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Energy-Efficient Data Transmission Scheme for Resource-Constrained IoT Devices

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Abstract

The proliferation of Internet of Things (IoT) applications and services has created tremendous demand for supporting IoT in large scale and with huge number of resource constraint IoT devices. Most of the IoT devices are battery powered, have limited processing power and communication resources. Hence, the energy efficient transmission of data from these devices is a great challenge. Most of the existing approaches of data transmission in IoT result into generating unnecessary communication overheads in form of redundant data transmissions. These approaches result into increased energy consumption of devices and thereby reduction in their lifetime. This paper proposes an approach for energy efficient transmission of data in IoT. In this approach, frequency of communication is controlled and unnecessary communications are minimized. The proposed approach includes adaptive control for transmission, energy aware scheduling and intelligent communication management. The approach has been evaluated using several performance metrics including energy consumption, packet delivery ratio, end to end delay, throughput and network lifetime. The experimental results show that the proposed approach causes significant reduction in energy consumption and thus results into increased lifetime of networks. The proposed approach is simple, lightweight and can be easily scalable to support large number of IoT devices in various application environments including smart environments, health care, industry and large wireless sensor networks.

Keywords: Internet of Things (IoT); Energy-Efficient Communication; Resource-Constrained Devices; Data Transmission Optimization; Wireless Sensor Networks; Low-Power Communication; Adaptive Transmission; Network Lifetime; Energy-Aware Scheduling; IoT Optimization.

1. Introduction

Internet of Things (IoT) technology has advanced rapidly to enable a new generation of intelligent systems that incorporate sensing, monitoring and autonomous decision making in a wide range of application fields including healthcare, agriculture, smart cities, industry, environmental monitoring and domestic applications[1]. These systems are comprised of a large number of distributed sensors that communicate with and are processed by edge or cloud-based systems[2]. However, most of these sensors are constrained by low power batteries, limited processing capability, small memory, and low communication bandwidth[3]. Hence, it is a challenge to enable long-term and reliable operation of these systems, especially in remote locations where batteries cannot be easily replenished on a regular basis[4].

Energy consumption in IoT communication is mostly associated with wireless transmission between sensor nodes, gateway(s) and application servers. In many existing IoT applications, sensor nodes periodically send collected information to the application servers without any consideration whether the information is important, varying or redundant[5]. This type of communication results in huge amount of redundant information exchange, which in turn increases energy consumption and results in quick die-out of batteries powering the nodes[6]. Reducing redundant transmissions in such applications is a major challenge towards efficient energy consumption in IoT and to extend lifetime of batteries used to power IoT sensor nodes[7].

A number of energy-efficient communication methods have been developed to tackle the problems faced by IoT sensor nodes[8]. Aggregation of sensor data to reduce the volume of information to be sent, energy-efficient routing that routes packets through the parts of the network where there is the most energy, communication scheduling, duty cycling that enables a sensor to switch to an idle state when there is no communication taking place for long periods of time, are some of the existing techniques[9]. Most of the current methods are based on complex algorithms that impose additional overhead to the communication in the network, and are not adaptive

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to varying environmental situations and different data generation patterns[10].

To achieve the targets of next-generation IoT applications, the development of intelligent and lightweight data transmission methods is becoming increasingly important. A good energy-efficient data transmission approach must minimize communication as much as possible, deliver data reliably, keep latency low, and be implementable with low computational power on small IoT devices. Data variation analysis-based adaptive transmission approaches can efficiently decrease the amount of redundant packets by allowing IoT devices to adapt their communication to the changing information that they have sensed and to transmit important information in time.

In this work, present an energy-efficient data transmission approach for IoT devices. In the proposed scheme, an energy-efficient data transmission approach is presented for the IoT applications by optimising communication and optimising energy consumption for communication. An adaptive approach is proposed to minimize communication of unnecessary data while maintaining acceptable performance metrics such as packet loss, throughput, end-to-end delay, etc. The approach has been evaluated using typical performance metrics such as energy consumption, packet delivery ratio, throughput, end-to-end delay, and network lifetime. Results obtained can be used to design and develop energy-efficient, sustainable, and scalable communication approaches for future IoT applications.

2. Literature Review

As IoT applications are rapidly emerging, many studies are exploring energy efficient communication methods for IoT nodes that are usually battery powered and hard to maintain. In order to achieve energy efficient IoT communication, most of the current studies are exploring energy efficient routing, data aggregation, adaptive transmission, duty cycling and many others[11]. These approaches can improve the energy efficiency and sustainability of IoT communication systems.

Most of the current IoT communication methods implement periodic transmission of sensor data. Although these approaches guarantee a fixed rate of information delivery, they typically generate a lot of waste since many pieces of information are redundant or even insignificant[12]. In order to save energy, several recent studies have therefore proposed event-driven or even adaptive communication approaches[13]. In these approaches sensor nodes only send information when significant changes have occurred to the monitored quantity[14].

Data aggregation in wireless sensor networks (WSNs) and IoT environments is one way to decrease the overhead of communication[15]. Aggregation of data from multiple sensor nodes before they send the aggregated information instead of individual sensor readings reduces the amount of information that has to be forwarded in the network[16]. Early approaches for energy efficient communication in sensor networks, like Low-Energy Adaptive Clustering Hierarchy (LEACH), organized sensors into clusters and selected cluster heads to forward the aggregated data of their respective clusters[17]. Although these approaches for in-network aggregation and sensor clusterization are able to better distribute the energy consumption in a network of sensors, there are several challenges, i.e., cluster formation, aggregated data overhead, unbalanced sensor energy dissipation, especially in very large-scale and highly dynamic IoT scenarios[18].

Many energy-aware routing approaches in WSNs and IoTs are designed based on the nodes' residual energy, distance, etc. In order to provide efficient communication in low-power and lossy networks, there are several routing protocols, i.e., Routing Protocol for Low-Power and Lossy Networks (RPL), which are designed for constrained IoT devices[19]. However, the existing routing approaches in WSNs and IoTs mostly rely on pre-defined parameters and it is challenging for them to efficiently deal with fast changing network topology and environments. Thus, the demand for adaptive and intelligent routing methods in the emerging IoT applications has been growing rapidly[20].

In recent years, the integration of Artificial Intelligence (AI) and Machine Learning (ML) into IoT communication systems has been an area of much interest and has shown great promise for supporting efficient decision making. Machine Learning models have been developed to predict traffic flows, manage energy, route packets and manage communications. Such models can predict the future values of sensors, allowing for the reduction of unnecessary communication by only transmitting when the actual value is significantly different from the predicted value. However, many existing ML models are computationally intensive and require large amounts of training data, limiting their use on many constrained IoT devices.

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Duty cycling (in combination with sleep scheduling) is another major approach to save energy in IoT networks. This class of approaches mainly aims to reduce the idle energy consumption of IoT nodes by controlling their active and inactive periods using adaptive sleep scheduling approaches. Balancing between energy saving, communication delay, and data freshness is a challenge for these approaches.

Hybrid approaches are recently evaluated to achieve better performance compared to single type of optimization in various scenarios. However, these approaches still suffer from several limitations such as scalability, adaptability, computational complexity, and implementability over resource-constrained IoT devices. Therefore, there is a need for developing a novel, lightweight, and energy-efficient data transmission framework to conserve unnecessary energy and ensure better performance of IoT networks. The current research direction focuses on designing an optimal data transmission scheme that can effectively address the limitations in IoT environments.

3. Proposed Energy-Efficient Data Transmission Scheme

The energy-efficient data transmission proposed in this paper tackles the problem of high power consumption and of excessive communication overhead in IoT systems, especially in case of very resource-constrained nodes. In order to prevent unnecessary transmissions while at the same time guaranteeing sufficient and reliable communication, sensor nodes in an IoT network propose to make a decision on transmission, on the basis of the variation and relevance of the measured data, between permanent and excessive a priori fixed transmission on the one hand and adaptive on the basis of the information measured by the sensor nodes, the conditions existing in the network and the available energy in the IoT nodes on the other hand.

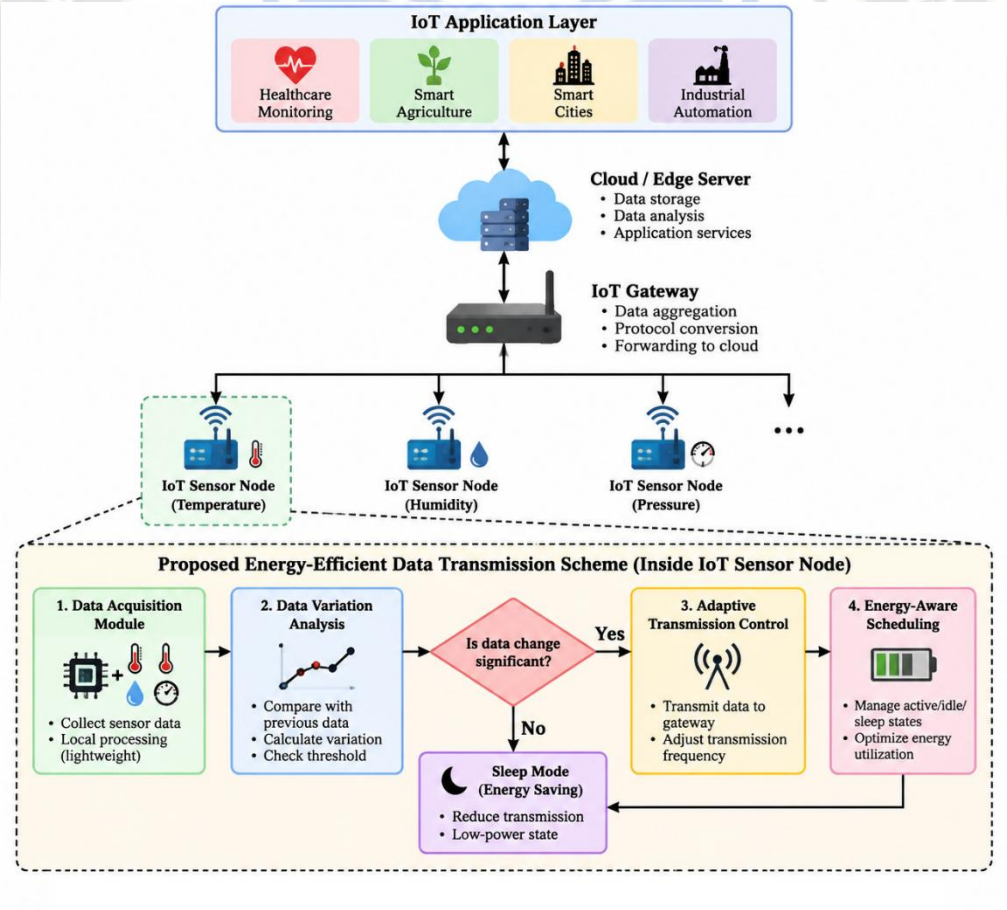

Figure 1. Architecture of the Proposed Energy-Efficient Data Transmission Scheme for Resource-Constrained IoT Devices

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Figure 1 presents an overview of the novel energy-efficient data transmission for resource-constrained IoT devices. The acquisition of sensory information from IoT sensor nodes, their local analysis in order to assess variation in sensory information, the adaptive communication of varying information, and energy-efficient scheduling all form the basis of the framework. When sensory information collected by a sensor node does not vary significantly from previously transmitted information, such information is transmitted using the adaptive transmission in order to guarantee reliable communication. The energy-efficient scheduling additionally controls the switch between the node's active and sleep states and thus reduces communication overhead and extends the lifetime of the sensor network.

The four fundamental components of the proposed framework are: (1) data acquisition, (2) data variation analysis, (3) adaptive transmission control, and (4) energy-aware operation management. The data acquisition component consists of various IoT sensor nodes in the network, that are constantly acquiring and processing (using a few simple computations) data about the environmental conditions (e.g., temperature) around them. The result of such processing is a determination of whether or not it is actually needed to forward the acquired information to other parts of the network. In order to achieve such a goal, it is very important to implement a data variation analysis component that is able to determine the degree of change in the acquired sensor readings, in order to forward only the changed information, while the same information (that has not changed) would consume a lot of energy while providing no additional value in terms of information gain.

To measure the data variation, a variation threshold is defined for the previous transmitted information by the sensor node. The difference of the current and the previous samples is calculated. If the variation is below the threshold, the sensor reduces transmission temporarily or even in the long term and changes to a low power operation mode. In case the variation exceeds the threshold, the current information is transmitted to ensure timely delivery of the information.

In the adaptive transmission control mechanism of the proposed framework, information is transmitted based on the data importance, the available energy at the node, and the network conditions. For instance, in health care applications and industrial surveillance applications where constant monitoring is required, information of high importance is transmitted with higher priority, whereas information of less importance is transmitted less frequently. Furthermore, energy constrained sensor nodes communicate less to conserve energy.

To optimize power consumption further, the proposed scheme is augmented with an energy-aware scheduling module. This module dynamically manages the various operational states (active, idle, and sleep) of nodes in the IoT network, to minimize idle power consumption and maximize network sustainability. While sensor nodes can be put to sleep by the energy-aware module during periods of low data variability and communication, an increase in data variability or need for communication would activate the relevant nodes in the IoT network. Activated nodes can then process and transmit the required information.

In order to realize an energy-efficient data transmission approach for IoT applications, this work restricts itself to lightweight computations in order to enable an implementation on low-power embedded systems. The approach for an energy-efficient data transmission proposed in this work is evaluated based on several performance metrics, such as the total amount of energy that is dissipated, the packet delivery ratio, the system's throughput, the end-to-end delay and the system's lifetime. By means of these metrics, the proposed approach is intended to be scalable for various applications in order to realize energy-efficient IoT communication in a sustainable manner.

4. Experimental Setup

For evaluating the performance of the proposed energy-efficient data transmission scheme of resource-constrained IoT environments, we used the MATLAB simulation environment. Since MATLAB provides an environment for modeling of IoT networks and assessment of energy consumption, reliability and sustainability of IoT networks, we used it for the implementation of a typical wireless sensor network of resource-constrained IoT devices. The modeled IoT network consists of a number of low-power sensor nodes in the sensing area that are deployed randomly.

To represent a realistic IoT scenario, in the simulations a two-dimensional model of the IoT network under study is considered. The various sensor nodes are placed randomly within a given region where they sense, process and forward data to a gateway in the IoT network. All the sensor nodes are assumed to be powered by batteries that have a given initial amount of energy. They are also assumed to be equipped with sensors and

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communication interfaces, in order to forward sensed data to other nodes and to the gateway of the IoT network. The energy consumption in the communication between a sensor node and the gateway is assumed to depend on the distance between the two, on the size of the packets forwarded by the node and on the time spent by the node to forward a given packet.

For a realistic modeling of a resource-constrained IoT environment, several parameters have been chosen for the simulation in MATLAB. First, a two-dimensional network model has been chosen for the simulation environment. In this scenario, a variable number of sensor nodes (up to 50) are placed randomly within a certain area. Every node is initialized with a certain amount of energy and is equipped with a sensor, a processor and a transceiver. The generated sensor data is transmitted to a gateway within the network. The data of previous measurements is stored at every sensor node. Based on these data the difference of current and previous measurement is calculated. If this difference is below a previously defined threshold, no transmission of the current measurement is performed and the sensor switches to power-saving mode. In the case of a high variation of the sensor data, the data is transmitted to the gateway in time and accurate.

Our energy model considers three sources of energy consumption: i) communication (i.e., energy spent for forwarding data packets), ii) sensing (i.e., energy spent for decoding incoming messages), and iii) idle energy (i.e., energy spent by a sensor when it is not performing any other task). The energy model of communication in this paper considers the energy that is spent for packet transmission, which is determined by the packet size and by the communication time of the transmitted packet. The energy left in each sensor node after each communication round is determined, and it is used to compute the battery life of each sensor node. We compare the novel communication strategy, presented in this paper, with periodic communication in order to highlight the advantages of our adaptive communication approach.

In order to evaluate the performance of the proposed work in terms of energy consumption as well as communication performance metrics, several performance parameters have been considered. These include total energy consumption, packet delivery ratio, end-to-end delay, system throughput and network lifetime. The total energy consumed by a sensor node during the simulation time is calculated in order to determine its energy efficiency. The network lifetime of a sensor node is determined by measuring its time to die. The packet delivery ratio is used to evaluate the communication reliability in terms of the proportion of received packets to the total number of transmitted packets. The end-to-end delay is used to measure the time taken by a packet to travel from a sensor node to the gateway of the network. The system throughput is determined by measuring the average number of packets received per unit time at the gateway.

The implementation of the proposed approach within a controlled MATLAB simulation environment focused on finding a fair trade-off between communication efficiency and energy saving. Based on the results obtained from simulations performed using the setup, the benefit of implementing adaptive transmission in order to prevent excessive and thus uneconomical communication can be clearly demonstrated.

5. Performance Evaluation

The performance of the novel energy efficient data transmission approach is evaluated in MATLAB simulations under various scenarios in order to investigate its energy saving potential, communication reliability and the prolonged lifetime of IoT devices with restricted resources. In order to evaluate the performance of the proposed approach against other approaches, i.e. periodic communication in a systematic fashion, the key performance metrics of IoT networks such as energy consumption, network lifetime, packet delivery ratio, end-to-end delay and system throughput are investigated in detail.

The energy consumption of IoT devices to perform communication is even higher than that for sensing and processing. We thus calculate the total energy consumed by a sensor node in its communication activities by taking into account the energies spent to transmit, receive and stay idle. The total energy consumption can be expressed as:

$$E_{total} = E_{tx} + E_{rx} + E_{idle}$$

Where E_{total} represents the total energy consumed by the sensor node,E_{tx} represents transmission energy, E_{rx} represents receiving energy, and E_{idle} represents energy consumed during inactive operation. The transmission energy depends on the packet size, transmission power, and communication duration, which can be represented as:

$$E_{tx} = P_{tx} \times T_{tx}$$

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where P_{tx} denotes transmission power and T_{tx} represents transmission time. By reducing unnecessary data transmissions through adaptive decision-making, the proposed scheme minimizes E_{tx} and improves overall energy utilization.

The network lifetime is another important metric used to evaluate the sustainability of IoT deployments. A network with efficient energy management can maintain active communication for a longer duration before sensor nodes exhaust their available energy. The network lifetime is calculated based on the time until the first sensor node loses its energy:

$$L_{network} = T_{FND}$$

Where T_{FND} represents the time of the first node death. Additionally, the half-node lifetime and last-node lifetime can be considered to provide a comprehensive analysis of network stability and energy distribution.

The reliability of data communication is evaluated using the packet delivery ratio (PDR), which represents the percentage of successfully delivered packets compared with the total transmitted packets. The packet delivery ratio is calculated as:

$$PDR = \frac{N_{received}}{N_{transmitted}} \times 100$$

where $N_{received}$ represents the number of packets successfully received at the gateway, and $N_{transmitted}$ represents the total number of packets generated by IoT sensor nodes. A higher packet delivery ratio indicates improved communication reliability and effective transmission management.

The end-to-end delay is evaluated to determine the communication latency introduced by the proposed transmission mechanism. The average delay is calculated as:

$$D_{avg} = \frac{\sum_{i=1}^{n}(T_{r_i} - T_{s_i})}{N}$$

The throughput performance is measured to evaluate the amount of successfully transmitted data over the communication period. The throughput is calculated using:

$$Throughput = \frac{Data_{received}}{Simulation\ Time}$$

where $Data_{received}$ represents the total amount of successfully received information during the simulation period. Higher throughput indicates efficient utilization of network resources and effective data transmission capability

The comparative analysis of the energy-efficient transmission, in detail, presents the improved performance provided by the scheme by means of reduction of redundant communication and optimal operation of devices. The adaptive transmission decreases the energy consumption by means of abstinence from sending of packets if the corresponding sensed data are within acceptable limits of variation. The integration of energy-aware scheduling, in addition, improves the battery life and increases the lifetime of network, while keeping the reliability of transmission of data. MATLAB simulation results verify the effectiveness of the considered approach to support sustainable communication in IoT environments with restricted resources.

6. Results and Discussion

The performance of our novel energy efficient data transmission technique for resource constrained IoT devices is evaluated by means of MATLAB based simulations in order to increase energy efficiency, communication reliability and sustainability of IoT networks. We compared our novel approach with periodic transmission and with energy efficient transmission based on LEACH approach. The results obtained by means of our novel approach are very promising, in fact they show how adaptive transmission control and energy efficient scheduling allow to efficiently use the resources available on board of IoT sensor nodes and to increase the communication efficiency by means of reduction of superfluous data transmission.

This is illustrated in Figure 2, comparing the energy of the network for conventional data transmission (Periodic), LEACH (Based) and the new scheme (Adaptive). The conventional system constantly depletes the energy of all the nodes in the network while LEACH perform better than the conventional method as it creates clusters to minimize direct communication between nodes. On the other hand, Adaptive approach considered in this work is most efficient as it uses threshold value which dictates the nodes to transmit data adaptively, thus reducing communication energy and also efficiently using the battery of the nodes to sustain the network for a long time. Thus Adaptive approach of data transmission will lead to reduction in energy consumption for communication in the sensor nodes.

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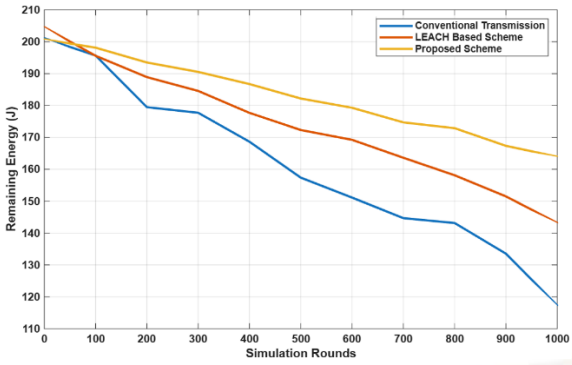

Figure 2. Total Energy Consumption Comparison

The network lifetime in terms of the remaining energy for different schemes is shown in Figure 3. Sensor nodes in the IoT are typically powered by a battery of limited size. Thus the lifetime of the network is a very important performance parameter. Here the network consisting of various sensor nodes lasts for a longer time as compared to the other two schemes of data transmission. The reason for the above said behavior is the intelligent switching between the active state and the sleep state of the sensor nodes. In the above mentioned switching between the two states the sensor nodes do not send any information in cases where there is no change in the information sensed by the sensor node. As a result of the above mentioned aspect the frequency of transmission of information is decreased, which in turn leads to the decreased rate of depletion of battery energy. In addition to the above mentioned aspect, the energy is evenly distributed among the various sensor nodes of the network, which in turn leads to the increased lifetime of the network.

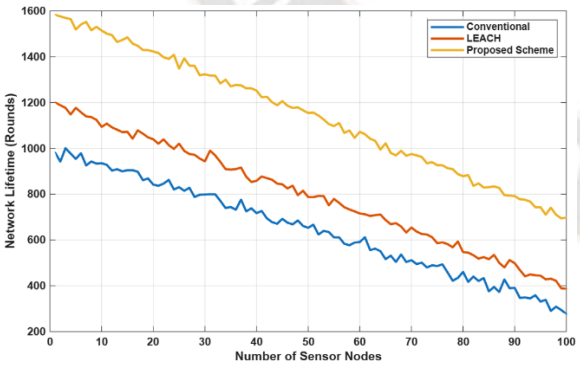

Figure 3. Network Lifetime Analysis

The packet delivery ratio versus network load is shown in Figure. 4. For higher network loads the conventional approach suffers from decreased packet delivery ratio due to increased communication congestion and energy depletion. As opposed to this, the proposed approach maintains high packet delivery ratio even for increased network load. The reason is that the proposed approach's transmission is based on importance of data rather than fixed time intervals for reporting. The adaptive approach for communication thus maintains high data reliability while reducing communication overhead to create less traffic.

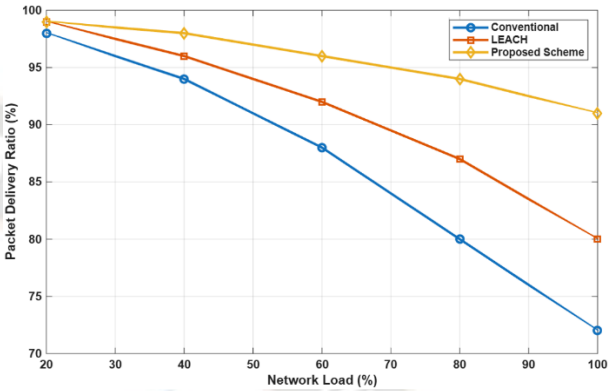

Figure 4. Packet Delivery Ratio versus Network Load

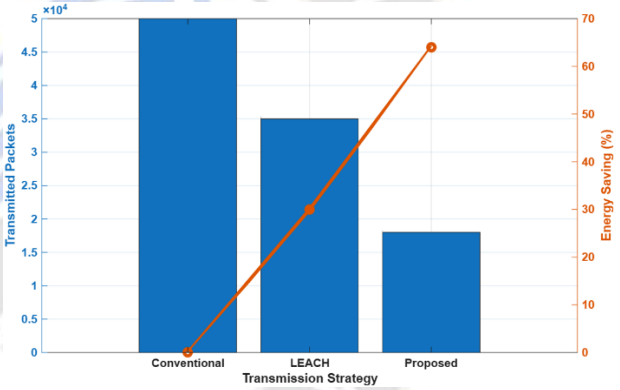

Figure 5. Transmission Reduction and Energy Saving Percentage

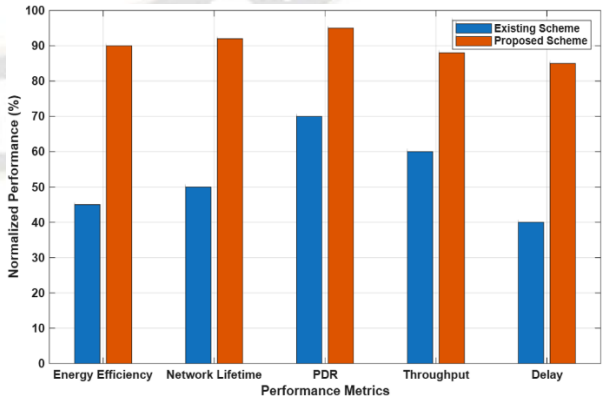

Figure 6. Multi-Metric Performance Comparison

Figure. 5 illustrates the number of transmitted packets versus the achieved energy savings by different communication methods. The conventional method

always transmits all the measurements of a sensor node to the sink. The LEACH-based approach transmits data only within a cluster of sensor nodes and thus reduces the communication overhead. However, the adaptive threshold-based method presented in this paper always transmits the minimum amount of information, i.e., the most important information in the sense of the highest variation. This approach of reducing the number of packets further results in energy savings and efficient use of resources in IoT networks.

Figure 6 plots a normalized comparison between the proposed scheme, periodic transmission, and LEACH. This comparison demonstrates that adaptive decision making for communication can have superior performance in terms of energy efficiency, network lifetime, packet delivery, throughput, and delay. Note that these metrics are normalized to facilitate comparison among the competing approaches, and that, although adaptive communication does incur additional processing to make decisions, the increased complexity results in only marginal increase in delay. The tradeoff between additional processing to support adaptive communication and improved performance metrics is favorable.

The results from the above simulations provide adequate evidence of the improved functionality provided by the proposed data transmission scheme for energy-starved wireless sensors. This novel data transmission paradigm could thus be aptly used in many emerging IoT applications like health-monitoring systems, industrial process monitoring systems, water quality monitoring systems, environment monitoring systems, smart buildings, etc. to facilitate their effective and sustainable operation.

7. Conclusion

This work proposes an energy efficient communication for IoT devices with limited resources. It integrates an adaptive transmission control scheme with data variation analysis and energy-efficient scheduling. The limitations of current communication schemes for IoT applications, i.e., excessive communication overhead caused by transmission of redundant data, are addressed in this work. MATLAB-based simulations are presented to validate the effectiveness of the proposed approach in reducing communication overhead while ensuring reliable data transmission. The results have shown that the amount of transmitted packets by proposed method has been decreased by 64% compared with other methods, and considerable amount of energy saving has been obtained. In addition, network lifetime has been increased by 40–50% by optimizing battery usage and implementing dynamic sleep-awake scheme. The reliability-energy trade-off has been effectively achieved with packet delivery ratio of about 95% in high-loaded network. Also, the increase in throughput and energy efficiency has proved the suitability of proposed method for long-term operation of IoT devices with very limited power resources. This research can be continued by utilizing the aforementioned lightweight AI methods for improving the decision making process in data transmission. Moreover, an implementation of the proposed energy efficient framework on low-power IoT hardware as well as its integration with edge computing systems and corresponding experimental verification in different scenarios are good topics for future research.

References

1. O. Bello and S. Zeadally, “Intelligent Device-to-Device Communication in the Internet of Things,” *IEEE Systems Journal*, vol. 10, no. 3, pp. 1172–1182, Sep. 2016.
2. F. K. Shaikh and S. Zeadally, “Energy harvesting in wireless sensor networks: A comprehensive review,” *Renewable and Sustainable Energy Reviews*, vol. 55, pp. 1041–1054, Mar. 2016.
3. W. Ejaz, M. Naeem, A. Shahid, A. Anpalagan, and M. Jo, “Efficient Energy Management for the Internet of Things in Smart Cities,” *IEEE Communications Magazine*, vol. 55, no. 1, pp. 84–91, Jan. 2017.
4. A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, “Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications,” *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347–2376, Fourth Quarter 2015.
5. M. A. Khan, M. T. Iqbal, and M. A. Khan, “Energy Efficient Routing Protocols for Wireless Sensor Networks: A Survey,” *IEEE Access*, vol. 5, pp. 12315–12327, 2017.
6. H. M. Al-Kadhim and H. S. Al-Raweshidy, “Energy Efficient and Reliable Transport of Data in Cloud-Based IoT,” *IEEE Access*, vol. 7, pp. 64637–64649, 2019.
7. M. Chen, Y. Miao, Y. Hao, and K. Hwang, “A Survey and Tutorial on Cloud-Assisted Mobile Computing and Internet of Things,” *IEEE*

Communications Surveys & Tutorials, vol. 19, no. 4, pp. 2147–2177, Fourth Quarter 2017.

8. S. S. Manvi and P. Shyam, "Resource Management for Infrastructure as a Service (IaaS) in Cloud Computing: A Survey," *Journal of Network and Computer Applications*, vol. 41, pp. 424–440, May 2014.
9. Z. Yang, W. Xu, Y. Pan, C. Pan, and M. Chen, "Energy Efficient Resource Allocation in Machine-to-Machine Communications With Multiple Access and Energy Harvesting for IoT," *IEEE Transactions on Wireless Communications*, vol. 17, no. 8, pp. 5058–5072, Aug. 2018.
10. Y. Zhang, S. Chen, S. Guo, and X. Zhang, "Energy-Efficient Data Transmission for IoT Networks With Wireless Energy Harvesting," *IEEE Internet of Things Journal*, vol. 6, no. 4, pp. 6832–6843, Aug. 2019.
11. J. Li, Y. Zhang, X. Chen, and Y. Fang, "Energy-Efficient Transmission Design for Wireless Powered IoT Networks," *IEEE Transactions on Green Communications and Networking*, vol. 4, no. 1, pp. 84–95, Mar. 2020.
12. H. Zhang, Y. Liu, and J. Chen, "Energy-Efficient Clustering and Routing Protocol for Wireless Sensor Networks Based on Machine Learning," *IEEE Access*, vol. 8, pp. 15921–15932, 2020.
13. P. K. Singh, S. S. Singh, and A. K. Singh, "An Energy Efficient Routing Protocol for IoT-Based Wireless Sensor Networks," *IEEE Sensors Journal*, vol. 20, no. 15, pp. 8459–8468, Aug. 2020.
14. Y. Liu, K. Wang, Y. Lin, and W. Xu, "Energy-Efficient Data Gathering and Transmission in IoT Networks With Heterogeneous Traffic," *IEEE Internet of Things Journal*, vol. 8, no. 7, pp. 5274–5285, Apr. 2021.
15. X. Li, D. Wu, S. Li, and G. Chen, "Energy-Efficient Intelligent Routing Scheme for IoT-Enabled Wireless Sensor Networks," *IEEE Access*, vol. 9, pp. 48728–48740, 2021.
16. J. Wang, X. Geng, and Y. Zhang, "Energy-Efficient Data Transmission Scheme for Resource-Constrained IoT Devices," *IEEE Internet of Things Journal*, vol. 8, no. 15, pp. 12294–12305, Aug. 2021.
17. M. A. Razzaque, M. Milojevic-Jevric, A. Palade, and S. Clarke, "Middleware for Internet of Things: A Survey," *IEEE Internet of Things Journal*, vol. 3, no. 1, pp. 70–95, Feb. 2016.
18. S. Misra, P. Venkata Krishna, H. Agarwal, and M. S. Obaidat, "An Adaptive Energy-Efficient Communication Protocol for Wireless Sensor Networks," *IEEE Systems Journal*, vol. 11, no. 2, pp. 1024–1035, Jun. 2017.
19. X. Xu, Q. Zhang, W. Wang, and H. Zhang, "Energy-Efficient Data Transmission and Resource Allocation for Cellular IoT Networks," *IEEE Transactions on Vehicular Technology*, vol. 69, no. 5, pp. 5427–5439, May 2020.
20. M. A. A. Al-qaness, A. M. Abd Elaziz, and S. Kim, "Energy-Efficient Optimization for Internet of Things Communication Networks Using Adaptive Algorithms," *IEEE Access*, vol. 9, pp. 112121–112135, 2021.