Enabling Green Video Streaming over Internet of Things

(6^{th} Quarter Deliverable)

Dr. Ghalib Asadullah Shah (PI)

Next-generation Wireless Networking (NWN) Lab,
Al-Khawarizmi Institute of Computer Science,
University of Engineering and Technology, Lahore

29-5-2015

Contents

List of Figures

List of Tables

About this Document

This document reports the activities performed in the 6th quarter of our project 'Enabling Green Video Streaming over Internet of Things' and the corresponding deliverable to be submitted to ICT R&D Fund.

In the 4th deliverable, a novel power saving mechanism for IEEE 802.11 is proposed named as PSMP-Plus (now renamed as mPSMP). The proposed technique is an enhanced version of the existing power saving mechanism, PSMP, of IEEE 802.11 n. Firstly, multi-hop communication that is a critical requirement in IoM based systems is enabled by the proposed mechanism which was not supported by the previous power saving mechanisms. Moreover, to provide application specific QoS to the multimedia traffic, the delay bound is considered while allocating bandwidth resources to the network nodes. Similarly, to minimize protocol overhead frame aggregation is also utilized by the multimedia sensor nodes to save energy. To evaluate the performance of the proposed technique, a mathematical analysis is done, which suggest significant energy efficiency gain as compared to existing CSMA/CA based multi-hop communication in IEEE 802.11.

In this 6th deliverable, a report on link layer for green communication is included. Particularly, IEEE 802.11 MAC layer power saving functionalities are examined. In order to realize multimedia streaming over IoT, a multi-hop power saving protocol named as mPSMP is presented which allocates channel resources while considering the QoS requirements of various network nodes. The performance of this mPSMP protocol is evaluation through extensive simulations in Network Simulator NS-2 which suggest significant performance gains in terms of minimizing end-to-end delay and the duty cycling of multi-hop nodes of an IoT network.

Chapter 1

Report on Link Layer for Green Communication

1.1 Introduction

Internet of Things (IoT) refers to the possibility of connecting sensors, or any other device or 'thing' to the Internet. It has the potential to significantly influence our lives and the way we interact with the devices such as sensors, actuators, mobile phones, home automation devices, smart grid devices, etc [1]. The Internet of Multimedia Things (IoMT) is an enhancement to the IoT, whose prime objective is to enable video streaming as part of the realization of IoT. In IoMT, resource constraint low-power low-cost heterogeneous multimedia devices can be connected and each device can be globally accessible by a unique IP address with the same spirit as of the computers and other networking devices connected through the Internet. This approach enables a wide range of applications in the areas of home and building automation, factory monitoring, smart cities, transportation, smart grid and energy management [2]. However, the time-constrained multimedia content i.e. video and audio, and more specifically real-time multimedia traffic that is continuous in nature requires stringent communication requirements as compared to data communication such as bandwidth, delay, jitter and reliability. These network performance requirements are referred as the Quality of Service (QoS), which represents the level of user experience.

The current standardization activities of providing Internet-connectivity to 'Things' [3] are not focused to address the challenges of provisioning multimedia objects over Internet of Things. The main obstacles of realizing IoMT are limited available capacity and scarce battery resources. Many researchers have investigated a variety of techniques to limit the power consumption of WMSNs. However, these issues have not been addressed considering IoT architecture. ZigBee that is based on the IEEE 802.15.4 standard is adapted for IoT, since it is designed for tiny network devices performing simple operations. However, the maximum data rate supported by ZigBee (250 kbps) is not feasible for most of the IoM applications. Especially for real-time multimedia communication, the multimedia devices cannot provide satisfactory user experience with data rate of 250 kbps. For this reason, IEEE 802.11 standard [4] is suggested in the literature for wireless multimedia networks, since it provides a high data rate communication model and holds a great potential to be adapted for IoMT paradigm. ZigBee and other IEEE 802.15.4 based protocols have been considered for WSNs applications due to their energy-efficient design. However, recently developed power-efficient Wi-Fi models promise multiple years of battery lifetime, have become a strong candidate in this domain [5]. Reuse of existing Wi-Fi infrastructure offers cost savings and faster deployments and existing Wi-Fi networks deployed everywhere reduce the infrastructure cost as well. Wi-Fi devices have the advantage of native IP-network compatibility, which is a big plus for IoT. Well-defined and universally accepted IP connectivity overcomes the need of expensive gateway requirements. For these reasons, Wi-Fi has already been widely accepted for many commercial off-the-shelf video devices, which are largely deployed for video surveillance and monitoring applications, making it a good candidate for IoMT if the energy efficiency mechanisms of IEEE 802.11 are devised comparable to IEEE 802.15.4.

One of the main reason Wi-Fi was initially disregarded to be adapted for IoT networks is its higher energy consumption compared to ZigBee standard. Recently, lots of efforts have being made to improve energy efficiency of IEEE 802.11 based WLANs. Most of the studies focused on reducing collision probabilities, duty cycle, delay, etc. However, to the best of our knowledge none of them have the key optimization parameters considering resource constrained wireless multimedia devices running real-time video streaming applications. Moreover, the multi-hop operation which is essential element for IoT system, is not supported in current IEEE 802.11 standard power saving mechanisms such as PSM, APSD, PSMP, etc. Hence, a power-saving mechanism, compliant to IEEE 802.11 standard, which enables energy efficient multi-hop communication operations is inevitable for streaming multimedia content over IoMT.

In our prior work, we studied the feasibility of various existing power saving mechanisms to be adapted for IoT and therein we selected Power Save Multiple Poll (PSMP) protocol developed for IEEE 802.11n due to its contention free features. However, PSMP is infeasible for IoT based systems since it lacks support for multi-hop operations and therefore, we presented an algorithm which enables the multi-hop operations in existing IEEE802.11 PSMP power saving mechanism. In this report, we incorporated our previous work in to a Multi-Hop PSMP (mPSMP) protocol to enable energy efficient multimedia communication over IoT. In order to realize real-time multimedia streaming, the various QOS requirements in terms of bandwidth, jitter and delay along with frame rate are considered. Having these unique requirements, we formulated an ILP problem whose objective is to minimize the duty cycling utility function subject to several constraints including the data rate, frame rate, frame aggregation threshold and delay bound. Our mPSMP protocol provide solution to this ILP problem and allocates channel resources to network nodes in a time division multiple access manner while minimizing energy utilization of each node and assuring the required multimedia Quality of Service (QoS). The evaluation of mPSMP protocol is done using Network Simulator (NS-2). We also compared the simulation result with that of theoretical result calculated through the traffic scheduling model presented in our previous work. These results suggest significant improvements compared to existing power saving mechanisms in terms of energy efficiency and reduction in average end-to-end delay and duty cycling of multi-hop multimedia IoT network.

1.2 Related Work: Background

In recent years, lot of work has been done in the literature to reduce energy consumption of station such that the stations switch to doze state when they don't have any packet pending for transmission or reception. However, to the best of our knowledge, all these power saving mechanisms lacks the support for multi-hop communication. Recently, a multi-hop power saving saving mechanism based on IEEE802.11 PSM standard, named as MH-PSM, is proposed [6]. MH-PSM scheme propagates Announcement Traffic Indication Messages (ATIM) along multi-hop paths to ensure that all intermediate nodes remain awake to forward the pending data frames within a single beacon interval. The focus of MH-PSM is to reduce latency and decrease end-to-end delay in multi-hop networks. However, in the legacy PSM standard, the stations are notified about their pending packets buffered at the AP and then the stations contend for the channel to transmit PS-Poll or trigger frames to retrieve their buffered packets. Therefore, when multiple stations contend the channel and the probability of collision among the request frames increases. These collisions results in bandwidth wastage and additional energy consumption at the power saving stations. On the contrary, In IEEE 802.11n Power Save Multi-Poll (PSMP) [4], these packet transmissions are not required, thus the collisions are avoided. Instead, in PSMP power saving mechanism, AP notifies PSMP enabled station when they have to stay awake using the beacon frames. Unlike its predecessor power saving techniques, PSMP enables the stations to stay awake only on specific service times, like time slots in TDMA, i.e. only when they are required to be in a receiving or a transmitting state. The AP can schedule the transmission opportunities depending upon the application constraints like delay and/or bandwidth constraints. The station can transmit packets in their PSMP Uplink Transmission Time (UTT) or receive packets in Downlink Transmission Time (DTT), respectively. Hence, the PSMP mechanism is more efficient as compared to its predecessors, in terms of energy saving as well as bandwidth utilization.

Therefore, based on PSM standard, MH-PSM protocol although reduces the end-to-end delay over multi-hop nodes in multi-hop networks; but the inherent possibility of nodes contention and resultantly packets collision in MH-PSM protocol operations cannot be neglected. This results in retransmissions and thereby increases the wake-up time and energy consumption of power saving nodes. Consequently, we focus our work on on IEEE802.11n PSMP power saving mechanism and enhance its capabilities to make it capable to work with multi-hop IoT networks.

1.3 The mPSMP Protocol

1.3.1 Problem Definition

IoMT implication in is true color requires resource constraints multimedia devices to be connected and accessible through the Internet. However, the multimedia content being communicates over the network requires different traffic requirements as compared to data communication such as bandwidth, delay, jitter and reliability. These network performance requirements are referred as the Quality of Service (QoS), which represents the level of user experience. The mPSMP protocol propose an energy efficient multi-hop operations in current IEEE 802.11n PSMP protocol standard while considering the QOS requirement of real-time traffic by fulfilling the delay bound of each packet. This is done by using a three-fold methodology to make IEEE 802.11 more power efficient.

Firstly, we try to decrease the protocol overhead of the IEEE 802.11 to increase bandwidth efficiency by allocating a predefined schedule to each station which results in lowering their duty cycle and reduce energy consumption. Secondly, this scheduling is done considering the user level experience of multimedia traffic i.e. delay bound, video quality etc. To achieve this, the station adaptively selects appropriate frame aggregation value based on the QoS specified minimum frame per seconds and with respect to the delay bound of arrival time of the oldest pending packet in its queue. When a data packet is received at the MAC layer from the higher layer, it is appended in the pending packets queue maintained at a power saving station. If the current packet is the first packet in the queue, then its arrival time is retained. Further, depending upon the Channel State Information (CSI) received from the intended receiver, the transmitting station determines the highest data rate that can be supported in the given channel conditions. This enables reduction in the transmission and reception time and as higher data rate also alleviates the need of longer PSMP-UTT duration requirement, thus bandwidth resources are efficiently utilized. Moreover, real-time multimedia transmission requires stringent QoS, in terms of delay, bandwidth and latency; hence the choice of highest supported data rate also dictates the selection of frame aggregation threshold. This information is being fed to traffic scheduling model and once a transmitting station determines the optimal frame aggregation and achievable data rate, it can ask the PSMP-enabled AP for the TXOP or more accurately PSMP-UTT period.

Thirdly, as highlighted in [6], another pertinent issue is the requirement for a station to stay awake for its allocated TXOP even if it has no more pending traffic in its queue. This results into under utilization of energy as well as bandwidth. This issue is resolved in mPSMP by incorporating dynamic duty cycling, i.e. if a station has no more packets to be transmitted in its allocated TXOP, it can dynamically decide to go into sleep mode in real time of algorithm execution. Considering the three-fold methodology described above, we formulate an ILP problem whose objective function is to minimize duty cycling utility function, $U_u(\partial_i, \gamma_i, \Psi_i)$, subject to the delay bound ∂_i, supported data rate γ_i and frame aggregation threshold Ψ_i constraints. Let $N_u = \{u_1, u_2, ..., u_n\}$ be the set of multi-hop nodes u_i and let $Q_{u,i} = \{p_1, p_2, .., p_m\}$, be their corresponding set of queues. The problem is formulated as:

Minimize:

$$\sum_{u_i \in N_u} U_u(\partial_{i,} \gamma_{i,} \psi_i) \quad \forall u_i \in N_u \tag{1.1}$$

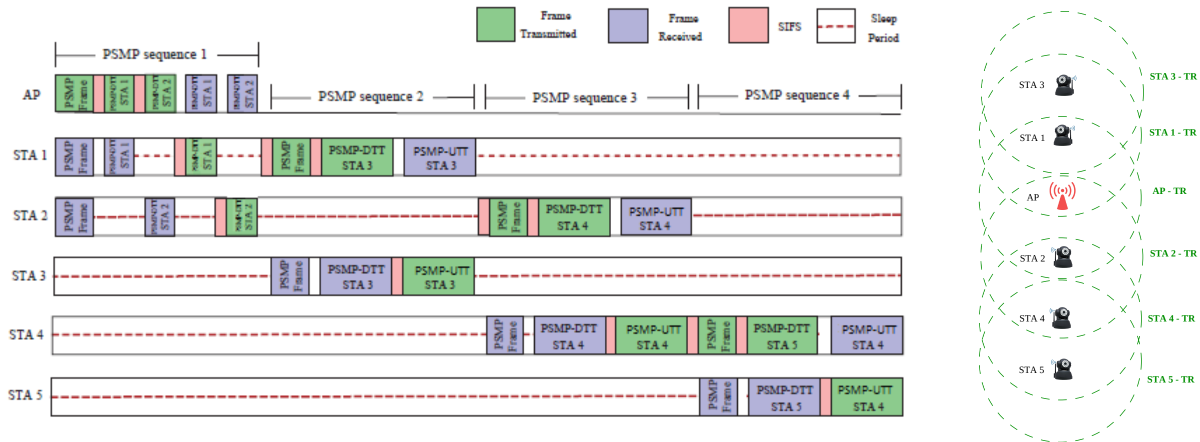
Subject to:

$$\sum_{i=1}^{m} \partial_{p,i} \leq \partial_{i,max} \quad \forall p \in Q_u, \forall u_i \in N_u \tag{1.2}$$

$$\frac{\rho_{p,i}\psi_{u,i}}{\gamma_{u,i}} \leq \partial_{p,1} \quad \forall p \in Q_u, \forall u_i \in N_u \tag{1.3}$$

$$\sum_{i=1}^{n} n\tau_{u,i} \leq 1 \quad \forall u_i \in N_u \tag{1.4}$$

The Constraint (1.2) in above formulation ensures that the delay associated with any packet p_i buffered at the queue Q_u of station u_i, should not exceed the maximum delay bound limit, $\partial_{i,max}$. In addition, the delay induced by buffering a packet in queue is in turn dependent upon the frame aggregation threshold and data rate; thus Constraint (1.3) mandates that aggregated packets are transmitted within the limitation of delay bound of oldest packet in queue, $(\partial_{p,1})$. While, the Constraint (1.4) corresponds to the allocation of TXOP $\tau_{u,i}$, and ensures that QoS requirements specified by frame rate are met within one second. In real-time multimedia streaming, the variation in QOS requirement for each multi-hop away station from AP varies which also affects the duty cycling of the next hop station along the flow of traffic towards AP, thus the solution to above problem is found out to be NP-Complete and very complex in nature. However, the multimedia power saving devices in an IoT infrastructures do not have enough computational resources to find the maximal solution of objective function in a given time. Therefore, we define a multi-hop PSMP protocol operations, details of which are given below, which schedules traffic opportunity to its various single and multi-hop away stations. To meet the specified QOS requirements, the traffic demand and associated parameters, such as data rate, delay bound, etc are being fed from stations to the traffic scheduling model to meet the QOS requirements for each of them.



(a) Time-line of Multi-hop PSMP

(b) Topology

Figure 1.1: mPSMP Operation for a 5 Node Network

1.3.2 Protocol Operation

The operation of mPSMP protocol is described as follows; and a sample operation for a five node network topology Fig. 1.1b is shown in Fig. 1.1a. A more detailed description of this algorithm is already included in 4th quarter deliverable report. For further understanding of PSMP operation, reader is referred to [4].

- First of all association between Access Point (AP) and stations is carried out.
- In the next step, AP send PSMP Action frame containing TIM bit set for each station, indicating that they have traffic buffered at AP. Within this PSMP frame, STA Info field exist which keeps the track of allocation of DL and UL traffic transmission opportunity, TXOP for each station and its PSMP-DTT and PSMP-UTT Start Offset.
- Correspondingly, each single hope away node will go into doze state or stay awake, according to their TIM bit value and their DL/UL traffic schedule in PSMP Action frame. This is carried out in an order starting from station with AID = 1. Therefore, at one time only a single station will stay awake for the time duration mentioned in its corresponding STA Info field.
- In this way, each single hop away station wakes up as per the order given in TIM bit of PSMP Action frame, receives its DL transmission from AP and upon its completion go into doze state for the remaining duration of DL traffic transmission of other station.
- Subsequently, after the completion of DL traffic transmission, again starting from AID =1, each single hope away station in turn wakes up and sends its

buffered UL traffic towards AP and then go into doze state for this remaining PSMP Sequence. At the end of first PSMP Sequence duration, all the single hop away stations from AP are served.

- All stations periodically wake up to listen to the PSMP frame transmission on the completion of every PSMP sequence duration.
- In subsequent PSMP Sequences, two-hop away nodes will get their traffic schedule. The number of PSMP Sequences to schedule traffic for two-hop away nodes equals to the number of child-stations of one-hop away nodes. Again pre-defined order will be followed as per allocated AIDs while scheduling this traffic transmission.
- Thus, within each of these PSMP Sequences, each single-hop away node will behave like AP for its child-stations and send PSMP Sequence to indicate the DL traffic buffered for their child-stations (which are two-hop away from AP) along with the transmission opportunity, TXOP for UL traffic.
- The other single-hop away nodes listen to the transmission of PSMP frame from one of their single-hop peers and hence go into doze state till the end of TXOP time advertised from their peer station, i.e till the end of current PSMP Sequence. Moreover, this information is also communicated by single-hop away nodes to their sub-child stations to make them sleep.
- After the exchange of frames between the current single hop away node and its immediate child-station(s), they both go into doze state for the remaining PSMP Sequence duration. In this way, all the single hop away stations acts like AP and communicate with their child-stations (two-hops away from AP) to complete their frame exchange within the assigned PSMP Sequence duration. These stations also eventually go intro doze state for rest of the PSMP Sequence durations corresponding to other stations.
- In the subsequent PSMP Sequence duration, algorithm operates recursively and following the similar pattern, only the two-hops away nodes (acting as AP) and their sub-child (three-hops away nodes) stay awake and exchange DL and UL traffic before falling asleep for rest of their PSMP sequence duration.
- The same pattern is repeated iteratively until the traffic demand of all the stations in the network is served. After these PSMP sequences, the AP starts the contention period till the next phase of PSMP sequences as specified in standard.

It is pertinent to mention that although this process is lengthy but it is by no mean computation or energy intensive since the duty cycling and traffic scheduling is done considering the QOS parameters and delay bound of traffic demand of each station. Additionally, as multi-hop functionality is not considered in prior work on PSMP protocol therefore, the algorithm provides a good way forward to enable and standardize the multi-hop communication while considering the QOS constraints of data and energy constraints of IoT devices (stations). Lastly, although AP is considered as powerful resource yet there is a fruitful option in this algorithm for AP to go into temporary doze state during the time period in which its one-hop away stations are behaving as acting APs to serve their child-station. Since AP is synchronized with its one-hop away stations and has already scheduled them their transmission, therefore it is possible for AP to go into doze to conserve energy and to further reduce the carbon footprints emission.

1.3.3 Traffic Scheduling Model

The traffic scheduling model is proposed in previous deliverable report, however for better understanding of protocol and comparison of our results, we include the important equations of traffic scheduling model.

Let the time spent in transmission is denoted by T_{awake}, and time spent in sleep mode is denoted by T_s. Correspondingly, the transmission power is denoted by P_t, and power consumed by node while sleeping is denoted by P_s. Let 'X' is the size of each packet and 'N_A' be the number of aggregated packets based on the achievable data rate 'Y' Mbps and 'ψ' is per second frame rate, i.e. ψ frames should be transmitted by a multimedia content-streaming station in a duration of one second in order to satisfy the QOS requirement. The cumulative PSMP Sequence duration,'T', required to send 'T_{thru}' amount of data by single station in one second in order to satisfy the delay bound is calculated as:

$$T = \frac{T_{thru}}{Y} = \frac{\psi \times N_A \times X}{Y}\ secs \tag{1.5}$$

It is important to note that cumulative PSMP Sequence duration, i.e. T, can be allocated contiguously one by one within a second in case we need to schedule only one-hop away nodes. However, to enable multi-hop stations communication and to allocate TXOPs to stations which are located beyond single-hop, each single-hop away station is supposed to carry its child-station traffic towards AP as well along with its own traffic. Hence, assuming the traffic demand of every child-stations is same as their peers belonging to other single-hop away stations. If every 'i' station has 'j' number of child-stations, then after identifying the required amount of transmission time for station 'i' ,i.e. T_{ti}, the updated required number of PSMP Sequences durations for the station 'i' within one second can be calculated as:

$$\lambda_{i,j} = \frac{T \times j}{T_{ti}}, \quad 0 \le i, j \le n \tag{1.6}$$

This essentially means that we uniformly schedule the traffic demand, T, of every child-station into number of occurrences of PSMP Sequences, λ, stretched over 1 second of time. Note that, i=0 implies that AP is the parent station while for rest of the values, station 'i' will be acting as AP.

Hence, T_{awakei} i.e. total awake time of station 'i' and T_{si}, it's total sleep time in one second duration can be calculated as:

$$T_{awakei} = \sum_{i=1,j=1}^{n} \lambda_{i,j}(2 \times n \times T_{ti} + 3 \times T_{sifs} + T_{psmp} + T_{wait}) \tag{1.7}$$

$$T_{si} = 1 - T_{awakei} \tag{1.8}$$

where 'n' is number of child-stations required to be scheduled in i^{th} PSMP Sequence duration and $2{\times}T_t$ is the transmission time of both DL and UL traffic. $3{\times}T_{sifs}$ is the number of SIFS intervals in each PSMP Sequence, T_{wait} is the additional short time spend for each node to stay awake before sending a lost TXOP request towards AP, and T_{psmp} is the time spent in sending PSMP frames. Likewise, is given by following expression:

It is significant to note that each station 'i' fell sleep between the time duration of any of its two 'i^{th}' TXOPs as described in proposed algorithm. However, if any station is also acting as the parent of any next hop child-station, then it has to stay wake till the time duration it communicate with and exchange frames to its child station. Finally, energy consumption is calculated as, E:

$$E = T_s \times P_s + T_{awake} \times P_t \tag{1.9}$$

$$E_s = T_s \times P_s = (1 - T_{awake}) \times P_s \tag{1.10}$$

$$E_{energysaving} = \frac{E_s}{E} \tag{1.11}$$

$$EnergyEfficiency(\%) = \frac{E_{total} - E}{E_{total}} \times 100\% \tag{1.12}$$

where E is the energy consumption, E_s is the energy consumption in sleep mode and E_{total} is the total Energy.

1.4 Simulation Results

To evaluate the performance of mPSMP protocol, we present the simulation model. The simulations consist of a multi-hop infrastructure network, depicted in Fig. 1.1b, having an Access Point (AP) and 5 mobile stations (STAs) where each station generates constant bit rate (CBR) traffic. The carrier sensing range of station is set to ensure the connectivity between any two stations. The packet size is changed from 128 to 2048 bytes and packet interval is distributed uniformly from 0.01 to 1.0 secs. The energy model is given in Table 1.1 and simulation parameters are shown in Table 1.2.

Table 1.1: Energy Consumption Model

Parameter	Value
Tx Power	660mW
Rx Power	395mW
Idle Power	35mW
Sleep Power	1mW
Initial Energy	1000J

Table 1.2: The Simulation Parameters

Parameter	Value
The number of AP	1
The number of STAs	5
Beacon Interval	100ms
Frame Rate	ψ
The number of aggregated packets	N_A
SIFS	20μ
Transmission Rate	11Mbps

Simulations are carried out extensively and results are averaged for distinct topologies and each simulation runs for 100 secs duration. We kept the packet size of 512 bytes, packet interval of 0.05 secs and frame rate of 25 frames per seconds unless specified otherwise. Firstly, the aggregate energy consumption is investigated for a multi-hop infrastructure scenario shown in Fig. 1.1b. The packet size is varied from 128 to 2048 bytes while the packet interval is kept fixed at 0.05. The simulation model presented here also validates the traffic scheduling model. The simulation result are compared with that of theoretical results computed from traffic scheduling model as demonstrated in Fig. 1.2. The variation (increase) in packet size results in more energy consumption due to an overall increase in throughput at each station as more time is utilized in awake state to meet the QOS requirement of 25 frames per second. However, as shown in Fig. 1.3, the effect of packet size increase on the energy efficiency of the stations having mPSMP protocol is negligible (4% reduction in energy efficiency) compared to the damaging effect (20% reduction in energy efficiency) of packet size variation when no energy saving mechanism is employed for multi-hop stations. Similarly, Fig 1.2 also depicts a comparison of mPSMP with the traditional TDMA approach of IEEE 802.11 standard without duty cycling and shows notable improvements in terms of energy consumption when mPSMP is employed. In standard PSMP protocol a station is not a TXOP holder which means that station has to stay awake for its allocated transmission opportunity even if there is no pending traffic. The mPSMP protocol incorporate dynamic duty cycling which enables a station to go into doze state

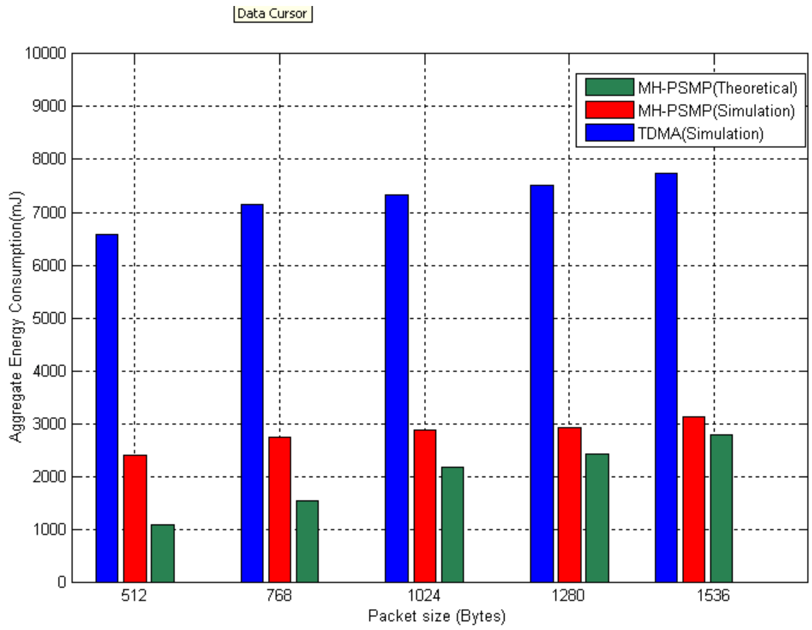


Figure 1.2: Energy consumption: TDMA vs mPSMP

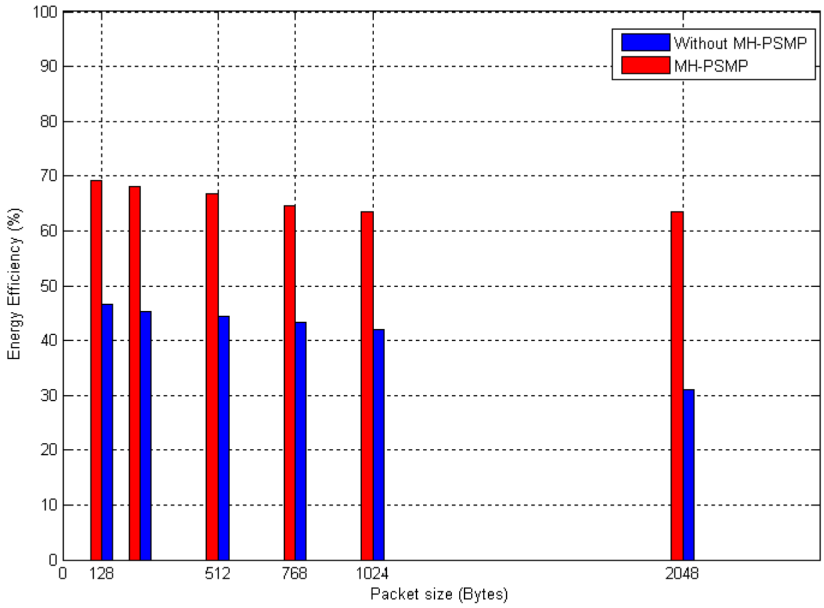


Figure 1.3: Energy efficiency: PSMP vs mPSMP

dynamically after sending its pending traffic. The effect of dynamic duty cycling on energy consumption for multi-hop stations across the flow (STA-2→STA-4→STA-5) of Fig. 1.1b is shown in Fig. 1.4. This effect is enhanced when packet interval is increased particularly for stations which are more than one hop away from AP. Thus, additional energy can be saved by incorporating dynamic duty cycling and is particularly useful for network scenarios where traffic rate is low or packet interval varies over the course of time.

Finally, the average end-to-end delay results are depicted in Fig 1.5. As expected, end-to-end delay increases with an increase in packet size. It is also incremented proportionally with the increase in number of hops, however, thanks to the mPSMP protocol, the maximum average end-to-end delay for 3 hop away nodes is around 20ms which is very much lower compared to the previous implementations of various power saving mechanisms. Moreover, although some packets are delayed and forwarded over multi-hops in more than one PSMP Sequences; but due to the traffic scheduling QOS will be guarantied according to given frame rate. It will be ensured that the end-to-end delay for frames at a given station doesn't go beyond per second delay bound.

1.5 Conclusion

Recently, lot of efforts has been presented in existing literature to improve the energy efficiency of MAC Layer operations for IEEE 802.11 based WLANs. However, these research studies lack the support for multi-hop communication and the key optimization parameters required for streaming multimedia traffic over resource constrained IoT devices are missing. In this work, an energy efficient multi-hop power saving mechanism named as mPSMP for green multimedia communication over IoT is presented. Various QOS parameters such as frame rate, delay bounds along with frame aggregation are incorporated while designing the protocol to realize real-time multimedia communication over multi-hop scenarios of IoMT devices. The performance evaluation of the proposed mPSMP protocol is done through Network Simulator NS-2. The simulation results suggest significant performance gains in terms of energy efficiency and reduction in end-to-end delay and duty cycling of network nodes.

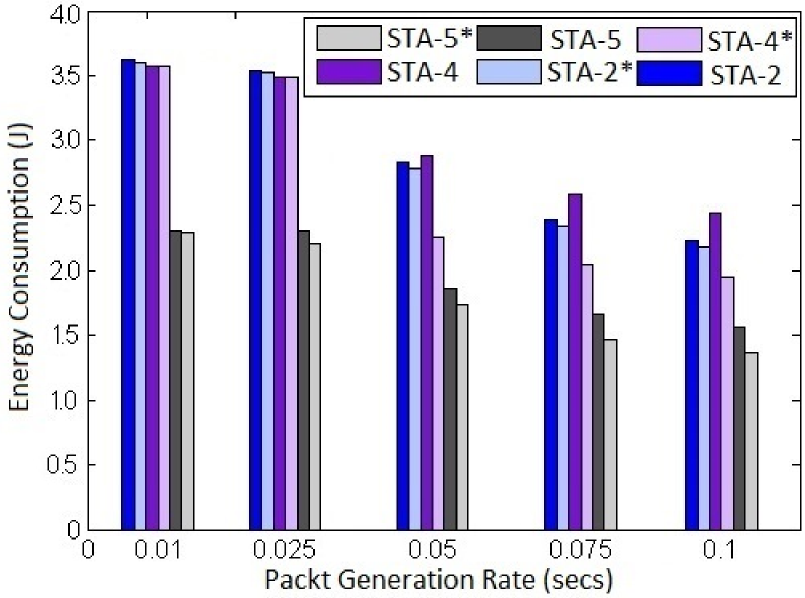


Figure 1.4: Energy efficiency gain due to dynamic duty cycling (*)

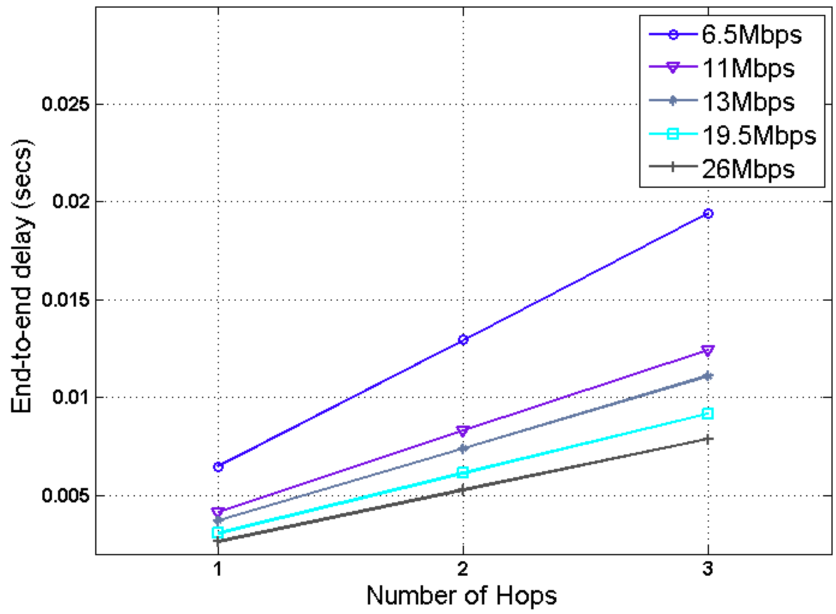
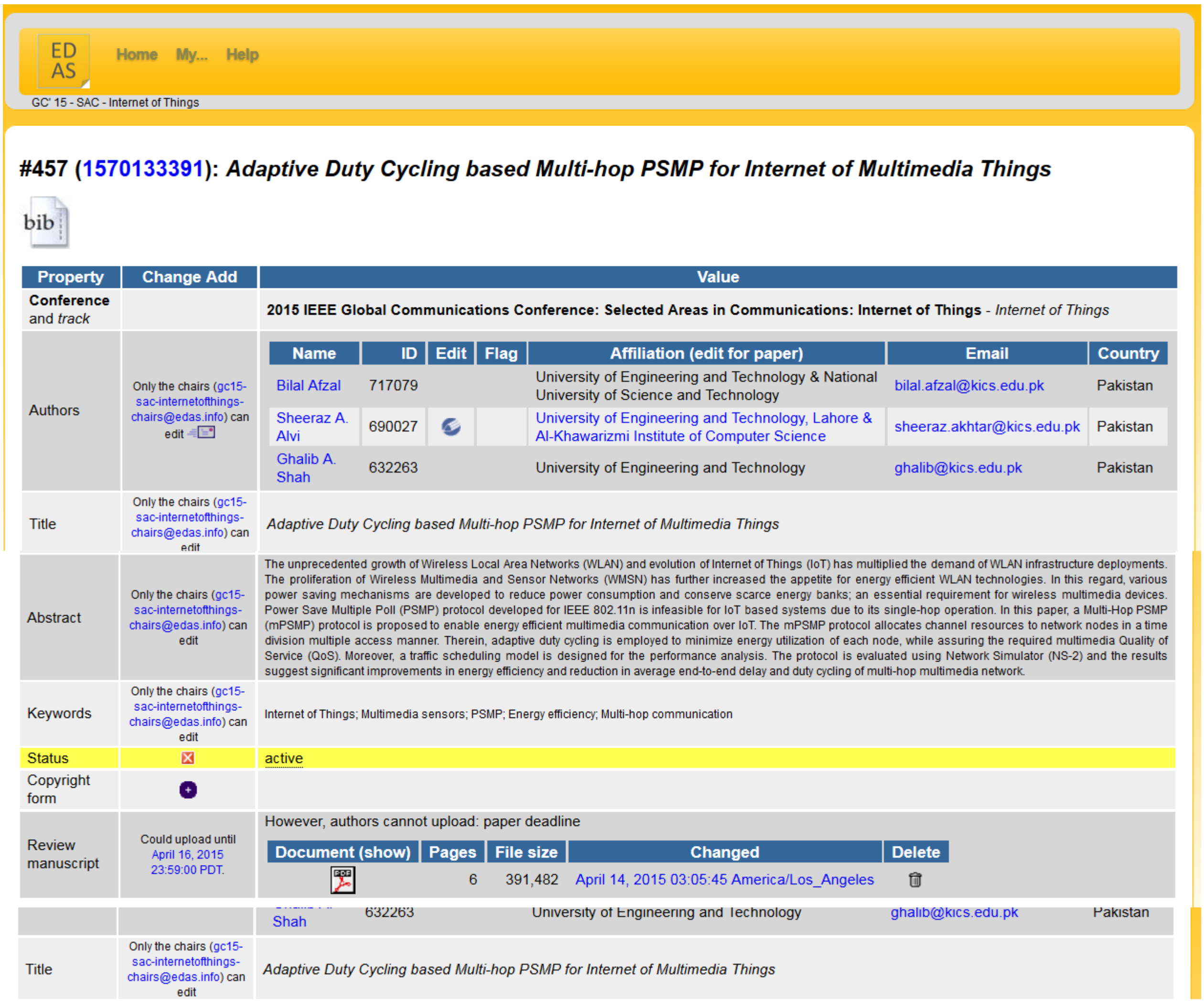


Figure 1.5: Data rate effect on traffic delay

Chapter 2

International conference paper on energy efficiency in IEEE 802.11 for IoM

The mPSMP protocol presented in previous Chapter of this report is submitted in the form of a conference paper in an international conference titled 'IEEE Globecom 2015', details of which can be seen in the Fig. 2.1:



ED AS Home My... Help

GC' 15 - SAC - Internet of Things

#457 (1570133391): *Adaptive Duty Cycling based Multi-hop PSMP for Internet of Multimedia Things*

bib

Property	Change Add	Value
Conference and *track*		**2015 IEEE Global Communications Conference: Selected Areas in Communications: Internet of Things** - *Internet of Things*
Authors	Only the chairs (gc15-sac-internetofthings-chairs@edas.info) can edit	see author table below
Title	Only the chairs (gc15-sac-internetofthings-chairs@edas.info) can edit	*Adaptive Duty Cycling based Multi-hop PSMP for Internet of Multimedia Things*
Abstract	Only the chairs (gc15-sac-internetofthings-chairs@edas.info) can edit	The unprecedented growth of Wireless Local Area Networks (WLAN) and evolution of Internet of Things (IoT) has multiplied the demand of WLAN infrastructure deployments. The proliferation of Wireless Multimedia and Sensor Networks (WMSN) has further increased the appetite for energy efficient WLAN technologies. In this regard, various power saving mechanisms are developed to reduce power consumption and conserve scarce energy banks; an essential requirement for wireless multimedia devices. Power Save Multiple Poll (PSMP) protocol developed for IEEE 802.11n is infeasible for IoT based systems due to its single-hop operation. In this paper, a Multi-Hop PSMP (mPSMP) protocol is proposed to enable energy efficient multimedia communication over IoT. The mPSMP protocol allocates channel resources to network nodes in a time division multiple access manner. Therein, adaptive duty cycling is employed to minimize energy utilization of each node, while assuring the required multimedia Quality of Service (QoS). Moreover, a traffic scheduling model is designed for the performance analysis. The protocol is evaluated using Network Simulator (NS-2) and the results suggest significant improvements in energy efficiency and reduction in average end-to-end delay and duty cycling of multi-hop multimedia network.
Keywords	Only the chairs (gc15-sac-internetofthings-chairs@edas.info) can edit	Internet of Things; Multimedia sensors; PSMP; Energy efficiency; Multi-hop communication
Status		active
Copyright form		
Review manuscript	Could upload until April 16, 2015 23:59:00 PDT.	However, authors cannot upload: paper deadline

Authors:

Name	ID	Edit	Flag	Affiliation (edit for paper)	Email	Country
Bilal Afzal	717079			University of Engineering and Technology & National University of Science and Technology	bilal.afzal@kics.edu.pk	Pakistan
Sheeraz A. Alvi	690027			University of Engineering and Technology, Lahore & Al-Khawarizmi Institute of Computer Science	sheeraz.akhtar@kics.edu.pk	Pakistan
Ghalib A. Shah	632263			University of Engineering and Technology	ghalib@kics.edu.pk	Pakistan

Review manuscript:

Document (show)	Pages	File size	Changed	Delete
	6	391,482	April 14, 2015 03:05:45 America/Los_Angeles	

Shah	632263			University of Engineering and Technology	ghalib@kics.edu.pk	Pakistan

Title	Only the chairs (gc15-sac-internetofthings-chairs@edas.info) can edit	*Adaptive Duty Cycling based Multi-hop PSMP for Internet of Multimedia Things*

Figure 2.1: International Conference Paper

Bibliography

[1] Luigi Atzori, Antonio Iera, and Giacomo Morabito. The internet of things: A survey. *Computer networks*, 54(15):2787–2805, 2010.

[2] Adam Dunkels and Jean-Philippe Vasseur. Ip for smart objects, september 2008. *IPSO Alliance White Paper*, 1.

[3] N Kushalnagar, G Montenegro, C Schumacher, et al. Ipv6 over low-power wireless personal area networks (6lowpans): overview, assumptions, problem statement, and goals. *RFC4919, August*, 10, 2007.

[4] *IEEE 802.11n-2009 Standard for Information technology, Local and metropolitan area networks, Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC)and Physical Layer (PHY) Specifications Amendment 5: Enhancements for Higher Throughput.* IEEE.

[5] K. Hall West and G. West. *Wireless Sensor Network Technology Trends Report.* West Technology Research Solutions, LLC, Tech. Rep., 2008.

[6] Vladimir Vukadinovic, Ioannis Glaropoulos, and Stefan Mangold. Enhanced power saving mode for low-latency communication in multi-hop 802.11 networks. *Ad Hoc Networks*, 23:18–33, 2014.