International Journal of Grid and High Performance Computing
Volume 15 • Issue 1

An Energy-Efficient Multi-Channel Design for Distributed Wireless Sensor Networks

Sunil Kumar, University of Surrey, UK*
https://orcid.org/0000-0002-8348-1553

ABSTRACT

This article discusses the importance of designing an efficient medium access control (MAC) protocol for wireless sensor networks (WSNs) to optimize energy consumption at the data link layer while transmitting high traffic applications. The proposed protocol, EE-MMAC, is an energy-efficient multichannel MAC that reduces energy consumption by minimizing idle listening, collisions, overhearing, and control packet overhead. EE-MMAC utilizes a directional antenna and periodically sleep technique in a multi-channel environment. Nodes exchange control packets on the control channel to choose a data channel and decide the beam direction of the flow. Simulation results show that EE-MMAC achieves significant energy gains (30% to 45% less than comparable IEEE 802.11 and MMAC) based on energy efficiency, packet delivery ratio, and throughput.

KEYWORDS

Energy Efficient, MAC, Multichannel, Wireless sensor networks

1. INTRODUCTION

Today most of the applications are running in wireless networking where anyone can access the resource from anywhere and anytime. Mobile computing, wireless sensor networks, ubiquitous computing and distributed computing are few examples of it. Now, WSNs are becoming critical to functionalities of upcoming emerging technology advancements than in the past decades, such as the Internet of Everything (IoE), smart city and digitization of world. WSNs are growing to be an important technology due to micro size sensors, increasing ability to sense, advancement in processing and communication are available in low cost. After reviewing research papers in the field of WSNs we identified issues like throughput, latency reliability and energy are very critical to it. Out of these, energy is a critical resource in the WSN because devices are independent, low powered, low computation and low storage where battery charging, and replacement is not possible. In such scenarios energy saving is of utmost importance. In the future, sensor nodes will be planned as disposable devices and unnecessary energy consumption must be avoided at every layer of communication, operating systems, application, and hardware. It is also found

DOI: 10.4018/IJGHPC.329601

*Corresponding Author

from the literature survey that much of the energy is consumed at data and network layers of the communication model. Hence our inspiration for this research work is energy saving in MAC sub-layer and IP layer. Today, many power management protocols exist but none of the protocols fulfill the future industry demands of the application such as scalability, load balancing and support of high traffic applications. Our major concern is to design the algorithm to optimize the energy in WSN. We are optimizing the energy to an extent that one battery will be sufficient for 5 to 6 years of continuous operation.

We can save energy at every layer of communication model, hardware, software, and operating system designing. After the literature survey found that main cause of energy consumption in communication model are data and network layer protocols. The main factors of energy consumption at data link layer are collision, overhearing, communication overhead and idle listening. Network layer protocols consume lots of energy in transmitting the packets without proper selection of route. We optimize energy at MAC layer by using sleep/wake up procedures and at network layer by designing a good clustering and routing protocol. A new energy saving algorithm for multichannel MAC (EE-MMAC) to support more bandwidth required applications has been designed. The primary objective of the proposed protocol is to reduce the energy consumption in MAC sub-layer by resolving the given multichannel issues. EE-MMAC is scalable protocol and optimizes energy by reducing the number of collisions. Proposed EE-MMAC supports IEEE 802.11 and considers its good power efficient techniques to save the energy at MAC sub-layer. When we used single channel MAC then there is a starvation problem and source station stops their packets transmission. Detection of starvation is difficult hence identification of source of starvation is very important. The main source in single channel are hidden nodes, way of carrier sensing and use of symmetric terminal. To remove this problem and to improve the data rate in high traffic applications a multichannel MAC with directional information has been proposed. Proposed EE-MMAC used two transmission modes and multichannel to provide higher data rates for high traffic applications. In this research work, our primary goal is to design a protocol that can better manage the energy resources in distributed WSNs. As a secondary goal, we aim to meet the demands of high traffic applications and guarantee load balancing and energy optimization in a WSN. In addition, NS3 simulations are used for the preliminary validation and testing.

The paper is organized in the given manner below. Section 2 shows a literature survey, MAC protocol issues and challenges, and details of relevant research works. We surveyed all aspects of MAC and Network layer regarding energy optimization. Section 3 discusses the role of multichannel in MAC layer and provides solutions for the given multichannel issues. A new "energy efficient & multichannel medium access control (EE-MMAC)" is detailed for heavy bandwidth applications. Section 4 presents the performance evaluation and simulation parameters. This section proves that improvement in the throughput, PDR, and optimization of energy in high traffic applications are brought out. Finally, Section 5, depicts the conclusions of work.

2. RELATED WORK

The present study was undertaken to find the relevant patents and technical documents (already in public domain) that could be used to support the novelty, or the lack of it on the various aspects of the invention. Based on the search conducted, a few technical publications and patents publications were found to be the most relevant. Medium access control (MAC) layer provides the access control, error control (using checksum), addressing, framing and to ensure of these services MAC protocols are used. MAC protocols are used to avoid collisions where two or more than two sensors are trying to transmit the frame simultaneously. These protocols classified mainly in to four categories like contention based, time division based, hybrid based and cross layer MAC. Proposed protocols must be designed in a way that guarantees energy saving and maximizes the lifetime of low powered WSN. The popular and standard MAC protocols list is given below.

1. Sensor-medium access control (SMAC)
2. Berkeley Media Access Control for Low-Power Sensor Networks (B-MAC)
3. Timeout- medium access control (T-MAC)
4. Predictive Wake-UP medium access control (PW-MAC)
5. Advertisement based-Time Division Multiple Access (ATMA)
6. Traffic-adaptive medium access control (TAMAC)
7. IEEE 802.11
8. Power aware multi-access signaling (PAMAS)

2.1 MAC Protocol Paradigms for Wireless Sensor Networks

The wide range of MAC protocols are designed in WSNs (Wang et al., 2018; Liu et al., 2018). There are two types of protocol used in MAC layer contention based and TDMA based. A TDMA MAC protocols arbitrate medium access by defining an order where a particular time is assigned to a user for the transmission. It uses time division multiplexing and assigns different time slots to users for transmission. This technique fails if nodes are not synchronized and suffers from dynamic topology. The scheduled based protocols allow sensor nodes to occupy the channel to avoid any collision over the channel, therefore these techniques require more bandwidth to become successful. Low-energy adaptive clustering hierarchy (LEACH) is the popular protocol of TDMA type, it provides clustering and routing in low powered WSNs (Mohammadi et al., 2018; Yang et al., 2016; Kumar et al., 2022). Contention-based MAC protocols allow wireless devices to use the same radio channel without pre-coordination. These protocols use the concept of "sense before the transmission" and are easy to implement, flexible and scalable in wireless sensor networks. The IEEE 802.11 is the standard MAC protocol based on the contention. Contention based protocols operate on the concept of "listen before talk", free from clock synchronization and no need of global information related to topology. Contention based IEEE 802.11 uses network allocation vector, request to send (RTC), clear to send (CTC) frames to avoid the collision and to solve hidden station problem in wireless communication (Kumar et al., 2022; Ma et al., 2023). However, contention-based IEEE 802.11 MAC consumes more energy due to the idle listening of sensor nodes even the nodes have nothing to do. Moreover, IEEE 802.11 MAC is a random technique-based protocol and in high bandwidth required applications, number of collisions are increased and performs poorly. The other contention-based MAC protocol is PAMAS. It reduces power depletion by applying the concept of sleep and waking up and turning the sensors to sleep mode while remaining nodes are in transmission mode (Kumar et al., 2017). However, this protocol is not intelligent enough to apply the sleep wake up method to reduce the idle listening time. Contention based protocols apply the concept of sleep/wake-up to optimize the energy in wireless sensor networks (Kumar et al., 2017). The popular and standard MAC protocols S-MAC (Punhani et al., 2019) and T–MAC (Dubey et al., 2020) are based on the contention. S-MAC is designed for WSN, and it is a self-configurable protocol. To optimize the energy in listening to an idle channel, it uses the concept of periodically sleeping. All S-MAC sensors are in either active or sleepy state. A sensor node forms the virtual clusters and auto-synchronizes by turning off/on its radio. Contention based S-MAC during sleep time turns off its transceiver to save energy consumption. During the time of sleeping mode S-MAC buffered all the packets and transmitted them during the active time of a node. Similar to PAMAS, it also uses in-channel signaling and configured by many parameters to assign a scheduled time for sensor nodes to set duration of active mode, network density and applies message passing to reduce the contention time. A new MAC protocol T-MAC is derived from S-MAC to support heavy band-with required applications. T-MAC remains in active mode till the time some activity is happening over the channel, if for certain fixed time no events are detected over the channel sensor node will go to the sleep mode. Sensor nodes will always renew their sensing time whenever an activation event occurs over the channel. However, if any active event occurs over the channel, all sensor nodes hearing this message renew their TT even if they are not participating in the communication. The other sensor nodes change their state to sleep state based on overhearing an RTS and CTS messages. These messages are for other nodes and optimize the energy by overhearing avoidance. A nonlinear utility optimization allocates bandwidth channel resources among the sensor nodes. The algorithms are designed to control the channel access information in dense network of multichannel environment to optimize the energy. Many algorithms are designed on the effects of economic viewpoint of wireless resources and technical effectiveness of wireless local area network. New algorithms are developed which leads to energy optimization at communication model and control of MAC and network layer resources in the best way. It is derived from TDMA/FDMA scheduling, further this algorithm is centralized in nature and improves the performance (Kumar et al., 2015; Singh et al., 2022; Sharma et al., 2020). The algorithm minimizes the interferences among the multi-channel direction-based interfaces derived from linear programming. Fairness and directional antenna concept can be used to improve the throughput, load balancing in the linear programmed algorithm (Kumar et al., 2020; Singh et al., 2020; Reghu et al., 2019). Thesis proposes a solution in the form of joint scheme of scheduling and routing based on the optimization formulation, its objective to provide the optimal solution. Network models represent the working and relation of IEEE 802.11s enhanced distributed channel access and hybrid wireless mesh protocol and the interference behavior for multi-interface directional mesh wireless sensor network. The standard IEEE 802.11 technology uses the enhanced distributed channel access protocol as a compulsory protocol and MCCA as an optional protocol (Kumar et al., 2015). Another protocol is the hybrid wireless mesh protocol used in data transmission (Kumar et al., 2015; Ye et al., 2023). The network model shows that IEEE 802.11 DCF is improved by EDCA, where multiple access priorities are given by implementing the multiple access categories and it improves the quality of service.

2.2 MAC Layer Issues

The various design issues need to be dealt with while designing the MAC protocols. The issues are given below:

1. MAC protocol must avoid collisions, idle listening and overhearing among the sensor nodes.
2. Congestion control algorithms designed in such a way that they easily manage duplicate packets, collided packets, and time out mechanism. Retransmission of packets is costly in terms of energy.
3. Implementation of priority scheduling algorithms to control overhead.
4. MAC protocols designed to support high traffic applications.
5. MAC protocols must be scalable in dense heterogeneous wireless sensor networks.

2.3 Channel Access and Data Forwarding of MAC Layer

IEEE 802.15.4 (ZigBee Technology) WSN provides low bit rates (bps) approximately 250 kb/s. The high bandwidth required applications are not implemented over such technologies and to run these applications with existing technologies is a challenging task. The use of multi-channel where different channels is assigned to the sensor nodes runs parallel transmissions and improves the data rate and high bandwidth applications runs successfully. Using the concept of multi-mode transmission in multi-channel environment increased the scalability and data rate. Heterogenous sensor nodes have different configuration and many of them support multi-channel. Both 802.11 and 820.15.4 specify the multiple frequencies and started a new era of multichannel communication in WSNs. ISM band 2.4 GHz is unlicensed and freely available to the devices. Many technologies like 802.15.4, 802.11 are using and sharing the same 2.4 GHz band. Therefore, the chances of interferences increased where electric appliances including microwave radiation, Bluetooth, hot spot, radars polluting the 2.4 GHz band. Wireless LAN supports IEEE 802.11 (Kumar et al., 2014; Sudhakaran et al., 2020; Adeogun et al., 2020; Lindsey et al., 2002) technology and operates over the 2.4 GHz and 5 GHz freely available bands. Many versions of IEEE 802.11 are in the market and vary according to the distance and data rate. Non-overlapping channels can be used to reduce the interferences among the wireless devices. Suppose three sensor nodes are deployed adjacent to each other, in that case they must operate over the 1, 6 and 11 channels to reduce the interferences. These channels are non-overlapping channels. In case only two sensor nodes are adjacent to each other they can use any channel with condition "both the channels must be five channels apart" like channels 4 and 9. The sensor nodes are self-configurable, and they have the capability to automatically select a channel based on the channel used by the adjacent sensor node. This concept reduces the interferences between the IEEE 802.11 and 802.15.4 technology also. By default, the available channels 15, 20, 25 and 26 of 802.15.4 do not overlap with the 802.11 available channels. The given channels guarantee the collision free environment only for the devices using 802.11 technology. There is some existence between both technologies and many researchers are working in this area.

2.4 Existing Protocol Comparison of MAC Layer

Simulation can be performed on NS2, NS3, MATLAB and many other open-source platforms. We worked on NS3 simulation tool and performed the simulation to compare the existing MAC protocols. We considered the simulation area of 1000m × 1000m and divided this area into 4 quadrants. The access points are fixed in the middle of each quadrant and these access points are configured on different frequencies to reduce the interferences. In each quadrant one node is randomly selected hence in total four. We simulated the protocols in unbalanced traffic scenario where any node selected as destination from the northeast quadrant and starts receiving the packets from access point (Ayoughi et al., 2019; Khusravirad et al., 2021; Chernyshev et al., 2018). Then we simulated balanced traffic that each quadrant selected as destination. This scenario we set up to simulate the two existing protocols. The first protocol is MCP where channels are assigned randomly and establish the path based on the available links, without considering the traffic factor over interface 2. The other simulated protocol is the UMA (utility maximization approach) which is running on interface 1. In this literature survey we studied various protocols already in use at MAC layer (Haas et al., 2020; Nyugen at al., 2022; Fany et al., 2021). We compared contention and TDMA based protocols and identified that contention-based protocol gives better performance compared to TDMA. We studied the channel access mechanism and how to forward the data among the nodes. We also found that each mesh node has multiple interfaces used to get maximum data rate in distributed environment. Based on data rate and data traffic at channels, algorithms select mesh access points which connect to external network. Finally, based on balanced and unbalanced traffic demand, algorithms select interfaces of every mesh node (Guo et al., 2021; Wu et al., 2018; Teja et al., 2023).

3. EE-MMAC CHANNEL DESIGN FOR DISTIBUTED WSNS

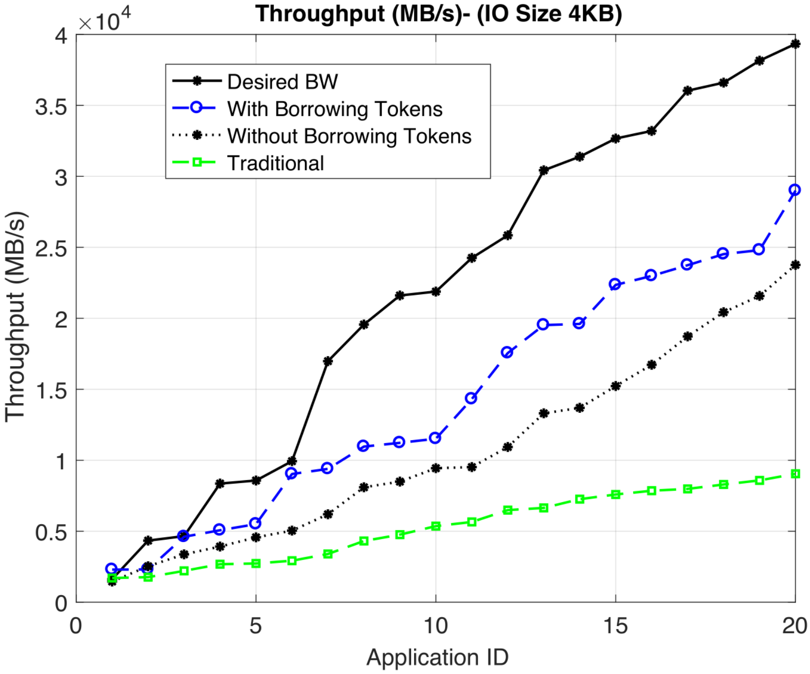
WSNs have become an important part of our life and supports various industrial applications from low bandwidth to high bandwidth (e.g., healthcare, military, civilian application, multimedia, Voice over IP, Internet of Things, and Internet of Everything) (Alsenwi et al., 2019; Tanab et al., 2019; Shahab et al., 2020). These critical applications require high bandwidth for the transmission of bulk amount of data without any delay. In WSNs, sensor nodes are randomly scattered and as per application demand of stay inactive and activate in case of sudden event detection. Generally, single channel is used in WSNs, but it creates a starvation problem which further stops the transmission and affects the performance. Mainly three reasons of starvation are hidden node, carrier sensing and symmetric terminal (Qiu et al., 2020; Chettri et al., 2020). To remove the starvation problem at MAC sub-layer and to improve the data rate, multiple channels are used in WSN. The use of multichannel access in the WSNs increases the throughput, packet delivery ratio and data rate in high traffic applications. The sensor nodes are designed to communicate on different free ISM band frequencies. This veracity has given new direction towards the multichannel communication standard in WSNs. The MAC protocols play an important role in energy saving at data link layer hence designing an appropriate MAC protocol is required (Kumar et al., 2020; Yung et al., 2023). Due to the advancement in hardware and software, the applications are exchanging bulk of data. Therefore EE-MMAC an energy efficient protocol is proposed which is based on multichannel and supports high bandwidth applications. The main concern of proposed EE-MMAC is to save the power at data link layer of communication stack. The EE-MMAC is focused on minimizing the time of idle listening, minimizing the time of overhearing, reducing the chance of packet collisions, and minimizing the control packet overhead.

EE-MMAC, a multichannel MAC protocol works with directional antenna unlike IEEE 802.11 and 802.15.4 (Mao et al., 2016; Karthikeyan et al., 2015). It uses the periodic sleep technique to save the energy at host to network layer. When a node is transmitting data, during that time other nodes must be in sleep mode motivated by S-MAC and PAMAS (Hsu et al., 2014). Proposed protocol uses n number of channels, one channel is configured as a control channel and other n-1 channels are configured as data channel. To mitigate starvation and in support of high traffic applications, nodes exchange control information over control channel to perform handshake, to decide the data channel and direction of the transmission respectively. Proposed protocol has been validated in NS3 and it achieves 20% to 35% energy saving in comparison to other existing protocols. The EE-MMAC, is a novel contention-based MAC protocol clearly designed for heavy traffic applications in low powered WSNs. The main concern of the proposed technique is power saving by enhancing throughput and minimizing packet collisions. To attain the predictable percentage of power saving, it is important to identify the origin of unusable resources and define the new algorithms to be incorporated to save energy. There are various deficiencies in existing MAC protocols and the main causes of energy waste are idle listening, control packet overhead, collision and overhearing. In idle listening, nodes always switch their transceiver on to listen to receive the possible packets that are never sent, and this is the main cause of power consumption at MAC layer. If there is nothing to receive over the channel, then no need to sense and node should switch to the inactive mode for a long amount of time. Many existing protocols are using the idle mode or sleep wake up procedure to save energy. The second deficiency in existing protocol is control frame overhead, these frames contain only protocol information and exchange no application data. Therefore, the number of control frames are exchanged by the sensor nodes to compete for the data transmission, node's energy is wasted in sending and receiving these control frames. The third deficiency is collision, and it occurs when packets collide with each other over the channel. The collided packets are discarded and retransmitted. The retransmission of packets increases congestion over the channel and results in more packets collision. This process consumes lots of energy from the sensor node. Fourth deficiency is overhearing means "sending a message during the time when receiver is not ready to receive" or "receiver receiving the frames intended for others". Transmitting these types of frames is a wastage of energy. The use of single channel MAC in data communication increases the chance of starvation which further stops communication. The starvation problem can be reduced by using the multiple channel concept. Proposed EE-MMAC Protocol based on existing MMAC and H-MMAC multi-channel protocols [5, 38, 29]. In a multichannel environment every sensor node works on different channels, one channel is used for transmission of control packets, for performing handshake and to select data channel from other channels. The EE- MMAC protocol considers that time is divided into beacon intervals which consist of an ad-hoc traffic indication messages (ATIM) window and a communication window. During ATIM window, all nodes listen to the control channel and exchange the number of packets to decide the data channel for data transmission. During communication window time, nodes adopt the negotiated data channel to transmit and receive the packets. Many sensor nodes are equipped with directional antenna and use network allocation vector to maintain the neighbors list and direction of channel respectively.

3.1 Algorithm Design Procedure

We propose a Multi-channel MAC protocol with Directional Antennas EEMMAC that adopts IEEE 802.11 Power Saving Mechanism (PSM) and exploits multiple channel resources and directional antennas. Participated sensor nodes are synchronized with each other according to the beacon frame during the ATIM window time [41]. Each EE-MMAC beacon frame is composed of ATIM and communication window time. ATIM window is mainly utilized for power saving. The participated sensor nodes must be active by the ATIM window time and perform handshake mechanism. During the handshake, nodes exchange the control information essential for the selection of channel. The participated sensor nodes complete handshake mechanism by exchanging the ATIM-R, ATIM-ACK control packets. After handshake successful nodes exchange the data and remaining nodes switched to the sleep mode to save energy. EE-MMAC protocol considers N channels, and each sensor node uses 2 channels in half duplex mode. It helps in solving the localization, multichannel issues and provides synchronization among the sensor nodes. Further, to improve the throughput and avoid collisions, two transmission modes are used. Omnidirectional mode is only used in handshaking over the control channel and directional mode is used in transmission of data packets over n-1 data channel. Directional mode works direction and solves multichannel issues like hidden node problems and sender block problems. In this mode sensor nodes send alert messages to hidden node in particular direction. One channel is defined as a Control Cannel (CC) and N-1 are Data Channels (DC). During ATIM window, all participated nodes exchange their RTS/CTS message over the CC to select data channel for sending and receiving the data. To improve the throughput and full utilization of resources, few nodes can transfer the data during the time of ATIM window and vice versa. Normal and advanced, two modes of transmission are considered in proposed EE-MMAC. Normal mode is in use where low volume of data is transferred over data channel only. Nodes having high volume of data used advance mode for the data transmission. In advance mode nodes can transfer the data over CC and data channel both to support the high traffic applications. Procedure for setting up of Transmission mode is shown in Figure 1.

Figure 1. Multi-channel transmission mode



EE-MMAC sensor nodes perform handshake over the control channel to select data channel and solve the multichannel issues. The handshake mechanism uses three types of control frames ATIM, ATIM-ACK, and ATIM-RES. Sensor node A starts the communication and transmits the ATIM control frame to designated sensor node B. ATIM frame has the knowledge of all the channels and provide the free channel information to the sensor nodes at that time. This information is very useful to avoid the congestion and status is available for all participated nodes. After knowing the available channel information, node B explores the beam direction towards the node A and based on the beam direction it selects the common data channel in the existing channel list and node A's existing channel list. In second phase, node B replies with ATIMACKNOWLEDGEMENT (AA) packet including the direction and common data channel for further communication. In third phase, node A acknowledges the packet AA by sending ATIM-RESERVATION (AR). Next, both nodes A and B broadcast the Directional Reservation (DR) packet in the opposite directions. Receiving the DR packets, the neighbors of nodes A and B get the information of AA, AR and DR packets and update data structures accordingly. Sensor nodes perform ATIM exchange to select data channel and beam direction as given in Figure 2, and then node transmits data over the selected data channel.

Every node maintains its Neighbor Information List (NIL) and Channel Usage List (CUL) to keep track of the information of the neighbor nodes. EE-MMAC is designed to find out the solutions of multichannel issues. ATIM, NIL and CUL techniques are used for the same. EE-MMAC NIL solves the receiver lost multichannel problem. Two types of antennae (omnidirectional and directional) are used in the proposed work to support the high bandwidth required applications. Omnidirectional antenna is used to transmit the ATIM message and directional antenna is used in transmission of DRES packets. These two channels aim to improve the throughput in the high bandwidth required applications. EEMMAC solves the head of line blocking of a node by considering a classifier to classify the data according to the direction and two array type buffers are required by each node per direction. These two techniques reduce the number of collisions and help in avoiding the node head block problem. Size of ATIM window is another important factor and its size should not be too low or high. In detail solutions to all the issues of multichannel are given below. If a node is transmitting at the DC during the ATIM window time, then the node will lose all communicated control messages. Consequently, it adopts that all other nodes that are on the CC (N_ATIM = 0) consider the advanced transmission mode and update N_ATIM = 2. An algorithm to update node NIL in each ATIM window is given in Figure 3.

Figure 2. Control channel and data channel selection during ATIM, data exchange

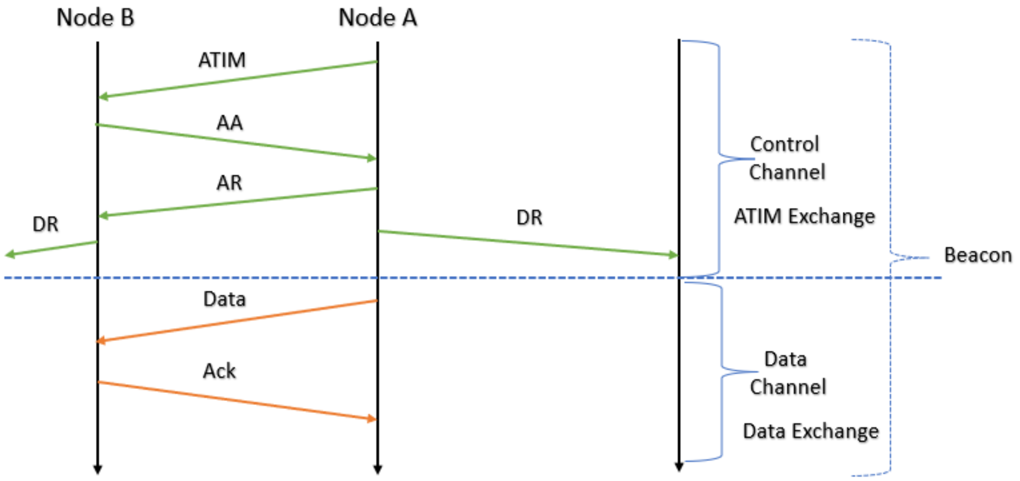
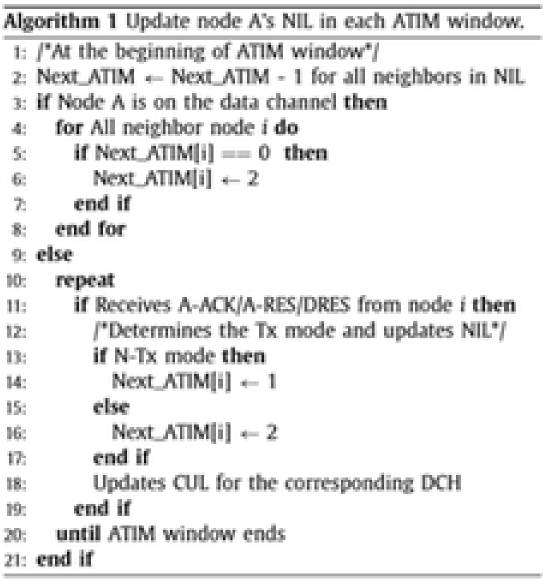


Figure 3. Node update algorithm

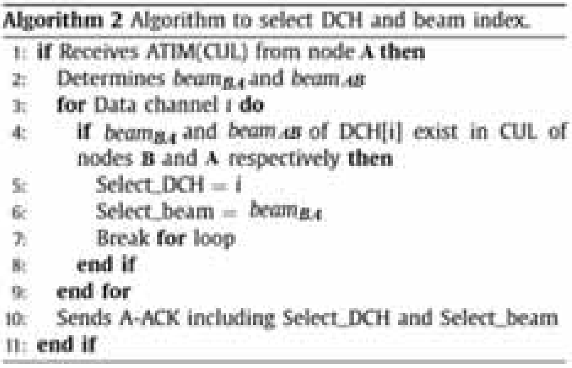


```
Algorithm 1 Update node A's NIL in each ATIM window.
/*At the beginning of ATIM window*/
Next_ATIM ← Next_ATIM - 1 for all neighbors in NIL
if Node A is on the data channel then
  for All neighbor node i do
    if Next_ATIM[i] == 0 then
      Next_ATIM[i] ← 2
    end if
  end for
else
  repeat
    if Receives A-ACK/A-RES/DRES from node i then
      /*Determines the Tx mode and updates NIL*/
      if N-Tx mode then
        Next_ATIM[i] ← 1
      else
        Next_ATIM[i] ← 2
      end if
      Updates CUL for the corresponding DCH
    end if
  until ATIM window ends
end if
```

3.2 Channel Usage List

EE-MMAC uses CUL to store the status and beam direction of every channel. CUL is updated based on the exchange of control message over CC during the ATIM window time. A node uses multiple beam directions on every control channel and data channel. Let us consider that a source node A does not know the location of the destination node B. First node A includes its CUL in ATIM message. Consider node A using two directions, dir1 and dir2 and node B using dir2 and dir3. Node A forwards ATIM message to B, then node B determines data channel and beam direction towards node A based on node A's CUL. Node B selects beam direction, from source to destination & vice-versa, based on receiving channel of ATIM message & A's CUL. Node A using dir1 and node B using dir4. Then node B determines the common beam of common data channel using CUL of node A and B. At last node B replies to acknowledgment of ATIM message including channel and beam direction dir4 information selected for communication. An algorithm to select DCH & beam index is given in Figure 4.

Figure 4. Algorithm to select DCH and beam index



```
Algorithm 2 Algorithm to select DCH and beam index.
if Receives ATIM(CUL) from node A then
  Determines $beam_{BA}$ and $beam_{AB}$
  for Data channel i do
    if $beam_{BA}$ and $beam_{AB}$ of DCH[i] exist in CUL of
    nodes B and A respectively then
      Select_DCH = i
      Select_beam = $beam_{BA}$
      Break for loop
    end if
  end for
  Sends A-ACK including Select_DCH and Select_beam
end if
```

3.3 EE-MMAC Protocol

The step by step working of EE-MMAC protocol is given below. We assumed that node A has an interest to transmit a few packets to node B.

Step 1: During the ATIM window of beacon frame, Node A checks its own NIL and find out the status of other node B. If the status of node B is active, node A transmits an ATIM packet towards node B in omnidirectional mode. This ATIM packet includes the information of CUL and transmission mode. Otherwise, node A waits till the next beacon.

Step 2: Node B is active and receives the ATIM message. Node B opens the ATIM message and reads the CUL and transmission mode status. Now based on node A CUL and its own CUL node B finds out the data channel and direction to reach to node A. Once direction and channel identify by node B then it replies to AA message using omnidirectional mode.

Step 3: On receiving AA message by node A, it replies to an AR message to node B. This reply message confirms the selected data channel and beam direction. The directions of both the nodes are opposite since the nodes are in opposite directions.

Step 4: Now both the nodes broadcast a DR message to alert their neighbors. Nodes use directional mode of transmission and on the opposite side.

Step 5: After overhearing the AA/AR/DR messages, neighbors update their data structure and CULs.

Step 6: Following the steps 1 to 5, node A and B are successful in channel selection and starts the data transmission. Other nodes which are not successful in channel selection or not able to complete the above steps due to any reason switch to sleep mode to optimize the energy at MAC sub-layer.

The proposed algorithm takes full advantage of channel resources and utilizes them accordingly. When nodes are busy exchanging control packets over the control channel during ATIM window time then data channels should not be free. Similarly, a control channel is used to send and receive the data during the communication window time. The active nodes use advance mode to transmit the data over the data channel during the ATIM window time. The control packets are exchanged during ATIM window over CC, and it creates little bit overhead. In EE-MMAC protocol after ATIM exchanged, nodes are eligible to transmit number of data packets without several contentions. Therefore, the proposed protocol reduces the contention overhead and controls packets overhead to transmit the individual data packets over the data channel. The example is explained in Figure 5, During the ATIM window time node C & D performed handshake and opted CC for the transmission of data. Now node A and B exchanged control packets during the same ATIM window and selected data channel 1 for data transmission because CC is already reserved. After performing handshake DR message helps other nodes to update their data structures about the reservation of channels. EE-MMAC uses the directional antenna therefore node G and node H opted the same data channel 1 for data transmission but in different directions. During the same ATIM window nodes E and F selected data channel 2 for the data transmissions. Now the first ATIM window time out and data transmission start over the opted channels and so on.

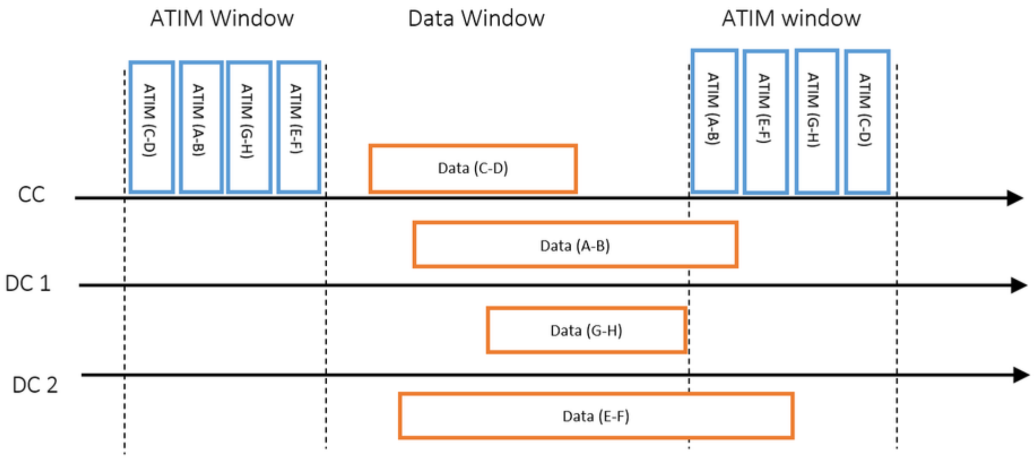
4. PERFORMANCE EVALUATION AND SIMULATION OF EE-MMAC

We analyze the throughput of the EE--MMAC mechanism for a data channel Ci as follows:

$$S^{i}_{C} = m / (T_{cp} + T_{m} + T_{h} + ACK + ATIM) \qquad (1)$$

Where T_{cp} is the contention period for a single data channel reservation on the control channel and other parameters given in equation are considered as a constant. To achieve maximum throughput of data channel we need to minimize the contention period T_{cp} and minimize the amount of time (T^{0}_{C}). Subsequently, T^{0}_{C} controls the number of data channels that the EE-MMAC can support. A sender and a receiver spend time on the control channel to make a data channel reservation using an equation:

Figure 5. Data transmission procedure



$$T^0_C = DIFS + T_{cp} + RTS + SIFS + CTS \tag{2}$$

We can express Tcp and T^0_C as follows:

$$Tcp = E\,[T_{i2}]\ st + E\,[Nc]\ (T_c + PIFS + E[T_{i1}]\ st) \tag{3}$$

$$T^0_C = DIFS + E[Ti2]\ st + E[Nc]\ (Tc + PIFS + E[Ti1]\ st) + RTS + SIFS + CTS \tag{4}$$

Where $E[T_{i2}]$ is the average number of idle slots, $E[T_{i1}]$ the average number of idle slots after a collision, E[Nc] is the average number of collisions, Tc is time duration for each collision, and st is the length of a slot during ATIM window. We showed that the transmission probability (p) for a finite load is equal to:

$$p = 2qi\ /(3Ws + 1)\ qi + 2(1\text{-}q0) \tag{5}$$

Where q0 is the probability that the user's buffer has at least one packet remaining after transmission of a packet, and qi is the probability that a user will generate a packet within a data channel reservation period. For the heavy load, where users working on high traffic applications and always has a packet to transmit then the transmission probability becomes:

$$p = 2/(3Ws + 1) \tag{6}$$

The probability P_idle and P_busy in each time slot during the ATIM window are given as:

$$P\{idle\} = Pi = (1\text{-}p)\ M \tag{7}$$

Where M is the number of users in the system.

$$P\{busy\} = P\{transmission\} = Pt = 1 - (1 - p)\ M \tag{8}$$

When the ATIM window size (Ws) is large enough, the number of users colliding will be fewer than two, which will provide the highest throughput. With this assumption, we can express the expected number of collisions E[Nc] as:

$$E[Nc] = E[Nc/Mt= 2\ ]\ Pr(Mt = 2/Mt \geq 1) \quad (9)$$

When two users enter with the same priority, they will collide initially. Then they will each choose a new backoff counter uniformly from the discrete range (0, Wc-1) after each collision. For every contention period, these two users collide with probability Pc = 1/Wc and succeed with probability Ps = (Wc -1)/Wc. Therefore, the expected number of collisions, including the initial one,

$$E[Nc/Mt = 2] = 1 + \sum j\ P^{j}c\ .\ Ps = 1 + Pc/\ Ps = Wc\ /(Wc\ -1) \quad (10)$$

EE-MMAC ATIM window size affects the number of successful ATIM handshakes. The subsequent number of contending nodes is decreased after every successful ATIM handshake. The optimal ATIM window size T_atim_window needs to be estimated in order to maximize the number of concurrent transmissions Ntx, where:

$$Ntx = \min\ (T\_atim\_window/Esuc,\ Ncon,\ Nch) \quad (11)$$

The simulations are conducted with 200 nodes which are placed in a 500 m ×500 m area. Every deployed node has the capability to communicate within its range. The node joins the cluster and forms a point-to-point connection. A node senses the event, generates the packets and forwards to cluster head node by a fixed rate. Every node is equipped with antenna and operates in directional and omnidirectional mode. Each simulation is conducted in 10s and the simulation results are an average of 200 runs of different topologies.

The EE-MMAC simulation is completed according to the evaluation metric presented in table 2. We simulated and compared the IEEE 802.11, MMAC, and EE-MMAC protocols and results are explained in the form of graphs. As per Figure 5, as the loads are increasing over the network resulting packet delivery ratio is decreasing. The reason is use of single channel, which is not scalable and cannot handle the load beyond certain threshold. The packet arrival rate creates congestion and increases the chance of collision. Due to collisions of packets retransmission happens which is the main cause of energy consumption. The EE-MMAC uses multiple channels where nodes concurrently transmit the data on different channels. Figure 6 shows that, as the packet arrival rate increases, EE-MMAC easily handles the situation compared to other protocols and gives better results in high bandwidth or traffic applications. Use of multi-channel, directional antenna, omnidirectional antenna, normal mode, and advance mode are the reasons for multiple concurrent transmissions which further improves the spatial reuse. Aggregate throughput is similar for all simulated protocols in low traffic environment. As traffic increases the throughput of EE-MMAC is higher compared to other protocols. The throughput comparison is given in Figure 7. Advanced mode improves the throughput in heavy traffic.

Figure 8 of simulation results shows that EE-MMAC gives a somewhat poor performance when data traffic is low, and delay is high as compared to other protocols. IEEE 802.11 gives better results for low load. IEEE 802.11 using the single channel and access the channel when a node has some data to send. The multichannel protocols first negotiate on the control channel to select a data channel for transmission. If a node is in doze mode, it waits till the next ATIM window, then negotiates on CC to select a data channel. This is the main cause of high delay in low traffic on the multichannel environment. As data rate increases the delay of EE-MMAC is less compared to the other since multichannel MAC is capable of concurrent transmissions compared to a single channel. EE-MMAC improves the quality of service of application till threshold point. Energy consumption results for

Figure 6. Packet delivery ratio results

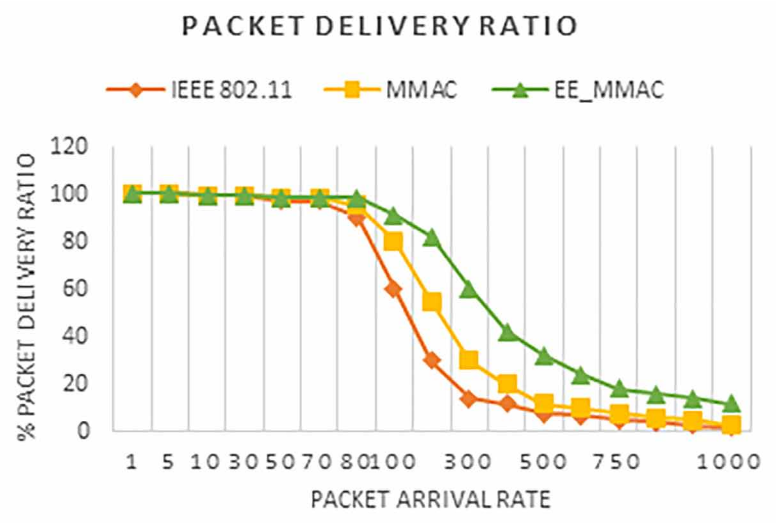


Table 1. Simulation parameters

S.No	Parameter	Value
1	Total DC and CC	4
2	Total beams	4
3	Beacon interval time/ATIM window time	100/20 ms
4	SIFS/DIFS/Slot time	16/32/10 Micro s.
5	ATIM	28 byte
6	AA/AR/DR	16/16/16 byte
7	Wireless Data Rate	54 Mbps
8	Size of transmitted packets	4096 bits
9	Thresh hold for retry	6
10	Wireless transmission range	250 m
11	Power consumption in transmission or receiving	1.65 w/ 1.4 w
12	Idle/Sleep mode consumption	1.15 w/ .04 w

simulated protocols are given in Figure 9. The nodes that have nothing to send go to sleep mode during ATIM window time to save energy while IEEE 802.11 uses idle mode in the same situation. Idle mode (1.15 w) consumes more energy compared to sleep mode (.04 w). EE-MMAC transmits more packets and consumes less energy compared to IEEE 802.11 and MMAC.

5. CONCLUSION

This work addresses some of the fundamental problems in multichannel MAC and protocol design for emerging wireless networks. On the basis of the search conducted through various patent databases and technical publications, an intelligent energy efficient multichannel MAC (EE-MMAC) is presented.

Figure 7. Throughput comparison results

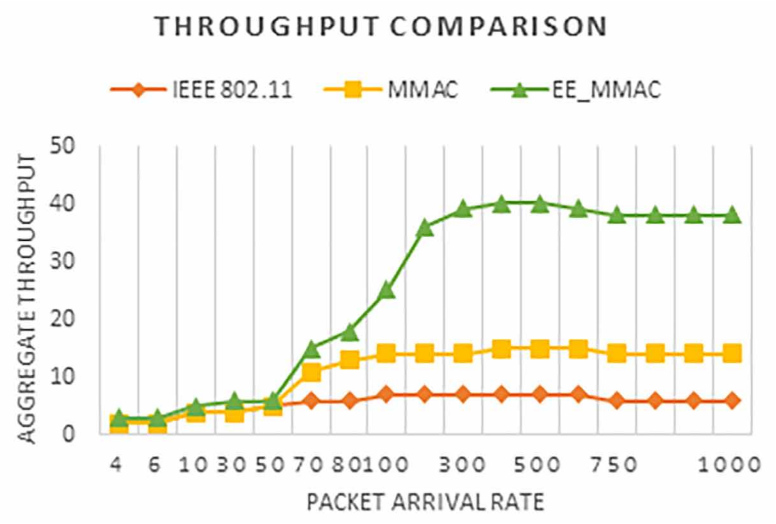


Table 2. Evaluation metric

S.No	Parameter	Function
1	Throughput	Pkt Size ∗No of Successful pkt/ Total simulation time
2	PDR	Total pkt received/Total pkt Generated
3	Average transmitted delay	Total Delay in transmission/No of transmitted Pkt
4	Energy Efficiency	Total Energy Consumption/No of transmitted pkt

Figure 8. Average delay comparison results

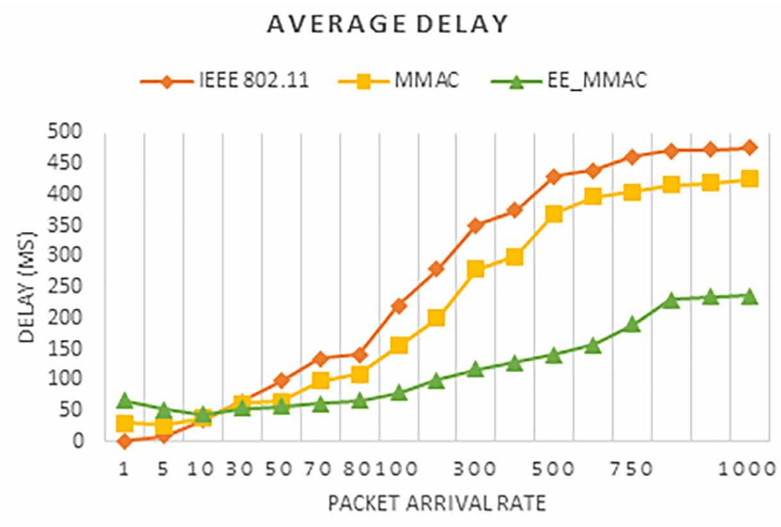
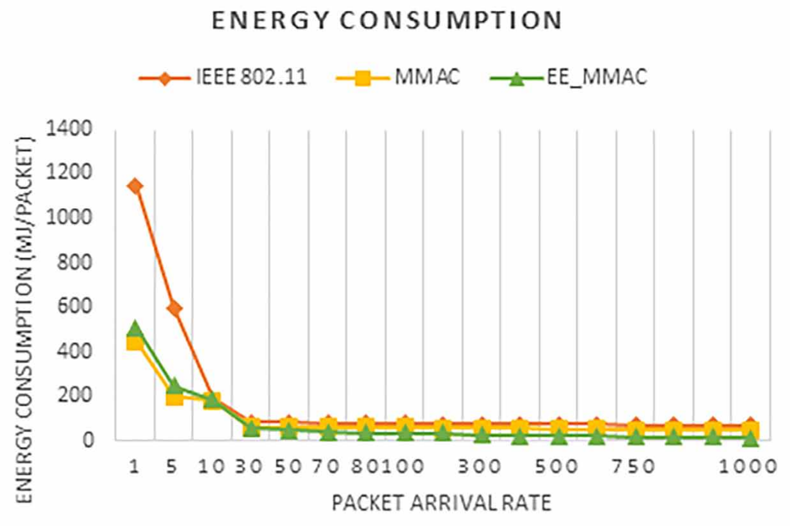


Figure 9. Energy consumption results



We have explored the efficient use of resources in WSNs at the MAC layer. The Intelligent EE-MMAC algorithm combines multichannel with directional information for high traffic applications. It achieves energy optimization by decreasing the idle listening and sleep cycles using the periodic listen and control information transmission over the control channel. Use of advanced mode, normal mode, multiple data channels and single control channels increases the QOS of networks. EE-MMAC reduces collisions by providing solutions for hidden node problems, receiver lost problem and sender block problem. Further, it optimizes energy by reducing the significant number of collisions at MAC layer. During the work our main aim was to optimize the energy at MAC layer of WSNs.

REFERENCES

Adeogun, R., Berardinelli, G., Mogensen, P., Rodriguez, I., & Razzaghpour, M. (2020). Towards 6G in-X subnetworks with sub-millisecond communication cycles and extreme reliability. *IEEE Access : Practical Innovations, Open Solutions*, *8*, 110172–110188. doi:10.1109/ACCESS.2020.3001625

Alsenwi, M., Tran, N. H., Bennis, M., Bairagi, A. K., & Hong, C. S. (2019). EMBB-URLLC resource slicing: A risk-sensitive approach. *IEEE Communications Letters*, *23*(4), 740–743. doi:10.1109/LCOMM.2019.2900044

Ayoughi, S. A., Yu, W., Khosravirad, S. R., & Viswanathan, H. (2019). Interference mitigation for ultrareliable low-latency wireless communication. *IEEE Journal on Selected Areas in Communications*, *37*(4), 869–880. doi:10.1109/JSAC.2019.2898786

Chernyshev, M., Baig, Z., Bello, O., & Zeadally, S. (2018). Internet of Things (IoT): Research, simulators, and testbeds. *IEEE Internet of Things Journal*, *5*(3), 1637–1647. doi:10.1109/JIOT.2017.2786639

Chettri, L., & Bera, R. (2020). A comprehensive survey on Internet of Things (IoT) toward 5G wireless systems. *IEEE Internet of Things Journal*, *7*(1), 16–32. doi:10.1109/JIOT.2019.2948888

Dubey, G., Kumar, S., Kumar, S., & Navaney, P. (2020). Extended Opinion Lexicon and ML based Sentiment Analysis of tweets: A novel Approach towards Accurate Classifier. *International Journal of Computational Vision and Robotics*, *10*(6), 505–521. doi:10.1504/IJCVR.2020.110640

El Tanab, M., & Hamouda, W. (2019). Machine-to-machine communications with massive access: Congestion control. *IEEE Internet of Things Journal*, *6*(2), 3545–3557. doi:10.1109/JIOT.2018.2888502

Fang, X., Feng, W., Wei, T., Chen, Y., Ge, N., & Wang, C.-X. (2021). 5G embraces satellites for 6G ubiquitous IoT: Basic models for integrated satellite terrestrial networks. *IEEE Internet of Things Journal*, *8*(18), 14399–14417. doi:10.1109/JIOT.2021.3068596

Guo, F., Yu, F. R., Zhang, H., Li, X., Ji, H., & Leung, V. C. (2021). Enabling massive IoT toward 6G: A comprehensive survey. *IEEE Internet of Things Journal*, *8*(15), 11891–11915. doi:10.1109/JIOT.2021.3063686

Haas, H., Yin, L., Chen, C., Videv, S., Parol, D., Poves, E., Alshaer, H., & Islim, M. S. (2020). Introduction to indoor networking concepts and challenges in LiFi. *Journal of Optical Communications and Networking*, *12*(2), A190–A203. doi:10.1364/JOCN.12.00A190

Hsu, C. H., Slagter, K. D., Chen, S. C., & Chung, Y. C. (2014). Optimizing Energy Consumption with Task Consolidation in Clouds. *Information Sciences*, *258*, 452–462. doi:10.1016/j.ins.2012.10.041

Karthikeyan, G. K., Jayachandran, P., & Venkataraman, N. (2015). Energy aware network scheduling for a data centre. *International Journal of Big Data Intelligence*, *2*(1), 37–44. doi:10.1504/IJBDI.2015.067573

Khosravirad, S. R., Viswanathan, H., & Yu, W. (2021). Exploiting diversity for ultra-reliable and low-latency wireless control. *IEEE Transactions on Wireless Communications*, *20*(1), 316–331. doi:10.1109/TWC.2020.3024741

Kumar, S., Cengiz, K., Vimal, S., & Suresh, A. (2022). Energy Efficient Resource Migration Based Load Balance Mechanism for High Traffic Applications IoT. *Wireless Personal Communications*, *127*(1), 385–403. doi:10.1007/s11277-021-08269-7

Kumar, S., Ranjan, P., Radhakrishnan, R., & Tripathy, M. R. (2015). A ns3 implementation of physical layer based on 802.11 for utility maximization of wsn. *2015 International Conference on Computational Intelligence and Communication Networks (CICN)*, Jabalpur, India. doi:10.1109/CICN.2015.25

Kumar, S., Ranjan, P., Ramaswami, R., & Tripathy, M. R. (2015). Energy aware distributed protocol for heterogeneous wireless sensor network. *International Journal of control and automation, 8*(10), 421-430. .10.14257/ijca.2015.8.10.38

Kumar, S., Ranjan, P., Ramaswami, R., & Tripathy, M. R. (2015). A Utility Maximization Approach to MAC Layer Channel Access and Forwarding. *Progress in Electromagnetics Research Symposium,* 2363-2367.

Kumar, S., Ranjan, P., Ramaswami, R., & Tripathy, M. R. (2015). EMEEDP: Enhanced multi-hop energy efficient distributed protocol for heterogeneous wireless sensor network. In *Proceedings of 2015 5th International Conference on Communication Systems and Network Technologies, CSNT 2015*, (pp. 194-200). IEEE. doi:10.1109/CSNT.2015.123

Kumar, S., Ranjan, P., Ramaswami, R., & Tripathy, M. R. (2017). Energy Efficient Multichannel MAC Protocol for High Traffic Applications in Heterogeneous Wireless Sensor Networks. *Recent Advances in Electrical & Electronic Engineering (Formerly. Recent Advances in Electrical & Electronic Engineering*, *10*(3), 223–232. doi:10.2174/2352096510666170601090202

Kumar, S., Ranjan, P., Ramaswami, R., & Tripathy, M. R. (2017). Resource efficient clustering and next hop knowledge-based routing in multiple heterogeneous wireless sensor networks. [IJGHPC]. *International Journal of Grid and High Performance Computing*, *9*(2), 1–20. doi:10.4018/IJGHPC.2017040101

Kumar, S., Ranjan, P., Singh, P., & Tripathy, M. R. (2020). Design and Implementation of Fault Tolerance Technique for Internet of Things (IoT). In *Proceedings of 2020 12th International Conference on Computational Intelligence and Communication Networks, CICN 2020*. IEEE.

Kumar, S., Rao, A. L. N., & Ramaswami, R. (2014). Energy optimization technique for distributed localized wireless sensor network. In *Proceedings of the International Conference on Issues and Challenges Intelligent Computing Technique (ICICT)*, 350-355. doi:10.1109/ICICICT.2014.6781306

Kumar, S., Trivedi, M. C., Ranjan, P., & Punhani, A. (2020). *Evolution of Software-Defined Networking Foundations for IoT and 5G Mobile Networks*. IGI Publisher. . doi:10.4018/978-1-7998-4685-7

Lindsey, S., Raghavendra, C., & Sivalingam, K. M. (2002). Data gathering algorithms in sensor networks using energy metrics. *IEEE Transactions on Parallel and Distributed Systems*, *13*(9), 924–935. doi:10.1109/TPDS.2002.1036066

Liu, J., Au, K., Maaref, A., Luo, J., Baligh, H., Tong, H., Chassaigne, A., & Lorca, J. (2018). Initial access, mobility, and user-centric multi-beam operation in 5G new radio. *IEEE Communications Magazine*, *56*(3), 35–41. doi:10.1109/MCOM.2018.1700827

Ma, J., Fan, L., Tian, W., & Miao, Z. (2023). Research on Data Classification Method of Optimized Support Vector Machine Based on Gray Wolf Algorithm. [IJGHPC]. *International Journal of Grid and High Performance Computing*, *15*(2), 1–14. doi:10.4018/IJGHPC.318408

Mao, L., De, Y. Q., Lin, W. W., Liu, B., & Li, Y. D. (2016). An Energy-Efficient Resource Scheduling Algorithm for Cloud Computing based on Resource Equivalence Optimization. [IJGHPC]. *International Journal of Grid and High Performance Computing*, *8*(2), 43–57. doi:10.4018/IJGHPC.2016040103

Mohammadi, M., Al-Fuqaha, A., Sorour, S., & Guizani, M. (2018). Deep learning for IoT big data and streaming analytics: A survey. *IEEE Communications Surveys and Tutorials*, *20*(4), 2923–2960. doi:10.1109/COMST.2018.2844341

Nguyen, D. C., Ding, M., Pathirana, P. N., Seneviratne, A., Li, J., Niyato, D., Dobre, O., & Poor, H. V. (2022). 6G Internet of Things: A Comprehensive Survey. *IEEE Internet of Things Journal*, *9*(1), 359–383. doi:10.1109/JIOT.2021.3103320

Punhani, A., Faujdar, N., & Kumar, S. (2019). Design and Evaluation of Cubic Torus Network-on-Chip Architecture. [IJITEE]. *International Journal of Innovative Technology and Exploring Engineering*, *8*(6), 1672–1676.

Qiu, J., Tian, Z., Du, C., Zuo, Q., Su, S., & Fang, B. (2020). A survey on access control in the age of Internet of Things. *IEEE Internet of Things Journal*, *7*(6), 4682–4696. doi:10.1109/JIOT.2020.2969326

Reghu, S., & Kumar, S. (2019). Development of Robust Infrastructure in Networking to Survive a Disaster. *4th International Conference on Information Systems and Computer Networks, ISCON 2019*, (pp. 250-255). IEEE. doi:10.1109/ISCON47742.2019.9036244

Shahab, M. B., Abbas, R., Shirvanimoghaddam, M., & Johnson, S. J. (2020). Grant-free non-orthogonal multiple access for IoT: A survey. *IEEE Communications Surveys and Tutorials*, *22*(3), 1805–1838. doi:10.1109/COMST.2020.2996032

Sharma, A., Awasthi, Y., & Kumar, S. (2020). The Role of Blockchain, AI and IoT for Smart Road Traffic Management System. In *Proceedings of 2020 IEEE India Council International Subsections Conference, INDISCON 2020*. IEEE.

Singh, P., Bansal, A., Kamal, A. E., & Kumar, S. (2022). Road Surface Quality Monitoring Using Machine Learning Algorithm. *Smart Innovation. Systems and Technologies*, *265*, 423–432. doi:10.1007/978-981-16-6482-3_42

Singh, P., Bansal, A., & Kumar, S. (2020). Performance analysis of various information platforms for recognizing the quality of Indian roads. In *Proceedings of the Confluence 2020 - 10th International Conference on Cloud Computing, Data Science and Engineering*. IEEE. doi:10.1109/Confluence47617.2020.9057829

Sudhakaran, S., Kumar, S., Ranjan, P., & Tripathy, M. R. (2020). Blockchain-Based Transparent and Secure Decentralized Algorithm. *International Conference on Intelligent Computing and Smart Communication 2019, Algorithms for Intelligent Systems.* Springer, Singapore. doi:10.1007/978-981-15-0633-8_32

Teja, S. B., Varma, G. P., & Indukurib, H. (2023). Mobile Edge Computing Architecture Challenges, Applications, and Future Directions. [IJGHPC]. *International Journal of Grid and High Performance Computing*, *15*(2), 1–23. doi:10.4018/IJGHPC.316837

Wang, C.-X., Bian, J., Sun, J., Zhang, W., & Zhang, M. (2018). A survey of 5G channel measurements and models. *IEEE Communications Surveys and Tutorials*, *20*(4), 3142–3168. doi:10.1109/COMST.2018.2862141

Wu, Y., Gu, Y., & Wang, Z. (2018). Channel estimation for mmWave MIMO with transmitter hardware impairments. *IEEE Communications Letters*, *22*(2), 320–323. doi:10.1109/LCOMM.2017.2769657

Yang, J., He, J., & Wang, X. (2023). Design of Intelligent Parking System Based on Internet of Things and Cloud Platform. [IJGHPC]. *International Journal of Grid and High Performance Computing*, *15*(2), 1–18. doi:10.4018/IJGHPC.316836

Yang, J. Z., & Zhao, C. (2016). Energy-efficient and self-adaptive routing algorithm based on event-driven in wireless sensor network. *International Journal of Grid and Utility Computing*, *7*(1), 41. Advance online publication. doi:10.1504/IJGUC.2016.073776

Ye, G., Gao, F., Fang, J., & Zhang, Q. (2023). Joint Workload Scheduling in Geo-Distributed Data Centers Considering UPS Power Losses. *IEEE Transactions on Industry Applications*, *59*(1), 612–626. doi:10.1109/TIA.2022.3214186

Sunil Kumar is a distinguished researcher, educator, and innovator in the field of Computer Science and Engineering, renowned for his groundbreaking contributions to academia and his pioneering work in network technologies. With a career spanning over a decade and a half, Dr. Kumar's journey has been marked by a relentless pursuit of knowledge and a commitment to fostering excellence in education and research. One of the hallmarks of Dr. Kumar's career has been his role as an Associate Professor in the Computer Science and Engineering Department at Amity University. Here, he fostered a dynamic and innovative learning environment, inspiring countless students to explore the frontiers of technology. His 16 years of teaching and training experience span both undergraduate and postgraduate levels, showcasing his versatility and dedication to nurturing the next generation of computer scientists. In addition to his teaching responsibilities, Dr. Kumar's research prowess has left an indelible mark on the academic landscape. He has authored many research papers in esteemed international journals and presented his work at renowned conferences, elevating the discourse surrounding computer networks, distributed systems, wireless sensor networks, and network security. His research has not only contributed to the theoretical underpinnings of these fields but has also paved the way for practical applications that address real-world challenges. In recognition of his exemplary contributions to research and academia, Dr. Sunil Kumar currently serves as a Postdoctoral Research Fellow at the University of Surrey, United Kingdom. This prestigious role allows him to collaborate with leading minds in the field and further his research into cutting-edge network technologies.