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Review Article

Survival Study on Energy and Bandwidth Efficient Data Transmission in Wireless Networks

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Abstract - *Wireless sensor network is a collection of sensor devices that monitor environmental conditions and arrange data at a central location. Each sensor device wirelessly sends the information to the base station. Sensor devices help each other relay the information to the base station. Routing selects the path for data packet transmission from the source node to the destination node. Energy, Bandwidth and Delay are demanding issues in WSN. Energy-efficient routing is performed to minimize the energy consumption of sensor nodes to increase the network lifetime. Many researchers researched energy and bandwidth-efficient routing in wireless sensor networks. However, the energy consumption and delay were not reduced during routing in WSN. Different energy and bandwidth-aware data transmission are carried out to address these problems in WSN.*

Keywords - *Base station, Destination node, Environmental conditions, Energy consumption, Routing.*

1. Introduction

The wireless sensor network (WSN) has large benefits for real-time monitoring. Wireless sensors examine the physical process and transmit information to the base station. WSN is an information technology that combines new technological achievements in network, micro-electronics and communications. Sensor nodes communicate over a minimum distance through a wireless medium and combine to achieve a single task. Data transmission in WSN is the method of transmitting data over the communication medium to one or more networks, communication or electronic devices. In wireless sensor networks, the power resource of every sensor node is inadequate. Minimum energy dissipation and maximum network lifetime are the essential problems in routing protocol design for sensor networks.

This article is organized as follows: Section II describes the review of various energy and bandwidth-efficient data transmission techniques in WSN, Section III describes the study and analysis of existing energy and bandwidth-efficient data transmission techniques, and Section IV explains the comparison between them. Section V discusses the limitations of conventional energy and bandwidth-efficient data transmission techniques, and the conclusion of the paper is discussed in Section VI

2. Literature Survey

Wireless Sensor Networks (WSNs) are considered an important technology for the twenty-first century. Bandwidth and Energy efficiency in wireless sensor networks (WSN) are important performance parameters. Compressed Sensing with Dynamic Retransmission (CSDR) algorithm was introduced in [1] to guarantee higher data reconstruction accuracy and network lifetime. Though the network lifetime was increased, the delay was not minimized by the CSDR algorithm. NOMA-enabled two-stage transmission architecture was designed in [2] for large cellular IoT communication. The queuing theory and stochastic geometry attained better network performance. However, the bandwidth utilization was not reduced by NOMA.

An optimized load balancing-based Admission Control Mechanism (Opt-ACM) was introduced in [3] for efficient network flow management with network congestion. But, the communication overhead was not minimized by Opt-ACM. An alternative device-to-device (D2D) strategy was introduced in [4] without the revolutionary hardware progress needs. D2D routing was employed to minimize the energy consumption level. Though the energy consumption was reduced, the delay time was not minimized by the D2D strategy.

A time scheduling algorithm was introduced in [5] for LoRaWAN networks with device maintenance for synchronization between the gateway and end nodes. The devices reduced the collision and increased the scalability by assigning the guard time to every end node. But, the energy consumption was not minimized by the time scheduling algorithm. WSN framework was designed in [6] based on the Internet of Things in smart agriculture with different levels. The signal strength of the communication link was established using the signal-to-noise ratio (SNR) to attain reliable information diffusion. However, the network lifetime was not increased through the WSN framework.

A deep-learning (DL) model was designed in [7] to predict the IoT communication system performance.

Every neural network forecasted improved results for the IoT network. But, the computational cost was not minimized by the DL model. An energy-aware system model was designed [8] for LPWAN IoT devices with many wireless communication methods to enhance life in the IoT environment. Though the energy efficiency was increased, the energy-aware system model did not minimize power consumption.

A dynamic routing algorithm with energy-efficient relay selection (RS) called DRA-EERS was introduced in [9] to improve the dynamics in wireless sensor networks. Though the computational cost was minimized, the dynamic routing algorithm did not increase network lifetime. A tree-based routing protocol was designed [10] to reduce power consumption and end-to-end delay in IoT networks with mobile sinks. The end-to-end delay was minimized, but the tree-based routing protocol did not minimize bandwidth utilization.

3. Energy and Bandwidth Efficient Data Transmission in WSN

Wireless sensor networks (WSNs) are interconnected sensor nodes that gather data about the surrounding environment. Nodes are low power and distributed in an adhoc and decentralized fashion. WSN helps in creating connectivity between computing devices, individuals and surroundings. Wireless sensor network plays an essential role in the future Internet of Things (IoT), with millions of devices exchanging confidential information in a multi-hop manner. WSN brought dramatic variation in technological advancement and provided opportunities for the effective usage of resources in critical environments. WSNs are collections of wireless nodes with limited energy capabilities randomly over changing atmospheres.

3.1. Compressed Sensing with Dynamic Retransmission Algorithm in Lossy Wireless IoT

Wireless sensor networks (WSN), depending on compressed sensing (CS), perform data sampling and data compression simultaneously by minimizing data transmission volume and energy consumption. Compressed Sensing with Dynamic Retransmission (CSDR) algorithm was introduced to improve the data reconstruction accuracy, network lifetime and energy utilization. CSDR algorithm determined the maximum packet loss retransmission time of diverse nodes consistent with residual energies for Internet of Things (IoT) devices. The maximum retransmission was implemented to preserve network lifetime. For energy-rich IoT devices, higher retransmission was used to increase the data transmission accuracy and performance of data reconstruction. The feature was consistent with the wireless sensor network requirement for data sampling and compression synchronization because of compressed sensing. It reconstructed the sampled data with high accuracy in WSN. When the sampled signal is sparse or compressible in the transform domain, the sampled signal gets projected and compressed through the observation matrix to attain high-dimensional signal reduction. CSDR algorithm inserted the data retransmission mechanism and improved the probability of several nodes.

3.2. Energy and Delay Aware Two-hop NOMA-Enabled Massive Cellular IoT Communications

NOMA-enabled two-stage transmission architecture was introduced to allow huge cellular IoT communication. The queuing theory and stochastic geometry ideas were developed to obtain the tractable model for diverse network performance parameters like coverage probability, two-hop access delay and served devices per transmission frame. The established model classified relations among network parameters and facilitated two-stage transmission architecture. The network parameters depend on the severity of the interference. The number of devices sharing similar resource channels and transmission power devices. The in-network interference components were classified and described the coverage probability in the system. The queuing theory and stochastic geometry were employed to attain tractable analytical results for different network parameters.

The designed framework collected the unique feature of future IoT applications with small-sized data packets created by the device, a huge number of network devices and limited radio resources. The NOMA-enabled two-hop network model was introduced for huge cellular IoT communications. An analytical framework was designed with a mathematical model to achieve the coverage probability, number of served devices, access delay, and energy consumption. Laplace transforms with interference components were derived from identifying expressions for transmission probabilities. The probabilities used to attain the coverage probability in the two-hop network. The coverage probability transmitted their packet to the core network through two-hop network architecture.

3.3. Opt-ACM: An Optimized load balancing-based Admission Control Mechanism for Software Defined Hybrid Wireless based IoT (SDHW-IoT) network

An Optimized load balancing-based Admission Control Mechanism (Opt-ACM) was designed for efficient network flow management. The designed mechanism minimized network congestion. A Software Defined Hybrid Wireless based IoT (SDHW-IoT) network architecture comprised of Software Defined Wireless Sensor Network (SDWSN) and Software Defined Wireless Mesh Network (SDWMN) for network management. Mixed-Integer Linear Programming (MILP) based optimization problem was addressed and tested through mathematical optimization solver termed as Gurobi. A multi-controller architecture was constructed for the SDHW-IoT network. SDHW-IoT network architecture comprised two network fields, namely, SDWSN and SDWMN. Every domain included the sensor controller (SC) and access point controller (APC).

The controllers were employed to handle the sensor network and mesh network. SC gathered the periodic updates from the distributed sensor and organized the flow admission process in the sensor network through the admission control module. APC managed the mesh nodes and balanced the network load in overload situations with the help of a load-balancing module. The multiple controllers enhanced the network fault tolerance. The modules were employed to preserve architectural simplicity and highlight the similarity between controllers. SC and APC devised the control plane of the SDHW-IoT network and synchronized it periodically through a synchronization link. Each domain controller preserved the domain statistics to provide efficient communication among modules.

4. Performance Analysis of Different Energy and Bandwidth Efficient Data Transmission Methods in WSN

To compare the different energy transmission techniques in WSN, the number of sensor nodes and data points is taken as an input to conduct the experiments. Experimental evaluation of three techniques: Compressed Sensing with Dynamic Retransmission (CSDR), NOMA-enabled two-stage transmission architecture and Software Defined Hybrid Wireless based IoT (SDHW-IoT) network architecture implemented using NS2 environment. The result analysis of existing techniques is estimated with certain parameters that are

- Energy Consumption,
- Processing Time and
- Packet Delivery Ratio

The performance of three existing methods is determined with the help of a table and graphs.

4.1. Impact on Energy Consumption

Energy consumption is the product of the number of sensor nodes and the amount of energy consumed by one sensor node. It is formulated as,

$$EC = N * Energy\ consumed\ by\ one\ sensor\ node$$

From (1), 'EC' denotes the energy consumption. 'N' symbolizes the number of sensor nodes. It is measured in terms of joules (J). The method is said to be more efficient when the energy consumption is lesser.

Table 1 explains the energy consumption for the number of sensor nodes varying from 10 to 100. Energy consumption comparison takes place on existing Compressed Sensing with Dynamic Retransmission (CSDR), NOMA-enabled two-stage transmission architecture and Software Defined Hybrid Wireless based IoT (SDHW-IoT) network architecture. The graphical representation of energy consumption is explained in Fig. 1.

Table 1. Tabulation of Energy Consumption

Number of Sensor Nodes (Number)	Energy Consumption (J)		
	CSDR	*NOMA-enabled two-stage transmission architecture*	*SDHW-IoT network architecture*
10	25	31	39
20	27	33	42
30	30	36	45
40	31	39	48
50	35	41	50
60	37	43	52
70	39	46	55
80	41	49	58
90	44	51	60
100	46	53	62

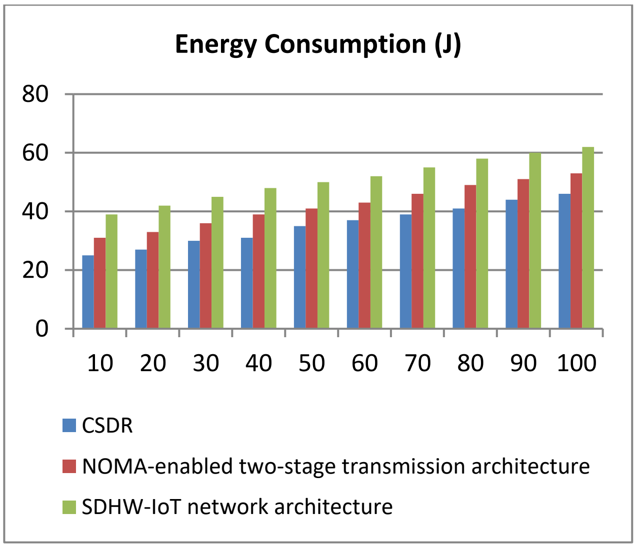

Fig. 1 Measurement of Energy Consumption

As described in figure 1, energy consumption depending on a different number of sensor nodes is illustrated. The blue colour cone represents the energy consumption of Compressed Sensing with Dynamic Retransmission (CSDR). The red colour cone and green colour cone symbolize the energy consumption of NOMA-enabled two-stage transmission architecture and SDHW-IoT network architecture, respectively. It is clear that energy consumption using CSDR is less than NOMA-enabled two-stage transmission architecture and Software Defined Hybrid Wireless based IoT (SDHW-IoT) network architecture. The CSDR algorithm reduced the maximum packet loss retransmission time of different nodes consistent with residual energy for Internet of Things (IoT) devices. CSDR algorithm inserted a data retransmission mechanism and increased the number of nodes. Consequently, the energy consumption of CSDR is reduced by 16% compared to the NOMA-enabled two-stage transmission architecture and 31% to the SDHW-IoT network architecture, respectively.

4.2. Impact on Packet Delivery Ratio

The packet delivery ratio is the number of data packets received at the destination node to the number of packets sent from source nodes. The packet delivery ratio is formulated as

$$PDR = \frac{Number\ of\ packets\ received\ at\ the\ destination}{Number\ of\ packets\ sent\ from\ source\ node} * 100 \qquad (2)$$

From (2), 'PDR' denotes the packet delivery ratio. It is measured in terms of percentage (%). The method is more efficient when the packet delivery ratio is higher.

Table 2. Tabulation for Packet Delivery Ratio

Number of Data Packets (Number)	**Packet Delivery Ratio (%)**		
	CSDR	***NOMA-enabled two-stage transmission architecture***	***SDHW-IoT network architecture***
10	78	84	71
20	80	86	73
30	82	89	75
40	85	91	78
50	83	88	76
60	81	85	74
70	84	87	77
80	87	90	80
90	90	92	82
100	92	94	85

Table 2 explains the packet delivery ratio for the number of sensor nodes varying from 10 to 100. Packet delivery ratio comparison takes place on existing Compressed Sensing with Dynamic Retransmission (CSDR), NOMA-enabled two-stage transmission architecture and Software Defined Hybrid Wireless based IoT (SDHW-IoT) network architecture. The graphical illustration of the packet delivery ratio is described in figure 2.

As described in figure 2, the packet delivery ratio depending on the number of data packets is illustrated. The blue colour cone represents the packet delivery ratio of Compressed Sensing with Dynamic Retransmission (CSDR). The red colour cone and green colour cone symbolize the packet delivery ratio of NOMA-enabled two-stage transmission architecture and SDHW-IoT network architecture, respectively. It is clear that the packet delivery ratio using NOMA-enabled two-stage transmission architecture is higher when compared to CSDR and Software Defined Hybrid Wireless based IoT (SDHW-IoT) network architecture. It is because of applying an analytical framework with a mathematical model for attaining the coverage probability. Laplace transform with interference component identified the expression for performing the transmission probabilities.

As a result, the packet delivery ratio of NOMA-enabled two-stage transmission architecture is increased by 5% compared to the CSDR and 15% to the SDHW-IoT network architecture, respectively.

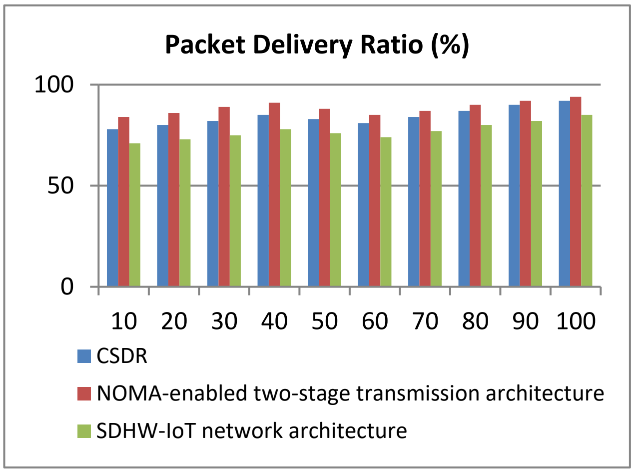

Fig. 2 Measurement of Packet Delivery Ratio

4.3. Impact on Processing Time

Processing time is the amount of time consumed to perform energy-efficient data transmission in WSN. It is a product of the number of sensor nodes and the amount of time consumed by one sensor node. It is formulated as,

$$PT = N * amount\ of\ time\ consumed\ by\ one\ sensor\ node \qquad (3)$$

From (3), 'PT' denotes the processing time. 'N' denotes the number of sensor nodes.

Table 3. Tabulation of Processing Time

Number of Sensor Nodes (Number)	**Processing Time (ms)**		
	CSDR	***NOMA-enabled two-stage transmission architecture***	***SDHW-IoT network architecture***
10	18	26	12
20	21	28	15
30	23	31	18
40	25	33	20
50	27	36	22
60	30	39	25
70	32	41	27
80	35	43	30
90	37	46	33
100	40	48	35

Table 3 describes the processing time for the number of sensor nodes varying from 10 to 100. Processing time comparison takes place on existing Compressed Sensing with Dynamic Retransmission (CSDR), NOMA-enabled two-stage transmission architecture and Software Defined Hybrid Wireless based IoT (SDHW-IoT) network architecture. The graphical illustration of processing time is illustrated in figure 3.

As shown in figure 3, processing time depending on the different sensor nodes is illustrated. The blue colour cone represents the processing time of Compressed Sensing with Dynamic Retransmission (CSDR). The red colour cone and green colour cone symbolize the processing time of NOMA-enabled two-stage transmission architecture and SDHW-IoT network architecture correspondingly. It is clear that processing time using Software Defined Hybrid Wireless based IoT (SDHW-IoT) network architecture is lesser when compared to CSDR and NOMA-enabled two-stage transmission architecture.

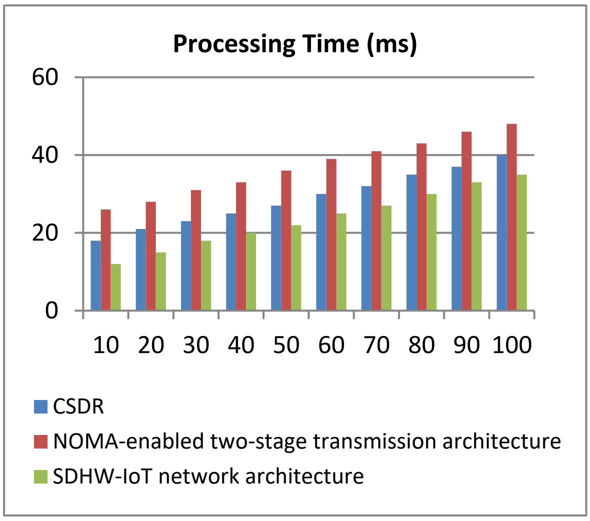

Fig 3. Measurement of Processing Time

It is due to the application of a multi-controller architecture for the SDHW-IoT network with two network fields: SDWSN and SDWMN. Every domain has a sensor controller (SC) and access point controller (APC) to handle the sensor network and mesh network. As a result, the processing time of the SDHW-IoT network architecture is reduced by 19% compared to the CSDR and 38% to the NOMA-enabled two-stage transmission architecture, respectively.

5. Discussion and Limitation on Energy and Bandwidth Efficient Data Transmission in WSN

CSDR algorithm guaranteed better data reconstruction accuracy and advanced network lifetime. The designed algorithm enhanced the network's lifetime performance. But the CSDR algorithm did not minimize the delay. NOMA-enabled two-stage transmission architecture was used for the large cellular IoT communication. In addition, the queuing theory and stochastic geometry were increased to attain better network performance.

The designed architecture enhanced the network radio resource and improved energy efficiency. However, the NOMA-enabled two-stage transmission architecture did not minimize bandwidth utilization. A Software Defined Hybrid Wireless based IoT (SDHW-IoT) network architecture performed network flow management with the network congestion. The designed architecture was constructed with improved efficiency. But, the communication overhead was not reduced by the designed method.

5.1. Future Direction

The future direction of energy and bandwidth-efficient data transmission in WSN is to improve the packet delivery ratio and reduce time consumption using machine learning and deep learning methods.

6. Conclusion

A comparative study of different energy and bandwidth-efficient data transmission techniques in WSN is carried out. The survival study did not reduce the communication overhead by the designed method. In addition, the bandwidth utilization was not minimized by the NOMA-enabled two-stage transmission architecture. The CSDR algorithm did not minimize the delay. The wide experiment on conventional techniques evaluates the results of different energy-efficient data transmission techniques and discusses its problem. From the result analysis, the research can be carried out using machine learning techniques for energy and bandwidth-efficient data transmission with a higher packet delivery ratio and lesser time consumption.

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