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Survey on Enhancing Energy Efficiency in Wireless Sensor Networks Based on Rapid Data Collection

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Abstract

Wireless Sensor Networks (WSNs) are widely used in various applications such as environmental monitoring, healthcare, and business automation. These networks rely on the integration of sensors to collect data quickly. However, operating WSNs efficiently, especially in scenarios where quick and reliable data acquisition is crucial, faces significant challenges due to the limited power resources of sensor nodes. This survey paper provides a detailed review of current methodologies and techniques focused on improving energy efficiency in WSNs for fast data collection. It begins by discussing the basic concepts of wireless sensor networks, highlighting the important role sensors play in gathering accurate information. Afterwards, the paper provides a summary of the issues surrounding power usage, underscoring the importance of creative solutions to prolong the network's longevity. An extensive section of the study delves into various energy-efficient protocols and algorithms aimed at improving data collection in Wireless Sensor Networks (WSNs). The paper classifies these approaches according to their strategies for forming clusters, communication protocols, and optimization algorithms.

Keywords: Sensor Integration, Data Collection, Energy Efficiency, Rapid Data Acquisition, Limited Energy Resources.

1. Introduction

Wireless Sensor Networks (WSNs) have become a game-changing technology that allows for continuous monitoring and data analysis in various fields like environmental monitoring, healthcare, industrial automation, and smart cities. These networks are made up of small sensor nodes that work together to collect, process, and send information to a central hub. WSNs are versatile and can be scaled up or down depending on the needs of the application, making them ideal for quick and efficient data gathering in diverse environments. However, a key challenge in operating WSNs is the limited power supply for each sensor node. Because AI models rely on batteries for power, it's crucial to have efficient power management strategies in place to ensure optimal network longevity and functionality. The need for fast data collection in time-sensitive applications adds complexity to the equation, making it necessary to develop creative approaches for energy optimization without compromising on the prompt and dependable acquisition of information.

There are many different clustering techniques that have been developed for Wireless Sensor Networks (WSNs) to improve energy efficiency. One of the most well-known techniques is Low Energy Adaptive Clustering Hierarchy, also known as LEACH. LEACH and its variations are fundamental to

the design of hierarchical WSNs. Recent developments in machine learning and deep learning have provided innovative solutions for optimizing energy usage in sensor networks. The aim is to provide a detailed overview of the latest energy-efficient practices in WSNs by conducting a thorough literature review, particularly focusing on their application in real-time data collection scenarios. Additionally, the review will carefully assess the constraints and potential areas for improvement in the current body of knowledge, which will guide future research endeavours. As WSNs progress towards more dynamic settings, the implementation of power-efficient strategies is crucial for ensuring the long-term sustainability and effectiveness of these innovative networks.

Although advancements have been made in wireless sensor network (WSN) technology, efficient and fast data collection is still a major challenge, particularly in situations where real-time information is needed. The main issue lies in the limitations of sensor nodes, such as limited energy resources, processing capabilities, and communication bandwidth. Quick data collection in WSNs is essential for various applications like environmental monitoring, healthcare, and industrial automation in smart cities, where timely and accurate information is crucial for decision-making processes.

The paper starts with an interesting introduction that explains the importance of energy-efficient statistics series in wireless sensor networks (WSNs). A clear problem statement outlines the challenges in this field, setting the stage for the survey. The scope and objectives section defines the parameters and goals, leading the reader through a thorough literature review that forms the basis for the analysis. A structured classification and taxonomy system offer an organized framework for presenting current WSN protocols, with a focus on energy efficiency.

In-depth comparison measures, including both conventional and innovative ones, offer a complete assessment of the examined methods. The crucial evaluation stage examines the pros and cons of protocols, enhancing understanding of design choices. Scrutinizing emerging trends and technologies illuminates the future outlook. Suggestions for upcoming research offer valuable perspectives, while the summary highlights important discoveries, underlining the survey's impact on advancing knowledge in WSNs and efficient data gathering. The structure of the paper guarantees a coherent progression, allowing readers to navigate the intricacies of WSN research smoothly.

3. LITERATURE REVIEW

The surveyed literature provides valuable insights into the realm of Wireless Sensor Networks (WSNs) and energy-efficient techniques for rapid data collection.

Generally, advancement made in Information and Communication Technology (ICT) has led to the development of wireless communication networks. Majority of wireless networks are used in various applications that help in sharing of information. Initially developed wireless network was first generation (1G). Later on, second generation (2G), third generation (3G), fourth generation (4G) was developed until fifth generation (5G) as of today. Further research works were being carried out to step into next generation of wireless network. Some research work related to evolution of wireless communication network will be discussed as follows.

Kurt et al. (2001) had designed a technique connecting several kinds of optimized access system, core network platform and common IP-employed medium access that can be used to develop wireless network beyond 3G network. The interworking of various access networks will be carried out through vertical and horizontal handover, global roaming, and service negotiation. These access networks can be effectively utilized in various applications and in different surrounding environments. These networks were assigned to different layers of cell as like of hierarchical cells. This arrangement was

performed on the basis of varying mobility, coverage and cell size to provide effective service to the users. Along with the above-mentioned technique, new air interference can be utilized to achieve reduced cost, increased mobility, and high speed of data.

Vasos et al. (2002) had presented the design of Radio Access Network (RAN) that was appropriate for next generation of communication such as 3G and 4G networks. Previously, the second generation of networks was deployed successfully using various architecture and that made them to work effectively with their own ability. But, demand of people towards high-speed data was growing tremendously. For satisfying the want and necessity of the users, next generation of network must be designed. Hence for transferring into next generation RAN was utilized in the present work. This RAN functions based on Hierarchical Mobile IP (HMIP) and Multi-Protocol Label Switching (MPLS). With the assist of this present technique, following benefits can be achieved: fast switching, fast table lookup, reduced latency handoffs, scalability, fast deployment, and lower. The developed architecture utilizing RAN can be used effectively in 3G network as well as in 4G networks without any modifications.

Hak et al. (2009) had designed Real Option Approach (ROA) for assessing effective transition of wireless network from 2G to 3G. This transition was majorly carried out to increase the speed of data services. Many information systems and multimedia rely on these high-speed data to assist the service provider in gaining more profit in future. So, to satisfy this approach 3G based technologies must be developed. This developed technology must achieve high quality service with minimal cost. But, entirely migrating the existing 2G network to 3G was slightly a difficult task. To accomplish this migration of network effectively migrate path was needed to be selected. Many approaches were developed by authors for selecting migration path. In the present work for selecting migration path Code Division Multiple Access (CDMA), Global System for Mobile Communications (GSM) was utilized and to access these selected migration paths on the way to 3G network Real Option Approach (ROA) was utilized.

Tinatin et al. (2012) extensively discussed evolution of wireless communication network and its impact on human’s life. The evolution of wireless network had reached fourth generation of network previously. In development of every generation of network a slight modification was made either in performance or in efficiency. Basically, first generation of network had provided primary voice. Further coverage and capacity were included in the second generation and in third generation mobile data was offered. To enhance speed of mobile data services as well as other requirements, fourth generation of network came into existence. Developed fourth generation of network may provide access to a wide range of services and further improve the data rates' speed.

Dario et al. (2014) had designed Radio-Access Network-As-A-Service (RANaaS) architecture to achieve energy efficiency for making advancement in 5G network. Developed architecture was found to be an effective concept. This helps to centralize function of RAN partially based on network features and their necessity. This present design based on cloud system will helps to attain effective utilization of network resources. The main motive of this present work was to attain energy efficiency with the assist of RANaaS and to design a model adopting consistent system-level power for improving function employed in 5G network. Virtualization of RAN will be progressed to meet incremental benefits needed in IT platforms. To evaluate performance attained on utilizing RANaaS architecture an analysis was carried out in terms of energy efficiency.

T. Wang et al. (2017): The paper proposes a fog structure with mobile sinks to enhance data collection from Wireless Sensor Networks (WSNs) to the Cloud. Mobile sinks act as fog nodes, forming a Multi-

Input Multi-Output (MIMO) network to maximize throughput and minimize transmission latency. The authors address the hotspot problem with a detailed routing algorithm, proving the NP-hard nature of the problem. The proposed method, supported by an approximation algorithm, outperforms traditional solutions

Xiaoxiao Zhuo et al. (2020): Zhuo and team address challenges in the Internet of Underwater Things (IoUT) by proposing an Autonomous Underwater Vehicle (AUV)-aided Underwater Acoustic Sensor Networks (UWSNs). They formulate an optimization problem to maximize energy consumption utility, balancing energy and network throughput. The approach involves cluster-based networks, a novel clustering algorithm, a Media Access Control (MAC) protocol, and AUV path planning. Two algorithms, AEEDCO and AEEDCO-A, are developed, demonstrating promising performance for large-scale communication, high data traffic load, and long-term monitoring in UWSNs.

S. N. Mohanty et al. (2020): Mohanty et al. propose a Deep Learning-Based Distributed Data Mining (DDM) model for Wireless Sensor Networks (WSN) to enhance energy efficiency and load balancing. The model, RNN-LSTM, reduces fusion center overhead and data transmission, achieving lower energy requirements. Simulations reveal improved throughput and reduced delays compared to other methods, highlighting the potential of RNN-LSTM in energy-efficient data collection for WSNs.

T. A. Alghamdi (2020): Alghamdi addresses energy efficiency in WSNs, focusing on optimal Cluster Head (CH) selection. The paper introduces a hybrid algorithm combining dragonfly and firefly algorithms for CH selection based on energy, delay, distance, and security criteria. The proposed approach demonstrates improved performance in terms of the number of alive nodes, network energy, delay, and risk probability compared to conventional models.

B. Jiang et al. (2020): Jiang et al. propose a Trust-Based Energy-Efficient Data Collection with Unmanned Aerial Vehicle (TEEDC-UAV) scheme for large-scale Internet of Things (IoT) systems. The scheme optimizes UAV trajectory through an ant colony-based algorithm, ensuring efficient data collection and trust-based sensor node selection. Experimental results show significant improvements in network life and trust degree identification compared to previous strategies.

Mohan Sahoo et al. (2020): Sahoo et al. tackle the challenge of limited sensor node battery life in Wireless Sensor Networks (WSN) using a Particle Swarm Optimization (PSO)-based Energy-Efficient Clustering and Sink Mobility (PSO-ECSM) algorithm. The proposed algorithm optimizes cluster head selection and introduces sink mobility for multi-hop network data traffic. Simulation results indicate improvements in stability period, network lifetime, and throughput compared to existing methods.

Umesh Kumar Lilhore et al. (2022): Lilhore et al. propose an energy-efficient routing protocol for Underwater Wireless Sensor Networks (UWSN) based on an enhanced genetic algorithm and data fusion technique. The protocol adjusts the depth of lower energy nodes and employs an enhanced cluster head selection strategy. Simulations demonstrate improved packet delivery ratio, reduced energy consumption, and enhanced overall network energy balance.

Zivkovic et al. (2020): Zivkovic and team introduce an Improved Grey Wolf Algorithm for optimizing network lifetime in Wireless Sensor Networks (WSN). The algorithm, applied to cluster formation and cluster head selection, outperforms traditional methods such as LEACH and Particle Swarm Optimization in simulations. The study highlights the potential of swarm intelligence heuristics in addressing the energy consumption challenge in WSNs.

Machine Learning-Based Approaches: S. N. Mohanty et al. (2020) propose a Deep Learning-Based Distributed Data Mining (DDM) version, RNN-LSTM, aimed towards improving strength overall performance and cargo balancing in WSNs. The version reduces fusion middle overhead and statistics transmission, carrying out lower strength necessities. Simulations display advanced throughput and reduced delays in comparison to distinct techniques, emphasizing the capability of gadget studying-primarily based tactics in electricity-efficient information series for WSNs [Mohanty et al. 2020].

Innovative Architectures and Optimization: T. Wang et al. (2017) contribute through the usage of providing a fog shape with cellular sinks to enhance records collection from WSNs to the Cloud. This revolutionary architecture entails cellular sinks acting as fog nodes in a Multi-Input Multi-Output (MIMO) network. The paper addresses challenges like hotspots and proves the NP-difficult nature of the trouble through an extensive routing set of guidelines. Their proposed method, supported through an approximation algorithm, outperforms conventional answers, showcasing the importance of progressive architectures in optimizing information collection in WSNs [Wang et al. 2017].

Table 1Review of the literature

Year	Author(s)	Methodology	Merits	Limitation
2016	Vishal Kumar Aror et al	Comparative analysis of six LEACH variants: LEACH-C, MM-LEACH, TL-LEACH, SEP, V-LEACH, and MOD-LEACH	Identified lack of classification as a drawback, limited examination to only six LEACH descendants	Lack of classification, limited examination to only six LEACH descendants
2017	T. Wang et al.	Proposed a fog structure with mobile sinks for data collection from WSNs to the Cloud, utilizing a Multi-Input Multi-Output (MIMO) network	Detailed routing algorithm to address hotspot problem, outperformed traditional solutions	NP-hard nature of the problem, hotspot problem
2017	Rishikesh et al	Review focused on LEACH protocol and its enhancement protocols, comparing them based on data aggregation, nodes' mobility, and scalability	Identified disadvantages: lack of taxonomy for classifying discussed protocols, omission of highlighting other factors and advantages/disadvantages of each protocol	Lack of taxonomy for classification, omission of highlighting other factors
2018	Mohammed Al-Shalabi	Overview of LEACH and its variants, categorized LEACH-based routing protocols into CHs selection and clusters formation	Provided insights into advantages, weaknesses, and contributions of various protocols	Lacked showcase of many WSNs metrics, some protocols not detailed
2019	Adnan Yousaf et al	Evaluated energy consumption evolution of several LEACH-derived protocols, particularly focusing on CH election mechanism	Limited by absence of taxonomy for classifying routing protocols, presented only eight variants of LEACH	Absence of taxonomy for classification, focused on few factors while omitting other main metrics
2019	Adnan Yousaf et al	Described LEACH and variant protocols, emphasizing communication techniques between CHs and the final destination	Identified limitations: lack of classification, absence of metrics for comparing protocols in terms of residual energy, scalability, energy efficiency, mobility, etc.	Lack of classification, absence of metrics for comparison

Year	Author(s)	Methodology	Merits	Limitation
2019	Pitchaimanickam & Murugaboopathi	Proposed Hybrid Firefly Algorithm with Particle Swarm Optimization (HFAPSO) for optimal cluster head selection in LEACH-C algorithm	Showed improvements in network lifetime, increased alive nodes, and reduced energy utilization compared to Firefly Algorithm	Focused on specific algorithm, may lack generalizability
2019	Jyoti Bhola et al.	Presented energy-efficient routing protocol, LEACH enhanced by Genetic Algorithm (GA) for WSNs	Demonstrated a reduction of 17.39% in energy consumption using GA, comparative analysis showed efficiency	Focused on specific algorithm, may lack generalizability
2020	Xiaoxiao Zhuo et al.	Addressed challenges in IoUT with AUV-aided UWSNs, formulated optimization problem for energy consumption utility, developed clustering algorithm, MAC protocol, and AUV path planning	Developed two algorithms, AEEDCO and AEEDCO-A, promising performance for large-scale communication, high data traffic load, and long-term monitoring in UWSNs	Focused on specific environment and algorithm, may lack generalizability
2020	S. N. Mohanty et al.	Proposed Deep Learning-Based Distributed Data Mining (DDM) model, RNN-LSTM, for WSNs to enhance energy efficiency and load balancing	Reduced fusion center overhead and data transmission, improved throughput and reduced delays compared to other methods	Focused on specific algorithm, may lack generalizability
2020	T. A. Alghamdi	Addressed energy efficiency in WSNs, introduced hybrid algorithm combining dragonfly and firefly algorithms for CH selection	Demonstrated improved performance in terms of the number of alive nodes, network energy, delay, and risk probability compared to conventional models	Focused on specific algorithm, may lack generalizability
2020	B. Jiang et al.	Proposed Trust-Based Energy-Efficient Data Collection with UAV (TEEDC-UAV) for IoT systems, optimized UAV trajectory through ant colony-based algorithm	Showed significant improvements in network life and trust degree identification compared to previous strategies	Focused on specific environment and algorithm, may lack generalizability
2020	Mohan Sahoo et al.	Tackled limited sensor node battery life in WSNs using PSO-based Energy-Efficient Clustering and Sink Mobility (PSO-ECSM) algorithm	Achieved improvements in stability period, network lifetime, and throughput compared to existing methods	Focused on specific algorithm, may lack generalizability
2022	Umesh Kumar Lilhore et al.	Proposed an energy-efficient routing protocol for UWSNs based on enhanced genetic algorithm and data fusion technique	Demonstrated improved packet delivery ratio, reduced energy consumption, and enhanced overall network energy balance	Focused on specific environment and algorithm, may lack generalizability
2020	Zivkovic et al.	Introduced Improved Grey Wolf Algorithm for optimizing network lifetime	Outperformed traditional methods such as LEACH and Particle Swarm Optimization in simulations	Focused on specific algorithm, may lack generalizability

Year	Author(s)	Methodology	Merits	Limitation
		in WSNs, applied to cluster formation and CH selection		
2023	Ala' Khalifeh et al.	A selective activation (SA) technique is used. Qualnet simulator and its performance has been evaluated	Enhances the energy efficiency of the IEEE 802.15.4 protocol.	Many related works should be done to take into consideration the physical obstacles within the wireless communication channel between the nodes.

5. CONCLUSION

The literature reviewed provides valuable insights into the placement of Wireless Sensor Networks (WSNs) and energy-efficient methods for real-time data collection. The study of hierarchical routing protocols emphasizes ongoing initiatives to improve energy efficiency in WSNs. The use of optimization techniques, such as genetic algorithms and machine learning-based approaches, indicates a rising trend in utilizing advanced methods to address power consumption issues. Cutting-edge designs, like fog systems with mobile sinks, demonstrate a comprehensive approach to optimizing data collection strategies. Despite progress, the surveys and papers examined frequently reveal limitations. Inclusive of the lack of systematic kind systems and the omission of important metrics in the evaluation of protocols.

6. APPLICATIONS

Various applications of WSNs are used in past days and also present days. WSN applications are classified as namely are: military, health, environmental, Education, agriculture, industrial, and urban.

6. FUTURE DIRECTIONS

In this paper, it is suggested that a wider range of metrics should be considered for protocol evaluations, including residual energy, scalability, and mobility. Future studies could look into combining swarm intelligence heuristics and machine learning algorithms to improve adaptive and practical Wireless Sensor Networks (WSNs). Practical implementations and real-world validations of proposed protocols are also necessary to ensure their effectiveness in different scenarios. Given the continued importance of WSNs in various applications, the development of energy-efficient strategies is crucial for maximizing network lifetime and overall performance.

REFERENCES

[1] Yang, Z., Chen, M., Saad, W., Hong, C. S., & Shikh-Bahaei, M. (2020). Energy efficient federated learning over wireless communication networks. IEEE Transactions on Wireless Communications, 20(3), 1935-1949.

[2] Ogbebor, J. O., Imoize, A. L., & Atayero, A. A. A. (2020). Energy efficient design techniques in next-generation wireless communication networks: emerging trends and future directions. Wireless communications and mobile computing, 2020, 1-19.

[3] Yang, Z., Chen, M., Saad, W., Xu, W., Shikh-Bahaei, M., Poor, H. V., & Cui, S. (2021). Energy-efficient wireless communications with distributed reconfigurable intelligent surfaces. IEEE Transactions on Wireless Communications, 21(1), 665-679.

[4] Yang, Z., Chen, M., Saad, W., Xu, W., Shikh-Bahaei, M., Poor, H. V., & Cui, S. (2021). Energy-efficient wireless communications with distributed reconfigurable intelligent surfaces. IEEE Transactions on Wireless Communications, 21(1), 665-679.

[5] Jia, S., Yuan, X., & Liang, Y. C. (2020). Reconfigurable intelligent surfaces for energy efficiency in D2D communication network. IEEE Wireless Communications Letters, 10(3), 683-687.

[6] Alamu, O., Gbenga-Ilori, A., Adelabu, M., Imoize, A., & Ladipo, O. (2020). Energy efficiency techniques in ultra-dense wireless heterogeneous networks: An overview and outlook. Engineering Science and Technology, an International Journal, 23(6), 1308-1326.

[7] Alamu, O., Gbenga-Ilori, A., Adelabu, M., Imoize, A., & Ladipo, O. (2020). Energy efficiency techniques in ultra-dense wireless heterogeneous networks: An overview and outlook. Engineering Science and Technology, an International Journal, 23(6), 1308-1326.

[8] Chowdhury, S. M., & Hossain, A. (2020). Different energy saving schemes in wireless sensor networks: A survey. Wireless Personal Communications, 114(3), 2043-2062.

[9] Han, S., & Bian, S. (2020). Energy-efficient 5G for a greener future. Nature Electronics, 3(4), 182-184.

[10] Nakas, C., Kandris, D., & Visvardis, G. (2020). Energy efficient routing in wireless sensor networks: A comprehensive survey. Algorithms, 13(3), 72.

[11] Jin, R., He, X., & Dai, H. (2022). Communication efficient federated learning with energy awareness over wireless networks. IEEE Transactions on Wireless Communications, 21(7), 5204-5219.

[12] Ahmed, S., Chowdhury, M. Z., & Jang, Y. M. (2020). Energy-efficient UAV-to-user scheduling to maximize throughput in wireless networks. IEEE Access, 8, 21215-21225.

[13] Wang, Q., Zhou, F., Hu, R. Q., & Qian, Y. (2020). Energy efficient robust beamforming and cooperative jamming design for IRS-assisted MISO networks. IEEE Transactions on Wireless Communications, 20(4), 2592-2607

[14] Zhuo, X., Liu, M., Wei, Y., Yu, G., Qu, F., & Sun, R. (2020). AUV-aided energy-efficient data collection in underwater acoustic sensor networks. IEEE Internet of Things Journal, 7(10), 10010-10022.

[15] Bhola, J., Soni, S., & Cheema, G. K. (2020). Genetic algorithm based optimized leach protocol for energy efficient wireless sensor networks. Journal of Ambient Intelligence and Humanized Computing, 11, 1281-1288.

[16] Mohanty, S. N., Lydia, E. L., Elhoseny, M., Al Otaibi, M. M. G., & Shankar, K. (2020). Deep learning with LSTM based distributed data mining model for energy efficient wireless sensor networks. Physical Communication, 40, 101097.

[17] Wang, T., Zeng, J., Lai, Y., Cai, Y., Tian, H., Chen, Y., & Wang, B. (2020). Data collection from WSNs to the cloud based on mobile Fog elements. Future Generation Computer Systems, 105, 864-872.

[18] Jiang, B., Huang, G., Wang, T., Gui, J., & Zhu, X. (2022). Trust based energy efficient data collection with unmanned aerial vehicle in edge network. Transactions on Emerging Telecommunications Technologies, 33(6), e3942.

[19] Sahoo, B. M., Amgoth, T., & Pandey, H. M. (2020). Particle swarm optimization based energy efficient clustering and sink mobility in heterogeneous wireless sensor network. Ad Hoc Networks, 106, 102237.

[20] Lilhore, U. K., Khalaf, O. I., Simaiya, S., Tavera Romero, C. A., Abdulsahib, G. M., & Kumar, D. (2022). A depth-controlled and energy-efficient routing protocol for underwater wireless sensor networks. International Journal of Distributed Sensor Networks, 18(9), 15501329221117118.

[21] Zivkovic, M., Bacanin, N., Zivkovic, T., Strumberger, I., Tuba, E., & Tuba, M. (2020, May). Enhanced grey wolf algorithm for energy efficient wireless sensor networks. In 2020 zooming innovation in consumer technologies conference (ZINC) (pp. 87-92). IEEE.

[22] Pitchaimanickam, B., & Murugaboopathi, G. (2020). A hybrid firefly algorithm with particle swarm optimization for energy efficient optimal cluster head selection in wireless sensor networks. Neural Computing and Applications, 32, 7709-7723.

[23] Vishal Kumar Arora (Research Scholar), Vishal Sharma, Monika Sachdeva, Asurvey on LEACH and other's routing protocols in wireless sensor network, Optik127 (16) (2016) 6590–6600.

[24] Adnan Yousaf, Faiza Ahmad, Shahzaib Hamid, Fahad Khan, Performance comparisonof various LEACH protocols in Wireless Sensor Netw., in: 2019 IEEE 15thInternational Colloquium on Signal Processing & Its Applications, CSPA, IEEE,2019, pp. 108–113.

[25] M. Mahmuddin, W.A. Alabadleh, L.M. Kamarudin, A comparative study onhoping mechanism of LEACH protocol in Wireless Sensor Netw.: A survey, IOPConf. Ser. Mater. Sci. Eng. 551 (2019) 012056.

[26] Rishikesh, Abhijeet Das, Parma Nand Astya, A relative survey of various LEACHbased routing protocols in wireless sensor networks, in: 2017 InternationalConference on Computing, Communication and Automation, ICCCA, IEEE, 2017,pp. 630–636.

[27] Mohammed Al-Shalabi, Mohammed Anbar, Tat-Chee Wan, Ahmad Khasawneh,Variants of the low-energy adaptive clustering hierarchy protocol: Survey, issuesand challenges, Electronics 7 (8) (2018) 136.