames of maximum size. The observation of presented figures allow us to draw the conclusion that transmitting frames of medium sizes (about 1500 bytes) is more reasonable because it brings the reduction of mean delay about 30%. It brings the reduction of throughput too, but in comparison to obtained profits only about 5%. The maximum packet delay for ATM frames transmission does not exceed the level of 0,4s. It is relative small value, but it brings the large degradation of overall throughput. Number of contesting to access to the medium stations has large influence on mean packet delay for all frame sizes. For 2 stations the maximum delay does not exceed 0,6s, for 5 stations – 1,5s, for 10 stations – 3s. For 20 stations the simulation results didn't reach value of saturation. Presented graphs allow us to suppose that this value can reach the level of 6s. On so large value of delay influences time of storage of packets in the station buffer, before it will obtain the access to the medium and will send prepared earlier packets (this time lengthens in case of 20 contesting stations).

CONCLUSIONS

The efficiency of the DCF function while transmitting frames of different length in an IEEE 802.11 network was presented in this paper. These are frames sent from other computer networks: Ethernet, Token Ring, FDDI, ATM etc. It allows us to check some aspects of operations for this kind of network. The realized transmission was an asynchronous one. Performed simulations were related to throughput and mean delays in turn of offered load for different number of stations. The presented analysis led us to some important conclusions briefly presented below (the detailed conclusions were presented in chapter before):

- The performance of network degrades when packet size decreases (especially while transmitting ATM frames).
- The growth of offered load above the nominal capacity of the network does not brings the degradation of the realized throughput like in some others wireless networks Aloha, Slotted Aloha, CSMA (IEEE 802.11 medium access control protocol is more stable).
- An unprofitable influence of number of contesting stations on efficiency of realized throughput is observed – especially in case of long frame transmission.
- Transmission of long packets brings the growth of mean packet delay, especially for large values of offered load.
- The mean packet delay saturated on constant level after exceeding certain value of offered load – this level is obtained much faster for shorter frames.

The presented conclusions allow us to increase the efficiency of IEEE 802.11 network across usage suitable fragmentation of too long frames or de-fragmentation of too short frames. Obtained efficiency is of course highly dependent from number of participating stations. The access point station – AP should have the suitable algorithm qualifying optimum length of frames based on the knowledge of number of active stations in the BSS area. The obtained results show that usage of too long frames can bring large values of mean packet delay.

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