Enabling Green Video Streaming over Internet of Things

(4^{th} Quarter Deliverable)

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About this Document

This document reports the activities performed in the 4th 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 1st deliverable we conducted a detailed literature survey of IoT communication protocols and identified the issues challenges for IoM. One of these challenges was to enabling green communication for IoM. Since, multimedia traffic is bulky in size requiring frequent data transmissions, which results in high carbon footprints emission. Therefore, enabling green communication for IoM is a critical issue. In the 3rd deliverable, we identified RPL as a potential routing protocol for IoM and on the basis of a simulation study in Cooja simulator of Contiki-OS. In addition, we implemented an energy metric based objective function in Contiki-OS and compared its performance with existing ones. The outcomes of this analysis suggested that RPL is highly flexible and dynamic routing protocol, however its existing implementations do not consider green communication. Therefore, in this deliverable we designed a green routing protocol based on RPL for IoM.

In this deliverable, our contributions are two-fold; First, we designed an energy efficient green routing protocol for IoM to minimize carbon footprints emission. To the best of our knowledge no green routing protocol based on RPL is designed in prior research activities. The proposed routing protocol is an enhanced version of RPL, we named it Green-RPL, in which a node chooses a preferred parent by considering a set of network metrics such as the delay constraint, battery consumption of potential parent nodes, type of energy sources along the route towards the root node, etc. In this way, the proposed Green-RPL routing protocol minimizes network carbon footprint emissions and energy consumption, while assuring application specific Quality of Service (QoS).

In the second part of this deliverable, a novel power saving mechanism for IEEE 802.11 is proposed named as PSMP-Plus. 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 the next deliverable, we will implement the proposed Green-RPL routing protocol design in the Contiki-OS for its performance evaluation. In addition, its performance will be compared with the existing objective functions. Similarly, in the 6th deliverable the proposed PSMP-Plus protocol for low-power IEEE 802.11 will be implemented in the Contiki-OS for its performance evaluation in a real system.

Chapter 1

Design specifications of green communication protocol

1.1 Introduction

Internet of Things (IoT) is defined as the global network of uniquely identifiable and addressable 'smart things' which possess the capability to interact and communicate with other 'smart things' with or without direct human intervention [1]. IoT has the potential to enable enormous number of applications and services which can significantly influence our lives and the way we interact with things [2]. Concurrently, there have been huge growth in online multimedia traffic, due to the eminent interest in development and usage of multimedia based applications, services and solutions, i.e. video conferencing, telepresence, online-gaming, etc. However, the current research and development activities have been restricted to scalar sensor data based IoT systems and overlooked the challenges of provisioning multimedia devices over IoT. Thereby, leaving a gap to benefit from services and application based on the multimedia information essentially provided by the Internet of Multimedia (IoM).

Thanks to Micro Electro Mechanical Systems (MEMS) and Complementary Metal Oxide Semiconductor (CMOS) technologies, IoM devices are envisioned to be tiny and low-cost, possessing a low-power transceiver, a microprocessor, a battery and a sensor. Consequently, they are expected to be deployed in huge numbers [3]. Smart multimedia things operate in wireless medium with instable links, frequent packet drop, and high bit-error-rate, that is referred as the Low-power and Lossy Networks (LLNs). Moreover, the acquired multimedia data, i.e. audio, video, and audio+video, possess distinct characteristics as compared to the scaler sensed data and impose stringent Quality of Service (QoS) requirements in terms of network bandwidth, delay, jitter, etc [4].

IoT systems are built on LLNs mandating a lightweight energy efficient routing protocol. Therefore, IETF Routing Over Low-power and Lossy networks (ROLL) working group has recently standardized Routing Protocol for Low Power and Lossy Networks (RPL) [5], which is a proactive distance vector routing protocol for LLNs. RPL forms a tree like network topology by maintaining a directed acyclic graph (DAG). In RPL each sensor node chooses a preferred parent towards the root node based on specific routing policies. RPL uses multiple routing metrics and constraints while optimizing an objective function to select the best path. The standard provides the choice to select appropriate objective functions as per the application requirements, which makes RPL highly adaptive and dynamic. However, so far no optimizations have been made for RPL to support multimedia communication.

Environmental awareness in society regarding the carbon dioxide (CO_2) emissions and its effects, has aspired the Information and Communication Technology (ICT) community to ensure low-power and greener operation of communication systems in order to minimize carbon footprint emissions [6, 7]. For this reason, the research community has specifically focused on minimizing CO_2 emission and energy dissipation in next-generation wireless networks, i.e. IoT or IoM, to enable green communication. Moreover, the multimedia traffic is bulky in nature and operating on high transmission rates. Thereby, the CO_2 emissions are significantly higher in multimedia networks or IoM. In heterogeneous wireless networks like IoM, the devices are equipped with different energy sources i.e. lithium batteries, solar cells, piezoelectric energy, etc. Therefore, green communication can be enabled by adopting routes with nodes equipped with green energy source in order to minimize carbon footprint emissions.

Energy efficiency of RPL have been addressed in multiple prior studies in order to optimize RPL for IoT systems based on scalar sensed data. However, to the best of our knowledge no RPL implementation is designed in prior studies that incorporates the QoS requirements for multimedia communication over IoM. Similarly, green communication has attracted lot of attention and motivated researchers to reduce CO_2 emissions, yet there is no RPL implementation to enable green communication. Therefore, in this work we design an energy efficient green routing protocol (Green-RPL) for IoM. The proposed Green-RPL routing protocol is an enhanced version of RPL in which a node chooses a preferred parent by considering a set of network metrics such as the delay constraint, battery consumption of potential parent nodes, type of energy sources along the route towards the root node, etc. In this way, the proposed Green-RPL routing protocol minimizes network carbon footprint emissions and energy consumption, while assuring application specific QoS.

1.2 Overview of RPL

Routing Protocol for Low Power and Lossy Networks (RPL) routing protocol create a Destination Oriented Directed Acyclic Graph (DODAG) to maintain network topology. DODAG contains multi-hop paths from leaf nodes towards the root node

[5]. Thus, leaf nodes choose a preferred parent considering an objective function which is minimized or maximized as per application requirements based on some routing metrics (e.g. ETX, OF0, Node-Energy, etc) representing quantitative path cost. To avoid loops in the route a rank 0 is assigned to root node and the rank increases towards the leaf nodes such that every child has higher rank than its parents.

RPL uses three ICMPv6 packets for routing signalling while creating and maintaining the routing table. (i) DODAG Information Object (DIO) messages are used to form, maintain and discover DODAGs. (ii) DODAG Information Solicitations (DIS) is used to explicitly solicit DIO message from neighbor nodes. (iii) DODAG Destination Advertisement Object (DAO) messages are sent form leaf nodes towards the root to support downward traffic. DODAG uses DODAGSequenceNumber to indicate freshness of the information. The creation and maintenance of network topology requires exchange of control packets. DIO packet pose the most significant overhead which can be controlled with a trickle timer. The smallest interval between two DIOs is equal to DIO-Minimum-Interval which keeps on increasing (doubling) until it reaches the maximum value determined by DIO-Interval-Doublings.

1.3 Green-RPL design

The smart things in IoT systems are envisioned to be deployed in huge numbers that is why there cost and size is kept to a minimum. In addition, these resource constrained devices are supposed to operate in extremely low-power mode in the LLNs so that the network lifetime could be prolonged. In typical IoT scenarios the scalar sensed data is periodic in nature, therefore energy efficient operation is guaranteed by employing a very low radio duty-cycle as low as 1% i.e. the radio is kept ON for only 1% of the total time. Moreover, with help of routing data over less energy consuming paths, a significant amount of energy can be saved. However, in an IoM scenario the smart low-power devices exchange multimedia data which is bulky in nature and requires higher bandwidth. Thus, packet transmission take place more frequently and the radios are kept in the ON state for longer durations, which results in higher energy consumption and higher carbon footprints emission. Consequently, the energy efficiency and green communication operation is more critical for smart multimedia things in IoM based systems in order to prolong the network lifetime.

It is noteworthy to mention here that by network lifetime we mean the time when first node drain all of its battery energy. In prior studies many efforts have been made to prolong network lifetime in IoT scenario. However, the multimedia communication over IoT or IoM along with its prospective requirements and challenges have been overlooked in previous studies on RPL routing protocol. Although lot of work is done on green communication for various wireless networking technologies, yet enabling green communication over RPL-based IoT systems is not given any consideration.

In this paper, a novel RPL implementation is presented in which the carbon footprints emission is minimized provided that the application delay requirement and energy efficiency is guaranteed. To ensure sufficient QoS for specific multimedia application the delay constraint is pre-determined. For example, the delay bound for a Voice over IP (VoIP) application is typically 120 msec, while for video application per packet delay bound varies with the video frame resolution, transmission rate, variable packet sizes, etc, yet transmitter must ensure that in 1 sec at least 25 frames are successfully delivered to the receiver node. Similarly, the energy efficiency is ensured by considering the quality of the intermediate links towards the root node, the energy already consumed by the possible preferred parent node, and by evaluating the potential of the parent node to support traffic requirements for yet another child node. To evaluate a parent node as per these constraints and requirements, an optimization model for the proposed Green-RPL routing protocol is designed in the following part of this section. Among all the parent nodes of a specific sensor node, the solutions of the optimization problem gives the preferred parent.

Consider the wireless link between node α and node β is denoted by (α, β). In practical wireless networks the wireless link quality (Bit Error Rate) is time varying, thus the packet transmissions are affected by the wireless channel conditions. Various methods have been proposed in the literature to estimate the link quality, such as Received Signal Strength Indicator (RSSI), Link Quality Indication (LQI), Signal to Noise Ratio (SNR). The RFC-compliant RPL routing protocol implementation in Contiki-OS provides ETX metric to estimate the link quality which measures the expected number of transmissions required to successfully deliver a packet over a specific link. Let the estimated link quality metric between node α and node β is denoted by $\ell(\alpha, \beta)$.

We define the neighboring nodes of a node α as the nodes which are in the transmission range of node α, i.e. node α can transmit packets towards them. Let the set of neighbor nodes of node α is represented by $\delta(\alpha) = \{\delta_1,\delta_2,...\}$. Since, signal power distributions are not uniform, thus it is possible that node α can listen to some node β, however node β may not listen to node α. So, we define another set of nodes, which are able to transmit packets to node α and represent it as $\vartheta(\alpha)$. Also, consider the rank of node α is denoted by $\phi(\alpha)$. As per the specifications provided by the IETF ROLL working group for RPL implementation, a node can be a parent node ρ for a node c, if it conform the following conditions:

$$\rho \in \delta(c) \tag{1.1}$$

$$c \in \delta(\rho) \tag{1.2}$$

$$\phi(\rho) < \phi(c) \tag{1.3}$$

Let the set of parent nodes of a node c is denoted by $\xi(c) = \{\rho_1,\rho_2,...\}$. Thereby, the nodes in set $\xi(c)$ send DIO messages to node c who then choose one of these parent nodes as a preferred parent as per the objective function. In our proposed Green-RPL routing protocol the preferred parent is chosen as per the solution of the optimization problem given below:

$$\min. \quad \Gamma(\rho) \tag{1.4}$$

$$s.t. \quad \rho \in \xi(c) \tag{1.5}$$

$$\Lambda(\rho) < \mu^d \tag{1.6}$$

$$\Omega(\rho) < \mu^\ell \tag{1.7}$$

$$\Psi(\rho) > \mu^b \tag{1.8}$$

$$\Upsilon(\rho) > \mu^i \tag{1.9}$$

Here $\Gamma(\rho)$, $\Lambda(\rho)$, $\Omega(\rho)$, $\Psi(\rho)$, and $\Upsilon(\rho)$ represent the cumulative path carbon footprints, cumulative path delay, cumulative path link energy, battery status, and idle time for the parent node (ρ), respectively. In this optimization problem, the objective is to minimize the cumulative carbon footprint emissions on all the links along the path from parent node ρ towards the root node. Therein, if when multiple parent nodes fulfill the given constraints then the node offering the most greener path will be selected as the preferred parent. The heterogeneous smart devices in a IoM network can be equipped with distinct energy source, thus emitting disparate amount of carbon footprints. Let the carbon footprints emitted by a link ℓ within the path from parent node ρ to root node is denoted by $cf(\ell)$, then $\Gamma(\rho)$ can be given as;

$$\Gamma(\rho) = \sum_{\ell \to 1}^{L} cf(\ell) \tag{1.10}$$

here L is the total number of links in the path. Moreover, the parent node ρ needs to fulfill some other constraints to enable application specific QoS and longer network lifetime. The first constraint is very basic that is the potential preferred parent node ρ should belong to set of parents of node c i.e. both ρ and c are neighbors of each other and rank of node ρ should be less than the rank of node c. The second constraint specifies the application QoS in terms of the delay bound that is the cumulative path delay for a data packet should not increase a predefined delay threshold μ^d. In LLNs a packet may experience different wireless channel conditions, thus undergo distinct packet delays per link. Thereby, if the delay induced by a link ℓ is denoted by $d(\ell)$, then the cumulative delay of the path can be given as

$$\Lambda(\rho) = \sum_{\ell \to 1}^{L} d(\ell). \tag{1.11}$$

Energy consumption of a node significantly depends upon the link quality of the path selected for packet routing. For example, if a path with poor link quality is selected then the probability of successful delivery of packet in single transmission attempt will be very low, which may result in several retransmissions before packet gets delivered to the destination, consuming significant amount of energy. Therefore, an important metric to consider while selecting a route is to evaluate the energy cost as per the quality of links along the path which can be given as

$$\Omega\left(\rho\right) = \bar{D}\sum_{\ell \to 1}^{L} \frac{ETX\left(\ell\right) \times P_t\left(\ell\right)}{\lambda\left(\ell\right)}. \tag{1.12}$$

Here $\bar{D}$ is the data packet size, while the $P_t\left(\ell\right)$ and $\lambda\left(\ell\right)$ is the transmit power and data rate of link ℓ, respectively. $ETX\left(\ell\right) = \left(\ell - \tau\right)\left(1 + \frac{1}{\tau}\right)$ is the expected number of transmissions required to successfully deliver the packet over link ℓ and τ is the probability of successful packet transmission.

The battery status of the parent node ρ is also a critical metric, since it can influence the network lifetime and traffic load on a particular node. Consider a scenario in which a single parent node is selected by multiple child nodes as a preferred parent for traffic forwarding, in this case the parent node will quickly drain its energy resources and network lifetime will be reduced. Similarly, selecting a parent node with low remaining energy will also result in route instability as the route will be required to change in a short time when the parent node battery dies. Therefore, we propose that the child node c only select a parent node ρ as the preferred parent if its available energy resources (battery level) is higher than a pre-defined threshold μ^b. If the maximum battery energy capacity and battery energy already utilized is given by E_c and E_u, respectively, then the battery status can be given as

$$\Psi\left(\rho\right) = \frac{E_c\left(\rho\right) - E_u\left(\rho\right)}{E_c\left(\rho\right)}. \tag{1.13}$$

Lastly, the $\Upsilon\left(\rho\right)$ constraint represents the amount of time the parent node ρ keeps its radio ON, yet no activity (transmission or reception) is done during this period. It is essential to know if a node has enough idle time to support a child node. For example, in a LLN the nodes operating on very low radio duty cycles can only support a limited number of child nodes within their radio ON period. For this reason, a parent node ρ should only be selected as a preferred node if its idle time is enough for supporting another child node, i.e.

$$\Upsilon\left(\rho\right) > \frac{t_{tx}\left(\rho\right) + t_{rx}\left(\rho\right)}{c\_n\left(\rho\right)}. \tag{1.14}$$

Here $t_{tx}\left(\rho\right)$ and $t_{rx}\left(\rho\right)$ represents the time parent node ρ spends in transmission and reception mode, respectively. While $c\_n\left(\rho\right)$ denotes the number of child nodes already supported by parent node ρ. This concludes our Green-RPL routing protocol design, which considers various constraints while selecting a parent node as a preferred parent, so that an energy efficient operation along with the minimization of carbon footprints emission can be guaranteed.

1.4 Conclusion

The current research and development activities for IoT systems have overlooked the incorporation of ‘multimedia things’. Similarly, there have been no consideration of green communication or carbon footprints reduction using the RPL routing protocol. For this reason, in this deliverable an enhanced version of RPL for IoM is proposed, Green-RPL, in which the sensed information is essentially provided by the smart ‘multimedia devices’. The proposed Green-RPL routing protocol minimizes carbon footprints emission and energy consumption, and supports application specific QoS requirements by considering various constraints while selecting routes towards the root node. To evaluate the performance of the proposed scheme a simulation study will be carried out in Cooja simulator for Contiki-OS, to evaluate its performance with the existing objective functions.

The Green-RPL routing protocol designed in previous Chapter 1, is submitted in the form of a conference paper in an international conference. Details can be seen in the snapshot below:

#162 (1570072301): ***Energy Efficient Green Routing Protocol for Internet of Multimedia Things***

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<tr><td>Title</td><td></td><td><i>Energy Efficient Green Routing Protocol for Internet of Multimedia Things</i></td></tr>
<tr><td>Abstract</td><td></td><td>Internet of Things (IoT) envisions the notion of ubiquitous connectivity of everything. However, the current research and development activities have been restricted to scalar sensor data based IoT systems, thus leaving a gap to benefit from services and application enabled by multimedia things or Internet of Multimedia Things (IoMT). Moreover, a crucial issue for Information and Communication Technology (ICT) community is the steer increase in CO_2 emissions, which mandates green communication to reduce energy consumption and carbon footprint emissions. Recently, IETF ROLL working group standardized an IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) for resource constrained devices. RPL builds a tree-like network topology based on some network metric optimization using RPL Objective Functions. Previous RPL implementations for scalar sensor data communication are not feasible for IoMT, since multimedia traffic pose distinct network requirements. The goal of this paper is to design an enhanced version of RPL for IoMT in which the sensed information is essentially provided by the multimedia devices. Our proposed RPL implementation minimizes carbon footprint emissions and energy consumption, along with the incorporation of application specific Quality of Service requirements. To evaluate the performance of the proposed scheme a simulation study is carried out in Cooja simulator for Contiki-OS, which suggests significant gains in terms of energy efficiency and delay.</td></tr>
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Figure 1.1: RPL Topology

Chapter 2

Design of new energy efficient IEEE 802.11 functions

2.1 Introduction

The explosive and ubiquitous adoption of Wireless Sensor Networks (WSNs) due to its low cost sensor technology has enabled by large-scale networks of small devices capable of harvesting information from the physical environment, performing simple processing on the extracted data and transmitting it to remote locations [8]. '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 [2]. However, recently due to the availability of low cost multimedia devices i.e. CMOS cameras and microphones, the Wireless Multimedia Sensor Networks (WMSNs) have gain lots of attraction. In WSMNs ubiquitously distributed low-power low cost devices communication to retrieve multimedia content from the physical environment in the form of video and audio streams, still images, or scalar sensor data. Conventionally, these tiny devices report data to a centralized network manager or gateway or application server device, which is responsible to store and fuse the data coming from different devices.

The Internet of Multimedia (IoM) is an enhancement to the IoT, whose prime objective is to enable video streaming as part of the realization of IoT. In IoM, 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 [9]. However, the delivery mechanism of the current Internet architecture, offers 'Best-Effort' transmission with no guarantee of successful packet delivery or the time of its delivery. Despite the fact that 'Best-Effort' transmission mechanism is suitable for non-real time data communication which is delay tolerable but requires error-free delivery, whereas this approach is not appropriate for time-constraint multimedia content i.e. video and audio.

ZigBee that is based on the IEEE 802.15.4 standard is promoted 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 [10] is suggested in the literature for wireless multimedia networks, since it provides a high data rate communication model and holds a great potential for WMSNs. 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 [11]. Reuse of existing Wi-Fi infrastructure offers cost savings and faster deployments. Widely deployed Wi-Fi networks reduce the infrastructure cost to a minimum while improving the total cost of ownership. 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 or any network address translation (NAT). In addition, IEEE 802.11 provides various mechanisms to support different types of traffic classes with desired QoS and the higher data rate provides support for better user experience for multimedia communication. Moreover, it can support transmission range corresponding to the view range of video devices that makes it a practical choice. Furthermore economy of scale is another important advantage of Wi-Fi with an expected 22 percent annual growth rate between 2010 and 2015 [12]. 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 IoM if the energy efficiency mechanisms of IEEE 802.11 are devised comparable to IEEE 802.15.4.

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 constraint wireless multimedia devices running real-time video traffic applications. In this work, we discuss the feasibility of IEEE 802.11 for IoM and further enhance its power saving mechanism to effectively improve energy efficiency considering the key optimization parameters for resource constraint multimedia devices. Moreover, The multi-hop operations are not standardized in IEEE 802.11 power saving mechanisms and existing power-saving methods such as APSD, PSMP, etc, only provide communication facility to nodes which are single hop away from AP. Although, a recent enhancement to IEEE802.11 standard i.e. IEEE802.11ah, which operate in different wireless spectrum (sub 1GHz), does specify the concept of relay AP and stations whereby stations are grouped and cooperate with each other in order to allow communication among low-power battery operated sensors/stations and to facilitate the concept of IoT. This power saving enhancement, however, is yet to be standardized (to be expected in 2016) and since it is based on IEEE802.11a/g specifications where each channel is down sampled and provide throughput up to 100 Kbps, therefore it is not suitable for IoM paradigm where high bandwidth is inevitable to facilitate multimedia streaming, smart IP Camera nodes, interaction of multimedia devices, among others.

2.2 Overview of IEEE 802.11 Power Save Multi Poll (PSMP)

The legacy-PSM and APSD power saving mechanisms notify the stations about their pending packets buffered at the AP, the stations then contend for the channel to transmit PS-Poll or trigger frames to retrieve the packet. However, 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. In IEEE 802.11n [10] Power Save Multi-Poll (PSMP), these packet transmissions are not required, thus the collisions are avoided.

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 and 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 in their PSMP Uplink Transmission Time (UTT) or Downlink Transmission Time (DTT) can transmit or receive without any clear channel assessment, respectively. It is worthy to mention here that during the service periods the stations are not the TXOP holders; instead the AP schedules their transmission in its own TXOP. The schedule of the PSMP-UTT and PSMP-DTT of each station is shared using PSMP Action Frames which includes the exact time of start of each transmission and how long it will last. The subsequent transmissions can be separated with RIFS or SIFS. The PSMP mechanism is more efficient as compared to its predecessor, in terms of energy saving as well as bandwidth utilization.

In case a station is assigned PSMP-UTT duration that is not enough to transmit all the packets in the transmission queue of the station, then it transmits as many packets as it can within the assigned PSMP-UTT duration and request more or larger UTT duration by sharing its queue size or TXOP it requires within the QoS control field of the QoS data frame. The requested PSMP-UTT duration can be assigned depending upon the AP resources, in the present PSMP sequence or in the subsequent PSMP sequence. Moreover, an AP can initiate back-to-back PSMP sequences as well to facilitate additional resource allocation and/or error recovery. These consecutive PSMP sequences is referred as PSMP burst, and this PSMP burst can only be used for QoS data frames and the AP can end a PSMP burst by transmitting a CF-End frame.

If a station doesn't start its transmission in start time of its schedule, then the AP transmits a PSMP recovery frame (similar to PSMP Action frame) after PIFS duration which notifies the station about its updated PSMP-UTT duration that is reduced due to the time wastage by the station. However, the schedule of the other stations remains unchanged. On the other hand, if the transmission has failed then the AP may allocate PSMP-UTT duration in the present PSMP sequence or it may allocate temporal resources in the next PSMP sequence to accommodate the retransmissions. The AP may transmit BlockAck response with the PSMP-DTT transmissions notifying what frames needs to be retransmitted and when they can be transmitted (schedule for retransmission). If a station requires more time for retransmission than the allocated duration, it can transmit packets in non-service period using EDCA. However, these packet transmissions are acknowledged in the PSMP-DTT period of the next PSMP sequence.

2.3 A Multi-hop PSMP-Plus protocol for low-power IEEE 802.11)

Current power saving mechanisms lacks the support for multi-hop communication. Several research studies, however, investigated and established the need of multi-hop communication in both infrastructure and ad hoc wireless networks where energy resources are limited [13]. Traditionally, transmit power of nodes are kept at maximum level to facilitate the maximum coverage area. In order to minimize the energy consumption, it is suggested that the transmit power of nodes along multi-hop route can be reduced (while still maintaining the accurate packet reception) [14]. Thus, the power utilization can be improved with the increase in number of hops between the source and destination nodes. Although, it is significant to determine the optimal transmit power for each node along the multi-hop route which in turn further depends on knowledge of precise number of nodes between source-destination pairs. Furthermore, infrastructure cost is another factor while considering the increase in number of hops. Nevertheless, energy efficient multi-hop communication algorithms are imperative and eventually can help to compliment the performance of existing power saving mechanisms.

IoM 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. For example, how fast is the data transmission, how much is the delay at the receiver, what is the probability of correct data reception at the receiver, what is the probability of the transmitted data to be lost, etc.

Most of the communication models and power saving techniques are designed considering the multimedia traffic to be downlink traffic i.e. end users retrieving multimedia content from or through the Internet. However, in many IoM scenarios the end device or sensor is the resource constraint device which is responsible for generating multimedia content, i.e. video camera node, and transmitting or uploaded to the Internet. The IEEE 802.11 power saving mechanisms and most of the proposed schemes to enhance these power saving mechanisms do not consider this uplink multimedia transmission scenarios. The current standardization activities of providing Internet-connectivity to 'Things' are not focused to address the challenges of provisioning multimedia objects over Internet of Things. Many researchers have investigated a variety of techniques to limit the power consumption of wireless multimedia sensor networks. However, these issues have not been addressed considering WMSNs based on IoM architecture. Moreover, multi-hop communication is considered as pre-requisite for IoM devices whereas, as discussed earlier, existing power saving mechanisms are not suitable for multi-hop networks. For this reason, a power-saving algorithm is proposed which facilitate and enable the energy efficient multi-hop communication in infrastructure networks. This algorithm is an enhancement to the current IEEE 802.11n PSMP protocol standard and therefore termed as 'PSMP-Plus'. Moreover, QOS requirement of real-time traffic is considered by fulfilling the delay bound of each packet. The prior method where each node is accessing the channel in a scattered manner is now restricted and assembled to an aggregated frame while keeping the delay restriction in consideration.

This is done by using a two-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 which results in lowering the duty cycle and saving energy. Secondly, we try to schedule the multimedia data transmissions to decrease the duty cycle considering the user experience level requirements i.e. delay bound, video quality etc. To achieve these improvements, in our proposed power saving communication mechanism the stations adaptively select appropriate frame aggregation threshold and the TXOP duration based on its current data transmission rate and the QoS specified delay bound. In addition, the stations provide certain quality of the multimedia content depending upon its battery status. To prolong the life time of the network the low priority frames are dropped if the remaining battery of the station is lower than a specific threshold level.

The proposed algorithm is designed on top of the IEEE 802.11n PSMP power saving algorithm, by optimizing it for real-time multimedia traffic requirements. At a power saving station, when a data packet is received at the MAC layer from the higher layer, it is appended in the pending packets queue. If the current packet is the first packet in the queue, then its arrival time is retained. Depending upon the Channel State Information (CSI) received from the intended receiver node, the transmitter determines the highest data rate that can be supported in the given channel conditions. Higher data rate enables reduction in the time of reception and transmission of the packets, which in turn reduces energy consumption. In addition, higher data rate alleviates the need of longer PSMP-UTT duration requirement, thus bandwidth resources are efficiently utilized.

Prior studies on IEEE 802.11 access mechanism have already proven that the frame aggregation mechanism is a bandwidth efficient which decreases the protocol overhead, thereby reducing power consumption. However, the frame aggregation threshold i.e. the amount of data that can be transmitted in a single packet transmission is a critical network performance metric. Since, real-time multimedia transmission requires stringent QoS, in terms of delay, bandwidth, latency etc; therefore frame aggregation threshold should be selected or adapted according to the application requirements. Therefore, in our proposed scheme the frame aggregation threshold is estimated in accordance to the supported data rate and the application specific delay bound with respect to the packet arrival time of the oldest pending packet in the queue. Once the amount of data that can be transmitted in an aggregated frame is known, the transmitter node waits for more packets till the data exceeds the frame aggregation threshold, till the delay bound for the oldest packet is acceptable. The pending packets in the queue are transmitted as soon as the amount of data in the queue exceeds frame aggregation or delay for oldest packet equals the delay bound.

Once a transmitting node determined the aggregation threshold and achievable data rate, it can ask the PSMP-enabled AP for the TXOP or more accurately PSMP-UTT service period. In PSMP AP shares its own TXOP to provide PSMP enabled stations to transmit uplink traffic and/or receive downlink traffic. Since, the real-time video traffic application been considered here doesn't require bi-directional traffic communication, thus the PSMP-DTT is mostly used just for transmitting the BlockAcks to respective stations. By adopting the proposals given above, a station generating real-time video traffic can effectively transfer the multimedia content with the AP by efficiently utilizing service period allocated to it and stay in the doze state as much as possible, saving substantial amount of energy.

2.4 Multi-hop PSMP-Plus Algorithm Operation

The operations of proposed multi-hop PSMP-Plus algorithm are described below while Fig. 2.1 depicts the time-line of whole functionality.

- AP advertise its service set identifier (SSID) periodically using 802.11 MAC management frame, Beacon frame.

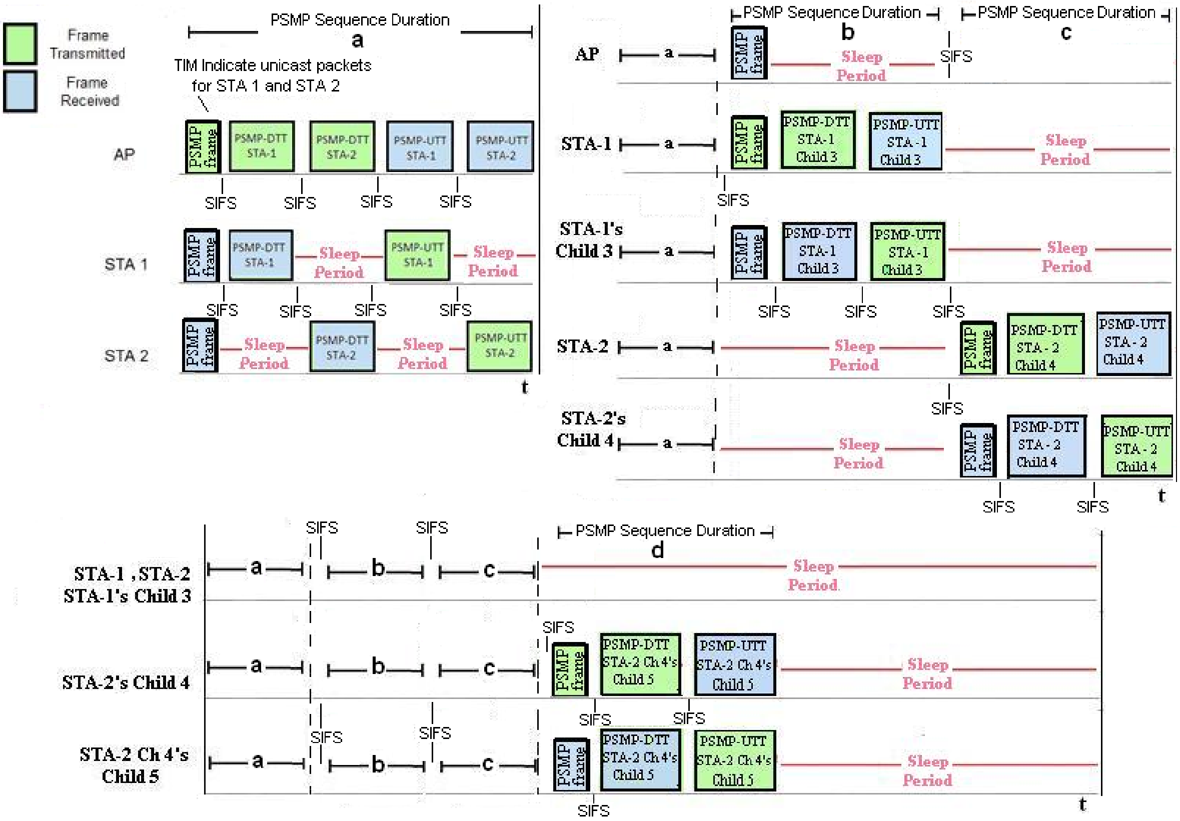


Figure 2.1: Time-line of Multi-hop PSMP-plus

- Stations will send Association request to the AP for Association IDs (AID) assignment.

- Beacon frame has Timestamp subtype which contains value of station's synchronization timer at the time the frame was transmitted. As a result, AP can keep track of the synchronization time of each station and accordingly assign association IDs (AIDs) to each of these stations and their childs starting from AID 1. AID 0 is kept reserved for AP itself.

- Hence, AP will reply with association response on first come first serve basis and AIDs are assigned to single hop away nodes by sending Beacon frame from AP. The child nodes of every single hop away nodes are also assigned AIDs in a similar manner.

- In 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 duration (in subfields PSMP-DTT Duration and PSMP-UTT Duration) and its offset order (in subfield: PSMP-DTT Start Offset and PSMP-UTT Start Offset) associated to each STA.

- Correspondingly, each single hope away node will stay awake or fell asleep, 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 Station Info field to receive traffic destined to it and except this STA rest of the stations will stay asleep as AP is busy in DL traffic transmission. After reception, the current STA will INFER from TIM bits in PSMP Action frame that there are DL transmissions scheduled for other single hop away stations and for that much duration it can stay asleep.

- In this way, each single hop away station wakes up as per the order given in TIM bit of PSMP Action frame and receives its DL transmission from AP and fell asleep upon completion for the remaining duration of DL traffic transmission for 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 fell asleep for this remaining PSMP Sequence. At the end of 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 one-hop away nodes. Thus, within each of these PSMP Sequences, one single-hop away node will behave like AP for its child-stations. Again pre-defined order will be followed as per allocated AIDs while scheduling this traffic transmission.
- Considering the number of their immediate child-stations, each single-hop away stations will transmit PSMP frame within their corresponding PSMP Sequence to indicate the DL traffic buffered for their child-stations along with the transmission opportunity, TXOP for UL traffic. Note that in this case, child-stations are two hops away from AP.
- Since the other single-hop away node are already woken up periodically, due to completion of a PSMP sequence, they listen to this transmission of PSMP frame from one of their single-hop peers and hence fell asleep till the end of TXOP time advertised (for its child-station) by 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.
- Whereas only the child-station of the currently awake station (first single-hop away node with AID =1) stays awake and receive DL traffic and subsequently, sends its own UL traffic towards the station in the advertised TXOP opportunity. After the exchange of frames between this single hop away node and its immediate child-station(s), they fell asleep for the remaining PSMP Sequence duration.
- At the completion of PSMP Sequence duration belonging to first single-hop away node, next single-hop station (as per AID value set in TIM bit starting from AID=2) and its child-station(s) are scheduled to wake up. Consequently, the next single-hop away station transmit PSMP frame indicating traffic destined for (and from) its child-station(s). The child-station(s) receive the DL traffic from the parent station and send their UL traffic in the TXOP advertised by their parent. After the frames exchange, again station itself and its child-station(s) (two-hops away) fell asleep for its remaining PSMP Sequence duration.
- In this way, algorithm operation is carried out recursively for all the single hop away stations who acts like AP and communicate with their child-stations (two-hops away from AP) to complete their traffic communication and then these stations also eventually fell asleep for rest of their corresponding PSMP Sequence durations.
- In the subsequent PSMP Sequence durations, 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.

- Once the entire group of one hop and multi-hop stations' traffic demand is met, AP exerts the control and schedules a new PSMP Sequence for the immediate neighbors in next PSMP interval.
- The whole process described above is replicated for subsequent PSMP Sequences so that the traffic demand of all the nodes can be served.

It is significant to highlight that although this process is lengthy but it is by no mean energy-intensive since the traffic scheduling is done considering the QOS parameters and delay bound of traffic demand of each station. Additionally, the simplicity of algorithm makes it scalable for multiple, including both dense and sparse, multi-hop network topologies. Moreover, 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 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 it's 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 reduce the carbon footprints emission.

2.5 USE-CASE - Multi-hop network scenario with PSMP-Plus

The functionality of proposed multi-hop PSMP scheme is illustrated by a simplified use-case comprising an infrastructure network with 6 nodes, depicted in Fig. 2.2. In this multi-hop network scenario, Node 0 is acting as an AP. Node 1 and Node 2 are present one-hop away from AP (Node 0) and are considered as immediate neighbors of AP. Node 3 and Node 4 are located two-hops away from AP and are being referred as child of Node 1 and Node 2, respectively. Node 5, three-hops away from AP, is referred as child of Node 4. All the nodes are attached through wireless links. Fig. 2.1 gives a visualization of time-line of all the steps explained for this use-case.

First of all, AP advertises its SSID in beacon frame and nodes send Association request to the AP for AID assignment. AP replies them with association response and AIDs are assigned to Nodes 1 and Node 2. Node 3 and Node 4 are also assigned AIDs in a similar manner. As explained in proposed algorithm, using the timestamp of beacon frame, AP can keep track of synchronization time of each node and accordingly assign them AIDs starting from AID 1 while AID

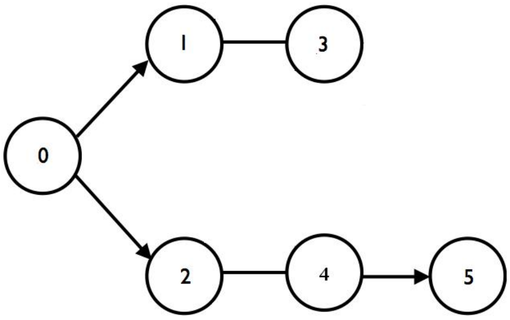


Figure 2.2: Multi-hop Network Scenario

0 is assigned to AP itself. In next step, AP send PSMP Action frame containing TIM bit set for node 1 and node 2, indicating that they have traffic buffered at AP (referred as PSMP sequence ***a*** in Figure 4.1). Hence, only Node 1 will stay awake for the time mentioned in PSMP-Action frame to receive traffic destined for it while Node 2 fell asleep after inferring from OFFSET subfield in PSMP Action frame that the current DL transmission is scheduled for Node 1. Subsequently, after receiving its DL traffic, Node 1 also infer from OFFSET subfield in PSMP Action frame that the next DL transmission is scheduled for Node 2 and for that time duration it can stay asleep. Node 2 wakes up for this duration and receives its DL Traffic sent from AP and again fell asleep upon completion. Once this operation is performed, Node 1 will in turn wakes up and sends its UL traffic towards AP and fell asleep for this remaining PSMP Sequence. Following this, Node 2 also wakes up as per calculated duration from OFFSET subfield value to send its UL traffic towards AP and fell asleep afterwards. In next PSMP Sequence duration(referred as PSMP sequence ***b*** in Figure 4.1), Node 1 wakes up and transmit PSMP frame to indicate the DL traffic buffered for its child Node 3 along with the transmission opportunity TXOP. Upon hearing this, Node 2 fell asleep (along with its child Node) till the end of the TXOP time advertised by Node 1. Node 3 receives DL traffic and subsequently, sends its UL traffic for Node 1 in its assigned TXOP. Consequently, in next PSMP Sequence duration (referred as PSMP sequence ***c*** in Figure 4.1), Node 2 which is one-hop away from AP and its child, Node 4, which is two-hops away from AP are now scheduled to wake up. Consequently, Node 4 transmits the PSMP frame indicating traffic destined to (and from) its child, Node 4. In this way, Node 4 receives the DL traffic from its parent Node 2 and sends its UL traffic toward Node 2.In the following PSMP Sequence duration (referred as PSMP sequence ***d*** in Figure 4.1), only Node 2 and 5 stay awake and exchange DL and UL traffic and after this both of them fell asleep. Once the traffic belonging to one-hop and two-hops away nodes is exchanged, AP will again schedule PSMP Sequence(PSMP-sequence ***a***) for its immediate neighboring nodes which will be listened to by them. The whole process described above is replicated for subsequent PSMP sequences so that the

traffic demand of all the nodes can be served.

2.6 Design Issues and Challenges

Some of the challenges handled by the proposed multi-hop PSMP-plus algorithm are explained below.
Packet loss: A usual packet exchange in a PSMP sequence between AP and station node is carried out like this: AP sets the TIM bit in PSMP Action frame corresponding to the node for which it has DL buffered packets and also reserves a TXOP for the UL transmission of that node. When a TXOP schedule is reserved for a node, it checks its TIM bit set and hence stays awake and receives its buffered packets (mostly ACK packets) at AP without any collision (contention) and subsequently transfers its own buffered packet in the UL PSMP schedule. After this exchange, a node can go into sleep mode and AP returns to its normal activity to facilitate other nodes. If the TXOP scheduled by AP for a particular node is lost, then it results into an invalid reservation as no other node is able to exchange its packet with AP. This issue is resolved by enabling the node which does not receive TXOP to wait for a short time, Twait , and send another request for allocation of TXOP. In this way, upon the reception of new request, AP will get a TXOP request from a node which is assumed to be sleeping and hence, become aware of the lost TXOP and cancels any invalid reservation for that node. It then determines another schedule according to the new request. Thus, packet loss of scheduled TXOP does not affect the normal operation of the proposed scheme.

Energy Efficient Scheduling and Synchronization: Another common challenge faced in multi-user network is the availability of channel when a node wakes up after the sleep interval due to the ongoing transmission between AP and other network node(s). As a result of this channel occupation, additional energy consumption occurs and the delay bound of packets buffered at a node may exceed which would result in packet drop, lack of provisioning of QOS and/or QOE, and retransmission will in turn consumes more energy. In traditional contention free power saving mechanisms, this issue is solved by ensuring that at most one node uses the channel at one time to send/retrieve the buffered packet in order to avoid packet collision by other transmissions. However, the fundamental knowledge required to enable this scheduling depends upon this requirement that each node is able to foresee if and when the channel will be idle when it complete its sleep duration and based upon this knowledge node can either wake up or extend its sleep duration. Thus, the knowledge of wake-up time of every node is required. However, in a multi-hop scenario every node may not keep the record of the presence of child nodes and their wake-up time as well which complicates the issue and eventually lead to packet delay or drop. Therefore, proposed scheme address these issues by providing a handshake between AP and all nodes and since AP is already synchronized with all nodes, keeping the record of node(s) and their child-nodes in PSMP Action frame, it is therefore able to provide them with a schedule of their sleep and wake-up time while keeping in view their traffic demand and delay bound. Having this information, AP can now foresee the future wake-up time of each node and accurately decide when the channel will be idle and correspondingly when a node needs to wake-up to avail the TXOP advertised in PSMP frame of AP. Since the task of scheduling and computation are bear by AP, the nodes (STAs) can be relieved of polling or any such mechanism which results in further reduction of their energy consumption.

Efficient Bandwidth Utilization: In traditional PSMP, when AP and station are both associated with each other and AP send the DL transmission towards a station then the first TXOP is scheduled by AP itself. There can be the case that the traffic requirement (UL transmission) of a station is less then TXOP assigned by AP. This leads to the bandwidth under-utilization. This situation may arise again whenever a station wakes up from sleep state and is assigned its TXOP. To mitigate this problem, one option is to assign a short slot for a new station rather than complete TXOP duration in first frame exchange with station. Station would then send a Null frame in this short time slot to mention about its traffic requirement. In addition, for each station it can be enabled that for every UL transmissions, if the traffic demand of station is less than standard TXOP duration assigned by AP, then Station can send the request for the allocation of pre-defined slots along with its current UL traffic for subsequent UL transmission. This helps a station to conserve more energy and also results in the reduction of bandwidth wastage.

Client table - Forwarding a multi-hop PSMP frame: Similar to the traditional routing protocol tables, each node will maintain a client table where the MAC address of destination node and the MAC address of its next hope node along the multi-hop link are stored Fig.2.3. This information can be gathered from either by sending ARP request messages to destination or the existing forwarding tables of routing protocols such as RPL, etc can be utilized so as to conserve energy. These client tables are also essential to keep track of the updated information of the associated child of each node (next hop). It is pertinent to highlight that MAC header has four fields for MAC address storage and these fields would help in enabling the multi-hop functionality at MAC level. Thus the forwarding operation of the Multi-hop PSMP frame will follow the similar operation like conventional forwarding in 802.11 protocols. On reception of the frame or upon the origination of its own frame, each node checks the destination address (DA) in the frame MAC header (which is usually the MAC address of AP in case of UL traffic) and look up its client table and correspondingly forwards the frame to next hope node; otherwise if there is no entry in client table to send the frame to next hope then node will simply broadcast it. Therefore, persistent to IEEE standard, the SA address and DA address within the frame header will remains the same throughout the packet journey towards (or from) AP. While the values of two of the four address fields (i.e. TA and RA) will keep on changing dynamically at each node along the journey of packet from source to destination. These two address fields will contain the MAC address of the current node, stored as TA, and the MAC address of next hop node, stored as RA. In this way each node will append its own address and the address of next hope node to follow in order to facilitate the transmission of frame from source node to AP (and vice versa).

2.7 Traffic Scheduling and Energy Model

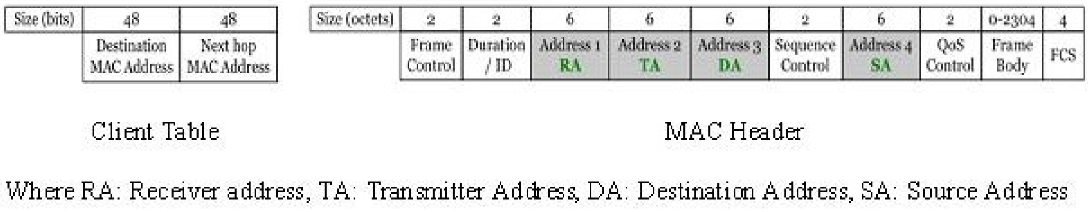
Consider the time spent in transmission is denoted by T_{awake}, and time spent in sleep mode is denoted by T_s. Correspondingly, the transmission power is denoted by P_t, and power spent in sleep time is denoted by P_s. Given the Frame Rate is 25 frames per second, i.e. 25 frames should be transmitted by a multimedia content-streaming station in a duration of one second in order to satisfy the QOS requirement. Ensuring frame rate is also significant as it is closely related to a key network performance parameter in multimedia streaming, i.e. jitter, which indicates the time lag between interval arrival packets; and thus needs to be considered in order to keep the jitter level within some specific bound to promise satisfactory user experience (QOE).

Within each frame N_A number of packets are aggregated. Thus, number of packets required to be sent in one second are $25 \times N_A$. Let the size of a single packet is X bits. Correspondingly, required amount of per second throughput is calculated as:

$$T_{thru} = 25 \times N_A \times X \, bits \tag{2.1}$$

Similarly, given the data rate of Y Mbps, the time required by each node to transmit this data while satisfying the QOS requirement of 25 frames per second is calculated as:

$$T = \frac{T_{thru}}{Y} = \frac{25 \times N_A \times X}{Y} \, secs \tag{2.2}$$



Size (bits)	48	48
	Destination MAC Address	Next hop MAC Address

Client Table

Size (octets)	2	2	6	6	6	2	6	2	0-2304	4
	Frame Control	Duration / ID	Address 1 RA	Address 2 TA	Address 3 DA	Sequence Control	Address 4 SA	QoS Control	Frame Body	FCS

MAC Header

Where RA: Receiver address, TA: Transmitter Address, DA: Destination Address, SA: Source Address

Figure 2.3: Client Table and Mac Header

Thus, ‘T’ is the cumulative PSMP Sequence duration required to send T_{thru} amount of data by one station in order to satisfy the delay bound. However, since the maximum duration of PSMP sequence is 8.184 msecs, therefore this cumulative time is scheduled in number of PSMP Sequence durations. Now, within a single PSMP Sequence, Downlink transmission time (i.e. DL_t) and Uplink transmission time (i.e. UL_t)or TXOP are allocated depending upon number of stations. If there are ’n’ number of stations required to be scheduled in single PSMP Sequence duration, then the possible per station allocated transmission time for both Downlink and Uplink traffic can be calculated as:

$$DL_t + UL_t = \frac{8.184\, msecs}{n} \tag{2.3}$$

Since transmission time, T_t, is equal for Downlink and Uplink traffic transmission, i.e $DL_t = UL_t = T_t$, therefore

$$2 \times T_t = DL_t + UL_t \tag{2.4}$$

$$T_{ti} = \frac{8.184\, msecs}{2 \times n} \tag{2.5}$$

It is important to note that cumulative PSMP Sequence duration, i.e. T, can be allocated contiguously one by one in a second in case we need to schedule only one-hop away nodes. However, in order 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:

$$\lambda_{i,j} = \frac{T \times j}{T_{ti}}, \quad 0 \leq i, j \leq n \tag{2.6}$$

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. Moreover, the time after which a single PSMP sequence will be scheduled again to allocate TXOP for a station is given by PSMP interval. A PSMP interval is the measure of time between two TXOPs. Knowing the value of λ, we can now determine the value of PSMP interval, i.e. K_i, after which TXOP in i^{th} PSMP Sequence is assigned again to any station (uniformly distributed over one second):

$$K_i = \frac{1}{\sum_j \lambda_{i-1,j}}, \quad 1 \leq j \leq n \tag{2.7}$$

where 'n' is number of child-stations required to be scheduled in i^{th} PSMP Sequence duration. Therefore, T_t can now be calculated by adding the total TXOPs allocated to all the stations within one second. Consequently, using Equation 4.5, 4.6 we can calculate T_{awake} i.e. total awake time of each station in one second duration:

$$T_{awakei} = [\sum_{i=1,j=1}^{n} \lambda_{i,j}(2 \times n \times T_{ti} + 3 \times T_{sifs} + T_{psmp})], \quad 1 \leq i,j \leq n \tag{2.8}$$

where 'n' is already described 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 and T_{psmp} is the time spent in sending PSMP frames. Likewise, the total Sleep-time of station 'i' , T_{si}, is given by following expression:

$$T_{si} = 1 - T_{awaketi} \tag{2.9}$$

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.Energy consumption is calculated as, E:

$$E = T_s \times P_s + T_{awake} \times P_t \tag{2.10}$$

$$E_s = T_s \times P_s = (1 - T_{awake}) \times P_s \tag{2.11}$$

$$E_{energysaving} = \frac{E_s}{E} \tag{2.12}$$

$$EnergyEfficiency(\%) = \frac{E_{total} - E}{E_{total}} \times 100\% \tag{2.13}$$

where E is the energy consumption, E_s is the energy consumption in sleep mode and E_{total} is the total Energy. Finally, improvement in energy efficiency can be calculated as:

$$\gamma = \frac{E'}{E} \tag{2.14}$$

E' is the energy consumption without applying the proposed protocol.

2.8 Mathematical Analysis and Results

Consider the same network scenario described in a multi-hop network use-case in previous section, shown in Fig. 4.2. We compare the performance of proposed protocol, algorithm with its energy model, in multi-hop network scenario and compare it with traditional CSMA/CA based multi-hop communication. Afterwards, energy efficiency of the proposed protocol will be calculated and potential improvements achieved by the proposed protocol is highlighted. In the given infrastructure multi-hop network, AP is required to schedule traffic demand for 5 network nodes. For brevity purpose, we are assuming that all the stations are streaming similar content, i.e. traffic demand of all nodes are same and the downlink traffic demand of each node from AP is also same. Considering the QOS requirement of frames rate of 25, each node is required to transfer 25 frames in one second in order to ensure satisfactory QOE. Frame aggregation is incorporated and each node will aggregate N_A=4 packets in one frame. Thus total per second demand of each node is $25 \times N_A = 100$ packets. However, in multimedia streaming packet size and/or number of packets in each frame is variable depending upon the varying nature of multimedia data acquisition. For example, in a static video scene, number of bits on then number of bits generated per packet per frame is less as compared to the video scene where motion is detected. Therefore, we consider the average value of packet size as 512 bytes in this case, and later on we vary packet size value in order to determine its effect on energy consumption.

Thus, per second throughput is calculated by multiplying number of packets (N_A) per frame with size of packet (X) ,i.e. $25 \times N_A \times Xbits = 409600bits$, and then by using the supported data rate, $Ybps$, the cumulative PSMP Sequence duration required to achieve this per second throughput is calculated. Thus, per node required scheduling time to satisfy the delay bound is, $T = \frac{409600}{6Mbps} = 69msecs$ within one second duration. Moreover, as mentioned in IEEE 802.11 Standard, the maximum possible PSMP Sequence duration is up to 8.184 msecs, so we divide the cumulative PSMP Sequence time will be divided in number of occurrences of 8.184 msecs. The number of nodes in this network scenario are $n = 5$ and these nodes are required to be scheduled in number of PSMP sequence durations. As per assumption, the uplink (UL) and downlink (DL) traffic demand of each user are same, thus for 'n' number of stations to be scheduled in single PSMP Sequence for both UL and DL traffic, per second possible allocated transmission time for each node 'i' , is calculated as $T_{ti} = \frac{8.184\,msecs}{2\times n}$. Each node is required to carry its own traffic along with the traffic demand(if any) of its child node towards AP, and this is calculated by $\lambda_{i,j} = \frac{T\times j}{T_{ti}}$ where j is the number of child nodes. Furthermore, $\lambda_{i,j}$ is also used to calculate the time between any two TXOPs assigned to same user, i.e. PSMP interval $K_i = \frac{1}{\sum_j \lambda_{i-1,j}}$ and it depends on number of child-nodes required to be scheduled in a given PSMP Sequence duration. Therefore, $K_1\, and\, K_2$ have similar value since both node 1 and node 2 are scheduled in same PSMP Sequence by AP. Consequently, we calculated the total awake time of any station in one second as T_{awakei} and the total sleep time of any station as $T_s = 1 - T_{awakei}$. Finally, energy consumption is calculated by $E = T_s \times P_s + T_{awake} \times P_t$ and energy efficiency is given by $EnergyEfficiency(\%) = \frac{E_{total}-E}{E_{total}} \times 100\%$. The energy consumed in this case depicts the amount of power utilized to transmit particular amount of multimedia traffic in one second duration. We ensured the frame rate of 25 frames per second which depicts the satisfactory user experience in real-time multimedia

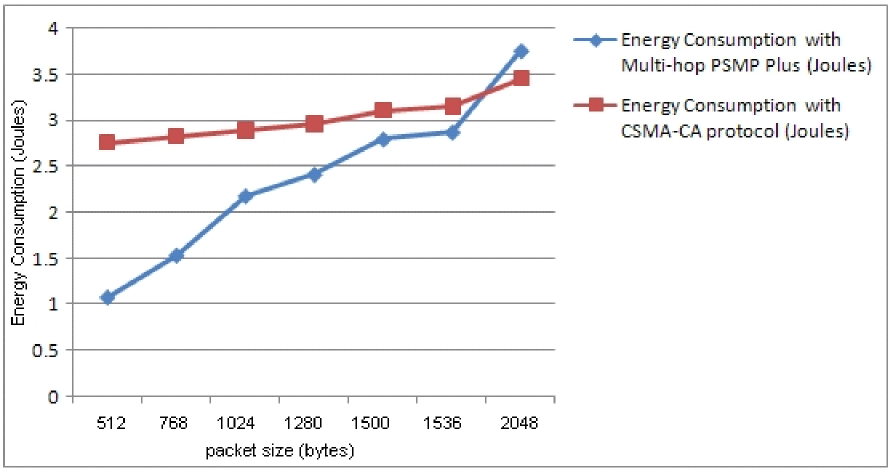


Figure 2.4: Energy Consumption comparison with variable packet size - PSMP-Plus vs CSMA/CA

communication. Similarly, we varied the packet size and calculated the effect on energy consumption. We also varied the data rate (where packet size is kept fixed at 1500 bytes in this case) and evaluated the performance of proposed algorithm. The current power saving mechanisms in IEEE Standards does not include multi-hop support, therefore in this performance analysis, we will compare our results with traditional IEEE 802.11 CSMA/CA standard for multi-hop communication. In CSMA/CA based multi-hop communication functionality, a station does not has the facility to fell asleep rather it can be in one of various states such as either in transmission/ reception state (uplink or downlink transmission) or contending for the channel or listening to the medium and staying idle. Moreover, their are several header values and idle slot values which are added as an overhead to the actual DATA required to be transmitted. $T_{overhead} = t_{difs} + t_{contention} + t_{preamble} + t_{header} + t_{sifs} + t_{preamble} + t_{ack}$. Where t_{difs} is the time interval required to sense and acquire the channel (28 secs). t_{sifs} is the time interval required for a receiving node to return a message to a transmiting node (Default value is 10 secs). $t_{contention}$ is dependent upon size of contention window (CW)with default value of 16. We are assuming that on average each node will wait half the time of size of contention window,i.e. 8 slots and considering the size of each slot as 10 secs, $t_{contention} = 80secs$. Another header, PLCP premable, $t_{preamble}$ informs the receiving node about the modulation scheme used in the following data so that in can synchronize itself accordingly (default value is taken 20 secs). Then another header used for identification of nodes is t_{header}, 48 secs, which is followed by $t_{ack} = 18.7secs$). Due to these overhead values, much of the energy consumption of a station is spend in listening and contention time as well along with the transmission/reception time. Assuming the approximate 5% packets are lost due to contention and hence the average contention window size for these 5 packets is doubled from 8 t 16. Overall calculation of energy consumption, again with varying packet size and data rate is carried out and depicted in following figures.

In Fig.2.4, it is shown that as the packet size is varied and increased the energy consumption of nodes also increase due to an increase in the effective throughput as more time is consumed in awake state to meet the QOS requirement of 25 frames per second.However, this effect is not as much large in our proposed scheme as compared to the case when only CSMA/CA multi-hop functionality is enabled. It is significant to note that, when the packet size reaches the value of 1500 bytes then the total awake time of node 1 and node is approaching 1 second, which means these two nodes hardly fell sleep. Hence, as we go beyond 1500 bytes, the QOS specified delay bound of 1 second will be exceeded and unless we don't increase the data rate nodes will have to schedule their traffic in next second. In case when packet size is 2048, all the nodes are unable to fell asleep as their traffic demand is not fulfilled within one second duration bounded by frame rate. Hence, in this particular case CSMA/CA is performing better. Similarly, the comparison of energy efficiency is depicted in Fig.2.5 which varies inversely as packet size is increased. This is due to the fact that as more packets are required to be scheduled, resultantly T_{awake} time will increase in case of PSMP-Plus and contention time will also increase in case of CSMA/CA thus resulting in reduction in energy efficiency. Similarly, in next phase, we kept the packet size fixed (i.e. 1500 bytes) and varied the data rate from 6 to $11Mbps$ over with a fixed increase of $1Mbps$. It can be visualized in Fig. 2.6. that by varying data rate, the energy consumption by employing the proposed protocol is reduced owing to the fact that the packets are now transmitted quickly and hence nodes are now getting longer time to stay in sleep state and conserve their energy. Further, we observe the performance comparison of proposed power saving multi-hop protocol with CSMA/CA based multi-hop protocol against various supported data rates offered in IEEE802.11n Standard is shown in Fig.2.7.

Again the packet size is kept fixed to 1500bytes. It is evident that by enabling multi-hop in PSMP with no contention and by utilizing our proposed PSMP-Plus protocol, the energy consumption results are more beneficial and very much less compared to the traditional CSMA/CA based approach. However, it is noteworthy that at data rate less then 6Mbps, the delay bound of sending 1500 bytes within one second is not satisfied. Therefore, their exist a trade-off between packet size, data rate and energy consumption. In real-life network topologies, AP holds the control and thus needs to satisfy the varying node-requirement and adjust the optimal value of data rate while employing the proposed algorithm in order to guarantee the satisfactory QOS and QOE limitations. Finally, effect of data rate on energy efficiency is depicted in Fig.2.8 in where Energy Efficiency (%) increases with an increase in data rate. However, the energy consumption is drastically reduced as we go towards higher data rates from 6Mbps towards 54Mbps. This is owing to the fact that traffic demands of all stations is being served earlier

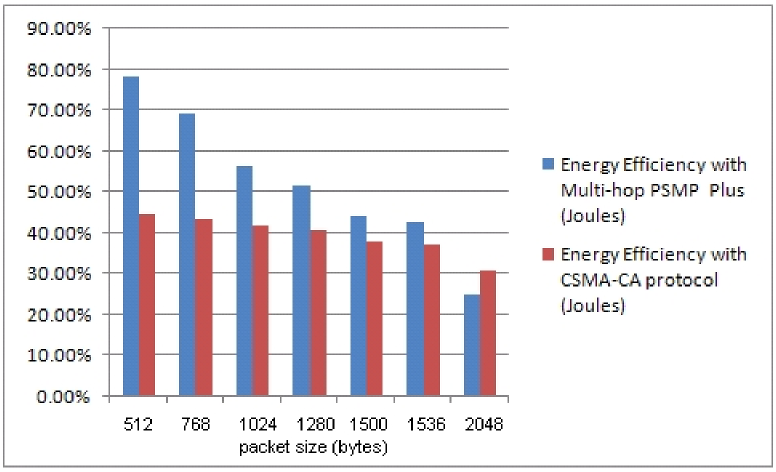


Figure 2.5: Energy Efficiency comparison PSMP-Plus vs CSMA/CA

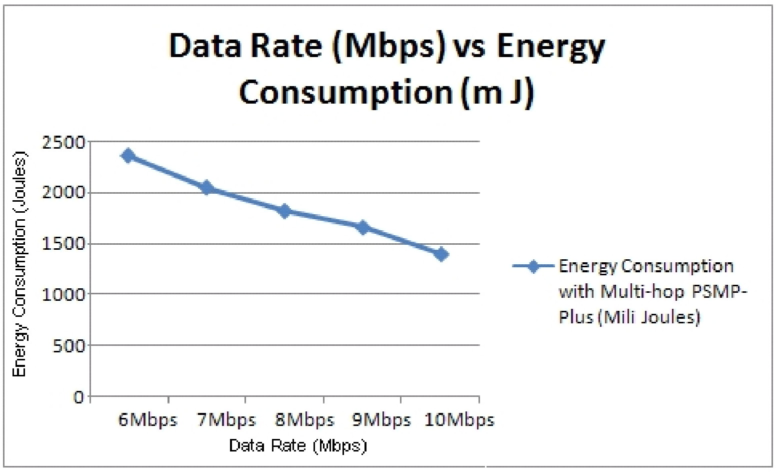


Figure 2.6: Data rate vs Energy comparison in Multihop PSMP-Plus

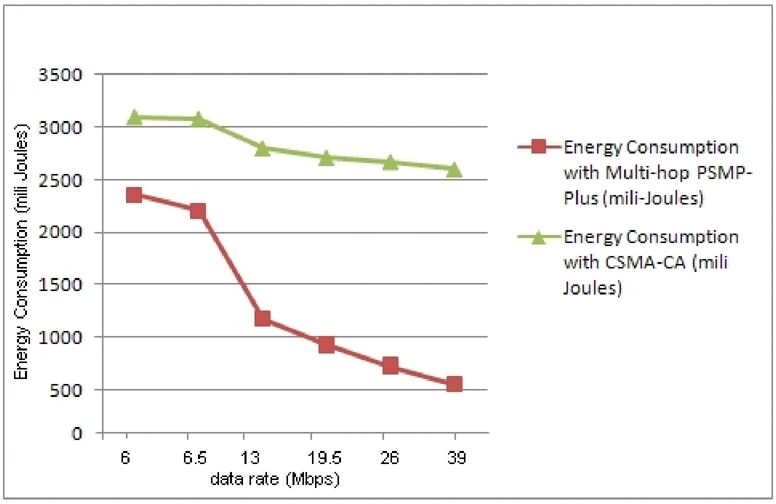


Figure 2.7: Energy consumption comparison(variable data rate): Multi-hop PSMP-Plus vs CSMA/CA

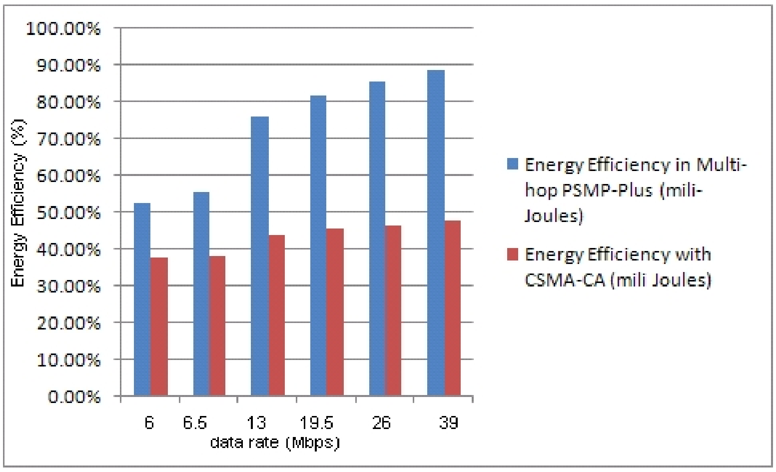


Figure 2.8: Energy efficiency comparison(packetsize:1500bytes): Multi-hop PSMP-Plus vs CSMA/CA

and hence they get more time to go into sleep state. On the other hand, their is a gradual increase in energy efficiency due to the fact that although data requirement of stations is fulfilled earlier, but the cost of stations which are waiting for their schedule while still being in listen state is also increasing and hence contributing to the effective energy consumption of whole network.

2.9 Conclusion

IoM is an enhancement to the IoT, whose prime objective is to enable resource constraint low-power low-cost heterogeneous multimedia devices to promote multimedia content as part of the realization of IoT. Specially in IoM, the 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. Thus, direct implication of IoT protocols for IoM is not straight forward, since these protocols are not designed considering multimedia content QoS requirements. ZigBee is promoted for IoT, since it is designed for simple operations and 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 lower data rate. For this reason, IEEE 802.11 standard is suggested in the literature for WMSNs, since it provides a high data rate communication model and holds a great potential for IoM if the energy efficiency mechanisms of IEEE 802.11 are devised comparable to IEEE 802.15.4. 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, none of them have the key optimization parameters considering resource constraint wireless multimedia devices running real-time video traffic applications. In this work, feasibility of IEEE 802.11 for IoM is presented. Multi-hop communication for power saving mechanism PSMP is enabled and its functionality is enhanced to effectively improve energy efficiency considering the key optimization parameters to enable and realize real-time multimedia communication over low-power and resource constrained multimedia devices. Lastly, a mathematical energy model is proposed to compute the energy consumption and improvements achieved by the multi-hop PSMP Plus protocol and numerical results are presented in final section.

Bibliography

[1] Hua-Dong Ma. Internet of things: Objectives and scientific challenges. *Journal of Computer science and Technology*, 26(6):919–924, 2011.

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

[3] Gartner. http://www.gartner.com/newsroom/id/2636073.

[4] P Venkataram and AP Shivaprasad. Wireless multimedia networks. *Journal of the Indian Institute of Science*, 80(3):187, 2013.

[5] T Winter, P Thubert, T Clausen, J Hui, R Kelsey, P Levis, K Pister, R Struik, and J Vasseur. Rpl: Ipv6 routing protocol for low power and lossy networks, rfc 6550. *IETF ROLL WG, Tech. Rep*, 2012.

[6] Aruna Prem Bianzino, Claude Chaudet, Dario Rossi, and J Rougier. A survey of green networking research. *Communications Surveys & Tutorials, IEEE*, 14(1):3–20, 2012.

[7] Xiaofei Wang, Athanasios V Vasilakos, Min Chen, Yunhao Liu, and Ted T Kwon. A survey of green mobile networks: Opportunities and challenges. *Mobile Networks and Applications*, 17(1):4–20, 2012.

[8] Jayavardhana Gubbi, Rajkumar Buyya, Slaven Marusic, and Marimuthu Palaniswami. Internet of things (iot): A vision, architectural elements, and future directions. *Future Generation Computer Systems*, 29(7):1645–1660, 2013.

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

[10] *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.

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

[12] *Wireless Connectivity Market Data*. ABI Research, 2011.

[13] Mira Andriani, M Irhamsyah, et al. Analysis of energy efficiency for wi-fi 802.11 b multi-hop networks. In *Communication, Networks and Satellite (COMNETSAT), 2013 IEEE International Conference on*, pages 64–68. IEEE, 2013.

[14] LN Gumbi, D Chatelain, and M Odhiambo. Power-efficient algorithm for ieee 802.11 b multi-hop networks. In *Proc. of Southern African Telecommunication Networks & Applications Conference (SATNAC06), Spier Wine Estate, South Western Cape, South Africa*, 2006.