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Energy Efficient MAC protocols for Green IoT: A survey

Garima Mann[1] and Rishipal Singh[2]

[1,2] Department of Computer Science and Engineering,
[1,2] Guru Jambheshwar University of Science & Technology, Hisar, Haryana

Abstract

As Internet of Things expands quickly, there is growing need for energy efficient communication protocols to guarantee long term sustainable network operations. There are number of devices connected to the IoT systems is increasing per day with technological enhancements. To focus on sustainable environmental development, the concept of green IoT is flourishing and procedures adopted for IoT should be energy convergent. The developments in enabling energy-efficient MAC protocols for green IoT are examined in this paper. It groups different MAC protocols on techniques like duty cycling, adaptive listening, and wake-up radio, according to how they use less energy. It also talks about the trade-offs between network scalability, latency, and energy efficiency. In order to improve performance of the system, the devices should be energy efficient. The review aims to provide insights into designing sustainable MAC protocols that support low-power, high-performance IoT MAC protocols. This paper analysis various current protocols for Mac layer that suggests ways to enhance energy efficiency.

Keywords: Energy; Efficiency; MAC Protocols; IoT; IEEE 802.15.4; IEEE 802.15.4.e

1 Introduction

Role of IoT is increasing day by day as these devices facilitates better services like monitoring, trekking and device management in industries, medical sector, logistics and other utility services. IoT has bright future prospects. Before covid-19 situation it is expected to have 12 billion IoT devices in 2020 but it has already crossed that limit and it is expected that in 2030, 40 billion IoT devices will be connected to internet. Now a days IoT devices play key role in real time monitoring of diverse applications like healthcare sector, smart cities, industries, smart homes and industrial automation. Remote monitoring is possible with these applications. The primary requisites for IoT to flourish are energy efficiency of sensor nodes because without elongated battery life aim of internet of things becomes null and void. Role of Mac layer protocols in IoT is important to manage data transmission, accessing shared communication channels by preserving energy and reliability. The main objective of green IoT is interconnection of IoT devices for flawless communication. To achieve this goal, more energy efficient MAC protocol with enhanced QOS is demand of present scenario. Energy efficiency plays key role in green IoT by extending device lifetime, reducing network congestion, enhancing reliability in wireless sensor networks, yielding scalable IoT networks and build sustainable environment.

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Energy efficiency of sensor nodes can be achieved during MAC layer of data transmission as MAC layer is responsible for channel access control mechanism. Smart devices embedded sensors communicate with cloud-based services for analysis and storage of data. The key factors like mobility of nodes, increased number of devices day by day, lossy wireless networks and power constraints are some of communication challenges in current scenario (Sethi, 2017; Azad, 2013). IoT devices has less storage resources and most of the devices are battery powered, so for proper functioning of the networks, energy efficiency of devices is to be enhanced.

To design and develop efficient MAC protocols for present times there is requirement to study the past journey of MAC protocols. The survey paper (Naik, 2004) reviews the early mac protocols on the basis of access mechanism. In paper (Huang, 2012) the survey evaluates the various designs of synchronous, asynchronous, frame slotted and multichannel categories with respect to energy efficiency, data delivery etc. The authors in (Koz lowski, 2019) provides taxonomy of duty cycling and wake up radio approach, synchronization problem and power consumption model for synchronous and asynchronous communication techniques. The authors in (Kumar, 2018) presents various MAC protocols in synchronous, asynchronous, TDMA, FDMA and provides comparison of the strength and weaknesses of various protocols. Overview of existing optimization energy techniques for green IOT in several layers is discussed in (Tahiliani, 2018). The research work in (Oliveira, 2019) broadly classify MAC protocols in short and long distance coverage which are Near field communication, Radio frequency Identification, Bluetooth IEEE 802.15.1, Bluetooth low energy 802.15.4, wireless highway addressable Remote Transducer Protocol, Z wave, weightless IEEE 802.11/a/b/g/n/ah etc. This paper surveys energy efficient MAC protocol for green IoT. The paper is organized in the following manner: section 2 provides overview about the factors affecting energy efficiency and section 3 classification of MAC standards. In Section 4 various energy efficient MAC protocols for IOT covered that provides scopes for further research enhancements and section 5 summarizes all details provided in the paper.

2. Factors affecting energy efficiency

MAC layer acts as unique identifier for IoT devices. MAC protocols provide addressing mechanism and channel access on same or other networks. During network communication, due to various topologies used and mobility of nodes, MAC layer ensures the transporting of frames from sender to receiver and send acknowledgement also. The factors like throughput, scalability, latency, error detection, reliability and packet loss can also be measured in various context (Azad, 2013).
This paper focuses on MAC protocol of IOT with respect to energy efficiency.

2.1 Factors responsible for wastage of energy

Collision

While sharing same channel if sensor nodes function with similar specifications than there will be chances of collision between data packages and this will lead to increase in energy consumption. Although MAC protocols specially provide techniques to avoid collision by CSMA/CD, CSMA/CA and contention window. Time synchronization method also contributes to save energy. Due to collision data packages will be damaged and retransmission of same message have to be

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done which leads to more consumption of power.

Idle listening

When an active sensor node pass message to other node assuming that the other node is receiving messages whereas other node is currently going to sleep after receiving half message, in that case also retransmission of messages has to be done and this leads to additional wastage of energy.

Over hearing

Sometime the node listens the message that has to be delivered to the other node, in that case due to overhearing energy is wasted by sensor node. It can be avoided by duty cycling of nodes. The control packet is smaller than the data packet and node can be in sleep state during transmission of data packet to overcome the problem of over hearing.

Over a meeting

Receiving node is not in the receptive mode whereas the sender is sending packets assuming that they are being received, which leads to wastage of energy.

Control packet overhead

When communication of packets without data occurs between sender and receiver than it is termed as control packet overhead leading to wastage of energy.

To obviate these issues and to save energy MAC protocol categorized into three types namely schedule based, contention based and hybrid.

3 Classification of MAC Protocols

MAC protocols can be classified in numerous ways like on the basis of channel access mechanisms, duty cycling of radios, medium access strategies. In this paper, we classify the MAC protocols for green IoT to observe the performance of energy efficient Mac protocols. Main MAC protocols related to IoT are contention based, scheduled based and hybrid. Contention based protocols are described as with reservation and without reservation and each one has further two types synchronous, asynchronous and sender initiated, receiver initiated respectively. Schedule based protocols are designed on the basis of fixed and demand assignment based. Fig 1 explains the classification of MAC protocols for IoT.

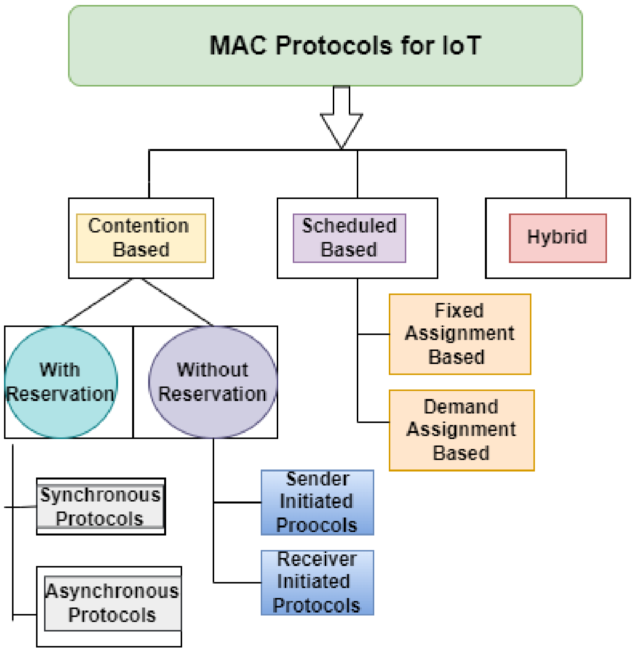

Fig 1: Classification of MAC Protocols

3.1 Contention based MAC Protocols

In contention-based MAC protocol, sensor nodes wait for certain period and perform channel sensing to check whether channel is currently busy before they actually transmit data. Contention based MAC protocol are simple as compared to scheduled based protocols. The disadvantage of contention-based MAC protocol is that they use energy inefficiently mainly due to its mechanism. They are of two types synchronous which require scheduling and asynchronous which do not require scheduling.

3.2 Scheduled-based MAC Protocols

In scheduled based MAC protocols time frequency slots assigned to avoid collision over hearing and ideal listening. The time synchronization technique facilitates sender node a dedicated time slot and scheduler allocates the time slot to sensor nodes. The non- transmitting nodes will remain in the sleep mode. The algorithm used for scheduling based on centralized and distributed techniques. The study shows that these protocols are energy efficient in case of less mobility and same topology. In case of large networks, fixed slots overhead problem occurs so for larger networks more adaptable algorithm must be analyzed and designed.

3.3 Hybrid MAC protocols

Hybrid MAC protocols are designed with utilizing strengths of contention based and scheduled based MAC protocols. 802.15.4 standards define the protocols with regard to inter-connection between IoT devices utilizing low power, low data rate and minimum complexity in wireless personal area networks. Diverse applications of IoT like Zig-Bee, 6 LoWPAN, Wireless HART, MIWI etc. utilizes IEEE 802.15.4 MAC protocols however IEEE 802.15.4e MAC overcomes the drawbacks of IEEE 802.15.4 MAC Protocols (Kurunathan, 2019) and the design of 802.15.4e MAC Protocols reveals extremely low power consumption with minimized duty cycle, multi- channel communication and dedicated slot access. It also supports varied application behaviour and there are further five modes that define/support various applications like remote control monitoring, home automation application, industry automation application, identification and trekking etc.

4. Energy Efficient MAC Protocols

MAC protocols for IoT plays important role for communication network. MAC layer deals with radios and access medium of nodes for channel sharing. Lots of energy is being consumed during this stage. Energy is being wasted due to various reasons like collision, idle listening, over hearing, energy outstanding over a meeting and control packet overheads so energy efficiency for MAC protocols has vital importance in prolonging life time of sensor networks (Kumar, 2018).

4.1 Classification on the basis of energy efficiency

Primarily MAC protocols are categorized into two types, contention based energy efficient protocols and scheduled based energy efficient protocols.

Contention based energy efficient protocols

In contention based MAC protocol excessive use of energy exists due to transmission delay, collision, overhearing of long preambles and increase in latency etc.

Scheduled based energy efficient protocols

Scheduled-based MAC protocols are more energy efficient as compared to contention

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based because scheduling prevents energy loss that occur due to message overhearing and idle listening.

This paper focuses on energy efficient MAC protocols which have been categorized on the basis of time division multiple access, frequency division multiple access and code division multiple access. Time division multiple access can be done by two types that is central TDMA and distributed TDMA. Guaranteed time slot mechanism is followed in central TDMA to enhance collision free transmission. Previous experiments show that distributed TDMA results in high throughput (De Guglielmo, 2016). Scheduled-based protocols provide more efficient solutions by avoiding collision, idle listening and overhearing but some grey areas need to be touched like larger network topologies, overhead scheduled adaptations, conflict free distribution and significant memory etc.

4.2 Energy efficient contention-based, scheduled based and hybrid MAC protocols

4.2.1 S-MAC

S-MAC is synchronous MAC protocol based on duty cycling of radios approach. It works on active and sleep cycle of nodes. MAC layer contention window size determine the length of wakeup period and sleep period depends on predefined duty cycle. All the nodes have same duty cycle. Sync packet contains sleep-awake schedule for synchronization of nodes. Node go to sleep after clear to send (CTS) and wakeup at Request to send (RTS).

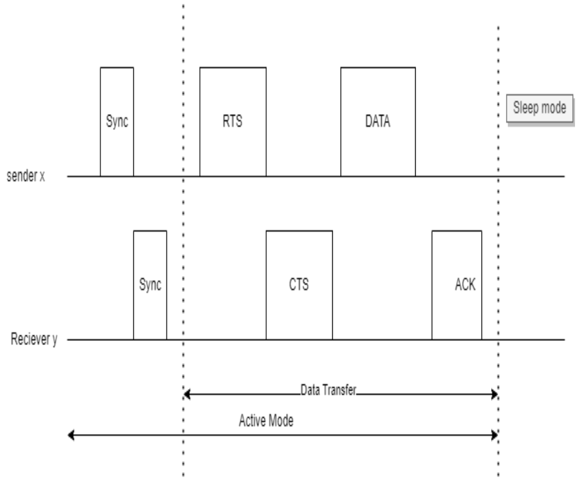

Fig 2: Basic S-MAC scheme representation

Sensor-MAC (S-MAC) proposed a scheduling mechanism to conserve energy by using battery operated computing and sensing. Periodic sleeping of nodes reduces the use of energy in idle listening but these nodes become active suddenly when something is detected. Auto synchronization of node for sleep schedule updated from virtual clusters (Ye, 2002). In case of Variable traffic loads decrease in efficiency observed due to constant sleep and listen periods. S-MAC uses message passing to reduce contention latency for sensor network applications that need store and forward processing as data move through the network. Energy consumption depends upon duty cycle of radios. Experiments at university of California show that S-MAC consumes 2-6 times less energy for traffic load with messages sent every 1-10 s as compared to 802.11 MAC. latency in case of S-MAC gets higher as more messages are waiting to be sent. In (Yang, 2012) the authors provide a model to optimize the performance of S MAC under different network conditions to estimate energy consumption, delay and throughput. The result shows that S MAC receive most data packets in contention window size 32 and duty cycle is of

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10%. In (Balobaid, 2016) studies show that S MAC uses low energy in low traffic conditions but sleep latency problem is detected. Though S-MAC reduces utilization of energy but other important factors like throughput, bandwidth utilization and latency are left out.

4.2.2 T-MAC

T-MAC (Time -out MAC) is an improved version of S-MAC wherein dynamic duty cycle is used in place of fixed one. T-MAC transmits waiting messages in burst of variable length at the start of frame and sleeps between bursts to save energy. It reduces wastage of energy in idle listening. T-MAC also determines the length of variable load by maintaining an optimal time (Ram, 2019). It utilizes RTS and CTS methods which results in high latency as it sends on one hope every duty cycle. The nodes go to early sleep even when neighbouring node has some message to be sent as a result throughput is decreased (Sun, 2015). The paper (Naik, 2004) provides solution to early sleep problem. The experiment recommended two solutions: Future RTS and Full buffer priority. In future RTS method, the sender sends FRTS packet to receiver and receiver can know blocking time period in advance. It means that node can be aware about the active state in advance and also knows about the time period used to receive data packets. By previously knowing the active state, sleep cycle can be adjusted accordingly. This solution provides high throughput but its drawback is consumption of more energy. In full buffer priority method, node send RTS without waiting for CTS to show its priority if buffer is full. In heavy traffic conditions, it leads to collision problem. The solution provided for that is to use priority only in case if contention has lost twice. No additional energy is required by this method but throughput is less as compared to previous one. T-Mac is more energy saving protocol as compared to S- Mac (Samant, 2016). Figure 4 shows the dynamic duty cycle state of T-Mac as compared to S-Mac

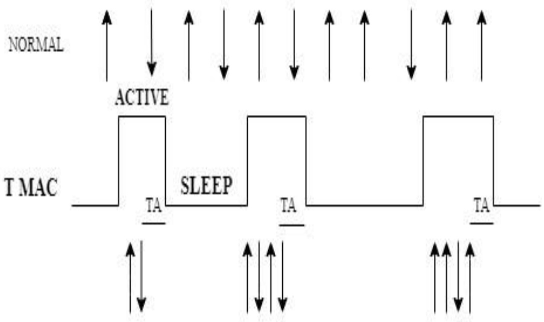

Fig 3: Basic T-MAC scheme representation

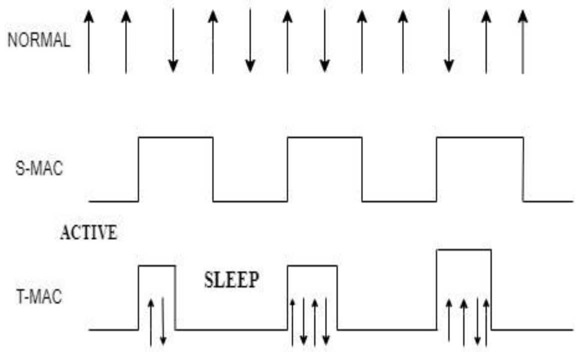

Fig 4: S-MAC & T-MAC comparison

4.2.3 DS-MAC

Demand sleep MAC protocols provides energy efficient solutions by adjusting sleep time, according to availability of data packets for longevity of networks. DS-MAC reduces the latency and sleep time but ideal listening increases due to frequent sleep periods. DS-MAC is asynchronous MAC protocol with low latency and dynamic/ adaptive distribution of node leads to energy efficiency (Kim, 2019) . In (Wang, 2015) the experiment shows increased throughput and reduced waiting time as ack packet contain prediction and duration field

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which results to predict the wakeup time of neighbouring nodes and node can decide its own sleep state. DS-Mac is suitable for varying traffic load as it adjusts node sleep time. Overhearing problem reduced by transmitting short token packets for waking up receiving mode. Energy consumption and delay both decreases in case of DS-MAC (Yin, 2010).

4.2.4 X-MAC

X-MAC protocol works on shortened preamble approach for low power communication. X-MAC is designed as asynchronous and energy efficient protocol to overcome the disadvantages like large preamble, incompatible packet radios and overhearing (Buettner, 2006). Its performance deteriorates during heavy load however short preamble approach saves energy at transmitter and receiver. It also curbs latency (Kim, 2019). In (Ullah, 2016) a binary exponential back off algorithm is proposed for heavily populated network and experiment results into enhancement of performance in terms of energy consumption, delay and throughput. Traffic adaptive duty cycling in X-MAC provides low throughput and high delay therefore it is not suitable for broadcast communication (Ye, 2002). These problems are overcome by hybrid protocols in which both CSMA and TDMA approached are implemented. Overhearing problem resolved in X-MAC as each preamble includes target address. It also supports early acknowledgment as short preamble approach supports early response from receiver. In (Hasan, 2017) author analyzed the impact of hidden terminal on X-MAC protocol and present a model to measure energy consumption, delay and throughput in varied traffic conditions for vehicular sensor networks.

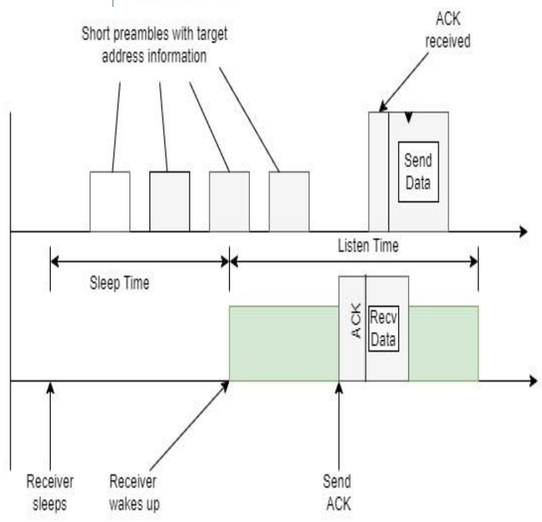

Fig 5: X-MAC Protocol Design

4.2.5 D-MAC

Dynamic MAC is an energy efficient and low latency MAC for data gathering in wireless sensor networks. In D-MAC protocol the wake up/sleep schedule of sensor nodes is staggered according to the depth of node in unidirectional tree. The design uses CSMA/CA mechanism for energy efficiency and lowering latency. The disadvantage of D-MAC is that it is limited to unidirectional traffic from multiple sensor nodes to sink mode. D-MAC is better than S-MAC in terms of energy consumption and end to end latency (Kumar, 2018). Dynamic short preamble periods used in D-MAC provides better throughput than X-MAC and energy consumption can also be lower by using short preamble. In paper (Kumar, 2012) provide traffic adaptive algorithm for D-MAC and study shows that D-MAC performed better than X -MAC and E-MAC in terms of throughput, delay minimized and energy consumption optimized.

4.2.6 TA-MAC

Traffic adaptive MAC protocol is a TDMA based energy efficient MAC protocol in which

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traffic load is estimated and dynamically adjusted according to priority and their QoS requirements. Being TDMA MAC all nodes are time synchronized and access period used is random and scheduled access. In (Azad, 2013) the three constituents described are schedule exchange protocol, neighbouring protocol, and adaptive election algorithm. Schedule exchange protocol is used for transmission of ongoing schedule to adjacent nodes and receive their schedules. Adjacent nodes till two hopes exchange their information by neighbouring protocol. Adaptive election algorithm facilitates the node to select unused neighbouring slot. A data dissimation model proposed to determine channel access priority. Further classifications done on the basis of delay, criticality, reliability and packet delivery ratio. Traffic adaptive duty cycle mechanism has been proposed to increase throughput and minimize packet delay by maintaining energy efficiency (Pack, 2006). Duty cycling technique employed for switching off and on the nodes for lesser energy consumption (Morshed, 2015).

4.2.7 C-MAC

To overcome the problem of latency and throughput C-MAC provides solutions for long preamble. Convergent MAC protocols operate on very low duty cycle and support low latency. It provides high output. Convergent packet forwarding, anycast based forwarding and synchronized based schedule are key features to save energy (Liu, 2009). Synchronized and unsynchronized schedule is followed during availability of traffic and without traffic respectively. In case of synchronized MAC energy is consumed in synchronization while in case of unsynchronized MAC latency occurs due to long preamble. To solve long preamble X-MAC provides short preamble approach but this protocol is not suitable for broadcast communication. C-MAC provides high throughput and long network lifetime by using features like aggressive RTS, anycast and convergence in high data traffic while in case of low data traffic it consumes more energy as nodes does not sleep (Kumar, 2018).

4.2.8 Queen-MAC

Queen-MAC is adaptive energy efficient MAC protocol which carries out uniform distribution of sensors and sync nodes resides in the corner. It follows dyadic grid quorum. Time synchronization in Queen -MAC algorithm is exhibited by awakening of nodes for data exchange at same time and sleeping of nodes for slot energy saving. This protocol uses multiple channel access but packet collision, reduced packet delivery ratio and maximized latency are disadvantages of QueenMAC protocol (Ekbatanifard, 2012). However, study in paper (Alzahrani, 2021) tried to minimize collision and end to end delay by implementing wake up scheduling and channel assignment. Quorum based wake up scheduling allows wakeup of forwarding nodes absolutely at same time and other nodes that don’t act as forwarder assigned different time slot. Data channels shared by channel assignment results to avoid end to end delay. Energy efficiency is achieved as each node utilize unique channel which results in reduction of collision but hidden terminal problem persist in this protocol.

4.2.9 Z-MAC

Zebra-MAC combines strengths of TDMA and CSMA based protocols. The performance of Z-MAC varies according to traffic load. In paper (Arshad, 2013) the experiment evaluates the Z-MAC and found that due to topology change slot assignment is difficult at initial level. Due to other limitations like hidden terminal problem, time synchronization, clock synchronization nodes consume more energy.

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DRAND algorithm perposed reduces energy consumption in case of high contention. During low contention, nodes can freely use the vacant time slot unlike TDMA synchronization in which nodes can travel in allocated time slots. By using priority technique, switching between CSMA and TDMA takes place. In (Rhee, 2008) the experiment done on one, two and multi-hop benchmarks and data throughput, fairness, latency and energy efficiency evaluated respectively. Under high contention Z-MAC protocol behaves like TDMA but still its performance continues as nodes can transmit data during authorized time slots and hidden terminal problems does not occur in this case. It performs vigorously in synchronization assignment of slots failures and varied channel conditions. The results show that Z-MAC is suitable for medium to high two hop contention.

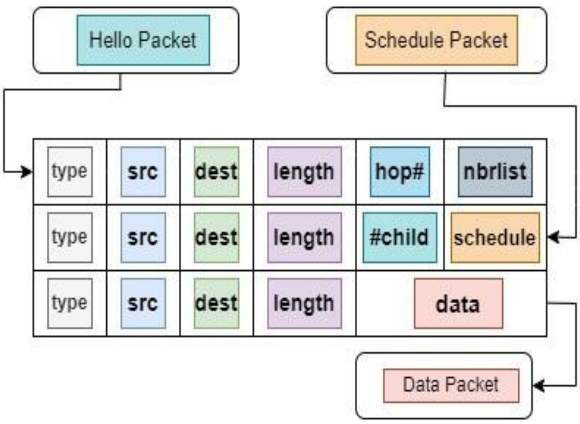

Fig 6: HY-MAC Packet Format

4.2.10 HY-MAC

HY-MAC protocols are based on TDMA /FDMA mechanism of MAC protocols. It is hybrid, multifrequency MAC protocol designed for end-to-end packet delivery and results in high throughput by avoiding overhearing, lowering idle listening and is proved as energy efficient protocol (Salajegheh, 2007). The frame format of HY-MAC (Fig 6) is divided into scheduled slots and contention slots. HY-MAC packet format contains Hello packet, schedule packet and data packet. Particular time slot and frequency assigned at base station for scheduled slots and hello packet send by the flooding method while contention slots used by random nodes joining the network. Neighbouring list updated for scheduling time to time. During this time control packet overhead exists. For sensor networks, it provides collision free communication due to usage of multifrequency communication and its best performance is achieved in applications like real time voice streaming (Kumar, 2018). Energy efficiency attained by switching all nodes to the same frequency while broadcasting using contention slots. End to end delay period is low in case of HY-MAC protocol.

4.2.11 ER-MAC

ER-MAC is hybrid MAC protocol based on TDMA/CSMA approach. This protocol provides energy efficiency by TDMA approach of slot scheduling. When there is no traffic available than sleep mode for power saving is activated. ER-MAC protocol is adaptable to traffic conditions and topologies. At base station tree constituted to find hop count, neighbouring list, parent and child details by flooding topology discovery message. After that slot assignment done by bottom up approach and schedule exchanged by sending schedule notification message (Sitanayah, 2010). Then synchronization message sent by base station. To handle parent-children broadcast synchronization local synchronization is done. Priority of packets determined by the remaining deadline expiry time and a pair of queues maintained to distinguish between high and low priority. Scheduled slots result into less chances of collision so a synchronized communication with low latency and high energy efficiency is

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achieved in case of ER-MAC. Overall performance of ER-MAC as compared to ZMAC is better as it achieves minimum latency, higher delivery ratio and less power consumption

4.2.12 EE-MAC

EE-MAC protocol designs are primary requirement for green computing. Now a day, with IoT devices and upcoming 5G technologies design and development of energy efficiency provide utmost requirement of society. The authors study of EE-MAC in various aspects like WSN, cognitive radio sensor network, tetra hertz communication, narrowband IoT and cellular IoT. The authors in (Kim, 2008) reviewed the energy efficiency protocols based on duty cycle approach such as contention based transmitter initiated and receiver initiated duty cycle MAC, contention free TDMA, FDMA, CDMA and hybrid duty cycle MAC. Still there is challenges to provide energy efficiency for massive IoT devices which are increasing day by day (Attiah, 2013), so more research and innovation in the field of EE-MAC proposed in 5G.

Table 1: Summary of energy efficient MAC protocols for IoT

4.3 IEEE 802.15.4

IEEE 802.15.4 is an energy efficient protocol which is used in IoT communications technologies such as electrical line monitoring in smart grids, detection of fouling in duct systems, smart load management etc. due to its low power consumption, better range and enhances security features. It is designed for personal area networks (PANs). Nodes in this network operate by synchronizing itself to a node called coordinator. IEEE 802.15.4 operate for three network topologies namely star, mesh and cluster tree topology. It performs channel access mechanism in either beacon enabled mode or non-beacon enabled mode which uses carrier sense multiple access with collision avoidance and unslotted carrier sense multiple access with collision avoidance. Duty cycle mechanism is utilized wherein transceivers in the node are either in active or sleep mode in a synchronized way.

IEEE 802.15.4 low-rate wireless standards describes the wireless connectivity of fixed and dynamic devices at extremely low cost, low data rate and less power consumption. IEEE 802.15.4 based devices are classified into full function devices (FFD) and reduced function devices (RFD). The full function devices are PAN coordinator capable and work on any topology whereas RFD cannot work as PAN coordinator and limited to star topology but its implementation is simple. The MAC layer of IEEE 802.15.4 protocols has two modes for channel access namely beacon enabled and non-beacon enabled (Oliveira, 2019).

Beacon enabled mode is duty cycled based having power management mechanism whereas in non-beacon enabled mode nodes are always in active state leading to consumption of additional energy. Beacon enabled and non-beacon enabled mode follows CSMA/CA collision avoidance technique and not bounded by delay time specified for data to reach the final destination. Data delivery ratio is comparatively low. In this standard, for the multi hope topologies the complex mechanism is required for beacon scheduling and synchronization. Various studies brought out that IEEE 802.15.4 protocols doesn’t fulfil all requirements in case of heterogeneous traffic network and different quality of service (QoS).

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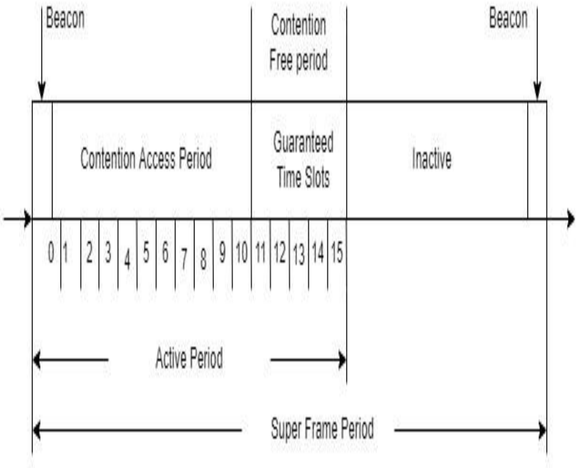

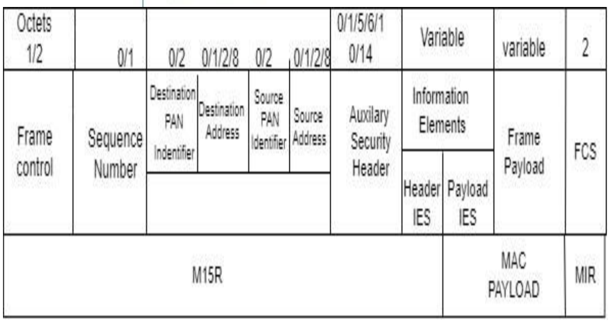

IEEE 8002.15.4e Frame Format

IEEE 802.15.4e is sub divided into five new MAC behaviour modes which are describes below:

4.4 IEEE 802.15.4e

IEEE 802.15.4e standards are modified version of IEEE 802.15.4 to overcome the limitations of IEEE 802.15.4. IEEE 802.15.4e standards covers multi-channel communication and designed for specific application domains (Kurunathan, 2019). The standards have general functional enhancements like flexible frame format, dynamic fragmentation of datagrams, enhance beacon, mechanism to exchange information and low duty cycle mechanism (De Guglielmo, 2016).

IEEE 802.15.4e is an enhanced version of IEEE 802.15.4 which functions on low energy by working on low duty cycle. IEEE 802.15.4e has got multichannel access, low latency and information element (IE) to exchange information at the MAC sub-layers with additional functions. IEEE 802.15.4e also provides multi-purpose frame format which can address a number of MAC operations. IEEE 802.15.4e also has enhanced beacons, MAC performance metrics, fast association and group acknowledgements.

4.4.1 Time slotted channel hopping (TSCH)

Time slotted channel hopping networks are more suitable for applications which are prone to interference from other wireless networks. It provides high reliability and time critical assurance for oil and refinery industries that concern humans and environmental safety. It is also used in food products, chemical products, pharmaceutical products water treatment etc. In these mode devices synchronizes within a periodic slot frame. It works on combination techniques of TDMA and FDMA (Javan, 2019). The energy efficiency can be achieved as nodes are aware about schedule and know about turning off and on the radios. TSCH communication is organized by a scheduler, each cell is represented by time slot and time slots used in particular on slot combines together to form slot frame (Khoufi, 2019).

4.4.2 Low latency deterministic network (LLDN)

LLDN is designed based on single hop and single network and is intended to be utilised in factory automation which needs very low latency. It works on star topology. Access medium followed in LLDN is time division multiple access. To provide synchronization

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and deterministic delay super frame concept utilized (Patti, 2014). Time scheduler schedules the nodes according to three states i.e. discovery, online state and configuration. It outperforms IEEE 802.15.4 in throughput, energy consumption, delay and reliability (Ouanteur, 2017).

4.4.3 Deterministic and synchronous multi-channel extension (DSME)

Deterministic and synchronous multichannel extension protocols target time critical applications both industrial and commercial like health monitoring systems, factory automation, smart metering, home automation and smart building etc. where reliability is of prime importance. It utilizes both contention based and time division medium access and it also offers two different channel diversity mode. The application also requires high scalability and robustness which are part of the design goals of DSME.

4.4.4 Asynchronous multi-channel adaptation (AMCA)

It is used where application domain needs large deployments such as smart utility networks, infrastructure monitoring networks etc. It is based on non-beacon enabled mode of IEEE 802.15.4. In asynchronous network, any two stations exchanging HELLO packets on the same frequency channel to communicate. Energy efficiency achieved by its asynchronous multichannel mechanism as it recognizes at early stage about ideal listening and contention (Choudhury, 2020). Asynchronous multichannel is appropriate for distributed networks as synchronization don't mandatory among users.

4.4.5 Radio frequency identification blink (BLINK)

Blink mode is to provide identification for people, item or location and tracking. Blink allows the devices to share their ID without any association process and acknowledgment. In this mode, without prior identification on, a device can communicate with its identifier and nodes.

5 Conclusion

The paper gives brief overview of energy efficient MAC protocols used for green IoT. The discussion of energy efficient MAC layer protocols for IoT explains the strength and weaknesses of existing MAC protocols with respect to energy efficiency considering various other factors like delay, throughput and latency etc. It is observed from the study that no single protocol fulfils the requirement and acts as perfect standard for green IoT, so further study is needed on the subject that satisfies the various criteria's like throughput, delay, minimum latency and diverse topologies along with energy efficiency. The open research challenges observed from the study are balancing low latency and energy efficiency in real time applications, handling ultra-dense networks with minimal delay and mobility in heterogeneous environments. The various studies show that modelling of existing MAC protocols leads to more energy efficient protocols having high throughput. Nowadays, recent studies are going on low power and lossy networks MAC protocols that are highly efficient and reliable. The IEEE 802.15.4e MAC protocols performance needs to be evaluated to enhance the energy efficiency or battery power of IoT devices for strengthening of networks.

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6. Declarations

All authors declare that they have no conflict of interest.

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Table 1: Summary of energy efficient MAC protocols for IoT

Protocol	Type/ Approach	Key Points	Throughput	Latency
S MAC	Contention based synchronous	Energy efficiency due to: low duty cycling collision and overhearing avoidance	Minimized	High
T MAC	Contention based synchronous	Adaptive duty cycle More energy efficient than SMac	Minimized	High
DS MAC	Contention based synchronous	Dynamic duty cycle Adaptable to varied load Provide better real time data than TMAC	Increased	Low
TA MAC	TDMA	Adaptive duty cycle mechanism Fast back off scheme	Increased	High
X MAC	Contention based asynchronous	Adaptive duty cycle to dynamic traffic loads Energy efficiency increased due to reduced overhearing and preamble cut	Minimized	Low
C MAC	CSMA	Energy efficiency at low duty cycling Uses long preamble	high	Low
Queen MAC	TDMA	Multichannel access Prolonged network lifetime Energy efficiency achieved with reduced wake up time	High	High
Z MAC	Hybrid TDMA & CSMA	Compatible for high contention in TDMA and low contention in CSMA High overhead so not good for event driven applications Energy used in clock synchronization	High	High
HY MAC	Hybrid TDMA & FDMA	High control packet overhead	High	Low
ER MAC	TDMA	More energy efficient in higher traffic loads, No packet loss, control overhead and contention	Moderate	Low