Software Defined Wireless Sensor Networks (SDWSN): A Review on Efficient Resources, Applications and Technologies

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Abstract

Wireless Sensor Networks (WSNs) play a greater role in short range communication networks. Their application adoption to mission critical systems has increased tremendously in the past decades, due to their deployment simplicity and reasonable implementation costs. However, these technologies have a number of limitations subsequent to their computing capacities. Hence a lot of past research approaches have tried to improve their capabilities in terms of processing, communication, resilience, etc. One approach is to implement WSNs that support some level of Quality of Service (QoS) guarantee in their applications, since it is difficult to provide the desired QoS results on them due to their dynamic architectural nature. However, this is difficult since efficient resource management is key to achieve the desired QoS in WSNs. This paper provides a review on QoS provision in WSNs particularly for mission critical applications. The review focuses on QoS metric implementation, QoS challenges and improved communication opportunities in WSNs. The paper, further proposes Software Defined Wireless Sensor Networking (SDWSN) strategies for efficient resource management and guaranteed QoS support to improve network performance. The proposed strategies are aimed at simplifying QoS provisioning for these constrained technologies using programming methods to advance WSNs applications and their implementations.

Keywords: Wireless sensor networks, Quality of service, Resource management, Software defined wireless sensor networking

1 Introduction

The use of WSNs for mission critical applications have brought to light concerns regarding QoS provisioning since the mentioned applications require performance guarantees from systems in which they are implemented. The rapid growth in the number of users and applications using WSNs has led to WSNs becoming increasingly complex. Hence, this growth has triggered high demands on WSNs to provide QoS requirements for every user and application that uses them, as a means to enhance their operation. Even though WSN technologies have limitations, they possess the potential to support modern

high demand network computing applications if they could be optimized accordingly. However, it is yet to be realized as to how WSN systems could support QoS provisioning in modern network application systems, since these technologies suffer in terms of computing capabilities. Hence, this work, makes reference to the need for efficient resource management to realize the required QoS in WSNs. QoS refers to the capability of a network architecture to support and provide adequate services to particular network traffic. In essence, the objective of QoS is to implement some level of network engineering priority for maintaining efficient network operations by ensuring resource control and availability for different network services or applications.

SDWSN is a network computing paradigm for applying software defined networking (SDN) strategies to WSNs with the purpose to improve their technological applications. This networking paradigm, promises to evolve how WSN systems operate for diverse application through the concept of programming. The SDWSN concept is aimed at, dedicating the controlling functionality of a WSN system to a global controller for compute intensive tasks and therefore maintain the underlying sensor nodes to only perform data forwarding. The controller manages numerous network devices, services, topology, traffic paths, and packet handling (QoS) policies. Hence, SDWSN is envisioned to; reduce network complexity, simplify device configuration and improve network management by introducing adaptive computing evolution and simplicity to the network. This paper is the first work to review work already done in Software Defined Wireless Sensor Networks (SDWSNs) with a specific focus on QoS provisioning. Moreover, it proposes strategies for ensuring continuous and reliable QoS provision in SDWSNs.

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Based on the proposed approach, the contribution of this work is: (1) Formulating SDN techniques to enhance QoS policy guarantees and implementations in WSNs. (2) Providing guidance for implementing software-oriented policies in WSNs to improve resource management and QoS scheduling. (3) Develop QoS-aware roles in distributed sink nodes to improve resource efficiency at sensor cluster-level.

The remainder of the paper is organized as follows: Section 2 deals with QoS challenges in WSN technologies; Section 3 discusses SDN opportunities for QoS support in WSNs; Section 4 discusses the SDWSN framework by providing a brief introduction in terms of its architectural operations; Section 5 critically discusses QoS related work in SDN-based WSNs; and Section 6 conclude the review and provides future research directions.

2 QoS Challenges in WSN Systems

Due to computing limitations that are experienced in WSN systems, it is still challenging to ensure guaranteed QoS support in tem. This is subject to their ever-changing network topologies, processing and routing limitations which are most critical in their operations. Therefore, the provision of rewarding QoS support in WSN systems, must be informed by appropriate system planning and design, with QoS requirements as critical aspects of the whole network infrastructure. Limitations in energy management and wireless routing are key concerns in WSN systems as these aspects are of most importance in ensuring network connectivity and reliability. Critical network services such as processing and routing must be prioritised to ensure efficient performance, as these services require enough energy for their success.

Though, QoS requirements must be implemented in a manner that prioritisation of critical network activities do not strain other network services. Smart routing techniques must be employed to ensure efficient delivery requirements. Routing modes such a buffering could be enhanced to advance efficiency in network performance. Buffering in routing is advantageous as it helps to receive many packets before forwarding them. However, there is a limitation in buffer size which increases the delay variation that packets incur while traveling on different routes and even on the same route, hindering the assurance of QoS requirements. Hence, SDN aims at providing a mechanism to deal with QoS requirements in an efficient manner.

Industrial WSNs (IWSNs) are time critical, if information is delayed the possibility of wrong decisions being made exist. Recurrently changing network topology is a challenge since IWSNs incur unstable wireless links, faulty and dead nodes. The wireless links are affected by signal interference, dust and noise amongst others.

Wireless Body Sensor Networks (WBSNs) employ sensor nodes hence the risk of packet drop and errors exist. Moreover, in and on body dynamic path loss and patient’s mobility increase the probability of packet loss in these systems and also introduces dire repercussions to the WBSN channels. Channel characteristics can also differ with body size and posture. The network topology might change frequently due to link failure, power failure, and node mobility these unstable conditions make routing and medium access very challenging. Unreliable nature of wireless links may be disastrous in emergency packet transfer since some packets in WBSN are time critical and require real time attentions. Hence it increases complexity of QoS support. WBSNs may unnecessarily consumes much needed energy when processing redundant data. They also experience and traffic imbalance since data flow from many sensor devices to a small number of sinks. The heterogeneous environment in WBSN makes QoS support more complex and challenging. Wireless Sensor and Actuator Networks (WSANs) are bandwidth constraint as a result some data transmissions may experience large delays, resulting in poor QoS provisioning. Consequently, memory constraints lead to data packets being dropped before nodes send them to the destination successfully. The platform heterogeneity makes it difficult to utilise resources in an efficient manner and to achieve real-time and reliable communication between various nodes. In WSANs some nodes may be mobile, this leads to dynamic changes in the network topology since sensor/actuator nodes may be added or removed at runtime. This may be due to dead nodes, energy saving nodes and node mobility. Various applications may need to share the same WSAN, actuating both regular and irregular information. This requires WSANs to support service differentiation in QoS provisioning.

Wireless Multimedia Sensor Networks (WMSNs) present high traffic and require more bandwidth to process multimedia data. Some applications may need various sensors to monitor the events and to capture images and videos of objects in motion. These applications produce heterogeneous data from different types of sensors at varying sampling rates based on different QoS limitations and delivery models. Hence, these heterogeneous WMSNs may impose significant challenges for the provision of QoS and WMSN routing protocols. Sensor nodes consume a large amount of energy when communicating and a significant amount of energy is also wasted when processing redundant data. This pose significant challenges for QoS provisioning. The network topology may change recurrently due to node failures or link failures caused by mobility. QoS provisioning is a challenge since nodes are added or removed from the network. WMSNs use radio as the communication medium and wireless links. Both are not reliable due to inherent features associated with them. Wireless links are affected by environmental factors in their surroundings.

Providing good QoS level for robotic sensor networks such as drone-based sensor networks proved to be challenging since these networks operate in more extreme environmental conditions such as earthquakes, chemical disaster environments and flooding. These networks experience QoS constraints in terms of data traffic since packets may be dropped before they reach their destinations due to congestion, broken communication links caused by node failures or node mobility, and bit errors caused by noise, interference, distortion or bit synchronization. Moreover, mobility pose another challenge to QoS provisioning since drones fast mobility leads to unpredictable links and there are delays resulting from path planning and navigation algorithms when mobile drones are relaying information. Finally drone-based sensor networks may incur connectivity challenges due to their fast mobility.

The involvement of human participation in crowd sensing poses QoS challenges since certain trust issues arise. Participants are likely to provide incorrect or even fake data to the system. Meanwhile, mischievous users may deliberately infect the sensing data for their own advantage. The lack of control mechanisms to guarantee source validity and data accuracy can lead to information credibility issues. Redundant sensing may lead to data inconsistency. One may find a group of collocated smartphones with different sensing and computing abilities running the same algorithm and sensing the same event can obtain different inference results, thus causing inconsistency issues. Delivering the sensed data from distributed participants to the backend server is another challenge due to a range of crowd sensing characteristics, such as the low bandwidth of wireless communication, frequent network partitioning caused by participants mobility, and numerous energy-constrained devices.

Since traditional SDN protocols were basically designed for wired networks, it remains a challenge to effectively apply them as they are in WSNs. Routing protocols for wired network technologies, have the advantage of physical energy sources and hard-connected infrastructure, whereas the opposite is experienced in wireless network technologies. In WSNs, routing plays an integral part of the whole system architecture, connectivity, network traffic, performance and lifetime. Other aspects of routing in WSNs directly relates to, QoS provisioning, energy management, scheduled processes, etc. Consequently, a well-planned WSN system must be sensitive on the manner of routing protocols used based on the actual system application. Therefore, an opportunity to effectively use traditional SDN protocols in WSNs, is somehow by means of modifying these protocols to well suit the type of routing applied by WSNs. Other methods of using these protocols could be achieved in terms of developing the same protocols but with the focus for wireless technologies or by integrating wireless network technologies with other systems such as in hybrid architectures. Accordingly, QoS mechanisms designed for WSNs technologies should be scalable, dynamic, energy efficient and robust. The addition or removal of sensor nodes should not affect the QoS of a WSN system.

3 SDN Opportunity for Improved QoS in WSN Systems

SDN is regarded as a potential mechanism to improve guaranteed QoS in WSNs, due to its nature of programmable control. Software oriented application interfaces could be developed and implemented to offer better QoS support since the dynamic nature of SDN processing is to allow and support flexible network experience. Either or with a combination of other wireless networking technologies could offer a great platform for improving the commonly used QoS tools for WSNs application systems, thereby improving network experience (in customer perspective) as well as the overall network performance. It is evident that most network design strategies, take into consideration QoS support and guarantee as an integral part of networking. A good network design should not leave out QoS requirements unaccounted for, as this would lead to poor network operations.

It is also possible that, through centralization of the control plane; more advanced routing algorithms could be developed, thereby improving resource and network management in WSNs. Instances such as writing controller applications that could be used to periodically collect information on sensor nodes such as; battery levels, current memory usage, etc. so as to maintain and implement energy-wise routing strategies. If these routing strategies are fully implemented especially in critical aspects of the network, some level of improvement in terms of the overall network performance will be achieved. In a SDWSN architecture, compute intensive tasks such as; function virtualization and service automation, provisioning of network QoS, traffic re-routing, etc. are directly executed or run on the controller since it is a fully resourced component of the system, thereby not causing the underlying network devices to use more compute power. Therefore this network aspect, will also improves the network lifetime by preventing rapid energy depletion of sensor nodes.

This review paper provides possible QoS guarantee mechanisms that could be realized with the use of SDN oriented strategies to: (i) Advance simple QoS assurance techniques, whereby priority rules could be implemented on distributed sink nodes with advanced methods of processing and routing aggregated data from cluster sensor nodes which have limited resources.

(ii) Provide options for guaranteed QoS support could be realized by implementing automated prioritization for high bandwidth demanding tasks and security event triggered data to ensure real-time detection and action on any system breaches or security issues through SDN programmable strategies. A perfect example of how SDN is envisioned to improve WSNs is exemplified in [1] where the authors proposed that the controller be placed at the base station. The controller makes all the routing decisions and has the global view of the entire network, it collects the state information by receiving monitoring messages and the sensor node serve as forwarding devices. Moreover, the controller calculates the routes by using the location of all the sensors.

In SDWSN, as depicted in Figure 1, QoS can be performed in three steps: Firstly a flow is regulated to ensure that it does not violate traffic contract and then placed in a queue. Then, the network node conveys its desired QoS requirements to the controller. For the controller to provide the QoS requirements, it has to examine the network traffic and QoS parameters and check whether the available resources are adequate to guarantee the requested QoS. Then the controller conveys QoS guarantees (either acceptance or rejection) to the network node. And finally flows are monitored by traffic policing functions evoked by the controller to ensure that they do not violate the agreed traffic contract.

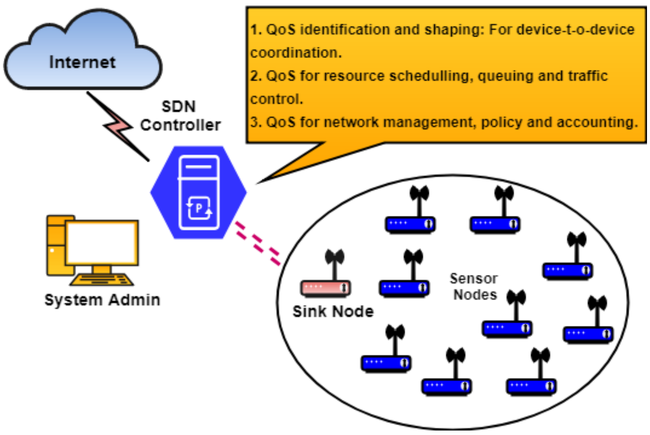

Figure 1. Basic QoS implementation in SDWSN

QoS is an important aspect of computing network, hence its implementation must be well planned to allow efficient guarantee. In addition, QoS requirements must be well aligned to network resource in terms of access and limitations, so as to allow effective network performance.

4 SDWSN Framework

In WSNs, the importance of guaranteed and enhanced QoS which should not be compromised is emphasized in accordance with the network dynamicity and performance. The shift towards SDN based WSNs stands to be an efficient approach for optimized QoS, since programmable applications could be developed to implement and handle QoS requirements pertaining to sensor nodes within the controller. Wang et al. [2] highlights that, QoS requirements are taken as inputs by the local manager of their proposed system to allocate a spectrum band which is ruled by the global manager for different flows. They further indicated that since a local manager is programmable, QoS policies could be updated by the system admins for different network functions.

SDWSN refers to a networking paradigm that entails separating the control mechanism of an operational wireless sensor network from the data forwarding plane of the underlying vertically integrated network system. In essence SDWSN is a networking computing model that uses Software Defined Networking (SDN) techniques in WSNs applications systems as a means to simplify and enhance WSNs' systems operations. In Figure 2, the overview of a SDWSN network is illustrated. The sensor nodes will be carrying out forwarding functions only and the network intelligence will be based on the SDN controller. The controller will have the global view of the entire network. Moreover, the compute intensive tasks such as traffic management, QoS management, resource allocation, path computations and others will be done by the controller.

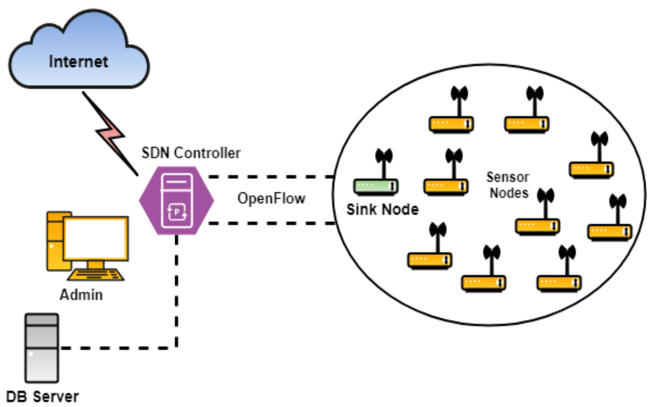

Figure 2. Overview of an SDWSN framework

To achieve effective and reliable communication between the SDN controller and the underlying network infrastructure, capable and compatible protocols must be implemented in the system. Communication between wireless sink nodes and the SDN controller is facilitated through the OpenFlow protocol. However, various communication technologies such as IEEE 802.15.4 and ZigBee, are common in sensor networks. These standards are widely used due to the low rate wireless transmission and simple access methods. The standards also provides, seamless interoperability from different devices. Hence, their relevance provides opportunities for Industrial Internet of Things (IIoT) platforms.

5 Related Work

The SDN architecture exposes rich possibilities to transform resource constrained networks such as WSNs in that it possess the capability to partition network operations depending on which services needs to run or be executed where in the network. QoS in WSNs has no to little research achievements or outputs that have transformed to actual practices in application networks. However, SDN presents limitless possibilities to change this, since developers could take the advantages brought about by the SDN programmability. Network services such as QoS guarantee and automation could immensely benefit from the SDN paradigm since these services may be software controlled and automated according to network requirements. In particular QoS requirements could be implemented using reprogrammable strategies as a means to enable on demand system responses.

Efficient QoS support could even transform WSNs in terms of improving them by reducing their limitations especially in processing. WSNs could benefit from SDN optimized QoS activities through the use of programmable strategies to initiate and guarantee QoS activities within the network. QoS activities such as service scheduling and bandwidth allocation for critical data or applications, could be automated by the network infrastructure accordingly. Software oriented strategies could also be used for the resource prioritization of network intensive tasks or services depending on the technicalities required to successfully execute them.

SDN bears the capacity to evolve WSNs in terms of how the perform computation by introducing simple programmable abstractions to their network operations. A novel SDN based framework called SensorSDN that was envisioned to meet the specific requirements of diverse WSNs was proposed in [3]. This architecture was also envisioned to operate in various IoT systems. Firstly, they proposed a new control plane services to promote automatic topology discovery, node mobility, sensor virtualisation as well as management of network policies. Additionally, they introduced SDN based customizable flow tables on existing Low-Rate Wireless Personal Area Networks (LR-WPAN) technologies to meet the requirements of various sensor network packets. Finally, a programmable MAC Layer was proposed to support fine-grained flow processing.

There is a general consensus that resource management (allocation and utilisation) in WSNs has significant effect on QoS support [4]. In that regard, numerous efforts have been made in the past to deal with sensor networks resource management since these types of networks have serious competence issues. [5] proposed a SDN driven framework for WSN applications- WARM, executed on a web browser to developed and manage sensor applications. They used TinySDN to facilitate a connection between sensor nodes running on the TinyOS which uses the nesC (network embedded systems C) language. Their framework controller was implemented using Python language. Their experiments indicate that, WARM, simplifies programming, decreases overhead and is practicable. However, when compared with Terra, TinyDB and Swiss QM for memory utilization, WARM seemed to be using the large amount of RAM with minimum ROM. On the hand, apart from other best-case performances by WARM, it is unclear as to how the authors mentioned a decreased overhead whereas in their statement, WARM used the largest RAM amount when compared to Terra, TinyDB and Swiss QM for memory use.

An SDN based model for resource management in Heterogeneous WSNs (HWSNs) that was intended to support the selection of sensor allocation strategies in an on-demand manner was proposed in [6]. Their proposed model takes the different applications requirements and the sensors' characteristics into consideration when choosing an appropriate allocation strategy. The sensor allocation strategies can differ according the goals set to be achieved. The authors conducted preliminary tests to validate the proposed model to show that the proposed model can handle the dynamic selection of allocation strategies.

In [7], a heuristic algorithm to solve the task allocation problem experienced in shared SDWSNs, was proposed. Their algorithm exploited of routing information and sensor battery measurements to improve energy efficiency and resource utilization among sensor networks. The algorithm is said to have attempted to avoid transmission bottlenecks by ensuring that there are no load imbalance over relay nodes. They compared their proposed algorithm with the traditional WSN architecture that tends to reduce energy consumption during task allocation. Their results suggested that their algorithm achieved promising results with respect to the network lifetime and application acceptance ratio. It also improved QoS for accepted applications.

For large scale WSNs, congestion is the main challenge experienced. If the network was not designed to scale up with the continuous growth, then it might be congested during high traffic volumes. As a result, this then leads to extra energy consumption hence network lifetime may be shortened. Recently, researchers have proposed ideas to use SDN strategies to ensure QoS guarantee.

A new approach that takes advantage of the SDNWISE [8] envisioned state information to support QoS provision in WSNs was proposed in [9]. Their approach used a network state to report the level of congestion on each node to the controller. By making use of this state, the controller could assign rules for different packets drop probabilities to different traffic flows depending on the current level of congestion at the sensor nodes along the path going from the source sensor node to the sink. Furthermore, in order to mitigate congestion, the controller searched for new routes to divert the traffic flow and sends the new corresponding rules to the network nodes in such a way that alternative paths were used. Hence, SDNWISE was intended for reducing the amount of information exchange between the SDN controller and the adjacent sensor nodes and also for enabling these sensor nodes to be programed as finite state machines. They reported that, their system approach increased network elasticity and provided simplified network programmability since it allowed system developers the freedom to use programming languages of their choice to implement the SDN controller. In our view this adds to be a great improvement in the aspect of WSN network programmability especially with the ability to use any high level programming language when implementing the SDN controller.

The network lifetime as well as energy policies implemented in WSNs have the aspect of being treated as QoS guarantees, in that they reflect how and what methods of deployment are taken in to account. Therefore, the essence of QoS guarantee in computing networks is a critical factor especially in application systems that needs to maintain quick and accurate data processing. As part of the strategy for SDWSN, the separation of network control from the device data forwarding, could effectively benefit the process of improving the network lifetime and to some level, slower the high rate of energy consumption in network critical devices, thereby allowing efficient operation of the entire network.

Researchers in [10] made an attempt in solving the energy consumption issue by proposing a general SDWSN framework where the SDN controller was placed at the base station and the sensor nodes in a cluster performs only the switching. They used OpenFlow as the core communication protocol between the controller and the switching elements. Their proposed architecture minimized the energy consumption as was anticipated. The realization of efficient WSNs technologies is still a heavily engaged matter in that these systems are extremely limited in terms of performance. Recent work sees SDN as a positive paradigm to revolutionize WSNs application systems for greater performance.

Huang et al. [11], proposed a SDN based routing protocol to be applied in multi-hop wireless networks in an effort to improve wireless traffic routing and sensor network lifetime. Their proposed protocol was implemented in OPNET. It is indicated on their arguments, as informed by their experiments that, their SDN based routing protocol achieved better results in terms of prolonging network lifetime compared to OLSR, since it uses less energy. They also reported that, their experiments indicated improvements in achieving shortest paths as well as achieved disjoint multipath for network nodes routing, thereby, increasing network lifetime as compared to OLSR and AODV for a certain value of traffic load.

Energy consumption has an effect on how long the network lifetime, accuracy of the sensed data, packet delivery ratio and network latency. Therefore it is considered more significant than other QoS parameters. In [12], an SDWSN prototype was proposed to improve the adaptability and the energy efficiency for WSN monitoring systems. In this work, an energy-efficient cognitive SDWSN prototype based on reinforced learning (RL) was developed for monitoring systems, wherein complex data fusion was managed centrally on the control plane while low complexity computations were done on the data plane. Experimental results suggested that their proposed prototype has the ability to enhance self-adaptability of WSN environment monitoring with QoS and significantly improved energy efficiency by effectively hindering the transmission of unnecessary loads, minimizing the amount of cross-plane communications and improving the load balancing in SDWSN.

[13] proposed a multi-tasking energy efficient routing algorithm for SDWSNs. In order to make the network convenient, their algorithm chose control nodes that were allocate various tasks. This selection of control nodes is conceived as a non-deterministic polynomial-time (NP)-hard problem considering the remaining energy of the nodes and the communication distance. As a solution to the NP-hard problem, they used a non-linear particle swarm optimization to create a cluster structure so as to reduce the communication distance. Their simulations suggested that their algorithm is energy efficient and thus prolonged the network lifetime.

An SDN based sleep scheduling algorithm SDN-ECCKN that reduces the total time of transmission of a network was proposed in [14]. SDN-ECCKN selects the most appropriate node to go to sleep by taking into consideration the remaining energy level of the sensor and the number of alive neighbours. By doing so, it ensures that the connectivity of the network is maintained and the network lifetime is maximized. All computations are performed by the controller rather than the sensor nodes and there is no sensor-to-sensor propagation in this algorithm. Their simulations suggest that SDN-ECCKN shows significant improvement compared to ECCKN considering the network lifetime, number of functional nodes and number of isolated nodes.

An energy efficient SDWSN with wireless power transfer was introduced in [15], where an optimal placement of minimum number of energy transmitters and energy-efficient scheduling of these transmitters was proposed. They investigated a trade-off between maximum energy charged in the network and fair distribution of energy for assigning the energy transmitter. A binary integer linear programming problem was formulated while satisfying the limitations on minimum energy charged by each sensor. They further proposed an energy-efficient scheduling scheme for energy transmitters, where the optimal solution was found with the help of branch and bound algorithm. Their results shows that, compared to traditional WSNs with wireless power transfer; energy consumption can be minimized considerably by scheduling energy transmitters in SDWSNs.

Designing an energy efficient reprogramming strategy with guaranteed quality-of–sensing for all sensing task was investigated in [16]. To address the following issues to: (1) reprogramming sensor selection and (2) program distribution routing, the two issues were jointly formulated into an Integer Linear Programming (ILP). They proposed an efficient ILP based heuristic algorithm which has a low computation complexity to address the high computational complexity of solving ILP. The results demonstrated that the proposed algorithm performs close to optimal. Furthermore the authors validated the efficiency of the proposed algorithm by comparing it with a two-phase algorithm that considers the 2 issues mentioned above separately and the IPL based heuristic algorithm proved to have significantly outperformed the two-phase algorithm.

An SDN based energy optimisation architecture for multitasking WSNs was proposed in [17]. The authors pointed out that the optimisation can be achieved through controlled sensor scheduling and management with quality of sensing for all sensing tasks. The minimum energy sensor activation problem was formulated as a Mixed-Integer with Quadratic constraints Programming (MIQP) problem by coupling sensor activation, task mapping and sensor scheduling. MIQP is then reformulated into a low computation complexity formulation through linearization in the form of Mixed-ILP (MILP). Additionally, an online algorithm was developed to address operational dynamics such as sensor admittance and departure during Software Defined Sensor Network (SDNS) runtime. The results revealed that the proposed online algorithm achieved approximately the same energy optimization as a global optimisation with lower rescheduling time and control overhead.

One of the critical issues in WSNs, is how limited these technologies are in terms of energy. This is a major challenge as it directly impacts on the overall performance of the system. [18] proposed a centralized algorithm with a focus in resource allocation to reduce energy consumption in a SDWSN system. Their system uses a semidefinite programming (SDP) relaxation technique as a programming model to solve the no-convex problem which negatively affect efficient resource allocation. Based on their aim to reduce energy utilization, they formulated the energy consumption issue as an optimization problem. Their experimental results, their proposed centralized adaptive bandwidth and power allocation (CABPA) indicated a significant energy utilization reduction and efficient bandwidth utilization, whereas their distributed adaptive bandwidth and power allocation (DABPA) also indicated better bandwidth utilization compared to the centralized adaptive bandwidth allocation (CAPA) algorithm, which in their report claim it used more power. However, they have also stated the trade-off experience in facilitating efficient power allocation and bandwidth utilization.

In an attempt to achieve energy efficiency and smart management in WSN, a generic base station architecture for SDWSNs was proposed in [19]. Moreover, they proposed an SDN based clustered architecture for WSNs where the controller is situated at the base station for generating the routing table for the cluster-head, controlling the data sensing of the sensor nodes, and providing more feasible and flexible and convenient management function for the users. Finally, they validated the efficiency of their proposed architecture by comparing its performance and energy consumption with LEACH Protocol. The authors explained the system overview but did not explain their experimentations. However, they discussed and compared the proposed architecture with LEACH protocol and came to the conclusion that the proposed architecture is outperformed LEACH with regards to performance and energy consumption.

In WMSNs it is important to take certain QoS parameters into consideration during route selection since lost packets needs to be retransmitted hence using extra energy. Moreover, throughput can be affected by delay in data transmission. Finally, control overhead should be kept at a minimum otherwise it will cause energy wastage. To deal with such challenges, [20] proposed a QoS-aware routing mechanism for OpenFlow-enabled WMSNs. The mechanism consisted of a framework and routing algorithms on the SDN controller. The framework was located at the application layer of SDN architecture and comprised of five components: link state detection, flow classification, flow management, QoS-aware routing algorithms, and per-flow routing policy. Routing algorithms were achieved in two steps. First, it seeks the feasible paths that satisfy QoS requirements of a flow. If there was no path that satisfied the required QoS, the path would be decided by the proposed algorithms depending on flow types. Their proposed QoS mechanism was evaluated against OSPF and RIP. Results suggested that QoS-aware routing mechanism increased throughput by 43% than RIP for video data transmission, and reduced the delay by 30% and 54% than RIP and OSPF for audio data transmission respectively. Thus, QoS-aware routing algorithm has advantages in QoS satisfaction for different types of flows.

In IWSNs, data transmission delay compromises the reliability of the system and also causes unnecessary energy consumption. Modified SEECH (MSEECH) - a mechanism for improving energy efficiency in Industrial WSNs (IWSNs) using SDN AND NFV was proposed in [21]. They used the global view of the network and the central control to monitor IWSNs. The topology of IWSNs and node modes were controlled by exploiting the programmability of SDN and the instant deployment capabilities of NFV. Furthermore, they proposed advanced algorithms for the controller. To prove its efficiency they compared MSEECH with LEACH and SEECH. Their results suggested that, MSEECH was more energy efficient than its two comparatives in WSNs with high data aggregation compression ratio and slightly less efficient than SEECH in WSNs with low data aggregation compression ratio.

It is important to make informed decisions in route selection since a large routing overhead can have adverse effects on latency. Large routing overheads use extra channel which then consume extra energy and bring about more latency. [22] proposed a routing approach which permits administrators to maintain the global view of each routing path and also simplifies the procedures such as troubleshooting and network provisioning by coupling link state routing with OpenFlow. Since all the routing decisions were to be made by the controller, the nodes wouldn't have to negotiate amongst each other. Their proposed architecture claimed to have provide a fault-tolerant system design as well as the possibility of an increase in network utilization.

An SDN-enabled node selection algorithm based on Cramer-Rao Lower Bound (CRLB) was proposed in [23]. They formulated the localization node selection into a 0-1 programming problem on the basis of energy satisfaction by exploiting the global network intelligence provided by the controller. In order to select the most reliable nodes for localization, they calculated the contributors of each anchor node in the metric of CRLB. Their results suggested that the proposed SDN based algorithm achieved significant improvements in localization performance.

SDWSN was also used in Smart Grid WSNs [24] where all sensing nodes were connected through a central, fixed position OpenFlow controller which can flexibly choose routing protocols according to changes in network topology. Compared to already existing WSN protocols, their solution was said to have reduced network complexity, power consumption in sensor nodes and hence prolonged the network lifetime.

[25] proposed a routing algorithm for a hybrid WSN architecture where a traditional WSN using MTE routing protocol was deployed together with a partial Software Defined Sensor Network (SDSN). The aim was to prove that if the controller had the global view of the network it could significantly increase the network life time of the WSN. Their simulations indicated that if the state information is available, the network performance could be improved and the network lifetime prolonged regardless of the network topology.

Huang et al. [26] proposed a software-defined QoS provisioning mechanism for WSNs that uses fog computing as their advancement. According to their architecture, a fog smart gateway (FSG) is designed to communicate with the SDN controller through the OF protocol. From their experimentations, they reported that their implementation achieved dynamic QoS configuration. They also claim that their approach has significantly improved network latency with up to 84%. This is fundamental as more work still needs to be done to efficiently impact on WSN and SDWSN systems [27-30] regarding the role that QoS plays in computing networks.

Even though some work such as in [2] have highlighted on how QoS requirements can be used to facilitate its guarantee, it remains unclear as to how the proposed programmability would be catered for in terms of QoS provisioning. Therefore, a clear strategy or approach for QoS requirements and support must be fully placed in terms of the parameters and mode of operation [31] that can be effective in this course such as in [21] where QoS-aware routing mechanisms where used to increase throughput for different data transmission.

Some effort has been made on [8-9], where some level of sensor application programmability was achieved and how state information was used to provide a technical understanding of traffic congestion on end devices as viewed by the controller. This is a remarkable achievement in terms of QoS guarantee and support. Even though, the work in [8] employed duty cycles and data aggregation to optimise energy efficiency, it could not provide any measurements on duty cycle and data aggregation. This approach may reduce information exchange, mobility, reconfiguration and localisation of distributed sensor nodes but lacks reliability and security. Finally, [8-9] are the only approaches mentioned above that had real life deployments. Hence their approach could still be improved to contribute to the standard and methods of QoS provisioning, as this would afford some Quality of Experience (QoE) to system users.

Some effort on the issue of energy management such as in [12-13] has been achieved, where SDN strategies have been used to manage high energy consumption issues on these systems. In their approach, the SDN controller is allowed efficient resources as the sink performs only the forwarding, some introduced or proposed energy sensitive algorithms to tackle this problem of which some level of energy saving has been achieved. Though, these strategies still need to be further enhanced for efficient energy utilization methods and management. Others [14-15, 20, 22] proposed algorithm control strategies and methods of energy management of which some remarkable improvements have been made.

[21] used information obtained with regards to the remaining energy to make routing decisions. Due to the centralised control, the transmission time was reduced but the authors failed to specify how OpenFlow and ECCKN would interact and also failed to clarify the implementation of SDN. However, these approaches were designed not taking other WSN core competencies such as scalability, mobility support, topology management, scheduling control and traffic engineering, security and robustness in to consideration. Though, not to disregard some of the remarkable achievements within the area, a lot must still be done since most of the work lack a complete system with adequate evaluation. Table 1 discusses the pros and cons of the solution mentioned above.

Table 1. Pros and cons for enabling QoS in SDWSN application systems

System Overview	Pros	Cons
Wang et al. [2]	Allocation of spectrum band for different flows. QoS policies can be dynamically modified for different active network functionalities. Innovations for improved QoS are possible in this system.	Applying QoS requirements on the local manager could be beneficial, however their proposition does not detail how QoS could be applied for different purposes.
Galluccioz et al. [8]	Simplified network programmability such that the network is more flexible. Sensor nodes are programmed as finite state machines. Reduce information exchange between the controller and end devices.	Since system developers have the liberty of using programming languages of their choice, security for such systems becomes a serious concern, as attackers can use that many platforms to mimic the system.
Di Dio et al. [9]	Status reports for traffic congestion are issued by sensor nodes and the sink to the controller. This process suggests an improved way of traffic handling.	The sink could also be overloaded by aggregated data in a system where network devices are less resourced in terms of memory and processing capacity.
Yuan et al. [10]	The system allows a global view of all routing paths as performed by the controller. Proposed a fault-tolerant system whit the focus of increasing network utilization.	The issue that there is no negotiation between sensor nodes is somehow a lack sing aggregation and redundancy are sometimes relevant the system's data integrity.
Jayashreel and Princy [12]	A general SDWSN framework was proposed. The system was reported to have reduced the energy consumption significantly. Sensor nodes saves a lot of energy since intensive tasks are performed on the controller and OpenFlow switch.	To some extent, non-OpenFlow systems might not be favoured by this framework. Since prioritizing the switching functionality through OpenFlow might require many propriety devices to be used for this process.
Ejaz et al. [20]	A wireless form of energy transfer was presented. A form of scheduled energy transmission was used to power network devices, which could be a solution for energy-limited sensor nodes for increased network lifetime.	This system could be efficient for as long as there is reliable connectivity amongst the transmitters and network device. Otherwise for limited network reach, some end devices could still be energy starved.

Qualified QoS guarantee in WSNs is still a challenge due to application limitations associated with them. To the best of our knowledge, none or little research outputs have focused on enforcing QoS requirements on them using SDN strategies. This could be mainly due to their shortcomings in terms of memory and processing. However, this does not oppose the vision that upon optimization, WSNs have the capacity to be evolved into rich application technologies due to their simplicity of deployment and relative cost measures. Hence, this paper, proposes SDN strategies as a means to fully realize efficient QoS support in WSNs [32-34].

To realize this, the central SDN controller could employ machine leaning and statistical models [35-36] to efficiently deal with compute intensive tasks that requires the intelligence of the network to execute or implement network services such as QoS policies [37] and application automation.

6 Conclusion and Future Work

Given the ever increasing number of QoS demanding applications in WSNs, guaranteeing QoS provisioning in WSNs is of paramount importance. It is not easy to maintain the desired QoS because WSNs go through changes recurrently, the changes may be due to the network topology change, load imbalance, faulty nodes and unstable wireless links. Consequently it is important to develop QoS techniques that are dynamic, energy saving and resilient to frequent changes.

In this paper we have studied recent advancements in QoS provisioning in SDWSNs specifically on how efficient management of resources improves QoS provisioning. We have therefore identified critical aspects of network design and implementation in terms of QoS requirements and guarantee in WSNs since not much work has been done in this area. Hence, the integration of SDN strategies in WSNs promises to positively impact on the network's data processing, error handling and resource management, thereby improving the overall network QoS and QoE. It is also concluded that coupling SDN with WSNs could be a potential solution for QoS limitations experienced in WSNs.

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