Energy Efficient Mobility Aware Clustering Hybrid MAC Protocol in WSN

M.Rajesh, B.L. Raju, B.N. Bhandari

Abstract*: *Mobility in Wireless Sensor Networks (WSN) poses many challenges to design Medium Access Control (MAC) protocol. In this paper, Energy efficient clustering Mobility Hybrid MAC (EMH-MAC) protocol is introduces to manage throughput, delay and energy consumption in WSN. EMH-MAC protocol merges the features of synchronous and asynchronous MAC protocols. EMH-MAC works in two stages: Clustering and Data transmission stage. In the clustering stage MMCDD protocol is used for election of Cluster Head (CH). Data transmission stage works in four segments: two-hop neighbor information, intra-semi synchronous, inter-synchronous communication and data transfer. EMH-MAC is evaluated using Network Simulator-3 and performance is compared with BN-MAC. Simulation results show that EMH-MAC performs well in comparison with BN-MAC in terms of throughput, delay and energy consumption by varying number of nodes and speed of nodes.

Keywords: Mobility, Hybrid MAC, Mobile Wireless Sensor Network, Clustering, Energy efficiency.

I. INTRODUCTION

Wireless Sensor Networks (WSN) gained tremendous applications such as environment monitoring, home automation, smart agriculture, wild life monitoring, structural monitoring, health monitoring, emergency operations and military surveillance [1]. These applications need sensor nodes to mobile for better efficiency and wide coverage [3]. WSN encounter problems like lack of energy, lack of bandwidth, coverage, scalability, congestion and mobility [2]. Mobility of node leads to frequent path breaks which affect the communication. In communication protocol stack, MAC and routing layers are responsible to handle mobility. To improve life time of the node the battery at a sensor node needs to be utilized in an efficient manner. Energy efficient clustering MAC protocols are developed to improve nodes life time in Mobile Wireless Sensor Networks (MWSN) [12].

MWSN has static and mobile nodes with low and high mobility. Mobility MAC protocols in [20] classified into common active/sleep period, preamble sampling, slotted TDMA and hybrid MAC protocols. Hybrid MAC protocols are developed in two ways: One merges the concept of the Common active/sleep period and slotted TDMA MAC protocols to achieve best results. Other manner combines the features of preamble sampling and slotted TDMA MAC protocols to get best results [13-21]. Some of the existing Hybrid MAC protocols not provided scalability and mobility support. To address above issues energy efficient clustering mobility hybrid medium access control (EMH-MAC) protocol is introduced. EMH-MAC protocol is developed by integration of synchronous and asynchronous mechanisms [8]. Proposed EMH-MAC protocol works in two stages: Clustering and Data transmission stage. In clustering stage MMCDD protocol is used for election of Cluster Head (CH).

Data transmission stage works in four segments: two-hop neighbor information, intra-cluster, inter-cluster communication and data transfer. The rest of the paper is organized as follows. Section 2 presents literature review of related work. In Section 3, EMH-MAC protocol design is presented. Section 4, the simulation setup and analysis of the results is discussed. Section 5, concludes the paper.

II. RELATED WORK

Existing Hybrid MAC protocols merge features of scheduling and contention approaches or scheduling and preamble sampling approaches based on synchronous and asynchronous mechanism. Some of the hybrid protocols handle node mobility at MAC and routing layers. In the -recent years researchers are focusing on Mobility aware hybrid MAC protocols.

In [4] authors proposed MH-MAC protocol, uses scheduled approach to static nodes and contention approach to mobile nodes. The main concept of this protocol is to decrease the duty cycle under strong mobility and also focuses on better latency. Nodes find out mobility using Received Signal Strength Indicator (RSSI). MH-MAC provides better latency under high mobility but as mobility increases, contention also increases which leads to more number of retransmissions in the network.

In [5] authors proposed ME-MAC hybrid protocol. It addresses the limitations of Mobility adaptive MAC by offering short control messages to contention slots and data messages to scheduled slots.

Manuscript received on March 15, 2020.
Revised Manuscript received on March 24, 2020.
Manuscript published on March 30, 2020.
* Correspondence Author
M. Rajesh*, ECE department, Assistant Professor, JNTUHCEH, JNTUH University, Hyderabad, India. Email: rajeshmitukula@gmail.com
B.L. Raju, ECE department, Professor and Principal, ACE Engineering College, JNTUH University, Hyderabad.
B.N. Bhandari, ECE department, Professor, JNTUHCEH, JNTUH University, Hyderabad

ME-MAC merges the features of CSMA (Carrier Sense Multiple Access) and TDMA (Time Division Multiple Access) for dynamic adjustment of topology and traffic conditions. ME-MAC frame format includes clustering slots and data transfer slots. The frame length is dynamically adjusted to handle mobility in network and mobility of the node is estimated using AR-1 model. ME-MAC protocol reduces delay and improves the packet delivery ratio. ME-MAC suffers with network adaptability and energy consumption due to computational complexity AR-1 model.

Versatile MAC (VMAC) [6] is a distributed scheduled MAC protocol which combines the concepts of TDMA and 802.11. VMAC has fixed frame length and uses non clustering mechanism, due to this it gives better results in short distance communication. Fixed frame length has random access slots for reservation and schedule slots for transmission. Fixed Contention Window (CW) size and number of slots are related to two hop neighbor nodes either static or mobile. Node mobility is calculated by using Global Positioning System (GPS). Smaller frame length is used to increase throughput but it increases delay and overhead in one-hop neighborhood. Due to this, energy consumption increases and the packet delivery ratio decreases.

Border Node MAC (BN-MAC) [7] is hybrid protocol which adapts the features of semi-synchronous approach to providing fast medium access and synchronous scheduled approach to reduce collisions and overhearing. Border node for every cluster is elected sporadically with DBNSP model based on signal strength, memory allocation and residual energy. Pheromone termite routing protocol is used for efficient transmission in the network. Dynamic election of border node increases network lifetime but it leads to additional control overhead and also energy consumes. BN-MAC reduces the latency because of Asynchronous duty cycle feature.

CTh-MAC proposed in [8], leverages the feature of CSMA and TDMA in MWSN. Network is divided into subsets based on transmission region of nodes to sink node. In CTh-MAC, initially sink node schedules slots to subsets based on the TDMA approach later CSMA/CA provides communication within subset. CTh-MAC protocol concentrates on energy utilization in high speed mobile environment and throughput enhancement in the networks. In large scale networks CTh-MAC need more powerful sink node. In each subset contending node transmit data to sink node on its timeslot due to this energy consumption and delay increases as the distance increases.

EMH-MAC is a hybrid protocol, which overcomes the limitations of BN-MAC by assigning contention slots to mobile nodes and schedule slots to static nodes. The design objective of EMH-MAC protocol is to reduce energy consumption, overhead and delay under high mobility scenario.

III. EMH-MAC DESIGN

(a) System model

EMH-MAC protocol leverages the features of schedule and contention approach in synchronous and asynchronous manner. Sensor nodes disseminate data in a short range single-hop communication to conserve energy. Data is disseminated in intra cluster and inter cluster communications by using efficient clustering protocol. The intra cluster communication takes place in a semi-synchronous manner with in each cluster. The semi-synchronous approach is developed with scheduled and contention features. Asynchronous preamble is used to check the availability of the channel in contention feature. Assign the schedules of nodes for sending and receiving data within a region is maintained by schedule approach.

Network consists of normal nodes and CHs. Normal nodes either static or mobile nodes in each region. In intra cluster region semi-synchronous mechanism is used which includes preamble sampling and slotted TDMA approach. Static nodes use slotted TDMA approach whereas mobile nodes use preamble mechanism to decreases delay, energy consumption and improves throughput. In inter cluster communication slotted TDMA mechanism transfer data from CHs to sink node.

b) Mobility Modeling and Estimation

Random Way Point (RWP) mobility model [11] is used to depict mobility in WSN. In RWP model nodes move freely in sensing environment without any restriction on mobility and chooses random destination. The mobile node selects one node as destination node and move towards that destination node with constant velocity from [0, V_{max}], where V_{max} is the maximum velocity of node. Each node chooses its velocity and direction independent of other nodes.

The mobility of a node can be determined by two parameters maximum velocity of node (V_{max}) and pause time (T_{pause}). In continuous network V_{max} is more and is T_{pause} small whereas in static network V_{max} is small and T_{pause} is long. Node can choose a pause time to accommodate variation in direction and speed. RSSI [9] uses radio propagation model to translate signal strength into distance and distance is calculated between sender and receiver without much deprivation in the link quality. Some of the existing protocols use RSSI to predict mobility because of no additional hardware is required.

c) Protocol architecture

EMH-MAC protocol works in two stages: Clustering stage and Data transfer stage.

i) Clustering stage: In Clustering stage, EMH-MAC segments the network into clusters. Region of cluster is changed whenever topology changes occur in network and elects CH sporadically. CH is elected with the parameters of one hop distance, residual energy, position and velocity of node as used in MMCDD [10] protocol.

After cluster formation each CH broadcast its advertisement message to all member nodes in a cluster. CH controls the channel access among nodes in each cluster. Sink node assigns schedules to all CH using TDMA mechanism to send and receive data. Each frame is composed of signaling phase and data phase which are handled by Preamble and TDMA mechanism. Synchronous and asynchronous frames are differentiated based on SYNC and beacon signal at beginning of each frame. To avoid the hidden terminal problem two-hop neighbor information is maintained in the intra cluster region by using one-hop neighbor information.

ii) Data transmission stage: In Data transmission stage sensor nodes reported data to Sink node through CHs. Data transmission phase works in four stages: two-hop neighbor information, intra-semi synchronous, inter-synchronous communication and data transfer.

In two-hop neighbor information phase, every node maintains two-hop neighbor information based on one-hop information. If a node wants to leave or join from/to cluster, node's two-hop neighbor information is changed. Each node maintains a periodic update to incorporate topology changes in a cluster.

In Intra-semi synchronous communication, CH makes nodes synchronization and slots allocation. Static nodes in each cluster needs synchronization and slots are scheduled using slotted TDMA mechanism. Mobile nodes in cluster need not maintain a strict synchronization with CH in highly dynamic network. Mobile nodes make synchronization with normal nodes and CH uses preamble sampling mechanism. In this approach beacon signal is used to maintain synchronization among nodes. Short Preamble (SP) makes the receiver ready for the upcoming data and also improve the performance of network leads to get bandwidth and energy efficiency.

In Inter-synchronous communication, communication link is established between all CH to sink node. Sink node schedules time slots to CHs with slotted TDMA mechanism. In data transfer phase, nodes use dedicated schedule slots for data transmission. After completion of network setup and scheduling phase, data has to report from sensor node to sink node in intra and inter communication approaches.

IV. SIMULATION SETUP AND RESULT ANALYSIS

4.1. Deployment

This paper compares the performance analysis of BN-MAC and EMH-MAC in Network simulator-3. Detailed comparison is also provided by varying number of nodes and speed of nodes in the simulation scenario.

Parameter	Range
Transmission Range	30 m
Sensing Range of node	12 m
Initial energy of node	10 J
Size of network	1000 * 1000 square meters
Packet transmission rate	40 Packets/s
Data Packet size	512 bytes
Simulation time	20 min
Pause time	10 s
Tx energy	16 mW
Rx energy	12 mW
Mobility	0-12 m/s
Routing Protocol	MMCDD

Table1. Simulation parameters for EMH-MAC protocol

In the simulation scenario, nodes are erratically placed in the network density of 1000*1000 square meters. Total energy of network is considered as 1000J and hence initial energy is set to 10J. Transmitting and receiving power consumption at node is set to 16mW and 12mW respectively. The sensing power consumption is set to 6mW and idle mode power consumption is set to 0.5mW. Generally if average speed is high then pause time should be less in mobile networks. Packet size is considered as 512 bytes and packet transmission rate in network is 40packets/sec.

4.2. Result comparison

The performance analysis of EMH-MAC is compared with BN-MAC in terms of energy consumption, throughput and delay by varying number of nodes and speed. In network 40% of nodes are assumed mobile nodes. The average speed of node is set at 0, 2, 4, 6, 8, 10 and 12 m/s by varying number of nodes.

a) Throughput Performance

Throughput of EMH-MAC and BN-MAC is determined by varying number of nodes and speed of nodes as shown in Figure 1 and 2. EMH-MAC and BN-MAC protocols generate an average throughput of 500 and 620 Kbps initially but as nodes increases performance of EMH-MAC decreases as compared with BN-MAC protocol shown in Figure1. EMH-MAC decreases the throughput from 620 Kbps to 560 Kbps when nodes varying from 10 to 100 nodes but BN-MAC decreases throughput from 500Kbps to 400 Kbps in the same scenario. By varying number of nodes, EMH-MAC achieves 25% to 34.7% higher throughput than BN-MAC.

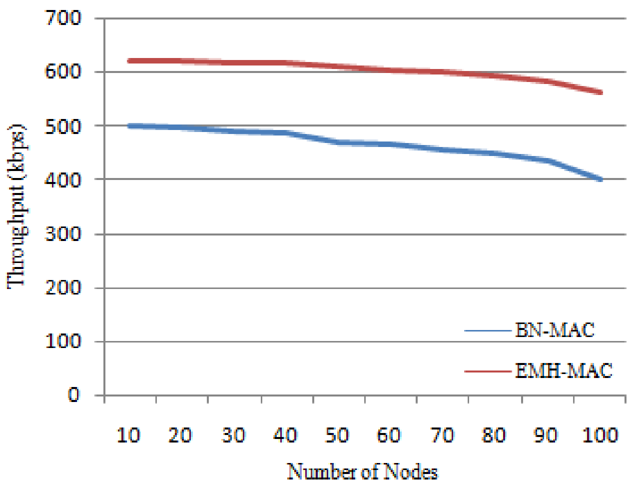

Fig. 1. Throughput at varying number of nodes

In Figure2, EMH-MAC and BN-MAC protocols generate an average throughput of 500, 475 Kbps at 0m/s initially. As nodes speed increases EMH-MAC performance reduces as compared to BN-MAC protocol.

EMH-MAC achieves 24 to 40.6 % higher throughput than BN-MAC in case of varying nodes speed. From the above simulations, it is observed that the throughput decreases slightly as number of nodes and speed of nodes increases.

b) Delay

Delay is time taken for transmission of one packet from sender to receiver. Total Delay includes propagation, transmission, router and storage delay. Average delay of EMH-MAC and BN-MAC is determined by varying number of nodes and speed of nodes as shown in Figure 3 and Figure4.

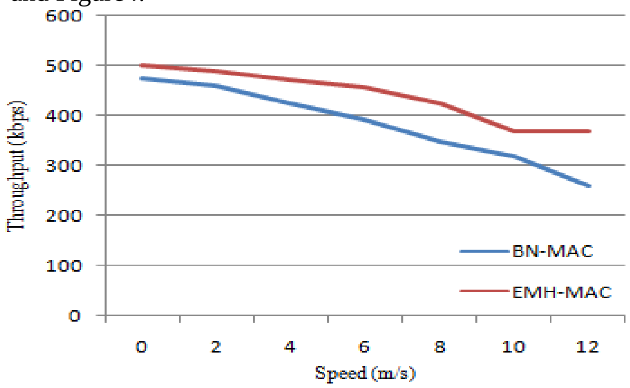

Fig. 2. Throughput at varying speed of nodes

From Figure3 it is observed that delay increases as number of nodes increases. EMH-MAC gets 1.1-13.25 milliseconds (ms) of delay with variations of 10- 100 nodes but BN-MAC produce delay around 2.06-16.0258 ms.

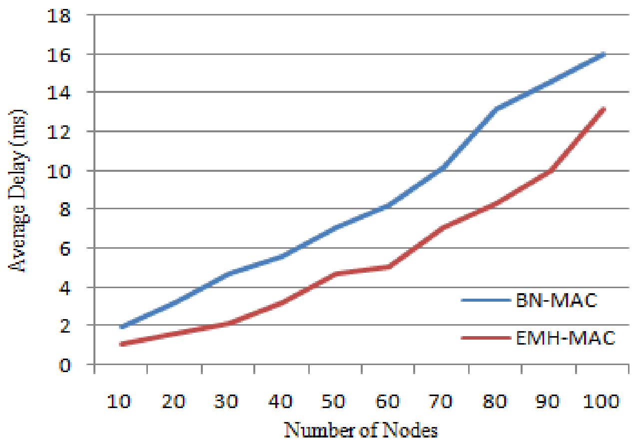

Fig. 3. Average Delay at varying number of nodes

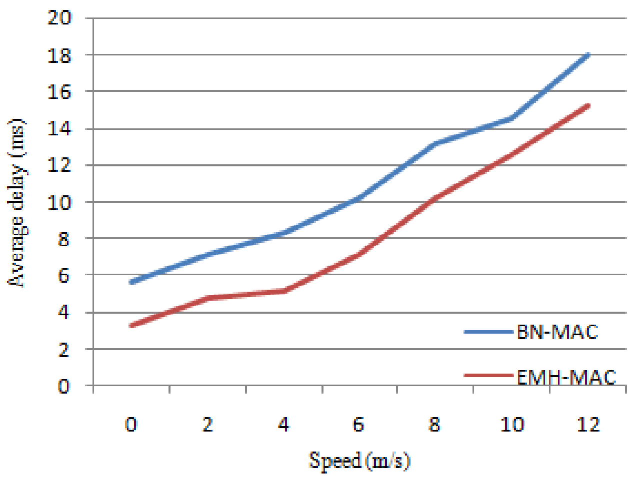

Fig. 4. Average Delay at varying speed of nodes

EMH-MAC achieves less delay at less number of nodes than BN-MAC but as number of nodes increases EMH-MAC achieves 20% less delay than BN-MAC. Figure 4 shows EMH-MAC gets 3.25-15.25 ms delay at 0-12 m/s speed variations whereas BN-MAC protocol show higher delay of 5.64 -18.02 ms. EMH-MAC achieves 15.39% less delay than BN-MAC protocol.

c) Energy Consumption

Energy consumption is considered as amount of energy consumed to transmit and receive data. In MWSN, nodes are energy constrained hence mobility aware hybrid MAC protocols are used to reduce energy consumption. Figure5 and Figure6 show energy consumption of EMH-MAC and BN-MAC by varying number of nodes and speed of nodes.

In BN-MAC, number of nodes increases average energy consumption increases linearly but in EMH-MAC energy consumption is less. The average energy consumption increases from 10-14% as speed increases at 0-12m/s in EMH-MAC but in case of BN-MAC the average energy consumption increases to 10-17% at 0-12m/s. By varying speed of nodes average energy consumption of EMH-MAC is less than BN-MAC. Overall EMH-MAC outperforms BN-MAC with varying number of nodes and speed.

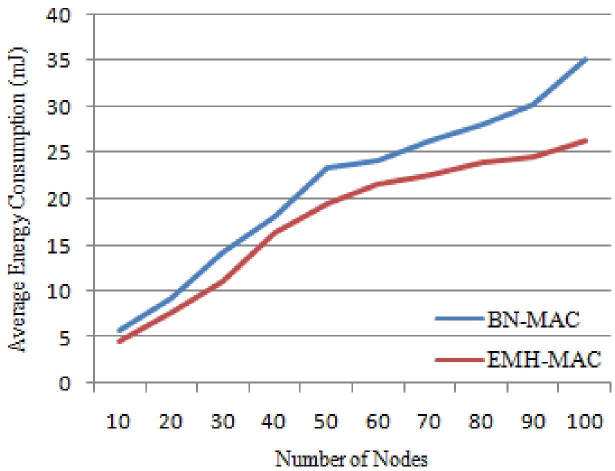

Fig. 5. Average Energy Consumption at varying number of nodes

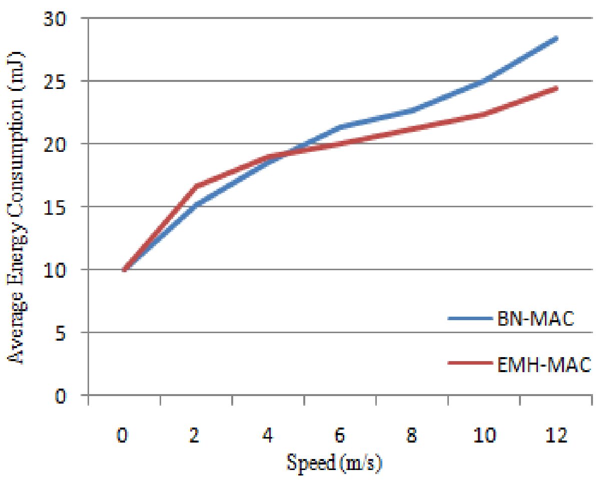

Fig. 6. Average Energy Consumption at varying speed of nodes

V. CONCLUSION

This paper introduces an Energy efficient Clustering Mobility Hybrid MAC protocol in WSN. EMH-MAC developed a hybrid scheme, static nodes in cluster uses synchronous schedule approach and mobile nodes use asynchronous preamble approach for data transmission. For data transmission between CHs and sink node, EMH-MAC uses synchronous slotted TDMA mechanism. Simulation results show that EMH-MAC and BN-MAC compared in terms of QoS parameters throughput, delay and energy consumption by varying number of nodes and speeds of nodes. EMH-MAC achieves 24 to 40.6 % of higher throughput than BN-MAC even at high mobility. An average delay and average energy consumption of EMH-MAC is 10% to 20% lesser than BN-MAC.

Further EMH-MAC protocol is improved to achieve better result in delay and energy consumption with the incorporation of adaptive dutycycle in frame structure for static and mobile nodes.

REFERENCES

1. Meng, W., Xie, L., & Xiao, W. Optimality Analysis of Sensor-Source Geometries in Heterogeneous Sensor Networks. IEEE Transaction on Wireless Communications, (2013) 12(4), 1958–1967.
2. Razaque, Abdul, and Khaled Elleithy. "Automated energy saving (AES) paradigm to support pedagogical activities over wireless sensor networks" International Conference on Ubiquitous Computing and Ambient Intelligence. Springer, Berlin, Heidelberg, 2012.
3. I.Demirkol, C.Ersoy, and F.Alagoz, "MAC protocols for wireless sensor networks: a survey, "IEEE Communications Magazine" vol. 44, no.4 , pp. 115–121, Apr. 2007.
4. Raja, Anjali, and Xiao Su. "A mobility adaptive hybrid protocol for wireless sensor networks." 2008 5th IEEE Consumer Communications and Networking Conference. IEEE, 2008.
5. Yahya, Bashir, and Jalel Ben-Othman. "An adaptive mobility aware and energy efficient MAC protocol for wireless sensor networks." 2009 IEEE Symposium on Computers and Communications. IEEE, 2009.
6. Ngo, Vincent, Alagan Anpalagan, and Isaac Woungang. "Versatile medium access control (VMAC) protocol for mobile sensor networks." 2011 7th International Wireless Communications and Mobile Computing Conference. IEEE, 2011.
7. Razaque, Abdul, and Khaled M. Elleithy. "Low duty cycle, energy-efficient and mobility-based boarder node—MAC hybrid protocol for wireless sensor networks." Journal of Signal Processing Systems 81.2 (2015): 265-284.
8. Yang, Xin, et al. "Hybrid MAC protocol design for mobile wireless sensors networks." IEEE Sensors Letters 2.2 (2018): 1-4.
9. Alhasanat, Abdullah, et al. "Efficient RSS-based collaborative localisation in wireless sensor networks." International Journal of Sensor Networks 22.1 (2016): 27-36.
10. Rajesh, M., B. L. Raju, and B. N. Bhandari. "Mobility based multihop clustering data dissemination in wireless sensor networks." 2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI). IEEE, 2017.
11. Camp, Tracy, Jeff Boleng, and Vanessa Davies. "A survey of mobility models for ad hoc network research." Wireless communications and mobile computing 2.5 (2002): 483-502.
12. Ramasamy, Velmani. "Mobile Wireless Sensor Networks: An Overview." Wireless Sensor Networks: Insights and Innovations (2017)
13. Zhong, Ping, et al. "Research on Medium Access Control protocols for mobile sensor networks." 2010 IEEE International Conference on Intelligent Computing and Intelligent Systems. Vol. 3. IEEE, 2010.
14. Dong, Qian, and Waltenegus Dargie. "A survey on mobility and mobility-aware MAC protocols in wireless sensor networks." IEEE Communications Surveys & Tutorials 15.1 (2012): 88-100.
15. Kakria, Arvind, and Trilok C. Aseri. "Survey of synchronous MAC protocols for Wireless Sensor Networks." 2014 Recent Advances in Engineering and Computational Sciences (RAECS). IEEE, 2014.
16. Sajat, Mohd Samsu, et al. "A critical review on energy-efficient medium access control for wireless and mobile sensor networks." Journal of Telecommunication, Electronic and Computer Engineering 8.10 (2016): 89-94.
17. Adrian Kacs´ "MAC Protocol Design Requirements for Mobility-aware Wireless Sensor Networks", SENSORCOMM 2017 : The Eleventh International Conference on Sensor Technologies and Applications
18. Kazmi, Syed Wajahat Abbas, Adrian Kacso, and Roland Wismüller. "Recent MAC protocols for mobility-aware wireless sensor networks—a survey and future directions." 2017 Ninth International Conference on Ubiquitous and Future Networks (ICUFN). IEEE, 2017.
19. Sudheendran, Sijo, et al. "Challenges of mobility aware MAC protocols in WSN." 2018 Advances in Science and Engineering Technology International Conferences (ASET). IEEE, 2018.
20. Zareei, Mahdi, et al. "Mobility-aware medium access control protocols for wireless sensor networks: A survey." Journal of Network and Computer Applications 104 (2018): 21-37.
21. Mutepfe, Cleophas DK, and Clement Nyirenda. "Comparative Analysis of MAC Protocols in a Mobility Aware Wireless Body Area Network." 2018 Open Innovations Conference (OI). IEEE, 2018

AUTHORS PROFILE

M. Rajesh received B-Tech degree in Electronics and communication engineering from JNTUH, Hyderabad, Telangana, India in 2011, and has M-Tech degree in Digital Communications from Kakatiya Univeristy, warangal, Telangana, INDIA in 2013. He is Presently working Assistant Professor at JNTUHCEH, Hyd. and pursuing the Ph.D. degree from JNTUH. His research interests include Wireless Sensor Networks, Ad-hoc wireless Networks, Machine and deep learning in Wireless networks.

B.L.Raju did his B.E in Electronics from Marathwada University, Aurangabad, in 1989, M.Tech in Digital Systems & Computer Electronics from JNTU College of Engineering, Hyderabad and Ph.D in ECE from JNTUH, Hyderabad, in 2010. Presently he is working as Principal and Professor of ECE in ACE Engineering College, Hyderabad. He has published papers in International, National Journals and Conferences. He is a member of ISTE, CSI, VSI, Fellow of IETE and Senior Member of IEEE.

B.N. Bhandari, did his B.Tech in ECE from JNTU Hyd. and M.Tech in Microwave and Radar Engg. from Osmania University, Hyderabad and Ph.D. from IIT, Kharagpur. He joined in Department of ECE, JNTUH College of Engineering, Hyderabad, as Assistant Prof. in 1989 and presently he is Professor of ECE. He has authored / co-authored more than 40 publications in reputed national and international conferences and journals. B.N. Bhandari is a member of Institution of Electronics, Telecommunication Engineers (IETE), Member of Institution of Electrical and Electronics Engineers, (IEEE) USA, and member of ISTE.