ISSN 2278-3091
Volume 8, No.1.5, 2019
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse6381.53019.pdf
https://doi.org/10.30534/ijatcse/2019/6381.52019

Energy Efficient Medium Access Control Protocols for Wireless Sensor Networks – A Survey

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ABSTRACT

The Wireless Sensor Networks (WSNs) are not centralized and doesn't have a proper infrastructure that enables it to be the dominant networking solution for major communication demands. Though, a number of efforts have been made to augment WSN routing protocols, however ever-increasing complexity including topological variations, resource constrained environment, event-driven deadline sensitive communication demands alarm for better routing scheme. Amongst major potential solutions optimizing Medium Access Control (MAC) of the standard IEEE 802.15.4 which is default protocol stack of WSN has always been the dominant solution. However, to cope-up with above stated demands augmenting MAC protocol has always been an open and broadened horizon for researchers. With this motivation, in this paper, surveys of numerous recently developed state-of-arts MAC protocols have been presented. In addition to this, different MAC protocols with respective strengths as well as weaknesses have been presented.

Key words: Cross Layer Architecture, MAC protocol, Quality of Service, Wireless Sensor Networks.

1. INTRODUCTION

The exponential up-surge in wireless communication systems and associated applications has revitalized industries as well as academicians to develop more efficient, reliable and Quality of Service (QoS) centric communication networks. Amongst major wireless networks Wireless Sensor Networks (WSNs) have gained immense attention across global horizon. The decentralized and infrastructure-less characteristics of WSNs enable it to be one of the dominant networking solutions. WSNs have been applied in major time-critical communication systems serving surveillance purposes, industrial monitoring and control, healthcare, battlefield, strategic infrastructure security, industrial process monitoring, tactical systems and target detection and tracking etc [1-5]. The recently developed technology called Internet-of-Things (IoT) has been exploiting the efficacy of Low Power Lossy Networks (LLNs), a variant of WSNs for major Machine-to-Machine (M2M) communication purposes. These all efficacies exhibit broadened horizon for WSNs applications. WSN based IoT applications are growing at a remarkably high pace thus leading development of advanced embedded systems and allied technologies. However, it demands efficient communication technologies to ensure optimal performance. Exploring in depth, it can be visualized that the aforesaid or similar applications demand reliable and event-driven communication for which ensuring optimal routing decision is inevitable.

A. Considering architecture of the WSNs, it is a network comprising a large number of low power, low cost sensor nodes interconnected by means of wireless medium that functions in a cooperative manner. Undeniably, WSN nodes are resource constrained and battery operated that undergoes continuous exhaustion leading node death. Under such conditions ensuring optimal routing decision and power control is must to retain a node for elongated lifetime. To achieve optimal performance different approaches [1-3] have been proposed where both system level routing optimization as well as physical level routing [1] have been recommended; however, optimizing Medium Access Control (MAC) as always been the dominant solution. Optimizing MAC can enable both resource efficiency (i.e., energy and/or spectrum efficiency) as well as QoS provision to meet mission critical communication. To meet major application's demands WSN requires supporting high data rate, low latency and low energy-exhaustive IEEE 802.15.4 protocol. To achieve it augmenting IEEE 802.15.4 standard with better resource scheduling, CSMA/CA provision etc has been recommended; however, developing a robust model with all associated parameter conditions has always been a challenging task. On the other hand, the recently introduced or recommended mobile-WSN [7] concept that often undergoes dynamic topological changes has alarmed scientific community to assure optimal MAC scheduling for reliable and QoS centric communication [2-5][7]. Mobile-WSN often undergoes topological variations, link-outage, data drop and retransmission imposing huge energy exhaustion, delay [8] and resource consumption [9] and hence requires optimal routing decision.

Typically, QoS in communication system is the network capability in fulfilling the requirements of user and application that is specific. Parallel to the recent advancements, there has been observed an urgent need of designing and developing QoS support in each layer of the typical protocol stack (i.e., standard IEEE 802.15.4) since up-coming applications are completely unique. Major applications such as M2M do operate on mission critical communication concept that demands reliable, resource-efficient and time-efficient routing. To ensure QoS it is important that the protocol stack entries is to be communicated well to work cooperatively [9]. Though, MAC layer dominates the process because its rules to share the medium and supports reliable communication can achieve network condition aware resource allocation and transmission control to avoid unwanted loss or retransmission. Undeniably, the support of QoS at the MAC layer constitutes the foundation of the communication stack and possesses the capability to adjust important parameters such as end-end delay transmission, duty cycle of sensor devices, node/link quality adaptive forwarding node selection etc. Undeniably, the role of MAC layers can't be ignored and hence augmenting it can reflect the efficacy of other layers as well to achieve better network performance []. The efficacies of MAC towards QoS centric routing motivate researchers to develop robust MAC models []. MAC layer has also unavoidable role to achieve energy-efficiency by duty cycling and network condition aware transmission scheduling. Considering the key roles and significance of MAC layer in WSN developing a novel MAC model can be of paramount significance. This factor can be stated as a driving force behind current study.

Before exploring in depth of the different MAC protocols for WSNs, understanding QoS constructs and key network demands is vital. A snippet of the key QoS intricacies and demands is given in the sub-sequent sections.

QoS Challenges in WSNs

Some of the key challenges towards achieving QoS provision in WSNs are given as follows:

Resource constraints: As already stated in above discussion, WSN node being resource constrained (battery as well as bandwidth constrained) requires optimal routing decision as an inefficient routing might force network to undergo packet loss, link-outage, retransmission etc. In such cases augmenting WSNs with better routing power management strategies, resource and link aware routing, data centric resource allocation or service differentiation etc can be vital.

Topological Variations: Undeniably, the inclusion of mobility can broaden the horizon of WSN applications; however, at the cost of increased challenges such as link-outage probability, losses etc. In such cases, augmenting routing protocols with better network and link sensitive routing is must. Furthermore, node-death sensitive supplementary path formation can also be vital.

Scalability: WSNs comprise so many hundreds and thousands of nodes but as the requirement the number of nodes can be increased further. This calls for the need of a well designed QoS centric routing mechanism that could cope up with varied network size or purposes.

Nodes deployment: Nodes can be taken in to consideration on the basis of two ways-randomly and deterministically. In deterministic deployment we can perform routing via already determined paths which is not possible with random deployment.

Dynamic Channel Capacity: Though, in wired communication systems, the link capacity is assumed to be predefined and fixed, in multi-hop sensor networks, the achievable capacity of each wireless link relies on the extent of interference at the receiver. This as a result primarily relies on the inter-communication of the different functions that are distinctly dealt by the network components including power control, routing control, and rate control approaches. Therefore, the parameters like network capacity and achievable delay at each link used to be (node) position dependent, varying dynamically, and might undergo bursty transmission. These all factors as cumulative outcomes make QoS provisioning really a highly tedious task.

Application-Specific QoS demands-Majority of the WSNs exhibits scalar network characteristics and transmits data in different forms, such as streaming multimedia data, still images, audio signals, audio-video signals etc. Typically, the streaming multimedia content is obtained over longer time periods that eventually need unrelenting data delivery, even on time delivery to meet QoS demands. In other words, enabling delay resilient or deadline sensitive transmission is of utmost significance for QoS delivery over WSNs. With this motivation, in this thesis a highly robust and efficient routing protocol for delay resilient or deadline sensitive communication is developed.

High Resource or Bandwidth Demand-Multimedia data, particularly video data streams need high data rate transmission which is usually higher than that supported by Commercial Off-The-Shelf (COTS) sensors. It assures high data rate transmission with minimum energy consumption and retransmission.

Cross-Layer Coupling of Functionalities-In major multihop communication systems, there exists strict correlation and interdependence among various functions dealt at the several layers of the protocol stack. Functions dealt or processed at these layers are inherently coupled because of the shared characteristics of the radio channel. Therefore, different functions emphasize at QoS delivery must not be considered distinctly when efficient solutions are needed. Due to the shared nature of the radio channel, there exists a strict interdependence amidst different functions at the various layers. Therefore, correlating different functions and parameters at these layers of the protocol stack can provide better strategic scheduling for QoS centric routing. With this motivation, in this thesis the emphasis is made on

exploiting different parameters form the different layers of the protocol stack to achieve QoS centric and reliable communication over mobile-WSNs.
Observing above discussions, it can be well understood that to achieve optimal performance MAC protocol requires retaining higher energy-efficiency, stable and reliable transmission under varying load conditions, minimum latency or minimum deadline violation, higher throughput, etc. To achieve these objectives a number of studies have been made. In this paper few of the key literatures discussed on MAC protocol optimization have been considered. Some of the key terms used in this manuscript are defined in Table 1.

The further sections of this paper are divided as follows: Section II presents some of the important recent literatures discussing MAC protocols, Section III on discussion of different MAC protocol features and then Section IV of the conclusion and followed by Section V of future scopes. References are specified in the survey are mentioned at the end of the paper.

2. RELATED WORK

Use either SI (MKS) or CGS as primary units. (SI units are strongly encouraged.) English units may be used as secondary

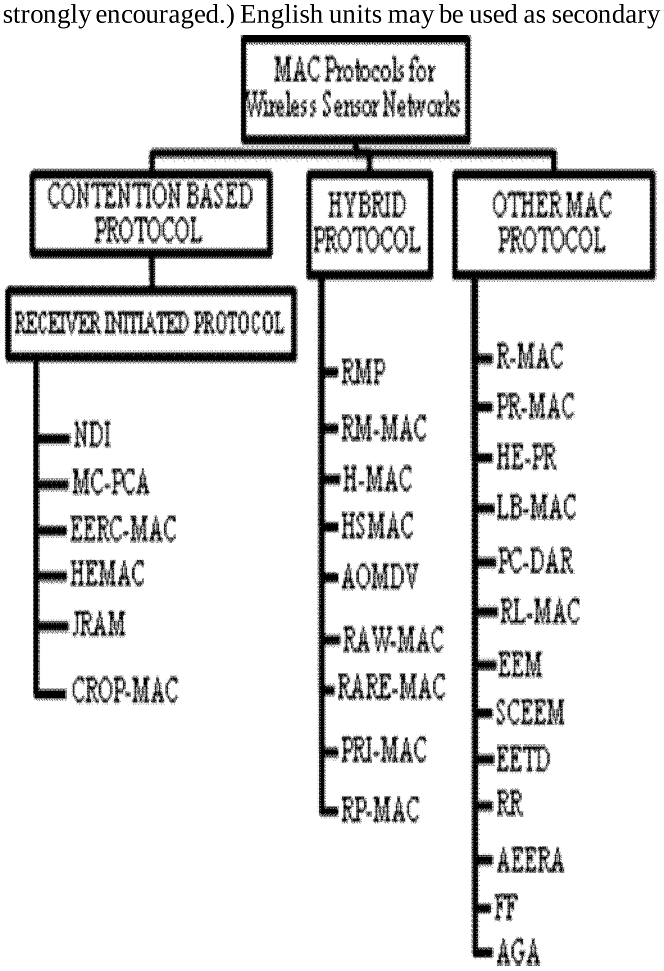

Figure 1: Classification of Mac Protocols

In the diagram (Figure 1: Classification of MAC protocols) were plotted according to the different categories based on their complexity.

In this section few of the key literature survey pertaining to the MAC protocol optimization in WSNs have been discussed.

Singh et al. [8] focused on achieving higher Packet Delivery Ratio (PDR) and reduced transmission delay in WSNs and developed three MAC protocols named Routing enhanced MAC (RMAC), Pipelined Routing enhanced MAC (PRMAC), and CLMAC. To further augment the MAC model, authors [9] developed a contention-based routing protocol (CR-MAC) where the prime emphasis was made on the optimization of the flow of the data packets of a particular node are continuously transmitted were in the regular time interval. Authors [9] recommended the energy-consumption and overhearing will be reduced in a small size control packet that transmits the message requested for data transmission. To further alleviate the issue of contention-based synchronous protocols, authors [10] developed a Joint Routing and MAC (JRAM MAC) protocol that exhibited satisfactory for data transmission in many to one communication environment. JRAM-MAC was found efficient in terms of higher PDR and low energy consumption. Perez et al. [11] proposed a JRAM MAC for ad-hoc networks by exploiting CSMA-CDMA technique with multi-rate transmission capacity and found it suitable for better communication efficacy. Arifuzzaman et al. [12] focused on achieving energy efficiency in WSNs by augmenting JRAM MAC where they incorporated instantaneous network information, reduced control overhead, load balancing concept as optimization measure. With similar intend but for large scale WSN, Sefuba et al. [13] applied integrated MAC and routing protocol and found that augmentation with a combined approach (Routing enhancement and MAC) can achieve better performance in comparison to the classical MAC based approach. Chen et al. [14] proposed adaptive operation cycle (AOC) MAC, an energy-quality balanced approach, placed at the MAC layer in unison with an energy-wave routing algorithm for wireless mesh devices. To augment energy efficiency of WSNs, Haqbeen et al. [15] proposed joint routing model with MAC and physical layer (RMP) and derived on the feature of Intelligent Hybrid (IH) MAC. Their proposed RMP protocol exploits the constrained shortest path information for packet forwarding decision. Authors [15] hypothesized that lower the communication path more reliable the communication would be. Liu et al. [16] developed Non-destructive interference MAC (NDI-MAC) protocol by integrating non destructive simultaneous transmissions into receiver-initiated protocols. NDI-MAC protocol proved its efficacy in terms of low-energy consumption and latency under varying data dissemination and traffic. In addition, to reduce the energy consumption and end-to-end delay (EETD), Wong et al. [17] proposed Multi-Channel Pure Collective Aloha (MC-PCA) MAC protocol, especially designed for satellite uplink random access asynchronously. To achieve it authors employed the technique of spreading out across multiple channels in the arrivals of each batch of packets to achieve higher throughput gains. Liu et al. [18] stated that there is the lack of transmission reliability in classical MAC model and hence recommended a routing enhanced MAC (RM-MAC) that was found efficient in terms of timely data delivery. RM-MAC protocol allows the nodes to choose their channel polling times in co-ordination with each other based on cross-layer routing information. In fact, this approach was based on resource allocation; however, its efficacy for resource constrained application remains suspicious. Mohapatra et al. [19] assessed different factors deliberately affecting the energy constraint in MACs and stated that energy efficacy of protocols plays vital role in guarantying QoS provision in WSN based IoT ecosystem. They compared various MAC protocols in sensor network and identified various metrics such as energy consumption, delay, and throughput and PDR considering Directed Diffusion Routing Protocol (DDRP). Khalil et al. [20] assessed the performance of various MAC protocols such as RC-MAC under a range of traffic load conditions (heavy and light) in conjunction with the energy-hole problem of Receiver-Centric MAC (RC-MAC). Further employing the beacon technique, authors [20] presented energy efficient receiver centric (EERC) MAC which exhibits higher energy efficacy and augmented throughput than RC-MAC. To achieve energy efficacy, Senthil et al. [21] exploited multi hop data transmission and comparatively examined various MAC protocols including RMAC and Harvested Energy Adaptive MAC (HEMAC). Their proposed HEMAC protocol performed the routing decision by exploiting the concept of the periodic listen and sleep along with two frames, pioneer (PION) and explorer (EXP) to perform routing decision. Additionally, employing the path length optimization algorithm, key parameters like latency, time delays were also considered.

For low-power and lossy networks (LLNs), Akhavan et al. [22] recommended receiver-based MAC protocol (RB-MAC) and adaptive RB-MAC. Authors found RB-MAC efficient in terms of low retransmission probability that resulted into increased energy efficiency and reduced delay. Hayes et al. [23] stressed on the issue of MAC limitations for flat architectures and developed three new MAC protocols for flat multimedia WSNs so as to ensure high throughput, low energy consumption and time delay. A joint routing and MAC protocols was developed for Wireless Body Networks (WBANs) was proposed Lahlou et al. [24] who incorporated a cross layer concept by amalgamated MAC and PHY to achieve better Energy-Aware Topology Design for WBANs (EAWD). Kalaivaani et al. [25] proposed three different hybrid MAC based protocols for WSNs.

Peng et al. [26] developed a new MAC protocol named Lifetime-Balancing MAC (LB-MAC) with embedded adaptivity feature for asynchronous, duty cycle sensor networks. LB-MAC was found better in terms of increased network lifetime and low en-to-end delay. Similarly, to perform network lifetime enhancement authors [27] exploited the restricted resources and the communication features. Pal et al. [30] presented a MAC protocol called energy efficient (EF) MAC that influenced network performance affirmatively for node energy, coverage capability and channel strength. Further, Bouachir et al. [28] addressed the issue of the finite network lifetime of sensors in WSNs and suggested that developing energy –harvesting sensitive routing decision can be vital for lower energy WSN system. In addition, they found their model more effective in alleviating interferences, noisy-resilient even under dynamic environment. Authors proposed the EAMP-AIDC protocol, an energy- aware (EA) MAC protocol for energy harvesting (EH) Wireless Sensor Network (WSN) which is based on optimizing Adaptive Individual Duty Cycle (AIDC) that considers residual energy of nodes and data requirements which defines Sleep and Active period’s duty cycles dynamically. Venkataramanan et al. [29] stated the criticality how the duty cycles of the nodes are adjusted in WSNs and hence considering the various EA solutions authors [29] derived a MAC protocol called Energy Aware Routing MAC Protocol (EARMP) uses the parameters of Routing layers and mac layers and then causes the network to do dynamic alteration of nodes duty cycles. Similarly, Luo et al. [30] presented an algorithm for adjusting duty-cycle for WSNs to minimize energy consumption and packet time delay simultaneously. They derived a representation to estimate the number of packets in the next amount of time and then formulate latency and energy utilisation as a multiple purpose optimization problem. With the estimated number of packets, Authors identified the optimum sleep time to ensure optimal energy-efficient and QOS centric routing. Cheng et al. [31] addressed the issue of prevailing duty-cycle MAC protocols (such as sensor MAC (S-MAC)) which will not apply any affect of network infrastructure derives in the inherent traffic distribution characteristic. They stated that such event often adversely affects QoS. To alleviate such issues authors [31] developed a duty-cycle MAC protocol, called Location-Based RMAC (RL-MAC) this protocol configures un-uniform CWmin (minimum contention window) values and location-based configuration and also the data packets will forward over multiple hops per cycle.

To alleviate the problem of connectivity between nodes and forming a reliable link Kurumbanshi et al. [32] proposed that nodes should be distributed using exponential and constant pattern based on which the scheduling of transmission time, MAC time and Queuing delay was decided for WAN applications under different channel conditions. They stated their routing approach better in achieving augmented performance of mobile Wireless adhoc network (WAN). A case of non-responsiveness of the transceiver was addressed by Tyagi et al. [33] who tried to increase sensitivity of the network by incorporating beamforming concept. Expedients such as Directional Request to Send (DRTS), Directional Clear to send (DCTS) in addition to it Directional Network Allocation Vector (DNAV) were exploited by Inzillo et al. [34] to mitigate the issue of irresponsiveness of the nodes. However, in complex directional network scenarios the above expedites are not sufficient even though the interconnection networks are fitted with Smart Antenna Systems (SAS), so Round-Robin MAC (RR-MAC) method was proposed which gives a formal partitioning of the transmission plane, controlling the nodes high beam forming time, to smaller the amount of collisions of frames in the channel and ensure high throughput gain in the network. Thenmozhi et al. [35] discussed the limitations of fully connected WANs and developed Adaptive Energy Efficient and Rate Adaptation based Medium Access Control Routing Protocol (AEERA - MACRP) that exploited adaptive energy strategy using periodic listen/sleep duty cycle technique. Authors found their model efficient in achieving energy-efficiency; however other QoS aspects could not be addressed. Furthermore, considering applications such as IoT, Cyber Physical Systems (CPS) and smart grids Prasad et al. [36] focused on state wise dynamic behaviour feature (of relay nodes) with 3-dimensional Markov MAC algorithm that achieved energy-efficient routing decision. Liu et al. [37] aimed at enhancing the performance of EH- powered WSNs in three aspects: scheduling, relaying and MAC control. Focusing on the properties of energy harvesting, a duty cycling method which is initiated by the receiver asynchronously was developed which reduces the duty-cycle of the transmitter and based on the energy levels of the sensors it controls the sleep and active interval. Khan et al. [38] examined different MAC protocols using Cooperative Diversity (CD) technique for WLANs and WSNs. The neighbouring nodes in CD protocols act as virtual multiple-input-multiple-output (VMIMO) systems, cooperating with the pair of transmitter and receiver to provide the receiver with a number of copies of packets through independent fading channels which are combined to obtain the original packet, thus improving reliability. Muneer et al. [39] focused on the significance of multi-hop ad-hoc networking in wireless communication systems and used CD scheme with Single Frequency Networks (SFNs), is called as Macro-diversity to derive for multi-hop ad-hoc networks like SFN based distributed cooperative routing protocol (SFNDCRP). They used of routing initiation phase with carrier-sense multiple access (CSMA) as a synchronization mechanism enabled this approach to exhibit better. Sevani et al. [40] surveyed the importance and lack of multi hop time division multiple access (TDMA) and its significance for wireless networks and highlighted the problems with respect to routing integration, time synchronization, spatial reuse, TDMA schedule dissemination, multi-channel support etc. To alleviate such issues a multi hop TDMA MAC approach, LiT MAC was developed that achieved low control overheads during transmission. Zhuo et al. [41] proposed iQueue-MAC, a hybrid CSMA/TDMA MAC that performs efficiently even under bursty traffic. During light load conditions a Contention-Based CSMA mechanism was applied, providing low delay with scattered transmissions and a contention-free TDMA mechanism during heavy traffic. Authors performed transmission slot allocation to alleviate the issue of packet buffering and resulting delay issue. Addressing the key issues of time delay, energy efficiency and reliability in WSNs Rachamalla et al. [42] proposed a framework for Power-Control and Delay Aware Routing MAC protocol (PCDARM). PCDARM was primarily developed to achieve energy efficiency and delay sensitive communication over WSN. To achieve it, it employed multipath transmission concept in MAC, while resource allocation was done in TDMA frames that resulted into optimal power control. Kirton et al. [43] developed the inexpensive message overhead in a TDMA MAC schedule which will provide SLP.

Anwar et al. [45] designed a multi-objective optimized RPL and MAC protocols for WSNs to be used for critical communication purposes like forest fire monitoring and industrial automation. Authors [45] derived the routing layer from the IPv6 routing protocol (RPL) and the MAC layer from the low power Asynchronous Scheduled MAC for low power and lossy networks. Considering the limitations of the classical routing schemes authors [46] focussed on MAC optimization to be used in cognitive radio networks (CRNs). Khan et al. [46] assessed the critical issues for routing and MAC protocols in the CR-based smart grid. Babu J et al. [47] developed radio RD-MAC to by amalgamating the Queue administration strategy that considers the intervals of rest periods to find out the shortest way in the system and the controlling of the obligation push through it. This calculation is further enhanced using a Selectively Directional (SD) MAC and demonstrated that the proposed strategy augments the execution by completely reducing the vitality spent. Li et al. [48] developed a DBR-MAC (Depth-Base Routing MAC) protocol, explained about reducing the cost of the data collection network effectively by increasing time efficiency energy and throughput. Authors [48] applied DBR-MAC to be used for Underwater Acoustic Sensor Network (UASNs). To further augment it Wahid et al. [49] developed a new cross layer MAC protocol where they integrated network layer and MAC layer as defined it as Fitness Function based MAC (FF-MAC) protocol. FF-MAC focussed on selecting a suitable forwarding node for successful transmission. In addition, a handshaking mechanism and scheduling algorithm was developed for channel allocation. Chen et al. [50] presented an underwater OR-based MAC protocol (UWOR-MAC) by integrating Opportunistic Routing and the characteristics of underwater sensor networks (UWSNs [51]). To evaluate the successful transfer of multi packets and enhance the channel utilization, an Event Relationship Graph was plotted. Algora et al. [52] implemented to fulfil better performance of the network introduced IoT based multichannel MAC protocols. MAC layer protocols using the Orchestra scheduling algorithm: Energy-Efficient Multichannel MAC (EM-MAC) and Time-Slotted Channel Hopping (TSCH) protocols. EM-MAC exhibited better in terms of lower power consumption while TSCH/Orchestra in terms of PDR. Based on a multi-channel MAC protocol, Omar et al. proposed a routing scheme, VeMAC using TDMA that allowed packets to transmit and then receive to and from gateway of the internet in a multi-hop communication network.

Though MAC protocols favour data transmission through a part with low latency, however with increased network size buffer management becomes inevitable and improper management could lead congestion, data drop and hence retransmission imposing hue latency [43]. Considering a model of cross layer which was developed by Leao et al. with latency of communication using Multi-sink WSN (MS-WSN). [56] who focussed on buffer control scheme. Seddar et al. [54] proposed a MAC protocol focusing bidirectional full-duplex WSNs for achieving high throughput gains by facilitating reservation of and the handshake among the different communicating nodes by adjusting different sizes of frames and resources. Trung et al. [55] proposed a QoS centric layered structure for an integrated version of target tracking system including the duty cycle XT-MAC protocol related with EMRP routing algorithm. To augment the performance of WSNs, vitality effectiveness is the most critical issue was proposed and thus to mitigate the active utilizations of the sensors hubs in sensor-medium access control (S-MAC). Krishna et al. [56] an active proficient grouping calculation in the form of low energy adaptive clustering hierarchy (LEACH) matter was proposed. Filter-LEACH utilizes a TDMA-based MAC convention to maintain adjusted vitality utilization. To meet IoT demands Yaala et al. [57] recommended MAC optimization from IEEE802.15.4 to IEEE802.15.4e, which is having better network management capacity than the classical one. Chen et al. [58] proposed a MAC protocol for massive WSNs, served by the distributed antenna system (DAS). It utilizes an ID allocation algorithm to provision more throughput with heavy traffic compared to traditional Distributed Coordination Function (DCF) and Point Coordination Function (PCF). Heimfarth et al. [59] proposed AGA-MAC, an Adaptive Geographic Any Cast (MAC) protocol for WSNs by giving solution for sleep-delay problem of preamble-based MAC protocols which is asynchronous and selected next relay node opportunistically to achieve energy-efficiency. Idoudi et al. [60] emphasized the criticality of energy efficiency in WSNs to increase lifespan and recommended using residual energy, energy consumption balancing and PDR sensitive routing decision. To achieve it, authors [60] applied cross-layer functioning that enabled an adaptive duty cycling and hence reduced routing overhead. Realizing the need of power efficient WSN routing for IoT applications, Lin et al. [61] developed Green-MAC, a favourable and possible configurable protocol to be used for corona-based WSN. This protocol features advanced ATF-ratio, greater lifetime, better throughput gain etc.

Shah et al. [62] exploited cluster concept to meet QoS and energy-demands and developed a Spectrum-aware Cluster-based Energy-Efficient Multimedia (SCEEM) routing protocol for cognitive radio sensor networks (CRSNs) that overcomes the better limitations of energy and spectrum simultaneously. Formidable limitations of energy and spectrum simultaneously Akhtar et al. [63] proposed a protocol which enhances the performance of the network layers, MAC and physical layers that causes reduction of the energy consumption in the total network with a reduced co-operative routing algorithm were also developed which exploit the derived cooperative link cost to perform routing decision. Considering the factors causing energy consumption and mitigating the effect of increasing the lifetime of the network. Paraskevas et al. [64] presented suitable for the routing decision scheme suitable for routing metrics. They merged their multi-metric routing scheme into optimized link state routing (OLSR), a standard an adhoc network in the mobile. To meet the demands of protocols with low energy exhaustion in WSNs Reddy et al. [65] formulated a cross-layer implementation by employing routing and MAC layer. At the MAC layer they [65] introduced dynamic duty cycling that reduced energy consumption significantly. On the contrary, at the routing layer unequal clustering was applied that eliminated the burden on nodes to achieve higher scalability.

By incorporating the pipelined flow by exploiting parameters such as efficient synchronization, employment of routing layer and hindered sleep/wake scheduling information Singh et al. [66] proposed Contention based Synchronous Cross-Layer MAC protocol, (CROP-MAC). Tsuboi et al. [67] proposed the multi-channel MAC protocol with cross-layer design and the RPL that degrades the performance as it is a single channel interference in ad-hoc networks they augmented the data transmission as compared to the multi-hop communication. Hsieh et al. [68] developed a MAC protocol which is hybrid to energy consumption and latency in WSN's will be minimized. Based on the routing information of AODV this protocol derived a cross-layer approach that dynamically switches the MAC behavior between TDMA and CSMA. Louail et al. [69] assessed the efficacy of Cross-layer protocols over traditional layered protocol architecture and derived a new a MAC-Aware Routing protocol for WSNs (MAR-WSN). MAR-WSN on the basis of TDMA scheduling and two-hop neighbourhood knowledge made the next hop decisions. The routing in MAC protocol would have taken coherent decisions in space which have proved very efficient in many metrics: hop number, delay, and energy consumption. Gonizzi et al. [70] stated that the protocols employing asynchronous radio duty cycling can exhibit reduced delay because of the decoupled wake-up periods of the nodes. By the intention of authors [70] proposed RAWMAC, a cross-layer approach for RPL, a tree-based routing protocol. This protocol manages the asynchronous duty-cycled ContikiMAC MAC layer and dynamically aligns the wake-up instants of the nodes with respect to the RPL topology by reducing the delay for data collection. Mansoor et al. [71] proposed a spectrum aware cRoss-layEr (RARE) MAC protocol for Cognitive Radio Ad-Hoc Networks that withstands relatively a fewer number of clusters and a uniform number of common channels in order to enhance the performance. Khanh et al. [72] assessed the limitations of MAC protocols such as pattern MAC (P-MAC) and PRI-MAC to augment QoS. Authors [72] derived a cross-layer duty-cycle MAC protocol, called RP-MAC (Reduced Pipelined-Forwarding) protocol that increases the performance by reducing idle listening time and control overhead.

Observing the above discussed literature survey, it can be stated that undeniably numerous efforts have been made to achieve better performance; however, majority of the efforts are primarily done to achieve better energy efficiency and delay performance. On contrary, in major real time systems enabling QoS provision, mission critical (say, deadline sensitive transmission), data sensitive resource allocation and routing decision, etc are inevitable. These factors can be the driving force for further research efforts and optimization.

3. DISCUSSION

Considering the significance of a QoS centric and resource efficient routing protocol for WSNs, in this manuscript the focus is made on exploiting key contributions made for MAC layer optimization. Undeniably, augmenting MAC layer of the protocol stack can be of utmost significance to achieve better performance. However, up surging application complexity and QoS demands have broadened the horizon for further enhancement. In this study, some of the key recent literature of MAC routing protocol were studied and their strengths as well as limitations were assessed. The literatures studied reveal that undeniably a number of efforts have been made to augment MAC; however most of the works are at first dedicated for static WSN topology and hence are not suitable to handle topological variations as is in the mobile-WSNs. Furthermore, majority of the existing solutions are either focussed on energy-enhancement or throughput optimization; however, developing a routing protocol with cumulative network management and network-condition aware decision making capacity is not yet explored significantly. To achieve energy efficiency duty-cycling, sleep-awake scheduling, control packet optimization, load balancing, etc approaches have been explored distinctly. In some efforts shortest path based routing decision is made; however, its suitability with recently proposed M2M communication or other IoT ecosystem application (under dynamic topology and residual energy depletion condition) remains suspicious. In a few efforts contention based MAC scheduling is performed so as to retain higher PDR without imposing packet losses. A few models have made better effort by exploiting delay and power of a node to decide routing. However, their efficacy under adverse network conditions remains unexplored as authors have considered static and low load condition for simulation. Queue administration schemes too have been applied to reduce delay; however, they are not definite to serve optimal in case of simultaneous real-time data and non-real-time data transmission. To achieve resource scheduling MAC has been augmented with handshaking concept. Undeniably being a novel effort, it requires better service differentiation and resource scheduling to balance the trade-off of the QoS centric resource allocation and packet drop for relatively low prioritized data. To alleviate such problem a few efforts have been made by emphasizing on buffer control to reduce network latency as supplementary outcome. The use of clustering has also been the key effort to achieve energy efficiency. Realizing the need of the best relay node selection for QoS centric communication an affirmative response has been witnessed across academia-horizon. The literatures studied revealed that unlike single layer optimization effort amalgamating multiple layers to constitute a cross layer routing model can be better alternative. In a few efforts network and MAC layers were integrated to enable node stability when transmitting. However, its efficacy remains unexplored during mobility.

SUMMMARY

Protocols	Description
RMAC	Routing Enhanced MAC
PRMAC	Pipelined Routing Enhanced MAC
CRMAC	Contention based Routing protocol
JRAM MAC	Joint Routing and MAC
CDMA	Code Division Multiple Access
AOC MAC	Adaptive Operation Cycle MAC
RMP	Joint Routing Model with MAC and Physical Layer
IH MAC	Intelligent Hybrid MAC
NDI MAC	Non-destructive

	Interference MAC
EETD	End to End Time Delay
MC-PCA	Multi Channel Pure Collective Aloha
RMMAC	Routing Enhanced MAC
DDRP	Direct Diffusion Routing Protocol
RC-MAC	Receiver-centric MAC
EERC MAC	Energy Efficient Receiver Centric MAC
HEMAC	Harvested Energy Adaptive MAC
PION	Pioneer
EXP	Explorer
RB-MAC	Receiver-based MAC
WBAN	Wireless Body Area Networks
EAWD	Energy Aware Topology Designs for WBANs
H-MAC	Hybrid Medium Access Control
HSMAC	Hybrid Sensor MAC
AOMDV	Adhoc on Demand Multipath Distance Vector
LB-MAC	Lifetime-balancing MAC
EF-MAC	Energy Efficient MAC
EA	Energy Aware
EH	Energy Harvesting
AIDC	Adaptive Individual Duty Cycle
EARMP	Energy Aware Routing MAC protocol
S-MAC	Sensor MAC
RL-MAC	Location based RMAC
CW	Contention Window
WAN	Wireless Adhoc network
DRTS	Directional Request to Send
DCTS	Directional Clear to Send
DNAV	Directional Network Allocation Vector
SAS	Smart Antenna Systems
RR-MAC	Round-robin MAC
AEERA-MACRP	Adaptive Energy Efficient And Rate Adaption based MAC Routing Protocol
CPS	Cyber Physical Systems
CD	Cooperative Diversity
VMIMO	Virtual Multiple Input Multiple Output
SFN	Single frequency network
SFNDCRP	SFN based Distributed Cooperative Routing Protocol
TDMA	Time Division Multiple Access
PCDARM	Power control and Delay Aware Routing MAC Protocol
HE-PRMAC	Hop Extended Pipelined Routing MAC
CRN	Cognitive Radio Network
SD MAC	Selectively Directional MAC
DBR MAC	Depth base Routing MAC
UASN	Underwater Acoustic Sensor Networks
FF-MAC	Fitness Function MAC
UWOR MAC	Underwater OR based MAC
UWSN	Underwater Sensor Network
TSCH	Time Slotted Channel Hopping
EM-MAC	Energy Efficient Multichannel MAC
VeMAC	Vehicular MAC
MS-WSN	Multi-sink WSN
LEACH	Low Energy Adaptive Clustering Hierarchy
DAS	Distributed Antenna System
DCF	Distributed Coordination Function
PCF	Point Coordination Function
AGA-MAC	Adaptive Geographic Any Cast MAC
SCEEM	Spectrum Aware Cluster-Based Energy Efficient Multimedia Routing Protocol
SNR	Signal to Noise Ratio
OLSR	Optimized Link State Routing
CROP-MAC	Contention-Based Cross-Layer Synchronous MAC
RARE	Spectrum Aware Cross-Layer MAC
P-MAC	Pattern MAC
RP-MAC	Reduced-Pipelined MAC
ALBA-R	Adaptive Load-Balanced Algorithm-Rainbow

4. CONCLUSION

Considering the inevitable significance of a robust MAC routing protocol for QoS enabled-WSN system, this paper discusses some important literatures pertaining to MAC designs were discussed. Different recent literatures with their respective pros and cons were discussed. The overall survey revealed that the majority of the classical approaches are uni-centric where the effort is made either for energy-efficiency optimization or for resource allocation; however, developing a MAC model for mission critical communication under uncertain network conditions, varying network parameters remained a least explored research region. This study revealed that the classical methods employing duty-cycling, sleep-awake scheduling, buffer management etc are undeniably better effort; however are not optimal to cope up with recent up-surging demands and network complexities. To meet the demands, developing robust cross-layer architecture can be vital. Exploiting different network parameters from the different layers and employing them to select an optimal relay node can avoid link-outage vulnerability. A better service differentiation and application-sensitive resource allocation can also be vital for MAC to ensure reliable communication. Further, identifying a node with maximum possible transmission rate can help achieving deadline sensitive mission critical communication. In future, these all parameters can be exploited to make optimal routing decision and MAC control so as to achieve timely data delivery, higher throughput, low energy exhaustion, low drop ratio, low deadline miss probability etc to eventually meet QoS demands of the WSN applications..

5. FUTURE SCOPES

Considering overall literatures, it can be stated that considering different parameters from the several layers of the protocol stack can enable better MAC based scheduling and routing decision. For example, an application demanding mission critical communication or event driven transmission needs timely data delivery for certain application specific real-time data. Under such conditions, assessing each forwarding node for its resource efficiency, congestion probability, dynamic link quality, type of data and fair resource scheduling etc can be of utmost significance for routing decision. However, exploring in depth it can be found that these all parameter are the protocol stack of different layers and inevitable in a cross-layer routing model. On the other hand, to achieve mission critical communication assessing node for its maximum velocity, minimum congestion, higher link reliability etc can help timely data delivery over WSN. Such network variables can be obtained from MAC layer in conjunction with other layers of the protocol stack. It can also help in enabling optimal power control strategy to achieve resource efficiency. Thus, implementing above stated routing model a novel and robust MAC optimization model can be developed that could accomplish overall efficacy (timely data delivery, higher throughput, low energy exhaustion, low drop ratio, low deadline miss probability etc) to meet QoS demands of WSN applications. These all factors motivate academia-industries to make optimal effort and exploit above stated possibilities for a novel and robust (cross layered MAC protocol) for real-time, mission critical communication.

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Table 1: List of Abbreviation

Variable	Description
QoS	Quality of Service
IoT	Internet of Things
MCC	Mission Critical Communication
WSN	Wireless Sensor Networks
MAC	Medium Access Control
LLN	Low Power Lossy Networks
M2M	Machine to Machine
IEEE	Institute of Electrical and Electronics Engineers
CSMA	Career Sense Multiple Access
OSI	Open System Interconnection
COTS	Commercial off-the Shelf
PDR	Packet Delivery Ratio