

Review Article

Survey of Energy-Efficient Techniques for the Cloud-Integrated Sensor Network

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The sensor cloud is a combination of cloud computing with a wireless sensor network (WSN) which provides an easy to scale and efficient computing infrastructure for real-time application. A sensor cloud should be energy efficient as the life of the battery in the sensor is limited and there is a huge consumption of energy in the data centre in running the servers to provide storage. In this paper, we have classified energy-efficient techniques for sensor cloud into different categories and analyzed each technology by using various parameters. Usage percentage of each parameter for every technology is calculated and for all technologies on average is also calculated. From our analysis, we found that most of the energy-efficient techniques ignore quality of service (QoS) parameters, scalability, and network lifetime. Multiparameter optimization including other QoS parameters along with energy may be the future direction of research. Our study will be helpful for researchers to get information regarding current methods used for an energy-efficient sensor cloud and also to build advanced systems in the future.

1. Introduction

Sensors are used for various applications at present, a number of sensors can combine to form a WSN. Every sensor can communicate with each other through a wireless communication medium using a transceiver to perform specific applications. Each sensor operates on a battery with limited lifetime, so building an energy efficient network model, to maximize network lifetime, is a research challenge. In cloud computing technology, the end user gets a platform, infrastructure, and software support in rent from the cloud service provider. A sensor cloud is an integration of WSN with cloud computing for providing access of sensor to the user through cloud computing and to strengthen the performance of cloud computing applications or sensor networks, by applying the powerful cloud to store, share, and process the collected data by a mixture of sensors. End users do not have to worry about the detail configuration, location, and types of sensor in the cloud sensor infrastructure which virtualizes many physical sensors into virtual sensors. Virtual sensors automatically

group to provide services in response to a request from the user. The services like interface for user registration or removing the physical sensor and monitoring and controlling the virtual sensor are provided by the sensor-cloud infrastructure. The sensor cloud uses the virtualization technique for the wireless sensors and gives sensing as a service to users as users use this service on demand from the sensor cloud. The owners of the sensor own the physical sensors, which allow the user to use those physical sensors for a rental fee through a sensor-cloud infrastructure. There is a different owner for each WSN. The owner of the sensor registers the physical sensors to the sensor-cloud infrastructure with their properties and deletes the registration once the owner does not have an interest to share its physical sensor. A sensor-cloud infrastructure is proposed by which a physical sensor is managed on a computing infrastructure [1], WSN nodes are connected to a cloud infrastructure [2], and also in which WSN nodes transmit data to the cloud which stores, processes, analyzes, and sends it to various clients [3]. A survey of various works in sensor-cloud infrastructure is proposed which gives

current challenges to current existing technology solutions and also mentions the future direction of research [4]. A review of the current work for designing energy-efficient sensing is proposed based on location information in mobile cloud computing environment [5]. A review of recent works for an energy estimation model is proposed for various mobile nodes, and a survey is made on saving of energy during transmission, which focuses the future direction of research [6]. The sensor cloud should be energy efficient as the life of the battery of sensor is limited, and there is a huge requirement of energy in data centres for running servers and providing storage. A comparative study of different architectures of an energy-efficient sensor cloud which compares the layers, main components, and the applications is given in Table 1.

In this paper, we survey efficient techniques for the sensor-cloud environment. To begin with, Section 2 discusses the classifications of energy-efficient techniques for the sensor cloud. Section 3 explains the parameters used for the energy-efficient sensor-cloud techniques. Section 4 discusses the relative analysis of parameters. Finally, Section 5 provides the conclusion of the paper with final remarks.

2. Classification of Energy-Efficient Techniques for the Sensor Cloud

In our review, we have classified energy-efficient techniques for the sensor cloud into six categories including scheduling techniques, sensing techniques, data transmission techniques, advanced system designing, data processing, and load balancing techniques as shown in Figure 1.

2.1. Scheduling Techniques. Energy-efficient and delay-aware computing system (E2DAWCS) is used to reduce the consumption of power by controlling both network connectivity and sleep scheduling within admissible delay [7]. Data aggregation, physical sensor scheduling, and low-power listening techniques are used to minimize the sending of sensed packets for transmission. As a result, energy consumption is further minimized [8]. Time division multiple accesses (TDMA-) based scheduling for fine granularity tasks is used for energy saving, providing less response time and high throughput [9]. Optimizing scheduling of transmission and adjustment of the clock frequency technique is used to minimize the consumption of energy for mobile resource constraint device [10]. A task execution framework is proposed which selects the favorable sensors for less energy consumption, optimizing concurrent task execution by removing redundancy [11]. Clustered multichannel scheduling scheme accumulates data concurrently from multiple sections and sends it to the sink while reducing power consumption and yielding high throughput and delivery ratio [12]. Real-time thing allocation heuristic algorithm is used to minimize the total energy consumption using the QoS-aware selection of service problem for the IoT-based cloud platforms [13]. A scheduling technique is proposed based on dynamic duty cycle which minimizes energy consumption and cost in the sensor cloud [14]. The benefits, methods used, and drawbacks

of various research studies for energy-efficient scheduling techniques for the sensor cloud are given in Table 2.

2.2. Sensing Techniques. Cloud sensing and optimization of query processing techniques are used so that energy overhead is reduced and improves scalability [15]. Location, context, and activity-aware selective sensing is used to reduce the consumption of energy, storage, and data processing requirements [16]. The cloud-offloaded global positioning system (CO-GPS) which provides sensing devices to assure duty cycle of the GPS receiver device and logging the millisecond raw data from the GPS signal for processing technique is helpful to conserve energy [17]. Collaborative sensing and aggregation of information using trusted middleware provide energy saving [18]. Sensing as a service mechanism provides energy efficiency, supports multiple applications in a flexible and secure loading on various platforms, and also supports the incentive mechanism [19]. The benefits, methods used, and drawbacks of various current research papers for energy-efficient sensing techniques for the sensor cloud are shown in Table 3.

2.3. Data Transmission Techniques. The optimal decision rule method is used which selects the best bridge node to reduce the transmission energy consumption of every node [20]. Customizable sensor information system model is used to modify data transmission and frequency of data collection to make it energy efficient, and this approach also reduces CO₂ emissions [21]. A framework for wirelessly powered based on mobile computing under the constraints of deadlines and energy harvesting is proposed to minimize the energy consumption of local computing and maximizing the energy saving for offloading computing [22]. The sensor-cloud integrated platform is used to perform push-pull communication among the three layers of the system architecture for energy-efficient data transmission. This approach uses lesser bandwidth while collecting a high amount of data from the user [23]. The Senud compression algorithm which is used to reduce replicated data as a result of transmission energy consumption is minimized, and this method is also suitable for high volume numerical data [24]. The benefits, methods used, and drawbacks of various recent papers for energy-efficient data transmission techniques for the sensor cloud are given in Table 4.

2.4. Advanced System Designing. A cloud orchestration approach which supports dynamic workflow among service components is used to coordinate services based on cloud computing, as a result, it provides energy efficiency [25]. A data prediction model is used so that energy consumption is minimized in a sensor-cloud infrastructure [26]. A self-managed sensor-cloud technique is used to automatically carry out energy management, management of the event, aggregation of data, and management of connection and to handle critical applications. This approach also provides fast response in case of an emergency [27]. A cloud architecture uses a publishing or subscribing middleware which manages the sensors. It also removes the redundant sensors and minimizes energy consumption [28]. An architecture proposes balancing of energy efficiency and data quality.

TABLE 1: A comparative study of different architectures of the energy-efficient sensor cloud.

References	Layers/levels	Main components	Applications
[8]	Application, sensor-cloud, physical WSNs	Sensor-cloud sensing as a service, request aggregator, and virtual and physical sensor manager	Generalized for any type of applications
[9]	Client centric, middleware, sensor centric	User membership management, provision management, service catalogue, billing management, data collection, and WSN maintenance	Support multiple application environments
[11]	Application, internet, sensor network	User smartphone, internet, server, gateways, resources nodes, monitor, and camera	Framework for task execution
[14]	Sensor cloud, on-field sensor network	Sensor cloud, on-field sensor network, soil moisture sensors, gateway nodes, and terrestrial sensors	Specialized in agricultural field
[16]	Global sensor network (GSN), mobile sensor data engine, and devices	Context aware mobile sensor data engine, activity-aware module, location aware module, and GSN middleware	Environment monitoring and health services
[18]	Sensor, middleware, application, cloud	Mobile devices embedded with sensor, middleware, applications, and cloud server	Mobile sensing
[19]	Cloud user, cloud systems, sensing	Sensing server, load balancer, web server, and database server	Sensing service
[20]	End user, sensor cloud, physical sensor	Sensor owners, sensor cloud, access point, virtualization, and processing	Environment monitoring and target tracking
[21]	Application, virtual, physical	Data quality (DQ) services catalogue, DQ monitor, and DQ aware adaptation	Environmental management
[23]	Sensor layer, edge layer, cloud layer	Sensor nodes, virtual sensor nodes, and cloud applications	Physiological and environmental monitoring
[24]	Service, storage, data, activities, transportation, physical	Web service, storage allocation, security management, data analyzing, filtering & reconstruction units, response monitoring, service monitoring, router, and physical or virtual sensor group	Numerical data compression
[25]	Physical, internet of things (IoT)	Data processor, participating devices, big data storage, control and wisdom box, decision enhancer, and knowledge graph	Smartphones in the IoT
[28]	Application, cloud system, middleware, physical device	Quality of service broker, decision-making engine, and configuration module	Urban crowd sensing and data analysis
[29]	Consumer, cloud services, controller, producer	Customizable motes, network controllers, DQ energy optimizer cloud services, and cloud service customer interface	Producer consumer data flow
[30]	User, server, mobile client	Network, server, database, task information, mobile client, and users	Mobile computing system
[31]	Internet, virtual sink, sensor zone	Internet, sink point/cloud nodes, sensor zone, and scheduler	Distributed storing and processing data
[32]	Cloud, edge and beneath	Gateway, sensor, and cloud systems	Monitoring environment
[33]	Applications, smartphone access layer, smartphones	Smart phone resource monitoring, query registry, query evaluation engine, and rule mining engine	Query evaluation
[34]	Sensor layer, coordinator layer, supervision layer	Sensors, XBee platform, REST web services, firewall, web app, and iPhone app	Smart homes, healthcare, vehicular networks
[36]	Application, sensor, physical	Crowd-sourced route database and mobile device with GPS-enabled and altitude sensors	Altitude matching
[38]	Remote clouds, camera sensor, local cloud access point, scalar sensor	Sensor, virtual machine, camera selector, camera controller, coverage optimizer, and cloudlet status	Complex event monitoring

It manages the trade-off between the quality of data reception and energy consumption [29]. Green energy mobile cloud (GEMCloud) system for distributed computing to support complex, parallel jobs and saves energy consumption by 55 to 98% with many mobile devices that works cooperatively [30]. The architecture, based on cloud

computing, for WSN where the virtual sink is used for collection of sensed information and there are many sink points to process the sensed data, in a distributed manner to reduce energy consumption, transmission error, delay, and the number of end to end hops [31]. Optimal push/pull envelope with lazy sampling technique is used to

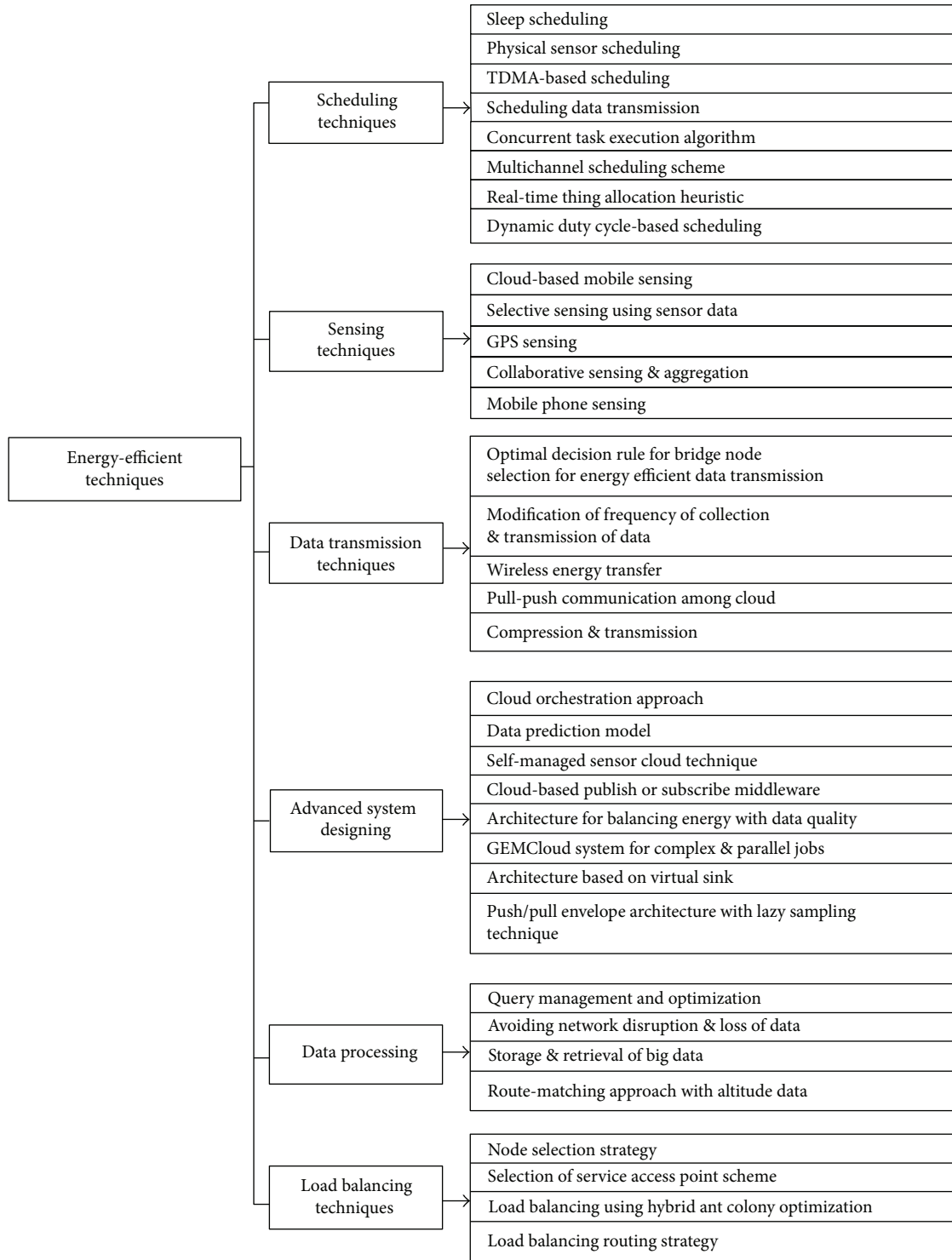


FIGURE 1: Classification of energy-efficient techniques for the sensor cloud.

minimize energy consumption [32]. The algorithms used, benefits, and drawbacks of various current research papers for energy-efficient advanced system designing for the sensor cloud are given in Table 5.

2.5. Data Processing. Cloud-based query management and optimization techniques are used to lower the cost involved

in sensing, reduces the maximum uncertainty, and propagates the query-evaluated result intelligently to reduce energy consumption [33]. A framework of integrated WSN and cloud is proposed which avoids network disruption, reduces loss of data, and increases network lifetime. Using this technique, sensor data can be accessed anywhere at any time with the help of the internet [34]. An algorithm is proposed by

TABLE 2: Energy-efficient scheduling techniques for the sensor cloud.

References	Algorithm/methods	Problem discussed	Benefit/achievement	Drawback/limitation
[7]	E2DAWCS	Network connectivity and sleep scheduling	Less energy consumption	Does not support scalability and QoS
[8]	Scheduling, data aggregation, and low-power listening	Minimizing the sensed packets for transmission	Energy efficient, reliable, less latency, and scalable	On demand requests for applications is yet to be analyzed
[9]	TDMA-based scheduling	Scheduling for fine granularity tasks	Provides less response time, high throughput, and energy efficient	Scalability and reliability are yet to be addressed
[10]	Optimize scheduling of transmission	Dynamic adjustment of clock frequency	Minimizes the energy consumption	Does not support real-time application
[11]	Task execution	Selecting the favorable sensors	Energy efficient	Does not support load balancing
[12]	Clustered multichannel scheduling	Multichannel hierarchical scheduling	Provides high throughput, high delivery ratio, and energy efficient	Real-time implementation is yet to be done
[13]	Real-time thing allocation heuristic	QoS aware selection of service	Less energy consumption	Sporadic service is yet to be supported
[14]	Dynamic duty cycle scheduling	Scheduling to improve efficiency in WSN	Minimized cost and energy consumption	Does not support real-time cloud applications

TABLE 3: Energy-efficient sensing techniques for the sensor cloud.

References	Algorithm/method	Problem discussed	Benefit/achievement	Drawback/limitation
[15]	Cloud sensing and optimization of query processing	Coordinate sensing and executing tasks	Energy efficient and scalable	Testing of working version is yet to be done
[16]	Selectively sensing	Location and context and activity based	Reduced energy consumption, storage, and data processing requirement	Privacy is not preserved
[17]	CO-GPS	Sensing devices to assure duty cycle of the GPS receiver device	Energy efficient	Location accuracy and processing speed are yet to be analyzed
[18]	Collaborative sensing	Information aggregation	Utilization of energy is improved	Not scalable and privacy is not preserved
[19]	Sensing as a service	Multiple applications and incentive mechanism	Energy efficient, flexible, and provides secure loading on various platforms	Not scalable and more costly

TABLE 4: Energy-efficient data transmission techniques for the sensor cloud.

References	Algorithm/method	Problem discussed	Benefit/achievement	Drawback/limitation
[20]	Optimal decision rule	Selection of the bridge node in the virtual sensor network	Reduces the energy consumption of every node	Heterogeneity and node mobility are yet to be considered
[21]	Customizable sensor information system	To modify the transmission of data and frequency of data collection	Energy efficient and reduces the emission of CO ₂	Not scalable
[22]	Wireless energy transfer	Energy harvesting and deadline constraints	Less energy consumption	Does not support multitasking
[23]	Pull-push communication	Sensor and cloud integration	Less bandwidth consumption, energy efficient, and collects more data	Does not support QoS
[24]	Compression algorithm	Reduction of replicated data	Transmission energy is minimized	Data prediction is yet to be implemented

TABLE 5: Energy-efficient advanced system designing for the sensor cloud.

References	Algorithm/method	Problem discussed	Benefit/achievement	Drawback/limitation
[25]	Cloud orchestration approach	Dynamic workflow and coordination of services	Flexible and energy efficient	Data mining and filtering techniques are yet to be analyzed
[26]	Data prediction	To minimize energy consumption using data prediction	Energy efficient and provides less error rate	Does not support scalability and QoS
[27]	Self-managed sensor cloud	Automation and aggregation of data	Energy efficient and fast response in case of an emergency	Hardware testing is yet to be implemented
[28]	Publish or subscribe middleware	Satisfying sensing and removing redundant sensors	Reduction in consumption of energy by 40% to 80%	Data analysis is not performed
[29]	Balancing energy consumption with respect to data quality	Managing the quality of the reception data while saving energy	Less energy consumption and QoS is maintained	Not scalable
[30]	GEMCloud	To support complex and parallel jobs in the distributed computing environment	Energy efficient	Security is yet to be analyzed
[31]	Architecture based on virtual sink	Processing and storing the information through many sinks	Energy efficient, less transmission error, and less end to end delay	Not scalable
[32]	Push/pull envelope with lazy sampling	Optimal sampling for transmitting the sensor data between edge and sensor	Energy efficient	Energy-aware scheduling is yet to be implemented

which storage and retrieval of big data in an energy efficient manner for wireless sensor networks where the distribution of the node is not uniform [35]. The route-matching approach was used with altitude data by using the cheap and energy-efficient air pressure sensors instead of the GPS system for measuring the altitude [36]. The techniques used, benefits, and drawbacks of various research papers for energy-efficient data processing for the sensor cloud are given in Table 6.

2.6. Load Balancing Techniques. A novel selection of node strategy reduces the consumption of energy by using the concept of cooperation in which tasks are partitioned optimally and can be executed by the sensors. As a result, computing resources are optimally used [37]. Cloud-assisted monitoring of complex event is used to select the service access point scheme for QoS support under energy-efficient constraint. This approach is reliable, takes less response time, and is energy efficient [38]. A load balancing technique uses the virtual machine approach by which the processing tasks are assigned to the appropriate server, so that the performance is optimized and energy consumption is further reduced [39]. A load balancing strategy for routing, in which the wireless sensor routes the packets, balances the energy consumption of all nodes. So, the network lifetime of the model increases [40]. The benefits, methods used, and drawbacks of various research papers for energy-efficient load balancing techniques for the sensor cloud are given in Table 7.

3. Analysis

In this section, we have discussed various parameters used in six categories of techniques. The parameters we have taken

into consideration are bandwidth, data size, computational energy, total energy, communication energy, accuracy, reliability, throughput, deadline, availability, network lifetime, packet delivery ratio, data rate, CPU clock frequency, query processing, packet loss, number of hops, response time, total time, storage requirements, scalability, and cost. The parameters used in energy-efficient scheduling techniques for sensor clouds are displayed in Table 8.

According to our classification, eight research papers have used energy-efficient scheduling techniques for the sensor clouds. The parameters which are used in most of the papers for efficient scheduling techniques are total energy, total time, cost, data rate, communication energy, data size, number of hops, CPU clock frequency, and throughput. Accuracy and query processing parameters are not used by any one of the research papers in this scheme. Scalability, storage requirements, response time, and availability parameters are used rarely. Most of the research paper ignores network lifetime and QoS parameters. The parameters used in the energy-efficient sensing techniques for the sensor cloud are displayed in Table 9.

Five research papers have used the energy-efficient sensing techniques. The parameters which are used in most of the papers for energy-efficient sensing techniques are total energy, total time, scalability, and accuracy. Throughput, network lifetime, packet delivery ratio, number of hops, and response time parameters are not used by any of the research paper for these techniques. QoS parameters are not taken into consideration in most of the research papers in these techniques.

The parameters used in energy-efficient data transmission techniques for the sensor cloud are displayed in Table 10.

TABLE 6: Energy-efficient data processing for the sensor cloud.

References	Algorithm/method	Problem discussed	Benefit/achievement	Drawback/limitation
[33]	Query management and optimization	Reduction of the uncertainty and propagating the query result intelligently	Reduced energy consumption and sensing cost	Latency constrained optimization is yet to be addressed
[34]	Integrating WSN and Cloud	Avoiding network disruption and loss of data	More network lifetime and availability of data	Does not support real time patient monitoring
[35]	Storage and retrieval of big data	To work in an environment where distribution of the node is not uniform	Energy efficient, less data loss rate, and efficient query processing	Deployment issue in the real world scenario is not yet addressed
[36]	Routes matching with altitude data	To use cheap air pressure sensor instead of GPS	Increased mobile battery lifetime	Does not support multiuser environment

TABLE 7: Energy-efficient load balancing techniques for the sensor cloud.

References	Algorithm/method	Problem discussed	Benefit/achievement	Drawback/limitation
[37]	Cooperative node selection policy	Fair use of nodes	Less energy consumption	Issues related to multihop transmission with the resource constraint environment are not addressed
[38]	Selection of access point scheme	Monitoring of complex events	Reliable, less response time, good coverage, and energy efficient	Does not support QoS related to video processing
[39]	Load balancing using hybrid ant colony optimization	Dividing tasks and scheduling	Less time to compute, less end to end delay, and more network lifetime	Scalability and node failure issues are not addressed
[40]	Routing technique	Balancing the energy consumption of all nodes	Increased network lifetime	Does not support scalability and QoS

According to our classification, five research papers have used efficient data transmission techniques for the sensor clouds. The parameters which are used in most of the papers for energy-efficient data transmission techniques are total energy, communication energy, data rate, total time, data size, bandwidth, storage requirement, and the number of hops. Computational energy, throughput, query processing, and scalability parameters are not used by any of the papers.

The parameters used in energy-efficient advanced system designing for the sensor cloud are displayed in Table 11.

According to our classification, eight research papers have used the technique of energy-efficient advanced system designing for the sensor clouds. The parameters which are used in most of the papers for energy-efficient advanced system designing techniques are total energy, total time, communication energy, accuracy, packet loss, reliability, and CPU clock frequency. Deadline parameter is not used in any of the research papers. Network lifetime and QoS parameters are not used in most of the research papers. The parameters used in energy-efficient data processing for the sensor cloud are displayed in Table 12.

Four research papers have used energy-efficient data processing for the sensor cloud. The parameters which are used in most of the current papers for energy-efficient data processing are computational energy, total energy, total time, data size, network lifetime, packet loss, and storage

requirements. Bandwidth, throughput, delay, and availability parameters are not used in any of the research papers for these techniques. Most of the research papers have not considered QoS parameters.

The parameters used in energy-efficient load balancing techniques for the sensor cloud are displayed in Table 13.

Four research papers have used energy-efficient load balancing techniques for the sensor cloud. The parameters which are used in most of the recent papers for energy-efficient load balancing techniques are total energy, total time, and communication energy. Accuracy, CPU clock frequency, query processing, packet loss, number of hops, and scalability parameters are not used in any research papers for these techniques. Most of the research papers ignore QoS parameters.

4. Discussion

Various architectures of the energy-efficient sensor cloud in the research papers target many applications such as environmental monitoring, health care services, target tracking, designing the vehicular network, smart homes, agriculture filed, sensing, data analysis, smartphone, complex event monitoring, and task execution. Most of the research papers for an energy efficient sensor-cloud focus on monitoring the environment. Most of the research papers in energy-efficient scheduling techniques do not support

TABLE 8: Parameters of energy-efficient scheduling techniques for the sensor cloud.

Reference	Bandwidth	Data size	Computational energy	Total energy	Communication energy	Accuracy	Reliability	Throughput	Deadline	Availability	Network lifetime	Packet delivery ratio	Data/traffic rate	CPU clock frequency	Query processing	Packet loss	Number of hops	Response time	Total time	Storage requirements	Scalability	Cost
[7]	✓	✓	✓	✓	✓					✓			✓				✓		✓			✓
[8]	✓			✓			✓					✓	✓			✓			✓		✓	✓
[9]				✓							✓			✓				✓	✓			✓
[11]		✓	✓	✓	✓				✓				✓	✓					✓			✓
[11]				✓	✓			✓					✓	✓			✓		✓			
[12]		✓		✓	✓			✓					✓	✓			✓		✓	✓		
[13]	✓	✓		✓	✓		✓	✓				✓	✓	✓		✓	✓		✓			✓
[14]				✓					✓		✓		✓						✓			✓

TABLE 9: Parameters of energy-efficient sensing techniques for the sensor cloud.

Reference	Bandwidth	Data size	Computational energy	Total energy	Communication energy	Accuracy	Reliability	Throughput	Deadline	Availability	Network lifetime	Packet delivery ratio	Data/traffic rate	CPU clock frequency	Query processing	Packet loss	Number of hops	Response time	Total time	Storage requirements	Scalability	Cost
[15]	✓		✓	✓	✓	✓									✓				✓		✓	
[16]				✓	✓			✓		✓					✓				✓	✓	✓	✓
[17]				✓		✓							✓	✓		✓			✓	✓	✓	
[18]	✓	✓		✓		✓										✓						
[19]				✓			✓		✓										✓			✓

TABLE 10: Parameters of energy-efficient data transmission techniques for the sensor cloud.

Reference	Bandwidth	Data size	Computational energy	Total energy	Communication energy	Accuracy	Reliability	Throughput	Deadline	Availability	Network lifetime	Packet delivery ratio	Data/traffic rate	CPU clock frequency	Query processing	Packet loss	Number of hops	Response time	Total time	Storage requirements	Scalability	Cost
[20]		✓		✓	✓		✓				✓		✓				✓		✓			✓
[21]				✓	✓	✓	✓			✓			✓	✓		✓			✓	✓	✓	✓
[22]	✓	✓		✓	✓				✓				✓	✓					✓		✓	
[23]	✓	✓		✓	✓							✓	✓				✓		✓			
[24]	✓	✓		✓	✓	✓							✓				✓	✓	✓	✓	✓	

TABLE 11: Parameters of energy-efficient advanced system designing for the sensor cloud.

Reference	Bandwidth	Data size	Computational energy	Total energy	Communication energy	Accuracy	Reliability	Throughput	Deadline	Availability	Network lifetime	Packet delivery ratio	Data/traffic rate	CPU clock frequency	Query processing	Packet loss	Number of hops	Response time	Total time	Storage requirements	Scalability	Cost
[25]		✓	✓	✓	✓	✓		✓					✓	✓					✓		✓	
[26]		✓		✓	✓										✓	✓			✓			
[27]				✓	✓					✓				✓				✓	✓	✓		
[28]	✓			✓		✓	✓			✓	✓					✓			✓			
[29]				✓		✓	✓			✓					✓	✓			✓			✓
[30]			✓	✓										✓					✓			
[31]	✓			✓	✓	✓	✓	✓				✓	✓			✓	✓		✓			
[32]				✓	✓	✓									✓		✓		✓		✓	✓

TABLE 12: Parameters of energy-efficient data processing for the sensor cloud.

Reference	Bandwidth	Data size	Computational energy	Total energy	Communication energy	Accuracy	Reliability	Throughput	Deadline	Availability	Network lifetime	Packet delivery ratio	Data/traffic rate	CPU clock frequency	Query processing	Packet loss	Number of hops	Response time	Total time	Storage requirements	Scalability	Cost
[33]			✓	✓		✓									✓	✓			✓	✓		✓
[34]		✓	✓	✓							✓							✓	✓	✓		
[35]		✓	✓	✓	✓		✓				✓	✓	✓	✓	✓	✓	✓		✓	✓		
[36]		✓	✓	✓		✓					✓					✓	✓		✓	✓	✓	✓

TABLE 13: Parameters of energy-efficient load balancing techniques for the sensor cloud.

Reference	Bandwidth	Data size	Computational energy	Total energy	Communication energy	Accuracy	Reliability	Throughput	Deadline	Availability	Network lifetime	Packet delivery ratio	Data/traffic rate	CPU clock frequency	Query processing	Packet loss	Number of hops	Response time	Total time	Storage requirements	Scalability	Cost
[37]		✓	✓	✓	✓				✓	✓									✓			
[38]	✓			✓	✓		✓	✓	✓	✓			✓					✓	✓	✓		✓
[39]				✓							✓	✓							✓			✓
[40]				✓	✓						✓		✓						✓			✓

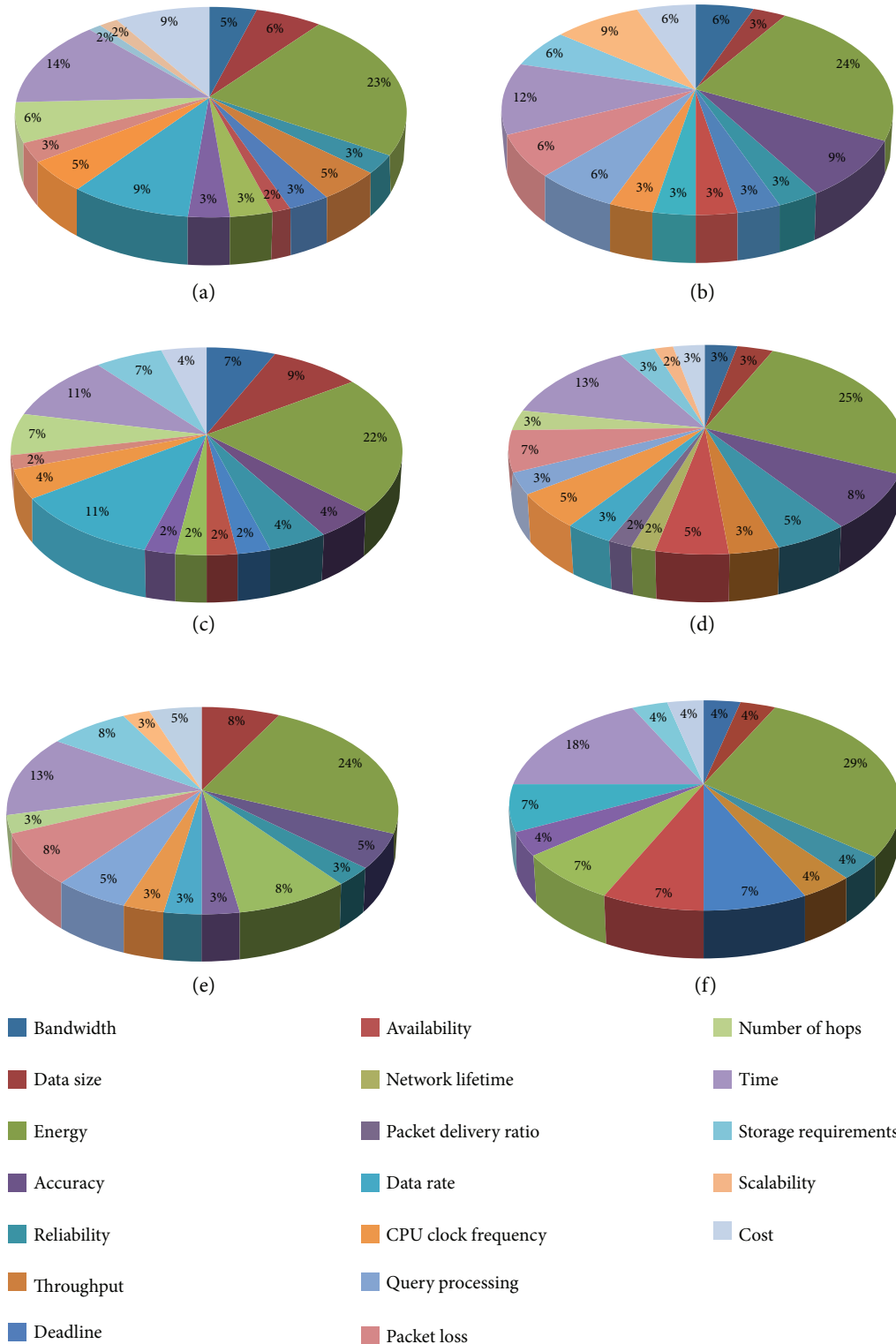


FIGURE 2: Percentage of parameters used in (a) scheduling techniques, (b) sensing techniques, (c) data transmission techniques, (d) advanced system designing, (e) data processing, and (f) load balancing techniques for the energy-efficient sensor cloud.

scalability and also are not suitable for real-time applications. Accuracy, availability, and scalability parameters are ignored in most of the research papers for this technique. The research papers on energy-efficient sensing techniques generally have security-related issues. Throughput, network

lifetime, packet delivery ratio, number of hops, and response time parameters are not considered in most of the research papers in this category. Some research papers on energy-efficient data transmission techniques ignore multitasking, scalability, mobility, and QoS. Computational energy,

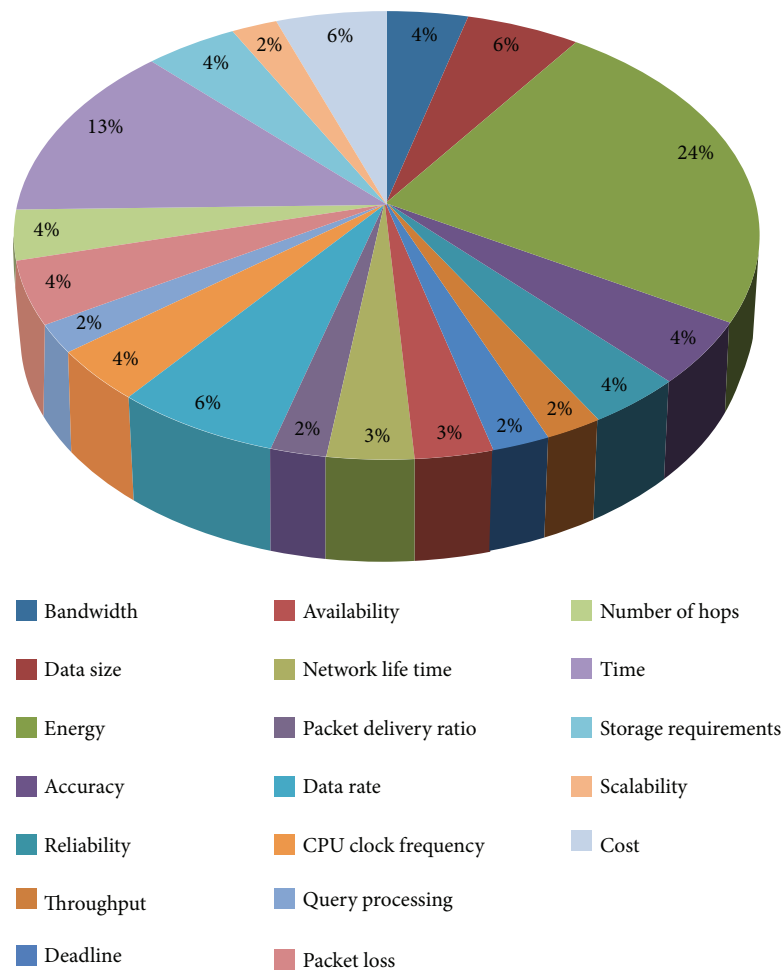


FIGURE 3: Percentage of parameters used in average for the energy-efficient sensor cloud.

throughput, query processing, and scalability parameters are ignored in most of the research papers for this technique. Some research papers on energy-efficient advanced system designing do not support scalability, QoS, data mining, and data filtering. Deadline, network lifetime, packet delivery ratio, number of hops, response time, and scalability parameters are not considered in most of the research papers in this category. The majority of the research papers on energy-efficient data processing do not support real-time applications. Bandwidth, throughput, deadline, and availability are not considered in most of the research papers for this technique. Most of the research papers on energy-efficient load balancing techniques do not support scalability, QoS, and multihop transmission. Accuracy, CPU clock frequency, query processing, packet loss, number of hops, and scalability parameters are not considered in most of the research papers for the abovementioned technique. The parameters we have taken for our analysis are bandwidth, data size, computational energy, total energy, communication energy, accuracy, reliability, throughput, deadline, availability, network lifetime, packet delivery ratio, data rate, CPU clock frequency, query processing, packet loss, number of hops, response time, total time, storage requirements, scalability, and cost. For simplicity, we have combined computational

energy, total energy, and communication energy parameters into a single parameter named as energy and we have also combined response time and total time parameters into one parameter named as time. Percentages of parameters used in various energy-efficient techniques are given in Figure 2.

The percentage of the energy parameter used in energy-efficient techniques for the sensor cloud ranges from 22 to 29%. Energy parameter is used at 29% for the load balancing technique whereas for the data transmission technique, it is used only at 22%. Percentages of parameters used on average for energy-efficient sensor-cloud techniques are given in Figure 3.

On an average, energy and time parameters are used 24 and 13%, respectively. Throughput, deadline, packet delivery ratio, query processing, and scalability parameters are used on average of 2%. Availability and network lifetime parameters are used on an average of 3 percent. Bandwidth, accuracy, reliability, CPU clock frequency, packet loss, number of hops, and storage requirement parameters are used 4 percent on an average. Data size, data rate, and cost parameters are used 6 percent on average. Most of the energy-efficient techniques ignore QoS parameters, scalability, network lifetime, and deadline.

5. Conclusion

In this paper, we have made a survey of energy-efficient techniques for the sensor-cloud environment using various parameters. The energy-efficient techniques are classified into six categories according to the techniques used in each research paper. We have taken twenty-two parameters for our analysis. Relatively, the analysis is done by using all twenty-two parameters for all energy-efficient sensor-cloud techniques and we provide the usage percentage of each parameter for every technology. We have also calculated the usage percentage of parameters on average of all technologies we have classified. QoS-related parameters are ignored in most of the energy-efficient techniques for the sensor-cloud computing. Many applications such as health care services, environmental monitoring, designing of the vehicular network, smart homes, and complex event monitoring need optimization of energy as well as QoS parameters. Thus, in the future research, QoS-related parameters such as reliability, availability, throughput, deadline, and accuracy must be optimized along with the energy parameter. Multiparameter optimization including QoS parameters along with energy is suggested for the future direction of research.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

Kalyan Das and Satyabrata Das have selected various research papers for the survey, classified energy-efficient techniques, and analyzed the parameters used in various research papers according to various categories. Rabi Kumar Darji and Ananya Mishra provide helpful suggestions. All the authors approved the final manuscript.

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