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Multimedia Internet of Things: A Comprehensive Survey

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ABSTRACT The immense increase in multimedia-on-demand traffic that refers to audio, video, and images, has drastically shifted the vision of the Internet of Things (IoT) from scalar to Multimedia Internet of Things (M-IoT). IoT devices are constrained in terms of energy, computing, size, and storage memory. Delay-sensitive and bandwidth-hungry multimedia applications over constrained IoT networks require revision of IoT architecture for M-IoT. This paper provides a comprehensive survey of M-IoT with an emphasis on architecture, protocols, and applications. This article starts by providing a horizontal overview of the IoT. Then, we discuss the issues considering the characteristics of multimedia and provide a summary of related M-IoT architectures. Various multimedia applications supported by IoT are surveyed, and numerous use cases related to road traffic management, security, industry, and health are illustrated to show how different M-IoT applications are revolutionizing human life. We explore the importance of Quality-of-Experience (QoE) and Quality-of-Service (QoS) for multimedia transmission over IoT. Moreover, we explore the limitations of IoT for multimedia computing and present the relationship between the M-IoT and emerging technologies including event processing, feature extraction, cloud computing, Fog/Edge computing and Software-Defined-Networks (SDNs). We also present the need for better routing and Physical-Medium Access Control (PHY-MAC) protocols for M-IoT. Finally, we present a detailed discussion on the open research issues and several potential research areas related to emerging multimedia communication in IoT.

INDEX TERMS Multimedia Internet of Things (M-IoT), multimedia communication, Internet of Multimedia Things (IoMT), multimedia computing, Quality-of-Experience (QoE), Quality-of-Service (QoS), multimedia routing, medium access control (MAC).

I. INTRODUCTION

The amalgamation of the physical and digital world over the traditional Internet paved the way for the future Internet of Things (IoT). IoT is envisaged as the network model to fill the gap between the cyber and physical world [1]. The core concept of the IoT is to connect the pervasive objects around us, such as Radio Frequency Identification (RFID) tags, mobile devices, sensors and actuators to the Internet through a wired or wireless network. Hence, it enables the objects to interact with each other and their neighbors to enhance the efficiency of the system [1]. Several researchers have defined IoT in various contexts [2]: "*The integration of tiny devices known as Smart Objects (SO), usually battery operated equipped with a Microcontroller (MCU) and transceivers into the global Internet. The services offered by these smart objects are known as Smart Services (SS)* [3]–[6]. IoT has created new opportunities for machines to communicate with each other

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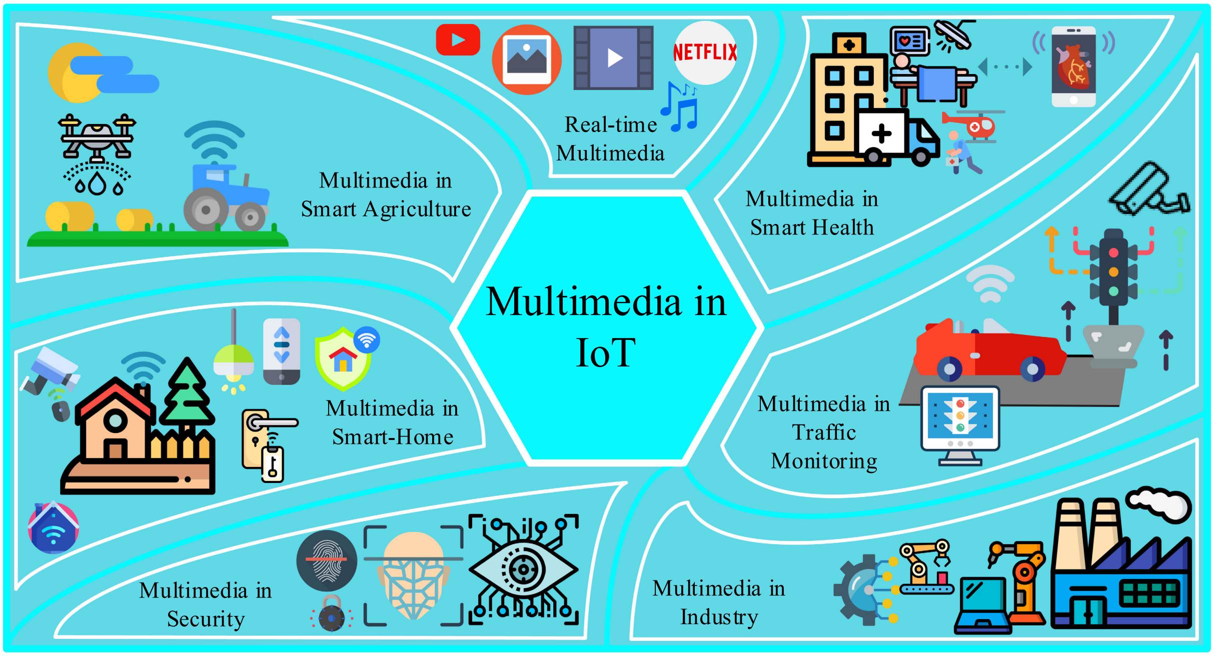

FIGURE 1. The overall vision of integrating multimedia applications of every domain in IoT, developing a smart city and transforming human lives, i.e., multimedia in agriculture, smart health, security, industrial process, road management systems, and real-time applications.

and extend the offered applications. Currently, 23 billion devices are connected to the Internet [7], and these numbers will stretch to 30 billion by 2020 [8]. Conventionally, IoT was assimilated relatively in data sensing devices, particularly in the Machine to Machine (M2M) environment [9]. Vigorous growth in the connected devices to the Internet during the last decade and abrupt demand for multimedia traffic has given rise to the emergence of the Multimedia Internet of Things (M-IoT). The equilibrium between QoS data and best-effort data is now in transit towards an increase in multimedia QoS data.

Currently, IoT is an assortment, comprising of M2M, Human-to-Machine (H2M), Human-to-Human (H2H), and Machine in/or Humans (MiH) communications (MiH devices may include human embedded chips, medical monitoring probes, and Global Positioning System (GPS)) [10].

M-IoT smart objects are usually resource-constrained, in terms of energy, memory storage, and processing power. To make the devices smaller, cost-effective and energy-efficient, sensors are usually designed to be battery operated or solar powered with only a few kilobytes of memory, and limited processing power in megahertz. Multimedia QoS data shows antagonistic behavior as compared to emblematic IoT scalar data. M-IoT devices require higher bandwidth, bulky memory resources, and higher computational power to analyze and process the procured multimedia data. Table 1 shows the difference between scalar and multimedia IoT data. The traditional multimedia application involves the data transmission of point-to-point, point to multipoint, or multipoint to multipoint. On the contrary, M-IoT applications require immense data transmission during multipoint-to-point communication (e.g., the surveillance system of the entire smart city) or multipoint-to-multipoint. Dynamic network, heterogeneous data, higher throughput, QoS, and delay sensitivity over such resource-constrained M-IoT smart objects escalates the challenges for M-IoT.

TABLE 1. Comparison of scalar and multimedia IoT data.

Required Parameter	Scalar IoT Data	Multimedia Data
Data Size (Approximate)	Bytes to Kilobytes	Mgebytes to Gigabytes
Memory	Kilobytes to Megabytes	Mgebytes to Gigabytes
Processing	Kilohertz to Megahertz	Megahertz to Gigahertz
Storage	Kilobytes to Megabytes	Gigabytes
Bandwidth	Kilobytes	Megabytes
Delay Sensitivity	Low	High
Power Consumption	Low	High

Multimedia data i.e., audio, image, and video is set of unstructured features. Transmission of such bulky and unstructured data over bandwidth and computationally scarce network requires efficient and intelligent network topology. The addition of multimedia data acquisition and communication requires revision and amplification of the traditional IoT system, which we refer to as M-IoT. The revision of IoT for multimedia communication requires efficient feature extraction, event processing, encoding/decoding, energy-aware computation, lightweight and priority-based routing, QoS and QoE maintaining performance metrics, effective channel access, and fair-MAC protocols.

Real-world multimedia applications include an example of rescue vehicles based emergency response systems, traffic monitoring, GPS based path tracking, agricultural monitoring, crime inspection, smart cities, smart homes, smart museum, surveillance systems, security system for authentication and authorization, multimedia-based e-health, patient monitoring in smart hospitals, and industrial monitoring systems. Fig. 1 conceptualize the multimedia communication in IoT in every domain-specific applications.

This article presents a comprehensive state of the art survey on M-IoT. There are several published research papers that cover different aspects of IoT. To the best of our knowledge, this article is the first that covers the studies specifically targeting multimedia communication in IoT in the context of the above-mentioned requirements.

A. CONTRIBUTIONS OF THIS SURVEY ARTICLE

In summary, this work aims to make the following contributions:

- To provide a detailed survey of various M-IoT network architectures.
- To survey the various M-IoT applications i.e., traffic monitoring, habitat monitoring, surveillance for public safety, industrial monitoring, and health monitoring.
- To discuss the design for M-IoT communication by summarizing performance metrics for M-IoT architectures.
- To survey the M-IoT computing paradigm comprising multimedia data compression, event processing, fog/edge computing, cloud computing, and Software-Defined Networks (SDNs) for data computing.
- To discuss various routing protocols in the context of multimedia data delivery in M-IoT.
- To provide a survey on different physical MAC (PHY-MAC) protocols for M-IoT.
- To provide open issues, challenges, and future research directions involving M-IoT.

B. COMPARISON OF RELATED SURVEY ARTICLES

Alvi *et al.* in [4] delineate the concept of M-IoT. The article is classified into two categories: M-IoT vision and, M-IoT applications and use cases. In the first category, authors have presented the vision of M-IoT and proposed four-layer multi-agent-based M-IoT architecture. Requirements and open issues in each layer are also discussed in this section. Moreover, IoT has been analyzed in-depth in the context of multimedia data. The authors have also discussed several video encoding and compressing techniques. The second section outlines the various multimedia applications and uses cases concerning M-IoT. However, this article does not cover a detailed survey on M-IoT specifically. An in-depth discussion on various enabling technologies, i.e., MAC protocols and network layer protocols, is missing. Discussion on future machine-type-communication and integration with 5$^{\text{th}}$ generation (5G) cellular communication is not found. Furthermore, various QoS and QoE depending factors and Information-Centric Network (ICN) approach regarding M-IoT are not discussed. Multimedia computation technologies are not found in this article.

The discussion on M-IoT in the context of architecture, enabling technologies, MAC and routing protocols is not found in the recent survey articles on IoT [2], [11], [12]. The existing survey on energy-efficient M-IoT is presented in [13]. This study explains the working of each layer of the traditional IoT architecture; however, the intrinsic nature of multimedia data is not considered in any aspect.

Different routing protocols are discussed in [14]–[18]. A detailed survey on multimedia routing in wireless sensor networks is presented in [17], [19]. However, these articles present a brief overview of multimedia routing and the comparison of various routing standards. It merely discusses the issues and challenges of current multimedia data requirements. Current M-IoT takes not only QoS but QoE into consideration that is dependent not only on network parameters but user's hardware capabilities itself.

MAC protocols and efficient resource allocation standards are presented in [20]–[23]. BlueVoice has been evaluated for multimedia services in real-time IoT devices in [24]. QoS is analysed in [25]–[29], while QoE is studied in [30]–[35]. The concept of Quality of Information (QoI) and ICN using a distributed algorithm for multimedia data collection is proposed in [36]. Kaaradi *et al.* [30] have presented the concept of Quality of Things (QoT) for M-IoT. However, it lacks QoS objectives. The rest of this article discusses the introduction of the virtual layer for virtual object representation and cross-layer communication. Cross-layer design related to M-IoT is presented in [33], [37], [38].

Thiyagarajan *et al.* [39] have proposed a secure video transmission energy-aware encryption scheme for M-IoT. Using Dictionary Learning (DL) and Approximate Message Passing (AMP). A compressed sensing technique is proposed for M-IoT in [40]. Various video encoding schemes and multimedia sensing are outlined in [41], [42]. Performance comparison of Advance Video Codings (AVC) H.265 and H.264 is presented in [43]. A detailed survey on multimedia big data computation is presented in [44]. Salman *et al.* in [45] present a survey on IoT from the perspective of Fog and SDN technologies. Articles [46]–[48], present review on multimedia in road traffic management and biometric security.

However, all these studies do not include a survey on multimedia communication in any form. Existing challenges, issues, and proposed work from the perspective of M-IoT are not presented in any of the articles.

Comparison: From the word comprehensive, this article provides an in-depth overview of M-IoT. This article specifies the limitations of IoT architecture and user requirements of multimedia data in order to revise IoT architecture. This enables us to cover a review of various IoT architectures supporting wireless multimedia communication. Computation is the key feature required for M-IoT. Limitations of cloud computing in exhausting the bandwidth and energy-constrained networks are identified. Advantages of Fog/Edge computation to assist cloud computing are pre-

TABLE 2. The comparison of comprehensive survey on M-IoT.

Article	Year	**Survey of Existing Work on M-IoT Architectures** • Agent Based • SDN Based • Big Data Based • Fog/Edge Based • AI Based	**Survey of Existing work on M-IoT Applications** • Road Management • Biometric and Retina Scanning • Surveillance • Industrial • Health	**Survey on M-IoT Computing** • Event Processing • Multimedia Compression • Cloud Computing • Fog/Edge • SDN Computing	**Survey on QoE and QoS Metrics for M-IoT** • MOS Metric for QoE • DMOS Metric for QoE • User Satisfaction for QoE • QoS Objective Metrics	**Existing works on M-IoT Routing Protocols** • Multimedia Routing • Distributed Routing • Cross Layer Routing • Multicast and Multi-hop • QoS-Aware	**Existing work on M-IoT PHY-MAC Protocols for** • Industrial Applications • Healthcare Applications • Surveillance • Military Applications • Precision Agriculture
[4]	2015	×	×	×	×	×	×
[13]	2014	×	×	×	×	×	×
[12]	2018	×	×	×	×	×	×
[17]	2016	×	×	×	×	✓	×
[11]	2015	×	×	×	×	×	×
[44]	2018	×	×	✓	×	×	×
[45]	2018	×	×	×	×	×	×
[19]	2017	×	×	×	×	×	×
This Article		✓	✓	✓	✓	✓	✓

sented. SDNs are moving the IoT architecture towards network virtualization. SDNs in the perspective of M-IoT is detailed in this article. This article also discusses the use of Machine Learning (ML) as an important aspect for feature extraction from multimedia data which extracts meaningful information from unstructured multimedia data. In addition, this paper presents various event processing mechanisms to reduce network overhead and latency. QoS and QoE metrics are well defined and evaluated in this article by comparing it with existing work. Routing and PHY-MAC protocols are well surveyed in the literature. However, contemporary literature lacks the consideration of multimedia data nature and requirements.

This article presents a comprehensive overview of multimedia applications and uses cases. This article only includes research work that specifically considers multimedia (audio, video, image, visual) data in IoT. To the best of our knowledge, this article is the first to present a comprehensive survey on M-IoT. A comparison of this article in the context of M-IoT with other survey articles is presented in Table 2.

C. ARTICLE STRUCTURE

The remainder of the paper is organized as follows: Section II presents an overview of IoT architecture and a comparison of different architectures of multimedia communication in IoT. Diverse applications of M-IoT are discussed in Section III. Section IV summarizes the performance metrics, design requirements and existing work to maintain quality in M-IoT. Section V presents the M-IoT computing paradigm, including multimedia coding, event processing, cloud, Fog/Edge computing, and computing using SDNs. Section VI covers various routing protocols for M-IoT, while PHY-MAC protocols are discussed in Section VII. Section VIII discovers the open issues, challenges, and future research directions for multimedia communication in IoT. Finally, section IX concludes the article. Table 3 accords the list of acronyms used throughout this article. Fig. 2 shows the classification of this article.

II. IoT AND MULTIMEDIA IoT ARCHITECTURE

A. IOT ARCHITECTURE

"*Anything, anytime, anywhere, any media*" has become the axiom for IoT communication. *Kevin Ashton* first coined the term IoT in 1999 [49]. The concept of the M2M has gained momentum after the development of the first RFID. RFID uses an electromagnetic field that automatically detects and wirelessly tracks the object. RFID is a vital component of the IoT since it links millions and billions of physical objects with the cyber world [50]. Currently RFID is used in various IoT applications such as supply chain management, gestural detection [51], E-health [52], mobile-based payments [53], and intelligent restaurants [54]. Diverse IoT applications and devices from various manufacturers create heterogeneity in the network, which increases the challenges to achieve a unified and interoperable standard. Thus to speak and understand various languages, numerous architectures are proposed. However, no one has converged to a standardized architecture.

Cloud computing layer-based architecture is proposed in [12]. The motivation and requirement of middleware based IoT architecture are presented in [55]. The integrated architecture of short-range micro IoT (e.g., IEEE 802.15.4 and IEEE 802.11 standards) and macro Sub-GHz technologies is proposed in [56]. Hu *et al.* [57] proposed the concept of the Software-Defined Device (SDD) layer-based IoT architecture. Security and cognitive layer-based IoT architecture

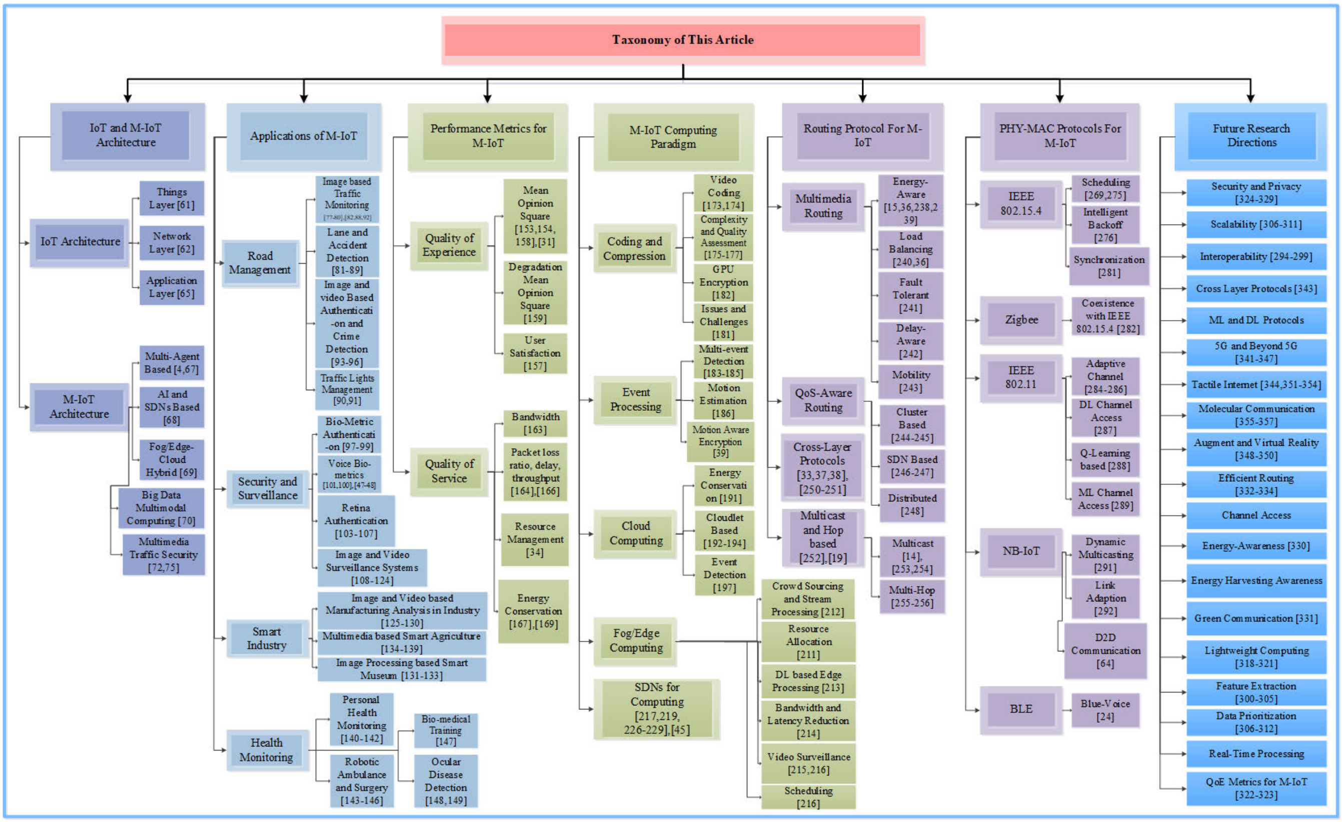

FIGURE 2. Taxonomy of this article.

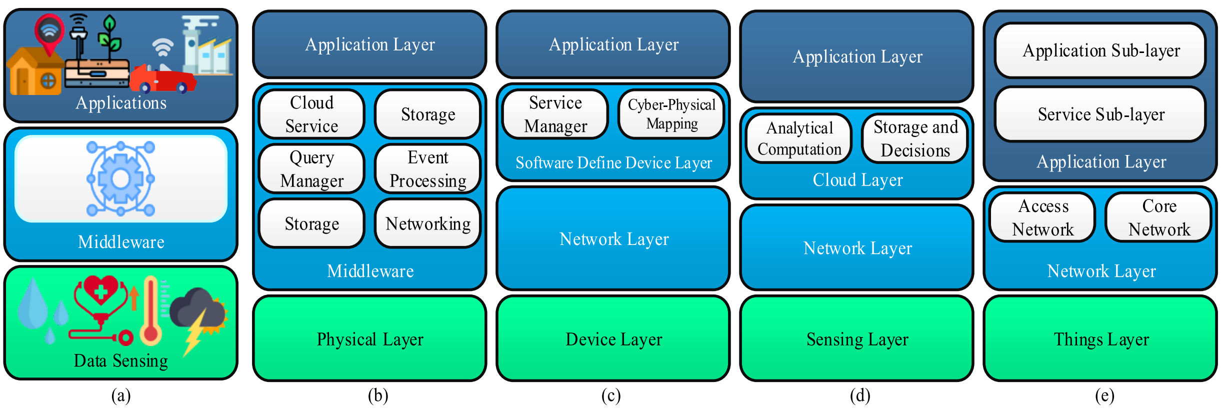

FIGURE 3. (a) Basic three elements of IoT: power-constrained hardware sensors or devices to sense and acquire the data, a middleware to process, analyze, and transmit the desired data, and application which visualizes the processed data and results. The existing proposed IoT architectures. (b) Middle-ware based [55] , (c) Software-defined-device based [57], (d) Cloud-based [12], (e) Traditional three-layer IoT architecture [60].

for enhancing efficiency, scalability, security, and privacy is presented in [58]. The article [59] proposes an energy-efficient IoT architecture based on cloud computing, sensor sleep intervals, and QoI. Fig. 3 shows the IoT architectures proposed in the literature.

The traditional IoT comprises three fundamental elements: mostly power-constrained hardware devices to sense and acquire the data, a middleware to process, analyze, and transmit the desired data, and application which visualizes the processed data and results. These three fundamental elements are depicted in Fig. 3(a), and it forms the basis of IoT architecture: 1) things layer, 2) network layer, and 3) application layer [60].

1) THINGS LAYER

It is the bottom layer in IoT architecture, also known as the perception layer, device layer, or sensor layer [61]. This layer is composed of a sensing hardware, scalar or multimedia

TABLE 3. The list of acronyms and corresponding definitions.

Acronyms	Definitions
AI	Artificial Intelligence
BS	Base Station
CNN	Convolutional Neural Network
CMOS	Complementary Metal Oxide Semiconductor
CoT	Cloud of Things
DL	Deep Learning
DNN	Deep Neural Network
GHz	Gigahertz
H2H	Human to Human
H2M	Human to Machine
IoT	Internet of Things
ICN	Information Centric Network
IMS	IP Multimedia System
LAN	Local Area Network
LLN	Low Power and Lossy Network
LTE	Long-Term Evolution
MAC	Medium Access Control
MCU	Microcontroller
MEC	Mobile Edge Computing
M-IoT	Multimedia Communication in IoT
M2M	Machine to Machine
MiH	Machine in Human
ML	Machine Learning
NB-IoT	NarrowBand Internet of Things
NN	Neural Network
PHY	Physical Layer
PLR	Packet Loss Ratio
QoE	Quality of Experience
QoI	Quality of Information
QoS	Quality of Service
RPL	Routing Protocol for Low-Power and Lossy Networks
SDD	Software Defined Devices
SDN	Software Defined Network
SVM	Support Vector Machine
SVR	Support Vector Regression
THz	Terahertz
UE	User Equipment
V2V	Vehicle-to-Vehicle
WAN	Wide Area Network
WPAN	Wireless Personal Area Network
5G	5^{th} Generation
6LoWPAN	IPv6 over Low-Power Wireless Personal Area Networks

sensors, and actuators, depending upon the services required by the application. Sensing devices have uplink data transmission mode while actuators have downlink data functionality. Access devices have the competency to operate in both uplink and downlink data transmission mode [57]. The main objective of this layer is to interconnect things in the IoT network. These devices sense, acquire and pre-process data from the physical world either locally or send the data to the centralized servers through gateways using Local Area Network or Wireless Personal Area Network (LAN/WPAN) via short-range low power enabling technologies like Zigbee, Bluetooth Low Energy (BLE), Ethernet, IEEE 802.15.4, etc.

2) NETWORK LAYER

It is the middle layer in IoT architecture, also known as the transmission layer [62]. Virtually it is divided into two sub-layers: the access network and the core network. The main functionality of the network layer is to process the received data from the things layer. Therefore, it determines the energy-efficient optimum route to transmit the data to the IoT servers, devices and applications via the Internet using one of the communication networks such as WiFi, Ethernet, 3G, Long-Term Evolution (LTE), 5G or satellite network [63]. The access network layer is responsible for interconnecting various devices and applications through interfaces or gateways among Heterogeneous Networks (HetNet) using various communication protocols. The core network is responsible for determining the optimum route. Currently, the network layer should also support both Internet Protocol version 4 (IPv4) and IPv6 networks considering the requirements of cross-domain interoperability in heterogeneous IoT networks. Furthermore, to optimize the IoT uplink transmission, devices (e.g., smartphones and vehicles) are also exploited as sink nodes for an end to end communication, such as Device-to-Device (D2D) communication [64]. Various data link layer and network layer protocols are presented in section VI and section VII.

3) APPLICATION LAYER

It is the top layer in IoT architecture, also known as the business layer [11]. Based on the functionality of the layer, it is virtually subdivided into two layers, i.e., service sublayer and application sublayer [65]. The service sublayer provides information management, data mining, data analytics, and decision-making services. The application sub-layer needs to provide the required services to end-user or machines. The application layer primarily analyzes the required services of IoT application and transforms the physical world data into the expressions of cyber world demands. Constrained Application Protocol (CoAP) is proposed by IEEE 802.15.4 standard [66] to improve data packets delivery and to reduce overheads. The messaging layer and request/response layer are two defined layers in CoAP. Other proposed IoT application layer protocols are Data Distribution Service (DDS), Advanced Message Queue Protocol (AMQP), and Extensible Messaging and Presence Protocol (XMPP) [11].

B. M-IoT ARCHITECTURES

The characteristics of IoT make it possible to support multimedia applications. However, it poses enormous challenges as multimedia applications are bandwidth-hungry and delay-sensitive. Radio and computational resources are preciously scarce for IoT devices. The rapid surge of multimedia data in IoT leads to vast amorphous data. Researchers have proposed different M-IoT architectures to efficiently analyze, process, and utilize the resources with more reliability. Novel M-IoT architectures are presented in this section. Fig. 4 and Table 4 summarizes existing M-IoT architectures.

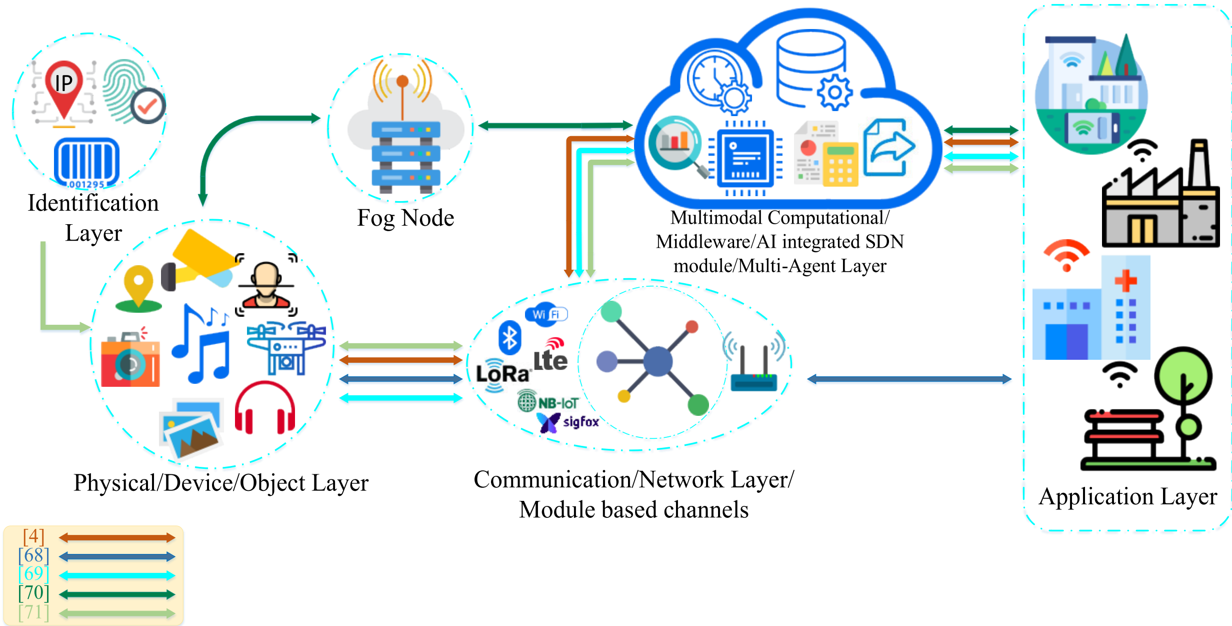

FIGURE 4. The existing proposed M-IoT network architectures: multi-agent-based M-IoT architecture [4], agent-based M-IoT architecture [67], AI-based SDNs for multimedia traffic management architecture [68], Fog-Cloud hybrid M-IoT architecture [69], and Big data layered M-IoT architecture [70].

TABLE 4. M-IoT proposed architectures.

<table>
<tr><th>Architecture Proposal</th><th>Proposed Layers</th><th colspan="2">Article</th><th>Year</th></tr>
<tr><td rowspan="4">Multi-agent Based M-IoT Architecture</td><td>Multimedia Sensing</td><td rowspan="4" colspan="2">[4]</td><td rowspan="4">2015</td></tr>
<tr><td>Reporting and Addressability</td></tr>
<tr><td>Multimedia-Aware Cloud</td></tr>
<tr><td>Multi-Agent Systems</td></tr>
<tr><td rowspan="5">Agent Based M-IoT Architecture</td><td>Applications</td><td rowspan="5" colspan="2">[67]</td><td rowspan="5">2018</td></tr>
<tr><td>Service Execution Agents</td></tr>
<tr><td>Resource Connectors</td></tr>
<tr><td>M-IoT Services and Resources</td></tr>
<tr><td>Multimedia Devices and Communications</td></tr>
<tr><td rowspan="3">AI-Based SDN for Multimedia Traffic Management Architecture</td><td>IoT Network</td><td rowspan="3" colspan="2">[68]</td><td rowspan="3">2018</td></tr>
<tr><td>Network Heads</td></tr>
<tr><td>AI-Based Cloud SDN</td></tr>
<tr><td rowspan="3">Fog-Cloud Hybrid M-IoT Architecture</td><td>Remote Cloud</td><td rowspan="3" colspan="2">[69]</td><td rowspan="3">2018</td></tr>
<tr><td>Fog Node</td></tr>
<tr><td>Mobile Client</td></tr>
<tr><td rowspan="6">Big Data Layered M-IoT Architecture</td><td>Identification Layer</td><td rowspan="6" colspan="2">[70]</td><td rowspan="6">2018</td></tr>
<tr><td>Physical Layer</td></tr>
<tr><td>Communication Layer</td></tr>
<tr><td>Middleware Layer</td></tr>
<tr><td>Multimodal Computational Layer</td></tr>
<tr><td>Application Layer</td></tr>
<tr><td rowspan="4">Multimedia Traffic Security Architecture</td><td>Key Management</td><td>[73]</td><td rowspan="4">[72]
[75]</td><td rowspan="4">2011</td></tr>
<tr><td>Batch Rekeying</td><td>[74]</td></tr>
<tr><td>Authentication</td><td>[75]</td></tr>
<tr><td>Watermaking</td><td>[76]</td></tr>
</table>

1) MULTI-AGENT BASED M-IoT ARCHITECTURE

Based on the bulky and unstructured nature of the multimedia content, researchers in [4] propose a multi-agent cloud computing-based architecture for multimedia communication in IoT. The authors have outlined multiple open issues in M-IoT over different communication layers. The presented architecture is separated into four main parts; Multimedia sensing, reporting and addressability, multimedia aware cloud, and multi-agent systems. Multimedia sensing is responsible for pre-transmission processing, which includes transformation, quantization, estimation, and compression techniques to reduce the bandwidth requirements.

In addition, authors have suggested equipping the network with energy harvesting capabilities to balance the tradeoff between feasible compressions and the energy-constrained M-IoT devices. The report and addressability comprise the abilities of the link-layer enabling technologies, i.e., IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN) based IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL), green communication, transport, and application layer. The multimedia-aware cloud performs four main jobs that are:

- Multimedia-aware middleware is responsible for understanding various requirements/services of the end-users and adapts itself to aggregate, process, learn, filter, and deliver the services.
- The device should be uniquely identified to globally access and control remote multimedia devices based on several techniques, i.e., Internet Protocol (IP), Domain Name System (DNS), Uniform Resource Identifier (URI), and Object Name Sevices (ONS).
- Naming the multimedia content to manage huge multimedia data using Digital objects Identifiers (DOI), Digital Item Identification (DII), or Digital Item Declaration (DID).
- Data storage and processing are responsible for offering massive storage with the scalability, accessibility, and security. Along with stored multimedia, data should be categorized and indexed according to the end-users requirement. Multimedia content access requires security and privacy policies. Content-Delivery-Network (CDN) is proposed to process multimedia content in a distributed manner to overcome resource constraints.

The multi-agent cloud performs data mining and data analysis, service composition, and content sharing. Authors have defined agents as autonomous software working independently to achieve objectives subject to design constraints.

Kaeri *et al.* [67] further enhance the multi-agent M-IoT architecture to make it more practical by proposing and implementing the five-layer architecture. The proposed architecture includes a novel concept of modules based channel that comprises multimedia device communication, M-IoT services, resources, and a resource connector layer. Service execution agents and applications layer holds the upper position in the proposed architecture. Various multimedia devices and communication stack form the things layer.

Multimedia data stream to or from the devices forms M-IoT service of the resource layer. Cloud resource is a special type that performs asynchronous communication. Edge nodes operate on synchronous communication for real-time processing. Resource connector exchanges messages to or from M-IoT service and resource layer with service execution agents layer which serves modules according to application requirement. It also provides Application Programming Interfaces (APIs) for applications. The authors have conducted experiments by implementing their proposed architecture in the remote collaboration support system for video conferencing [67].

2) AI-BASED SOFTWARE-DEFINED M-IoT ARCHITECTURE

The robust increase in multimedia traffic necessitates an efficient network traffic management system. Rego *et al.* [68] propose an intelligent network management system for the IoT video surveillance system based on SDN and Artificial Intelligence (AI). The AI module is integrated into SDN to guarantee the QoS and QoE based on delay, loss rate, and jitter. The authors define two main functionalities for the AI module, i.e., data classification and resource estimation. The SDN controller governs SDN. After the SDN controller receives the data from IoT Network Heads (NHs), the SDN controller sends a request to the AI module to classify the data. Multimedia data is classified as critical traffic. The article also highlights the preprocessing standards to prioritizes the data set by classifying it as critical and label it in increasing order with 1 being non-critical traffic and 5 being very critical traffic. Various Machine Learning (ML) approaches are compared to train AI traffic classification module to achieve the best performance that is a Support Vector Machine (SVM), Neural Network (NN), and statistic method (Kernel). Bayes statistic model is used for network resource estimation based on traffic priority, route traffic, bandwidth variation, buffer management, nodes sleeping duration in the network, and activate backup nodes. Open Flow architecture is used to communicate between the SDN controller and NHs. The authors also propose a customized message protocol for communication between the SDN controller and the AI module, and NH and IoT nodes. Experiments are conducted using emulator Mininet, and several results are presented. Results depict 77% accuracy of the AI module.

3) FOG-CLOUD HYBRID M-IoT ARCHITECTURE

Rahman *et al.* [69] propose a context-aware fog-cloud hybrid based framework that integrates spatio-temporal multimedia data from IoT mobile and stationary nodes for the massive ad-hoc crowd. In the article, a three-tier architecture: mobile client tier, fog node tier, and remote cloud tier, is presented. The authors aim to optimize energy resource utilization and reduce end-to-end delay for the massive crowd in the smart city. The mobile client tier includes service consumers. Fog nodes tier comprises smartphones and other IoT fog nodes distributed in the city to assist in real-time processing of spatio-temporal collective or individual queries. Cloud tier is formed of IP based massive big data architecture to analytical compute, store, and process offline queries. BLE, WiFi Direct, 5G, or D2D spectrum can be used for communication within the fog tier. Cloud comprises of four different platforms that are the crowdsensing service, social network service, mobile or stationary IoT service, and crowdsourcing service. Smartphone acting as a context manager and fog node, provides storage, computation, and communication-based on an individual's historical context. Thus, it decreases a large amount of payload to the backend cloud. The eventual storage and complex analytical computation can be pushed to the cloud. User context requirements are defined according to their subscribed IoT services. Moreover, semantics is added to the system using the 3A model which assimilates the data from Body Sensor Network (BSN), crowdsourcing, social networks and IoT devices to a unified, generic context by the smartphone's context manager to deduce elevated semantics overlay.

A query can be responded by one or all four platforms. To find a dust-free path, dust sensors deployed in the city can provide real-time data, crowdsourcing delivers the query response, human or mobile IoT sensors provides the dust level. The response to the query can be made available on social network services. Crowdsensing provides congestion and weather-related statistics. The article presents a practical implementation of the proposed framework and development of smartphone application considering Hajj pilgrims as a massive ad-hoc crowd.

4) BIG DATA LAYERED M-IoT ARCHITECTURE

Authors in [70] proposed a novel concept of six-layered M-IoT architecture based on big data aggregation, computation, and extraction of multimedia content. Instead of word media authors have considered modal, which refers to the way the data is interpreted to convey meaning. Moreover, they have listed three main problems associated with multimodal big data computation that is to compute the huge amount of data, to detect and extract meaningful information and the current limitation of big data processing platforms for multimedia. The six layers proposed in M-IoT architecture are:

- Identification: Devices are first identified based on their object ID that is Electronic Product Codes (EPC) and Ubiquitous Codes (uCodes). Objects are further discriminately identified based on IPv4 or IPv6. An efficient identification technique based on the 6LoWPAN compression mechanism over IPv6 is presented in [71].
- Physical Object: This layer represents the data aggregated from scalar or multimedia objects based on their modality and passes on the data to the central unit for further processing.
- Communication: It has the same functionality of link, network, and transport layer as in traditional IoT architecture.
- Middleware: It is defined to provide software level support for functional services that is resource discovery, data management, and non-functional services, which include reliability, scalability, and security.
- Multimodal computation: It is responsible for providing hardware components for computation and Real-Time Operating Systems (RTOS). Authors have proposed a sub-layer for big data analytics, which includes a centralized data unit, multimodal data aggregation unit, multimodal divide and conquers computation unit, and fusion and decision-making unit. These units are specifically designed to aggregate, analyze, process, and extract the desired features from the big multimodal data.
- Application layer: It provides the required services through a set of standardizing protocols.

Moreover, the article presents a unique and efficient technique that is Divide and Conquers Principal Component Analysis (DC-PCA) to reduce the dimensions, subdivides the data, process the subdivided data in parallel fashion, and fuse the final parallel processed data to extract the features. Thus making the required decision for services and applications. The practical implementation of the proposed DC-PCA for face recognition application using Yale and ORL databases is presented. The authors efficiently presented the functionality of each layer.

5) SECURITY BASED ARCHITECTURE

Zhou and Chao [72] devised Mediaware Traffic Security Architecture (MTSA) for M-IoT based on four main components. These components are key management which comprises service control, user control, flow control scalable, and nonscalable schemes [73]. Batch rekeying accommodates multiple multimedia applications based on periodic batch keying, periodic batch leave keying, and periodic batch join rekeying [74]. Authentication is achieved by group authentication, source authentication, and individual sender authentication employing access control list, ability certificates, and mutual authentication methods [75]. Watermarking is used to identify the origin of multimedia content, trace illegal distribution, and block unauthorized access by embedding a unique watermark into multimedia content [76]. The proposed framework exploits visual secrecy measures to provide generic multimedia security solutions that degrade comparatively to the number of shares in possession of an attacker. MTSA inherits content-awareness characteristics from media-aware based middleware security architecture for multimedia services [75].

C. SUMMARY AND INSIGHTS

This section defines IoT and elaborates each layer of traditional IoT architecture. It also covers various architectures and the design requirements for M-IoT. Multimedia communication in IoT needs flexible and interoperable architecture to support HetNET and different multimedia applications with various application requirements. Multiagent, fog-cloud hybrid, big data, and multimedia traffic security architectures have been investigated in detail. However, quality-aware architectures and M-IoT computation are presented in the latter section of the article. The existing work on M-IoT are mostly focussed on application-dependent requirements, and it does not take into the consideration of standardizing M-IoT architecture. Standardized M-IoT architecture is in need to support multimedia content in various IoT applications. The use of multi-agent base ML algorithms can effectively improve the learning and understanding of an individual's multimedia demands in M-IoT architecture. This section is summarized in Table 4.

III. APPLICATIONS OF M-IoT

Multimedia objects equipped with Internet connectivity and interaction with other objects without human intervention

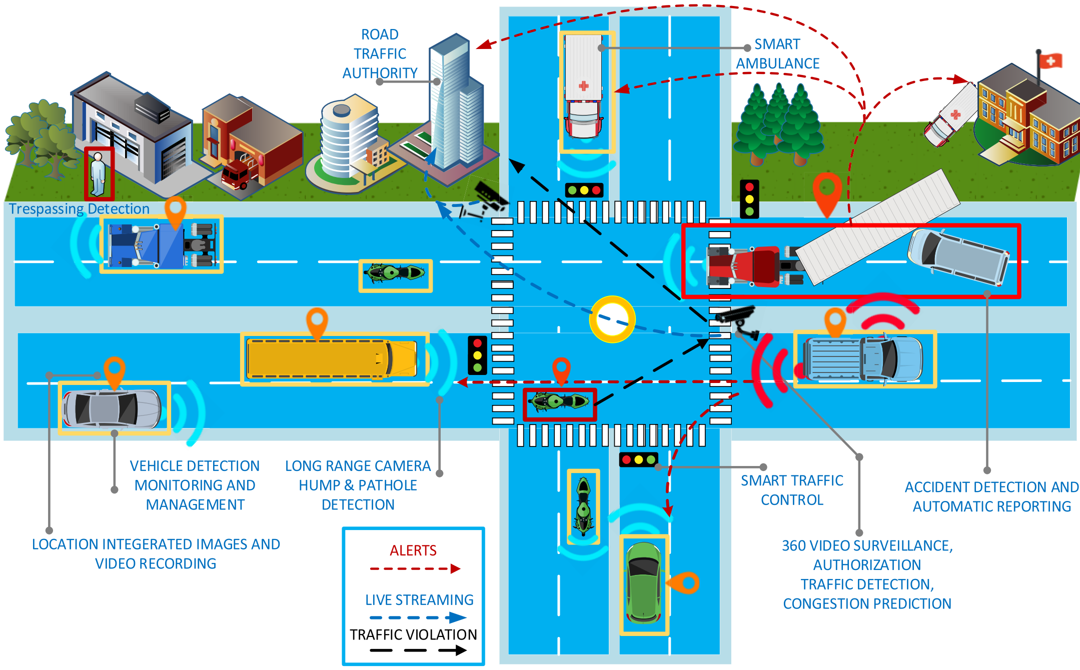

FIGURE 5. The use case of M-IoT for road management systems that includes accident detection and prevention system ([46], [82]), traffic estimation and congestion prevention systems [77], lane and path hole detection ([81], [83]), trespassing detection [91], automatic emergency detection and alerts generation systems [86], and traffic signal monitoring system ([78], [90]).

leads toward the vast opportunities for the betterment of humankind in daily life. Since multimedia data is rich in information. Features like face recognition, motion detection, license plate identification, driver drowsiness indication, patient state, crowd detection, path hole, and obstacle detection, retina scanning for authorization and crime detection can be extracted employing various data aggregation, analytics and extraction tools. A heterogeneous network of multimedia objects, ubiquitous data transmission, and cloud-based multimedia content analytics paved the path for smart cities. In this section, we have classified numerous M-IoT applications based on different roles in the smart city. Table 5 classifies and summarizes the applications of M-IoT.

A. ROAD MANAGEMENT SYSTEM

1) TRAFFIC MONITORING

Efficient traffic monitoring and control is one of the major issues in the smart city. To handle this problem, there are different solutions based on infra-red detectors, magnetic loops, and microwave radars. These conventional techniques incur huge installation, maintenance costs, and lack of accuracy. The researcher put forward M-IoT based techniques to effectively detect and identify the volume of traffic and predict the reason for a traffic jam. Fig. 5 conceptualize the M-IoT to enhance the road management system. Authors in [77] presented computer vision-based ontology-driven context-aware M-IoT architecture to estimate the traffic by tracking the number of vehicles present on the road in real-time from CCTV camera video and segregate moving vehicles from stationary vehicles. Based on the density of stationary traffic that occupies the road is compared to a threshold value. Multimedia Web Ontology Language (MOWL) has been adopted, which utilizes time-varying Dynamic Bayesian Networks (DBN) for comparison and predicts the cause of traffic congestion. Automatic alerts can be triggered by road traffic authorities to avoid a traffic jam. Raspberry Pi and Pi camera-based IoT architecture are presented in [46] for traffic surveillance and road accidents. The authors used a Gaussian Mixture Model (GMM) with canny edge detection on VIRAT and MIT traffic data set to evaluate their proposal. The article also presents several surveyed efficient methods, i.e., hidden Markov and neural network, Lucas-Kanade, and K-means clustering techniques for accurate accident detection and vehicle tracking.

George *et al.* [78] proposed an Adaptive Nero Fuzzy Inference System (ANFIS) and image processing based technique using M-IoT for the better traffic light management and monitoring system. Camera images are obtained and analyzed on a ThinkSpeak based cloud server. Based on the analysis, control actions are given to traffic lights. Machine vision blob analysis technique is used to detect and locate the vehicle. Due to poor illumination conditions during night, the Otsu image processing technique is used. Low Power Wide Area Network (LoPWAN) and Long Range (LoRa) receiver and transmitters are adapted to propose IoT smart traffic monitoring and control architecture in [79]. A comparative survey on the M-IoT based traffic management system is presented in [80].

TABLE 5. Applications of wireless multimedia communication in IoT.

Different Applications			Proposed Methodology	Articles	Year
Road Management System	Traffic Monitoring		Image Processing based Ontology-Driven Context-Aware	[77]	2017
			Multimedia based Smart Traffic Light	[78]	2018
			Image and Video based Smart Traffic Monitoring	[79]	2017
			Review on Traffic Management	[80]	2018
			Cloud Proceesing for Mobile Multimedia-Based Traffic Monitoring	[82]	2018
			IoV for Traffic management	[88]	2017
			M2M Based Multimedia Traffic Management	[92]	2011
	Multimedia based Path Detection, Lane Detection and Accident Reporting		Image-based Obstacle Detection	[81]	2016
			A Survey on Road Traffic Surveillance and Accident Detection	[46]	2017
			Humps and Pothole Detection using	[83]	2018
			UAV Path Planning	[84]	2010
			Vehicle Monitoring System	[85]	2018
			Life Monitoring in Vehicle	[86]	2018
			V2V Communication	[87]	2016
			Android IoT Based Vehicle Monitoring	[89]	2018
	Image and Video based Traffic Lights Management		Street Lights management	[90]	2017
			Guidance System for Smart City	[91]	2018
	Multimedia based Authentication and Crime Detection		Autonomous Taxi for Smart City	[93]	2018
			Crime Detection	[94]	2014
			Network Architectures for Smart City	[95]	2012
			IoT Based Toll Payment	[96]	2016
Habitat Monitoring	Security Surveillance	Bio-Metric Authentication	Internet of Biometric Things	[97]	2016
			Biometric Authentication for IIoT	[98]	2018
			Biometric Secure Telecare System	[99]	2014
		Voice Bio-Metrics	Voice Biometrics	[101]	2017
			Voice User Interface Security	[102]	2018
			Secure H-IoT	[100]	2019
			Biometric IoT Security-Comprehensive Survey	[47],[48]	2015-18
		Retina Authentication	Retina Authentication	[103]	2015
			Iris and Retina Fusion Scanning For M-IoT	[104]	2018
			Face Recognition using Retina Scan	[105]	2014
			Diminishing Effect of Ocular Diseases	[106]	2015
			Iris Localization Authentication Method	[107]	2011
		Surveillance System	Pi camera based M-IoT Surveillance System	[108]	2018
			RTP and RTSP based Android Surveillance	[109]	2015
			Speech with Ontology Driven Public Transport Surveillance System	[110]	2009
			Infants Monitoring System for SIDS Prevention	[111]	2017
			Video Summarization for Smart Surveillance	[112]	2017
			KNN Based Multi-view Video Summarization for IoVT	[113]	2017
			Distributed Video Summarization in IoVT	[114],[115]	2015
			Secure MVSS in M-IoT	[116]	2018
			Automatic TBS Selection for Video Transmission in Environmental Monitoring	[117]	2016
			VIPS for M-IoT Surveillance System	[118]	2017
			Multiview Video Compressive Encoding/Decoding for M-IoT	[119]	2017
			Vigil Edge Computing Node for Video Surveillance	[120]	2015
			Slicing and Parallel Processing in IoVT, an application of M-IoT	[121]	2014
			SCORPIO a SDN Based Multipart Transport Mechanism in M-IoT	[122]	2016
			SDN Based Network Selection Algorithm for Real-Time Services	[123]	2017
			Quadrotors Based IoT Tracking Application	[124]	2016
Smart Industry	M-IoT Industrial Monitoring		Automatic Vision Depth Based Steel Billets Inspection	[125]	2018
			3D Modeling Based Steel Billets Inspection	[126]	2017
			Condition Monitoring for Petroleum Industry	[127]	2018
			Online Flame Color Analysis for Combustion Quality Maintenance	[128]	2017
			Optical Character Recognized Meter Reader	[129]	2016
			Energy Harvested Sky Camera for Smart Grids	[130]	2013
	Image Processing Based Smart Museum		Smart Museum Industry using M-IoT	[131]	2017
			Smart Museum using Beacon Based Content Delivery	[132]	2017
			Application of M-IoT for Transport Robots in Automated Warehouse	[133]	2018
	M-IoT in Smart Agriculture		M-IoT based Agriculture Crop Monitoring	[134]	2014
			Agricultural Production System using M-IoT	[135]	2013
			Crop Growth Monitoring System using M-IoT	[136]	2012
			Food Recognition Application of M-IoT	[138]	2014
			Food Freshness Recognition using Image Processing in M-IoT	[139]	2018
E-Health	Health Monitoring using Multimedia		Personal Health Multimedia Architecture	[140]	2018
			M2M Communication Architecture for E-Health Wearable Devices	[141]	2018
			Cloud of Things for Remote Health Care	[142]	2016
			5G Small Cell Network for Smart Ambulance	[143]	2018
			Robotic Ambulance for Sudden Cardiac Arrest	[144]	2016
			X-ray Images for Robotic Fracture Surgery	[145]	2017
			Robotic Surgery Assistant	[146]	2017
			M-IoT for Biomedical Training	[147]	2017
			Smartphone Retinal Cataract Detection	[148]	2015
			Smart Ocular Disease Detection	[149]	2016

2) PATH DETECTION, LANE DETECTION, AND ACCIDENT REPORTING

Autonomous or Unmanned Ground Vehicles (UGV) are the key element in the development of a smart city. Lane detection is considered a vital feature to avoid a collision in UGVs. Image-Based obstacle detection and path planning are discussed in [81], which includes the conversion of video into fixed-rate image frames. Frames are then analyzed using image processing techniques, i.e., edge extraction and thresholding. A cloud-based M-IoT system is proposed for accident prevention in [82]. HoneyBee Optimization (HBO) based IoT road monitoring system is proposed in [83] to detect humps and pothole to prevent accidents. A driving algorithm for path planning is proposed for autonomous vehicles exploiting potential field methods and lane detection in [84]. Data is acquired using CCD cameras, differential GPS, 2-dimensional laser scanner, and digital compass. The analysis is performed using the proposed algorithm for lane detection. CDN and MPEG Dynamic Adaptive Streaming over HTTP (DASH) are used for a real-time vehicle monitoring system in [85]. Ni *et al.* [86] present a novel life-saving concept for the individuals left behind in the vehicle. The article incorporates life recognition, environmental monitoring, and alarming subsystem. Vehicle-to-Vehicle (V2V) communication in M-IoT based on Direct Short-Range Communication (DSRC) for Intelligent Transport System (ITS) is proposed in [87]. Several benefits of using the multimedia Internet of Vehicle Things (IoVT) for a traffic management system are identified in [88]. Android-based IoT vehicle monitoring system accessing various vehicle parameters and driver behavior analysis using a Controller Area Network (CAN) is presented in [89].

3) TRAFFIC LIGHTS MANAGEMENT

An efficient, cost-effective traffic and street light control mechanism based on M-IoT is outlined in [90] for smart cities. The solar panel-based streetlights with Direct Current (DC) power supply as a backup along with Light Dependent Resistor (LDR) is used to control the intensity of the light when no vehicle is present in the street. Traffic bollards are used to avoid an accident during red and yellow lights. Cameras are deployed for the surveillance systems. Latif *et al.* [91] proposed the smart city model having intelligent traffic monitoring and guidance system. The proposed model incorporates multimedia data for authentication, verification, registration, authorization, shortest path identification, to high light the congested areas. Public places like schools, colleges, hospitals, hotels, petrol pumps, and banks are considered as objects and are identified by specific IDs. Cameras are used to monitor the flow of traffic. The shortest path is determined based on time or distance. Vienna Development Method-Specification Language (VDM-SL) is opted-in this article for modeling purposes.

4) AUTHENTICATION AND CRIME DETECTION

IP Multimedia System (IMS) based M2M metropolitan platform for traffic management to restrict vehicles entering the prohibited area is detailed in [92]. Authors in [93], proposed a Deep Neural Network (DNN) based autonomous Taxi model for a smart city. Authors in [94] presented a novel concept of M-IoT based crime detection in a smart city by analyzing human emotions and CCTV videos. After detection and identification of crime, it is stored in the database and visualized using a Geographic Information System (GIS). As the smart city is the set of heterogeneous devices and networks, various network architecture supporting heterogeneity, e.g., Information-Driven Architecture (IDRA), participatory sensing in building the smart city is high lightened in [95]. Automatic toll tax payments are one of the essential features in a smart city. Beforehand payments based on source and destination location, and authentication based on license plate reading as JavaScript Object Notation (JSON) data are described in [96]. A detailed survey on M-IoT based road traffic surveillance and accident detection is presented in [46].

B. HABITAT MONITORING

1) SECURITY AND SURVEILLANCE

The revolutionary IoT, transforming millions of lives by providing ease in almost every aspect of daily routine, could turn into the worst enemy. For example, hackers can hack to intercept every document you print and redirect it to an isolated site. They could have control of your smart TV to bug your home. The smart metering system could be hacked to control the appliances of the ventilation system of your home. A traffic light management system could be controlled to achieve specific tasks. Variation in the pacemaker of your heart could be made to kill. The autonomous vehicles could be hacked to control the braking system for your car. These issues lead to serious threats.

Traditional use of passwords was the authentication system until now. However, the researcher has proposed various IoT security and surveillance system based on multimedia data, i.e., retina scanning, biometric scanning, voice recognition, and video surveillance systems to minimize security loopholes. Enthusiastic researchers have further extended the usage of M-IoT to gain maximum advantage in various fields. The following are M-IoT authentications, surveillance, and monitoring application. Fig. 6 shows the M-IoT application of security and surveillance for habitat monitoring.

a: BIO-METRIC AUTHENTICATION

Al-alem *et al.* [97] presented the sketch map leading towards the Internet of Biometric Things (IoBT) using various multimedia devices. Authors have outlined various steps for efficient biometric identification, i.e., image acquisition, segmentation, pre-processing, and feature extraction. Moreover, the article presents insights about different fingerprint acquisition devices, i.e., optical sensors, capacitive sensors, thermal, artificial fingerprints generation, ultrasonic, and digital cameras. Several fingerprint databases are also plotted. The smart objects in Industrial-IoT (IIoT) share information on open channels over the Internet that makes confidential industrial plants vulnerable to an eavesdropper.

Das *et al.* [98] presented the cloud-based Biometric-Privacy Preserving User Authentication (BP2UA) technique. The security analysis of the proposed model is conducted using the Oracle-based Real-or-Random (RoR) model. Telecare Medical Information System (TMIS) has been introduced for critical patients to communicate with doctors.

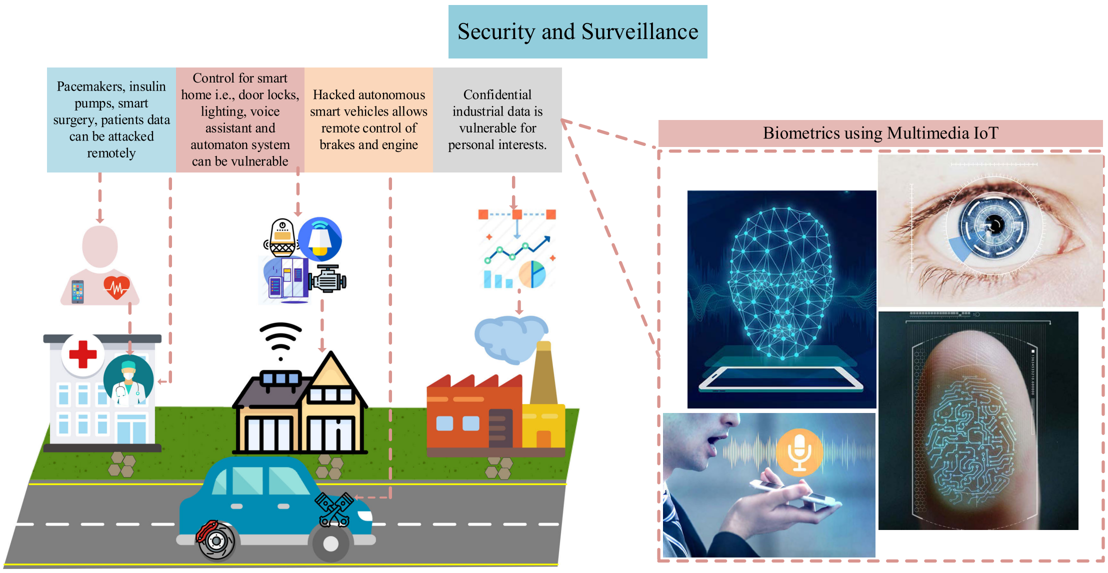

FIGURE 6. **The use case of M-IoT applications for security and surveillance in a smart city. Existing work in security using multimedia data mostly includes fingerprint biometrics ([97]–[99]), voice bio-metrics ([101], [102]), retina and iris scanning ([103], [107]), and face recognition [105]. Multimedia data in IoT is widely used in surveillance systems ([108]–[124]).**

An un-registered adversary, i.e., attackers can find the loop opportunity to mislead the patient to achieve specific goals. An efficient, secure smart card based on biometric and password double authentication procedures for remote authorization is proposed in [99]. *H. Hamidi,* in [100] presented a secure biometrics-based technique for Health IoT (H-IoT).

b: VOICE BIO-METRICS

With the growing deployment of smart homes and smart banking applications, i.e., voice to control everything, and authentication by voice recognition, provide attackers with an easy loophole which is one of the vital security challenges ahead. Voice biometrics are proposed by several researchers stretching up to the verification level of the security system. Voiceprint verification system based on DL exploiting SVM-Neural Network (SVM-NN) and Mel-Frequency Cepstral Coefficients (MFCC), and feature extraction technique to increase the security for M-IoT systems is proposed in [101]. In this work, the LibriSpeech dataset is utilized for training. Meng *et al.* [102] present a novel system based on a voice liveness detection system that utilizes wireless signals from IoT devices and received vocal samples for verification of Voice Control User Interfaces (VUI) decreasing spoofing attacks. The authors named their technique as WiVo. The feasibility and effectiveness of the proposed system are evaluated on the Samsung SmartThings testbed. The article also listed several attacks on VUI. A comprehensive survey on biometric-based IoT security issues, challenges, and techniques are presented in [47], [48].

c: RETINA AUTHENTICATION

The researcher further enhances the security level of IoT using multimedia communication by proposing various techniques to implement retina scanning and iris recognition. Pjatkin *et al.* [103] proposed a probabilistic iris recognition approach using the UPOL database to overcome the PCA technique. HSI and YC_bC_r color spaces are used to generate the Probability Density Function (PDF). The KLD tool is used to extract colored eye iris information. Ocular Recognition (OR) for a secure IoT application has been proposed in the literature.

Different OR techniques have been investigated in [104]. An algorithm based on the fusion of iris and retinal scanning is proposed for user authentication in Apple and Andriod devices. Retina based face recognition authentication system is presented in [105]. In this article, retina modeling is improved by accurate truncation adaption, illumination classification, and lighting estimation. Yale B database is utilized to validate their model. Ocular maladies damage the vascular patterns and create abnormalities in the retina, which hinders the accurate recognition for authentication. Researchers in [106], proposed an efficient vascular recognition technique to overcome the effects caused by lesions and to extract region-based features from retina images. Gabor Wavelet is utilized for noise reduction and pre-processing, followed by segmentation. Blood vessel validation is performed to eliminate false detection by a 5-D feature extraction algorithm and classification based on SVM. The database is formed by 5-D extracted features. Finally, authentication is performed with the created database. Zhang *et al.* [107] proposed an improved Iris localization authentication method. The authors modeled the system by first evaluating the quality of the image taken according to the image intensity, clarity, and integrity. The clarity of the image is evaluated by using a block-variance method, and integrity is defined on the location of the pupil, i.e., the pupil must be in the center. The algorithm works by estimating the range of center, radius of the pupil, and pupil region extraction, thus reducing the delay in iris recognition.

d: SURVEILLANCE FOR PUBLIC SAFETY

With the increasing deployment of IoT in our daily life and decline in the implementation costs, video surveillance systems became a key requirement for the smart city to ensure public safety for crime detection, home security system, industrial surveillance, and other localization-related features. The immobility of the PC based surveillance system encourages the researcher to propose IoT based security systems. Multimedia communication over IoT enables us to achieve this objective. Basri *et al.* in [108] proposed IoT residential surveillance system. The proposed scheme is an Android-based application and hardware which includes Raspberry Pi, Pi camera, PIR sensor, and ultrasonic sensors to alert the owner of a house with an intruder. PIR sensor detects the suspicious movement within the specified range, and the image taken by Pi camera is stored in the memory card. An email or alert message is sent to the owner by Raspberry Pi.

To detect emergency and generate alerts for the older person at home, an Android application is designed and implemented based on the Real-Time Stream Protocol (RTSP) and Real-time Transport Protocol (RTP) [109]. The video is captured, processed, and encoded using H.264 at the server end. Client-end includes smartphones, tablets, or PC, can access live streaming using RTSP and video is decoded using FFMPEG. Security is further enhanced for the elderly by face detection feature using OpenCV library for intrusion detection, and critical screenshots are saved for emergency alerts. A natural language processing interface combined with ontologies and image analysis based video surveillance approach is proposed in [110] for content-based retrieval of visual data. The proposal aims to achieve passenger safety in the public transport system. Four ontologies are utilized, i.e., DAML time, properties, object, and event. PCA and SVM are used for face detection and gender classification. Sphinx is used for audio mapping with semantics formed by ontology vocabularies.

Infants baby monitoring system for the detection of sudden infant death syndrome (SIDS) is presented in [111]. A video camera exploiting the Eulerian motion magnification technique developed by MIT to monitor and detect infant chest motion during breathing is proposed. When an emergency is identified, an alert message is sent to a parent's smartphone via Twilio, which is a cloud-based communication platform [111]. Video summarization to reduce the search time from big multimedia data generated by the surveillance system and content image-based retrieval techniques for smart surveillance is detailed in [112]. Aggregated Channel Feature (ACF) extraction and bounding box approach for moving objects are used, and the cost is determined if any critical situation is observed. Image with a high-cost box is summarized and utilized for video retrieval on search, which reduces the time, memory, and computation requirements of the system. Lin *et al.* [113] proposed a multi-view video summarization method to address the high bandwidth transmission requirement for the Internet of Video Things (IoVT). The proposed scheme is based on the K-Nearest Neighbour (KNN) model. The performance evaluation is measured by making a comparison with the GMM based summarization model based on precision metrics, i.e., removal of redundant data, and the security of critical information. An online multi-view summarization algorithm and RPi based distributed video summarization sensor node is developed in [114] and [115].

Al-Saleh *et al.* [116] presented a secure framework for Mobile Video Surveillance Systems (MVSS) by considering a key management system to secure channels between all the entities, i.e., camera, Mobile Edge Computing (MEC), MEC to MEC, and MEC to cloud. An optimized spectrum utilization scheme for video streaming in environment monitoring by automatic Transport Block Size (TBS) index selection using narrow-band Beyond 4G (B4G) is proposed in [117]. Video-based Indoor Positioning System (VIPS) estimating the precise face detection of each individual with centimeter grade accuracy is presented in [118]. The prototype comprises two units, i.e., an Indoor Positioning System (IPS) and Mobile Handled Unit (MHU). IPS is responsible for capturing the frame of individuals approaching an area, the face is detected for all individuals and mapped to the area location, after which the positioning information is broadcasted to MHU which compares the individual information in its database with the received information.

Cen *et al.* [119] proposed an efficient video compression and encoding/decoding technique for wireless multiview video streaming applications in IoT to enhance the energy efficiency of the system. The researcher in [120] presents the concept of distributed edge computing to minimize the video processing load at the cloud for real-time wireless multiview surveillance systems. Authors name this approach as Vigil, a camera with Edge Computing Node (ECN), which priorities the video frames from multi-camera deployed in the same region for multiview and intelligently schedule them for efficient resource utilization. It also provides a user input interface for a specific query.

Slicing and parallel processing approaches to efficiently handle the bulky nature of IoVT are proposed in [121]. sTune architecture is followed in this approach, in which a metadata manager manages several cloud storage endpoints. The processing unit is composed of a master node and several slave nodes. The master node is capable of retrieving data from sTune and assigns the slave nodes to process the sliced video data in parallel. After processing master nodes stores the processed data back to the cloud. CPU and memory usage are considered as performance metrics to evaluate the performance. A multimedia application requesting the same content from M-IoT is delivered separately over the core network that increases the overhead. To cope with this issue, Silva and Neto [122] propose SCORPIO, an SDN control plane to provide multimedia multipart transport services to duplicate the multimedia packets at the edge of the network and map them with the applications of common interest in the data plane path. The performance metrics to evaluate the proposed methodology are throughput, jitter, and packet dropping ratio.

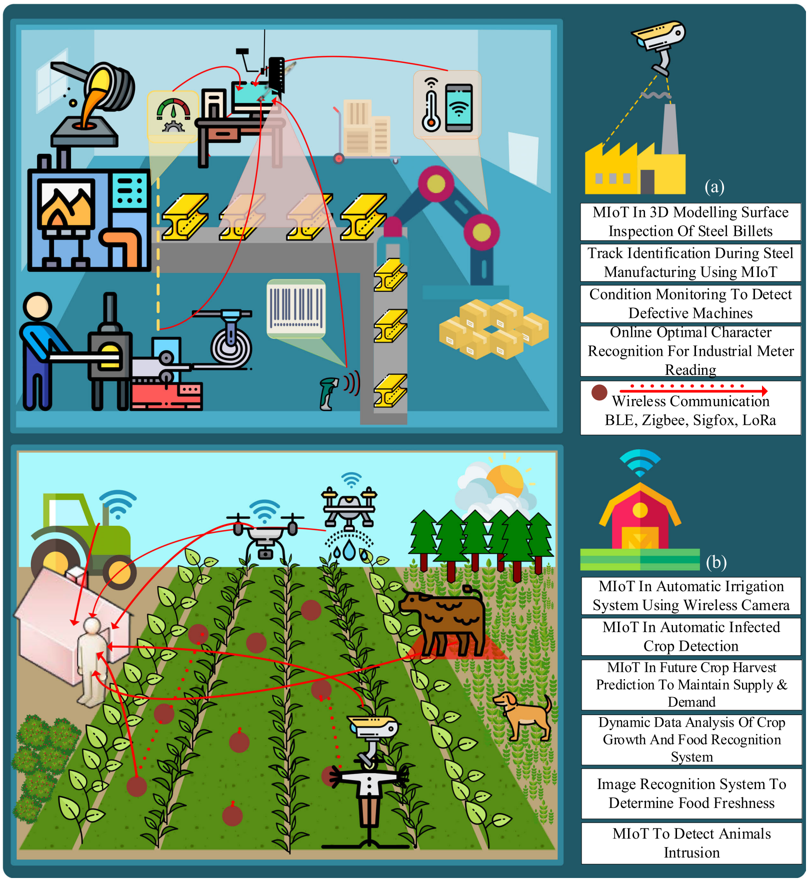

FIGURE 7. The use case of M-IoT in industrial and agricultural applications. (a) Multimedia data flow in industrial IoT for inspection of steel manufacturing ([125], [126]), combustion quality maitenance [128], and industrial meter reading [129]. (b) Agricultural application of M-IoT for crop monitoring for production control ([134]–[139]).

Quality of Computing (QoC) is introduced in [123] to determine the occupancy of the network. The article presents an SDN based network selection approach to maintain QoC in HetNet. The proposed approach selects between the licensed band (LTE) or unlicensed (WiFi) for real-time services. The data aggregated at the sensor is transmitted to the edge processor over upstream links, i.e., LTE and WiFi. The Edge processor evaluates the received packets according to the data path and computational goals, and feedback is sent on a reverse path. Kougianos *et al.* [124] proposed a novel concept of using quadrotors for IoT real-time automatic tracking applications.

C. MULTIMEDIA IoT IN INDUSTRIAL APPLICATIONS

1) SMART INDUSTRY

IIoT is the main component of the smart industry, enhancing product manufacturing, and optimizing the industrial process. Multimedia characteristics further enhance the outcome of the industrial process, as shown in Fig. 7a. The steel industry is known as the backbone of any nation. The steel industry modernizes civilization by playing a lead role in technology development. Steel manufacturing is performed at high temperature. Therefore track identification is challenging under such circumstances. Automatic depth-based vision feature extraction and track identification in steel billet to maintain the quality of steel products in a smart industry by M-IoT is proposed in [125]. Online images are taken once steel billets are manufactured. Features are extracted using Local Binary Pattern (LBP) and stored in a database with identification codes. The framework for 3D surface inspection of steel billets is presented in [126]. 3D scanning is performed using a camera by continuously capturing multiple images, and green-line lasers are utilized to extract the depth information of steel billets to inspect the object from various angles in the smart industry.

Condition Monitoring (CM) system based on M-IoT is defined in [127]. It detects defective machines to prevent production outage and reduce the operational cost in the oil-gas petroleum industry. Thermal and gas turbine power plants are the biggest assets of the nation. Flame color video recording and images are analyzed to optimize air to fuel ratio that ensures combustion quality. Sujatha *et al.* [128] proposed Fishers Linear Discriminant (FLD) analysis technique for dimension reduction and classification. An Artificial Neural Network (ANN) based on Back-Propagation Algorithm (BPA) and Ant Colony Optimization (ACO) for feature extraction from flame images and videos are utilized to maintain the combustion quality. An automatic industrial meter reading device based on online Optical Character Recognition (OCR) is designed in [129]. After extracting readings of various industrial meters from images, the device logged the readings to the cloud. At the cloud, data is processed and made centrally available to authorized users on PC, smartphones, and laptops. The proposed smart device improves time utilization by reducing human intervention. Solar-powered grid estimation employing sky camera based on Energy Harvesting Wireless Sensor Networks (EHWSN) is presented in [130]. Authors in this article maximize the transmission quality of sky camera images and minimize the energy consumption of multimedia data transmission by determining the best forward relay path.

2) SMART MUSEUM

Preservation of culture is essential for our future generation to establish and strengthen their identity. The Museum industry plays a critical role in preserving cultural heritage and displaying knowledge about it. It is the primary source of promoting tourism and improves economics statistics. Smart Museum is the need for a smart environment to inspire tourists from all over the world. A smart device is proposed in [131] to gather localization information of the visitor using BLE. It automatically provides the information related to art in front of it using image processing and stores it to the cloud to be accessible on smart devices. Foreground detection and background subtraction are utilized in the proposed work for extraction and image processing.

To manage the huge historical data and enhance the guiding system for tourist in a smart Museum, M-IoT beacon devices based on Raspberry Pi for content delivery operating on BLE is proposed in [132]. The researcher further takes M-IoT benefits by implementing computer vision-based image recognition transport robots for an automated warehouse in [133]. Neural network-based image classification is performed using the Orange Pi hardware platform. CvCanny library is utilized in this work for object edge detection to track the path inside the warehouse facility.

3) SMART AGRICULTURE

Agriculture is another important industrial sector. Researchers are trying to revolutionize the agriculture sector to increase its productivity by incorporating M-IoT (See Fig. 7b). Nisha and Megala [134] present automatic irrigation and an infected area monitoring system using a wireless camera in the crop field to aid farmers. Zigbee transceiver is deployed to incorporate low power Zigbee over IEEE 802.15.4 protocol for communication and managing sensors data. K-means clustering machine algorithm is used for the detection of disease, color determination, and pest detection. Agricultural production framework to monitor and predicts the future harvest of crops to maintain balance in supply and demand is proposed in [135]. The software-based visual general user interface is implemented, and live streaming of the field crop is obtained by deploying a wireless camera. Dynamic data analysis for crop growth management system using IoT is proposed in [136]. The dynamic system equips the farmer with the historically analyzed data on a smartphone while moving in the field by communicating with the nearest deployed sensor node. An efficient low power MAC-based WSN working in a dynamic duty cycle scheme is presented in work to resolve the congestion condition. The system is evaluated in the context of packet delivery ratio, end-to-end delay, and duty cycles.

Authors in [137] present a detailed study of various IoT agricultural crop monitoring systems. Android-based food recognition application to automatically recommend a cooking recipe is presented in [138]. The proposed work employs Speeded-Up Robust Features (SURF) with the Hessian detector to extract 144 64-dimension features, Bag-of-Features (BoF) for feature representation technique and SVM as a classifier. The proposed scheme gives 84% of the recognition rate. Witjaksono *et al.* in [139] exploits IoT based application for images recognition to determine the freshness of the food. The application also discriminates halal meat from non-halal meat for Muslims.

D. HEALTH MONITORING

Multimedia data provides the medium to communicate, monitor, and cooperate with various aspects of daily life at numerous levels of granularity across various applications, which in terms of health is known as personal health media. Incorporating personal health media in one device to measure everything using IoT is the features of the future health system, as shown in Fig. 8. For this purpose, highly elaborative personal health data features are required. Boll *et al.* [140] presented a logical device layer-based architecture for mapping multimedia signals from various devices to the smallest elaborative unit named as primary health feature. Mapping is also performed to fuse multiple features and deploy advanced analytics to gain minor health details.

Zafra *et al.* [141] addressed the issue of coexistence wearable devices for e-health with traditional three-layered IoT architecture and proposed a pervasive layered architecture to integrate M2M communication between e-health wearable and IoT devices. Shah *et al.* [142] highlight the challenges in analyzing big data generated from remote health monitoring and decision making by comparison with the patient's history. The authors also provided details of various QoS driven Cloud of Things (CoT) based data processing for remote health applications. Rehman *et al.* [143] proposed 5G small cell network deployment in an ambulance for efficient uplink medical video streaming to enhance the medical QoS (m-QoS). Ultrasound video is considered as uplink traffic. Medical QoS performance is analyzed on the basis of throughput, delay, and Packet Loss Ratio (PLR). Results depict that implementing small cell networks augments the performance of the system. However, improvements are still required for deploying remote medical health systems as packets drop in critical medical condition is not tolerable.

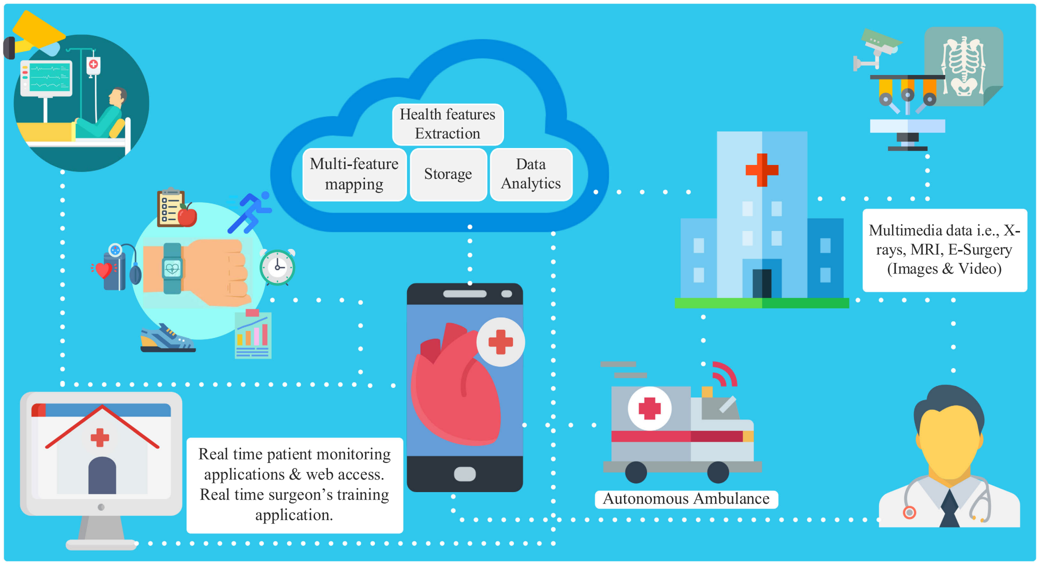

FIGURE 8. **The use case of M-IoT for Health. The existing work of M-IoT for smart health includes remotely personal health monitoring ([140]–[142]), robotic ambulance [144], X-ray for robotic surgery ([145], [146]), biomedical training for surgeons [147] and ocular diseases detection using smartphones [148], [149]. All these applications could be integrated using cloud service to be available for online and offline access.**

Sudden cardiac arrest is a heart condition in which heart stops due to lack of oxygen leading to death if immediate Automated External Defibrillator (AED) is not given. AED is a small device for untrained or minimal trained personnel to use it until the first aid arrives. Samani and Zhu [144] designed an intelligent robotic ambulance named AmbuBot to provide AED to save a life. AmbuBot is equipped with a GSM module for remote connectivity and high-resolution cameras for Lane Keeping System (LKS) to track lanes and prevent accidents. The system can be further extended for multiple conditions, body sensors, and multiple robots for collaborative work. Robot-Assisted Fracture Surgery (RAFS) is revolutionizing the medical health care by reducing infection risk during surgery and perfectly manipulate each bone fragment into the perfect position. The coordination system is in need between the detected bone track and an external robotic tool to exact position the broken bone. Automatic tool detection for surgery assistance based on computer vision X-ray images is proposed in [145]. Block detection, geometric model matching, and principal component analysis are utilized to achieve a 91% success rate. The robotic arm can extend the perfection provided by 3D positioning. Smartphone controlled Raspberry Pi based robotic arm is designed to assist the doctor in surgery [146]. The platform offers built-in compatibility of WiFi, camera and other sensors.

Surgical skills and effectiveness directly affect the patient's health. To minimize the harm to the patient, surgeons should be highly trained with subjective skills. To overcome this problem, research scientists, along with the medical Doctors in [147] have designed a biomedical IoT data extraction technique to train surgeons and provide real-time feedback on their skills efficiently. The proposed biomedical trainer architecture comprises virtual images, medical images, patients data, and journal data. The performance of the surgeon is evaluated by capturing the surgeon's technique, visualizing the data, and comparison with the benchmark.

Multimedia data features in IoT further benefits the field of medical health by retinal cataract detection technique for remote area patients. To achieve this, authors in [148] proposed a design to implement a microscopic lens over a low-cost smartphone camera and real-time detection by FeedForward Neural Network (FFNN) trained the algorithm. Yin *et al.* [149] enhance the system to detect multiple ocular diseases. The proposed automatic architecture includes retinal images of data acquisition using a fundus camera. Cloud platform stores patient history, process, analyze and extract features of stored images. The reports are generated after analysis, and corresponding ophthalmologists are referred. The proposed methodology aims to reduce the workload on medical specialists and save time.

E. SUMMARY AND INSIGHTS

This section covers the wireless multimedia delay-sensitive applications supported by IoT. Feature extraction from audio, video, and images are studied in detail for different applications in security surveillance, traffic, health, and industry monitoring. Various proposed methods for biometric authentication to enhance security systems are highlighted. Multimedia data in optimizing the performance of the industrial process is also detailed in this section. The existing M-IoT applications are more focused on feature extraction, mapping, and analysis of multimedia data. However, mobility has not been considered in the M-IoT network for the successful transmission of the delay-sensitive real-time application. Table 5 classifies the existing work on M-IoT applications and summarizes this section.

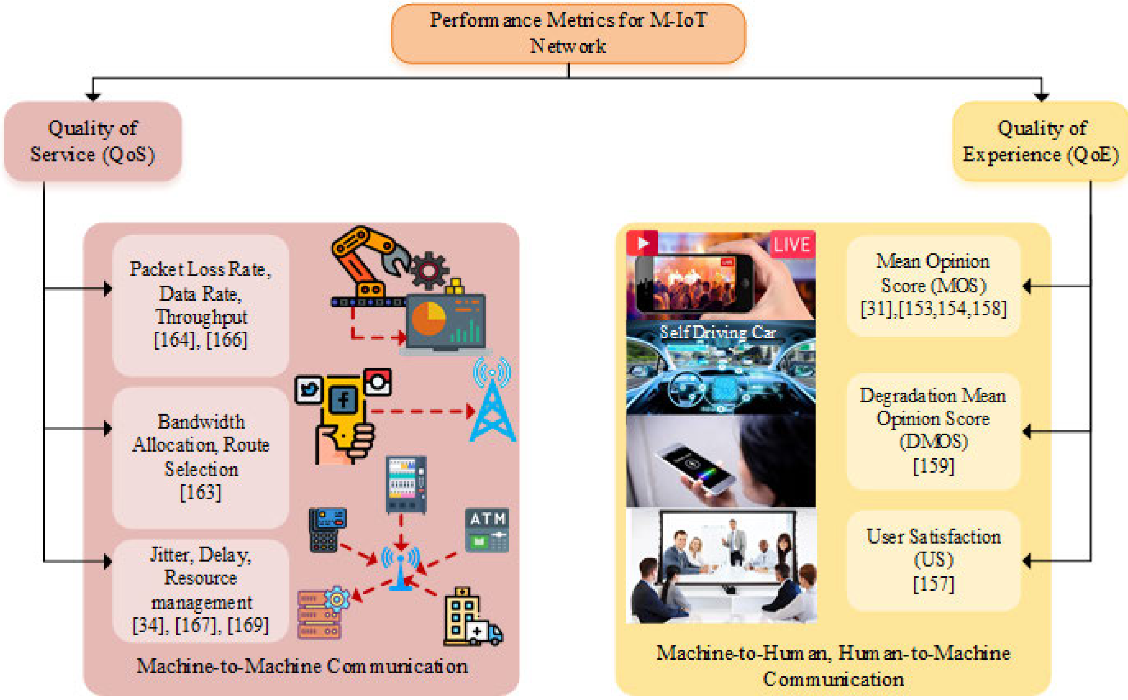

FIGURE 9. The classification of performance metrics for M-IoT network. The existing work on quality can be studied based on the objective-based QoS metrics or subjective-based QoE metrics.

IV. PERFORMANCE METRICS FOR M-IoT

As compared to traditional IoT, multimedia services are gaining admiration in IoT. Multimedia services are delay-sensitive and require efficient network models to maintain quality. The bulky nature of multimedia data increases the challenges to satisfy the network end-user. User-centric and network-centric metrics can assess quality. QoS can be determined by network-centric metrics, while user-centric metrics estimate QoE. QoE symbolizes the user perspective of QoS, i.e., measurement of the overall performance of service or network to evaluate delay-sensitive traffic. QoE is further influenced by two factors, i.e., objective and subjective factors. The subjective QoE is measured from experience evaluated by humans, which is problematic to measure. The objective QoE data includes network-related manageable and quantifiable parameters. Multimedia content over IoT can be evaluated through subjective QoE metrics such as Mean Opinion Score (MOS), Degradation Means Opinion Score (DMOS), and user satisfaction [150]. MOS is quantified by rating a user's experience in the range from 1 to 5, where 5 represents the best experience and 1 as bad. Each MOS rating corresponds to a solo M-IoT service/session/application required by one or set of users and delivered by only one multimedia application. In DMOS, users are asked to quantify the degradation of the services as 1 being very annoying to 5 as degradation is inaudible. User engagement or satisfaction method can be adopted only when the user interacts with the application, i.e., video playtime, or several likes, and views. In the case of M2M communication, where the recipient of the application is a machine, the performance is evaluated by QoS. QoE and QoS perspective related to M-IoT architectures and optimization metrics are studied and detailed. Fig. 9 shows classification of QoS and QoE metrics to evaluate network and application quality. The elucidation of each study concerning QoE and QoS has been presented in the following subsections (See Table 6).

TABLE 6. Performance metrics for M-IoT frameworks.

Performance Metrics for M-IoT Frameworks		Quality Optimization Metrics	Articles
	Quality of Experience (QoE)	QoE Definition	[151],[152]
		MOS	[31], [153], [154],[158]
		US	[157]
		DMOS	[159]
	Quality of Service (QoS)	QoS Definition	[160],[161]
		Bandwidth	[163]
		PLR, delay, Throughput	[164],[166]
		Resource Management	[34]
		Energy Conservation	[167],[169]

A. QUALITY OF EXPERIENCE (QoE) AWARE ARCHITECTURES

According to Qualinet White Paper [151], QoE is defined as *"QoE is the degree of delight or annoyance of the user of an application or service. It results from the fulfillment of his or her expectations concerning the utility and enjoyment of the application or service in the light of the user's personality and current state."*

International telecommunication union (ITU) defines QoE in ITU-T Rec. P.10 [152] as follows: *"The overall acceptability of an application or service, as perceived subjectively by the end-user."* Subjective and objective QoE data of the

M-IoT network is mostly acquired and evaluated separately. The fusion of the subjective QoE data, i.e., user's experience rating with the objective QoE data, i.e., bandwidth allocation, route selection, etc., is important to optimize the system. Huang *et al.* in [31] proposed a novel NN based self-learning self-updating framework to fuse QoE subjective and objective metrics named as QoEDF. MOS is adopted in this framework to quantify user experiences per service. Various factors affecting QoE has been presented in the article. Bandwidth allocation, jitter, and best route selection are considered as objective metrics. Two-layered NN based framework is presented to map the subjective MOS value with objective metrics. The optimization problem is formulated to optimize QoE by first selecting the best route and then assigning the required bandwidth for the selected route.

Floris and Atzori in [153] and [154] proposed virtual layered based QoE-aware architecture. The term Quality of Data (QoD) is introduced to evaluate the quality or precision of acquired data by M-IoT devices, and QoS parameters are considered as influencing factors for QoD. QoE-aware framework for smart surveillance and vehicle monitoring system has been presented. The authors adopted MOS for numerically measuring QoE.

Karaadi *et al.* [155] defined the term QoE and QoS in the rapport of M2H, H2H, H2H, and M2M. In the case of humans as the recipient of the multimedia services, the performance of the service is evaluated as QoE, otherwise, when a receiver is a machine, then the concept of QoT is utilized. QoT is defined as the acceptable quality to satisfy or complete a service session successfully. The bandwidth utilization is optimized by considering the minimum bandwidth at an acceptable level to meet the minimum requirement of an application. Results depict that the requirement for QoE is greater than QoT. The system can be further enhanced by utilizing ML approach to allocate minimum bandwidth as required to maintain QoT. Ikeda *et al.* [35] proposed M-IoT framework to evaluate QoE based on physical metrics and metaphysical metrics. The metaphysical metric is proposed to understand the user's quality and service requirement, which varies with applications and model them with available physical metrics to achieve desired QoE. However, this work lacks subjective experiments and qualitative modeling.

SDN and Network Function Virtualization (NFV) based QoE optimization for adaptive video streaming applications is proposed in [156]. Video streaming comprises four main tasks, i.e., caching, encoding, forwarding, and playing back. Node selection for best-path selection is defined as the objective function subject to the constrained node in terms of resources. The proposed model is evaluated on Mininet a network emulator and OpenDaylight as an SDN controller. Performance evaluation of the model is studied based on end-to-end delay, packet loss, and user's QoE. He and Wang [157] studied the effect of interference between Non-Orthogonal Multiple Access (NOMA) UE's on QoE at the consumer end. Authors utilize the user satisfaction method, i.e., several clicks or playtime to quantify QoE and formulated Cournot competition Oligopoly game problem to optimize power allocation among NOMA UE's to upload the acquired real-time video surveillance data to the BS with minimum interference and maintain QoE.

Statistical learning, prediction, and automatic network resource management mechanism to optimize multimedia QoE has been presented in [158]. By statistical monitoring, the QoE is predicted, computed and managed by evaluating objective network metrics, i.e., jitter, packet loss rate, frame rate, frame resolution, data rate, codec, and data volume. MOS has been utilized for QoE. The mobile node frequently switching network has been tested for the proposed model. Ahmad *et al.* [159] presented a multi-dimensional passive QoE monitoring approach at the user terminal based on quality degradation, where the probes at UE becomes online when quality is degraded below a specific threshold. The analyzed data at UE will be sent to the service provider to take critical actions to overcome the degradation. The proposed system could be improved by the implementation of cloud-based QoE analysis and monitoring. *Wang W.* and *Wang Q.* in [32] introduce a novel concept of Smart Media Pricing (SMP) by implementing Price as a Resource (PaaR) instead of smart data pricing. The authors have proposed to price the end-user according to its required QoE as the criticality of a self-driving car is higher to ensure the QoE due to high data rate requirement for precision than the telepresence of a user in which bandwidth requirements are low. Premium quality content should be priced higher than an economy class user.

B. QUALITY OF SERVICE (QoS) AWARE ARCHITECTURE

The quality of telecommunication services is defined by ITU in recommendation ITU-T E.800 [160] as: *"Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service."* Microsoft defines network QoS in [161] technical white paper as: *"Network QoS refers to the ability of the network to handle this traffic such that it meets the service needs of certain applications."*

A framework to assess the quality of stereoscopic images for 3D product modeling in M-IoT has been presented in [162]. The authors proposed a blind image Deep Belief Network (DBN) based on natural science feature extraction and Support Vector Regression (SVR) for training. More effective machine and Deep Learning (DL) algorithms could be adopted to reduce the image distortions. Bellavista *et al.* in [163] proposed an SDN controller based Fibre optics-Wireless (FiWi) and edge M-IoT hybrid network architecture to optimize QoS in HetNet. Resource allocation, i.e., bandwidth, is considered as QoS optimization metrics. FiWi and Edge M-IoT hybrid network enhance the performance by communicating via the SDN controller. Reserved and excess bandwidth are offered by FiWi network to edge network in case of spontaneous network addition at consumer end via SDN heads. SDN based HetNets integration offers better network management.

Statistical QoS metrics analysis of HetNets gateway is studied in [164] for betterment in M-IoT network designing. PLR, throughput, and delay are considered as QoS data. Results show that delay is the same for all types of devices. However, PLR and throughput affect more on low data rate gateways as compared to high data rate gateways. Aazam *et al.* [34] proposed a fog resource estimation and utilization to improve QoS based on service Relinquish Rate (RR) and previous Net Promoter Score (NPS). Resources are managed according to past Service Level Agreement (SLA) or disagreements. Fog computation enhances the performance of the system model by equipping the devices to estimate and utilize resources more efficiently.

Quality-aware Universal Communication Framework (UCF) to handle mobile connectivity and reduce signaling overheads repeatedly between end devices for M2M communication has been presented in [165]. Network QoS parameters have been analyzed in [166] to evaluate to satisfy QoE for IoVT at various network conditions. QoS-aware framework for the Narrow-Band Internet of Things (NB-IoT) network by utilizing a Partial Observable Markov Decision Process (POMDP) to optimize energy consumption is outlined in [167]. To conserve energy, Poison distribution in POMDP is used to estimate traffic arrival rates and adopt dynamic network configuration changes according to future traffic prediction. The proposed model conserves power for BS and UE. Implementation of various optimization problems and ML algorithms to predict traffic arrival can further improve the system. Web Real-Time Communication (WebRTC) for video conferencing in connection with cloud computation has been studied in [168]. The proposed model analyzes QoS parameters in comparison with WebRTC in connection with local networks. Traffic load and the computational delay has been considered as QoS metrics for analysis. Elhammouti *et al.* [169] form a game theory problem named satisfaction equilibrium with an objective function to optimize energy instead of maximizing QoS. The authors have highlighted key motivation for optimizing energy subject to achieve satisfactory QoS constraint. Several applications related to multimedia have specific data rate requirements, therefore maximizing the QoS above that level will waste the energy. The energy management can be further enhanced by allocating power based on the intrinsic requirement of the application.

C. SUMMARY AND INSIGHT

In this section, work related to the quality of the M-IoT network in terms of network performance has been discussed in detail. Quality of network is further evaluated in terms of a subjective measure of user experience, which is QoE and performance of network parameters, i.e., QoS. Various QoE-aware and QoS-aware frameworks have been discussed. Issues and further enhancements in these works are highlighted. The Key Performance Indicators (KPIs) of communication are network metrics. Due to the scarcity of the network's bandwidth, bandwidth utilization is one of the major KPI. As multimedia data consume a huge amount of bandwidth therefore researchers are considering exploiting un-utilized wideband available in Terahertz (THz) band i.e., 30-300 GHz that can loosen the strict limitations on bandwidth utilization. However, several issues related to human exposure index due to high penetration power, antenna designing, resource allocation, physical and MAC designing are open for research. Studies related to QoS and QoE are highlighted in Table 6.

V. M-IoT COMPUTING PARADIGM

A significant increase in multimedia big data generated from IoT devices, this volume increases with diminishing size and mobile nature of IoT devices. The amount of data generated is expected to be 600 Zettabytes (ZB) annually by 2020 [170]. One of the particular multimedia IoT data generated online is audio, video, images, and graphics [171]. The characteristics of multimedia data are specified as huge volume, structured and unstructured data, velocity, unpredictability (frequently changing), and accuracy [172]. The current IoT frameworks to analyze and process scalar data are unsuitable for multimedia data in IoT. Multimedia data in IoT poses challenges including storage and sharing, real-time computation, processing and provision, energy optimization, resource allocation, feature extraction from unstructured multimedia data, addressing and routing, QoS and QoE preservation, delay sensitivity, data reduction, compression and encryption, security and privacy [171]. Previously we have discussed M-IoT architectures, use cases, QoS, and QoE optimization techniques. In this section, various computation, processing, compression techniques have been discussed. Fig. 10 shows the classification of multimedia computing in IoT. Routing and resource allocation MAC approaches are present in the later sections. Four main phases of multimedia data computation are shown in Fig. 11. A detailed survey on multimedia big data computing in IoT is presented by Kumari *et al.* [44]. The authors have discussed in detail the difference between big data and big multimedia data. This section has been specifically subdivided into multimedia data compression and event processing, fog/edge frameworks for M-IoT computation, cloud computation for M-IoT and SDNs for M-IoT computing. Table 7 classifies and summarizes the existing work related to multimedia data computing in IoT.

A. MULTIMEDIA CODING AND COMPRESSION

In conventional multimedia data encoding techniques, data is compressed once and decoded whenever played. M-IoT devices are more concerned with uploading the data in uplink transmission, which poses challenges on computationally powered constrained M-IoT devices. Traditionally video encoding/compression is achieved by utilizing spatial and temporal redundancies.

The techniques for multimedia encoding are known as High-Efficiency Video Coding (HEVC) jointly developed by ITU-T and International Organization for

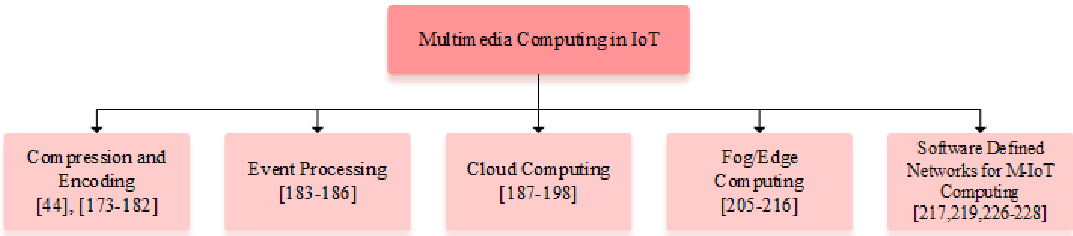

FIGURE 10. Classification of M-IoT computing. The existing work on multimedia computing can be studied based on compression and encoding, event detection and processing, cloud computing, fog/edge computing, and SDNs for computing.

TABLE 7. Multimedia computing paradigm in M-IoT.

M-IoT COMPUTING PARADIGM	Proposed Schemes		Articles	Year
	Multimedia Coding and Compression	Survey on Multimedia Big Data	[44]	2018
		High Efficiency of Video Coding	[173]	2013
		VP9 and DAALA for Video Coding	[174]	2013
		Comparative Analysis of H.264, H.265, VP9, DAALA	[43]	2013
		Computation Complexity Reduction Transcoder	[175]	2018
		Truncation Based Compression Technique 'Scalerelativemax'	[176]	2017
		Full Reference Quality Assessment Metric (JQAM) based on Humn Visual System	[177]	2016
		Dictionary Learning and Approximate Message Passing for MM reconstruction	[40]	2017
		Lyapunov Optimization Scheme For Power Constrained Multisensor Wearable Devices.	[178]	2017
		Approximate Task Computation Allocation Strategy For Multiprocessor System On Chips (MPSOC)	[179]	2018
		Life Expectancy Maximization Of The Network	[180]	2019
		Issue And Challenges In Distributed Video Cameras	[181]	2012
		Graphics Processing Unit (GPU) Encryption System	[182]	2017
	Event Processing	Multimedia Stream Processing Engine (MSPE) As A Middleware	[183]	2018
		Multimedia Semantic Sensor Network Ontology (MSSN-Onto) for Multievent Detection	[184]	2018
		Attention-In-Attention (AIA) Network For Multievent Recognition	[185]	2018
		Block-Based Motion Estimation (BME)	[186]	2018
		Energy Aware Selective Encryption For The High Motion Video Frame	[39]	2019
	Cloud Computing	Cloud Computing Architecture and Issues	[187], [188], [189]	2008,2009,2010
		Comprehensive Study on Integration of IoT and Cloud Computing	[190]	2016
		Efficient Energy Conservation by Optimal Cloud Resource Allocation	[191]	2016
		Cloudlet Based Distributed IoT Video Surveillance System to Reduce Latency	[192], [193]	2015-16
		Cloudlet Based Face Detection and Face Denaturing for Privacy and Safety	[194]	2017
		Optimal Cloud-Video Crowdsensing	[195]	2016
		Flexible Analytical Cloud Framework To Be Accessible From Any Network	[196]	2017
		Cloud-Based Dynamic Programming Event Detection, Prediction and Bandwidth Allocation	[197]	2017
		Multimedia Sensing As A Service 'MSaaS' To Optimize Resource Allocation For Energy Constrained M-IoT Devices.	[198]	2017
	Fog Comuting	Optimizing Workload Scheduling in Fog-Cloud Framework for Maximizing Power Conservation and Latency	[205]	2016
		Fog Based Video Surveillance for Urban Traffic Monitoring System	[206]	2016
		Collaborative Fog Computing for Load Sharing to Minimize Service Delay	[207]	2017
		Priced Timed Petri Nets (PTPNs) Based Fog Resource Allocation And Time Cost Prediction To Improve QoS	[208]	2017
		Improving Stream Processing In Real-Time Crowdsourcing, Event Processing And Real-Time Stream Analytics By Incorporating Fog Computation In M-IoT Network	[209]	2017
	Edge Computing	Workload Allocation And Multimedia Data Prioritization Using In-Memory Edge Closedloop Schedulling Method	[210]	2018
		'Geelytics' A Geo-Distributed Real-Time Stream Processing For Dynamic Edge-Cloud Network	[211]	2015
		Complex Event Processing Engine and Distributed Assignment Model for Reducing Data Volume Flow in Fully Distributed Edge-Cloud Network	[212]	2017
		DL Based Edge Computing In M-IoT Network To Reduce Data Traffic From Iot Devices To Cloud	[213]	2018
		Collaborative Edge-Cloud Framework to Analyze Live Data	[214]	2017
		Cooperative Video Processing in Edge M-IoT Network for Improving Human Detection in Surveillance Systems	[215]	2018
		Where's The Bear, An Image Recognition Method At Edge To Conserve Bandwidth And Reduce Latency	[216]	2017
	Software Defined Network	Event-Driven SDN Based Network Control Framework 'Procera' By Controlling And Managing Dynamic Changes In The Network	[217]	2013
		SDN Flow Coordination For Persistent Data Delivery To Minimize Latency And Maximize Packet Delivery Ratio In IoT SDN-Cloud Frame Work	[219]	2017
		Multiobjective Energy Minimization Optimization Problem Based On Classified Workflow To Incorporate Dynamic Changes Using SDNs.	[226]	2018
		Software Defined Mobile Edge Computing 'SD-MEC' Framework to Minimize Latency and Bandwidth Usage	[227]	2015
		Publish/Subscribe Unified Software Defined Framework to Reduce Network Latency and Increase Throughput	[228]	2018
		How SDNs Improves Cloud-Edge Computing	[229],[45]	2017-18

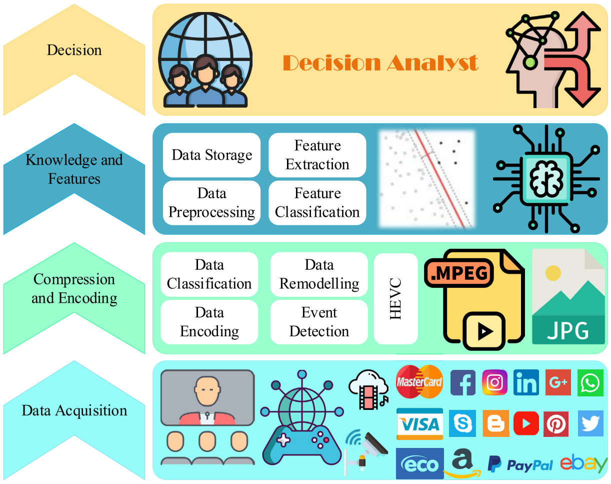

FIGURE 11. Multimedia data computing phases. Data is first efficiently acquired, compressed, and transmitted to computing unit for feature classification and extraction, and then the decision is made on classified data.

Standardization (ISO). The current standard jointly designed in 2013 is H.265, which shows efficient performance as compared to H.264 developed in 2003 [173]. The major features of H.265 include maximum block size of 64 × 64, adaptive block sub splitting and prediction, and up to thirty-five intra-frame prediction directions. Google developed VP9 and DAALA is designed by Mozilla Corporation, both compete with H.264 [174]. Comparative analysis of H.264, H.265, VP9, and DAALA has been presented in [43]. Results depict that H.265 outperforms other encoding techniques. Liu *et al.* [175] devised a computation complexity reduction transcoder solution for real-time video communication. After mapping the relationship among H.264/AAVC decoding information, the Coding Unit (CU), and the Prediction Unit (PU) decision process, the proposed model exploits SVM to classify either to select PU decision mode or CU depth decision process. The objective of the algorithm is to optimize the interframe prediction process of the HEVC re-encoder. Energy consumption can be significantly minimized by applying compression techniques to avoid energy transmission costs. Santos *et al.* [176] proposed a truncation based compression technique named ScaleRelativeMax based on Energy Packing Efficiency (EPC) for sensitive biomedical applications. For a biomedical application, the reconstruction of the signal without losses is of great importance. The impact of different truncation strategies on the Compression Ratio (CR) has been discussed in detail and compared with the proposed strategy. Results illustrate that the proposed technique offers linear reconstruction growth with comparable CR to other techniques. Compressed Sensing (CS) uses sparse signal structures to diminish the size of the transmitted or stored data.

Multimedia data is sparse in structure. CS is used for multimedia data acquisition and reconstruction. Li *et al.* [40] exploit DL and AMP for improving IoT multimedia data reconstruction quality and minimize bandwidth utilization. Performance comparison of the DL-AMP technique with EM-GM-GAMP, Gauss-AMP, fast-BM3D-AMP, and other proposed CS techniques in the literature validates the proposed framework is suitable for multimedia. A Joint full reference Quality Assessment Metric (JQAM) based on the Human Visual System (HVS) by considering binocular perception and image properties is projected in [177]. The proposed technique efficiently measures the image pixel, contrast, and structural distortion by considering the luminance masking of the image to access the quality of the image. Hu *et al.* in [178] proposed a joint compression and transmission technique to optimize energy usage based on the canonical Lyapunov optimization scheme for power-constrained multisensor wearable devices.

M-IoT devices are energy and resource-constrained. M-IoT devices are required to be computationally efficient as most of the devices are battery operated. An efficient task allocation strategy to maintain the QoS is required to assign the task to process in parallel dynamically. Wei *et al.* [179] proposed a real-time approximate task computation allocation strategy for MultiProcessor System on Chips (MPSoC) to increase the number of executions in a hybrid energy environment. In a hybrid renewable energy system, the power supply is unpredictable. Authors designed a dynamic task scheduler to adapt real-time varying conditions in fluctuating energy availability. Khernane *et al.* [180] discussed the tradeoff between video data coding and quality at the user end while optimizing the energy for the maximum life expectancy of the network. An entirely distributed algorithm is presented to balance the power utilized to encode the video and video encoding rate. The authors considered the dynamic nature of link capacity. The transmission errors are minimized by incorporating retransmissions based on the two-state Markov chain. However, in this work, spectrum efficiency is not taken into account, which is the key requirement for multimedia data transmission.

A detailed survey on M2M communication is highlighting the issue and challenges in distributed video cameras in [181]. Various video coding techniques, power consumption analysis, and energy harvesting approaches is detailed in this article. Aljawarneh *et al.* [182] devised a Graphics Processing Unit (GPU) encryption system based on Feistel Encryption Scheme (FES) and Advanced Encryption Standard (AES) to secure medical multimedia data. The multimedia data is divided into equal-sized blocks, which are subdivided into plain text and keys. Each key and plain text is then encrypted separately using FES and AES, respectively. The genetic algorithm integrates separately encrypted keys and plain text to secure the data from vulnerability. The system utilizes the GPU to process graphics efficiently and provides parallel processing to execute maximum tasks to increase system throughput.

B. EVENT PROCESSING

The M-IoT encompasses myriad applications in every field which varies in data capacities, features, nature of outputs, and encoding formats. An increasing number of devices and applications transits the nature of multimedia traffic more towards unstructured events. Generic event detection and query processing framework is in need to process structured and unstructured multimedia events. Aslam and Curry [183] proposed a Multimedia Stream Processing Engine (MSPE) as a middleware with an operator to analysis unstructured events in multimedia data and DNN processor to extract and match the features. Publish/subscribe mechanism is adapted in which multimedia devices send captured events to the middleware and subscribers can access the desired events by relevant classifiers from middleware by DNN based matchers. Optimization models are adapted to analyze and process a user's query to achieve optimized throughput and accuracy to serve the query. The integration of diverse image analysis techniques could enhance the genericity of the framework. Angsuchotmetee *et al.* in [184] offered Multimedia Semantic Sensor Network Ontology (MSSN-Onto) to detect various events in a HetNet to provide syntactic and semantic interoperability. A multimedia application that involves more than one user requires syntactic and semantic interoperability to understand different data encoding techniques and content-aware modeling. The proposed framework constitutes MSSN indexer, application manager, and event processing engine to process and index the data stream concerning their feature levels, and serving the queries of the users from the stored, indexed data.

Xu et al. proposed an attention-in-attention (AIA) network in [185] for multievent recognition and representing the salient features of visual modality and semantic modality exploiting Convolutional Neural Network (CNN) for visual features extraction. AIA comprises Encoder Attention Modules (EAM) and Fusion Attention Module (FAM) for desired features matching and fuses multi-dimensional features into a single-dimensional feature. The authors employed a Recurrent Neural Network (RNN) based Long Short-Term Memory (LSTM) unit on decoding fused data into multi-events labels. Multiple AIA modules can enhance event recognition and representations of multimedia video streaming. Saha *et al.* [186] presented a context-aware Block-based Motion Estimation (BME) approach to enhance multimedia compression. The author uses the pixel distortion ratio to characterize the motion into a Large Diamond Search Pattern (LDSP) or Small Diamond Search Pattern (SDSP). The proposed scheme intends to reduce the computation time significantly. Parallel processing incorporating GPU and directional motion estimation can further augment the performance. Thiyagarajan *et al.* [39] devised energy-aware selective encryption for the high motion video frame. The detection of high motion is performed by the texture energy level of the frame which is classified by the DC coefficient in Discrete Cosine Transform (DCT) and the motion vector which expresses descriptive information of video magnitude and phase angle. The high value of the motion vector indicates high motion activity and vice versa. For securing multimedia data and conserving energy in M-IoT, all syntax elements of high motion frames are encrypted. However, in low energy frames, alternate syntax elements are encrypted.

C. CLOUD COMPUTING FOR M-IoT

The miniature IoT devices and bulky nature of multimedia data necessitate excessively large and time-sensitive computation resources. Cloud computing offers computing resources in a centralized manner instead of localized computing to augment energy conservation, QoS and improves the life expectancy of the M-IoT network. Computing pioneer *'John McCarthy'* speculated cloud computing in 1961 as ' *computation may someday be organized as a public utility'* [187], which raises the question, what exactly cloud computing refers to. National Institute of Standards and Technology (NIST) defined cloud computing in [188] as: *"Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction."*

Cloud computing encompasses five essential elements [189]: *1)* On-demand self-service: user with urgent requirement of CPU, storage, and software can avail the resources without human intervention. *2)* Broad network access: the user required computation resources are available over the Internet for heterogeneous platforms. *3)* Resource pooling: similar resources are organized in pools exploiting virtualization to serve multiple users. *4)* Rapid elasticity: the consumer resource requirements vary according to the network condition and application regardless of having any knowledge about cloud computation capacity. Therefore cloud servers are flexible to address every user. *5)* Measured services: The cloud server monitors the resource usage of each user through metering capabilities. In addition to these elements, the cloud services are categories as; Software as a Service (SaaS): accessing application from cloud, Platform as a Service (PaaS): providing application development platform as a service, Infrastructure as a Service (IaaS): providing hardware infrastructure i.e., storage, processing servers and network as a service [187] as depicted in Fig. 12. The cloud services are deployed in four models; private cloud, community cloud, public cloud, and hybrid cloud [189]. In this section varied proposed cloud computing schemes for M-IoT have been enlisted. A comprehensive study on the integration of cloud computing and IoT has been presented in [190].

1) MULTIMEDIA CLOUD COMPUTING IN IoT

The ubiquity of audio processing and cameras even in low-end devices increases the audio and visual recognition applications. However, due to small size IoT devices, multimedia data processing requires additional computational services that are readily available. To cope with this issue, the researcher has put forward several remote cloud computing scheme for multimedia processing. Renna *et al. in* [191] presented a framework to provide the optimal balance between energy consumption to process the query

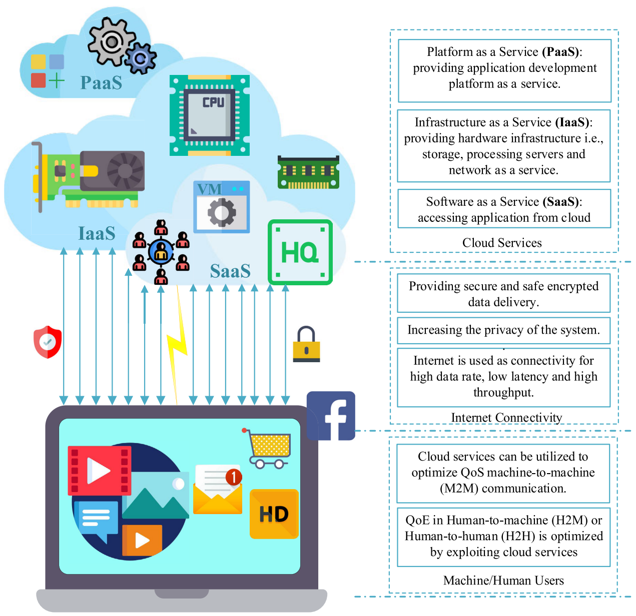

FIGURE 12. Cloud computing services for M-IoT. Cloud services are categorized as the platform as a service (PaaS), infrastructure as a service (IaaS), and software as a service (SaaS). Cloud services can be studied for M2M and M2H communication. Cloud services require a secure and safe connection between device and cloud.

and the cost incurred for cloud computing by incorporating resource consumption according to the volume of query which either lies in the idle state or active state.

Ubiquitous and heterogeneous data generated from the surveillance system is transmitted to a centralized processing unit over limited bandwidth incur high latency. Ali *et al.* [192], [193] proposed a cloudlet based, lightweight distributed computing framework for IoT video surveillance systems to minimize network latency. The cloudlet system brings cloud computation resources closer to the IoT network to compute critical and sensitive data in real-time. In this article, face recognition is considered as a use case to validate the framework. Cloudlet exists between surveillance cameras and the public cloud. Image/video captured by the camera is sent to the cloudlet for face recognition and feature extraction, which is transmitted to the public cloud for matching and identification purposes. Cloudlet is a device with significant storage, CPU, and GPU. Preprocessing the captured data before transmitting to the public cloud significantly reduces the network latency. DNN based face detection 'OpenFace' in real-time video stream and face denaturing named 'RTFace' technique for privacy and safety has been presented in [194]. The proposed algorithm is implemented on cloudlets for speedy and efficient face detection and denaturing.

Crowdsensing is an important aspect of smart cities which provides ease in multimedia data aggregation by exploiting multimedia sensor of public mobile phone, wearable devices, and tablets. The acquired data is wirelessly transmitted to the cloud in real-time due to the limited storage capacity of the devices. Hong *et al.* [195] addressed three problems in cloud-based video crowdsensing: *1)* optimal transcoding, *2)* the optimal data transfer protocol and meta-data selection to upload a video over WiFi, *3)* camera parameters which require complete video lookup. The authors presented three algorithms: Adaptive Transcoding Algorithm (ATA) based heuristic algorithm for video representation without quality compromise. Protocol Selection Algorithm (PSA) to dynamically select transmission protocol by comparing average throughput normalized value achieved from FDT and UDT. Cloud Database Algorithm (CDA) based on Field-of-View (FoV) approach to manage videos in the cloud database.

Authors in [196] devised an analytical framework to serve the cloud access request from the access network, core, or edge network by maintaining an optimal number of replicas to improve resource utilization. Cloud computing for event detection in a video stream and probabilistic future event prediction is detailed in [197]. Authors proposed a dynamic programming based framework to efficiently allocate bandwidth resources from limited uplink bandwidth based on future event predictions to transmit only meaningful information. The results show 80% event detection with 97% QoS satisfaction, utilizing 10% of essential bandwidth. Wang *et al.* [198] devised multimedia sensing as a service (MSaaS), an energy-efficient framework work to upload multimedia data by prioritizing it first and then optimally allocate network resources. The authors exploit the quad-tree decomposition algorithm to segregate regular and premium blocks. In this article, the truncation based resource allocation optimization problem is formulated. A unified resource allocation metric is considered based on Automatic Repeat Request (ARQ), channel coding for Forwarding Error Correction (FEC), data rate, transmission power and packet length subject to energy-constrained quality optimization.

D. FOG/EDGE COMPUTING

For decades cloud computing served as pay-as-you-go, managing and providing alternative solutions for data centers and enterprises by providing remote storage units, processing units, networks, servers and applications to serve multiple customers [199]. Cloud computing flows a centralized processing infrastructure which is usually located far from users or IoT proximity. However, cloud computing upsurges network overheads by transmitting the aggregated data from sensors to the centralized processing cloud and then acquiring back the analyzed data over bandwidth, latency, and energy-constrained network. M-IoT network requires a model that can handle high velocity, volume, and variety of data with minimum latency, conserve bandwidth, reliability, globally secure and chooses the best processing unit in the least possible time. In 2012, Cisco introduced and defined fog computing as [200]: *"The fog extends the cloud closer to the things that produce and act on IoT data."*

Fog computing is the virtualized platform that offers computation, storage units and routing devices between User Equipment (UE) and traditional cloud, located at the edge of the network, reducing the response time of the system [201].

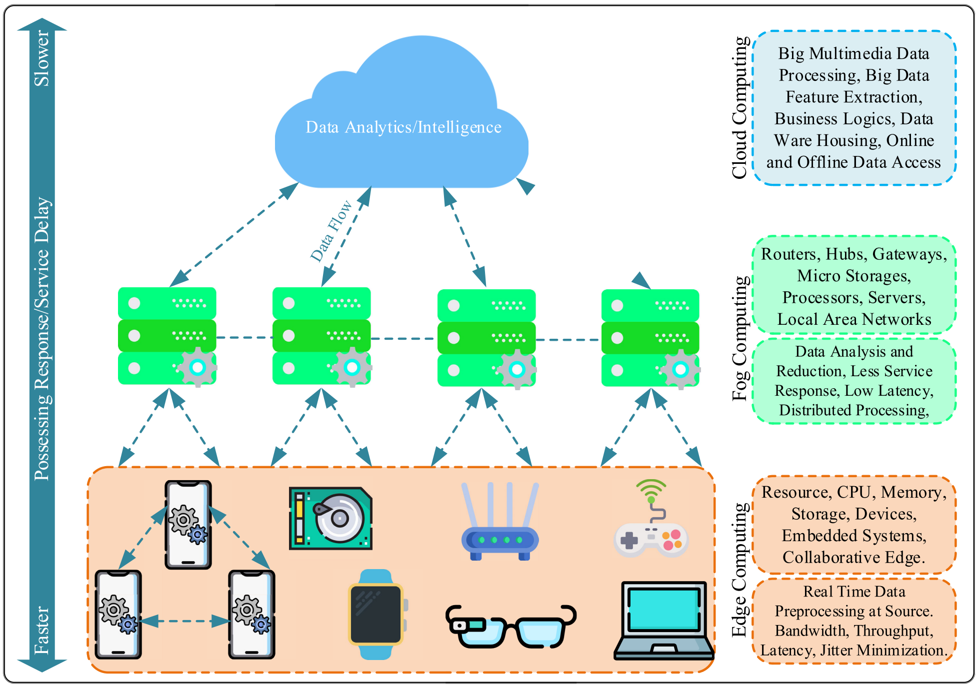

FIGURE 13. Fog/Edge computing in M-IoT. Fog/Edge devices reduce network overhead and latency by preprocessing the acquired multimedia data at Fog/Edge nodes. Fog/Edge devices can be a smartphone, network hubs, gateways, routers, and servers.

The fog-cloud hybrid computing architecture process the data in the following pattern. Critical time-sensitive and real-time data are processed on the fog node, while less critical data that can tolerate minute delay is processed and stored on fog gateway node for a few hours. The regular periodic data that is not delay-sensitive is sent to the cloud to be processed and stored for offline access [200]. Stojmenovic *et al.* [202] outlined a detailed overview of fog computation applications and challenges.

The term edge computing also refers to the notion of providing computation at the edge of the network. The edge computing is defined as network processing and resources progressing between data origin and cloud unit [203]. Detailed edge computing architecture and issues are presented in [203]. The smartphone act as an edge between the user and the cloud. The processing unit is placed within the proximity of data producers to increase energy efficiency, response time, and bandwidth allocation optimization. Fog computing is referred to as edge computing. However, the difference lies in the location of the computing unit is placed. Fog computing is employed at the Local Area Network (LAN) or the gateways of the network, whereas edge computing is embedded within the end or edge device, as shown in Fig. 13. Linthicum *et al.* describe edge computing as the concept, while fog computing as a protocol to implement edge computing [204]. The authors also highlighted the limitations of both the architectures in data computing. Various fog and edge computing frameworks, vision, and challenges in the M-IoT network are studied and presented in the subsection.

1) FOG COMPUTING IN M-IoT

Extending the computing closer to the edge or access network raises several issues and challenges. Determining and classifying critical multimedia data is necessary for load balancing on fog node and the cloud for optimal efficiency. Excessive workload on fog node increases the power consumption, causing efficiency degradation. Deng *et al.* [205] formulated a primal problem for maximizing power conservation in fog-cloud hybrid systems. Four layered fog-cloud frameworks have been proposed.

Moreover, the authors decompose the problem into three subproblems by specifying the tradeoff between latency and power consumption. The problem is subject to various constraints: *1)* delay at fog node, *2)* Wide Area Network (WAN) communication system between fog and cloud server, *3)* bandwidth and network overheads at the cloud server. Simulation results show that the proposed framework improves latency and power consumption for delay-sensitive traffic. Chen *et al.* [206] devised a fog-based video surveillance system to monitor a speedy road traffic system in urban areas using a drone camera. The authors proposed a tracking algorithm that extracts and transmits image frames of interest to fog node to meet minimum computation and delay requirements. The tracking algorithm utilizes Bayes estimation and probabilistic Monte Carlo simulations.

Yousefpour *et al.* in [207] presented a fog-cloud hybrid generic framework to minimize the service latency by sharing the load among fog nodes. The framework considers the queue length and the type of service requested, as the different application requires different service time. The Fog layer offers collaborative architecture to process a request exploiting the concept of load sharing by offloading the service request to neighbor fog nodes. Authors also put forward an approach to find the best fog node to process the request in minimum time by using a centralized fog node for maintaining a reachability table to offload the request to the node which offers minimum service delay. Minimum service delay and propagation delay are measured using a recursive analytical process. Simulation results depict the proposed model outperforms No Fog Processing (NFP).

Ni *et al.* [208] put forward a fog computation resource allocation strategy based on Priced Timed Petri Nets (PTPNs) that considers price and time cost of task completion. The proposed scheme utilizes a dynamic recursive algorithm for fog resource allocation. The authors also presented a probabilistic model to predict the time cost of task completion. The framework provides a novel scheme for users to select the resource pool that fulfills their requirements. The innovation can still be improved by implementing the ML technique to train the system by mapping the nature of services with required fog resource and service time. *Yang* in [209] discussed fog architectures for data stream processing in four different applications: *1)* IoT stream analytics, *2)* real-time crowdsourcing, *3)* network control, *4)* event processing. The author investigates various issues and challenges in applications focused on real-time monitoring and crowdsourcing. The main objective of this architecture is to incorporate fog computation in the M-IoT network that augments the network throughput, latency, fairness, stability, and reliability.

2) EDGE COMPUTING IN M-IoT

Communication between M-IoT devices, edge devices, and cloud incur additional delay if the tasks are not properly scheduled. Xu *et al.* [210] introduced the concept of optimizing in-memory processing to reduce the delay and latency of the network. Three-tier architecture is proposed to formulate closed-loop feedback scheduling and prioritization model to integrate memories of all the edge devices to balance workload allocation. Results depict improvement in latencies for M-IoT systems and rational workload allocation. *Genetics* a geo-distributed real-time stream processing for the dynamic edge-cloud network is proposed in [211] to achieve low latency by exploiting minimum bandwidth allocation and task sharing. A distributed Complex Event Processing engine (CEP) for a fully distributed edge IoT network is presented in [212]. CEP utilizes both events based and stream-based approaches. The authors proposed a heuristic assignment model for task distribution for a balanced workload between edge devices and cloud. Results show 6.6 times less data volume flow as compared to a centralized framework.

Li *et al.* [213] proposed CNN based deep leaning optimization problem to maximize the number of tasks for edge devices subject to limited bandwidth and system capacity. The authors aim to reduce the network traffic and overheads from M-IoT devices to the cloud. The system is designed for online and offline video processing, as video processing is the integration of computer vision and image processing. Sharma and Wang [214] devised a collaborative edge-cloud framework. The framework utilizes the historic cloud computing data to aid edge computation to analyze live data for maintaining QoS. The authors also highlighted the issues, challenges, and limitations of both edge and cloud computing. Furthermore, the motivation for a collaborative edge-cloud framework is also outlined.

Long *et al.* in [215] proposed an edge M-IoT framework to process video on edge devices to improve the accuracy of human detection in surveillance systems. The proposed framework utilizes D2D communication to transmit the divided and compressed video frames to nearby edge nodes that form cooperative groups to process the video frames transmitted to them in multicast or unicast fashion. The authors deduced that human detection accuracy is positively correlated with the video coding rate and formulates an optimization problem to maximize the average video coding rate subject to deadline and group formulation constraint. Group formulation problem is solved by considering it as Winner Determination Problem (WDP), which states that the video chunks are allocated to the group of edge nodes which maximizes the overall utility. Simulation results validate that the proposed work outperforms no cooperation and an arbitrary model. Elias *et al.* [216] devised Where's The Bear (WTB), an image processing technique for edge computing based on NN to recognize animals in wildlife monitoring systems. The objectives of WTB are to conserve bandwidth and improve accuracy. WTB exploits Google TensorFlow for image recognition and classification, and OpenCV for analysis. Results show that implementing image recognition at the edge of the network where the images are acquired reduces latency and conserves bandwidth.

E. SOFTWARE-DEFINED NETWORKS

Several devices are responsible for handling network in IoT, such as, routers, switches, and embedded devices. These devices are equipped with integrated circuits, that are preprogrammed to execute predetermined tasks. Such devices are not reconfigurable with dynamic changes in the network to support real-time multitasking. The expected 50 billion connected devices could generate 600 ZB annually by 2020 [170]. Transmitting such a huge amount of data to the cloud for analysis and processing may lead to developing network congestion, which can cause latency and bandwidth issues affecting overall QoS and QoE. To cope with this problem, most of the technology giants like Cisco and IBM offered to process the data closer to the network's edge to achieve high data rates and low latency. However, edge processing may incur high energy consumption.

To deal with issues mentioned above a flexible, scalable, reprogrammable, and reconfigurable M-IoT architecture is in need to manage multimedia traffic flow and data computation to optimize energy consumption and performance. SDN is an emerging network technology that offers flexible, interoperable, reconfigurable, and reprogrammable network architecture to satisfy dynamic changes in the network. SDN compromises network management [217], network virtualization [218], network accessibility [219], resource utilization [220], energy management [221], security and privacy [222] by segregating network control from hardware devices [223]. The main objective of the SDN is to decouple the control plane from the data plane to rationalize the network. This network device now acts as a Forwarding Device (FD), that forwards a sequence of packets from source to destination by regulatory policies [224]. The control plane in SDN is a centralized unit while the data plane works in a distributed manner.

The Telecommunication Management Network (TMN) architecture comprises three planes: management, data, and control plane. Management plane forms the maintenance and operations unit of the network, i.e., human operators and software that monitors the status, configure and update the network. The data plan performs data transmission by following the flow decisions of the controller in the control plane. This plane constitutes all the FDs such as routers, switches, firewalls, and embedded circuits. The control plane is a centralized controller to configure and reprogram the network, for instance, network path, routing protocols, network policies according to the application requirements [225]. The SDN comprises two Application Programming Interfaces (APIs), i.e., northbound API that is responsible for providing communication between application plane and controller, whereas southbound API supports communication between the controller and network devices as shown in Fig. 14. This section presents studies and proposed schemes associated with multimedia data computation by employing SDN.

1) MULTIMEDIA COMPUTING IN SDN

SDNs are not specifically introduced for data computing. However, managing the network proficiently by SDNs could reduce the computing complexity to yield low latency and fewer overheads. Kaur *et al.* in [226] devised SDN as a middleware in edge-cloud hybrid architectures to improve the energy efficiency of the stream processing. The framework provides the classification of data flow into batch processing and stream processing. Batch processing is more focussed on network service bandwidth while stream processing comprehends real-time applications that are latency-sensitive. Upon the classification of workflow, network control logic are configured and implemented. The authors have formulated multi-objective optimization problems for each control logic, which exploits the Tchebycheff decomposition algorithm to solve the problems to minimize energy consumption by efficient routing path selection and scheduling. Results show that incorporating dynamic network changes according to the classified workflow enhances the energy efficiency meeting SLA. Salman *et al.* [227] proposed Software-Defined Mobile Edge Computing (SD-MEC) architecture to reduce latency and bandwidth by combining the features of both SDN and edge computing. The proposed framework offers scalability by managing the distributed edge network with SDN controllers to incorporate network changes and developing new services. Wang *et al.* [228] presented SDN-based-Publish/Subscribe (SDNPS) unified framework to serve multiple IoT applications. The presented framework aims to reduce the latency and throughput of the network with publishers that publish the generated data and offer services tagged with specific event topics to SDN. The subscribers that require specific event services receive their desired services from SDN based middleware without interaction with the publisher. SDNPS leads to a unified, interoperable framework. Baktir *et al.* [229] detailed the limitations and challenges of cloud-edge computing with increasing data traffic and proposed a vision of SDN based network management strategy to decrease the complexity of cloud-edge architectures. Authors have highlighted several use cases, including multimedia data computation in IoT for face detection and revealed the benefits of incorporating SDNs to add scalability and reliability in the network. A comprehensive survey and future research direction on SDN and fog computing is presented by Salman *et al.* [45].

F. SUMMARY AND INSIGHTS

In this section, the limitations of underlying M-IoT architectures for multimedia communication has been discussed. Various multimedia encoding and compression techniques to reduce the complexity of multimedia data transmission in IoT has been detailed in [43], [173]–[182]. Detection, extraction, and event processing of meaningful information from multimedia data has been studied in [39], [183]–[186] for efficient network resource utilization. The vision of cloud computing and various studies to analysis and process multimedia data over the Internet through remote access is present in [187]–[198]. Increasing network overheads and the latency due to cloud computing has been discussed, the concept of fog\edge computing to minimize network latency for real-time applications is discussed in [205]–[216]. The notion of SDNs to enhance the scalability and interoperability to support heterogeneous M-IoT devices has been explained. Various studies related to SDN based fog\edge-cloud computing to reduce computing latency and overheads have been presented in [31], [32], [34], [35], [45], [46], [46]–[170]. SDNs, not only provides reconfigurability but also offers a more scalable and interoperable architecture. A tabular summarization of this section can be seen in Table 7.

VI. ROUTING PROTOCOLS FOR MULTIMEDIA IN IoT

Multimedia data exhibits stringent requirements according to diverse characteristics in terms of volume, variety, velocity, and value, especially for efficient bandwidth utilization and reliability. The deviation from Moore's law, multimedia devices are now becoming smaller in size, with a decrease in cost and memory to support mobility [3]. The current standards and protocols, as shown in Fig. 15, consume a significant amount of bandwidth and energy to ensure reliability. These communication protocols are not optimized for low power multimedia communication.

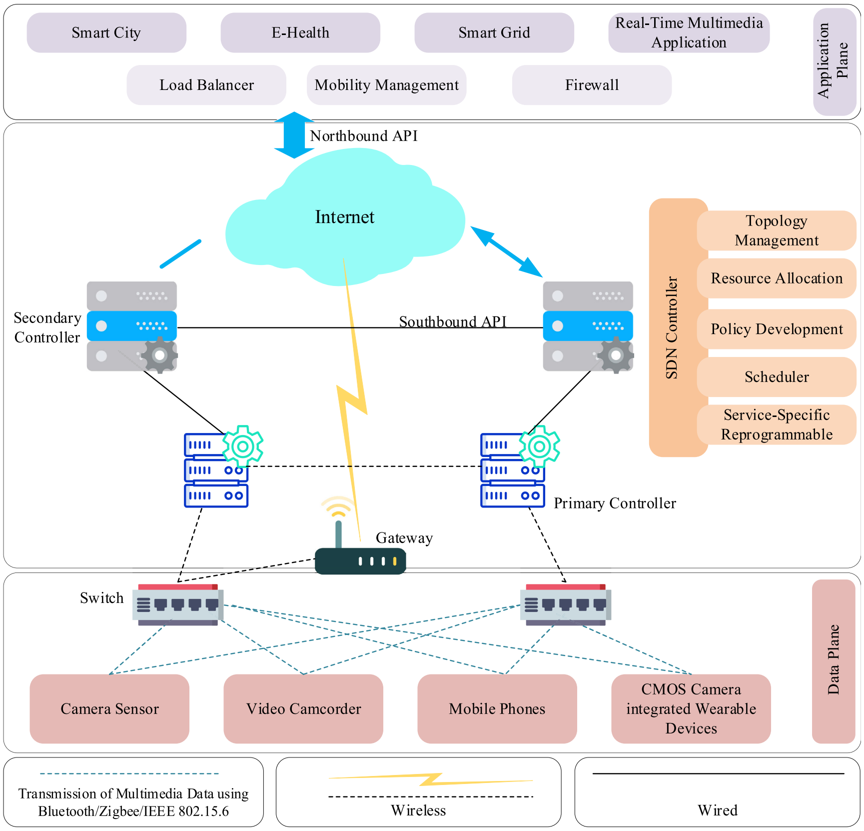

FIGURE 14. **The architecture of Software-Defined Networks (SDNs) for multimedia computing. SDNs offers scalability, flexibility, reconfigurability, and re-programmability for efficient network management. SDNs separates data planes from the control plane and provide four APIs.**

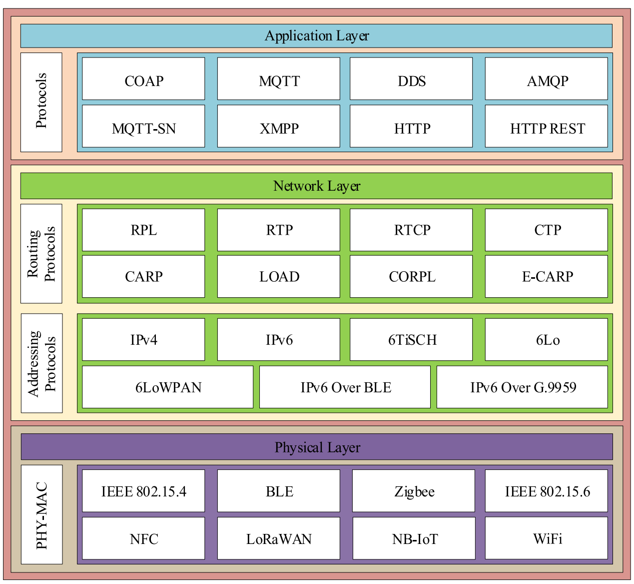

FIGURE 15. **Standards and protocols of three layered IoT framework [2].**

The current standardization activities are not focussed on multimedia communication over IoT. ITU defines traffic routing of mobile services in ITU-T Recommendation E.170 [230] as: "*establishing a successful connection between two exchanges or the selection of path between source and sink node in the network*." An intelligent routing protocol is in need to select an efficient route for multimedia content transmission over bandwidth and memory-constrained wireless IoT network.

The scarcity of IPv4 urges the recommendation of IPv6 for smart IoT objects. 6LoWPAN is an IP based technology for Low-power and Lossy Networks (LLNs) to bridge the gap between low-power devices and the IP world [231]. 6LoWPAN compresses IPv6 headers and fragmentation of large packets to make IPv6 suitable for resource-constrained devices [232]. International Engineering Task Force (IETF) proposed an IPv6 Routing Protocol for LLNs (RPL) [233], [234]. RPL is now widely adopted as a promising standard with increasing popularity because it offers flexibility and interoperability by adopting different network topologies. RPL exploits key network metrics such as throughput, node energy, latency, hop count, and link reliability. RPL supports Point-to-Point (P2P), Point-to-MultiPoint (P2MP) and MultiPoint-to-Point (MP2P) communication paradigm. Kim*et al.* [18] provided a detailed picture of the research that has investigated RPL. The authors presented the distribution of research carried out on RPL in the context of the geographical region, operating systems, hardware platforms, and network metrics. A plethora

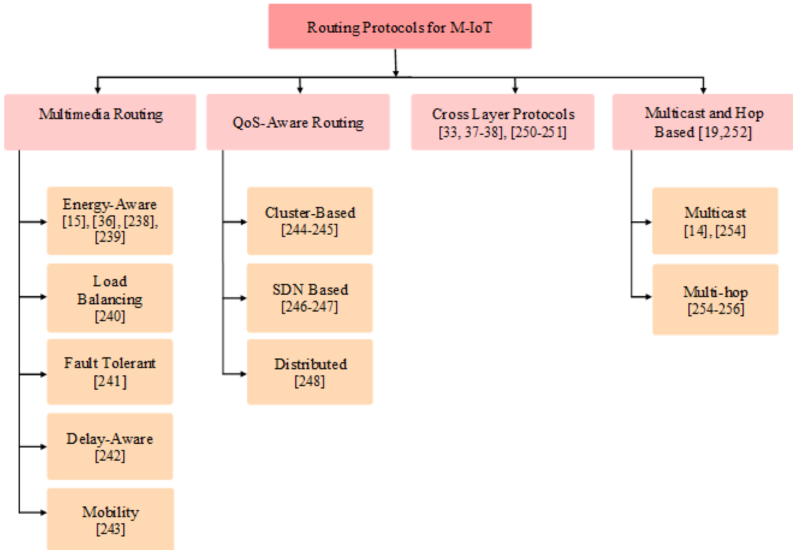

FIGURE 16. Existing work on routing protocol for M-IoT is classified on their capability to transmit multimedia data in single-hop or multi-hop or multicast manner or on the basis of QoS requirements.

of work and survey studies of the IoT communication protocols mentioned in Fig. 16 are present in the literature [11], [3], [235], [236]. In this section, we have extensively studied routing of multimedia content, i.e., audio, image, and video in IoT to meet the stringent requirements of multimedia communication in IoT while maintaining QoS and QoE with efficient bandwidth and energy utilization. Fig. 16 shows the classification of the existing works on multimedia routing in IoT. Cross-layer communication protocol for multimedia data routing in IoT has been discussed. Routing protocols for multimedia data streaming in a multicast or unicast manner to provide the required QoS has been extensively studied. Table 8 tabulates the performance summary and comparison of studies on multimedia data routing in IoT.

A. MULTIMEDIA DATA ROUTING IN M-IoT

The recent studies on routing protocols for M-IoT discuss the transmission of data in varied perspectives, i.e., the transmission of audio, image, and video streaming in the context of energy, workload balance, fault tolerance and delay in time [17], [237].

1) ENERGY-AWARE ROUTING

Xu *et al.* [36] proposed EQRoute, an energy-aware, and QoI-aware routing algorithm. The EQRoute is a distributed algorithm, designed for ubiquitous multimedia transmission based on the information value of data and capacity of the mobile user concerning it's moving speed. In the proposed model, a mobile user constructs the data collection tree, based on its capacity and moving speed. The route is selected based on information gain, which is calculated in the context of communication cost and information value. The aim of the proposed work to maximize information gain and reduce energy consumption.

Energy harvesting has shifted the design paradigm from energy-aware to Energy-Harvesting-Aware (EHA). Nguyen *et al.* [238] devised the EHA Routing Algorithm (EHARA) based on the energy-backoff process and energy prediction process that defines cost metrics to select the best route. A hybrid energy harvesting sources are considered in the proposed work, i.e., solar panels, moving vehicle-based, and RF-based. The energy prediction process utilizes a Kalman filter approach that considers previous time step and current statistics to determine an improved estimation of current energy arrivals from different sources. The energy backoff process is proposed to extend the network lifetime by putting the nodes with minimum energy to sleep that are unable to perform operations until the energy level is recovered. The node with the highest energy level and minimum cost link based on Dijkstra's shortest path is selected to route the data.

Carbon Dioxide (CO_2) emission is one of the vital factors affecting the network or node lifetime in green communication. Alvi *et al.* [15] proposed green-RPL routing for M-IoT to route the multimedia data by selecting the parent node operating on green energy that consumes minimum energy and delays to the sink. The objective of the green-RPL is to minimize carbon footprint subject to path delay, path energy, residual energy, and idle time. Trinh *et al.* in [239] presented SPIDER, a sustainable policy-based intelligence-driven edge routing algorithm based on MEC to detect geographical obstacles using DL to aid the routing engine to efficiently offload the data and route the priority data in an emergency for energy conservation. The proposed work presents a facial recognition use case in a disaster scenario.

TABLE 8. The existing work on M-IoT in context of multimedia data routing.

Articles		Year	Performance Metric: Bandwidth	Latency	Throughput	Energy	Mobility	Reliability	Fault Tolerance	Load Balancing	Performance Evaluation
Multimedia Data Routing	[36]	2018	×	✓	×	✓	✓	×	×	✓	'EQRoute' a distributed routing algorithm to maximize information gain and reduce energy consumption. Performance is evaluated based on received packets vs speed, energy consumption vs speed and packet delay vs speed. Results show EQRoute outperforms λ-flooding algrithm.
	[238]	2018	×	✓	✓	✓	×	✓	×	×	'EHARA' an energy-harvesting-aware routing algorithm to select the best route based on energy prediction, energy backoff process and minimum link cost based on Dijkstra's shortest path. Performance is evaluated on various traffic load. Results show that EHARA improves statistics in terms of average energy consumption, network lifetime, PLR, throughput and end-to-end delay.
	[15]	2015	×	✓	✓	✓	×	×	×	×	'Green-RPL', an enhanced version of RPL that considers the minimization of carbon footprint by selecting the parent node that consumes minimum energy and delays to route the data to sink. Results show that Green-RPL delivers a significant amount of packets as compared to OF0 and ETX objective function but consumes more energy, however, a packet transmitted in a similar time is much higher than ETX and OF0.
	[239]	2018	×	×	✓	✓	×	✓	×	×	'SPIDER' MEC based a sustainable policy-based intelligence-driven edge routing algorithm. Results show SPIDER improves routing sustainability, energy awareness and throughput.
	[240]	2018	×	×	✓	✓	×	✓	×	✓	'CLRPL' a context-aware and load balanced RPL to improve network lifetime, PLR and energy conservation. Results show that PLR of CLRPL is 100% less than RPL with 10% improvement in keeping a node alive, less energy consumption as compared to RPL with enhanced network lifetime.
	[241]	2019	×	×	×	✓	×	×	✓	×	Fault-tolerant routing exploiting virtual CH with minimum energy consumption for backup. Results show that proposed work reduces 84% of average backup energy consumption and improves the network's lifespan.
	[243]	2018	×	×	×	✓	✓	✓	×	×	'MAPLE' a mobility support asymmetric transmit power in LLNs. Results show MAPLE outperforms RPL, ORPL, LOADng and improves performance by 27%/55%, and 18% in the context of uplink\downlink reliability and energy.
	[242]	2018	×	✓	×	×	×	✓	×	×	'DDSV', mobile sensing vehicles for multimedia data collection to optimize delay and delivery ratio. Results show 17% decrease in delay 16.9% improvement in delivery ratio as compared to optimal vehicular data forwarding (OVDF).
QoS-Aware Routing Protocols	[244]	2017	×	✓	✓	✓	×	✓	✓	✓	'QHCR' provides QoS-aware multipath routing protocol for real-time delay sensitive applications in HetNets. Results shows significant improvement in network life-time, throughput, stability, energy conservation and end-to-end delay.
	[245]	2012	×	✓	×	×	×	✓	✓	×	TCNet based QoS routing protocol for self-configurable networks to mitigate latency. The proposed protocols follows MPLS to maintain QoS criteria.
	[246]	2018	✓	✓	✓	×	×	✓	×	✓	'SmartAlloc' adaptively allocates bandwidth according to SLA. Performance is evaluated for VoIP, video transmission and HTTP applications. Results shows 69% lower jitter, 18% reduced delay, 69% reduced HTTP page response and 69% better throughput.
	[247]	2018	✓	✓	×	×	×	✓	×	×	'Sway', a SDN based QoS-aware routing protocol to determine an optimal path according to the type of traffic for HetNets. Performance is evaluated on the basis of end-to-end delay and QoS violation.
	[248]	2016	✓	✓	×	×	×	✓	✓	×	Distributed QoS-aware meta-routing protocol to achieve efficient reliability and timeliness. Performance is evaluated in comparison with Flooding algorithm. Results show a significant reduction in the number of packets transmission to achieve better reliability and timeliness.
Cross-Layer Protocols	[37]	2017	×	✓	×	✓	×	×	×	×	Cross layer communication protocol based on multi-objective optimization and ME-CBCCP routing protocol. Result shows 10-15% improvement in energy and time.
	[33]	2018	×	✓	✓	✓	×	✓	×	×	EQM cross layer protocol to reduce latency and energy consumption with improved throughput. Results depicts improvement in delay gain by 100%, 30% in packet delivery ratio and 80% delivery ratio of video content. MOS value of 2.5/5.0 was achieved for video content.
	[250]	2014	✓	✓	×	✓	✓	✓	×	×	'LinGO', a cross-layer opportunistic routing protocol that considers link quality, distance and energy of the forwarding node for video transmission. Results are evaluated using structural similarity (SSIM) and MOS values with 30% video quality improvement in SSIM gain.
	[38]	2018	×	✓	×	✓	×	×	×	×	QoS aware agent based cross layer protocol to reduce end-to-end delay. Results depicts 100% reduction in end-to-end delay.
	[251]	2018	×	✓	✓	✓	×	×	×	×	M/M/1 queuing model for adaptive switching between end-to-end transmission or hop-by-hop transmission. Duty cycling is based on bit error rate and critical path loss. Results depict that end-to-end transmission with non-return-to-zero (NRZ) encoding shows better efficiency in terms of throughput, energy consumption and delay over the multi-hop transmission.
Multicast and Hop-Count Based Routing	[252], [19]	2017	✓	✓	✓	✓	✓	✓	✓	✓	A comprehensive review in the context of multipath and multi-hop routing for best effort and real-time data. Authors presented a mechanism for multipath routing and discussed each performance metrics.
	[14]	2017	×	✓	×	×	×	✓	×	×	'FAMOUS', a multiconstrained multicast routing algorithm based on SPT and MST for multimedia real-time applications. Results show a comparison in the context of speed and accuracy.
	[253]	2018	×	✓	×	✓	×	✓	×	×	'EEMGR' protocol based on ETX, residual energy and distance approximate the good link for successfully delivering the data. Results are compared with TPGF algorithm in the context of link quality approximation, network lifetime and discovery of reliable and energy efficient paths.
	[254]	2016	×	✓	×	×	×	✓	×	×	CM2MNs for opportunistic relay selection to route multimedia data based on the M/M/1∞FCFS queueing model. Performance of the model is evaluated on the basis of the probability of delay violation. Results show CQC keeps the traffic within the threshold of tolerable delay violation.
	[255]	2016	×	✓	×	✓	×	×	×	×	MPSS and MPMS routing algorithms to transmit multimedia data using spline trajectories. Performance is evaluated in the context of energy consumption and end-to-end delay. Results show proposed algorithm can efficiently meet QoS requirements.
	[256]	2018	×	✓	×	✓	×	×	×	×	TCP based node ranking for D2D communication to route data in IoT. Performance is evaluated based on connectivity probability that depends on the geographical distance between source and receiver.

2) LOAD BALANCING

Packet loss due to heavy traffic and power depletion are two main reasons for network congestion. Taghizadeh *et al.* in [240] address these problems by proposing Context-aware and Load balancing RPL (CLPRL). The proposed work offers Context-Aware Objective Function (CAOF) and Context-Aware Routing metric (CARF) to improve RPL. CAOF ranks the nodes for the selection of a parent node based on the residual power level of the node and the Expected Transmission Count (ETX). After ranking, CARF takes the buffer queue utilization, node rank and network traffic dynamicity index that indicates the utilization of link in the past, to compute the route during heavy traffic conditions. The authors ensure the load balancing by considering the number of children node with a parent from the list of candidate parent nodes for parent selection. It helps in load balancing even if a node is eligible to be a parent node, but a large number of children node can create loops and network congestion.

3) FAULT-TOLERANT

The miniature multimedia sensors are equipped with limited battery power. The exhaustion of the battery leads to network failure. Lin *et al.* [241] proposed a fault-tolerant routing for Cluster Head based (CH) HetNets. The proposed scheme addresses three problems that are the pre-verifying the fault-tolerant capability, distributing the load and optimizing the fault-tolerant cost. These problems are dealt with by the sink node with a virtual CH approach that estimates all the traffic in the network and verifies the sustainability of IoT application. Virtual CH combines all the energy resources of non-failure CHs, estimates the size of sensed data to be transmitted and verify the capability of tolerance offered by non-failure CHs in the network. After which an optimal fault-tolerant route is determined from the flow-bipartite graph that represents all the possible routes between faulty and non-faulty CHs.

4) DELAY-AWARE

Multimedia data poses delay-sensitive characteristics. Dropping priority and meaningful multimedia data packets decrease the reliability of the application. Li *et al.* in [242] proposed mobile sensing vehicles for multimedia data collection to optimize delay and delivery ratio (DDSV). Mobile vehicles equipped with IoT devices are exploited to deliver data to and from multimedia IoT devices to data centers. The proposed work addresses three problems in the context of multimedia data packets that are data collection impartiality, delivery ratio, and delay. DDSV proposes priority assignment based-upon distance from the data center to overcome data collection impartiality. The vehicle with a high probability to pass through a data center is given high priority to deliver high priority data packets, which will augment delivery ratio and reduces delay in return. Performance is evaluated in the context of delivery ratio and average delay for data collection.

5) MOBILITY

Mobility is one of the key requirements of rapidly evolving multimedia IoT applications. However, the majority of research has ignored mobility. Jeong *et al.* in [243] proposed MAPLE, a routing architecture based on mobility support Asymmetric Transmit Power (ATP) for LLNs. MAPLE utilizes a single high power periodic beacon in the downlink from the gateway to create a Received Signal Strength Indicator (RSSI) gradient field network. Any low power node can route the data for uplink transmission in a multi-hop manner using the RSSI gradient values of neighboring nodes. High RSSI value indicates high proximity to the gateway. Each high power beacon updates the RSSI gradient metric for uplink routing, which addresses the mobility problem, improves reliability and reduces the overheads in the network. MAPLE also reduces energy consumption because of single high power downlink transmission using ATP architecture.

B. QoS AWARE ROUTING

QoS-aware frameworks to route wireless multimedia data in IoT network for bandwidth-hungry and delay-sensitive applications have been taken into consideration. The definition and requirements of the QoS-aware framework have been discussed in the earlier section. Below is the description of some of the QoS-aware routing protocols to support multimedia communication in IoT.

1) CLUSTER-BASED QoS-AWARE ROUTING

Amjad *et al.* in [244] proposed centralized energy-efficient QoS-aware and Heterogeneously Clustered Routing (QHCR) for delay-sensitive real-time applications. The network area is divided into different energy levels, and Cost Values (C_V) that are determined based on distance from the Base Station (BS), initial energy levels, number of nodes, and weights. The cluster head is elected on it's C_V. The shortest path to the destination is selected based on path metric that is the combination of the initial energy of node, ETX, and inverse ETX, cost value of cluster head and minimum loss with QoS as a constraint. The proposed model offers intra-cluster multipath communication for the nodes that are at a significant distance from BS. Real-time multimedia and non-real-time data are transmitted over separate paths to reduce end-to-end delay and conserve energy. Filho and Amazonas [245] devised a QoS-aware routing protocol to eliminate the need for a routing table. The proposed scheme is based on a Trellis Coded Network (TCNet) utilizing a Mealy Machine (MM) or Finite State Machine (FSM). QoS is maintained using MultiProtocol Label Switching (MPLS).

2) SDN BASED QoS-AWARE ROUTING

Bahnasse *et al.* in [246] devised QoS-aware SDN based smart and dynamic model to allocate bandwidth (Smart Alloc) for MPLS Traffic Engineering DiffServ Aware (DS-TE) network. The proposed architecture translates the QoS requirements of an application into commands that indicates bandwidth and priority requirements. The SLA of each application is detected in terms of delay, loss rate, jitter, HTTP load time, and TCP session delay, and threshold values are set. Smart-alloc adaptively allocates the bandwidth according to the status of SLA. Sway, an SDN based QoS-aware routing protocol for delay-sensitive and loss-sensitive application, is presented in [247]. Sway exploits Yen's K-shortest path algorithm to compute traffic-aware (delay-sensitive or loss-sensitive) best routing path while considering QoS requirements for each packet. Multi-constrained QoS metrics are considered that are the delay, packet loss probability, and bandwidth. Integer linear programming is utilized to solve a multi-constrained QoS-aware route.

3) DISTRIBUTED QoS-AWARE ROUTING

Shih *et al.* [248] devised a meta routing protocol for QoS-aware architectures to select the optimum path between gateways of HetNets. Gateways are registered in the network by broadcasting messages comprising the information of all the network interfaces. Nodes in each network update their table with the addresses of reachable network gateways and interfaces. The optimum path is selected by measuring QoS metrics of each gateway link that is timeliness and reliability. When the QoS requirement is not satisfied, the meta-router will transmit data on multiple paths to achieve maximum QoS.

C. CROSS-LAYER PROTOCOLS FOR MULTIMEDIA ROUTING

Rani *et al.* [37] proposed a cross-layer protocol to minimize energy consumption and response time. The authors formulated a multi-objective optimization problem to minimize the end-to-end packet error rate, time, and energy. These parameters are interlinked and dependant on cross-layer parameters such as path loss, modulation scheme, BER, transmission power, ARQ, duty cycling, and network routing protocol. The optimization of these parameters requires cross-layer communication and coordination. Authors exploit the Minimum Energy consumption Chain-Based Cluster Coordination Algorithm (ME-CBCCP) presented in [249], which finds the shortest path not only at the local cluster level but also takes the intercluster path into consideration. Bennis *et al.* [33] devised Efficient Queuing Multimedia (EQM), a cross-layer communication protocol for transmitting multimedia data over wireless networks. A carrier sense aware disjoint multipath routing protocol is presented to transmit high priority independent video frames by reserving 2-hops neighbor nodes for video frames. The routing layer coordinates with the MAC layer to be aware of priority video data. An enqueuing and dequeuing approach is presented to process high priority multimedia data first and scalar data at the last of the queue. The proposed work aims to reduce waiting for the time and energy consumption of wireless networks.

Rosario *et al.* [250] proposed LinGO, QoE aware link quality and geographical beaconless opportunistic routing protocol for video transmission in IoT. Forwarding node selection and routing path are determined according to cross-layer parameters that are: *1)* link quality indicator classified by packet reception ratio, *2)* progress which is the Euclidian distance between forwarding node to the destination, *3)* energy of the forwarding node. The proposed model increases the reliability by adding redundancy packets for high priority video packets which improve QoE. Devi *et al.* [38] proposed an agent-based cross-layer protocol for optimal path selection and reducing end-to-end delay to transmit important multimedia data with minimum latency. The proposed model exploits the agents to transmit the data when the channel consumes more time than a threshold time. Hassan *et al.* [251] presented a cross-layer framework to ensure QoS satisfaction. A channel access mechanism based on queuing model M/M/1 is formulated for the duty cycle to handle the packets of real-time applications. The impact of multi-hop communication is analyzed using PHY-MAC parameters that are transmission power, hop distance, path loss, and packet error ratio (PER) for adaptive switching between end-to-end transmission or hop-by-hop transmission scheme.

D. MULTICAST AND HOP-COUNT BASED ROUTING

Routing protocols for multimedia bandwidth-hungry and real-time applications of M-IoT have been designed based on multicast and hop-count metric [252]. A detailed survey on multipath routing protocols of M-IoT to ensure QoS parameters has been presented in [19]. Below-mentioned are few studies in the context of multicast and multi-hop routing protocols of M-IoT.

1) MULTICAST ROUTING

Multimedia real-time critical applications require the network to guarantee multiple QoS metrics that are maximum throughput, minimum delay, and minimum PLR. Multimedia communication requires multicast routing with minimum end-to-end latency for delay-sensitive health applications. A Fast Multiconstrained Multicast Routing Algorithm (FAMOUS) is proposed in [14]. The proposed routing scheme is based on Shortest Path Algorithm (SPT) and Minimum Steiner Tree (MST) algorithm. Authors exploit entropy-based weight aggregation to reduce multicriteria decision problems into a single criterion problem. The objective of FAMOUS is to determine the shortest path and optimal multicast tree from source to destination for better accuracy and speed. Aswale and Ghorpade in [253] presented Energy and ETX Aware Multipath Geographic Routing (EEMGR) protocol. ETX is a link quality metric that estimates the number of transmissions required to deliver a packet from source to destination successfully. EEMGR exploits ETX, node remaining energy and distance between a node to sink to determine the optimal path for reliable and energy-efficient multimedia routing. Performance comparison is made with the Two-Phase Geographic Greedy Forwarding (TPGF) algorithm.

2) MULTI-HOP ROUTING

The real-time multimedia applications demand a probability of zero percent delay violation. A cooperative relaying model incorporating Cognitive M2M Network (CM2MN) is proposed in [254] for effective end-to-end QoS. Probabilistic forwarding protocol (PFP) based on a network-aware routing algorithm for multi-hop routing is presented. Cooperative Quality Controller (CQC) is formulated to guarantee QoS requirements. The opportunistic relay selection as a routing extension is based on the M/M/1 queueing model with First-Come-First-Serve (FCFS) strategy. Chen *et al.* [255] presented Multipath Planning for the Single source (MPSS) and Multiple Sources (MPMS) for multimedia transmission in IoT. The proposed work is based on B-spline trajectories. MPSS comprises two units that are the calculation of the hop count module, which determines the number of hops required to satisfy QoS delay and energy-saving module that determines the minimum power required to deliver the data successfully. Utilizing spline trajectories, the source can determine the direction of next-hop by integrating parametric functions for geographical routing. The aim is to determine multiple paths that satisfy QoS with minimum energy consumption. The optimum path with the least energy consumption is selected. The performance of the system is evaluated based on end-to-end delay and energy consumption. Chen *et al.* in [256] devised a Trusted Connectivity Probability (TCP) based D2D relay selection model for routing data in a multi-hop manner. A ranking model is adapted to select the next-hop node with the highest rank. Rank is allotted based on Trust Probability (TP) that depends on the geographical distance between the current and next-hop nodes. An optimization problem is formed to select the optimal route with maximum TCP. The problem is solved with the help of the Dijkstra algorithm that determines the TCP value from a source node to all the nodes in the network. The model offers the D2D communication in both Channel State Information (CSI) aware and unknown condition to calculate the minimum power required to transmit between D2D device and BS.

E. SUMMARY AND INSIGHTS

In this section, routing protocols for M-IoT has been discussed. The existing research presents the routing protocols from the perspective of energy-awareness, load balancing, fault tolerance, mobility, delay awareness [257]. QoS–aware routing [258] for multimedia data is investigated and presented in [244]–[248]. Cross-layer protocols to improve routing strategies in terms of energy, delay, throughput, and reliability [259] have been presented in [37], [33], [249]–[251]. Challenges and issues in multicasting [260] and hop-count based routing schemes have been discussed in [252]–[256]. However, to support multimedia bandwidth-hungry and delay-sensitive applications, cross-layer and energy-aware protocols need to be explored in detail. The existing studies on multimedia routing protocols do not consider efficient bandwidth utilization and fault tolerance. Lightweight and energy efficient ML algorithms like reinforcement learning, Q-learning, Epsilon greedy are yet to be investigated for latency reduction and improve power conservation for multimedia routing in IoT. Table 8 presents a detailed overview of this section, classifying each study and highlighting it's key features.

VII. PHY-MAC PROTOCOLS FOR M-IoT

The network protocol stack of the IoT architecture rests on the joint PHY-MAC layer as depicted in Fig. 16. The protocols under this layer, feature low power operations and guarantee a stringent QoS compliant performance. The discussion of the M-IoT applications in the preceding sections indicates a general guideline for the design of the PHY-MAC protocols. These guidelines include an ability to manage a dense, as well as a sparse network, with a small network overhead, over a wide range and with a low energy requirement [261]. The applicability of M-IoT in the wide range of applications like industrial monitoring, healthcare, security, and smart services in smart city applications implies that there are multiple QoS and QoE parameters for each application. Additionally, the heterogeneity of the devices in the network creates a set of challenges in terms of interoperability. That results in a need for application-oriented data transformations at the network gateway [262]. Therefore, the PHY-MAC layer for each application is designed to fulfill these QoS and QoE parameters. This section discusses the different MAC-PHY standards and protocols designed for specific applications. The major standard in use today is the IEEE 802.15.4 that covers the physical layer specifications for the global application. It forms the basis of the ZigBee standard that is usually used in the smart living IoT scenarios. Additionally, the IEEE 802.15.6 standard is defined for the healthcare scenarios. The other standards used for specific application cases are BLE, Long Range Wide Area Network (LoRaWAN), NB-IoT, and Near Field Communication (NFC). These provide the physical layer as well as MAC specifications for the M-IoT networks.

The IEEE 802.15.4 family of Low Rate Wireless Personal Area Networks (LR-WPANs) was first approved in 2003 [263]. Since then, several amendments have been made to the standard. There have been numerous region-specific amendments as well as application-specific amendments in the 2003 approved standard. The features of the PHY-MAC standards, along with the amendments, are tabulated in Table 9. This standard supports both, a star topology as well as a peer-to-peer topology. The MAC layer resides above the PHY layer in the OSI model and provides an interface between the PHY and the higher layers [263], [264]. The MAC specifications for the IEEE 802.15.4 (2003 release) envisages the use of a Carrier Sense Multiple Access with Collison Avoidance (CSMA/CA) mechanism for Channel Access. The CSMA/CA supports the beaconed mode as well as the non-beaconed mode [265], [266]. The CSMA/CA mechanism for this standard and the IEEE 802.11 differs due to the absence of a request to send/clear to send (RTS/CTS) frame exchange in the IEEE 802.15.4 family.

Additionally, in the IEEE 802.15.4a-2007 amendment, the ALOHA is used for the channel access for the Ultra-Wide Band (UWB) [267]. The 802.15.4 standard serves as the PHY-MAC standard for a large range of applications which requires a unique approach to each problem such as in industrial systems. Additional applications include multimedia surveillance, traffic management, advanced healthcare, and environmental monitoring [268]. Therefore, the focus of this section remains the IEEE 802.15.4 standard as most of the M-IoT scenarios are operated by this standard. The application-oriented PHY-MAC approaches are discussed under the following sub-headings.

A. EXISTING WORK ON M-IoT APPLICATIONS IN THE CONTEXT OF PHY-MAC PROTOCOLS

1) INDUSTRIAL APPLICATIONS

The IEEE 802.15.4 standard has been identified as a suitable technology for industrial applications owing to the features it offers in this domain such as support for a peer-to-peer topology and beaconing in the MAC protocol. The different beacon intervals for the IEEE 802.15.4 superframes leads to a scheduling problem in the network. Toscano and Bello [269] present a solution for the scheduling problems in the multichannel networks. The key concept underlying the Multichannel Superframe Scheduling (MSS) algorithm is utilizing the maximum superframe duration to determine the length of the timeslice and to schedule all the superframes within the same timeslice on different channels [269]. The experimental results reveal the beacons are perfectly aligned, and through the tracking of the parents, the synchronization is maintained. This is not feasible in the time-division approach. Chen *et al.* [270] present a case for the use of IEEE 802.15.4 in the industrial scenario. The experimental evaluation of the standard is carried out in the OMNET++/INET framework that tests the large scale deployment of the nodes in an industrial setup. The node energy efficiency and the goodput support the argument for industrial applications. The Time Division Multiple Access (TDMA) approach is used with the Guaranteed Time Slot (GTS) that enhances reliability. The authors in [271] also propose a GTS based real-time messaging service in the industrial environment. Kim *et al.* in [272] allow a periodic synchronization of the node network clocks using Enhanced Beacons (EBs). The synchronization allows efficient scheduling in the proposed Time Slotted Channel Hopping (TISH) mode. The overall result is the reduction in energy consumption and traffic collisions compliant with industrial standards.

TABLE 9. Description of PHY-MAC standards and amendments.

Name	Year	Frequency Band	Locale	Channels	Modulation	Max Data Rate	Security	Salient Features
802.15.4/ZigBee	2003	2.4 GHz	Global ISM	16	O-QPSK	250 kbps		• In the 2.4 GHz a 32-chip PN sequence is used for signifying a symbol • For the 868 and 915 MHz a 15-chip PN-sequence is used for the spread spectrum
		868 MHz	Europe	1	BPSK	20 kbps		
		915 MHz	America	10	BPSK	40 kbps		
802.15.4b	2006	2.4 GHz	Global ISM	16	O-QPSK	250 kbps		• This release introduces two optional PHY that enhances the data rate • The channel pages introduced in this PHY allow the accommodation of additional channels introduced by the optional PHY
		868 MHz	Europe	1	BPSK	20 kbps		
					O-QPSK	100 kbps		
					PSSS	250 kbps		
		915 MHz	America	10	BPSK	40 kbps		
					O-QPSK	250 kbps		
					PSSS			
802.15.4a	2007	2.4 GHZ	Global ISM	16	O-QPSK	250 kbps	• Confidentiality • Integrity • Authenticity • Replay attack protection • Access control	• In addition to the features of 2006 release, an additional UWB and chirp Signal PHY was introduced • The FCC cleared the use of the 3.1-10.6 GHz channel in 2002 • Three universally supported mandatory channels
		868 MHz	Europe	1	PSSS	250 kbps		
		915 MHz	America	10	PSSS	250 kbps		
		UWB 249.6-749.6 MHz	Global	16	BPM + BPSK	0.11-27.24 Mbps		
		UWB 3.1 - 4.8 GHz						
		UWB 6-10.6 GHz						
		CS PHY 2410-2486MHz		14	DQPSK	250 kbps (64-ary) 1 Mbps (8-ary)		
802.15.4c	2009	780 MHz PHY	China	8	O-QPSK	250 kbps		• The O-QPSK uses a 16 chip- PN sequence for spread spectrum which maps 4 bits to 1 symbol • The MPSK uses the same mapping but modulates the chip phases over the carrier using PSK
					MPSK			
802.15.4d	2009	2.4 GHz	Global	-	Previous Standard	250 kbps		• 2 additional PHY introduced • 9-stage shifter is used for spread spectrum for GFSK
		868 MHz						
		915 MHz						
		950 MHz	Japanese		BPSK	20 kbps		
					GFSK	100 kbps		
NB-IoT	2016	LTE and GSM Bands	Global	12	QPSK, BPSK OFDMA	200 kbps	• Authentication • Confidentiality • Integrity • Access control	• Direct deployment in GSM or LTE • Better range and coverage
Wi-Fi	1997	2.4 GHz	Global	11	QPSK	150+ Mbps	• Authentication • Confidentiality • Integrity	• Easy to deploy and access
LoRaWAN	2012	868 MHz	Europe	12	CS PHY	50 kbps	• Confidentiality	• Highly immune to interference • Adaptive data rate and longer battery lifer
		915 MHz	America					
		Sub 1 GHz						
BLE	2016	2.4 GHz	Global ISM	36	GFSK	1 Mbps	• Confidentiality • Integrity • Authenticity	• Optimal for small data chunks

Legend	
O-QPSK	Offset Quadrature Phase Shift Keying
BPSK	Binary Phase Shift Keying
PN Sequence	Pseudo Noise
PSSS	Parallel Sequence Spread Spectrum
CS PHY	Chirp Signal PHY
DQPSK	Differential Phase Shift Keying
MPSK	Multiple Frequency Shift Keying
GFSK	Gaussian Frequency Shift Keying
Optional PHY	

2) HEALTHCARE APPLICATIONS

Healthcare is one of the most important applications of M-IoT. The PHY-MAC layer for the healthcare applications is designed taking under consideration, the QoS parameters like low latency and high data integrity [273]. The IEEE 802.15.4 standard has been successfully used for healthcare applications. However, a new standard from IEEE 802.15.6 was approved in 2012 for wireless body area networks (WBANs). The IEEE 802.15.4 supports a large range for monitoring the complete health status of the user. One of the primary concerns with regards to the healthcare applications in the M-IoT scenario is prolonging the lifetime of the nodes. The nodes may be surgically implanted. Thus, it becomes imperative that the nodes have a large battery lifetime to prolong its use without causing inconvenience to the user.

Fahmi *et al.* [274] provide a fuzzy logic-based sleep scheduling algorithm. This algorithm aims at optimizing the sleep schedule of the nodes and introducing an adaptive sleeping mechanism. The fuzzy logic uses an inference table that has a set of 81 rules to govern the sleeping times. The energy savings are significant, which are reflected in the experimental results.

An intrinsic challenge faced by wireless networks is that of coexistence with multiple wireless networks. The WBAN based M-IoT networks also face a similar challenge, particularly in the IEEE 802.15.4 network. Deylami and Deylami [275] have presented an evaluation of the coexisting IEEE 802.15.4 based networks for health monitoring applications. The coexistence of multiple networks results in loss of data that may be critical, especially in the time divided slot approach and GTS based mechanisms. Therefore, a dynamic mechanism for resynchronizing the network clock according to the network coordinator is required. To evaluate the security of the network by analyzing the efficient usage of the bandwidth, authors in [276] foresee an exploitation attack on the contention period during the MAC layer operation. The mechanism to remedy the problem is required to enhance the reliability of the system, which is the paramount QoS parameter. This includes an intelligent backoff mechanism that offers a fair chance during the Contention Access Period (CAP).

3) MULTIMEDIA CONTENT STREAMING INCLUDING SURVEILLANCE

The development of the advanced and cost-efficient Complementary Metal-Oxide Semiconductor (CMOS) sensors has led to the widespread growth of visual and audio content across many platforms. Its impact is profound in the IoT domain as well and has led to the development of the Wireless Multimedia Sensor Networks (WMSNs) [277]. These WMSNs have found their application in surveillance and telemedicine. The constraints these networks face are in terms of computing power, energy supply, and memory. Additionally, they struggle with limited channel bandwidth and variable capacity.

Lin *et al.* [278] propose a system to mitigate the challenges of the limited network capabilities in the multimedia framework. This involves a dynamic scheme to adjust the beaconing interval and the superframe duration. This dynamic approach helps in the network synchronization and efficient scheduling, thus, resulting in enhanced transmission efficiency. The proposed method is effective for a dynamic data load, as well. Pham *et al.* [279] have presented an evaluation of the IEEE 802.15.4 standard for the image transmission applications real deployment scenarios. The evaluation is a representative of the Universal Asynchronous Receiver Transmitter (UART) and Serial Peripheral Interface (SPI) based boards for surveillance. The authors present a compression scheme for Joint Photographic Experts Group (JPEG) format image data as well as a block interleaving scheme that enhances the reconstructive accuracy after encoding the images. The authors identify the possible bottlenecks that induce higher latency.

4) MILITARY APPLICATIONS

Mendes *et al.* [280] propose a cross-layer and cross standard methodology for an improved surveillance system in a military application. The proposed method involves support for the multimedia sensors as well as auxiliary sensors for improved enemy movement detection. The proposed method involves the superframe synchronization for improved transmission reliability by allowing cross-standard compatibility between the IEEE 802.15.4 and IEEE 802.15.3 standard. The reliability is the key performance indicator for the applications.

5) PRECISION AGRICULTURE

The implications of M-IoT in the agricultural field are immense. The data rates for the various metrics that are sensed vary greatly amongst each other. Additionally, the priority of each data is different, so the channel access mechanism has to adapt accordingly. Kone *et al.* [281] propose a fine-tuned MAC layer for precision agricultural applications in the IEEE 802.15.4 standard. Precision agriculture is closely monitored and controlled agricultural practice. The proposed method involves the selection of optimal values for the sampling frequency based on the recorded parameter. Additionally, the MAC parameters like the minimum value of the backoff exponent as well as the maximum number of backoffs. The proposed method demonstrates the increased sampling frequency for applications that require higher resolution, thus, improving the granularity.

B. ZIGBEE STANDARD

ZigBee is another standard that is used in the M-IoT scenario. It is particularly utilized in the consumer electronics sphere for home automation. However, the ZigBee and IEEE 802.15.4 can be used interoperably. Some applications with higher security requirements utilize ZigBee while coexisting with the IEEE 802.15.4 standard. Han and Lim [282] explore such a scenario. The authors present a planned overview of automated systems for efficiently deploying smart living systems.

C. IEEE 802.11 STANDARD

Institute of Electrical and Electronics Engineers created the first standard for Wireless Local Area Network (WLAN).

The standards in the IEEE 802.11 family are also known as Wi-Fi. These standards provide PHY and MAC protocols for M-IoT devices. The key characteristics of this standard can be seen in Table 9. From the day first, WLANs have been facing the challenge of efficient MAC layer resource allocation while accessing the channel [283]. CSMA/CA is one of the popular collision avoidance mechanisms used by the MAC layer. In CSMA/CA, a randomized backoff mechanism is performed by the devices before accessing the channel resources. However, a blind exponential increase and reset of contention values in this backoff mechanism induce performance degradation.

Ali et al. proposed solutions in [284]–[286] to tackle the blindness of currently implemented CSMA/CA. Their proposed channel observation-based mechanisms adaptively increase and decrease the contention parameters. Besides, ML-based techniques have been playing a vital role in the performance optimization of MAC layer resource allocation mechanisms [287]. Such ML-enabled techniques are also utilized for other low-power energy-constrained networks of IoT applications, such as smart healthcare systems [288]. In the context of M-IoT, an ML-enabled distributed channel access (MEDCA) mechanism is proposed in [289]. The proposed MEDCA mechanism utilizes Q learning algorithm to optimize the performance of channel access in multimedia-based WLANS (that is IEEE 802.11e).

D. NARROW-BAND IoT

NB-IoT is one of the Low Power Wide Area (LPWA) technologies released by the 3rd Generation Partnership (3GPP). It is designed for heterogeneous IoT devices to achieve improved spectrum efficiency, extended, and in-depth coverage. The key feature of NB-IoT is that it can be directly deployed in the Global System for Mobile communication (GSM) or LTE spectrum [290]. However, the NB-IoT device has to continuously monitor the data transmission channel for service announcements and updates that waste energy resources. Tsoukaneri *et al.* [291] present an NB-IoT communication approach that dynamically creates a group of devices that are subscribed to receive multimedia services in a multicast transmission. To enhance the coverage area, the repetition of control and data transmission signals has been considered. The Adaptive Coding and Modulation (ACM) scheme and repetition numbers are in need of link adaption for NB-IoT systems. However, traditional link adaption techniques without repetition numbers are not applicable to NB-IoT systems. Yu *et al.* [292] proposed an inner loop and outer loop link adaption that copes with block error ratio and coordination between ACM and repetition numbers. The direct communication link between user and BS usually does not satisfy QoS for transmitting vital data. Li *et al.* [64] exploit D2D communication as an opportunistic communication with improved link quality to upload critical data to BS. The proposed optimization aims to improve end-to-end delay and packet delivery ratio. NB-IoT is an emerging technology that yet needs to be explored in-depth for deployment.

E. BLUETOOTH LOW ENERGY

BLE is also known as Bluetooth Smart was introduced in Bluetooth 4.0. BLE is a short-range PHY-MAC communication protocol for low power battery operated devices [293]. BLE is mostly used for scalar parametric monitoring applications. Multimedia communication using BLE has not been yet investigated in-depth in IoT, as BLE is only suitable for a small chunk of data. Gentili *et al.* [24] proposed BlueVoice, an application for voice communication over BLE. However, results in the proposed study have not been compared with other PHY-MAC protocols.

F. LONG RANGE WIDE AREA NETWORK

LoRaWAN developed by LoRa Alliance is another LPWA communication standard that provides PHY-MAC protocol for IoT applications. LoRaWAN utilizes LoRa modulation based on Chrip Spread Spectrum (CSS) and ALOHA medium access mechanism. To the best of our knowledge, no substantial work has been done in M-IoT exploiting LoRaWAN.

G. SUMMARY AND INSIGHTS

The PHY-MAC layer is responsible for the resource allocation and management of hardware and networking resources. The IEEE 802.15.4 standard is the most widely utilized standard for the M-IoT deployment. The various authors present solutions for improving reliability and reducing the delay by synchronizing the network clocks periodically. The MAC protocols are modified according to the application QoS. Various proposed work on PHY-MAC protocols mentioned in Table 9 has been presented in this section. ML and DL based resource allocation and management techniques are yet to be explored for M-IoT applications. Security is another critical challenge in the wireless medium. Efficient authentication, authorization, and validation technique are required for critical M-IoT. Table 10 classifies and summarizes this section.

VIII. FUTURE RESEARCH DIRECTIONS

In spite of the plethora of research activities and incredible progress in recent years, M-IoT still possesses many open issues that are still waiting to be resolved. The main goal of M-IoT includes carrying out multimedia communication with maximum QoE in terms of packet delivery ratio, throughput, and extending network lifetime while minimizing energy expenditure and preventing connectivity degradation. These goals can be achieved by employing efficient data aggregation, interoperable and scalable architecture, efficient feature extraction, intelligent routing, and adaptive MAC protocols, and managing energy while maximizing computing. Additionally, there are restrictions on IoT devices to be miniscule with the capability of mobility and multiple communication interfaces. Therefore, there are extensive research issues that should further be explored in the field of M-IoT. Fig. 17 depicts the major areas that demand novel

TABLE 10. Existing work on PHY-MAC protocols for M-IoT applications.

		Application Area	Articles	Year	Description
PHY-MAC Protocols for M-IoT	IEEE 802.15.4	Industrial	[269]	2012	Scheduling mechanism using beaconing and super frames
			[270]	2010	Feasibility study of IEEE 802.15.4 standard for LR-WAN using GTS
			[271]	2010	GTS based real-time messaging service for industrial scenario
			[272]	2017	Enhanced beaconing based synchronization of network clock
		Healthcare	[273]	2015	QoS based healthcare application for heterogeneous WBAN
			[274]	2016	Fuzzy logic based rules for improving the network lifetime
			[275]	2012	Evaluation of coexisting M-IoT systems for healthcare systems using advanced scheduling mechanism
			[276]	2011	Intelligent backoff mechanism for CAP to tackle scheduling attacks
		Multimedia	[277]	2011	Dynamic mechanism to adjust the beaconing interval and the super frame duration to improve transmission efficiency
			[278]	2011	Data compression and block interleaving scheme for improved data integrity and evaluation in UART and SPI boards
		Military	[280]	2014	Improved reliability in coexisting IEEE 802.15.4 and 802.15.3 systems by efficient transmission scheduling of the super frames
		Precision Agriculture	[281]	2015	Fine tuning of MAC parameters and adaptive sampling for improving the data resolution in heterogeneous agricultural management system
	ZigBee	Home Automation	[282]	2010	ZigBee and IEEE 802.15.4 coexistence evaluation for home automation systems with support for multimedia sensors
	IEEE 802.11	Multimedia	[284], [285], [286].	2018 -2019	Channel observation-based mechanisms adaptively increases and decreases the contention parameters to tackle the blindness of currently implemented CSMA/CA
			[287]	2019	Deep reinforcement learning based performance optimization of channel observation–based MAC protocols in dense WLANs
			[288]	2019	Q-learning-enabled channel access in next-generation dense wireless networks for IoT-based eHealth systems
			[289]	2019	ML-enabled distributed channel access (MEDCA) mechanism to optimize the performance of channel access in multimedia-based WLANs
	NB-IoT	Multimedia	[291]	2018	NB-IoT communication approach that dynamically creates a group of devices which are subscribed to receive multimedia services in a multicast transmission
			[292]	2017	Inner loop and outer loop link adaption that copes with block error ratio and coordination between ACM and repetition numbers
			[64]	2018	D2D communication as an opportunistic communication with improved link quality to upload NB-IoT users critical data to BS. The proposed optimization aims to improve end-to-end delay and packet delivery ratio
	BLE	Voice Communication	[24]	2016	BlueVoice, an application for voice communication over BLE

contributions and innovations. In this section, a wide range of research issues are delineated for future exploration.

A. INTEROPERABLE AND SCALABLE ARCHITECTURE

M-IoT requires redefined efficient network architecture to offer scalability and interoperability for multiple multimedia heterogeneous devices while considering the spectrum scarcity and limited power resources. SDN based middleware is extensively studied with regard to software-defined IoT architectures [294], [295]. SDNs addresses the hardware and reconfigurability limitations of IoT devices [296]. Publish/subscribe is a communication mechanism for distributed IoT systems [297], [298]. In the publish/subscribe model, the user does not have to be in direct contact with the service provider. Software-defined publish/subscribe based agents for M-IoT architecture offers new opportunities to add scalability and interoperability in the network [299]. However, no dedicated work has been done to devise SDN based publish/subscribe M-IoT architecture. There is a need to explore SDNs in the context of standardizing M-IoT architecture.

B. FEATURE EXTRACTION

Multimedia devices generate a huge amount of data that comprise structured and unstructured data. The processing of such amount of unstructured data over an energy-constrained network requires the transmission of only meaningful information.

An Intelligent feature extraction mechanism is required to identify and classify multimedia data with minimum energy consumption [300], [301]. DL addresses the limitations of

FIGURE 17. Overview of the open issues, challenges, and future research directions for M-IoT systems.

ML to process a huge amount of data [302]. DL offers proficient multimedia feature extraction models [303], [304]. Extracting semantic from multimedia data could transform unstructured data into structured, indexed data for efficient processing [305]. Implementing DL over SDNs and adding semantics to multimedia data are yet to be explored for intelligent multimedia feature extractions.

C. DATA PRIORITIZATION

Prioritizing multimedia data addresses a lot of issues related to energy [306], scheduling [307], video streaming [308], memory [309], improving PLR, enhancing QoS [310], security [311], and reduce network latency [312]. A large number of M-IoT applications mentioned in the previous sections are real-time delay-sensitive that require multimedia data prioritization. Multimedia applications require ubiquitous transmission for which AI-based data classification and priority optimization in M-IoT should be extensively studied concerning the requirements of the application.

D. EVENT PROCESSING

Events are defined as real-world occurrences that reveal over space and time. A huge volume of event content is being captured in multimedia, of which YouTube videos, TV shows, and animations cover 60% of the Internet traffic [313]. The tremendous increase in real-life events captured in multimedia requires event analysis to associate metadata with events for efficient query processing. Event detection [314], feature representation [315], and adding semantics [316], is known as event mining [317]. An intelligent event mining in audio, videos, and images are required in M-IoT for efficient resource utilization to process the required service with minimum delay.

E. COMPRESSION AND ENCODING/DECODING TECHNIQUES FOR M-IoT

M-IoT necessitates compression techniques to become more vigorous with low complexity and to produce low bandwidth output while adhering to limited network and spectrum resources. Compression techniques are extensively studied in the context of multimedia transmission over wireless networks in [318], [319]. However, no enthusiastic work has been done on compression or encoding techniques for the transmission of multimedia data over the M-IoT network. There is a need to explore the coding methodologies related to multimedia services in M-IoT while considering the power and interface constraints.

F. COMPUTATION RELATED ISSUES

The difference between multimedia data and scalar data has been shown in Table 1. Processing and analysis of such high power consumption, and processing data requires efficient computing models for minimizing the network overheads and energy consumptions [320]. Multimedia processing is dependant on multiple factors, i.e., feature extraction, prioritization, network coding, compression, efficient routing, and MAC protocols. The limitation of cloud computing and compensation offered by Fog/Edge computing is detailed in the previous sections [321]. However, minimal work has been performed in SDNs as multimedia computing in IoT. Due to the diverse nature of multimedia applications, applications dependent software-defined computing architectures are required to offer interoperability in HetNets. To increase network throughput with minimum energy utilization, the intelligent transmission of only meaningful information to cloud and fog/edge is required for processing.

G. QoE RELATED RESEARCH DIRECTION

User satisfaction of multimedia content in M-IoT is measured by exploiting QoE subjective metrics. Recent studies of QoE evaluation for M-IoT applications are conducted with primary QoE metrics that are packet loss, MOS, DMOS, and user satisfaction. Other QoE metrics such as buffering time, data rate, interruption time, and failure rate should also be used for evaluation of M-IoT (as discussed in [322]). Most of the work on M-IoT considers network performance metrics (QoS metrics) that are jitter, end-to-end delay, bit error rate, and frame loss. Both QoS and QoE metrics should be jointly evaluated to achieve better multimedia quality and network services [323].

H. SECURITY AND PRIVACY

The transmission of bandwidth-hungry and delay-sensitive multimedia applications over the scares spectrum requires protection from eavesdroppers and threats. Confidential industrial and health multimedia data needs P2P, MP2P, and P2MP encryption. Very partial research has been conducted on securing multimedia transmission over the IoT network [324], [325]. There are several threats that compromise the user's data and privacy [58]. New approaches should be adopted to secure the network from any attack. Multimedia is content-based data [75]. However, content-aware secure transmission of multimedia data over M-IoT has not been studied. The authentic distribution of multimedia content is also required to verify legal copyrights.

The miniature M-IoT devices are computational and energy-constrained. Thus, lightweight data cryptography is required for secure communication. AI offers to secure multimedia data at the cost of high power consumption due to complex algorithms, that are not feasible to implement on IoT devices [326], [327]. Fog/Edge enables IoT devices to perform computationally better and faster. Fog/Edge offers to implement blockchain-based secure and transparent systems [328], [329]. However, security issues related to multimedia data has not been explored in detail.

I. ENERGY-AWARE AND GREEN COMMUNICATION

Energy is a scarce resource. Bandwidth and power-hungry multimedia applications require vast energy resources for their transmission. Thus, to transmit multimedia data over IoT, energy-aware and energy harvesting methods need to be explored. There are many energy harvesting solutions for harvesting energy from the environment. These solutions can assist in prolonging network life and promoting green communication [330]. SDNs provide a better softwarization and virtualization approach to manage hybrid energy resources in future communication networks [331]. To the best of our knowledge, SDNs are not studied for energy harvesting approaches to transmit multimedia content over the IoT network.

J. ROUTING AND MAC RELATED ISSUES

The routing and MAC layer protocols for M-IoT exploit QoS metrics to make their routing or medium access decisions. Cross-layer protocols provide multi-layer metrics for better decisions to select route and access medium for multimedia data in a wireless network [332], [333]. Cross-layer metrics evaluation for user satisfaction of multimedia data (QoE) has not been thoroughly explored [334]. Selecting route and medium by evaluating cross-layer and mapping them with the user's QoE will enhance the performance and lifetime of the M-IoT network.

D2D communication provides an efficient routing and medium access extension for the delivery of multimedia content in a smart city [335]–[337]. Due to bandwidth scarcity and delay the urgency of multimedia data, D2D supports a proficient mechanism to reduce PLR, latency, and power consumption [338]. D2D communication as a routing and medium extension can be investigated for M-IoT.

Lightweight ML algorithms like reinforcement learning do not consume a significant amount of energy. IoT devices equipped with these ML approaches for efficient route and medium selection. DL learning algorithms could be implemented on edge devices to extract multimedia features and map them with routing and MAC metrics to achieve better user's QoE of multimedia content in IoT. To the best of our knowledge, no substantial amount of work has been proposed in this domain.

K. MULTIMEDIA APPLICATIONS AND SMART CITY

M-IoT applications support a wide variety of applications, assisting in building a smart city by providing varied networks and architectures [339], [340]. These applications contribute a major portion in the industry, agriculture, road management systems, and security (as discussed comprehensively in section III). However, work to secure and authenticate voice assistant systems has not been studied. The collaboration of these applications in the smart city requires integration in 5G. The integration of M-IoT has not been studied significantly.

L. 5G AND BEYOND 5G

The future 5G of wireless cellular communication is expected to lay the basis of an intelligent network for multimedia communication in smart cities. Massive Mulitple-Input-Multiple-Output (MIMO) systems for spectral efficiency [341], Non-Orthogonal Multiple Access (NOMA) for multimedia broadcast services [157], [342], micro and femtocells to increase cellular capacity, Ultra-Reliable Low-Latency

Communication (URLLC) to achieve low latency for multimedia applications [343], [344], and NB-IoT for machine type communication are few solutions to achieve objectives of 5G [345].

However, a fully intelligent on-demand self-reconfigurable network to enhance many folds in the services and performance will be released in Beyond 5G (B5G). ML, DL, Quantum Computing (QC), and Quantum ML (QML) are considered as a core enabler of Sixth Generation (6G) or B5G [346]. Gigahertz (GHz) and Terahertz (THz) frequencies provide solutions to bandwidth scarcity and high date rates to deliver multimedia content [347]. All these areas are yet to investigate and explored for integrating M-IoT with 5G and 6G.

M. AUGMENTED AND VIRTUAL REALITY IN M-IoT

Multimedia Augmented Reality (AR) and Virtual Reality (VR) in IoT will reveal many hidden and open the close doors for humanity [348]. 5G and B5G will enable user-friendly wireless AR and VR interfaces. AR and VR in M-IoT will revolutionize the health, industrial, and education sector [349]. It could be helpful for several patients suffering from immutable diseases, education and training, guidance and assistance, construction and architecture, and games. In brief, it could expedite the development of the smart city [350]. To achieve the development of a smart city, the requirements of end-user should be known, preferred, and satisfied by the interaction of end-user, telecommunication industry, content developers, and research scientists.

N. TACTILE INTERNET

Certain real-time application areas of M-IoT such as robotic surgery, remote physical interaction, teleoperation, automation industry, and AR/VR require even minor tactile sensing information that occurs due to the interaction between the application and the environment [344]. IEEE recently launched activities to standardize tactile Internet (IEEE P1918.1) [351]. The requirements of tactile information are ultra-low latency in milliseconds. URLLC seems to satisfy these requirements. There are a lot of research areas from the perspective of the tactile Internet that is yet to be studied in detail. Compression of tactile information, intelligent and scalable network traffic engineering for audio and video, and edge caching and computing for AR/VR has received very little attention [352]–[354]. Efficient routing and MAC protocols for tactile information are in need.

O. MOLECULAR COMMUNICATION

The ability to integrate all the five sensory features of humans that are olfactory (smell), gustatory (taste), tactile (touch), ocular (sight), and hearing (audio) in information and transmit is known as Human Bond Communication (HBC) [355]. In humans, the exchange of information is based on the synthesis, transformation, emission, propagation, and reception of molecules through biochemical and physical processes. In telecommunication engineering, this information exchange is classified as molecular communication [356]. With the emergence of NanoThings, molecular communication is the key research areas to revolutionize M-IoT [357].

IX. CONCLUSION

The evolving Multimedia Internet-of-Things (M-IoT) has promoted several innovative applications, aiming to improve the quality of life by connecting numerous smart devices through emerging enabling technologies. Multimedia communication in IoT can support countless applications. The objective of this survey is to highlight the overview of M-IoT and the importance of M-IoT applications. The main issues while designing M-IoT architectures, protocols, and computing approaches are explored to provide stable IoT architecture to support maximum QoE. However, it is challenging to achieve because of constraints imposed by multimedia content, which distinguish it from traditional IoT. Various application-use cases were presented to illustrate how M-IoT can revolutionize the world. Various requirements and proposed solutions on Quality-of-Experience (QoE) for M-IoT on their subjective and objective-based metrics have been presented. Moreover, the relation between multimedia content, cloud computing, big data analytics, event processing, fog/edge computing, multimedia data coding, feature extraction, and SDNs have been discussed. Also, this article provides a comprehensive survey of various routing and Medium Access Control protocols (MAC) used for M-IoT. Finally, this article points out the open and potential research areas that need to be solved in future M-IoT systems. This article should deliver a sound basis for researchers to understand issues and challenges in M-IoT.

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