



QoS Strategies for Wireless Multimedia Sensor Networks with Energy-Efficient Routing Techniques & QoS Assurances

Abdul Haseeb Mohammad, Abdul Sameer Mohammed,
Aaqib Ihraz Mohammad, Mohammad Riyaz Naik,
Azeem Hussain Syed and Amairullah Khan Lodhi

EasyChair preprints are intended for rapid dissemination of research results and are integrated with the rest of EasyChair.

March 8, 2023

QoS Strategies for Wireless Multimedia Sensor Networks with Energy-Efficient Routing Techniques & QoS Assurances

¹Mohammed Abdul Haseeb, ²Moammad Abdul Sameer, ³Mohammed Aaqib, ⁴N. Mohammed Riyaz, ⁵Syed Azeem Hussain, ⁶Amairullah Khan Lodhi
^{1,2,3,4,5} Assistant Professor, ⁶ Associate Professor
ECE Department, Shadan College of Engineering and Technology, Peerancheru, Hyderabad.
lakresumes@gmail.com

Abstract:

In recent years, for delivering multimedia information such as images and videos, wireless multimedia sensor networks (WMSNs) have emerged as an outstanding technique. Due to the fast Advancements in sensor technology and the availability of low-cost hardware, the development of Wireless Multimedia Sensor Networks (WMSNs) has emerged. WMSNs are composed of resource-constrained wireless nodes through which both the scalar data and multimedia data (i.e., audio, still images, and video) can be sensed and acquired from the environment. However, the resource-constrained nature of multimedia sensing devices has made the WMSNs face several challenges. To tackle these challenges, different authors developed different methods. In this paper, we have surveyed all such kinds of methods. Initially, we study the basic architecture of multimedia sensor nodes followed by the characteristics and applications of WMSNs. Next, we have conducted a detailed survey over different methods and all those methods are segregated into three categories. Under the segregation, we have considered different aspects and segregated them as Data-Aware methods, QoS Aware methods, and Energy-Aware methods. In the end, we also summarized the existing solutions and outlined several pros and cons. In this paper, recent developments in techniques for designing highly energy-efficient and QoS-capable WMSNs are surveyed.

Keywords—Wireless Multimedia Sensor Networks; Energy proficiency; Quality of Service; Reliability; Dynamic power control; wireless communication protocols; multipath routing; medium access control;

I. INTRODUCTION:

In current advancements, the field of Wireless Sensor Networks (WSNs) has extended an increased research interest in the networking community. WSNs are low-power, low-cost multi-functional, and feasible due to the proliferation of wireless communications, integrated digital electronics, and advanced features of "Micro-electro-mechanical systems (MEMS)" [1]. WSNs have an extensive variety of applications including environmental monitoring, object tracking, health condition monitoring, ubiquitous computing, etc. Generally, the WSMN is composed of a larger amount of battery-operated sensing devices with which the devices process as well as communicate with each other [2]. Under sensing, the sensor nodes sense the environmental conditions (ex. electrical signal transformation, light or humidity, and temperature, etc.) of their surroundings through sensing circuitry. Next, under processing, the detail of data is analyzed. At the transmission phase, the processed data (Scalar data) is transmitted through a radio transmitter to an information center (sink or base station) moreover directly or through various hops [3, 4].

Nonetheless, the fastest growth in sensor technology, the inexpensive and flexible "Complementary Metal Oxide Semiconductor" (CMOS) cameras and microphones having an adaptive coding capacity, embedded computing, and MEMS have made the emergence of a new paradigm of WSNs, called Wireless Multimedia Sensor Networks (WMSNs) [5]. The data redundancy method mainly focused on the removal of redundant information from multimedia to optimize the resource constraints. Next, the QoS aware methods focused on the improvisation of QoS by optimizing the reliability and delay. Finally, the energy-aware method intends to preserve the energy of sensor nodes thereby improving the network lifetime.

The remaining part is organized as, 2nd section demonstrates the basic details of WMSN architecture, characteristics, and applications of WMSNs. In the 3rd section, we have outlined the complete details of the

literature survey. Section 4th discusses the details of the pros and cons of the proposed methods discussed in section III and finally, section V concludes the paper.

II. LITERATURE SURVEY:

A. Multimedia Architecture

The simple architecture of the WSN multimedia sensor device is displayed in Fig.1 [6]; it is composed of several basic modules such as sensing circuitry, central processing unit (CPU), a communication system, a memory unit, a co-ordination system, and optional actuation or mobility system. Further, the sensing unit is built up with two basic components as Sensors (Scalar sensors, microphones, and cameras) and Analog-to-digital converters (ADC). Once the signals recorded by sensing circuitry are completed with sensors, and then they are processed to ADC to convert them from analog to diagonal and then fed to CPU. The input digital signals to the CPU are processed and executed by the software concerning the communication scenario and then interfaced to the memory unit. Next, the communication system consists of a radio devices transceiver and a piece of communication software. Next, the main responsibility of the coordination system is to ensure perfect and synchronized coordination between different devices of the network in several aspects like location management and network synchronization. The actuation or mobility unit is used to enable the manipulation or movements in the object. Finally, the entire device is powered by a power unit which can be a battery of energy harvester such as solar cells.

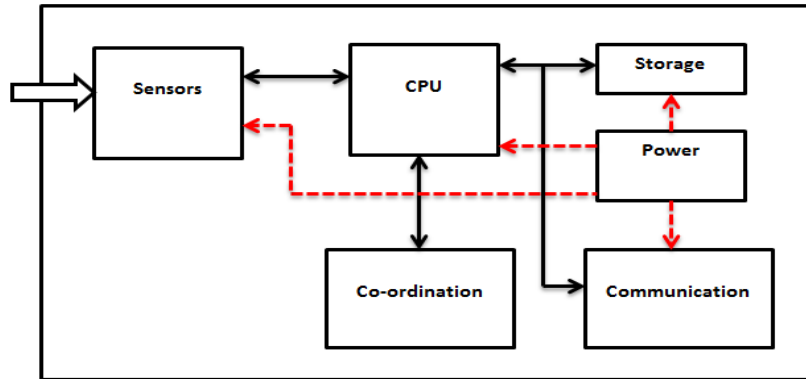


Figure.1 Internal modules of a wireless sensor multimedia network

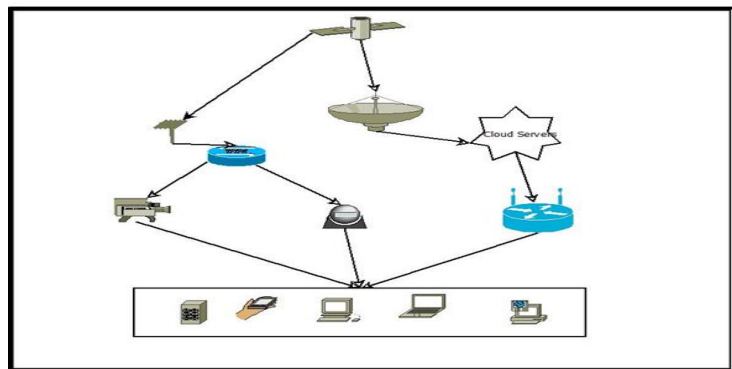


Figure.2 Basic Architecture of WSMN

B. Characteristics of WMSN

The major and beneficial characteristics of WMSNs those were attracted most of the recent network-based researchers are outlined as follows [6];

1) Multimedia In-network processing

The required QoS will get a maximum value if it considers both the in-network processing of raw multimedia data and the optimization of the cross-layer communication process.

- 2) *Multimedia Source Coding*
A new coding paradigm called Distributed Source Coding (DSC) [7] was recently found to have a balance between complexity and energy consumption. An implementation of such a type of encoding in WMSNs gives promising results.
- 3) *Cross-layer Conjunction*
Cross-layer optimization is very important when modeling data communication in WMSNs. When designing a QoS aware design needs to be deliberated strictly on the resource-constrained sensor devices.
- 4) *Resource constraints*
In WMSN, the embedding sensor devices are resource-constrained, i.e., they have limited resources such as memory, bandwidth, energy, achievable data rate, and processing capabilities.
- 5) *Dynamic Channel capacity*
The dynamic channel capacity has a serious effect on the QoS provision.

C. Applications of WMSNs

WMSNs have widespread applications and they are broadly discussed and classified into four classes; they are Industrial, Personal Health care, Traffic Monitoring, and Visual surveillance applications. In table .1 few WSMN existing applications are given with examples.

1) *Industrial and Environmental applications*

This process is accomplished by processing the video data acquired by sensors through image processing algorithms [8].

2) *Personal Health Care*

In the medical field, the WMSNs have numerous applications like patient care, drug administration, elderly assistance telemedicine, etc. For example, multimedia sensor devices can be used to study and monitor elder people's performance such that the main causes of illness can be identified that affect them, for instance, dementia [9]. In this model, patients will carry medical sensors to observe the time to time updates regarding breathing activity, electrocardiogram, Oximetry, blood pressure, and body temperature. Wrist devices [10] are a better example of this operation through which a patient can measure the details and also can forward them to the medical expert.

3) *Traffic Monitoring*

Smart parking [11] can also be done through multimedia sensors which will permit scrutiny of the accessible stopping spaces Furthermore advising drivers for automated driving systems. The U.S. Transportation Department proposed in 1995 named as "National Project Planning Intelligent Transportation System."

4) *Visual Surveillance*

Under visual surveillance, a large-scale network of multimedia sensor devices can help law-enforcement agencies to detect crime activities against crime and terrorist attacks.

III. LITERATURE SURVEY AND METHODOLOGIES:

The complete approaches are categorized into three categories; they are Multimedia data-aware approaches, QoS aware approaches, and Energy Oriented approaches. In the case of multimedia data-aware approaches, the complete focus is kept on data redundancy. Further, in energy efficiency-based approaches, the focus is kept on energy efficient communication and energy efficient computation.

A) *Multimedia data-aware approaches*

Generally, the volume of multimedia data is very large when compared with the size of scalar data. For WMSNs in which the multimedia sensor nodes have limited resources, transmitting a larger volume of data is one of the biggest problems. Hence to solve this problem, there is a need to decrease the data size which needs to be transmitted. Multimedia in-network processing, distributed source coding, and local processing algorithms are the best example algorithms that can lessen the size of multimedia data that needs to get transmitted. Moreover, in-network data storage methods are used for this purpose.

1) *Distributed Source Coding*

The transfer of entire source data to the centralized location is a very tough problem because the multimedia source nodes are resource-limited. Distributed Source Coding (DSC) [12], [15-18] is one possible solution in which every multimedia sensor node encodes its information independently and leaves the complex decoding task to sink node.

2) *Multimedia In-network processing*

Next, In-network processing multimedia data is demonstrated as a transitional process that happened at local multimedia sensor nodes which obtain network scalability through reduced energy consumption [20]. Under this strategy, there exist two types of processing strategies. The first one is based on the fusion of multi-modal data [21], [23] and this is generally happening at the cluster level after receiving the entire data from its cluster members. Due to the nature of heterogeneity, the data fusion may be of multiple types such as audio, images, and video and non-image data. The next type is online multi-view video summarization [22], [31].

Table.1 Existing Applications of WMSN with few examples

Application Fields	Applications used
Visual Surveillance	Live CCTV monitoring systems that help to improve security
Traffic Monitoring	"National project planning intelligent transportation system in the USA"
Military	(C4ISR) - The command, control, communications, computing, intelligence, surveillance, reconnaissance, and targeting System
Health care	Remote Monitoring patients and especially Physically disabled
VR Gaming	VR games with live multiplayer, Can YOU See Me Now (CYSMN), etc.
Target tracking	Centralized tracking and Distributed tracking such as Traffic congestions
Environmental Monitoring	Forest and Ocean live monitoring and Sand Storms
Space exploration	Jet Pollution Laboratory (JPL) by NASA
Usage in Society	Smart Cities and Home Automation for locking systems and Security

Under the first category, a new multi-modal data fusion strategy is proposed by M. Koyuncu et al., [24] for accurate object detection and energy efficiency. After capturing the audio and video data from sensor nodes, the objects are recognized and the results are improved by the recognition performance at sensor nodes. The conclusive outcomes are sent in the text data format to sink. A similar method is proposed recently by A. Yazici et al., [25] but this time clustered-based routing is applied over wireless multimedia sensor nodes after recognizing the objects through machine learning algorithms. The proposed cluster-driven data forwarding algorithm is to achieve energy-efficient communication in WMSNs. Next, Rui Gao et al., [26] proposed a cooperative audio data fusion that combines seamless audio editing with wavelet transform. In this approach, initially, the audio data is divided into multiple parts and for every part, a graph matching algorithm is employed to obtain the most appropriate part and transform the shape information.

Under the second category, S. H. Ou et al., [22] considered the Multi-View Video Summarization (MVVS) [27] for WMSNs to eliminate the excess information required energy and compression with the reduced transmission. This approach has less complexity also. Next, S. Colonnese et al., [28] proposed a new "Multi-view video coding (MVC)" to compress the video by considering the correlation of FoVs of spatially separated cameras [29]. A Common Sensed Area (CSA) is defined here based on geometrical relationships between the relative position of different cameras, motions, occlusions, and illumination variations. Next, in this proposed method by S. Colonnese et al., [30], the CSA is used to create clusters in WMSNs

and created a clustered WMSN by exchanging the local information through which the resulting transmission rate is measured. However, the Multi-view video summarization is a challenging problem because the sensed data have thematic diversity and content overlaps within multi-view videos.

B) QoS Aware Approaches

Generally, most of the applications of WMSN expect a real-time delivery of video data. For this purpose, the WMSNs have to transmit the entire captured video to the sink before a specific time deadline and also need to concentrate on packet loss such that it should not exceed the threshold.

1) Reliability

Generally, the guaranteed reliability is ensured by either retransmission or redundancy [32]. Unlike this multi-path routing, a network coding can be applied, for example, "Random Linear Network Coding (RNLC)" [33] in which the packets are generated from x packets and the reliability is guaranteed even the sink has received at least x packets where $y \geq x$. In the case of bit-level redundancy, some extra segment orbits are concatenated for the original packet. Several authors focused on the error control in WMSNs [39]. Min Chen et al., [34] focused on the problem of real-time streaming video over energy and constrained bandwidth WSN with a small volume of Video Sensor Nodes (VNs). This approach applied FEC [35] along with a novel multipath routing scheme called "Directional Geographic Routing (DGR)". After encoding the FEC secure H.26eL real-time streaming video data, DGR establishes an application that required multiple disjoint paths for a VN to sink. R. Mohammadi et al., [36] a "Delivery Ratio Based Network Coding (DRNC)" is developed to the improvement of the reliability of real-time video data exchanging transmission in WMSNs. In this approach, initially, the packets are coded and transmitted through the shortest path. At any intermediate node, if it is found any packet is lost, then it is recovered through coded packets. P. Chau et al., [37] proposed a "Distributed Systematic Network Coding (DSNC)" to achieve data transmission reliability in WMSNs. B. Sarvi et al., [38] introduced a New Adaptive Cross-Layer Error Control Protocol (NAC) for the real-time and reliable transmission of multimedia data in WSN. This approach employed FEC at the application layer and a hybrid FEC/Automatic Repeat Request (ARQ) [39, 40] and Unequal Error Protection (UEP) [41] at the link layer.

2) Delay

The first one is that the Medium Access Control (MAC) can utilize service differentiation and prioritization mechanisms to adopt higher priority for real-time video data or they can grant early access to high-quality channels [42]. In the second strategy, the routing protocol can employ such techniques which have QoS knowledge and can select the paths that have minimum accumulated delay over the established paths [43]. Several authors developed several approaches based on MAC design [51]. Focusing on the enhancement of QoS (bandwidth and end-to-end delay requirements), N. Saxena et al., [44] a new QoS MAC protocol based on sensors is proposed. This is an application-specific QoS, and also endeavors to preserve QoS energy constraints without violating. Next, M. A. Yigitel et al., [45] focused on the design and implementation of a QoS-aware MAC protocol called Differentiated MAC (Diff-MAC) in which several methods are integrated to achieve the requirements of quality of

services QoS to deliver heterogeneous traffic. The goal to meet Diff-MAC requires enhancing the utilization of channels with effective service differentiation such that the data delivery will be more efficient and fast. O. Farrag et al., [46] proposed a novel Medium Arbitration Scheme for QoS support, called MAQ, over a single channel available for communication. MAQ decentralizes the communication resources control and completely integrates the TDMA and CSMA/CA for medium access such that the incurred delay is within the limits and also achieving an increased throughput with perfect channel utilization.

Lu Wei et al., proposed an energy-efficient, scalable, and collision-free MAC protocol, DTFMM [47] based on the principles of the time and frequency division for sharing medium. DTFMM is employed over a clustered network and a distributed local coordinate algorithm is applied for channels assigning among clusters. The information from sensor nodes is transmitted to CH based on time slots and the CH forward gathered information to sink based on "Minimum Spanning Tree (MST)" [48] routing. Cheng Li et al. [49] are proposing a similar strategy called 'Clustered On-Demand Multi-Channel MAC Protocol (COM-MAQ)' to achieve secure and energy-efficient data transmission in WMSNs. Under the scheduling process, the COM-MAQ scheduled multi-channel medium access for every cluster and traffic-adaptive and QoS-aware scheduling algorithm for the selection of dynamic time slots and channels for every multimedia sensor node. Y. Ozen C. Bayilmis [50, 52] concentrated on the urgency challenges and proposed new traffic and QoS aware cross-layer MAC protocol, called UrgMAC. Some new mechanisms namely; Two Tired Service Differentiation, Multimedia Message Passing, Traffic Adaptive Duty Cycle, Urgency based Content Window Size adaption, Adaptive data Rate Adjustment are proposed to support diverse applications like military border surveillance, habitat monitoring, etc.

3) *Energy-Aware Approaches*

In WMSNs, the multimedia sensor nodes have limited power because they are equipped with non-rechargeable batteries. Hence the operational time of every sensor node must be done in a strict manner such that the network will gain a long lifetime. The basic operations those need to be done by sensor nodes are;

- (1) System's basic operation
- (2) Computations over sensed multimedia information
- (3) Communicating the data [53].

To achieve an increased lifetime, the design can be done at different phases; the first one is the design of a low-power multimedia sensors platform, the second one is energy efficient communication algorithms and the last one is the design of optimal and dynamic power management principles.

4) *Computational Energy*

Generally, the energy consumed during the computation process is neglected in WSN because the size of scalar data is very less and it is in the order of kilobytes, but the computational energy in WMSNs is accountable [54]. Since the data size of a multimedia (ex. video) is very high (order of Megabytes), the energy consumed for processing such type of data is also high. For instance, in an application related to vehicle tracking, the energy consumption for the acquiring and processing of a frame is approximately 12% of total energy consumption [55]. Hence, the WMSNs need to try to use an energy-efficient algorithm for video compression [58], image processing [56, 57], etc. Further, care needs to be taken in the provision of a

tradeoff between quality and energy consumption [59]. Further, to maintain the same performance even under lossy wireless channels, an error control scheme is also deployed which is an integrated form of multipath routing and network coding [60]. A similar method is proposed by N. Khernane et al. and formulated the problem as NP-hard. This approach considered five constraints such as the flow conservation, video quality, network lifetime, convergence, and the shortest path [61].

5) *Communication Energy*

In WSNs or WMSNs, the energy consumption for data communication is a major factor by which the lifetime of a network varies. Generally, the energy consumption is directly proportional to the size of data that needs to be transmitted. Hence there is a need for energy-efficient communication and these needs to be considered at every stack layer of the protocol. For example, the energy consumption of a MAC layer can be reduced by modeling an appropriate duty cycle such that the nodes will remain active only for specific periods [62]. Next, at the network layer, energy-efficient modeling can be done by energy estimation and balancing load across the network [63]. The transport layer can be modeled as a function of the frequency of event reporting [64]. Further, a tradeoff needs to be maintained between computation and communication power. In WMSN QoS to improve the energy efficiency, P. Spachos et al., proposed an energy-aware dynamic and angle-based QoS aware routing. This approach is modeled concerning the transmission distance between nodes and the inclination angle of the next-hop candidate node. Further, S. Aswell and V. R. Gorpade presented a Link Quality and Energy Aware Routing (LEQAR) in which the next-hop forwarding node is selected based on the distance between the next-hop node and sink, remaining energy, and the quality of link associated with it. LEQAR discovers multiple paths between sources and sink nodes for reliable data delivery [65].

Lodhi et al., [66] proposed a "Multi-Path Multi-Priority (MPMP)" data communication method based on the optimization of cross-layer architecture which was oriented to the awareness of context. This approach employed a "Two-Phase Geographical Greedy Forwarding (TPGF)" multi-path routing scheme is used to discover node disjoint multiple paths at the network layer. At the transport layer, a "Context-Aware Multi-Path Selection" (CAMS) this algorithm is used to select the maximum number of paths to gather all possible information from the source node. Next, I. Bennis et al., combined the energy awareness with TPGF to achieve QoS with energy efficiency in WMSNs. Mainly the EA-TPGF considered the residual energy of nodes in the discovery paths. A novel dual scheme called PEMuR is proposed by Kandris et al., to achieve both QoS and energy saving. For this purpose, PEMuR is combined with intelligent video packet scheduling and the hierarchical routing protocol. Moreover, recently, D. Wang et al. proposed an Energy-Efficient Adaptive Distributed Cooperative Routing (EDCAR) by considering the energy consumption and QoS simultaneously. Specifically, a reinforcement learning algorithm is employed here to maintain a balance between energy, delay, and reliability [67].

6) *Dynamic Power Control*

Dynamic Power Control (DPC) is one more category of energy-aware routing mechanism in which the routing algorithm will keep continuous monitoring over the energy consumption at several parts of sensor nodes and makes them shut down or lie in sleep mode or hibernation mode if they found as idle. However, a guaranteed QoS is a very big challenge in the design of

the DPC framework. For instance, Fallahi and Hossain considered the operation modes of transceiver and multimedia sensor, varying network characteristics such as video traffic arrival rate, condition of channels, and buffering status at every node. Based on these factors a QoS aware DPC is modeled based on the Markov Decision Process (MDP) to extract an optimal policy for the network [68].

A similar method is proposed by A. K. Lodhi et al., [69] which use the MDP for dynamic power management based on only energy constraint. Several policies are derived and compared to obtain an optimal policy that maintains a tradeoff between energy consumption and throughput. Kate et al., [70] achieved an energy-efficient routing in WMSNs by applying DPM over CH selection, cluster formation, and multipath routing. Here the dynamics are realized through a genetic algorithm through which the best path is selected which optimized the cost function developed based on least energy consumption and minimum distance. Next, Habib and Moh [71] developed an evolutionary game-based routing (EGR) which is an evolutionary game theory is employed for CHs selection in WMSNs. Moreover, EGR also focused on the data redundancy based on the overlapped FOVs of camera sensor nodes.

IV. DISCUSSION:

P. Wang et al. [13] and Liu et al. [14] employed DSC based on entropy evaluation and Description coding. The major advantage of DSC is the shifting of computational complexity from the encoder to decoder. Even though the DSC has gained a better compression rate, it has certain theoretical bounds. Next, X. Liu et al, [19] applied WZC to attain a better compression rate at the risk of the more computational burden. Another way of data compression is the fusion of multi-modal data such as video and audio. The fusion is generally employed at the cluster level because the cluster heads (CHs) are assumed to have more resources than multimedia sensor nodes. M. Koyuncu et al. [24] and A. Yazici et al. [25] focused on the fusion of multi-modal data by applying object detection and machine learning algorithms. R. Gao et al. [26] employed Wavelet transform and extracted the shape of the object from a video. Extraction of the only shape removes much redundant information but wavelet transform needs two times the computational operation than conventional transforms like entropy etc. Moreover, the wavelet transform has the shift-invariance problem and results in less qualitative reconstructed image/video at the base station. Next, S. H. Ou et al., [22], and S. Colonnese et al., [28, 30] used correlation-based coding for data compression. For multi-view data, a common region is determined and it was only transmitted to the base station.

O. A. Fdili et al. [62] analyzed the energy consumption of the network based on frame rate and quantization parameter of H.264/AVC video coding. But the energy for transmission and reception of data is not concentrated. Next in the methods proposed by J. Zou et al. [60] and Khernane et al., [61], the energy consumption is related to the source or channel rate adoption. Along with this power consumption, they were focused on link rate and video coding rate and formulated the problem as weighted convex optimization. This kind of problem-solving strategy induces a huge computational burden over the network. P. Spachos et al., [65] and S. Aswale and V. R. Gorpade [66], [71] linked the energy consumption with the distance between communicating sensor nodes, sensor node to sink node distance, and remaining energy. Moreover, they have adopted multipath routing which is the main advantage. However, they didn't focus on the data rate which is the main factor and has a great impact on energy consumption. I. Bennis et al., [68] combined energy awareness with TPGF to achieve QoS with

energy efficiency in WMSNs. Mainly the EA-TPGF considered the residual energy of nodes in the discovery paths. However greedy forwarding mechanism introduces a delay in the data delivery because the greedy mechanism searches for the nearest node which results in the more intermediate node for a path between the source and the sink node. Fallahi and Hossain [72] and A. Kobbanne et al., [73] employed MDP for energy calculation. In these processes, the current energy level is predicted based on previous energy levels and can maintain a tradeoff between energy consumption and throughput. However, in WMSN, the energy consumption is related to data rate which was not focused on in these methods.

V. CONCLUSION

We have outlined all such methods to discover their pros and cons. Initially, we have outlined the basic architecture of multimedia sensor nodes followed by challenges and applications of WMSNs. Then we have surveyed different approaches and they are grouped according to the common objective they have focused to achieve. Under the segregation process, the entire methods are segregated into three different categories as Multimedia data-aware methods, QoS aware methods, and Energy-Aware methods. Further, a fine classification is done under every category based on sub-constraint or sub-objective intended to achieve. Finally, a detailed and simple comparison table is stipulated such that the readers will get a quick understanding. The comparison is done concerning methodology, performance metrics employed for performance evaluation. From this comparison, we have noticed that even though the approaches focused on load balancing, while they lack QoS provision when multimedia data is considered. Further, we also noticed that the multimedia data-aware approaches focused less on resource constraints. They purely tried to reduce the data redundancy through complex mathematical structures and such type of processing increases the computation energy.

References:

1. Chander, Bhanu. "Wearable sensor networks for patient health monitoring: challenges, applications, future directions, and acoustic sensor challenges." In *Healthcare Paradigms in the Internet of Things Ecosystem*, pp. 189-221. Academic Press, 2021.
2. Sattar, Syed Abdul, Amairullah Khan Lodhi, and M. S. S. Rukmini. "Energy-Efficient Wireless Sensor Networks: A Survey on Energy-Based Routing Techniques." In *ICEECCOT*. 2018.
3. Lim, Hyo-Ryoung, Hee Seok Kim, Raza Qazi, Young-Tae Kwon, Jae-Woong Jeong, and Woon-Hong Yeo. "Advanced soft materials, sensor integrations, and applications of wearable flexible hybrid electronics in healthcare, energy, and environment." *Advanced Materials* 32, no. 15 (2020): 1901924.
4. Lodhi, Amairullah Khan, M. S. S. Rukmini, Syed Abdulsattar, and Shaikh Zeba Tabassum. "Performance improvement in wireless sensor networks by removing the packet drop from the node buffer." *Materials Today: Proceedings* 26 (2020): 2226-2230.
5. Jiang, Wei, Sumit Majumder, Sophini Subramaniam, Xiaohe Li, Ridha Khedri, Tapas Monday, Mansour Abolghasemian, Imran Satia, and M. Jamal Deen. "A Wearable Tele-Health System towards Monitoring COVID-19 and Chronic Diseases." *IEEE Reviews in Biomedical Engineering* (2021).
6. Incel, Ozlem. "Design and implementation of a QoS-aware MAC protocol for Wireless Multimedia Sensor Networks."
7. Frost, Nollaig. *Qualitative Research Methods in Psychology: Combining Core Approaches* 2e. McGraw-Hill Education (UK), 2021.
8. Krishnan, Prabhakar, Kurunandan Jain, Pramod George Jose, Krishnashree Achuthan, and Rajkumar Buyya. "SDN Enabled QoE and Security Framework for Multimedia Applications in 5G Networks." *ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM)* 17, no. 2 (2021): 1-29.

9. Clerckx, Bruno, Kaibin Huang, Lav R. Varshney, Sennur Ulukus, and Mohamed-Slim Alouini. "Wireless power transfer for future networks: Signal processing, machine learning, computing, and sensing." arXiv preprint arXiv:2101.04810 (2021).
10. Fahmy, Hossam Mahmoud Ahmad. "Wsn applications." In *Concepts, Applications, Experimentation, and Analysis of Wireless Sensor Networks*, pp. 67-232. Springer, Cham, 2021.
11. Leask, Scott Benjamin. "Dynamical Feature Extraction of Atomization Phenomena Using Deep Koopman Analysis." PhD diss., University of California, Irvine, 2021.
12. Abdulkarem, Mohammed, Khairulmizam Samsudin, Fakhrol Zaman Rokhani, and Mohd Fadlee A Rasid. "Wireless sensor network for structural health monitoring: A contemporary review of technologies, challenges, and future direction." *Structural Health Monitoring* 19, no. 3 (2020): 693-735.
13. Puranik, Vishal V., and Amairullah Khan Lodhi. "Dynamic Resource Management of Cognitive Radio Networks Via Fuzzy Logic."
14. Chelliah, Ramachandran, Shuai Wei, Eric Banan-Mwine Daliri, Momna Rubab, Fazle Elahi, Su-Jung Yeon, Pianpian Yan, Shucheng Liu, and Deog Hwan Oh. "Development of Nanosensors Based Intelligent Packaging Systems: Food Quality and Medicine." *Nanomaterials* 11, no. 6 (2021): 1515.
15. Hajar, Muhammad Shadi, M. Omar Al-Kadri, and Harsha Kumara Kalutarage. "A survey on wireless body area networks: architecture, security challenges and research opportunities." *Computers & Security* (2021): 102211.
16. Awad, Atheer, Sarah J. Trenfield, Thomas D. Pollard, Jun Jie Ong, Moe Elbadawi, Laura E. McCoubrey, Alvaro Goyanes, Simon Gaisford, and Abdul W. Basit. "Connected Healthcare: Improving Patient Care using Digital Health Technologies." *Advanced Drug Delivery Reviews* (2021): 113958.
17. Singh, Pooja. "Vehicle Monitoring and Surveillance Through Vehicular Sensor Network." In *Cloud-Based Big Data Analytics in Vehicular Ad-Hoc Networks*, pp. 165-190. IGI Global, 2021.
18. McCarthy, Jessica, S. R. Chaudhry, Perumal Kuppuudaiyar, Radhika Loomba, and Siobhan Clarke. "QoS-ICN: An information-centric approach to QoS in vehicular environments." *Vehicular Communications* 30 (2021): 100351.
19. Almalkawi, Islam, Jafar Raed, Ayoub Alsarhan, Alaa Abdallah, and Emad Abdallah. "A Novel and Efficient Priority-Based Cross-Layer Contextual Unobservability Scheme Against Global Attacks for WMSNs." (2021): 43-69.
20. Nazir, Rashid, Kamlesh Kumar, Shibin David, and Munwar Ali. "Survey on Wireless Network Security." *Archives of Computational Methods in Engineering* (2021): 1-20.
21. Lodhi, Amairullah Khan, and Syed Abdul Sattar. "Cluster head selection by optimized ability to restrict packet drop in wireless sensor networks." In *Soft Computing in Data Analytics*, pp. 453-461. Springer, Singapore, 2019.
22. Yang, Yang, Songtao Guo, Guiyan Liu, and Yuanyuan Yang. "Two-layer compressive sensing based video encoding and decoding framework for WMSN." *Journal of Network and Computer Applications* 117 (2018): 72-85.
23. Yang, Hong, Linbo Qing, Xiaohai He, Xianfeng Ou, and Xiaojuan Liu. "Robust distributed video coding for wireless multimedia sensor networks." *Multimedia Tools and Applications* 77, no. 4 (2018): 4453-4475.
24. Sumalatha, M. S., and V. Nandalal. "An intelligent cross layer security based fuzzy trust calculation mechanism (CLS-FTCM) for securing wireless sensor network (WSN)." *Journal of Ambient Intelligence and Humanized Computing* 12, no. 5 (2021): 4559-4573.
25. Holzinger, Andreas, Bernd Malle, Anna Saranti, and Bastian Pfeifer. "Towards multi-modal causability with Graph Neural Networks enabling information fusion for explainable AI." *Information Fusion* 71 (2021): 28-37.
26. Lodhi, Amairullah Khan, and Syed Abdul Sattar. "Cluster head selection by optimized ability to restrict packet drop in wireless sensor networks." In *Soft Computing in Data Analytics*, pp. 453-461. Springer, Singapore, 2019.
27. Hussain, Tanveer, Khan Muhammad, Weiping Ding, Jaime Lloret, Sung Wook Baik, and Victor Hugo C. de Albuquerque. "A comprehensive survey of multi-view video summarization." *Pattern Recognition* 109 (2021): 107567.
28. Lodhi, Amairullah Khan, M. S. S. Rukmini, Syed Abdulsattar, and Shaikh Zeba Tabassum. "Lifetime Enhancement Based on Energy and Buffer Residual Status of Intermediate Node in Wireless Sensor Networks." In *Advances in Automation, Signal Processing, Instrumentation, and Control*, pp. 2747-2757. Springer, Singapore, 2021.
29. Pereira, Marina Meireles, and Enzo Morosini Frazzon. "A data-driven approach to adaptive synchronization of demand and supply in omni-channel retail supply chains." *International Journal of Information Management* 57 (2021): 102165.

30. Popovic, Goran, Goran Djukanovic, and Dimitris Kanellopoulos. "Cluster head relocation based on selfish herd hypothesis for prolonging the life span of wireless sensor networks." *Electronics* 7, no. 12 (2018): 403.
31. Yap, Florence GH, and Hong-Hsu Yen. "A survey on sensor coverage and visual data capturing/processing/transmission in wireless visual sensor networks." *Sensors* 14, no. 2 (2014): 3506-3527.
32. Liu, Meiyin, SangUk Han, and SangHyun Lee. "Tracking-based 3D human skeleton extraction from stereo video camera toward an on-site safety and ergonomic analysis." *Construction Innovation* (2016).
33. Jiang, Xiantao, F. Richard Yu, Tian Song, and Victor CM Leung. "A Survey on Multi-Access Edge Computing Applied to Video Streaming: Some Research Issues and Challenges." *IEEE Communications Surveys & Tutorials* 23, no. 2 (2021): 871-903.
34. Basu, Subho Shankar, Mathias Baert, and Jeroen Hoebeke. "QoS Enabled Heterogeneous BLE Mesh Networks." *Journal of Sensor and Actuator Networks* 10, no. 2 (2021): 24.
35. Tiwari, Richa, and Rajesh Kumar. "Various Methods of Link Design for Transferring Data in Wireless Sensor Networks for different Applications." In *IOP Conference Series: Materials Science and Engineering*, vol. 1020, no. 1, p. 012006. IOP Publishing, 2021.
36. Yadav, Devendra Kumar, Pragyan Mishra, Singam Jayanthu, and Santos Kumar Das. "On the Application of IoT: Slope Monitoring System for Open-cast Mines Based on LoRa Wireless Communication." *Arabian Journal for Science and Engineering* (2021): 1-12.
37. Lodhi, Amairullah Khan, Mazher Khan, Mohammed Abdul Matheen, Shaikh Ayaz Pasha, and Shaikh Zeba Tabassum. "Energy-Aware Architecture of Reactive Routing in WSNs Based on the Existing Intermediate Node State: An Extension to EBRS Method." In *2021 International Conference on Emerging Smart Computing and Informatics (ESCI)*, pp. 683-687. IEEE, 2021.
38. Hayder, Israa Adil, Sundas Naqeeb Khan, Faisal Althobiani, Muhammad Irfan, Muhammad Idrees, Saeed Ullah, Faisal Alsaq et al. "Towards Controlled Transmission: A Novel Power-Based Sparsity-Aware and Energy-Efficient Clustering for Underwater Sensor Networks in Marine Transport Safety." *Electronics* 10, no. 7 (2021): 854.
3. Amutha, J., Sandeep Sharma, and Jaiprakash Nagar. "WSN strategies based on sensors, deployment, sensing models, coverage and energy efficiency: Review, approaches and open issues." *Wireless Personal Communications* 111, no. 2 (2020): 1089-1115.
40. Akhtar, Nikhat, Saima Rahman, Halima Sadia, and Yusuf Perwej. "A Holistic Analysis of Medical Internet of Things (MIoT)." *Journal of Information and Computational Science* 11, no. 4 (2021): 209-222.
41. Amulya, S. "Survey on Improving QoS of Cognitive Sensor Networks using Spectrum Availability based routing techniques." *Turkish Journal of Computer and Mathematics Education (TURCOMAT)* 12, no. 11 (2021): 2206-2225.
42. Waheed, Shaikh Abdul, S. Revathi, Mohammed Abdul Matheen, Amairullah Khan Lodhi, Mohammed Ashrafuddin, and G. S. Maboobatcha. "Processing of Human Motions using Cost Effective EEG Sensor and Machine Learning Approach." In *2021 1st International Conference on Artificial Intelligence and Data Analytics (CAIDA)*, pp. 138-143. IEEE, 2021.
43. Mei, Jie, Wudan Han, Xianbin Wang, and H. Vincent Poor. "Multi-Dimensional Multiple Access with Resource Utilization Cost Awareness for Individualized Service Provisioning in 6G." *arXiv preprint arXiv:2108.10396* (2021).
44. Zanj, Eljona, Giuseppe Caso, Luca De Nardis, Alireza Mohammadpour, Özgü Alay, and Maria-Gabriella Di Benedetto. "Energy Efficiency in Short and Wide-Area IoT Technologies—A Survey." *Technologies* 9, no. 1 (2021): 22.
45. Li, Shu, Jeong Geun Kim, Doo Hee Han, and Kye San Lee. "A survey of energy-efficient communication protocols with QoS guarantees in wireless multimedia sensor networks." *Sensors* 19, no. 1 (2019): 199.
46. Bellini, Emanuele, Pierfrancesco Bellini, Daniele Cenni, Paolo Nesi, Gianni Pantaleo, Irene Paoli, and Michela Paolucci. "An IoE and Big Multimedia Data Approach for Urban Transport System Resilience Management in Smart Cities." *Sensors* 21, no. 2 (2021): 435.
47. Nguyen, Phuoc Duc, and Lok-won Kim. "Sensor System: A Survey of Sensor Type, Ad Hoc Network Topology and Energy Harvesting Techniques." *Electronics* 10, no. 2 (2021): 219.
48. Yadav, Piyush, Dhaval Salwala, and Edward Curry. "VID-WIN: Fast Video Event Matching with Query-Aware Windowing at the Edge for the Internet of Multimedia Things." *IEEE Internet of Things Journal* (2021).
49. Deje, D. "A Novel Protein Sequence Alignment-Based Patch Similarity Estimation for Two-Level Data Aggregation in WMSNs." *Wireless Personal Communications* 117, no. 3 (2021): 2595-2633.
50. Libutti, Angela, Anna Rita Bernadette Cammerino, and Massimo Monteleone. "Management of Residues from Fruit Tree Pruning: A Trade-Off between Soil Quality and Energy Use." *Agronomy* 11, no. 2 (2021): 236.

51. Cappellini, Vito. "Electronic imaging & the visual arts: EVA 2021 Florence: 14 June 2021." *Electronic imaging & the visual arts* (2021): 1-170.
52. Barathy, M. Nava. "Two-level data aggregation for WMSNs employing a novel VBEO and HOSVD." *Computer Communications* 149 (2020): 194-213.
53. Albahri, Ahmed Shihab, Jwan K. Alwan, Zahraa K. Taha, Sura F. Ismail, Rula A. Hamid, A. A. Zaidan, Osamah Shihab Albahri, B. B. Zaidan, A. H. Alamoodi, and M. A. Alsalem. "IoT-based telemedicine for disease prevention and health promotion: State-of-the-Art." *Journal of Network and Computer Applications* 173 (2021): 102873.
54. Rastogi, Eshita, Navrati Saxena, Abhishek Roy, and Dong Ryeol Shin. "Narrowband Internet of Things: A comprehensive study." *Computer Networks* 173 (2020): 107209.
55. Rukmini, M. S. S., and Amairullah Khan Lodhi. "Network lifetime enhancement in WSN using energy and buffer residual status with efficient mobile sink location placement." *Solid State Technology* 63, no. 4 (2020): 1329-1345.
56. Anhar, A. "Routing and Medium Access Control (MAC) in wireless sensor network for monitoring emergency applications." (2020).
57. Ma, Mengyuan, Kai Liu, Xiling Luo, Tao Zhang, and Feng Liu. "Review of MAC Protocols for Vehicular Ad Hoc Networks." *Sensors* 20, no. 23 (2020): 6709.
58. Elhoseny, Mohamed, and K. Shankar. "Energy efficient optimal routing for communication in VANETs via clustering model." In *Emerging Technologies for Connected Internet of Vehicles and Intelligent Transportation System Networks*, pp. 1-14. Springer, Cham, 2020.
59. Zeadally, Sherali, Faisal Karim Shaikh, Anum Talpur, and Quan Z. Sheng. "Design architectures for energy harvesting in the Internet of Things." *Renewable and Sustainable Energy Reviews* 128 (2020): 109901.
60. Chen, Feng, Jie Zhang, Mingkui Zheng, Jiyan Wu, and Nam Ling. "Long-term rate control for concurrent multipath real-time video transmission in heterogeneous wireless networks." *Journal of Visual Communication and Image Representation* 77 (2021): 102999.
61. Jo, Seng-Kyoun. "TOWARD A GREENER INTERNET-Design and evaluation of green IP and content routing for sustainable communication networks." (2021).
62. Deje, D. "A Novel Protein Sequence Alignment-Based Patch Similarity Estimation for Two-Level Data Aggregation in WMSNs." *Wireless Personal Communications* 117, no. 3 (2021): 2595-2633.
63. Ullah, Farman, M. Zahid Khan, Mohammad Faisal, Haseeb Ur Rehman, Sohail Abbas, and Foad S. Mubarek. "An energy efficient and reliable routing scheme to enhance the stability period in wireless body area networks." *Computer Communications* 165 (2021): 20-32.
64. Shair, Jan, Xiaorong Xie, Wei Liu, Xuan Li, and Haozhi Li. "Modeling and stability analysis methods for investigating subsynchronous control interaction in large-scale wind power systems." *Renewable and Sustainable Energy Reviews* 135 (2021): 110420.
65. Bradbury, Matthew, Arshad Jhumka, and Carsten Maple. "A Spatial Source Location Privacy-aware Duty Cycle for Internet of Things Sensor Networks." *ACM Transactions on Internet of Things* 2, no. 1 (2021): 1-32.
66. Lodhi, Amairullah K., M. Santhi S. Rukmini, and Syed Abdulsattar. "Energy-efficient routing protocol for network life enhancement in wireless sensor networks." *Recent Advances in Computer Science and Communications (Formerly: Recent Patents on Computer Science)* 14, no. 3 (2021): 864-873.
67. Lodhi, Amairullah Khan, M. S. S. Rukmini, and Syed Abdulsattar. "Energy-Efficient Routing Protocol Based on Mobile Sink Node in Wireless Sensor Networks." *International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN* (2019): 2278-3075.
68. Amairullah Khan Lodhi, Nikhat Nawaz "Watermarking and Compression of Digital Image Using WT and SPIHT" Publication date 2009/3/21 Conference Futuristic Advancements on Computing and Electronics FACE-09.
69. Lodhi, Amir. "Wideband Speech Coding & Its Application."
70. Amairullah Khan Lodhi, Ingole Snehal Diliprao, Kale Sindhu Subhas "Wavelete Based Texture Feature For Content Based Image Retrieval" 2013/12, IJETAE, Volume 3, Issue 12.
71. Amairullah Khan Lodhi, S. R. Madkar, Prof. A. V. Karande "Wireless Monitoring of Soil Moisture & Humidity using Zigbee in Agriculture" 2014/10, International Journal of Advanced Research in Computer Science and Software Engineering, Volume 10, Issue 4, Pages 817-821.
72. Aaqib Ibrah Amairullah Khan Lodhi, Mohammed Riyaz, Shaikh Ayaz Pasha, "Design & Implementation on Gas Leak Detection & Location System Based on Wireless Sensor Network" 2018, International Journal of Research in Mechanical, Mechatronics, and Automobile Engineering (IJRMMAE), Volume 3, Issue 4, Pages 84-87, Jupiter Publications Consortium.

73. M. Riyaz M. A. Sameer, A. K. Lodhi, M. Ilyas “Design & Implementation of Wireless Sensor Networks” 2018, International Journal of Research in Mechanical, Mechatronics and Automobile Engineering (IJRMMAE), Volume 3, Issue 4, Pp 102-105, Jupiter Publications Consortium.