Analysis of Energy-efficient Techniques for SDWSN Energy Usage Optimization

Ishmael Mathebula
Department of Computer Science
North-West University
Mafikeng, South Africa
ishimathebula@gmail.com

Bassey Isong
Department of Computer Science
North-West University
Mafikeng, South Africa
isong.bassey@ieee.org

Naison Gasela
Department of Computer Science
North-West University
Mafikeng, South Africa
naison.gasela@nwu.ac.za

Adnan M. Abu-Mahfouz
Council for Scientific and
Inductarial Research (CSIR)
Pretoria, South Africa
a.abumahfouz@ieee.org

***Abstract*— Software-Defined Wireless Sensor Networks (SDWSN) has received significant attention in recent years due to its inherent challenges such as network security, trust management, inefficient energy consumption, and so on. In particular, inefficient energy utilization has remained a core critical challenge as sensor nodes are naturally resource constraint and mostly deployed in unattended environments. This challenge has a direct impact on SDWSN performance and reliability. Albeit, several techniques have been proposed and developed to address the challenge in the traditional WSN and few for SDWSN, optimal efficient energy utilization is yet to be achieved. Therefore, this paper survey some of the energy efficiency techniques reported in the literature. The goal is to gain insights into these techniques, strategies employed, their pros and cons which could be utilized to design an efficient-energy mechanism for SDWSN. The findings obtained show that the existing approach ensures efficient energy utilization and improve network performance. While some have routing protocol and security mechanisms, fault tolerance, and battery fault detector mechanisms are not incorporated.**

Keywords*— *WSN, SDWSN, Energy Efficiency, Security.

I. Introduction

Wireless sensor network (WSN) is a network paradigm that has received significant attention in recent years in terms of development and deployment to address the inherent limitations confronting the network technology. The technology is inherently resource-constrained which includes network security challenges, high energy utilization on the battery-powered sensor during sensor computation, and so on [1], [2]. With these challenges, given the context, distribution, and the heterogeneous nature of today's networks, the traditional networks find it difficult to cope with complex network challenges [3], [4]. Consequently, the Software Defined Network (SDN) paradigm was developed to improve networking and to dynamically manage network resources. On the WSN perspective, SDN incorporation resulted to a paradigm called software-defined wireless sensor network (SDWSN) which has been known as the building block for the Internet of Things (IoT) and serves as a network technology that aims to resolve most issues faced by WSN [5]–[7].

SDWSNs is an SDN-based network combined distributed sensor nodes that can sense, transmit, communicate, and compute information on a particular environment. This deployed sensor nodes communicate with each other, transmitting and receiving packets in the form of a relay to the base stations. During the relay, nodes are required to convey sensed data with less computation and without consuming too much energy resources. In most cases, sensor nodes are deployed in an unattended environment and it is important to ensure security on the network as they are prone to attacks and threats. To this end, encryption is one of the effective security mechanisms traditionally guard against attacks such as eavesdropping [8], [9]. In general, SDWSN comes with great benefits and improvements to the WSN such as network programmability, security, energy efficiency, collision detection, etc. [10], [11].

Despite the benefits of SDWSN, several challenges inherent to the traditional WSN still exist. In particular, is the energy efficiency challenges faced by traditional WSN [12]. Inefficient energy utilization in the WSN is an important challenge that requires proactive attention as an optimal solution is yet to be achieved. However, several solutions have been proposed and developed, but more research is needed to ensure that efficiency is at its optimum. Therefore, this paper surveyed and analyze some of the existing energy efficiency mechanisms reported in the literature to optimize them for SDWSN to ensure a long lifespan and network reliability especially on the sensors [13]. That is, this paper aimed at providing insight into the existing techniques and how they could be used to solve the energy problem of SDWSN sensors. The adopted energy efficiency schemes should not only consider prolonging network lifetime, but it should also consider security, fault tolerance, trust management, and so on.

The remaining sections of this paper are structured as follows: Section II presents energy efficiency in SDWSN. Sections III and IV discuss the existing energy-efficient solutions and discussions respectively. Lastly, sections V and VI present the related works and the conclusion of the paper.

II. Energy Efficiency in SDWSN

WSN has various limitations which include network security, quality of service (QoS), inefficient power utilization, real-time data management, network programmability, and management [14]–[16]. The introduction of SDN, particularly, SDWSN is centered on providing solutions to the various WSN challenges. With sensor networks development, network reliability challenge is considered one of the most significant research area that requires improvement as it is related to energy [17]–[20]. Previous literature highlights that SDWSN has the potential to improve energy usage by endorsing strategies that can relieve sensor nodes from intensive computations due to the control plane and the data plane coupling [21], [22]. Accordingly, recent SDWSN's energy efficiency solutions propose sleep scheduling strategies that are managed on the control plane which reduces power utilization on sensor nodes and increases network life span [13], [23]. Costanzo *et al.* [24] stated that SDWSN considers energy consumption strategies adopted from traditional WSNs such as cross-layer optimization and duty cycling. Thus, energy efficiency is the most important aspect of designing SDWSN. Moreover, energy utilization is categorized into three functional areas namely; data-processing domain, sensing domain, and the communication domain which requires optimization [25], [26]. In the post-deployment of SDWSN sensor nodes, the lifespan of sensor nodes relies on the battery lifespan. A sensor node architecture has a sensing unit which is responsible for environmental sensing while its power unit ensures the availability of the entire sensor node interconnected to the power harvester component. The architecture also consists of the communication and the computation components.

Some of the concepts associated with energy efficiency and their rationale are discussed as follows:

1) Network lifespan vs energy consumption: The lifespan of a wireless network relies mostly on the utilization of battery energy on sensors [27]. Dead sensor nodes can have a negative impact on the network lifetime, this can lead to inefficient energy consumption due to the rearrangement of the efficient routing path, and unnecessary computation [28]. Thus, efficient power utilization and energy preservation management schemes are significant during the design and deployment of SDWSN, to extend network lifespan and ensure persistency during conditions of uncertainty. Sensor nodes deployed in an SDWSN environment requires a certain amount of energy to complete the required computation [29]. The power consumption rate on the sensor node must be equivalent to avoid depletion of node battery power which can result in network failure. External energy sources such as wind energy and solar power are often used to preserve energy on nodes [30], but since external energy gets interrupted the aim should be to minimize energy utilization techniques to prolong network lifetimes.

2) Routing protocol: Routing is the process of forwarding packets from the source node to the desired destination node on the network and packets transmission is one of the critical functions of SDWSN sensor nodes [31]. The taxonomy of routing protocols includes geographic routing [32], [33], clustering routing [19], [34], and data-centric routing [35]. Efficient routing protocols play a major role in the network, the algorithms to improve power consumption, prevent against sensor nodes attacks, and reduce sensor node failures. Designing robust routing protocols is a major problem due to inconstant energy on the network. That is, it is unknown how long the nodes will remain active to receive and forward packets that are broadcasted, making packet broadcasting difficult [36]. Most routing protocols lack security vulnerabilities and fail to ensure the CIA property [27], [37]. Lack of efficient routing protocols significantly has a significant impact on the battery energy depletion and the network lifetime on SDWSN [38].

3) Energy harvesting: Sensor nodes battery has a short or limited power lifespan [19], therefore, it is imperative to design techniques that will ensure less energy consumption and extends the SDWSN network lifespan. Energy harvesting has been considered as a favorable solution that can be used to minimize energy inefficiency limitation on sensor nodes [42] [43]. Energy harvesting can be achieved by utilizing natural resources such as hydroelectric power, solar energy, vibrational energy, etc. Traditionally wind power and Solar energy are the common renewable form of energy that is mostly used on wireless networks [39], [44]–[46]. On Solar energy, energy can be harvested during the day and stored for later use, i.e. load profile controllers play a significant role. According to [39], the sensor's battery life is extremely utilized during computation, sensing, and wireless communication. Thus, the energy harvesting mechanism is important to ensure the continuous operation of the sensors.

III. Analysis Of Existing Approaches, Challenges and Solutions

SDWSN is a powerful network paradigm that has significantly improved the dynamics of wireless sensor networks is largely adopted in the industry and academia for small, medium, and large networks due to the advantages the technology offer [47]. In this section, we performed a survey on existing energy efficiency in WSN and SDWSN using the content analysis approach to identify energy-efficiency techniques and protocols that can be potentially used to optimize energy efficiency in the SDWSN. An in-depth analysis of the papers considered was performed and parameters used to identify techniques used for energy efficiency and other mechanisms on sensor nodes are efficient resource utilization techniques, battery failure detection mechanisms, exception handling, and routing mechanisms, network performance, security, and implementation. These parameters were all used to evaluate each paper for adoption. TABLE I present the summary of each paper while TABLE II presents the quality associated with each approach.

A. Wang et al.[48]

Wang *et al.* [48] introduced ETMRM that aims to improve trust management, energy-efficiency, routing mechanism for SDWSNs as well as simultaneously eliminate net-flow and selective forwarding attacks. This approach adopts the use of trust routing protocols, trust management, and report message aggregating methods to decrease energy utilization and increase security on SDWSN. Wang *et al.* [48], claimed that the proposed solution can efficiently identify and counters act when the network is posted with Black-hole, new-flow, and

Grey-hole attacks. Some of the advantages identified on ETMRM [48] are; improved node residual energy and trust level, prolonged network lifetime, balanced and decreased energy consumption. One of the drawbacks of ETMRM [48] is that it only focuses only on malicious forwarding attacks and the trust management scheme does not cater to trust between the SDWSN controller and SDWSN network applications to detect malicious applications.

B. *Yang et al. [49]*

Yang *et al.* [49], presented a Cross-layer Energy Efficiency (CEE) model proposed to handle high energy consumption. CEE model integrates the three network layers operation namely; the network layer, data link layer, and the physical layer. The CEE scheme employed nodes placement information on the network layer, it utilizes the MAC protocol in the MAC layer and the physical layer for full-duplex interfaces i.e. interfaces of nodes.

TABLE I. SUMMARY OF ENERGY-EFFICIENCY TECHNIQUES IN WSN AND SDWSN

Authors	**Strategy or scheme used**	**Implemented / Simulated**	**Advantage (Pros)**	**Restriction or limitation identified (Disadvantages)**
Wang *et al.* [48]	- Trust management and routing mechanism	- Implemented (Prototype)	- Packet delivery ratio enhancement - Energy consumption minimization and balancing - Lengthens network lifetime but experiences lower control overhead, node's residual energy and trust level	- The proposed solution focuses much on SDWSN security issues - Only focuses only on malicious forwarding attacks - Lack of trust management between the controller and network applications.
Yang *et al.* [49]	- Cross-layer transmission model	- Simulation or Model, theoretical analysis	- improvement throughput, Increased energy efficiency, low delay - The proposed solution can be used for IoT	- The proposed cross-layer model does not include practical applications
Chen *et al.* [50]	- EeB	- Simulation (MNET++)	- Enhance network upgrade performances and reliability	- Sensor nodes are too naive - Redundant packets retransmissions
Chu-Fu *et al.* [51]	- EASR method	- Simulation - Theoretical and numerical analysis	- EASR method can significantly extend the network lifetime	- It uses theoretical analysis and numerical analysis during the evaluation - This scheme was not implemented
Guerroumi *et al.* [52]	- Dynamic power threshold and sink mobility scheme	- Simulation	- Improves power consumption on the source node and nodes playing a part in the data dissemination action. - Stable response time - Energy consumption and density increases in parallel	- Only the detected events - User's requests are not considered in this protocol - The scheme does not focus on security on the network, their assumption is the network is already secured
Ejaz *et al.* [53]	- Energy-efficient scheduling scheme - The wireless power transfer scheme	- Simulation	- It has sensor node charging techniques - Ensures efficient energy utilization	- The proposed solution was simulated it was not implemented - The proposed solution does not address how sensor nodes can overcome path losses during energy transmission
Zhou *et al.* [54]	- Energy-Balanced Heuristic	- Experiment (Prototype)	- This scheme creates an optimal grid cell division. - During the experiment, it was noted that the network lifetime can be improved by the scheme as compared to Prin.	- The grid overlay was not tested on many sensors node
Kadel *et al.* [55]	- Adaptive Error Control Code	- Simulation	- Adaptability is supported at the receiver and transmitter - The scheme merges a combination of multiple techniques	- The scheme cannot detect battery failure
Lei *et al.* [56]	- Controller handover	- Simulation	- The scheme is superior that the E-TORA and LEACH-C in terms of reducing energy consumption - The balance energy consumption extends the lifetime of the network	- This approach does not cater for Network Performance and network security. - There was no accurate evaluation on controller handover mechanism
Xinying *et al.* [57]	- Energy hierarchy, - DACR	- Simulation	- This scheme has efficient routing protocols that ensure the lifetime of the network	- The proposed scheme lack fault-tolerant techniues to cater for faults occurring during packet transmission. - The scheme cannot ensure security on the network.

Authors in [49] highlighted that based on the performance evaluation, their proposed model significantly decreases power utilization and increases performance transmissions. It was also claimed that their proposed model offers the following benefits: power control, energy efficiency, reduced packet transmission delay, and improved throughput. The approaches applied in CEE addresses power consumption challenges on WSNs without affecting any transmission performances.

C. Chen et al. [50]

Chen *et al.* [50], proposed an Energy-efficient Broadcast (EeB) scheme with the aim to advance network upgrade performance. This scheme adopts a novel strategy for expanding the radius transmission of data packets for nodes that are distant from the base nodes using their residual energy. EeB scheme has a modifiable broadcasting radius and the non-hot-spots sensor nodes use the remaining energy produced during the process of collecting data and concurrently enhance network reliability and advance network upgrade delay. Moreover, it decreases broadcasting delay by expanding the broadcasting radius i.e. transmitting energy. In this approach [50], the authors claimed that nodes only broadcast its packets once, this prevents packet repetition or retransmission packet, i.e. reducing residual energy. Nevertheless, redundant or retransmissions packet is still experienced by the scheme, and nodes are unable to confirm whether transmitted code packets were obtained by the nearby nodes causing them to retransmissions packet unnecessary.

D. Chu-Fu et al. [51]

Chu-Fu *et al.* [51] introduced an Energy-Aware Sink Relocation (EASR) technique that is used to expand the network lifetime for mobile sinks in WSNs. The strategies employed in EASR [51] put into focus the residual battery power of sensor nodes to modify the sensor nodes transmission range and adjust the sink relocating scheme (which instructs the sink where and when to locate to). This scheme uses numerical simulation and mathematical performance to analyses and shows how the EASR method increases the network lifespan on WSN. It also employs an energy-efficient routing scheme that integrates with the EASR scheme which aims to ensure energy efficiency. The EASR technique utilizes the energy-aware routing Maximum Capacity Path (MCP) as the core routing method relay messages. The MCP method is used to check the routing path on the network. Authors in [51] claim that the results from the simulation indicate their energy efficiency scheme performed better than the other network lifetime methods.

E. Guerroumi et al. [52]

Guerroumi *et al.*[52] proposed a new data dissemination protocol based energy management scheme that utilizes a dynamic energy threshold and a new sink mobility scheme for network load balancing on sensor nodes, thus enhancing network performances [52]. This protocol is established on the virtual grid structure containing a head selected frequently in accordant to the dynamic power threshold. Authors in [52] claimed that the protocol increases network lifespan by cutting down energy consumption using cluster head management and nodes having high residual energy are elected as cluster heads. To evaluate the new protocol's effectiveness and performance, Glomosim simulator was used to compare it against the LEACH and CODES protocols. The results obtained show the new protocol outperformed these two protocols. However, the shortcoming of this protocol is that it does not cover the user's requests.

F. Ejaz et al. [53]

Ejaz *et al.* [53] introduced an SDWSN wireless power transfer scheme to ensure the continuous operation of sensor nodes. To determine the optimal solution, the authors in [53] applied the branch and bound algorithm and it supports the optimal placement of the energy transmitters, which checks the minimum number of power transmitters. The proposed solution also deploys a utility function mechanism to ensure fair energy distribution and to increase the energy-charged on the SDWSN's sensor nodes. Additionally, the energy transmitters in this scheme also have power-efficient scheduling techniques for energy-charging. The benefit of this proposed scheme its ability to ensure less power consumption and ensures that sensor nodes are charged automatically. [53]Ejaz *et al* used binary integer linear programming to manage the challenge of efficient power utilization taking into consideration the requirement for energy harvesting.

G. Zhou et al. [54]

Zhou *et al.*[54] introduced a triple-phase Energy-Balanced Heuristic scheme [54] that aims to solve the challenge of ensuring optimal network lifespan and energy efficiency while scheduling mobile sinks. This achieved by dividing the network region into grid cells with an equivalent geographical size [54], to represent the network region, grid overlay was used. The scheme was developed using Java program and the techniques use a k dimensional tree algorithm to assign the grid cells to clusters which ensures that the utilization of energy for each cluster is the same during sink movement and data gathering. To evaluate the performance of the scheme, experimental results indicate that the scheme created optimal grid cell division thus, increases the network lifespan.

H. Kadel et al. [55]

Kadel *et al.* [55] proposed an adaptive SDWSN error control framework that utilizes the forward error correction (FEC) and SDN features to ensure network reliability, adaptability, and dependability. The framework supports a heterogeneous network by using various FECs on various sections of the link of a network. The techniques minimize energy utilization for power-constrained sensor nodes, leading to increased network lifespan. It applies the sensor node energy-constrained properties on data-centric storage-network. Its benefit lies in allowing adaptability both at the receiver and transmitter, and it combines several strategies that ensure energy efficiency and adaptive error control code implementation. However, the drawback is that the simulations performed did not consider the performance of the network, rather the performance of standalone FEC's Codes.

I. Lei et al. [56]

Lei *et al.* [56] introduced an energy consumption algorithm that ensures energy efficiency using the controller handover technique. This is achieved by selecting an eligible sensor node to take over as the new controller to reduce the residual energy of the controller. The selecting system was simulated using MATLAB neural network toolbox and the results show the superiority of the approach over approaches like the E-TORA and LEACH-C in terms of reducing energy consumption on the network and increasing the lifespan of the network. However, the approach lacks an accurate evaluation of the controller handover mechanism to ensure its reliability.

J. Xinying et al. [57]

Xinying *et al.* [57] also proposed an SDWSNs energy efficiency approach that is based on energy shell, energy hierarchy, and Dynamic Adjusting Communication Radius. On the proposed algorithm, the node with a high energy hierarchy is considered to relay data and as compared to other existing algorithms. Results show that the energy-efficient approach has a better energy balance, network lifetimes, and network consumption compare to other schemes.

TABLE II. SUMMARY OF QUALITY ANALYSIS

Ref	**Energy Efficiency**	**Battery Failure Detection**	**Fault tolerance**	**Routing protocols**	**Network Performance**	**Security**	**Implementation**
[48]	Yes	Yes	No	Yes	Yes	Yes	Yes
[49]	Yes	No	No	Yes	Yes	Yes	No
[50]	Yes	No	No	Yes	Yes	Yes	No
[51]	Yes	No	No	Yes	Yes	No	No
[52]	Yes	No	No	Yes	Yes	No	No
[53]	Yes	No	No	No	Yes	No	No
[54]	Yes	No	No	No	Yes	No	No
[55]	Yes	No	Yes	No	No	No	No
[56]	Yes	No	No	Yes	No	No	No
[57]	Yes	No	No	Yes	Yes	No	No

IV. DISCUSSIONS

The lack of energy efficiency on wireless networks introduces problems such as hardware and software failure, and dead sensor nodes [58]. This is due to the resource-constrained nature of sensor nodes such as low storage and energy capacity, low computation, and processing power as well as low communication bandwidth [59]. Moreover, this also results in the links between the sensors being always prone to failure and other security threats posed to it. As it stands, inefficient energy consumption is one of the challenges that need more attention during the design of an SDWSN. Thus, to save energy, it is important to deploy sensor nodes that can be redundant when idle or jobless and allow their neighbors to manage their sleeping schedules to lengthen up the node energy life-cycle while satisfying both network observability and connectivity requirements [60]. To achieve this, several approaches have been designed, proposed, and developed as shown in the analysis of some of the approaches reported above to address energy efficiency problems. TABLE I present a summary of the studies considered in this paper while TABLE II presents whether the schemes meet the parameters considered for a good energy-efficient system.

The analysis indicates that all the approaches were energy-efficient while some incorporated security, the ability to detect a failing battery, routing protocol, validated by the implementation, and so on. For instance, Wang *et al.* [48] scheme focused on both energy efficiency and network security and was implemented. [53] and [54] proposed approaches with routing protocols and network security. Moreover, all approaches did not incorporate mechanism fault tolerance and exception handling; a limitation that has to be addressed while the majority of the studies did not show the implementation of the approach, making it questionable to accept its effectiveness. Though these approaches were proposed to address energy efficiency, it worth knowing that some form of limitations still exist since efficiency is not optimal yet in the SDWSN. Thus, there is still the need for improvement especially by ensuring that they cater to some of the materials parameters outlined in TABLE II.

V. RELATED WORKS

Energy utilization remains a critical requirement when designing wireless sensor network systems. This section presents some of the related works on energy efficiency surveys and reviews in WSN and SDWSN. Buzzi *et al.* [61] conducted a survey of energy efficiency for 5G wireless networks. Their findings showed energy efficiency plays a major role when designing communication networks, and highlighted several other network challenges that need to be solved before addressing the energy efficiency problems in totality. Hameed *et al.* [62] also surveyed cloud-based systems focusing on energy-efficient resource allocation strategies. They focused on energy inefficiencies problems in software and hardware systems and identify existing techniques, outline the pros and cons of each technique. In another study, Balobaid [63] conducted a survey that compares different existing energy-efficient MAC protocols on WSN. The survey aimed at improving performance on MAC protocols and identify the advantages and disadvantages of each protocol. Moreover, routing protocol plays a critical role in ensuring energy efficiency, thus, Al-Mekhlafi *et al.* [64] researched on routing protocol for energy harvesting on WSN. They elaborated on different protocols that can be used to reduce energy utilization and improve sensor nodes' lifetime. Similarly, Ali [65] also presented a survey on SDN approaches that can utilize energy efficiency constraints in WSN. The findings obtained provided evidence that SDN approaches can be used to decrease energy utilization in WSN via control and data plane separation. However, it was evident that the decoupling between the planes does not solve energy efficiency challenges on SDWSN.

The above highlights some of the related survey. However, this work remains different since it focuses on understanding existing energy efficiency schemes that stand the chance of being optimized along other parameters to address energy efficiency in the SDWSN paradigm. This is important to improve its performance, reliability, and security. To the best of our knowledge, no review focuses on identifying existing energy efficiency schemes that can be adopted to address energy efficiency in the SDWSN. Moreover, the summary of the quality analysis in Table II shows that amongst all approaches considered in this paper. As can be seen, the work in [55] is the only approach that incorporated fault tolerance mechanism called the FEC and scheme for error correction and detection. Nevertheless, [55] lacks the property of battery failure detection. The study also shows that [48] can detect battery failure but lacks fault tolerance. In order to avoid this in the SDWSN, it is therefore important to implement an energy-efficient technique that has both fault tolerance and battery failure detection mechanisms which will in turn significantly decrease energy utilization.

VI. Conclusion

Inefficient consumption of energy on wireless sensor nodes remains a critical challenge because sensors are resource-constrained and therefore, it is imperative to pay more attention to research on energy optimization techniques to increase the life-time of SDWSN and its reliability. Though research has been proposed and developed to improved energy efficiency on WSN, some of these approaches can also be used to optimize efficient energy utilization in SDWSN. This paper has analyzed and presented the findings from existing approaches to address energy efficiency challenges. TABLE II presents the advantages and disadvantages of each analyzed energy efficiency schemes. The aim was to explore the technique used to manage energy on sensor nodes to prolong network lifespan to improve the SDWSN. The study findings show that all approaches reduced energy overheads and increase network performance by incorporating mechanisms such as routing protocol, while others introduced security measures to secure the network. Moreover, mechanisms such as fault tolerance, battery failure detector were not incorporated while most studies did not show their implementation, thereby putting a question mark on their claims. Given the findings, SDWSN should be designed by considering parameters such as energy efficiency, network performance, fault tolerance, scalability, time efficiency, security, and so on to make it more secure and dependable. As for future works, we intend to design energy-efficient trust management and fault tolerance for the SDWSN.

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References

[1] B. B. Letswamotse, R. Malekian, C. Y. Chen, and K. M. Modieginyane, "Software defined wireless sensor networks (SDWSN): A review on efficient resources, applications and technologies," *J. Internet Technol.*, vol. 19, no. 5, pp. 1303–1313, 2018.

[2] K. M. Modieginyane, B. B. Letswamotse, R. Malekian, and A. M. Abu-Mahfouz, "Software defined wireless sensor networks application opportunities for efficient network management: A survey," *Comput. Electr. Eng.*, vol. 0, pp. 1–14, 2017.

[3] Z. Latif, K. Sharif, F. Li, M. M. Karim, and Y. Wang, "A Comprehensive Survey of Interface Protocols for Software Defined Networks," pp. 1–30, 2019.

[4] L. Zhu, M. M. Karim, K. Sharif, F. Li, X. Du, and M. Guizani, "SDN Controllers: Benchmarking & Performance Evaluation," pp. 1–14, 2019.

[5] R. Tumuluri, A. Kovi, and B. K. Raju Alluri, "An Energy-efficient algorithm using layer heads for Software-Defined Wireless Sensor Networks," *Proc. 2018 Int. Conf. Recent Trends Adv. Comput. ICRTAC-CPS 2018*, pp. 103–108, 2019.

[6] I. Mathebula, "Analysis of SDN-Based Security Challenges and Solution Approaches for SDWSN Usage," *2019 IEEE 28th Int. Symp. Ind. Electron.*, pp. 1288–1293, 2020.

[7] K. Sood, S. Yu, and Y. Xiang, "Software-Defined Wireless Networking Opportunities and Challenges for Internet-of-Things: A Review," *IEEE Internet Things J.*, vol. 3, no. 4, pp. 453–463, 2016.

[8] J. Yao, Z. Han, and M. Sohail, "A Robust Security Architecture for SDN-Based 5G Networks," pp. 1–14, 2019.

[9] T. Mahboob, I. Arshad, A. Batool, and M. Nawaz, "Authentication Mechanism to Secure Communication between Wireless SDN Planes," *Proc. 2019 16th Int. Bhurban Conf. Appl. Sci. Technol. IBCAST 2019*, pp. 582–588, 2019.

[10] M. Karakus and A. Durresi, "Economic Viability of Software Defined Networking (SDN)," *Comput. Networks*, vol. 135, pp. 81–95, 2018.

[11] W. Ziyin, W. Muqing, and Z. Min, "Design and Analysis of Dual-Channel Structure for Software-Defined Wireless Sensor Networks," *2018 IEEE 4th Int. Conf. Comput. Commun.*, pp. 889–893, 2018.

[12] A. De Gante, M. Aslan, and A. Matrawy, "Smart wireless sensor network management based on software-defined networking," *2014 27th Bienn. Symp. Commun.*, pp. 71–75, 2014.

[13] T. Zhao, H. Wang, M. Mukherjee, and L. Shu, "Design of a low control-flow overhead-based software-defined wireless sensor network with link failure," *ICNC-FSKD 2017 - 13th Int. Conf. Nat. Comput. Fuzzy Syst. Knowl. Discov.*, pp. 2805–2811, 2018.

[14] S. V. Manisekaran and R. Venkatesan, "An analysis of software-defined routing approach for wireless sensor networks," *Comput. Electr. Eng.*, vol. 56, pp. 456–467, 2016.

[15] H. C. Silva, A. Pereira, Y. Solano, B. T. de Oliveira, and C. B. Margi, "WARM: WSN Application development and Resource Management," *Xxxiv Simp. Bras. Telecomunicacões*, pp. 708–712, 2016.

[16] A. Msolli, A. Helali, and H. Maaref, "New security approach in real-time wireless multimedia sensor networks," *Comput. Electr. Eng.*, vol. 0, pp. 1–16, 2018.

[17] H. I. Kobo, G. P. Hancke, and A. M. Abu-Mahfouz, "Towards a distributed control system for software defined Wireless Sensor Networks," *IECON 2017 - 43rd Annu. Conf. IEEE Ind. Electron. Soc.*, vol. 2, no. October, pp. 6125–6130, 2017.

[18] S. Kumari *et al.*, "User authentication schemes for wireless sensor networks: A review," *Ad Hoc Networks*, vol. 27, no. 3, pp. 159–194,

2015.
[19] C. M. Liu *et al.*, “Energy efficient data aggregation in wireless sensor networks,” *ACM Int. Conf. Proceeding Ser.*, vol. 2015-June, no. 1, pp. 34–40, 2018.
[20] Z. Ding, S. Xing, F. Yan, W. Xia, and L. Shen, “An interference-aware energy-efficient routing algorithm with quality of service requirements for software-defined WSNs,” *IET Commun.*, vol. 13, no. 18, pp. 3105–3116, 2019.
[21] D. A. G. Oliveira and C. B. Margi, “Combining Metrics for Route Selection in SDWSN: Static and Dynamic Approaches Evaluation,” *Proc. - 2018 10th IEEE Latin-American Conf. Commun. LATINCOM 2018*, pp. 1–6, 2019.
[22] L. Yajun, W. Muqing, and Z. Min, “Network-Balanced Algorithm Based on Hierarchical Subnet Space for Software- Defined Wireless Sensor Networks,” *2018 IEEE 4th Int. Conf. Comput. Commun.*, pp. 894–898, 2018.
[23] M. Mukherjee, L. Shu, T. Zhao, K. Li, and H. Wang, “Low control overhead-based sleep scheduling in software-defined wireless sensor networks,” *Proc. - 18th IEEE Int. Conf. High Perform. Comput. Commun. 14th IEEE Int. Conf. Smart City 2nd IEEE Int. Conf. Data Sci. Syst. HPCC/SmartCity/DSS 2016*, pp. 1236–1237, 2017.
[24] S. Costanzo, L. Galluccio, G. Morabito, and S. Palazzo, “Software Defined Wireless Network (SDWN): An evolvable architecture for W-PANs,” *2015 IEEE 1st Int. Forum Res. Technol. Soc. Ind. RTSI 2015 - Proc.*, pp. 23–28, 2015.
[25] S. Karthik and A. A. Kumar, “Challenges of Wireless Sensor Networks and Issues associated with Time Synchronization,” *Ijana*, no. Special issue, pp. 19–23, 2015.
[26] K. S. Adu-Manu, C. Tapparello, W. Heinzelman, F. A. Katsriku, and J. D. Abdulai, “Water quality monitoring using wireless sensor networks: Current trends and future research directions,” *ACM Trans. Sens. Networks*, vol. 13, no. 1, 2017.
[27] N. Kumar and D. P. Vidyarthi, “A Green Routing Algorithm for IoT-Enabled Software Defined Wireless Sensor Network,” *IEEE Sens. J.*, vol. 18, no. 22, pp. 9449–9460, 2018.
[28] P. Kuila and P. K. Jana, “Energy efficient clustering and routing algorithms for wireless sensor networks: Particle swarm optimization approach,” *Eng. Appl. Artif. Intell.*, vol. 33, pp. 127–140, 2014.
[29] R. Kadel, K. Ahmed, and A. Nepal, “Adaptive error control code implementation framework for software defined wireless sensor network (SDWSN),” *2017 27th Int. Telecommun. Networks Appl. Conf. ITNAC 2017*, vol. 2017-Janua, pp. 1–6, 2017.
[30] Deepti and S. Sharma, “Piezoelectric energy harvesting and management in WSN using MPPT algorithm,” *Proc. 2016 IEEE Int. Conf. Wirel. Commun. Signal Process. Networking, WiSPNET 2016*, pp. 2228–2232, 2016.
[31] W. Xiang, N. Wang, and Y. Zhou, “An Energy-Efficient Routing Algorithm for Software-Defined Wireless Sensor Networks,” *IEEE Sens. J.*, vol. 16, no. 20, pp. 7393–7400, 2016.
[32] C. Petrioli, M. Nati, P. Casari, M. Zorzi, and S. Basagni, “ALBA-R: Load-balancing geographic routing around connectivity holes in wireless sensor networks,” *IEEE Trans. Parallel Distrib. Syst.*, vol. 25, no. 3, pp. 529–539, 2014.
[33] X. Yang, D. Deng, and M. Liu, “An overview of routing protocols on Wireless Sensor Network,” *Proc. 2015 4th Int. Conf. Comput. Sci. Netw. Technol. ICCSNT 2015*, vol. 01, no. Iccsnt, pp. 1000–1003, 2016.
[34] H. Y. Shwe and P. H. J. Chong, “WSN-based energy-efficient data communication protocol for smart green building environment,” *INTELEC, Int. Telecommun. Energy Conf.*, vol. 2016-Septe, pp. 1–5, 2016.
[35] K. Wrona, M. Amanowicz, S. Szwaczyk, and K. Gierlowski, “SDN testbed for validation of cross-layer data-centric security policies,” *2017 Int. Conf. Mil. Commun. Inf. Syst. ICMCIS 2017*, pp. 1–6, 2017.
[36] F. Engmann, F. A. Katsriku, J. D. Abdulai, K. S. Adu-Manu, and F. K. Banaseka, “Prolonging the Lifetime of Wireless Sensor Networks: A Review of Current Techniques,” *Wirel. Commun. Mob. Comput.*, vol. 2018, 2018.
[37] L. Schehlmann, S. Abt, and H. Baier, “Blessing or curse? Revisiting security aspects of Software-Defined Networking,” *Proc. 10th Int. Conf. Netw. Serv. Manag. CNSM 2014*, no. 1, pp. 382–387, 2015.
[38] M. Benaddy, B. El Habil, M. El Ouali, O. El Meslouhi, and S. Krit, “A mutlipath routing algorithm for wireless sensor networks under distance and energy consumption constraints for reliable data transmission,” *Proc. - 2017 Int. Conf. Eng. MIS, ICEMIS 2017*, vol. 2018-Janua, pp. 1–4, 2018.
[39] H. I. Kobo, A. M. Abu-Mahfouz, and G. P. Hancke, “A Survey on Software-Defined Wireless Sensor Networks: Challenges and Design Requirements,” *IEEE Access*, vol. 5, pp. 1872–1899, 2017.
[40] M. A. Razzaque and S. Dobson, “Energy-Efficient Sensing in Wireless Sensor Networks Using Compressed Sensing,” pp. 2822–2859, 2014.
[41] G. Thangarasu, P. D. D. Dominic, K. Subramanian, M. Bin Othman, and R. Sokkalingam, “An Efficient Energy Consumption Technique in Integrated WSN-IoT Environment Operations,” *2019 IEEE Student Conf. Res. Dev. SCOReD 2019*, pp. 45–48, 2019.
[42] I. Ahmed, M. M. Butt, C. Psomas, A. Mohamed, I. Krikidis, and M. Guizani, “Survey on energy harvesting wireless communications: Challenges and opportunities for radio resource allocation,” *Comput. Networks*, vol. 88, no. 2015, pp. 234–248, 2015.
[43] J. Meyer, H. Meyer, and G. Von Colln, “An Energy Measurement System for Characterization of Energy Harvesting Systems,” *IEEE Int. Conf. Emerg. Technol. Fact. Autom. ETFA*, vol. 2018-Septe, pp. 1225–1228, 2018.
[44] H. Sharma, A. Haque, and Z. A. Jaffery, “Solar energy harvesting wireless sensor network nodes: A survey,” *J. Renew. Sustain. Energy*, vol. 10, no. 2, 2018.
[45] H. U. Yildiz, V. C. Gungor, and B. Tavli, “A hybrid energy harvesting framework for energy efficiency in wireless sensor networks based smart grid applications,” *2018 17th Annu. Mediterr. Ad Hoc Netw. Work. Med-Hoc-Net 2018*, pp. 1–6, 2018.
[46] H. Sharma, A. Haque, and Z. A. Jaffery, “An efficient solar energy harvesting system for wireless sensor nodes,” *2018 2nd IEEE Int. Conf. Power Electron. Intell. Control Energy Syst. ICPEICES 2018*, vol. 3, pp. 461–464, 2018.
[47] R. Thupae, B. Isong, N. Gasela, and A. M. Abu-Mahfouz, “Software defined wireless sensor networks mangement and security challenges: A review,” *Proc. IECON 2018 - 44th Annu. Conf. IEEE Ind. Electron. Soc.*, pp. 4736–4741, 2018.
[48] R. Wang, Z. Zhang, Z. Zhang, and Z. Jia, “ETMRM: An Energy-efficient Trust Management and Routing Mechanism for SDWSNs,” *Comput. Networks*, vol. 139, pp. 119–135, 2018.
[49] X. Yang, L. Wang, and J. Xie, “Energy Efficient Cross-Layer Transmission Model for Mobile Wireless Sensor Networks,” vol. 2017, 2017.
[50] Z. Chen, A. Liu, Z. Li, Y.-J. Choi, H. Sekiya, and J. Li, “Energy-Efficient Broadcasting Scheme for Smart Industrial Wireless Sensor Networks,” *Mob. Inf. Syst.*, vol. 2017, pp. 1–17, 2017.
[51] C. F. Wang, J. Der Shih, B. H. Pan, and T. Y. Wu, “A network lifetime enhancement method for sink relocation and its analysis in wireless sensor networks,” *IEEE Sens. J.*, vol. 14, no. 6, pp. 1932–1943, 2014.
[52] M. Guerroumi, N. Badache, and S. Moussaoui, “Mobile sink and power management for efficient data dissemination in wireless sensor networks,” *Telecommun. Syst.*, vol. 58, no. 4, pp. 279–292, 2015.
[53] W. Ejaz, M. Naeem, M. Basharat, A. Anpalagan, and S. Kandeepan, “Efficient Wireless Power Transfer in Software-Defined Wireless Sensor Networks,” *IEEE Sens. J.*, vol. 16, no. 20, pp. 7409–7420, 2016.
[54] Z. Zhou, C. Du, L. Shu, G. Hancke, J. Niu, and H. Ning, “An Energy-Balanced Heuristic for Mobile Sink Scheduling in Hybrid WSNs,” *IEEE Trans. Ind. Informatics*, vol. 12, no. 1, pp. 28–40, 2016.
[55] R. Kadel, K. Ahmed, and A. Nepal, “Adaptive error control code implementation framework for software defined wireless sensor network (SDWSN),” 2017 27th Int. Telecommun. Networks Appl. Conf. ITNAC 2017, vol. 2017-Janua, pp. 1–6, 2017.
[56] C. Lei, W. Muqing, and Z. Min, “Balancing Energy Consumption Algorithm Based-on Controller Handover for Software-Defined

Wireless Sensor Network," 2018 IEEE 4th Int. Conf. Comput. Commun., pp. 909–915, 2018.

[57] C. Xinying, W. Muqing, and L. Wenxing, "Energy efficient algorithm for SDWSNs based on DACR and energy hierarchy," 2017 3rd IEEE Int. Conf. Comput. Commun. ICCC 2017, vol. 2018-Janua, pp. 182–187, 2018.

[58] G. Wu, C. Lin, L. Yao, and B. Liu, "A cluster based WSN fault tolerant protocol," *J. Electron.*, vol. 27, no. 1, pp. 43–50, 2010.

[59] K. Parmar and D. C. Jinwala, "Concealed data aggregation in wireless sensor networks: A comprehensive survey," *Comput. Networks*, vol. 103, pp. 207–227, 2016.

[60] A. Willig and V. D. E. Itg, "Wireless sensor networks : concept , challenges and approaches," pp. 224–231, 2006.

[61] S. Buzzi, I. Chih-Lin, T. E. Klein, H. V. Poor, C. Yang, and A. Zappone, "A survey of energy-efficient techniques for 5G networks and challenges ahead," *IEEE J. Sel. Areas Commun.*, vol. 34, no. 4, pp. 697–709, 2016.

[62] A. Hameed *et al.*, "A survey and taxonomy on energy efficient resource allocation techniques for cloud computing systems," *Computing*, vol. 98, no. 7, pp. 751–774, 2016.

[63] A. Balobaid, "A survey and comparative study on different energy efficient MAC-protocols for Wireless Sensor Networks," *2016 Int. Conf. Internet Things Appl. IOTA 2016*, pp. 321–326, 2016.

[64] Z. G. Al-Mekhlafi *et al.*, "A survey on energy harvesting routing protocol for WSN," *Proc. Int. Conf. Trends Electron. Informatics, ICOEI 2019*, vol. 2018-January, no. Icoei, pp. 1188–1208, 2017.

[65] N. F. Ali, A. M. Said, K. Nisar, and I. A. Aziz, "A survey on software defined network approaches for achieving energy efficiency in wireless sensor network," *2017 IEEE Conf. Wirel. Sensors, ICWiSe 2017*, vol. 2018-January, pp. 28–33, 2017.