Towards Energy-Efficient MAC Protocols

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ABSTRACT

During the past two decades, the ICT (Information and Communication Technology) has become an integral part of our lives with exponentially increasing user interest and the vast number of applications being developed and used. The downside of the increase in these numbers is the continuous increase in the energy consumption. Various resources indicate that nowadays ICT is responsible for around 2% to 5% of the total global energy consumption and as new technologies are being developed, these numbers are very likely to increase in a proportional manner. In the past, networking protocols were developed for maximum efficiency, however without any energy constraints. Because of the analyses and expectations specified above, it has now become very important to develop new energy efficient networking protocols which will replace their corresponding ones. For all layers of the Internet protocol stack, studies have shown that significant energy savings can be achievable. This paper classifies the MAC protocols and describes some of the recent energy efficiency studies in the MAC sublayer. The reduction of energy consumption will not only have economical benefits but also environmental benefits that will have a positive impact for our lives in the future.

Keywords: Energy Efficient Protocols, MAC Sublayer, Green Communications

1. INTRODUCTION

ICT (Information and Communication Technology) has become an integral lifestyle commodity for most of the people around the world as it has played a central role in bringing people of the globe together. People and the companies have become dependent on the ICT for different kind of reasons such as social networks, e-commerce, online banking, home shopping, instant access to music, books and videos. With the wide usage of Internet of Things, Smart Cities and the invention of new technologies and applications, ICT's impact on human life will continue to increase rapidly.

It is estimated that ICT now uses approximately 1500 TWh of power per year which is equivalent to the combined power production of Germany and Japan. The power consumption of ICT is doubling every five years at an alarming rate. Thus, significant measures need to be taken to reduce the ICT power consumption. A significant number of studies are going on for each layer of the Internet protocol stack. While new energy saver applications are being developed, most of the energy hungry protocols are being modified or rewritten.

In this paper, the latest research on energy efficient MAC (Medium Access Control) protocols are described. The rest of the paper is organized as follows: Section 2 describes and classifies traditional MAC protocols into asynchronous MAC, syncronous MAC, frame slotted MAC and multi-channel MAC. Section 3 gives a summary of recent energy efficient MAC protocols with their properties and the paper concludes with the conclusions made in Section 4.

2. MAC PROTOCOLS

Medium Access Control data communication protocol is considered as a sublayer of the data link layer. A MAC protocol defines the rules of how a frame is transmitted on a communication link. When multiple nodes share a single link, the MAC protocol coordinates the channel access. This channel may provide unicast, multicast or broadcast communication services. In order to have high throughput in an energy-efficient way, designing an efficient MAC protocol is very important because MAC layer coordinates the access of the nodes to the shared wireless medium.

Traditionally, the MAC protocols are classified into four categories: synchronous MAC in which the neighboring nodes are synchronized to wake up at the same time, asynchronous MAC which aims to establish communication between two nodes which have different active/sleep schedules efficiently, frame-slotted MAC that is used for assigning time slots to nodes for receiving on behalf of transmission and multichannel MAC which provides parallel transmission by assigning nodes different channels.

2.1 Asynchronous MAC

In asynchronous MAC protocols, each node selects its active schedule autonomously without paying the price for synchronizing the neighbors' schedules. Asynchronous MAC protocols provide ultra-low duty cycle however they have to search efficient ways to constitute communication between two nodes.

Switching off lightly loaded devices is one of the extensively studied energy efficiency methods. Switching off network devices can result in significant energy savings provided that it doesn't have a significant impact on the network traffic. In preamble sampling (PS) a node turns on its radio when it has data to send. It aims to allow a node periodically wake up for a short time, the node goes back to sleep when the channel is idle.

However it brings overhearing problem because the node continues listening until the subsequent data frame is received or a timeout happens. This causes energy dissipation therefore this idea is not energy efficient. The PS is introduced together with the Mica wireless platform in [1]. Also, the performance of Aloha with PS and carrier sense multiple access (CSMA) are analyzed in [2,3]. To avoid collisions a transmitter performs clear channel assessment (CCA) in CSMA with PS. B-MAC [4] provides more accurate CCA and names its PS as low power listening (LPL). By the help of adaptive preamble sampling it reduces duty cycle and minimize idle listening thus obtain low power operation.

In PS, there is an unawareness of neighboring nodes' activities thus a node's preamble transmission may collide with the ongoing data transmission between neighboring nodes. For this reason STEM [5] uses two radios to distinguish the data transmission channel from wake-up channel.

To improve energy-efficiency the long preamble can be divided into a series of short packets which take some useful information. The non target nodes which have the destination address can instantly go back to sleep when they receive a short preamble packet thus more energy savings can be possible. Many protocols such as ENBMAC [6], MFP [7], B-MAC+ [8], SpeckMAC [9], DSP-MAC [10] and SyncWUF [11] use this idea for different problems. MH-MAC [12] and DPS-MAC [13] also contain timing information for broadcast messages, letting receivers to turn back to sleep and become active at the beginning of the data transmission.

The idea of shifting communication initiation from the sender side to the receiver side are presented in RICER [14] and PTIP [15]. Koala [16], AS-MAC [17], RI-MAC [18] and A-MAC [19] are also proposed for sensor networks. RI-MAC employs receiver created beacon packet to initiate data transmission instead of preamble packet. The beacon messages which are broadcasted by the nodes to announce that they are ready for receiving. RI-MAC unties collisions by reusing the beacon messages when a node broadcasts a beacon. According to [20], RI-MAC provides higher throughput, packet delivery ratio and power efficiency under a wide range of traffic loads compared with X-MAC [21]. However, only the receiver takes advantage of the receiver-initiated design. The sender has to stay awake until the data packets delivered. This is not energy-efficient thus PW-MAC [22] allows senders to predict target receiver's wake-up time. It also provides an efficient prediction-based retransmission scheme to obtain high energy efficiency even though wireless collisions happen and packets have to be retransmitted. The drawback of the PW-MAC is that the constant calculation of the neighbors' schedules brings necessary computational overhead which induces additional energy wastage.

2.2 Synchronous MAC

Synchronizing active time of neighboring nodes causes additional synchronization overhead. In prediction based synchronous MAC protocols only senders wake up at the target receiver's probing time while a cluster of nodes awake at the same time in synchronous MAC protocols. S-MAC [23] is specifically designed for Ad hoc wireless sensor networks and its primary goal is energy efficiency. In sleep period, nodes that are not involved in communication turn back to sleep. It also has collision and overhearing avoidance. However, it brings latency and adaptive listening mechanism causes overhearing and idle listening brings inefficient battery usage. Instead of fixing the length of the active period, in T-MAC [24], the non sleep and sleep periods are fixed. It can easily manage variable load due to dynamic sleeping schedule. Nevertheless, there is an early sleep problem in T-MAC that nodes may sleep as per their activation time and data may get lost especially for long messages. Also, overhearing is still introduced because a node has to stay awake while it is not involved in data transmission thus this causes additional energy dissipation.

Shifting data transmission to the sleep period is discussed in RMAC [25] where instead of exchanging data, a control frame is forwarded by multiple hops and DW-MAC [26] which is same as RMAC but also introduces a one-to-one mapping function to procure collision-free data transmission in sleep period. Both RMAC and DW-MAC are not energy efficient because all downstream nodes are going to wake up pointlessly to receive the expected data packet that will not arrive due to the false alarm.

DMAC [27] is a proper approach for data gathering applications in wireless sensor networks where data are delivered from multiple sources to a sink. It gradates the active/sleep schedules of nodes thereby packets can flow continuously to toward the sink. Also Q-MAC [28] is very similar to DMAC. The energy efficiency of these protocols are questionable when the route length is difficult to determine.

2.3 Frame Slotted MAC

TDMA procure high throughput with maximized channel utilization under intensive contention. It is generally defined for global time synchronization. It has low channel utilization when slight number of nodes have data to send because a node can transmit only in its assigned time slot. To develop channel utilization of TDMA under low contention the one of the frame slotted MAC protocols Z-MAC which combines CSMA into TDMA is proposed in [29]. In every time slot a sender has to wait for a certain amount of time to ensure that the slot is abandoned by the owner. Also, each receiver has to be awake to control whether it is the target receiver. This brings additional energy consumption. TDMA-ASAP [30] is designed to improve the energy-efficiency of this idea. When a node abandons a slot, the data included nodes for the same parent can steal the slot, so other nodes do not need to wake up to check whether they have data to receive.

PMAC [31] reduces duty cycle by switching sending slots to receiving slots. It considers traffic load. A node is emboldened to increase its sleep time exponentially until the upper bound is reached if it does not have data to send. A node can quickly respond a new flow however it also increases energy consumption if only several packets will be delivered.

2.4 Multi-channel MAC Protocols

The radio bandwidth in WSNs is restricted and thus it is desirable to devise multichannel MAC protocols to conduct bursty traffic or provide multi-task support. By considering the energy efficiency and the cost, the channel allocation and cross channel communication problems can be achieved in multichannel MAC protocol designs.

For obtaining energy-efficient multichannel MAC schemes, authors in [32] aim to group nodes which communicate frequently into the same channel and separate nodes that communicate rarely into another channels. TMCP [33] similarly disintegrate a sensor network to several vertex-disjoint trees.

A TDMA based dynamic hybrid channel selection design Y-MAC is proposed in [34]. Time slots are assigned to nodes for receiving and less nodes wake up at each slot compared with scheduling senders thus it is energy-efficient but multiple senders in contention for sending. Also MuchMAC [35] is another hybrid design of TDMA and FDMA. It provides independent receiving channel selection for each slot for the nodes. It produces extra subslots, therefore the efficient way of assigning channel/slot to nodes is still an open issue.

3. RECENT ENERGY EFFICIENY STUDIES FOR MAC

Forcing the nodes to sleep adaptively while ensuring the continuation of communication is the purpose of [36]. The Base Station Controlled MAC (BSC-MAC) conserves energy by switching off the idle nodes. The source nodes generate the data and forward it to the base station through the root nodes. In BSC-MAC, the list of all nodes reaches the base station by flooding. The nodes with subsets are detected and they are designated as the root nodes. The seize of a path causes the neighbor nodes to go to sleep mode. This mechanism provides power savings, reduces packet collisions, inhibits packet losses and also prolongs the network lifetime. NS-2 simulator is used for simulations. BSC-MAC is compared with P-MAC, T-MAC and S-MAC. BSC-MAC performs better than S-MAC. It has worse results than P-MAC when the total number of generated packets increases. Also, BSC-MAC is compared with Adaptive AEEMAC which provides more energy efficiency than MAC by using additional improvements: adaptive sleep, reuse of the channel and combined control packets. BSC-MAC can result in energy savings compared with the AEEMAC.

[37] compares the performance of RI-MAC and S-MAC protocol for two different scenarios: contending flow and data gathering. In the first scenario, the RI-MAC outperforms S-MAC in terms of energy efficiency. For the second scenario, when the number of node increases average energy consumption is quite increased in RI-MAC even as in S-MAC it slightly decreases. Consequently, RI-MAC is more energy-efficient than S-MAC but it provides preferable packet reception ratio and throughput.

In [38], an Energy Efficient MAC (EE-MAC) protocol for distributed wireless sensor networks is presented. Protocol aims to reduce energy consumption and delay performance improvement. The goal is achieved by designating the optimal value of the sleep interval based on dominant conditions. A weighted linear combination of energy and delay is proposed for the objective function. To obtain the optimal value of the sleep times the objection function is minimized. In simulations, 700 nodes are scattered over a square area and the EE-MAC is compared with S-MAC in terms of energy consumption and delay. According to results, the energy saving of EE-MAC is little more than S-MAC for the small number of nodes, however when the number of nodes increase the energy saving of EE-MAC also increases accordingly.

Energy Efficient Sensor-MAC (ES-MAC) which focuses on optimizing energy efficiency of the practical applications of wireless sensor nodes is proposed in [39]. The protocol uses two schemes: Dynamic Data Cycle (DDC) and Selective Data Transmission (SDT) in other words it is substantially derived from S-MAC and T-MAC. ES-MAC aims to reduce the number of transmitted packets and also to let the mote to sleep for a short time when it is idle. However, the proposed protocol does not regard node discovery, multiple schedules of the nodes and network allocation vectors. For the simulations, TinyOS environment is used. A single sender in combination with a single receiver is considered. The number of transmitted packets and acknowledged packets are monitored. It is obtained that significant reduction in number of transmitted packets occurs when the DDC and SDT is used together. When only DDC is used the number of transmitted packets is increased. It is clearly shown that the proposed protocol provides significant energy savings and extends the battery life.

In [40], earliest deadline first (EDF) which is the dynamic priority algorithm based energy efficient earliest deadline first (EEDF-MAC) protocol is presented. The included scheduling algorithm increases the energy efficiency of the network and provides less latency. EEDF-MAC is proposed for WSN with both event-driven and clock driven nodes. Turning off the radios of nodes which are not involved in data transmission or data reception provides energy efficiency. Ns-3 is used for the simulation analyses of the EEDF-MAC. A single-hop network with an augmenting number of clock-driven nodes is designed. The nodes are separated into groups based on the period of data generation. The proposed protocol is compared with CSMA/CA which is widely used as a MAC protocol in WSNs in terms of latency, collision and energy efficiency. It is obtained that significant amount of energy consumption on listening can be saved by using EEDF-MAC. Also all the energy spent on channel sensing in CSMA/CA is saved by the use of EEDF-MAC.

T-MAC fulfills well in predefined stationary networks. Recently in some studies the performance of T-MAC is evaluated with mobile nodes. Authors in [41] present the performance of T-MAC protocol by considering node mobility. An energy-efficient solution is proposed to solve the mobility problem and it is called MT-MAC. The proposed protocol commences the scheduling process similar to T-MAC but it develops T-MAC by dividing the nodes into three different types: cluster-head, stationary-node and border-node. The improvements provide mobility detection and efficiently handling the movement of nodes between clusters. For simulations OMNET++ platform is used. The node mobility models are random walk and random waypoint. Average packet delivery ratio and average power consumption are the performance measurement parameters. The results show that MT-MAC provides slightly higher power consumption than T-MAC but on the other hand it outperforms T-MAC in terms of packet delivery ratio for all scenarios. As a result, MT-MAC does not show a marked improvement on energy-efficiency of T-MAC.

IEEE 802.15.4 standard defines the physical layer and MAC sublayer specifications. It defines 16 channels in the 2.4 GHz band. Especially it is proposed for low-rate wireless personal area networks (PANs). Low cost, low power consumption and low data rate are the key features of this standard. In [42], a novel wireless MAC mechanism which allows the IEEE 802.15.4 standard to procure an energy-efficient, reliable, and delay bounded data transmission for hybrid monitoring WSNs is presented. The proposed protocol improves the IEEE 802.15.4 MAC standard by introducing a TDMA schedule to transmit neat long-term periodic monitoring (LTPM) traffic at the same time utilizing the standard CSMA/CA scheme to transmit seldom and randomly produced event detection (ED) traffic. The performance of proposed hybrid protocol is analyzed using ns-2 simulation based experiments. For all scenarios, a beacon enabled star topology network which includes several sensor nodes and a common coordinator is used. Standard IEEE 802.15.4 MAC is used for comparison. According to results, for all network sizes the proposed hybrid protocol provides less power consumption compared with the standard protocol. In addition, the energy stability and consuming constant amount of power unconcerned of the network size are also achieved by using proposed protocol.

4. CONCLUSIONS

Power conservation has become a very crucial research area to support the enormous growth of the ICT industry. This paper describes recent research completed at the MAC sublayer of the Internet protocol stack which has addressed energy efficiency or in other words green communications. As the ICT sector growth rate is expected to accelerate with the invention of new technologies and applications, the traditional MAC protocols will not be able to satisfy the needs for green communications. However, the development of new MAC protocols is promising to reduce energy consumption as significant power savings can be achievable.

5. REFERENCES

[1] J.L.Hilland, D.E.Culler, "Mica: A wireless platform for deeply embedded networks", **IEEE Micro,** Vol. 22, No. 6, 2002, pp. 12–24.

[2] A. El-Hoiydi, "Aloha with preamble sampling for sporadic traffic in adhoc wireless sensor networks," **in Proc. ICC**, 2002.

[3] El-Hoiydi, Amre, "Spatial TDMA and CSMA with preamble sampling for low power ad hoc wireless sensor networks", **7th International Symposium on Computers and Communications (ISCC),** 2002, pp. 685–692.

[4] J. Polastre, J. Hill, and D. Culler, "Versatile low power media access for wireless sensor networks", **2nd international conference on Embedded networked sensor systems ACM,** 2004.

[5] C. Schurgers, V. Tsiatsis, S. Ganeriwal, and M. Srivastava, "Optimizing sensor networks in the energy-latency-density design space", **IEEE Trans. Mobile Computing,** Vol. 1, No. 1, 2002, pp. 70–80.

[6] S. Lim, S. Kim, J. Cho, and S. An, "Medium access control with an energy-efficient algorithm for wireless sensor networks", **in Personal Wireless Communications, ser. Lecture Notes in Computer Science,** Vol. 4217, 2006, pp. 334–343.

[7] A. Bachir, D. Barthel, M. Heusse, and A. Duda, "Micro-frame preamble MAC for multihop wireless sensor networks", **IEEE International Conference on Communications (ICC),** Vol. 7, 2006, pp. 3365 –3370.

[8] M. Awenuti, P. Corsini, P. Masci, and A. Vecchio, "Increasing the efficiency of preamble sampling protocols for wireless sensor networks", **First Mobile Computing and Wireless Communication International Conference (MCWC),** 2006, pp. 117 –122.

[9] K.-J. Wong and D. K. Arvind, "SpeckMAC: low-power decentralized MAC protocols for low data rate transmissions in specknets", **2nd International Workshop on Multi-hop Ad Hoc Networks: from Theory to Reality,** 2006, pp. 71–78.

[10] S. Lim, Y. Ji, J. Cho, and S. An, "An ultra low power medium access control protocol with the divided preamble sampling", **Ubiquitous Computing Systems, ser. Lecture Notes in Computer Science,** Vol. 4239, 2006, pp. 210–224.

[11] X. Shi and G. Stromberg, "SyncWUF: An ultra low-power MAC protocol for wireless sensor networks", **IEEE Trans. Mobile Computing,** Vol. 6, No. 1, 2007, pp. 115 –125.

[12] L. Bernardo, R. Oliveira, M. Pereira, M. Macedo, and P. Pinto, "A wireless sensor MAC protocol for bursty data traffic", **IEEE 18th International Symposium on Personal, Indoor and Mobile RadioCommunications (PIMRC),** 2007, pp. 1–5.

[13] H. Wang, X. Zhang, F. Nait-Abdesselam, and A. A. Khokhar, "DPSMAC: An asynchronous MAC protocol for wireless sensor networks", **14th International Conference on High Performance Computing (HiPC),** 2007, pp. 393–404.

[14] E.-Y. Lin, J. Rabaey, and A. Wolisz, "Power-efficient rendez-vous schemes for dense wireless sensor networks", **IEEE International Conference on Communications (ICC),** Vol. 7, 2004, pp. 3769 – 3776.

[15] El-Hoiydi, Amre, and Jean-Dominique Decotignie, "Low power downlink MAC protocols for infrastructure wireless sensor networks", **Mobile Networks and Applications,** Vol. 10, 2005, pp. 675–690.

[16] R. Musaloiu-E, C.-J. Liang, and A. Terzis, "Koala: Ultra-low power data retrieval in wireless sensor networks", **7th international conference on Information processing in sensor networks. IEEE Computer Society,** 2008, pp. 421–432.

[17] B. Jang, J. B. Lim, and M. L. Sichitiu, "AS-MAC: An asynchronous scheduled MAC protocol for wireless sensor networks", **Mobile Ad Hoc and Sensor Systems, 25th IEEE International Conference,** 2008, pp. 434-441.

[18] Y. Sun, O. Gurewitz, and D. B. Johnson, "RI-MAC: A receiver-initiated asynchronous duty cycle MAC protocol for dynamic traffic loads in wireless sensor networks", **6th ACM conference on Embedded network sensor systems,** 2008, pp. 1–14.

[19] P. Dutta, S. Dawson-Haggerty, Y. Chen, C.-J. M. Liang, and A. Terzis, "Design and evaluation of a versatile and efficient receiver-initiated link layer for low-power wireless", **8th ACM Conference on Embedded Networked Sensor Systems,** 2010, pp. 1–14.

[20] Lakshmisudha, K., and C. Arun, "Research on power optimization in physical and MAC layer of wireless sensor networks-A survey", **IEEE International Conference on Intelligent Systems and Signal Processing (ISSP),** 2013, pp. 262-267.

[21] Buettner, Michael, et al. "X-MAC: a short preamble MAC protocol for duty-cycled wireless sensor networks", **4th international conference on Embedded networked sensor systems,** 2006, pp. 307-320.

[22] Tang, Lei, et al. "PW-MAC: An energy-efficient predictive-wakeup MAC protocol for wireless sensor networks", **IEEE INFOCOM,** 2011, pp. 1305-1313.

[23] Ye, Wei, John Heidemann, and Deborah Estrin. "An energy-efficient MAC protocol for wireless sensor networks", **IEEE INFOCOM,** Vol. 3, 2002, pp. 1567-1576.
[24] Van Dam, Tijs, and Koen Langendoen. "An adaptive energy-efficient MAC protocol for wireless sensor networks", **1st international conference on Embedded networked sensor systems,** 2003, pp. 171-180.
[25] Du, Shu, Amit Kumar Saha, and David B. Johnson, "RMAC: A routing-enhanced duty-cycle MAC protocol for wireless sensor networks", **IEEE INFOCOM,** 2007, pp. 1478-1486.
[26] Sun, Yanjun, et al. "DW-MAC: a low latency, energy efficient demand-wakeup MAC protocol for wireless sensor networks", **9th international symposium on Mobile ad hoc networking and computing. ACM,** 2008, pp. 53-62.
[27] Lu, Gang, Bhaskar Krishnamachari, and Cauligi S. Raghavendra, "An adaptive energy-efficient and low-latency MAC for data gathering in wireless sensor networks", **18th International IEEE Parallel and Distributed Processing Symposium,** 2004, p. 224.
[28] Vasanthi, N. A., and S. Annadurai. "Energy efficient sleep schedule for achieving minimum latency in query based sensor networks", **IEEE International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing,** Vol. 2, 2006, pp. 214-219.
[29] Rhee, Injong, et al. "Z-MAC: a hybrid MAC for wireless sensor networks", **IEEE/ACM Transactions on Networking (TON),** 2008, pp. 511-524.
[30] Gobriel, Sameh, Daniel Mosse, and Robert Cleric, "TDMA-ASAP: Sensor network TDMA scheduling with adaptive slot-stealing and parallelism", **29th IEEE International Conference on Distributed Computing Systems,** 2009, pp. 458-465.
[31] Zheng, Tao, Sridhar Radhakrishnan, and Venkatesh Sarangan, "PMAC: an adaptive energy-efficient MAC protocol for wireless sensor networks", **19th IEEE International Parallel and Distributed Processing Symposium,** 2005, p. 8.
[32] Le, Hieu Khac, Dan Henriksson, and Tarek Abdelzaher, "A practical multi-channel media access control protocol for wireless sensor networks", **7th IEEE international conference on Information processing in sensor networks,** 2008, pp. 70-81.
[33] Wu, Yafeng, et al. "Realistic and efficient multi-channel communications in wireless sensor networks", **IEEE INFOCOM,** 2008.
[34] Kim, Youngmin, Hyojeong Shin, and Hojung Cha, "Y-mac: An energy-efficient multi-channel mac protocol for dense wireless sensor networks", **7th IEEE international conference on Information processing in sensor networks,** 2008, pp. 53-63.
[35] Borms, Joris, Kris Steenhaut, and Bart Lemmens, "Low-overhead dynamic multi-channel mac for wireless sensor networks", **Wireless Sensor Networks. Springer Berlin Heidelberg,** 2010, pp. 81-96.
[36] Toklu, Sinan, and O. Ayhan Erdem, "BSC-MAC: Energy efficiency in wireless sensor networks with base station control", **Computer Networks 59,** 2014, pp. 91-100.
[37] Simaiya, Deepak, Utkarsh Sharma, and Abhishek N. Tripathi, "Simulation and performance evaluation of energy efficient MAC protocols for wireless sensor networks", **10th IEEE International Conference on Wireless and Optical Communications Networks (WOCN),** 2013, pp. 1-5.
[38] Attiah, Afraa, et al. "EE-MAC: Energy efficient sensor MAC layer protocol", **38th IEEE Conference on Local Computer Networks Workshops (LCN Workshops),** 2013, pp. 116-119.
[39] Siddiqui, Shama, and S. Ghani, "ES-MAC: Energy Efficient Sensor-MAC protocol for Wireless Sensor networks", **10th IEEE International Conference on Networking, Sensing and Control (ICNSC),** 2013, pp. 28-33.
[40] Mohiuddin, Maaz M., I. Adithyan, and P. Rajalakshmi, "EEDF-MAC: An energy efficient MAC protocol for wireless sensor networks", **IEEE International Conference on Advances in Computing, Communications and Informatics (ICACCI),** 2013, pp. 1323-1329.
[41] Zareei, M. ; Islam, A.K.M.M. ; Baharun, S. ; Komaki, S. “Energy-efficient and mobility-aware MAC protocol for wireless sensor networks ”, **19th IEEE Asia-Pacific Conference on Communications,** 2013, pp. 110-114.
[42] Wijetunge, S. ; Gunawardana, U. ; Liyanapathirana, R. “IEEE 802.15.4 based hybrid MAC protocol for hybrid monitoring WSNs ”, 3**8th IEEE Local Computer Networks (LCN),** 2013, pp. 707-710.