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Empirical Analysis on Energy Efficient and Secured Data Transmission in Wireless Networks

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Abstract: Wireless Sensor Networks (WSNs) comprised number of sensor nodes to sense and to transmit the data packets to the base station. The sensor nodes are battery-powered with limited energy capabilities. Routing in WSN is a significant component of communication network. Energy is considered as an important factor for performing efficient data transmission in WSN. Machine learning algorithms are employed to perform energy-efficient data transmission. Different optimization methods are used to perform energy-efficient data transmission in WSN. The optimization method is to minimize the energy consumption and to increase the network lifetime during data transmission in WSN. In optimization process, energy-efficient sensor nodes are selected for performing data transmission. With selected energy-efficient sensor nodes, the network lifetime gets improved in WSN. But, the energy efficiency remained key problem in WSN. Consequently, an artificial intelligence with optimization methods is introduced for energy-efficient data transmission in WSN to increase the network lifetime with lesser energy consumption.

Keywords: Wireless sensor networks, energy-efficient sensor nodes, data packets, energy, optimization, network lifetime, artificial intelligence

1. INTRODUCTION

Wireless Sensor Networks (WSN) is employed for efficient data communication with number of sensor devices to position the geographically distributed. The nodes of WSN transmitted the data packets through different network nodes. The key challenge of WSN performs efficient data transmission across all sensor nodes. Energy and Data security is complicated during data transmission between sensor node and base station through wireless channel. Energy efficient and secured data transmission is an essential one in WSN for performance enhancement. Energy management is an important one to increase the network lifetime, to perform reliable communication and to provide services for improved reliability and data delivery with minimum delay. Secured data transmission is an essential one to find the trusted route path in the WSN. In WSN, the trust level of sensor nodes in route path are computed for secured data transmission in WSN.

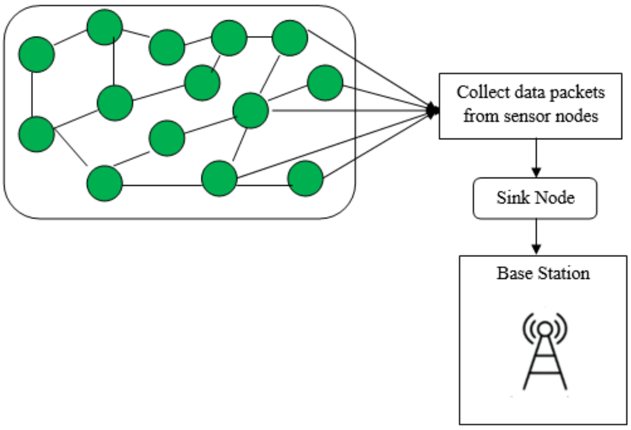

Figure 1 Wireless Sensor Network Architecture

Figure 1 demonstrates the architecture diagram of WSN. WSN comprised the number of sensor nodes for performing efficient data collection. Sink node collects the data packets for decision making. Finally, the sink node transmits the data packets to the base station in WSN.

The contribution of survey article is given as:

- To review different energy efficient and secured data transmission techniques in WSN
- To discuss the clustering and blockchain methods for secured and energy-efficient data transmission in WSN with lesser time complexity
- To evaluate the energy efficient and secured data transmission techniques for increasing the data confidentiality rate and data integrity rate in WSN

The survey paper is organized as follows: Section 1 presents introduction for energy efficient and secured data transmission in WSN. Section 2 reviews different energy efficient data communication methods. Section 3 gives the dataset description. Section 4 explains the methodologies of energy efficient data transmission with architecture diagram. Section 5 illustrates the performance parameters for energy efficient data transmission. Section 6 provides the result and discussion of existing techniques in WSN. Section 7 concludes the survey.

2. LITERATURE REVIEW

An energy-efficient clustering and routing technique based on Coot Optimization Algorithm (COA) was introduced in [1] to enhance the WSN performance. Though the delay was reduced, the energy consumption was not minimized by energy-efficient clustering and routing technique. Hybrid methodology was introduced in [2] to reduce energy consumption with better network performance. ANN improved the CH selection with minimum data transmission overhead. However, the network lifetime was not enhanced by hybrid methodology.

Forest Fire Optimization for Energy-Aware Routing (FFO-WSN) Model was designed in [3] depending on energy levels. But, the designed FFO-WSN model failed to consider the less hop count for reducing the jitter. Hexa Decimal ASCII-based Arithmetic Encoding (HDASCII-AE) and Double Right Shift Compliment (DRS2C) with Glorot Entropy Kernal-Gated Recurrent Unit (GEK-GRU) model was introduced in [4] for secured and energy-efficient data transmission in WSN. However, the data integrity rate was not improved by HDASCII-AE model. Adaptive Chaotic Ant Colony Optimization algorithm (AC-ACO) was introduced in [5] to optimize energy utilization for increasing WSN lifetime. But, the hybrid energy saving algorithm was not employed to optimize and balance CH selection through mobile sink.

Multi-Level Trust Based Secure Routing (MLTSR-BC) model was introduced in [6] for providing the data security and routing performance in WSN. MLTSR-BC model increased QoS performance through trust analysis. But, the data confidentiality rate was not enhanced by MLTSR-BC model. Machine Learning-based Secure

Routing Protocol (MLSRP) was introduced in [7] to improve the energy efficiency. MLSRP improved WSN security with the reduced data loss. But, the authentication time was not reduced by MLSRP.

Blockchain_SecAuth approach was designed in [8] for secured data communication in WSNs. However, the authentication accuracy and scalability was not improved by Blockchain_SecAuth approach. FOAEAUC-SARP was introduced in [9] with Fox Optimization Algorithm (FOA) and Snake Algorithm (SA) for addressing energy balancing and routing issues in WSNs. But, the computational time was not reduced by FOA and SA. Particle Swarm Optimization (PSO) with fuzzy multi-objective framework was introduced in [10] to enhance the energy efficiency. However, the designed framework failed to address the resource constraints challenges.

A hybrid optimization approach was designed in [11] with clustering protocol to minimize transmission latency. But, the designed framework failed to handle the large-scale routing challenges in WSN. A new multi-level clustering technique was designed in [12] with heuristic optimization algorithm. However, the energy consumption was not reduced and time complexity was not minimized by designed multi-level clustering technique.

Energy-Efficient Hyperheuristic Routing Protocol (EHRP-WSN) was introduced in [13] with Q-learning algorithm. Machine learning based Expected Transmission Count (ETX) Optimization Approach was designed in [14] depending on network conditions and historical transmission patterns. Energy-Efficient Artificial Intelligence-based Routing Protocol (EE-AIRP) was designed in [15] to increase the network lifetime in WSN applications. A*-based routing algorithm minimized communication overhead and increased energy efficiency.

Energy-Efficient and Balanced Cluster-based Routing protocol (EEB-CR) was introduced in [16] for increasing operational lifetime and energy distribution in WSNs. An energy-efficient clustering protocol was introduced in [17] with fuzzy graph-theoretic idea in WSN. Aurora-Based Clustering Protocol was introduced in [18] with electrical drift for cluster head selection. The sensor node was computed through computing energy level. An adaptive type-2 fuzzy unequal clustering algorithm was designed in [19] with energy-aware routing. The designed algorithm employed the fuzzy inference mechanism to choose the optimal cluster heads. An enhanced energy aware clustering approach was designed in [20] with K-Means algorithm and adaptive distance threshold for relay node selection.

Fuzzy Controller-Based Low Energy Adaptive Clustering Hierarchy (LEACH) protocol was introduced in [21] with rendezvous node (RN) for energy consumption and network lifetime. An energy efficient communication model was carried out in [22] for resource constrained IoT environments. The designed model computed remaining energy, distance and node degree for cluster head selection. An innovative model was introduced in [23] for cluster head selection in WSN based on sensor node residual energy. The neural network model was used to identify the best cluster head.

Hybrid Whale-Ant Optimization Algorithm (WAOA) was designed in [24] for energy-efficient routing in WSNs. WAOA employed the Whale Optimization Algorithm (WOA) to choose the cluster head in search space. Energy-Aware Routing Multi-Objective Cluster Head Selection was introduced in [25] with Binarized Spiking Neural Network Honey Badger Algorithm in WSN. The designed algorithm improved routing, and energy consumption. Link Quality based Energy-Efficient Routing (LQEER) protocol was designed in [26] to improve the dependability through link quality estimation. LQEER protocol enhanced packet delivery ratio and minimized delay.

An energy-efficient secure QoS routing model was introduced in [27] to minimize the energy cost, latency and packet loss rate. Heuristic Wing Ant Fly Optimization (HWAFO) was designed in [28] depending on distance, residual energy and node degree to choose the optimum path. HWAFO improved throughput and packet delivery ratio. A whale swarm algorithm with iterative counter-based routing (WSA-ICR) algorithm was designed in [29] in WSN. WSA-ICR algorithm minimized the energy consumption and improved path length. An energy efficient tree-based routing algorithm was introduced in [30] for energy consumption in WSN. The designed algorithm reduced the energy consumption and increased network lifetime.

3. METHODOLOGY

Wireless Sensor Networks (WSNs) are self-organized networks with number of sensor nodes. The sensor nodes are used to monitor, gather and transmit the information from environment. With development of information technology, WSNs are employed to attain the automated solutions. WSNs addressed the limited node energy and network coverage. Energy consumption among sensor nodes leads to energy depletion in wireless networks. Energy efficient routing algorithm is an important one for minimizing the energy consumption of network through combinatorial optimization problem. WSNs provide the powerful technology for data transmission across huge geographical regions. Energy efficient and secured routing in WSN is an essential one to partition the sensors into clusters for energy conservation. Machine learning algorithms are used to reduce the energy consumption and increase the network lifetime.

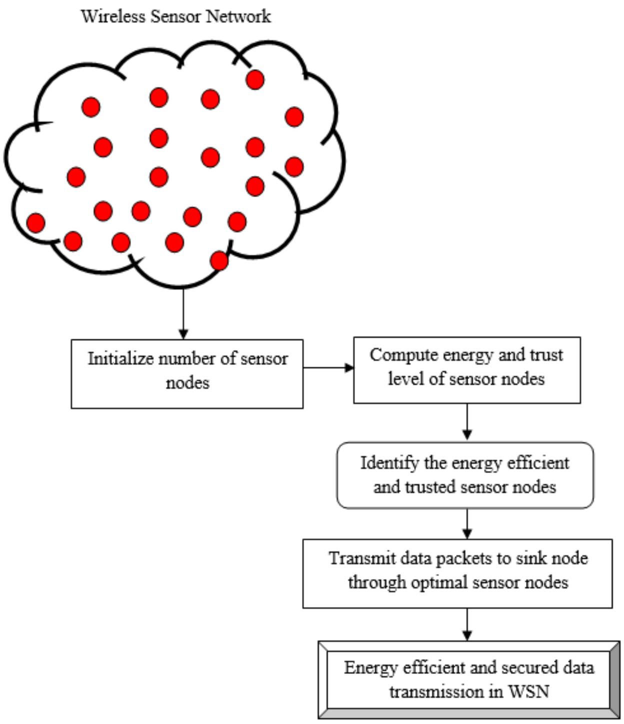

Figure 1 Energy Efficient and Secured Data Transmission in WSN

Figure 1 illustrates the energy efficient and secured data transmission in WSN. In WSN, the number of sensor nodes. After that, the energy and trust level of sensor nodes are calculated in WSN. Then, the energy efficient and higher trust sensor nodes are identified in WSN. The sink node gathers the data packets from energy efficient and trusted sensor nodes. Finally, the base station gathers the data packets from the sink node in wireless networks.

3.1 Coot Algorithm-based Energy Management Model

An energy-efficient clustering and routing technique was introduced with Coot Optimization Algorithm (COA) performance in WSN. The designed technique addressed energy consumption, communication delay and security issues. The fitness function determined the cluster heads and best routes depending on energy savings and network reliability limitations. The routing path was identified based on residual energy, delay, security, trust, distance and link quality. The energy load was distributed and data flow was maintained across network. The multiple clustering and routing was carried out to address the WSNs problems. COOT employed the Butterfly Optimization Algorithm, Genetic Algorithm, Grey Wolf Optimization Algorithm and Bird Swarm Algorithm for enhancing the network functionality and protection.

3.2 Deterministic Clustering, Neural Networks and Energy-Aware Routing

WSN performed the real-time environmental monitoring with number of sensor nodes (SNs). A hybrid methodology was introduced to minimize the energy consumption and increased the network performance. Low Energy Adaptive Clustering Hierarchy with Deterministic (LEACH-D) protocol was designed with the Artificial Neural Network (ANN) and Bayesian Regularization Algorithm (BRA). LEACH-D reduced energy consumption across sensor nodes through CH selection. ANN performed the CH selection and routing decisions through reducing data transmission overhead and idle listening. ANN increased the CH selection and routing process through minimizing data transmission overhead and idle listening. LEACH-D-ANN model minimized the EC and increased the network lifetime. The designed framework improved energy efficiency in WSNs for reliable network deployments.

3.3 Adaptive Forest Fire Optimization Algorithm

Energy-efficient routing was key challenge in WSN due to limited node energy. Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) addressed energy and network changes leading to energy utilization and node depletion. Forest Fire Optimization for Energy-Aware Routing (FFO-WSN) was introduced with the fire propagation dynamics. FFO-WSN model optimized the routing paths depending on energy levels. FFO-WSN model prioritized the high-energy node through eliminating energy depleted ones for increasing the network longevity and data transmission efficiency. FFO-WSN model reduced the energy consumption and end-to-end delay. FFO-WSN model increased the network lifetime, packet delivery ratio and throughput. FFO-WSN model achieved better solution for IoT-based health monitoring and smart city applications.

3.4 Energy-Efficient Aware and Secure Model

Hexa Decimal ASCII-based Arithmetic Encoding (HDASCII-AE) and Double Right Shift 2 Compliment (DRS2C) was introduced with Glorot Entropy Kernal-Gated Recurrent Unit (GEK-GRU) model in secured and energy-efficient WSN. WSN sensor nodes were initialized through Fisher Median Naive Sharding-based K-Means (FMNS-K-Means) algorithm. The initialized nodes were grouped depending on features. The node localization was carried out through Kendall Correlation-Serval Optimization Algorithm (KC-SOA). HDASCII-AE based secure routing methodology was introduced for secured data transmission. The optimal paths were chosen by KC-SOA for transmitting the sensor data transmission. The sensed data enhanced the network lifetime in prediction phase through GEK-GRU method.

3.5 Clustering Algorithm for Lifetime and Energy Efficiency Enhancement

Adaptive Chaotic Ant Colony Optimization algorithm (AC-ACO) was introduced to optimize the energy utilization and lifetime. AC-ACO joined path-planning through Ant Colony Optimization (ACO) with chaotic mapping. An adaptive mechanism was introduced to enhance the flexibility and adaptability. An efficient node clustering was carried out through adjusting pheromone evaporation factor and heuristic weights. The chaotic mapping initialization strategy increased the population diversity and avoided the premature convergence. AC-ACO algorithm computed with energy consumption, network lifetime and communication delay. AC-ACO algorithm attained efficient solution for increasing the energy efficiency and guaranteeing the long-term stable operation in WSNs.

3.6 Multi-Level Trust-Based Secure Routing

An efficient Multi-Level Trust Based Secure Routing (MLTSR-BC) model was introduced with different features of neighboring nodes in network. MLTSR-BC model was used to examine the trust level for secured route path selection. MLTSR-BC model employed the transmission rate, retransmission rate, energy, frequency and success rate for computing the node trust. The designed model gathered the different features of wireless node from diverse transmissions. The designed model examined the trust value of nodes from their neighboring nodes. MLTSR-BC model computed the Localized Trust Factor (LTF) and Globalized Trust Factor (GTF) for secured route path selection. The source node was used for computing LTF. An intermediate node was employed to determine GTF value. MLTSR-BC model employed Adaptive Blockchain Security Algorithm for secured data transmission between the nodes in network. MLTSR-BC model improved the QoS performance in WSNs through multi-level trust analysis with blockchain.

3.7 Secure Routing Protocol with Energy Efficiency Enhancement

WSNs performed the continuous tracking, digitization and data collection. WSNs addressed the security concerns with limited energy resources owing to number of devices. WSN addressed the security and energy efficiency issues. The secure and energy-efficient routing protocol was introduced to improve the network lifetime and to reduce the operational costs. The designed protocol enhanced the security and reliability for industrial monitoring system in WSN. Machine Learning-based Secure Routing Protocol (MLSRP) was designed to increase the energy efficiency with reduced data loss. MLSRP performed clustering, cluster head election and data routing. MLSRP examined network elements that affected node, route and improved the data quality. MCDM performed accurate data transmission in WSN. MLSRP model was employed in energy-efficient, secure, and long-lasting IoT solutions.

3.8 Energy-Efficient protocol with Unequal Clustering and Intelligent Routing

WSN helped in reducing the energy consumption and increasing the network lifetime. The hierarchical structure improved the energy efficiency and prolongs network longevity. FOAEAUC-SARP technique minimized the energy consumption in WSN through Fox Optimization Algorithm (FOA). FOAEAUC-SARP technique constructed the dissimilar-size clusters and chosen the high-energy nodes as cluster heads (CHs). FOAEAUC-SARP technique employed the Snake Algorithm (SA) to carry out efficient data transmission process through choosing the energy-efficient routes. FOAEAUC-SARP technique identified optimal communication paths for reducing the energy wastage and improving network lifetime. FOAEAUC-SARP increased the energy efficiency and attained robust solution for improving the WSN performance. The analysis of FOAEAUC-SARP technique was carried out with case scenarios in real-world applications.

3.9 Hybrid Bio-inspired Optimization based Routing Protocol

Internet of Things (IoT) in WSNs collected the data in real-time application for smart homes and healthcare. Energy efficiency was important one for considering sensor nodes with limited energy. The node failure, network segmentation and minimum quality of service (QoS) reduced energy consumption among sensor nodes during data transmission and cluster head (CH) processes. A hybrid optimization approach was introduced with clustering protocol. Bi-objective Tabu Search and Ant Colony Optimization (ACO) reduced the transmission latency and increased the energy efficiency. The key objective of designed protocol was to increase the network lifetime through data transmission and optimal cluster head (CH) selection. The designed protocol increased residual energy, network stability, and network lifetime with lesser transmission delay.

3.10 Enhanced multi-level K-means clustering and cluster head selection

WSN employed the optimization for increasing the network coverage, data efficiency, and energy conservation to increase network lifetime and system reliability. A new multi-level clustering technique was introduced with heuristic optimization algorithm to improve the network capacity. Modernized Pufferfish Optimization Algorithm (MPOA) was designed for enhancing the WSN performance with the pufferfish strategies. The multi-level K-means algorithm (MKA) was employed to group the nodes dynamically based on network conditions. MPOA was employed for choosing suitable Cluster Head (CH) with random parameter to perform convergence and to attain global optimum solution. The multi-level clustering technique enhanced CH selection, network lifetime, residual energy and reduced energy consumption, path loss, cost function depending on number of nodes and rounds.

4. DATASET DESCRIPTION

The first dataset used is Wireless Sensor Network Dataset. URL of the dataset is given as https://www.kaggle.com/datasets/ziya07/wireless-sensor-network-dataset. The dataset is used for research and

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development in WSN decentralized power scheduling for reliable signal detection. The designed dataset simulates the sensor nodes with attributes related to energy consumption, transmission power, signal strength, noise levels, and environmental factors. The target attribute is Detection_Accuracy (%). The dataset is influenced by factors, namely signal strength, noise level, energy efficiency, and optimization algorithms. The dataset is employed for IoT network optimization, energy-efficient communication and adaptive WSN deployments.

The dataset comprised the simulated data for decentralized power scheduling in WSNs to enhance the accuracy to optimize the energy consumption.

5. PERFORMANCE ANALYSIS ON ENERGY EFFICIENT AND SECURED DATA TRANSMISSION IN WSN

The result analysis of energy efficient and secured data transmission methods in WSN with four different parameters, namely

- Energy consumption,
- Network lifetime,
- Data confidentiality rate and
- Data integrity rate

5.1 Energy Consumption

Energy consumption is defined as the product of number of sensor nodes considered for efficient data transmission and amount of energy consumed by sensor node to perform efficient transmission in WSN. It is determined in terms of joules (Joule). It is determined as,

$$EC = \sum_{i=1}^{m} SN_i * Energy(one\ sensor\ node\ for\ data\ transmission) \quad (1)$$

From (1), 'EC' symbolizes the energy consumption. 'SN_i' denotes the total number of sensor nodes.

5.2 Network Lifetime

Network lifetime is the ratio of the number of sensor nodes for efficient data transmission to the total number of sensor nodes. Network lifetime is measured in terms of percentage (%). It is defined as,

$$NL = \sum_{i=1}^{m} \left[\frac{N_{DA}}{SN_i}\right] * 100 \quad (2)$$

From (2), 'NL' denote the network lifetime. 'N_{DA}' symbolizes the number of sensor nodes addressed.

5.3 Data Confidentiality Rate

The data confidentiality rate is the ratio of number of data packets received by the base station in WSN. The data confidentiality rate is formulated as,

$$DCR = \sum_{j=1}^{m} \left[\frac{n_{AR}}{dp_j}\right] * 100 \quad (3)$$

From (3), 'DCR' symbolizes the data confidentiality rate. 'n_{AR}' indicates the number of data packets received by authorized user. 'dp_j' represent the total number of data packets. It is measured in terms of percentage (%).

5.4 Data Integrity Rate

Data integrity rate is the ratio of number of data packets that remained unaltered by the unauthorized sensor nodes to the total number of data packets. The data integrity rate is computed as,

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$$DIR = \sum_{j=1}^{m} \left[\frac{dna}{dp_j}\right] * 100 \quad (4)$$

From (4), 'DIR' symbolizes the data integrity rate. 'dna' represents the number of data packets that are not altered. 'dp_j' denote the total number of data packets. It is measured in terms of percentage (%).

Table 1 Tabulation of Energy Consumption, Network Lifetime, Data Confidentiality Rate and Data Integrity Rate with Wireless Sensor Network Dataset

Methods/ Parameters	**Energy Consumption (J)**	**Network Lifetime (%)**	**Data Confidentiality Rate (%)**	**Data Integrity Rate (%)**
Energy-efficient clustering and routing technique [1]	25	92	91	93
Hybrid methodology [2]	29	90	89	92
FFO-WSN Model [3]	33	89	86	88
HDASCII-AE and DRS2C [4]	45	81	79	83
AC-ACO Algorithm [5]	38	83	81	85
MLTSR-BC model [6]	35	86	84	87
MLSRP [7]	36	85	83	86
FOAEAUC-SARP technique [9]	30	89	87	89
Hybrid optimization approach [11]	33	86	83	85
New multi-level clustering technique [12]	28	90	88	91

Table 1 shows the performance results for ten different energy efficient and secured data transmission techniques for four diverse performance metrics. From the above table, it is clear that Energy-efficient clustering and routing technique attained enhanced energy efficient and secured data transmission performance results than other existing methods. For Wireless Sensor Network Dataset, an energy-efficient clustering and routing technique [1] attained 25 Joules of energy consumption, 92% of network lifetime, 91% of data confidentiality rate and 93% of data integrity rate. Figure 3 illustrates the performance energy efficient and secured data transmission analysis of wireless sensor network dataset.

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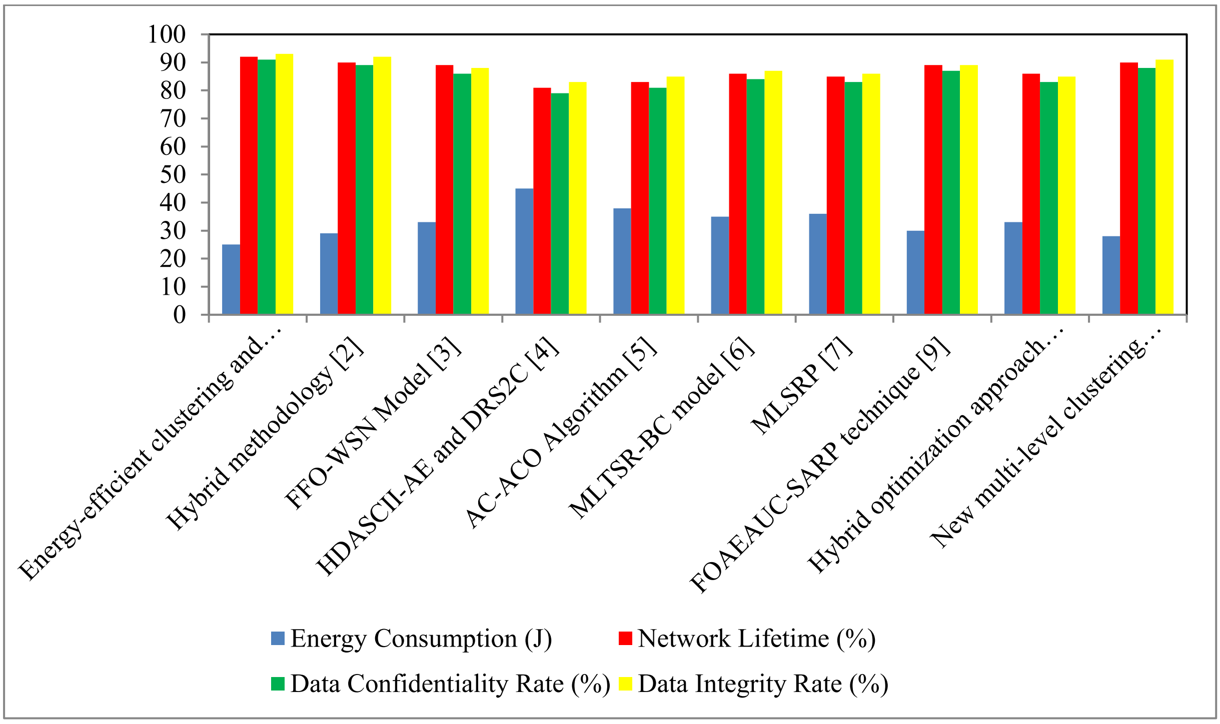

Figure 3 Measurement Analysis of Energy Consumption, Network Lifetime, Data Confidentiality Rate and Data Integrity Rate

Figure 3 illustrates the performance metric comparison of ten different metrics. From graphical representation, it is clear that the performance of energy-efficient clustering and routing technique is higher than other existing methods. This is due to the application of COA in WSN. The designed routing technique addressed energy, communication delay and security problems. The fitness function identified the cluster heads based on residual energy, delay, security, trust, distance and link quality parameters for identifying the best routes based on energy savings limitations. The routing path was identified to address the data flow problems across WSN. For Wireless Sensor Network Dataset, the energy-efficient clustering and routing technique minimized energy consumption by 25%, increased network lifetime by 6%, increased the data confidentiality rate by 8% and increased the data integrity rate by 7% when compared to the conventional techniques.

CONCLUSION

In the survival review, the discussion of different energy efficient and secured data transmission is carried out in WSN. Various metrics are employed in WSN to examine the performance different energy efficient and secured data transmission. When performance results of existing methods are determined, the energy-efficient clustering and routing technique has attained better results in WSN. In this work, clustering and optimization techniques have attained higher network lifetime and security with WSN dataset. Artificial intelligence and clustering techniques are used to achieve improved data confidentiality and data integrity results result than other existing energy efficient clustering and routing techniques in WSN. These performance results recommend that the clustering and artificial intelligence models can be implemented in future for performing energy and security optimized data transmission in WSN when compared to state of-the-art techniques.

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