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Enhanced Traffic Aware Scheduling Protocol for Variable Bit Rate Traffic in IEEE 802.11e WLAN

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Abstract: In wireless multimedia transmission, scheduling mechanism needs to be designed in an efficient manner to maintain the traffic stream and enhance the Quality of Service (QoS) for Variable Bit Rate traffic (VBR). In this study, an Enhanced Traffic Aware Scheduling (ETAS) Protocol for VBR Traffic in IEEE 802.11e Wireless Local Area Network (WLAN) is proposed. Here, a queue length notification scheme is used for efficient transmission of queue length and data rate information to QoS Access Point (QAP). Based on the queue length information, Transmission Opportunity (TXOP) is estimated. In case, the data rate is high, overboost scheduling algorithm is used which efficiently deals with traffic stream by transferring excess data to the Enhanced Distributed Channel Access (EDCA). Moreover, to recover the lost TXOP an Unused Time Shifting Scheduling Algorithm is used. Simulation results show that the proposed protocol achieves better bandwidth utilization for VBR traffic with reduced delay.

Key words: IEEE 802.11e, WLAN, scheduling, variable bit rate, queue length, data rate

INTRODUCTION

IEEE 802.11e WLAN: IEEE 802.11 is an international standard for Wireless Local Area Network (WLAN). The 802.11 WLAN consists of Basic Service Sets (BSS) that includes wireless stations (STAs). It provides two coordination functions: Distributed Coordination Function (DCF) and Point Coordination Function (PCF). It is very challenging to satisfy a service level in terms of guaranteed bandwidth, bounded delay and jitter. For this purpose, an enhanced version of IEEE 802.11 standard called IEEE 802.11e is used to provide Quality of Service (QoS) support for time-sensitive applications. It specifies a new coordination function called the Hybrid Coordination Function (HCF) that is under the control of a Hybrid Coordinator (HC). The HC is positioned in the QoS Access Point (QAP) consisting of two channel access modes, the Enhanced Distributed Channel Access (EDCA) and the HCF Controlled Channel Access (HCCA). The EDCA is based on a distributed control and it enables prioritized channel access. HCCA requires centralized scheduling and allows the applications to negotiate parameterized service guarantees in the context of Traffic Streams (TSs). The Hybrid Coordinator (HC) provides scheduling for both the QAP and QoS Stations (QSTAs), by dispensing Transmission Opportunities (TXOPs) of variable size to both downlink and uplink TSs (Saheb *et al*., 2011; Politis *et al*., 2010; Huang *et al*., 2008). Easy installation, reliability and high data rates are some of the advantages of IEEE 802.11e WLAN (Cecchetti and Ruscelli, 2008).

The challenges are listed as follows:

- Providing QoS is a very challenging task
- In EDCA, the traffic with lower priority values have to wait in the queue for a longer time when large number of QoS stations with real-time traffic contending to access
- The 802.11e standard does not specify how to schedule TXOPs in order to provide the required QoS for Variable Bit Rate (VBR) real time applications (Annese *et al*., 2004)
- If the derived number of arriving MAC Service Data Units (MSDUs) becomes smaller, it leads to insufficient channel allocation in the packet scheduler (Noh *et al*., 2009)
- It is difficult to achieve fairness, since multiple mobile hosts in the WLAN contend with each other for accessing the wireless channel to acquire resources (Shaik and Hemadrasa, 2013)

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- EDCA can provide higher QoS to only with high priority traffic, leading to the starvation of lower priority flows, when the network traffic load is high (Luo and Shyu, 2009)

Scheduling issues in ieee 802.11e WLAN: Scheduling is a key to share network resources fairly among users in a network and it provides service guarantees to time-critical applications. The scheduler is responsible for deciding the order of requests to be served and managing the queues of these pending requests. It poses the following issues:

- In wireless multimedia transmission, scheduling should be designed so as to accommodate retransmission traffic as well as newly generated traffic to improve QoS in a noisy environment (Noh *et al*., 2009; Ghazani, 2015)
- Dynamic assigning of TXOPs for bursty media flow and unpredictability of the traffic are challenging tasks to achieve the desired QoS requirements
- Adaptation of Service Interval (the interval between two successive service periods) and TXOP for each packet introduce computational overhead in the Media Access Control (MAC) layer
- If there are lots of flows, the packet scheduling becomes complex to guarantee fairness and QoS. On the other hand, bandwidth utilization ratio will be very low if there are few packets
- When scheduling, SI and TXOP will introduce unpredictable and considerable computational complexity if all the computation is required to be accomplished in the single MAC layer (Chou *et al*., 2011)
- For properly allocating resources to a flow, careful calculation of scheduling parameters such as SI, TXOP Duration (TD) or TXOP ordering is necessary.
- Due to fixed SI, selecting too short duration of TXOP increases the delay of the traffic that leads to failed QoS
- Large TXOPs have a weakness in terms of the session blocking probability. If large TXOPs are allocated for accepted traffic streams, QAP has to refuse many new stream requests. This takes away the chance to be admitted for other streams (Lee *et al*., 2011)
- When variation of VBR traffic rate with a peak rate is greater than the average rate, it cannot be served efficiently when traffic streams are provided with a fixed service rate (Cicconetti *et al*., 2007)

Literature review: Noh *et al*. (2009) have proposed packet scheduling scheme for audio-videotransmission over Error-prone IEEE 802.11e HCCA Wireless LANS for decreasing retransmission counter that allocated additional TXOP duration in a Service Interval (SI). The AP allocates TXOP for each station by calculating the number of MSDUs arrived in an SI, considering the inter-arrival time of audio samples and that of video frames together with the Traffic SPECification (TSPEC) at the application-layer. But the fixed TXOP is not suitable for variable data traffic over video transmissions.

Shaik and Hemadrasa (2013) have recommended an integrated approach to enhance Transmission Control Protocol (TCP) Fairness in HCCA Scheduler for 802.11e Wireless LANs. It considers unfairness problem of MAC layer and TCP along with bandwidth asymmetry problems by designing four stages. In the first stage, prioritization on AP is developed for sufficient bandwidth allocation using an adaptive buffering scheme. Then weighted fair assessment technique is used to manage fair and efficient access provisioning. After that December 23, 2016 an Acknowledgement (ACK) delaying technique is dealt to delay the TCP ACK packets of uplink flows to generate additional buffer space for downlink data transmission to ensure fairness between data transmission rate of uplink and downlink.

Luo and Shyu (2009) have suggested an efficient scheduling scheme for the 802.11e wireless LAN for allocating TXOP to each wireless station by AP using HCCA functionalities. The QoS requirements and incoming packet transmission rates of each flow are considered to obtain an optimal scheduling. Though it focussed about variable data rate for dynamic allocation of TXOP, polling the neighbour station on the polling list with the same SI the utilization of TXOP is low for each station.

Chou *et al*. (2011) have mentioned an efficient multipolling mechanism with Various Service Intervals for IEEE 802.11e WLANs. They have extended the adaptive resource reservation over WLANs for reducing overhead and improving channel utilization. The HC calculates the required TXOP Duration (TD) for each of QSTA based on the reported traffic demand. If another QSTA satisfies its minimum service interval constraint between time interval, the approach would add that QSTA into the polling list. However, when there are more QSTAs into the polling list, newly joined QSTAs must be queued after the previous QSTAs and suffer from a longer delay.

Lee *et al*. (2011), Explicit Queue length Notification (EQN) based explicit traffic aware scheduling

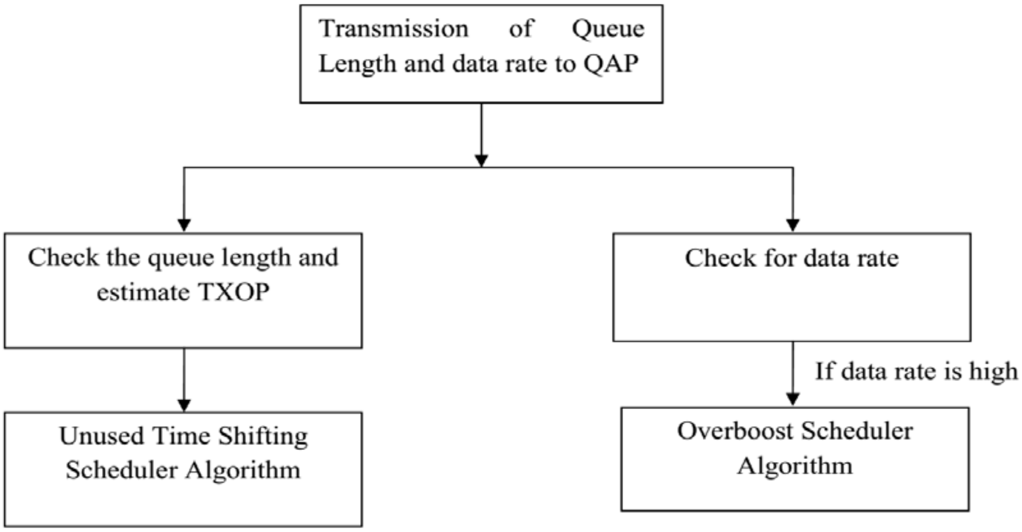

Fig. 1: Block diagram of the proposed ETAS protocol

(EAT-EQN) has been proposed. In this scheme, each station sends a special frame called EQN to the QAP which includes the queue length information of its own. This frame will be sent before the end of every SI via., EDCA channel access scheme with high priority. After collecting the queue length information of each station from the EQN frames, the QAP uses this information for calculating the TXOPs.

Chen and Chang (2012) have suggested the cross-layer Most-Emergent-First (MEF) scheduler with TXOP adaptation and SI controllers for scheduling the transmitting sequence of flows. Then, it is used to schedule the TXOP and SI by the MEF controller to determine transmit sequence of flows via cross-layer signalling. The bandwidth utilization in an IEEE 802.11e environment is maintained using four-rule policy based control. However, this approach focuses about adaptation of TXOP and SI for fixed and priority of data flows without considering variable data rate. It does not give guarantee for required QoS.

The wastage of resources due to the data rate variations affects the schedulers that do not implement any recovery policy. When the instant data rate drops down, the unused portion of TXOP is lost. Unused Time Shifting Scheduler (UTSS) (Ruscelli and Cecchetti, 2014) provides efficient resource management in the case of VBR traffic by recovering the unused transmission time. The basic idea is to remove the unspent transmission time from stations and to make that available for those stations requiring a longer transmission interval.

Ruscelli *et al.* (2012), an overboost scheduler is proposed. The overboost scheduler is located in each QSTA and works only if the transmitting QSTA does not deliver all the enqueued TSs data messages. Before the contention period begins, it moves the TSs data messages from HCCA queue to EDCA queue assigning them to a highest priority EDCA Access Category.

MATERIALS AND METHODS

Enhanced Traffic Aware Scheduling (ETAS) protocol overview: In this study, researchers propose to design a Traffic Aware and Unused Time Shifting Scheduler for VBR traffic. In this scheduler, along with the queue length information (Lee *et al.*, 2011) each station sends its instant data rate information also to the QAP. Then by checking the queue length information, the TXOP is estimated. After the transmission period, the instant data rate field is checked. If the data rate is high, then the QSTA may have still enqueued data which can be moved to the EDCA queue by the overboost scheduler (Ruscelli *et al.*, 2012) at QSTA. On the other hand, the unused portions of TXOP is recovered from the low data rate stations and reallocated to other stations (Ruscelli and Cecchetti, 2014).

Figure 1 represents the block diagram of the proposed ETAS Protocol. In our proposed method, first queue length notification scheme is used. According to this scheme each station transmits queue length information and data rate information to QAP. By checking the queue length information, TXOP is estimated. After that data rate field is checked, if the data rate is high, then overboost scheduler algorithm is used. In order to recover the unused portion of TXOP, Unused Time Shifting Scheduler Algorithm is used.

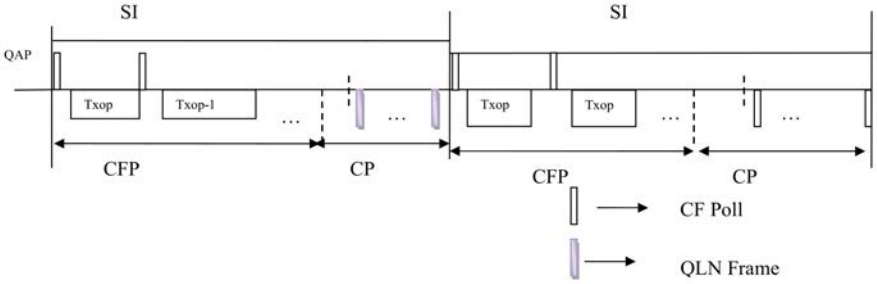

Fig. 2: Transmission of QLN frame

Queue Length Notification (QLN) technique: This section describes about the Queue Length Notification (QLN) (Lee *et al*., 2011) technique for the efficient network performance for VBR traffic. According to this scheme each station transmits a special frame called as QLN frame which consist of the queue length information along with the instant data rate information to the QAP. In order to reduce the waste of HCCA time resource, the QLN frame is transmitted via., EDCA channel access technique based on priority and is queued at the head of the queue to assure immediate transmission. After that, QAP gathers the queue length information of each and every station by receiving and retrieving information from the QLN frame. On the commencement of the Service Interval (SI), the QAP makes use of the queue length information to estimate TXOPs. As QLN frame consist of most recent queue length of each station, the Access Pointer (AP) can accurately estimate the TXOP of each station. Figure 2 illustrates the transmission of QLN frame to the QAP. The estimation of the $TXOP_j$ is given in Eq. 1.

$$TXOP_j = \max(\frac{X_j \times M_j}{P_j}, \frac{R_i}{P_j}) + Y \qquad (1)$$

$$X_j = |(SI.D_j)|\ M_j|\ \text{for}\ 1 \leq j \leq K$$

Where:

SI = The service interval
X_j = The number of bits transmitted during SI
D_j = The mean data rate, M_j is the nominal size of MSDU
R_i = The maximum allowable size of MSDU
P_j = The minimum physical rate
Y = Represents transmission overhead in time units

Moreover, the transmission time of the QLN frame must be suitably close to the commencement of the next SI. In case, the QLN frame is transmitted too early, it cannot show the latest information of the queue length. Also, in case the QLN frame is transmitted too late, the frame cannot get an option to be transmitted before the commencement of the new SI. In order to solve these problems, sending time of a QLN frame q_i^{QLN} is calculated as below:

$$q_i^{QLN(n)} = \min(q_i^{TXOP(n+2)} - \max SI_i, q^{SI(n+1)} - b^{QLN}) \qquad (2)$$

Where:

$q_i^{QLN(j)}$ = The start time of the jth QLN for station i
$q_i^{TXOP(j)}$ = Represents the start time of jth TXOP for station i
$q_i^{SI\ (J)}$ = Represents the start time of the jth SI
$q_i^{SI\ (J)}$ = Represents the minimum duration that QLN frame that can be successfully transmitted to the QAP

The first term inside the minimum value considers the maximum service interval for each traffic stream. As, max SI_i is always same or greater than scheduled SI at the QAP, traffic which arrives later than $q_i^{EQN(j)}$-max SI_i does not need to be sent at the very next SI as it does not interrupt max SI_i.

Data rate estimation: The data field is checked and then the data rate is estimated in case of VBR traffic. The bursty traffic is mainly described by variable bit rate and inter-arrival times that affects the admission control and permit to emphasize how Overboost reacts to VBR traffic with any active/silence intervals. The mean frame inter-arrival time $1/\mu$ of a busty traffic is variable in the interval $(1/\mu-\gamma_{u,}, 1/\mu-\gamma_l)$ where represents γ_u the upper tolerance during the burst and γ_l represents lower tolerance in case the inter-arrival time is longer. The burstiness factor (G) can be given as below:

$$G = \frac{D}{\Omega} \qquad (3)$$

Where:

D = Represents the mean data rate computed during a long interval
Ω = Represents the peak data rate during the activity interval

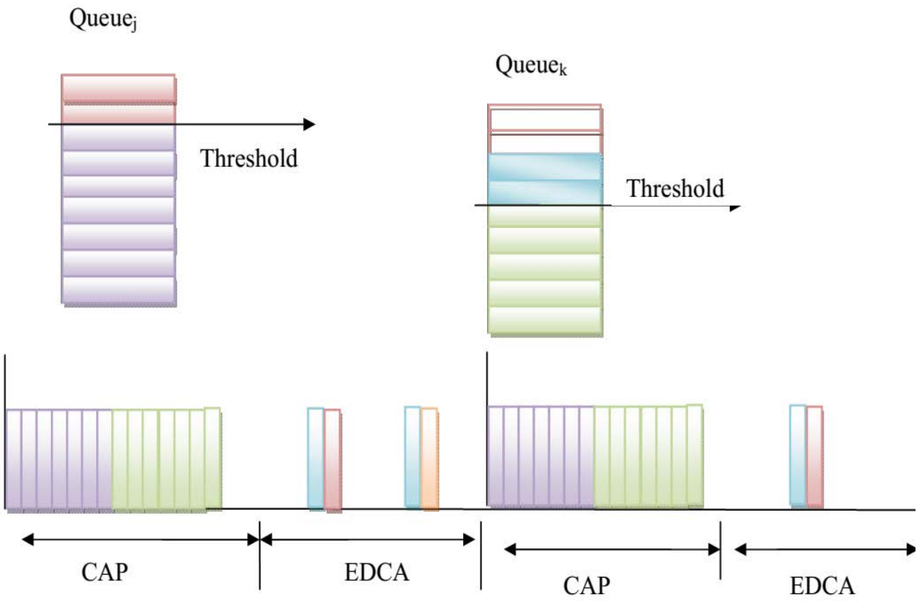

Fig. 3: Swapping of Queues in overboost

The peak frame rate can be given as below:

$$\eta = D / (G \cdot M) \tag{4}$$

where, M is the nominal size of MSDU. The bursty frame inter-arrival time then given as:

$$1/\mu = (G \cdot M) / D \tag{5}$$

Thus, Constant Bit Rate (CBR) is defined by G=1 whereas Variable Bit Rate (VBR) traffic sources by $G \leq 1$. For $1 \leq j \leq K$ each $TXOP_j$ can be calculated by including the traffic parameter G_j, by considering the traffic bursts when the resources are allocated:

$$TXOP_{Gj} = \max\left(\frac{X_j \cdot M_j}{G_j \cdot \Omega_j}, \frac{R_j}{G_j \cdot \Omega_j}\right) + Y \tag{6}$$

Where:

X_j = The number of bits transmitted during SI
R_i = The maximum allowable size of MSDU
Y = Represents transmission overhead in time units

The overboost scheduler: Once, the transmission period is over, the instant data rate field is checked. In case, the data rate is high, it shows that QSTA may have still some queued data which can be moved to the EDCA queue by using overboost scheduler at QSTA. The Overboost scheduler (Ruscelli *et al*., 2012) is mainly local at each node. It enhances performance of the HCCA schedulers substituting them and mainly deals with Traffic Streams (TSs) that are operated by HCCA that still consist of some data to transmit even after the Controlled Access Phase (CAP). Hence, before the commencement of the contention period, it transfers the TSs data messages from HCCA queue to EDCA queue allocating them to a highest priority EDCA access type as shown in Fig. 3 and 4 which is here the Voice Access Category (AC-VC) as shown in Table 1. Thus, the traffic that goes beyond the allocated HCCA TXOP (the HCCA transmission time period threshold) will not be operated with parameterized QoS, rather it will be operated with prioritized QoS. The Overboost Scheduler Algorithm can be explained as below.

Table 1: User priority table

Priority	User Priority	Access Priority	Traffic Type
Lowest	1	AC_BG	Background
	2	AC_BG	Background
	0	AC_BE	Best Effort
	3	AC_BE	Best Effort
	4	AC_VK	Video
	5	AC_VK	Video
	6	AC_VC	Voice
Highest	7	AC_VC	Voice

Step 1: In case, the CAP phase ends, the QoS Aware Hybrid Coordinator (HC) moves the control of the medium to Overboost technique.

Step 2: After that, it checks whether the HCCA is empty, if it is empty, it departs the control to the EDCA function.

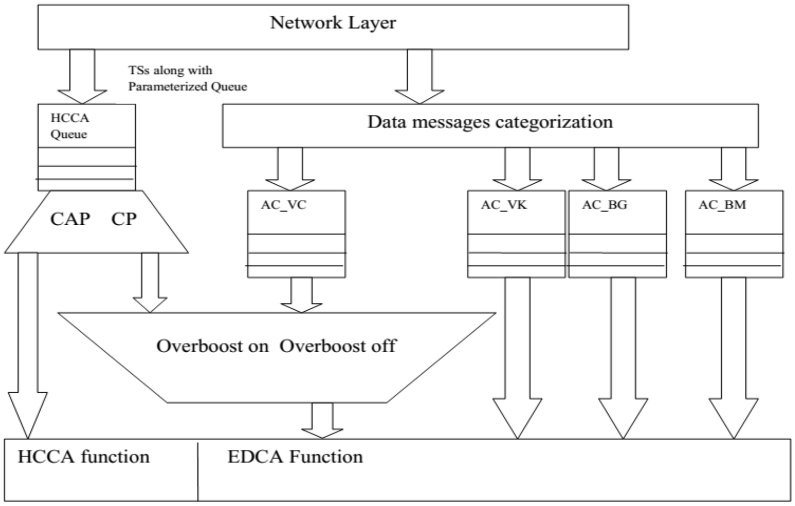

Fig. 4: Overboost mechanism

Step 3: Else, it transfers the queued data message of the HCCA queue to the EDCA function.

Step 4: In case the EDCA period is not still terminated, it again starts from the step 2.

The Overboost scheduler is mainly a local node scheduler who can easily collaborate with the MAC reference scheduling algorithm or with any alternative scheduling. The centralized scheduler situated in the QAP persists to manage the QSTA that request to transmit and perform admission control which continues to be unaffected. After that, it calculates the scheduling parameters and generates the polling list and ultimately it polls the allowed QSTAs. Moreover Overboost, located in each QSTA comes in action only in case the transmitting QSTA does not transfer all enqueued TSs data messages. Hence, it limits the delay practiced by TSs and boosts the network performance.

Unused time shifting scheduler algorithm: It is observed that the waste of resources mainly due to data rate variations affects the schedulers that do not implement any recovery scheme. In specific while the instant data rate drops down, a polled QSTA broadcasts data in shorter time than its allocated TXOP and hence easily transmitting the arriving traffic and ultimate enqueued packet. Moreover, listening the idle channel for a time period longer than a Short InterFrame Space (SIFS), presume the control of medium and polls to the next station. Hence, the unused portion of TXOP is lost and a flexible scheduling technique is required in case of variable data rate traffic.

For an efficient resource management, UTSS algorithm (Ruscelli and Cecchetti, 2014) is used by retrieving the unused transmission time. It offers a shortcut to have an instant dynamic TXOP without altering the admission control. The main objective is to eliminate unspent transmission period and to make it available to the next polled station especially to those station which requires a longer transmission time. To achieve this, UTSS commences a supplementary resource scheduling rule that manages the recovery of the unused time without any effect on the centralized scheduling technique. This particular approach is greedy as it does not make any difference between application and station but allocates the recovered resources to the next polled station which can utilize this additional transmission capacity without effecting admission control threshold.

UTSS combines the action of the centralized HCCA scheduler by maintaining the same admission control as well as scheduling algorithm. This is mainly due to the fact that the admission control that calculates the basic protocol parameters such as TXOP and SI used at the time of polling phases is executed at the association to the QAP (it is repeated only in case a new QSTA request to be admitted to broadcasts) and leads the consequent CAPs. It is unaware of information about the instant unspent time of any future transmission and its estimation is mainly based on mean value of QoS parameters as navigated with the subsequent QSTA. The above mentioned considerations are valid for all kind of centralized schedulers that do not make use of any kind of traffic prediction method.

The UTSS algorithm then adds more scheduling rule at the time of consequent CAPs, mainly at the time of revising of dynamics parameters and instantly before the polling of the considered station, by altering the related TXOP estimated at the time of admission control, in case of presence of unused time.

In specific, each time when QSTA does not make any use of its full allocated TXOP, UTSS make use of this unused time to the next scheduled TS taken out from the Earliest Deadline First (EDF) queue during the current CAP. To demonstrate the above mentioned bandwidth reclaiming scheme, the following notation is used:

q_{end} = Finishing time of the transmission. = q_p+TXOP, TXOP is completely used up. (q_p represents the polling time)

Q_{spare} = Spare time of TXOP, q_{end}-$q_{effecyive}$-$_{end}$ calculated as the difference. Where, $q_{effecyive}$-$_{end}$ represents the time when QSTA has really completed its transmission

Q_{spare} = Represents the variable utilized by UTSS and it is calculated each and every time QAP polls a QSTA. In specific, $Q_{spare}>0$, if

- A station terminates its transmission before q_{end} and it does not contain any queued data in traffic
- A station terminates its transmission before q_{end}, transmitting the incoming traffic and evacuating its transmission queue before the transmission of TXOP

Then, the current Q_{spare} is added to the allocated $TXOP_k$ of the next polled station $QSTA_k$ that receive a new $TXOP_k$ calculated as below:

$$TXOP_k^{'} = \begin{cases} TXOP_i, & \text{if } Q_{spare} = 0, \\ TXOP_i + Q_{spare}, & \text{if } Q_{spare} > 0 \end{cases}$$

The overall steps involved in the proposed ETAS Protocol:

- Each station transmits QLN frame with queue length and data rate information
- QAP gathers the queue length information
- On the commencement of SI, QAP uses queue length information to estimate TXOPs
- After that data rate field is verified
- If data rate is high
- Apply overboost algorithm
- // Overboost Algorithm//
- If CAP phases ends, HC moves control of medium to Overboost technique
- It checks whether HCCA is empty
- If it is empty
- It depart the control to EDCA function
- Else it transfers queued data message of HCCA queue to EDCA function
- If EDCA period is not terminated
- It go to step 9
- // UTSS Algorithm//
- If QSTA does not make any use of its full allocated TXOP
- UTSS make use of next scheduled TS taken out from the EDF queue during current CAP.

RESULTS AND DISCUSSION

Simulation parameters: Researchers have used network simulator 2 (NS-2) (Network Simulator) to simulate our proposed enhanced traffic aware scheduling technique. Researchers have adopted IEEE 802.11.e for wireless LANs as the MAC layer protocol. In this simulation, the packet sending rate is varied as 200, 400, 600, 800 and 1000 Kb. The area size is 100 × 100 m square region for 50 sec simulation time. The simulated traffic is Constant Bit Rate (CBR) and video traffic. The simulation settings and parameters are given in Table 2.

Performance metrics: To evaluate performance of the new protocol, the following metrics have been used. The performance of the proposed ETAS protocol has been compared with that of the existing UTSS (Sahik and Hemadrasa, 2013) protocol. The performance is evaluated in terms of bandwidth allocated (Mbsec^{-1}), bandwidth utilization (Mbsec^{-1}), average end-to-end delay and average packet drop.

Two statements of measurements have been presented in this section. The first set is obtained by varying the number of QSTA which is given in Fig. 5-8. The second set is based on transmission rate as given in Fig 9-12.

Results based on QSTA: When comparing the performance of the two protocols researchers infer that ETAS outperforms UTSS by 74% in terms of bandwidth allocated, 83% in terms of average end to end delay, 53% in terms of average packet drop and 74% in terms of bandwidth utilization.

Table 2: Simulation parameters

Parameters	Values
Area	100 × 100m
MAC	802.11.e
Simulation Time	50 sec
Traffic Source	CBR and VBR
Rate	200, 400, 600, 800 and 1000 Kb
Propagation	Two Ray Ground
Antenna	Omni Antenna
Number of QSTA	6,8,10 and 12

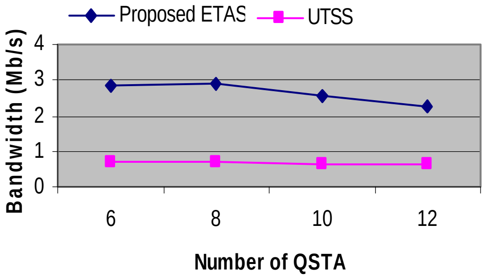

Fig. 5: QSTA vs bandwidth allocated

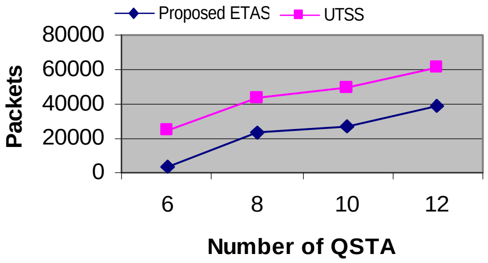

Fig. 6: QSTA vs average end to end delay

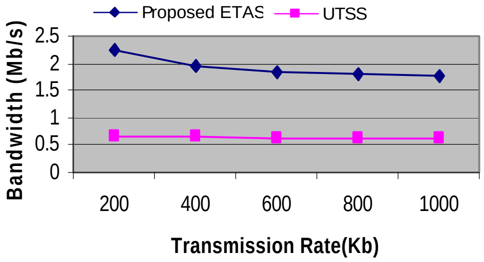

Fig. 7: QSTA Vs average packet drop

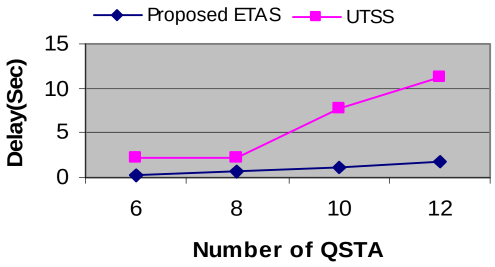

Fig. 8: QSTA vs bandwidth utilization

Results based on transmission rate: When comparing the performance of the two protocols researchers infer that ETAS outperforms UTSS by 66% in terms of bandwidth allocated, 42% in terms of average end to end delay, 24% in terms of average packet drop and 66% in terms of bandwidth utilization.

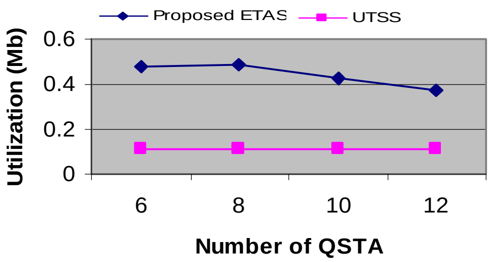

Fig. 9: Transmission rate vs bandwidth allocated

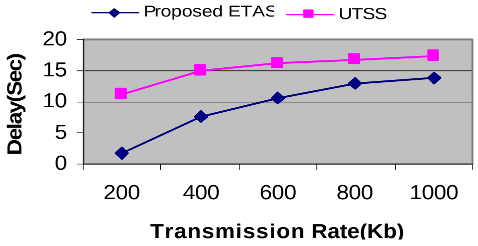

Fig. 10: Transmission rate vs average end to end delay

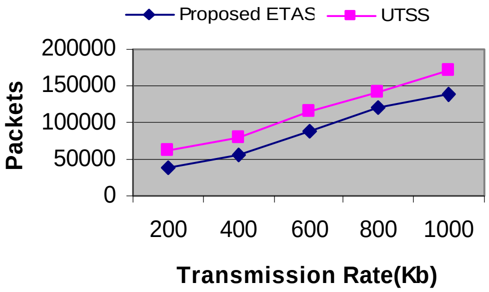

Fig. 11: Transmission rate vs average packet drop

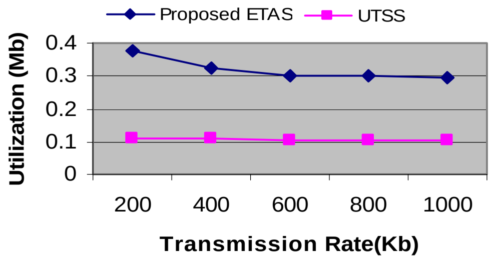

Fig. 12: Transmission rate vs bandwidth utilization

CONCLUSION

In this study researchers have proposed a Traffic Aware Scheduling Algorithm for VBR Traffic in IEEE 802.11e WLAN. First, a queue length notification scheme is used to transmit the queue length and data rate information to the QAP. Based on the queue length information TXOP is estimated. After that if the data rate information is high, then overboost scheduling algorithm is used to maintain the traffic stream by transmitting the excess data stream through EDCA. Unused time shifting scheduling algorithm is used for efficient resource management by recovering the unused portion of TXOP from low data rate station and allocating to the other station.

RECOMMENDATION

Future studies aim to extend this study for various traffic models and to compare with more recent studies.

REFERENCES

Annese, A., G. Boggia, P. Camarda, L.A. Grieco and S. Mascolo, 2004. Providing delay guarantees in IEEE 802.11 E networks. Proceedings of the 2004 IEEE 59th Conference on Vehicular Technology VTC 2004-Spring, May 17-19, 2004, IEEE, Italy, ISBN: 0-7803-8255-2, pp: 2234-2238.

Cecchetti, G. and A.L. Ruscelli, 2008. Performance evaluation of real-time schedulers for HCCA function in IEEE 802.11 E wireless networks. Proceedings of the 4th ACM Symposium on QoS and Security for Wireless and Mobile Networks, October 27-31, 2008, ACM, Vancouver, Canada, ISBN: 978-1-60558-237-5, pp: 1-8.

Chen, C.L. and C.R. Chang, 2012. Cross-layer most-emergent-first scheduler for wireless local area networks. Proceedings of the 2012 Eighth International Conference on Intelligent Information Hiding and Multimedia Signal Processing (IIH-MSP), July 18-20, 2012, IEEE, Kaohsiung, Taiwan, ISBN: 978-0-7695-4712-1, pp: 441-444.

Chou, C.W., K.C.J. Lin and T.H. Lee, 2011. On efficient multipolling with various service intervals for IEEE 802.11 E WLANs. Proceedings of the 2011 7th International Conference on Wireless Communications and Mobile Computing, July 4-8, 2011, IEEE, Taipei, Taiwan, ISBN: 978-1-4244-9539-9, pp: 1906-1911.

Cicconetti, C., L. Lenzini, E. Mingozzi and G. Stea, 2007. An efficient cross layer scheduler for multimedia traffic in wireless local area networks with IEEE 802.11 E HCCA. ACM. SIGMOBILE. Mob. Comput. Commun. Rev., 11: 31-46.

Ghazani, S.H.H.N., 2015. Light weight distributed QoS algorithm for wide area ad hoc networks. Asian J. Inf. Technol., 14: 221-230.

Huang, J.J., C.Y. Chang and H.W. Ferng, 2008. Flexible TXOP assignments for efficient QoS scheduling in IEEE 802.11 E WLANs. Proceedings of the 2008 5th IFIP International Conference on Wireless and Optical Communications Networks (WOCN'08), May 5-7, 2008, IEEE, Taiwan, ISBN: 978-1-4244-1979-1, pp: 1-5.

Lee, K.Y., K.S. Cho and W. Ryu, 2011. Efficient QoS scheduling algorithm for multimedia services in IEEE 802.11 E WLAN. Proceedings of the 2011 IEEE Conference on Vehicular Technology (VTC Fall), September 5-8, 2011, IEEE, Daejeon, South Korea, ISBN: 978-1-4244-8328-0, pp: 1-6.

Luo, H. and M.L. Shyu, 2009. An optimized scheduling scheme to provide quality of service in 802.11 E wireless LAN. Proceedings of the 11th IEEE International Symposium on Multimedia ISM'09, December 14-16, 2009, IEEE, Fort Wayne, Indiana, USA, ISBN: 978-1-4244-5231-6, pp: 651-656.

Noh, Z.A.B.M., T. Suzuki and S. Tasaka, 2009. A packet scheduling scheme for audio-video transmission over error-prone IEEE 802.11 E HCCA wireless LANs. Proceedings of the 2009 IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications, September 13-16, 2009, IEEE, Nagoya, Japan, ISBN: 978-1-4244-5122-7, pp: 1527-1531.

Politis, A., I. Mavridis and A. Manitsaris, 2010. Enhancing multimedia traffic performance in IEEE 802.11 E networks. Proceedings of the 2010 6th International Conference on Wireless and Mobile Communications (ICWMC), September 20-25, 2010, IEEE, Thessaloniki, Greece, ISBN: 978-1-4244-8021-0, pp: 125-130.

Ruscelli, A.L. and G. Cecchetti, 2014. A IEEE 802.11 E HCCA scheduler with a reclaiming mechanism for multimedia applications. Adv. Multimedia, Vol. 2014,

Ruscelli, A.L., G. Cecchetti, A. Alifano and G. Lipari, 2012. Enhancement of QoS support of HCCA schedulers using EDCA function in IEEE 802.11 E networks. Ad Hoc Netw., 10: 147-161.

Saheb, S.M., A.K. Bhattacharjee, A. Vallavaraj and R. Kar, 2011. A cross-layer based multipath routing protocol for IEEE 802.11 E WLAN. Proceedings of the 2011 IEEE Conference on GCC, February 19-22, 2011, IEEE, Durgapur, India, ISBN: 978-1-61284-118-2, pp: 5-8.

Shaik, M.S., B. AK and D. Hemadrasa, 2013. An integrated approach to enhance TCP fairness in HCCA scheduler for 802.11 E wireless LANs. J. Adv. Inf. Technol., 4: 51-57.