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Service Interval Impact over Delay and Power Efficiency for Real Time Streams in HCF WLAN

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Abstract: The IEEE 802.11e standard defines Hybrid Coordination Function (HCF) which provides QoS support for real-time multimedia applications. Real time multimedia applications having bounded delay constraint, demands frequent scheduling and sufficient amount of Transmission Opportunity (TXOP) to guarantee the delay bound requirement. When a station works with multiple calls, scheduler should choose the proper scheduling interval to meet the delay guarantees. At the same time this scheduling interval has impact over the power conservation of the station. Power conservation is also a much needed property as most of the WLAN stations are nomadic in nature and may be a handheld. This study combines the delay bound and power efficiency requirement and tries to address the solution. This study considers a scenario of stations working with multiple numbers of calls with different delay demands and proposed three different scheduler approaches which vary in scheduling nature. The 3 approaches vary in selecting the Service Interval (SI) to serve the stations. Each approach is analyzed on realizing the guaranteed delay and their effectiveness of power efficiency. The delay performance of delay bound streams under different call combination and varying number of stations for the fixed load is evaluated and analyzed.

Key words: WLAN, HCF, service interval

INTRODUCTION

IEEE 802.11 standard defines a mandatory Distributed Coordination Function (DCF) Media Access Control (MAC) access mechanism along with an optional centralized Point Coordination Function (PCF), both fails to differentiate traffic streams thus there is no QoS support. DCF uses Carrier Sense Multiple Access/ Collision Avoidance (CSMA/CA) with random backoff period which is a probabilistic approach and the performance is unpredictable and unstable. PCF is a centralized polling approach but is static and not QoS friendly. The round robin polling and fixed resource allocation independent of traffic nature are its drawbacks. To support QoS, the IEEE 802.11e (IEEE Standered 802:11, 2005) standard defines two other MAC mechanisms namely Enhanced DCF (EDCF) and HCF. EDCF is contention based, supports service differentiation and priority based QoS but lacks in supporting real time applications with guaranteed QoS that is offered by HCF. HCF overcomes the drawbacks of all other WLAN MAC mechanisms and been designed to provide the guaranteed QoS for real time applications. It offers parameterized QoS by traffic negotiations and is mostly suitable for real time, high delay sensitive multimedia applications. The HCF is made of a contention-based channel access, known as the Enhanced Distributed channel Access (EDCA) which uses EDCF mechanism and a polling based HCF Controlled Channel Access (HCCA). The HCF operation is based on the Traffic Specification (TSPEC) and it is capable of supporting real time QoS guarantees with efficient scheduling and resource allocation methodologies.

Even though HCF provides support for real time streams still fails to meet the delay demands according to the Service Level Agreement (SLA) policy of real time streams. The HCF mechanism defined by IEEE 802.11e standard specifies a simple round robin scheduler which does well for CBR but the realization of specified delay for VBR traffic is not guaranteed. Also, when the stations work with multiple calls of different types there is no specific information on scheduling interval which has impact on power efficiency. To achieve such a guaranteed delay performance with power efficiency, more intelligence is need to be added to the scheduling approaches. To serve the real time stream, HCF scheduler utilizes Service Interval (SI) of a Traffic Stream (TS) as the key parameter for scheduling QSTAs. This

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Corresponding Author: J. Jackson Juliet Roy, AU-KBC Research Centre, MIT Campus, Anna University, Chennai, India study proposes three different type of scheduling based on SI and the approaches are named as System SI (SSI), QSTA SI (QSI) and TS SI (TSI). The proposed approaches schedule the QSTAs in a different manner which leads to realization of different delay and power efficiency performance. The effectiveness of meeting the delay demands for different type of traffic streams by each approach is analyzed and compared under various traffic scenarios. The power conservation capability of each approach is also compared in this study. The significant contributions of this study are:

- Proposes three different service intervals based scheduling approaches with different power efficiency and delay capabilities for delay bound streams.
- Extensive study of the proposed approaches for delay and power efficiency capabilities under different realistic traffic scenarios (Effect of call combination in a QSTA, Impact of number QSTAs present on the system performance etc).

MOTIVATION AND PREVIOUS WORK

Various enhancements were proposed to improve the HCF system performance, especially for real time applications and majority of the approaches employ the SI segregation of the HCF superframe to support real time streams. Poumohammadi and Alnuweiri (2005), Wing *et al.* (2004), Pierre *et al.* (2004), Wolf *et al.* (2005) and Cicconetti *et al.* (2007) utilize the basic SI segregation mechanism specified in the standard and topped by scheduler enhancements to provide the required QoS support for real time VBR streams. Even though the HCF enhancements for providing QoS support for VBR real time streams is widely dealt with, a comprehensive analysis of multiple type delay bound streams and its impacts on the systems performance has not been made. Boggia *et al.* (2005) proposed a feedback based bandwidth allocation scheme by using a closed loop control system to achieve system stability that guarantees delay bounds for multimedia traffic streams. Here multiple types of delay bound streams are considered and the effectiveness of the scheduler in ensuring the delay bound under different loads is analyzed. The same authors have proposed a feedback based dynamic scheduler (FBDS) and Proportional-Integral FBDS (PI-FBDS) to guarantee the delay bound of different type of real time streams (Boggia *et al.*, 2007). In Ramos *et al.* (2007), an adaptation framework is proposed to improve the delay guarantees of various multimedia applications. In this study an adaptation to the resource allocation mechanism based on the dynamic nature of the flow is proposed which leads to enhancements in the delay performance of the real time streams. Even though in Boggia *et al.* (2005), Boggia *et al.* (2007) and Ramos *et al.* (2007) the authors have considered multiple types of delay bound streams and has proposed enhancement to attain the delay bounds, most of the quoted approaches, consider one call per station. But in practical scenarios (e.g., enterprise WLANs) each station may work with multiple numbers of calls which could be of different types. The WLAN standard (IEEE Standered 802:11, 2005) also suggests that 8 different streams can be initiated in each QSTA. In the case of enterprise WLANs, scheduling interval of station has impact over the delay performance.

Most of the reported works in the literature have not considered the power efficiency of the stations, a critical parameter for WLAN clients. Works reported in Chou (2003) and Zi *et al.* (2006) talk about power conservation in wireless clients but the solutions are not directly applicable to IEEE 802.11e standard based system. In Zi *et al.* (2006), a novel polling mechanism (UPCF) with power conservation is proposed for IEEE 802.11 WLANs with PCF based access mechanism. In this approach the polling list is prepared dynamically based on the current traffic to conserve power. To deliver the dynamic polling list (Zi *et al.*, 2006) proposes changes to the IEEE 802.11 specification by introducing a new frame. The authors have not considered stations with different types of delay bound calls in their study, On the other hand this study has considered stations with multiple types of delay bound streams with varying delay demands and the number of calls per station could be more than one. This study proposes three different methods of QSTA scheduling with different power efficiency capabilities to achieve the delay guarantees. Each scheduling mechanism varies in the way the scheduling interval is chosen and is capable of producing distinct performance in terms of delay and power efficiency. The procedure for the selection of scheduling interval in each of the three approaches is explained in the study. The performance of the system is analyzed under different traffic scenarios and it is observed that each approach produces distinct performance and each approach is found to be suitable for different traffic scenarios. A comparison of the three approaches is made and the observations are presented.

PROPOSED SCHEDULER DESIGN

In the WLAN system each TS will be initiated by sending ADDTS request from QSTA to the QAP with required QoS parameters such as Peak Data rate, Mean Data Rate, Tolerable Delay, Tolerable jitter, MAC Service

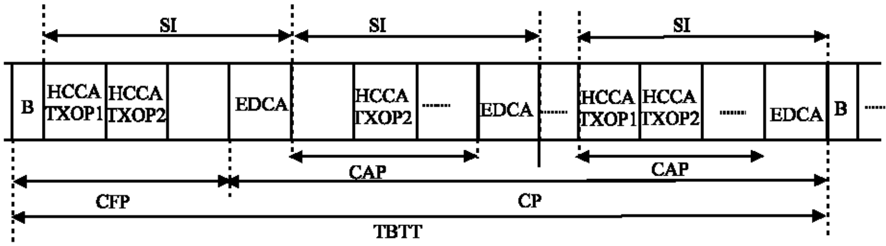


Fig. 1: HCF Superframe logical segregation

Data Unit (MSDU) size and Maximum Service Interval (MSI) etc. MSI is the time interval constraint within which the packet belonging to TS need to be serviced. MSI vary for each type of traffic class and it depends on the traffic nature and estimated from the higher layer delay bound. If n be the different type of streams, this study assume that:

$$\mathrm{MSI}^{j}_{\mathrm{TS}} = \mathrm{DB}^{j}_{\mathrm{TS}} / 2,\ \ j = 1,2,3,...,n \tag{1}$$

where, $\mathrm{DB}^{j}_{\mathrm{TS}}$ is the delay bound.

This ensures that the stream is serviced within the delay bound. The MSI relationship between the different types of TS with respect to the least delay bound stream is given as:

$$\begin{gathered}\mathrm{MSI}^{j}_{\mathrm{TS}} = k(j)\mathrm{MSI}^{1}_{\mathrm{TS}},\ j = 2,3,...,n; \\ k(j) \text{ range from } 2:\infty\end{gathered} \tag{2}$$

QAP receives the requests from all the QSTAs and calculates a minimum of all MSI values (mMSI) given in these requests. The highest sub multiple value of the beacon interval which is below or equal to mMSI is chosen as SI and it is given as:

$$\begin{gathered}\mathrm{SI} = \max_{m}(m \mid \mathrm{TBTT},\ m < \min \\ (\overset{x}{\underset{i=1}{\forall}}\overset{p_i}{\underset{l=1}{\forall}}\mathrm{MSI}_{i,l}),\ m < \mathrm{TBTT})\end{gathered} \tag{3}$$

where, TBTT the beacon interval, x is the number of QSTA and p_i is the number of calls in a QSTA i and MSI_{il} is the MSI value of 1th TS at QSTA i. The superframe is logically subdivided with the time duration SI and the logical repetition will occur for every SI period in the superframe as shown in Fig. 1. This logical separation is useful in repetitive polling and servicing of the delay bound streams.

Distinct si schedule approaches: The three distinct SI scheduling approaches are explained in detail in this study.

SSI approach: In this approach QSTAs will be scheduled in every SI interval independent of the type of streams initiated in it. In case of SSI approach, service interval ($\mathrm{SI}^{\mathrm{SSI}}$) is considered to be same for the all the QSTAs and is same as SI and is given as follows:

$$\mathrm{SI}^{\mathrm{SSI}}_{i} \rightarrow \mathrm{SI},\ \ i = 1,2,3...,x \tag{4}$$

The scheduling of QSTAs is given as:

$$\mathrm{QS}(i) = 1\ ,\ \ \forall\,\mathrm{SI}-\text{interval},\ i = 1,2,3,...,x \tag{5}$$

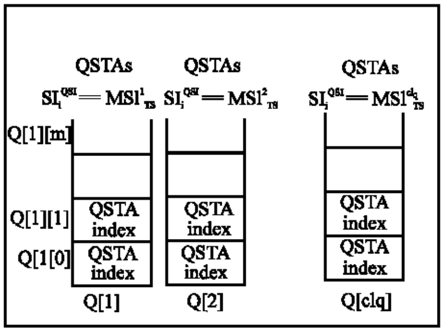
where, QS (i) is the schedule possibility of QSTA i . Due to its schedule policy, this approach demands the QSTAs to be active during every SI interval, but even high delay bound streams also will be transmitted with less delay.

$$\mathrm{QSTA}^{\mathrm{active}}_{i} = 100\% \quad i=1,2,3...x$$

as at any SI interval downlink packets may be transmitted by the QAP and the QSTAs should be awaken to receive the packets. In case of uplink packets QSTAs can send the deadline information once the packet is generated as the QSTA is scheduled in every SI interval. The allocation for uplink packets will be given in the next SI interval which leads to very short delay even for low priority streams. When the number of QSTAs increases, its performance will be degraded as the resource allocation algorithm will not be able to serve all the QSTAs in a SI interval.

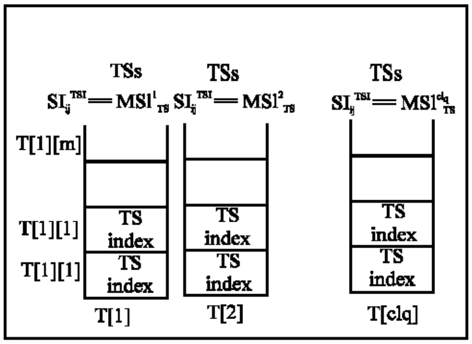
QSI approach: In this approach a QSTA will be scheduled depending on the highest priority stream ie. the least delay bound streams initiated in it. Each QSTA works with different service interval ($\mathrm{SI}^{\mathrm{QSI}}$) which depends on the traffic streams initiated in it thus and varies for QSTAs. The SI estimation in this approach is given as follows:

$$\begin{gathered}\mathrm{SI}^{\mathrm{QSI}}_{i} = \max_{m}(m \mid \mathrm{TBTT},\ m < \min(\overset{p_i}{\underset{l=1}{\forall}}\mathrm{MSI}_{i,l}), \\ m < \mathrm{TBTT}),\ i = 1,2,3,...,x\end{gathered} \tag{6}$$



(a)

Fig. 2a: QSI approach-QSTA subset classification



(b)

Fig. 2b: TSI approach- TS subset classification

where, $MSI_{i,l}$ is the MSI value of lth TS at QSTA i. The QSTA i is scheduled for every SI_i^{QSI} interval and given resources to satisfy their QoS requirement. In this approach QSTA will be distributed evenly along the SI intervals to attain load distribution. To achieve this, QSTAs working with same SI value will be classified in to subsets as shown in Fig. 2a.

Let C = {1, 2, 3, ...x}, where, C is the set of total QSTAs. Here, the QSTAs with same SI_i^{QSI} value are classified in to subsets and the number of possible subsets $cl_q <= n$.

The subset arrays are given as:

$$Q[j],\ \ j = 1,2,3,\ldots cl_q$$

A QSTA will be placed in any of the array which depends on the high priority streams initiated in it. QSTA i will be placed in r-th position in array Q[j] where r-1 QSTA are already placed in subset Q[j]. It is given as:

$$Q[j][r] = i \ \ \text{if} \ \forall j: \ SI_i^{QSI} == MSI_{TS}^{j} \tag{7}$$

The QSTA in a subset Q[j] will be scheduled once for every K(j) SI intervals. All the QSTAs in subset Q[j] will be distributed equally among K(j) SI intervals. For example if the number of QSTA is in subset Q[j] is 7 and k(j) is 5, then in a set of 5 SI intervals, 2 MS each will be serviced for the first two SI intervals and in the remaining 3 SI intervals one MS each will be serviced. Thus in any arbitrary SI interval p,

$$\begin{aligned} QS(i) = 1,\ &\text{if QSTA i } \varepsilon Q[j] \text{ and} (\text{pos}(\text{QSTA i}) \\ &\bmod k(j) == p \bmod k(j)) \end{aligned} \tag{8}$$

This approach requires QSTAs to be active only during their, respective SI^{QSI} interval and due to its schedule policy low priority streams will be serviced with less delay when they are generated along with high priority streams.

$$QSTA_i^{active} = SI/SI_i^{QSI}\ \% \qquad i = 1,2,3 \ldots x$$

as downlink packets will be transmitted at any SI_i^{QSI} interval and MS should be awaken to receive that packets. In case of uplink packets QSTAs can send the deadline information once the packet is generated as the QSTA is scheduled in every SI_i^{QSI} interval. The allocation for uplink packets will be given in the next SI_i^{QSI} interval.

TSI approach: In this approach each traffic stream in the QSTA will be serviced individually. Here each TS l in any QSTA i work with different SI (SI_{il}^{TSI}) value which depends on its type. This leads to multiple SI for a QSTA which corresponds to each of the TS initiated in it. The SI_{il}^{TSI} estimation is given as follows.

$$\begin{aligned} SI_{il}^{TSI} &= \max_m (m \mid TBTT,\ m < MSI_{i,l},\ m < TBTT) \\ i &= 1,2,3,\ldots,x;\ \ l = 1,2,3,\ldots,p_i \end{aligned} \tag{9}$$

Here, the TS l in QSTA i is given allocation for every SI_{il}^{TSI} interval to serve the l^{th} traffic stream. To distribute the load evenly along the SI intervals, TS initiated in various QSTA will be distributed. To achieve this, TS of same type will be classified in to subsets as shown in Fig. 2b.

Let, L = {1, 2, 3, ..., q}, where L is the set of total number of calls and q is the maximum number of calls. Here the calls of same type are classified in to subsets and maximum number of possible classification $cl_t <= n$.
The subset arrays are given as T[j], j = 1, 2, 3, ..., cl_t

A call will be placed in any of the array depends on type. A TS l initiated in QSTA i will be placed in r-th

Table 1: Deadline estimation mechanism for SSI, QSI, TSI

SI approach	SSI	QSI	TSI
DL buffered packets estimated if QSTA is scheduled	Buffered packets of all streams	Buffered packets of all streams	Buffered packets of streams which are currently scheduled in the QSTA
UL buffer feedback by QSTA if QSTA is scheduled	Buffered packet feedback of all streams	Buffered packet feedback of all streams	Buffered packet feedback of the currently polled streams.

position in array T[j] where r-1 calls are already placed in subset T[j]. It is given as:

$$T[j][r] = i \quad \text{if } \forall j: \ SI_{i1}^{TSI} == MSI_{TS}^{j} \qquad (10)$$

The call in a subset T[j] will be scheduled once for every K(j) SI intervals. All the streams in subset T[j] will be distributed equally among K(j) SI intervals Thus in any arbitrary SI interval p,

$$\begin{gathered} QS(i) = 1, \text{ if TS1 in QSTA } i \ \varepsilon \ T[j] \text{ and} \\ (pos(TS_{i1}) \bmod k(j) == p \bmod k(j)) \end{gathered} \qquad (11)$$

This approach demands each QSTA to be active whenever any of their respective stream's SI_{i1}^{TSI} intervals occur. Whether the scheduling of different streams belonging to a QSTA falls in the same SI interval or in different SI interval, depends on the call generation time and their position in their, respective subsets. Due to this nature, TSI approach generates varying QSTA active period. Thus the active period range can be given as:

$$\begin{gathered} QSTA_i^{active} = SI/\min(SI_{i1}^{TSI}) \text{ to} \sum SI/SI_{i1}^{TSI} \ \% \\ i=1,2,3...x;\ l=1,2,3..p \end{gathered}$$

Due to its schedule policy, it produces an independent delay performance respective to their delay bound for all type of streams. But due to the EDF transmission policy there may be effect from the presence of other streams.

TXOP estimation: This study estimate the TXOP based on the buffer information. As the service interval is chosen as half of the delay bound this will lead to better delay performance. So, the streams will be given proper allocation at the right time to be get transmitted within the delay bound. Also this approach considers the latest dynamic queue information which is more appropriate to serve the delay bound streams. The TXOP estimation is as explained below.

Downlink deadline bytes B_{DL} is known to the QAP from its own queue. To get the latest uplink deadline information QAP will poll the QSTA at every uplink scheduled time even though there are may not be any existing uplink deadline bytes. In this case, QSTA replies with a QoS-NULL packet containing deadline information. Thus QAP knows the uplink deadline bytes B_{UL} by the QoS header which is a part of the MAC header in the uplink MPDU transmitted. Once the scheduler knows B_{DL} and B_{UL}, it can estimate the amount of TXOP to be allocated for each QSTA at any SI interval.

Table 1 lists the downlink buffered deadline packet estimation and uplink buffer estimation parameters for all the three SI approaches at any arbitrary SI interval.

TXOP estimation is carried out for every SI interval. This algorithm works on the basis of scheduled QSTA information for any SI interval and their deadline bytes and is explained in Eq. 12.

$$TXOP_i^{DL} = \begin{cases} 0 & \text{if } QS(i) = 0 \\ 0 & \text{if } QS(i) = 1 \ \& \ B_{DL}^{i} = 0 \\ T(B_{DL}^{i} + OH) & \text{if } QS(i) = 1 \ \& \ B_{DL}^{i} != 0 \end{cases}$$

$$TXOP_i^{UL} = \begin{cases} 0 & \text{if } QS(i) = 0 \\ T(QoS - NULL) & \text{if } QS(i) = 1 \ \& \ B_{UL}^{i} = 0 \\ T(B_{UL}^{i} + OH) & \text{if } QS(i) = 1 \ \& \ B_{UL}^{i} != 0 \end{cases} \qquad (12)$$

Whenever the resource requirement exceeds the system limit, resources is allocated based on the deadline weight.

Scheduler data base: The scheduler will maintain the following details about each QSTA

- Next DL schedule time.
- Next UL polling time.
- DL and UL deadline.
- Streams to be serviced at every scheduling interval in case of TSI approach.

Packet transmission: Both the downlink queue at the QAP and uplink queue at the QSTA will be arranged with Earliest Deadline First (EDF) mechanism as all the streams considered are delay bounded. Whenever, a QSTA is scheduled, packet with earliest deadline will be first transmitted.

RESULTS AND DISCUSSION

System model and traffic streams: The simulation scenario is as given below:

Streams considered	:	4 type of streams with different delay demands.
Traffic nature	:	Type I-CBR, remaining types VBR.
Channel	:	Error free channel.
Data rate support	:	54 Mbps.

As error free channel is considered, there will not be packet loss due to channel effects. Type-I streams are generated with voice characteristics and remaining are VBR streams with an exponential distributed inter arrival times. All the 4 types of streams are symmetric in downlink and uplink. The traffic stream characteristics are shown in Table 2 with their delay bound, MSI interval and priority.

Comparison of power efficiency: To get an insight into the power efficiency of each of the three SI approaches the QSTA active periods are compared. Here QSTA active periods is compared for different possible traffic patterns in a QSTA for all the four types of streams considered in the study. Total 15 different traffic patterns are possible. The results are summarized and presented in Table 3.

When SSI is pressed into action, QSTA is active during every scheduling interval independent of type of streams initiated in it, which leads to more power consumption which is expected. Among the other two approaches it is observed that QSI is more power efficient. TSI either produces same performance as QSI or less depends on whether the individual streams belong to the QSTA scheduled at the same SI interval or at different SI intervals.

Delay performance: A comparative study of the performance of the three approaches in guaranteeing the delay limits of each type of stream under different traffic scnarios is made. The following scenarios are considered:

- Effect on delay of stream due to their presence with other steams.
- Effect of QSTA variation for fixed load where QSTA carries different type of streams.
- Effect of QSTA variation for fixed load where QSTA carries same type of streams.

Impact on delay performance due to co-existent streams: To comprehend the impact of coexistent streams on the delay performance, system is tested with 2 different loads L1 and L2 where L2 = 2L1. Here each QSTA will be working with any one of the traffic pattern listed in Table 3.

L1 → x = 15, L = 32, TP = 15, total load 7.6 Mbps
L2 → x = 30, L = 64, TP = 15, total load 15.2 Mbps

Figure 3 presents the impact of different combinations of calls present in a QSTA on the delay experienced by each individual stream under the SSI

Table 2: Traffic stream characteristics

Traffic stream	Mean data rate (one-way)	Mean IAT	Packet size in bytes	Delay bound preferred	Delay bound limit	MSI interval	Priority
Type I	64 kbps	20 ms	160	< =20 ms	40 ms	20 ms	Very high
Type II	256 kbps	10 ms	320	< =40 ms	80 ms	40 ms	High
Type III	128 kbps	40 ms	640	<= 100 ms	200 ms	100 ms	Medium
Type IV	32 kbps	200 ms	800	<= 500 ms	1000 ms	500 ms	Low

Table 3: Power consumption efficiency comparison of SSI, QSI, TSI

Traffic pattern (TP)	Traffic pattern in a QSTA	$QSTA_i^{active}$ in SSI (%)	$QSTA_i^{active}$ in QSI (%)	$QSTA_i^{active}$ in TSI (%)
1	Type-I	100	100	100
2	Type-II	100	50	50
3	Type-III	100	20	20
4	Type-IV	100	4	4
5	Type-I + Type-II (or)	100	100	100
6	Type-I + Type-III (or)			
7	Type-I + Type-IV			
8	Type-II+ Type-III	100	50	50 or 70
9	Type-II+ Type-IV	100	50	50 or 54
10	Type-III+ Type-IV	100	20	20 or 24
11	Type-I +Type-II+ Type-III (or)	100	100	100
12	Type-I Type-II+ Type-IV (or)			
13	Type-I+ Type-III + Type-IV			
14	Type-II+ Type-III+ Type-IV	100	50	50 or 70 or 74
15	Type-I +Type-II+ Type-III+ Type-IV	100	100	100

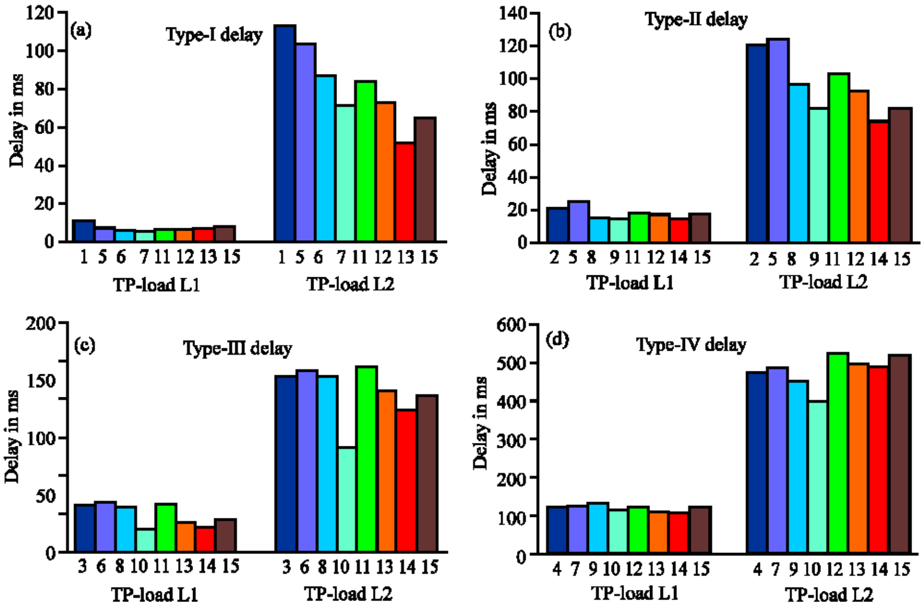


Fig. 3: Delay comparison for traffic streams in SSI-under different traffic patterns

approach. Here, the delay experienced by each type of stream in the presence of other type of calls is presented. In this approach each QSTA will be scheduled at each scheduling interval independent of the type of streams initiated. The following observations are made. During L1, SSI performs well, experiences very less delay. When the load is increased to L2, it is unable to meet the demands of higher priority streams. This can be attributed to the fact that scheduling QSTAs with lower priority streams is permitted at every SI interval. Due to the scheduling policy high priority streams attains less delay when they are accompanied with low priority streams. Low priority streams suffer with more delay when they work with high priority streams. High priority streams can exploit those allocations which are given to the low priority streams.

Type-I streams realizes less delay whenever, it is accompanied with the low priority streams. Their delay becomes lesser depending on presence of least priority streams. In case of Type-II streams, they suffer higher delays when they are present with Type I streams, but their delay reduces when they are present with low priority streams. Type-III shows less delay when initiated with Type-IV but produces more delay when accompanied with high priority type of streams. In case of Type-IV the best possible delay attained is when it accompanied with Type-III but when with other high priority streams delay is more.

Figure 4 presents the impact of different combinations of calls present in a QSTA on the delay experienced by each individual stream under the QSI approach. In this approach, QSTAs are polled only during their respective SI^{QSI} interval which is the MSI interval of the highest priority stream initiated in that QSTA. The following observations are made. Due to its distributed nature of scheduling it can support even higher loads than SSI. From the graph it is evident that even under load L2 all streams experience delays well within limit. All streams suffer high delays when they are alone in a QSTA. This is because each traffic stream will be scheduled only during their respective SI interval. Here, lower priority streams gain advantage when they are accompanied with higher priority streams as they will be scheduled frequently. Higher priority streams suffer higher delays when they are present with the lesser priority streams. So, every stream experience lesser delays when they coexist with higher priority streams and more delay related to their presence with least priority streams. It is observed that Type-I streams suffers higher delay when they co-exist with least priority streams. This is due to the fact these low priority streams exploit the frequent allocations given to the QSTA due to their presence with Type-I streams.

Figure 5 presents the impact of different combinations of calls present in a QSTA on the delay experienced by each individual stream under the TSI approach. In this approach, each stream is scheduled individually thus the delay variation effect due to call combination is not high as in the other two approaches. The observations are: Due to its distributed scheduling this method is capable of supporting delay guarantees for higher load as QSI mechanism and delay variation of a stream due to call

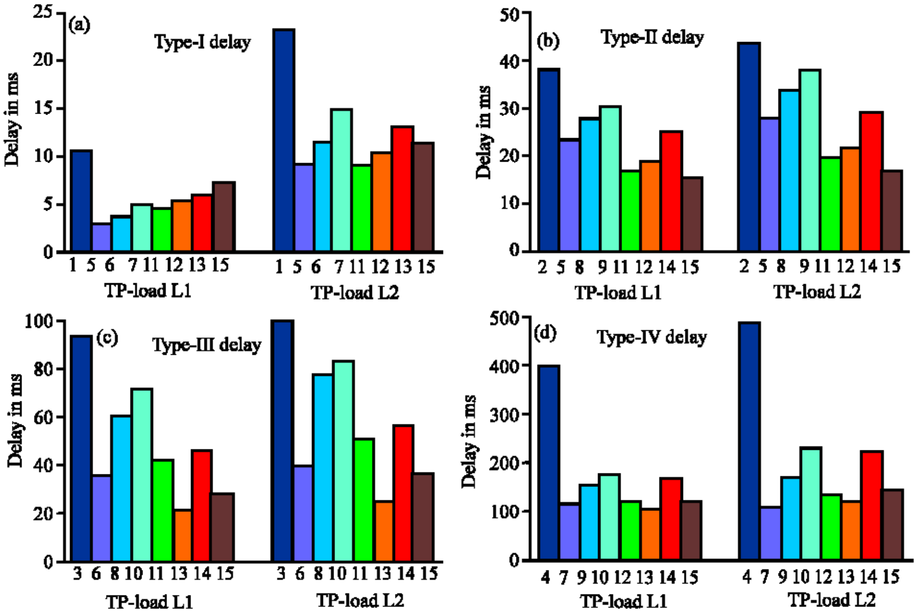


Fig. 4: Delay comparison for traffic streams in QSI-under different traffic patterns

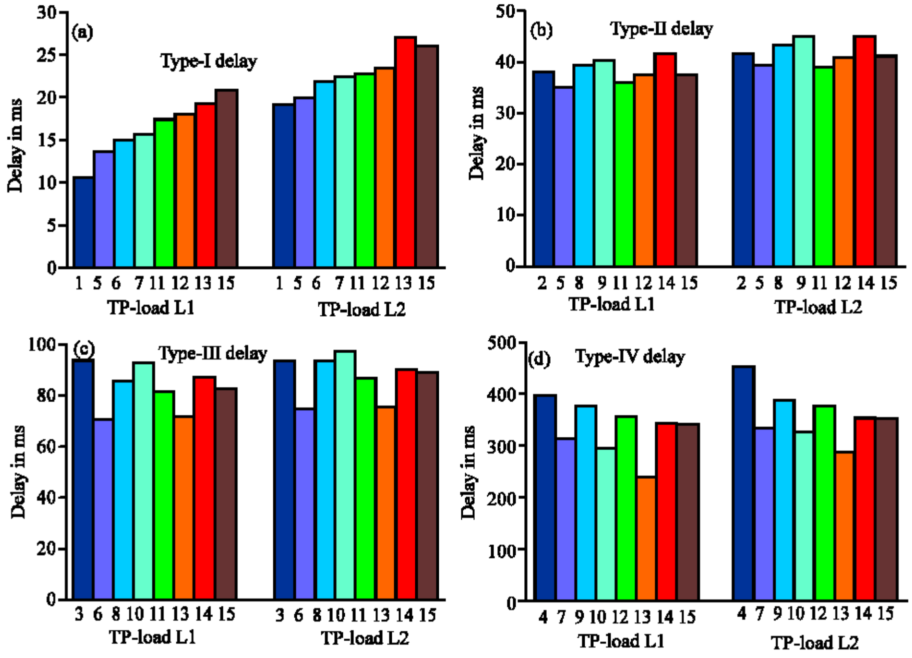


Fig. 5: Delay comparison for traffic streams in TSI-under different traffic patterns

combination is less, as here streams are treated independently for scheduling. But still high priority stream suffers slightly higher delay when they are accompanied with low priority streams and low priority streams suffer slightly lesser delay when they are accompanied with high priority streams. This happens due to the presence of EDF queuing mechanism during transmission.

The statistics on the delay for each type of streams is presented in Table 4. From the statistics on delay it is evident that SSI approach performs very well for lesser loads but as the load increases, its performance deteriorates. The mean delay in QSI approach is within acceptable limits in all the cases but its standard deviation is high which infers that streams suffer great variation due to the call combination. TSI produces high mean delay

Table 4: Mean and standard deviation of delay due to call combination effect

	Type-I stream				Type-II stream				Type-III stream				Type-IV stream			
	L1		L2		L1		L2		L1		L2		L1		L2	
SI approach	μ	SD	μ	SD	μ	SD	μ	SD	μ	SD	μ	SD	μ	SD	μ	SD
SSI	6.4	1.8	80.4	19.9	16.8	3.6	96.4	17.2	32.1	9.3	140.0	22.4	116.4	7.1	477.7	42.4
QSI	5.5	2.3	12.7	5.9	24.5	7.5	28.9	9.1	49.5	24.1	57.9	25.1	169.7	97.6	203.0	121.2
TSI	16.1	3.3	22.6	4.5	37.7	2.2	41.4	2.9	82.9	8.7	87.2	8.3	333.8	49.6	359.9	48.1

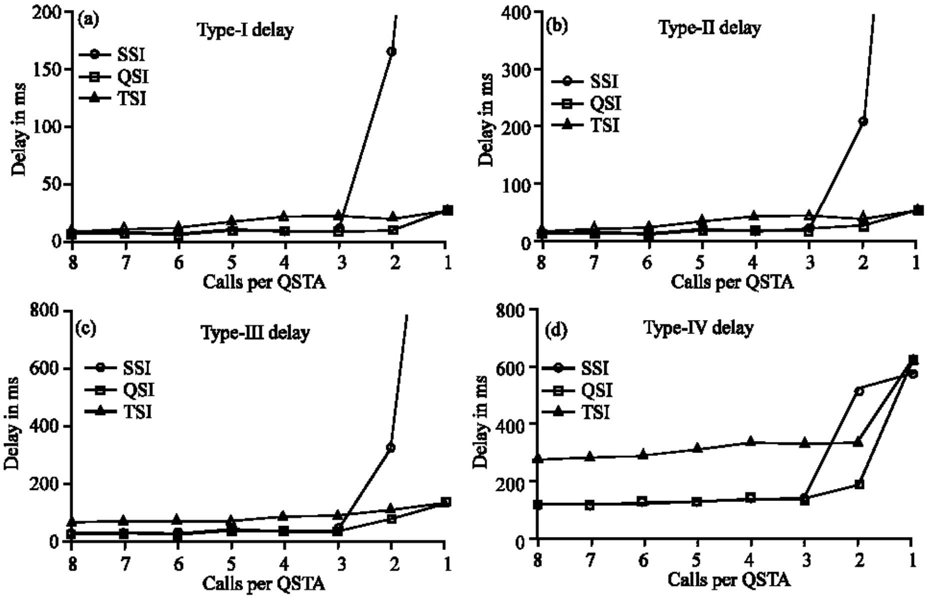


Fig. 6: Delay comparison for traffic streams with TSI,QSI and SSI for station variation impact

due to its scheduling policy but produces very less standard deviation and thus produces very less delay variation to call combination effect.

Effect of QSTA variation for same load where QSTA carries different type of streams: Figure 6 compares the delay performance due to the variation of QSTA for the same load. The load is maintained constant throughout the simulation and for each simulation scenario the number of QSTA varies which leads to different number of call per QSTA. The simulation scenario is as follows.

x = 8,9,16,32,64, p_i = 8,7,6,5,4,3,2,1. Here, QSTAs will generate different type of streams.

The performance of SSI and TSI are same upto x = 16 as:

$$SI^{SSI} = SI^{QSI} = MSI^{1}_{TS}$$

Until then atleast 4 calls are present in each QSTA and both approaches work with Type-I MSI for all QSTA.

But when the number of stations increases, QSI is still capable of producing fine performance ie. delay demands are met whereas SSI's performance deteriorates. It is also observed that if the number stations is increased upto 64 i.e., one call per station, SSI totally collapses whereas QSI is still capable of guaranteeing the delay demands. TSI also produces fine delay performance even though the number of stations increased up to 64, but in terms of delay attained, the performance is slightly inferior when compared to QSI.

Effect of QSTA variation for same load where QSTA carries same type of streams: Finally, the delay performance due to the variation of QSTA for the same load is compared in Fig. 7. The same simulation scenario is maintained but here each QSTA generates same type of streams. Delay comparison for traffic streams with TSI, QSI and SSI for station variation impact with same type of streams.

When the number of calls per station is more, it leads to high delay in case of QSI. As each QSTA carries same type of calls and the number of QSTAs are less, the distribution of QSTA will not happen, which leads to high delay in case of QSI. But when the number of QSTAs is increased QSI does well whereas SSI shows the reverse performance. TSI shows superior performance throughout QSTA variation scenarios due to

Table 5: Comparison of the SI approaches

QoS	SSI	QSI	TSI
Power conservation	superior	inferior	average
Mean delay	Low when load is less. Very high when load is high.	Less-independent of load	High-independent of load -within delay bound limit
Delay-call combination	HP streams-less delay when with LP streams LP streams - high delay when with HP streams	HP streams-more delay when with LP streams. LP streams-less delay when with HP streams	HP stream-slightly higher delay when with LP streams. LP streams-slightly lesser delay when they with HP streams
Delay variation-call combination	average	More	less
Delay-QSTA variation with different type of streams	Less QSTA-good performance More QSTA-worst performance	Performance independent of number of QSTA	Performance independent of number of QSTA
Delay-QSTA variation with same type of streams	Less QSTA-good performance More QSTA-worst performance	Less QSTA-degraded performance More QSTA-good performance	Performance independent of number of QSTA
Recommended scenario	• No need to bother about power efficiency • System load is less • Less number of stations with many number of calls per station	• More power conservation is needed • System load is high • Delay variation due to call combination is not bothered	• Delay variation due to call combination is less • System load is high • Average performance in all the scenarios.

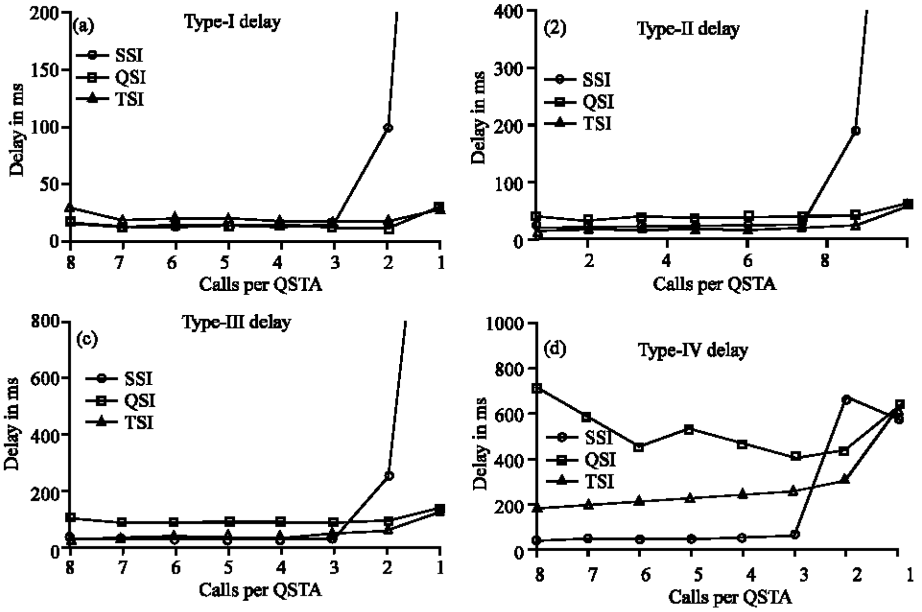


Fig. 7: Delay comparison for traffic streams with TSI, QSI and SSI for station variation impact with same type of streams

its scheduling policy of traffic stream distribution. It is independent of type of streams initiated and number of QSTAs.

Table 5 presents a comparison of all the three approaches from the observed results and the following conclusions are made.

CONCLUSION

This study has analyzed the performance of WLAN HCF scheduler when QSTAs work with several calls of different types. In this scenario it ts seen that service interval has big impact over the delay performance and power conservation capability. This study proposes three different SI approaches namely SSI, TSI and QSI. It was observed that the three approaches are capable of attaining different delay performance and power efficiency. This study compared power conservation when the QSTA works with different traffic patterns and concluded that QSI is best in power efficiency performance. In terms of mean delay it is shown that during lesser load SSI is superior and during higher load QSI performs well. This study also compared the delay performance of each type of stream when streams work with other streams. It is seen that delay variation due to call combination is effect is very less in case of TSI. Delay performance is evaluated for variation of QSTAs by maintaining fixed load. In this case QSI produces best performance when QSTAs work with different type of streams. But whenever QSTAs work with same type of streams TSI is superior to other mechanisms. After the comparison of three mechanism in terms various QoS performance, it is realized that each mechanism compensate each other under various traffic scenario for various QoS parameters. Finally, this study conclude that scheduling approach can be selected based on the QoS and power efficiency requirements. It can be even done dynamically of switching over between the mechanisms according to varying QoS requirements and traffic scenarios.

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