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A METHOD FOR IMPROVING TRANSFER QUALITY OF CBR STREAMS OVER WIRELESS LANS

The paper proposes a new mechanism for wireless LAN networks IEEE 802.11 fully dedicated to handling CBR (Constant Bit Rate) streams that require constant packet transfer delay. The mechanism is targeted on improving packet transfer characteristics. This mechanism, named Self-synchronization Packet Transfer (SPT), is implemented in each station on the top of the MAC layer and is focused on avoiding the transmission backoffs and packet contention caused by the MAC protocol that are responsible for producing large packet transfer delay variations. The objective of the SPT is to set the moment for packet transmission when the medium is idle. This is achieved by delaying the packet. The value of this delay is set independently in each station on the basis of observation of the previous successful transfer packet belonging to the same stream. Finally, for consecutive packets from this stream we observe no packet contention when we delayed each packet by the same (constant) value. In the paper we evaluate the effectiveness of the proposed mechanism for improving packet transfer characteristics of CBR streams in wireless LAN and compare them with the results for standard solution.

1. INTRODUCTION

Handling of CBR (Constant Bit Rate) traffic with the guarantees of low packet transfer delay variation is still not solved in IEEE 802.11 wireless LAN networks [1]. The main problem comes from the operation of MAC (Medium Access Control) protocol that assumes contention mechanism in the access to the medium. According to the MAC protocol, in the case when two or more stations want to transfer packets, then the transmission times of these packets are scheduled in a random way following the exponential backoff procedure. In addition, it is likely that the backoff procedure results in collision between contending packets, and when such situation takes place the packets are retransmitted. As a consequence, the packets in wireless LANs may experience large packet transfer delay variation. For example, the results for studies of VoIP traffic (CBR traffic) handled over wireless LANs [2,3,4,5] point out that packet transfer delay variation is at the level of 20-30ms and these values are not acceptable for telephony applications, which, according to [6], can tolerate up to 50ms in end-to-end scenario covering core network and two access networks.

Some approaches for improving packet transfer delay characteristics of the CBR traffic in the wireless LAN environment were recently investigated. For example, the solutions presented in [7,8,9] suggest that we can improve packet transfer delay characteristics for CBR streams by tuning values of MAC protocol parameters, such as congestion window size or inter-frame size. However, such approach leads only to provide relatively better handling of CBR streams but not to assure strict

QoS (Quality of Service) guarantees as required e.g. by VoIP. Other solutions [10,11] propose to engage the polling mechanism in MAC protocol that allows us to emulate synchronous TDMA (Time Division Multiple Access) access and in this way to assure strict QoS guarantees for CBR streams. However, this requires a centralised control with an advanced scheduling algorithm to govern the moments for starting transmission packets. In fact, the polling mechanism is rather complicated and it is not implemented in currently available equipment.

In this paper we consider a wireless LAN fully dedicated for handling CBR streams. For such a network, we propose a new mechanism, named the self-synchronized packet transfer (SPT) mechanism that allows us to improve the transfer quality of CBR streams. The main objective of SPT mechanism is to synchronize the moments when particular stations may submit the packets for transmission to the MAC layer in order to avoid transmission backoffs. For that purpose, we implement SPT mechanism in each station on the top of the MAC layer operating in standard DCF (Distributed Coordination Function) mode, as presented on Fig. 1.

For each CBR stream in the stations (including Access Point), the SPT mechanism delays the packets for a certain amount of time, called initial delay. This delay assures that each packet will be submitted to MAC layer only when the medium is idle. In this way, the packets will be transmitted immediately without going into the backoff procedure. Each SPT entity calculates in independent way the value of initial delay taking into account the time of the previous packet transmission. Anyway, the SPT requires a time for synchronization of the stations that is got when all stations set the values of their initial delays that are not changed for the consecutive packets. The important features of the SPT mechanism are that: (1) stations perform synchronisation in a distributed manner, and (2) SPT does not require any changes in the MAC layer.

The paper is organized as follows. In section 2 we present details of proposed SPT mechanism including station synchronisation algorithm. Then, in section 3, we focus on evaluation of SPT performances. Finally, section 4 summarizes the paper and gives an outline of further works.

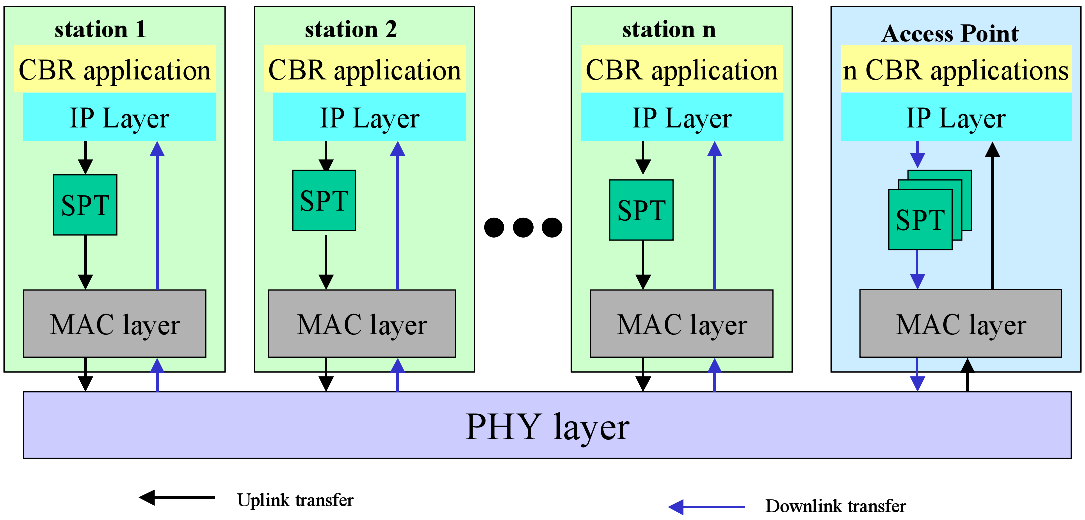


Fig. 1. SPT mechanism in wireless LAN network.

2. SPT MECHANISM

In this section we provide details about the SPT mechanism. As it was above mentioned, we assume that a wireless LAN handles CBR streams only. In addition, we consider the case of homogenous CBR streams that have the same packet inter-arrival period.

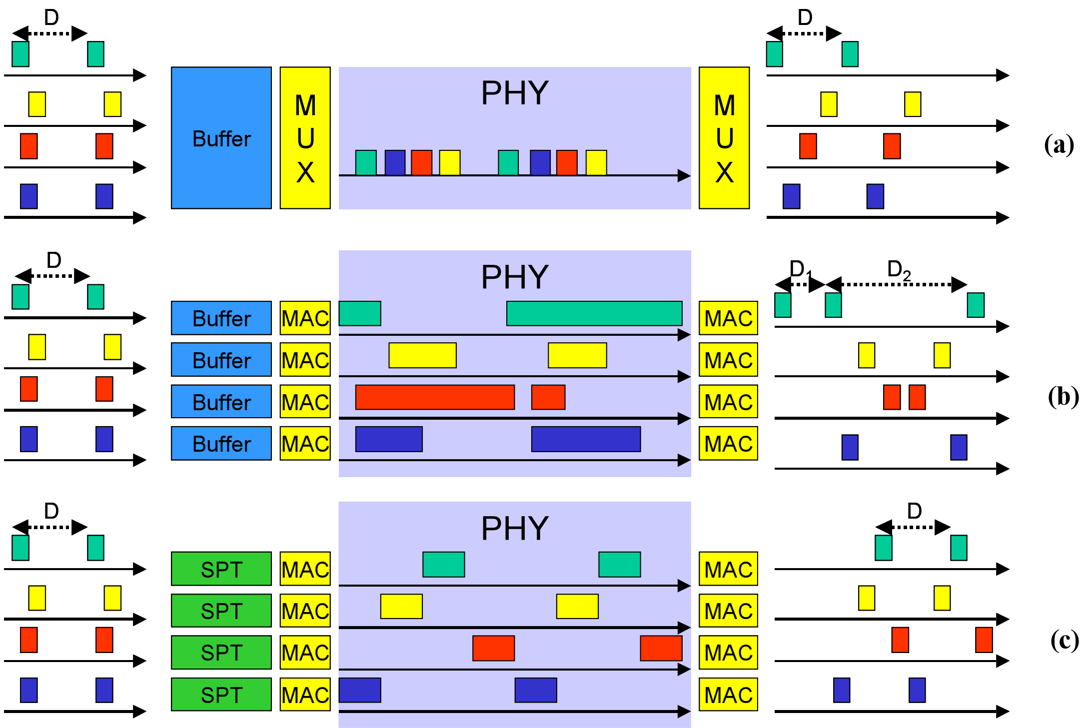


Fig. 2. Comparison of CBR streams multiplexing in case of: (a) wired link, (b) standard wireless LAN and (c) wireless LAN with applied SPT mechanism.

In order to explain the role of SPT mechanism we present in Fig. 2 an multiplexing example of CBR streams that correspond to: the wired system (Fig. 2a), standard wireless LAN (Fig. 2b) and wireless LAN with applied SPT mechanism (Fig. 2c). Notice that multiplexing in wired system keeps for each CBR stream both the order of packets as well as packet inter-departure times. However, multiplexing in standard wireless LAN differs essentially and we observe for particular CBR stream the following drawbacks: (1) the order of packets is random, (2) packet inter-departure times vary and (3) packet service times are not constant (denoted on Fig. 2 as length of packets on PHY layer). As a consequence, after passing wireless LAN system, the packets may experience significant delay variation that is caused by contention mechanism and random backoff procedure used in MAC protocol for governing access to the wireless medium. The aim of SPT is to eliminate contention between packets taking into account property of MAC protocol. When arriving packet observes an idle medium for duration of DIFS (Distributed Inter Frame Space) time then it is sent immediately without going into the backoff procedure. So, the SPT aims at injecting packets to the MAC layer only when medium is idle. For that purpose SPT mechanism, running in each station, delays arriving packets before submitting them to the MAC layer for a certain time, called initial delay. As an effect, we achieve a synchronised system, similar to TDMA, which always avoids backoffs before sending packets, and in this way it guaranties constant transfer delay as presented on Fig. 2c.

The main part of SPT mechanism is an algorithm that allows particular stations to set appropriate values of initial delays. This value is calculated as follows. When a new CBR connection with packet inter-arrival time (*D*) arrives at the station, the SPT entity sends first packet immediately to the MAC layer. Then, it observes the time instant when it receives confirmation from the MAC layer that the packet was delivered to the destination. For the next packet belonging to this stream, the SPT entity delays the moment when it will be submitted to the MAC layer in order to start its transmission exactly one inter-arrival time (*D*) later than the transmission of the previous packet was started. Formally, the value of initial delay for n[th] packet ($d^n_{initial}$) may be expressed as:

$$d^n_{initial} = T^{n-1}_{CONF} - T_T + D - T^n_{ARRIV}, \quad (1)$$

where: T^{n-1}_{CONF} denotes time instant when the SPT entity received confirmation from he MAC layer about the previous packet (n-1); T_T is the time needed for packet transmission including all overheads and acknowledgment; D is packet inter-arrival time and T^n_{ARRIV} denotes arrival time of n^{th} packet.

The SPT entity finishes synchronisation when the value of initial delay does not change for a few consecutive packets. If such situation takes place, the consecutive packets of CBR streams will be transferred with a constant packet transfer delay. The detailed algorithm for SPT entity in the form of the pseudocode is provided in Appendix A. We observe that wireless LAN enhanced by SPT mechanism can be in one of the following states: (1) synchronisation state, when at least one station is not synchronised and (2) operational state when all stations are synchronised. Following that, we state that the main performance issue for SPT is the system synchronization time (T_s) defined as the time needed to finish synchronisation by all SPT entities. Let us remark that the synchronisation state occurs only when a new CBR connection arrives to the system. Notice that such event may also cause that some of already synchronised stations may require resynchronisation.

The main constraints in implementation of the SPT mechanism comes from time granularity required for obtaining indication from MAC layer and moments of packet arrivals to the particular terminal. Let us recall that operating systems, which usually govern logical queues before sending packets to the transmission buffer of wireless card, allow us for controlling the events on the time scale in magnitude of milliseconds. However, our mechanism needs to be more precise as it exploits MAC behaviour scheme, where time intervals are measured in microseconds. Therefore, even if the MAC layer is unchanged, some support from the low level software, called firmware may be needed.

3. PERFORMANCE EVALUATION

In this section we analyse the effectiveness of SPT mechanism. For that purpose we study the packet transfer delay variation experienced by CBR streams handled by the wireless LAN network with and without using the SPT mechanism. Furthermore, we analyse duration of the synchronisation period required by SPT. Our studies were performed using NS-2 simulator [12] that was additionally enhanced with the model of SPT mechanism.

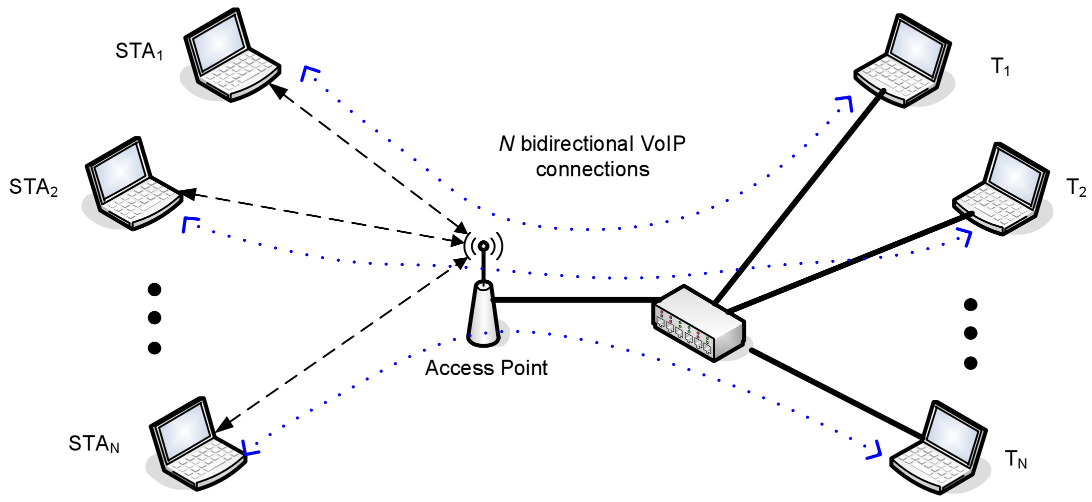


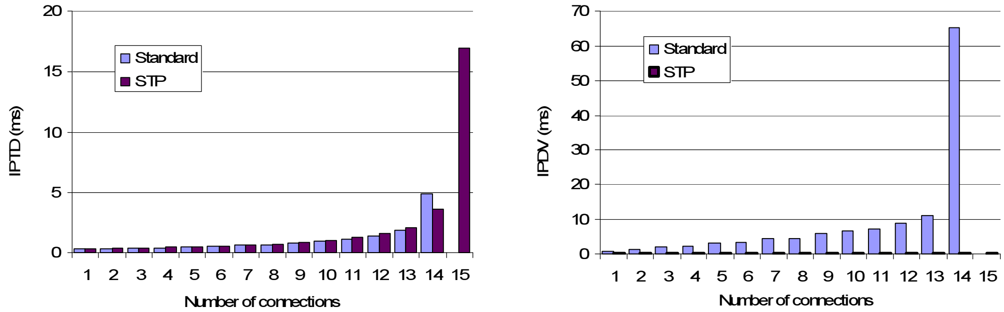
Fig. 3: The wireless LAN network assumed for the experiments.

For experiments we assume a simple wireless LAN network presented on Fig. 3 consisting of a single access point (AP) and a number of wireless stations (STAx) operating in DCF access method using 11Mbps physical layer with long preamble. We assume that the network is fully dedicated for handling bidirectional CBR streams established between pairs of wireless station STA_X and corresponding wired terminal T_X. The CBR streams were produced by VoIP application using G.729 voice codec that emits 60 bytes length packets every 20 ms. In addition, we assume error-free wireless channel. The presented results correspond to (1) mean value of IPTD (IP Packet Transfer Delay), (2) IPDV (IP Packet Delay Variation) defined as 0.999 quantile of IPTD distribution and (3) SPT synchronisation time that was defined as the time elapsing between arrival of new VoIP connection, consisting of two CBR streams, until the whole wireless LAN network is synchronised.

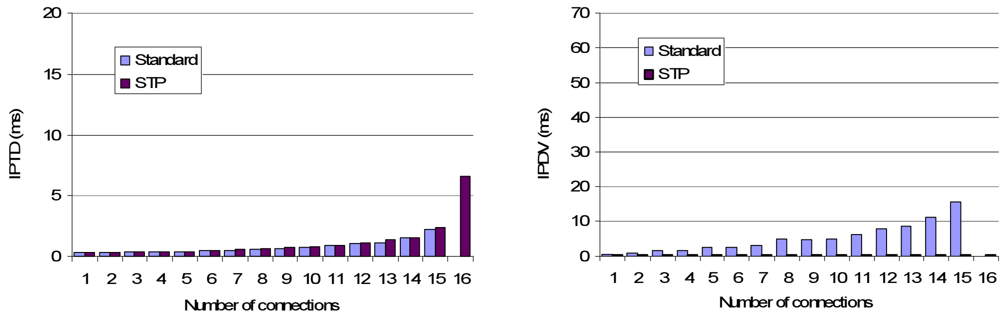
The reported results correspond to 100 simulation runs with randomly distributed moments when CBR streams were started. In each simulation run at least one million of packets was transmitted after completed synchronisation. In case when our objective was evaluation of synchronisation time, we studied a synchronised system with *n-1* VoIP connections and then we initiated a new bidirectional connection.

On Fig. 4 we present the comparison of packet transfer delay characteristics that were collected in a wireless LAN operating with and without SPT mechanism. The results are obtained as a function of number of running connections. Moreover, we analyse the impact of setting the minimum contention window (CW_{min}) parameter. As it was expected from SPT, the value of IPDV is equal to zero for all cases. The mechanism is not influenced by the traffic load and value of CW_{min} parameter. Comparing with the wireless LAN without the SPT mechanism, we observed a case where the value of IPDV exceeded 60ms (see Fig. 4a). However, in other cases of high load in system, we measured the value of IPDV close to 15ms and this still seems to be unacceptable considering end-to-end requirements.

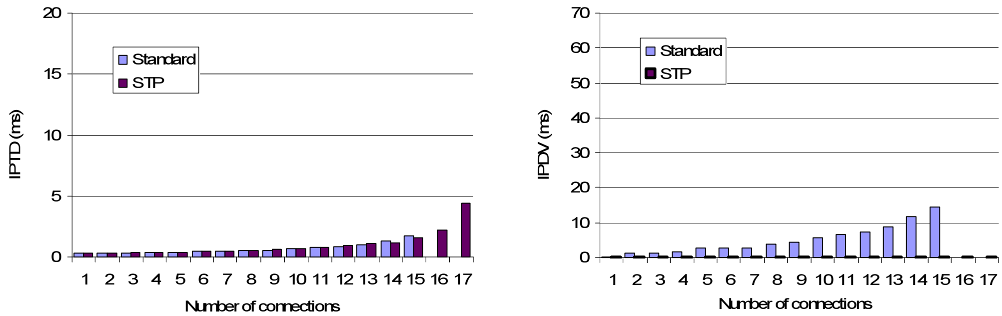
Moreover, we may observe that when the SPT mechanism was applied in the system, we may accept a few more VoIP connections. The reason of that is the nature of mechanism that reduces randomness in the access to the wireless medium and therefore allows for more connections. When wireless LAN operates with default value of CW_{min}, equal to 32 (for 11 Mbps physical layer), we can accept one additional VoIP connection (6% increase). However as we decrease the value of this parameter to 4 we achieve gain up to three VoIP connections (see Fig. 4d), which is 20% increase, related to the standard system in stable conditions.



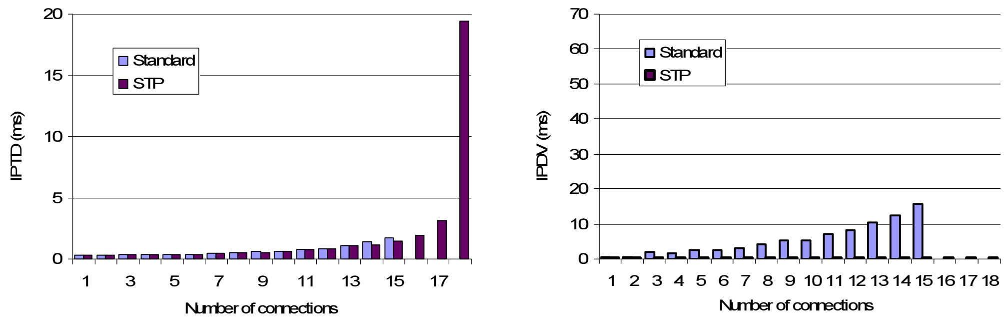
a) CW_{min}=32; CW_{max}=1024



b) CW_{min}=16; CW_{max}=1024



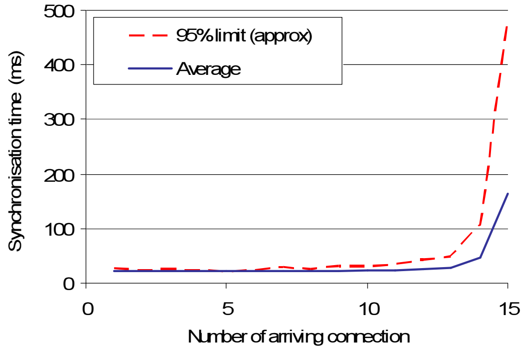
c) CW_{min}=8; CW_{max}=1024



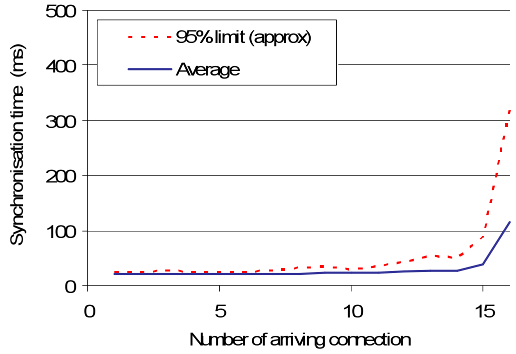
d) CW_{min}=4; CW_{max}=1024

Fig. 4: Comparison of packet transfer delay characteristics of standard and SPT enhanced wireless LANs obtained for different values of CW_{min}.

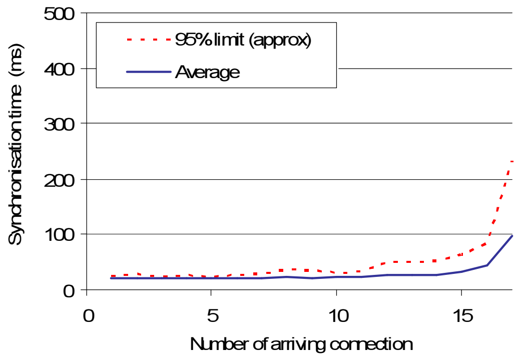
The SPT does not impact the mean value of IPTD, although we observe slight enlargement in case of CW_{min} equal to 32 and low and moderate load. On other hand when CW_{min} is set to 4 the SPT reduces the mean value of IPTD, however it is mainly connected to larger capacity of system in this case (by 20%).



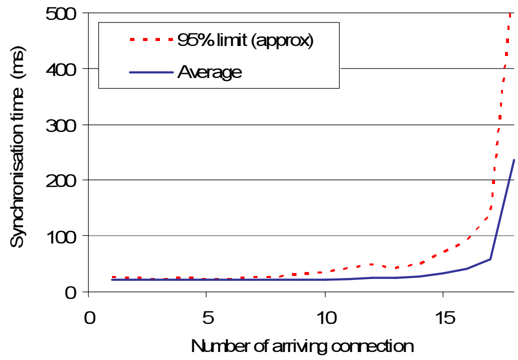
a) CW_{min}=32; CW_{max}=1024



b) CW_{min}=16; CW_{max}=1024



c) CW_{min}=8; CW_{max}=1024



d) CW_{min}=4; CW_{max}=1024

Fig. 5: SPT synchronisation time after arrival of n^{th} VoIP connection to the already synchronised system.

The results of characteristics of synchronisation time T_S are shown on Fig. 5. As mentioned above, T_S consider a time required for all SPT entities to achieve synchronisation after arrival of a new connection to already synchronised system. The plots provide value of average synchronisation time and an approximation with Gaussian distribution of 95% percentile of synchronisation time. Like in previous studies, we analyse the impact of CW_{min} parameter.. We can observe that in most cases the synchronisation takes less than 100ms, although when the last admissible connection arrives, its synchronisation time may be highly variable. For Fig. 5a and Fig. 5d the 95% limit reaches 500ms. It is also noticeable that when CW_{min} is fixed to 4, the average synchronisation time for the last admissible connection greatly increases. This effect is a result of high collision probability on the medium caused by a low value of CW_{min}.

4. CONCLUSIONS & FURTHER WORK

In this paper we proposed the SPT mechanism for improving the transfer quality of CBR streams handled in wireless LAN network. The objective of SPT is to synchronise the moments when particular stations submit packets for transmission to the MAC layer in such a way to eliminate transmission backoffs. The obtained simulation results confirm that SPT mechanism, after passing synchronisation phase, guaranties constant packet transfer delay for. Moreover, our experiments prove that the profit given by SPT mechanism increases in cases when the wireless LAN is heavy loaded. On the other hand, the time required by SPT for synchronisation can be treated as negligible, comparing with duration of call set-up phase, as in most cases it does not exceed 100ms.

Our further work will focus on evaluation of SPT mechanism for the case when the wireless LAN will handle heterogeneous CBR streams differing in both packet inter-arrival times and packet lengths. Moreover, we analyse impact of transmission errors occurring in the wireless medium on SPT synchronisation process.

APPENDIX A: PSEUDOCODE OF SPT ENTITY ALGORITHM

The Fig. 6 presents the pseudocode for SPT algorithm. It contains two procedures. The first one, `on_send_packet_request ()` is invocated after arrival of packet belonging to CBR stream, while the second `on_sent_packet_notification()` is performed when SPT entity receives confirmation from the MAC layer about packet delivery to destination.

```
/// variables:
D;               // inter-arrival period
next_send = 0;   // scheduled time for sending next packet to MAC
buffer;          // packet buffer for this stream
count = 0;       // number of packets in system

// arrival of packet
on_send_packet_request(new_packet)
{
    if (next_send > now()) than
        if (count == 0) than
            delay := next_send - now();          // send this packet
            delayedSendToMAC(delay, new_packet); // after delay
        else
            buffer.put_packet(new_packet);
        endif
    else
        sendToMAC(new_packet);
    endif
    count := count + 1;
};

// confirmation of sent packet
on_sent_packet_notification(sent_packet)
{
    next_send := now() - transmissionTime(sent_packet) + D;
    if (next_send > now() + D) than
        next_send := next_send - D;
    endif
    if (count > 0) than
        delay := next_send - now();
        delayedSendToMAC(delay, buffer.get_packet());
    endif
    count := count - 1;
};
```

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