Programmable Node in Software-Defined Wireless Sensor Networks: A Review

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Abstract*— Wireless Sensor Networks (WSN) and the Internet of Things play a critical role in many applications ranging from monitoring, tracking and surveillance, social enhancement and many more. Although WSN is used for applications above, still there are some challenges it faces. A few of the challenges faced by WSN include the inability to withstand a large number of sensor nodes deployed in a heterogeneous system leaving the WSN system unmanaged. So recently, there is a huge interest to utilize Software-Defined Networking (SDN) in WSN with more focus on the architecture, routing protocols, topology discovery, SDN controllers, etc. However, without an SDN-enabled sensor node, these systems/models will not be able to operate efficiently and reduce the complication of network configurations and management. Thus, this paper caters the design and development of SDN- enabled sensor node that is applicable to different applications and allowing functions of different processes within the WSN to run efficiently and reduce the costs, improving energy efficiency, scalability and render a system with multiple of functional sensors.

***Keywords*—WSN, SDN, SDN-enabled sensor node, and SDWSN**

I. Introduction

With the expansion use of internet among people around the world carry many questions on how the storage of data, networking, management of the systems used must be improved to meet all demands. Traditional Wireless Sensor Network (WSN) has been the main information technology utilized in the Internet of Things (IoT) for the collection of data, data fusion, and wireless transmission functions in the past years [1]. WSN is a promising network technology which can be used for many applications in the future. Recently, WSN had been applied in smart farming, smart grids and health sectors where many sensor nodes are deployed to monitor certain environments[2], [3], [4]. Due to some issues like energy consumption, lack of efficient management, inability to adapt to new changes by WSN, unable to satisfy all the applications and support innovations since they are designed for specific application use only, thus, the newly emerged Software-Defined Networking (SDN) has been proposed to be utilized in WSN with more focus on the architecture, routing protocols, topology discovery, management, SDN controllers [5]

Additionally, recent studies on existing WSN management based on SDN paradigm [5] proposed techniques on management and network configuration, where a system is proposed to manage itself through its programmable nodes. Programmable node enables SDN concept to cater solutions for many applications including hybrid network control, traffic engineering, data center networking, wireless networks and network security [6]. Many big industries including Google, Microsoft, HP, Facebook, Deutsche Telecom, Samsung, etc. encourage that SDN be used for enterprises and carrier networks. SDN paradigm which is decomposed into three parts; Application layers, control plane and data plane. In SDN, data plane and control plane are decoupled to deploy new protocols, reduce the complexity of the network reconfiguration. Through its programming interface, it opens the door for new applications, and management, moreover, support innovations in networking, so it is possible to overcome the inherent weakness of WSN through SDN for improved WSN Management communication between the application layer and control plane is normal through TCP/IP and multi-hop wireless communication is mostly utilized between the control plane and data plane in SDWSN [5]. The control plane is composed of a centralized operating system (SDN controller), where one or more programmable controller nodes be located, and data plane is composed of several of sensor nodes, where functions of SDN switch and end device are handled. SDN-enabled sensor nodes [7], [8] are employed in the SDN data plane for data collection, packet forwarding and wirelessly communication among nodes. WSNs are so important and cannot be abandoned in this generation since wireless communication are preferred by many people than wired communication, therefore, an interesting feature that can be archived through SDN enabled devices are node and resource management. Thus, the main purpose of this paper is to review existing works on the design and implementation of SDN-enabled sensor nodes (programmable nodes) which will enable rapid communication and responses between data plane and control plane throughout communications. In addition, will make use of SDN architecture shown in Fig. 1 which shows application plane, control plane being separated from SDN-enabled sensor node in the data plane. There are other SDN enabled devices like SDN switch and SDN end devices which operate like the SDN enabled sensor nodes that are utilized in SDWSN [9]

II. Software Defined Wireless Sensor Network

The combination of SDN with WSN have been given different names such as SDWSN, SDN-WISE, SDSN and SDWASN recently, though they all mean the same thing. WSN is becoming more popular due it's usage in IoT hence, many proposals are emerging to expand it despite the challenges on the management of networks and heterogenous-node networks which remain a burden. The proposal to use SDN in WSN enables what we call software-defined wireless sensor networks (SDWSN).

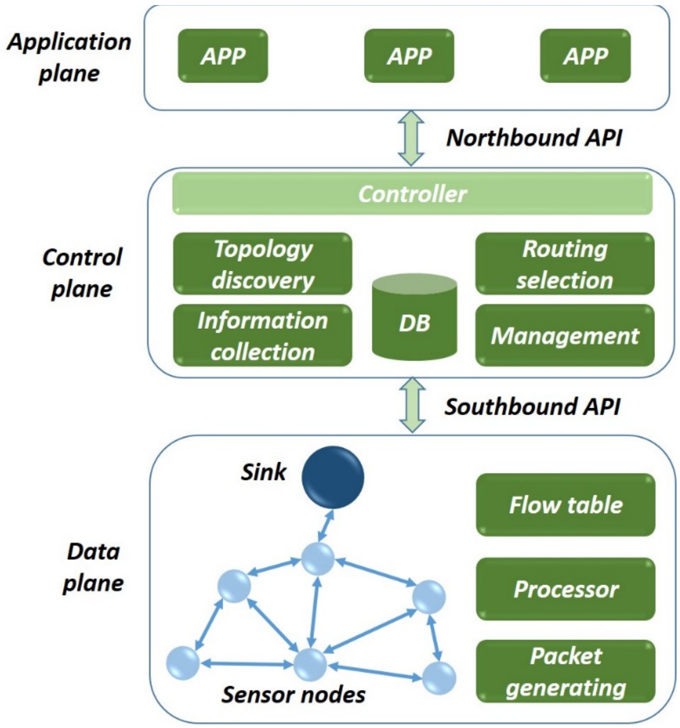

Fig. 1 SDWSN architecture.

SDWSN is a continuity of the SDN based on the wireless communication between the control plane and data plane and it is purposed to counter challenges that are faced in WSN such as limited resources and energy, security issues [10, 11], plus management issues [12]. Recently papers of SDN based on WSN [12, 13], [14] began to highlight techniques on management, securities, design and enabling nodes utilized in SDWSN. SDWN is one of the most interesting topics in SDN paradigm nowadays since issues concerning the management of network configuration, topology, energy limitations, QoS, security, network monitoring are addressed. In addition, SDN-enabled technologies based on hardware and software is a concern in SDN paradigm so studies like [15] have devoted themselves to research on SDN enabled sensor node for both hardware and software based on SDWSN. Several SDWSN architectures were proposed.

OpenFlow [16] was the first protocol employed in SDN concept for WSNs. Energy consumption, cost, and host-level security were reached since sensor devices can monitor themselves. SDWSN was introduced to hold important features such as data aggregation, the configuration of duty cycles, flexibility, scalability, and management of WSN based on SDN concept. Many sensor nodes are deployed around the environment to collect and forward data packets to the control plane hence careful control and management of SDN enabled devices must be looked at. There have been few discussions on the management of WSNs hence a paper survey presented by Ndiaye *et al.* [5] focused on SDN for improved WSNs, a review of techniques used for SDN-based management of WSNs were covered and managing classifications like managing of network configuration, topology, energy limitations, QoS, security, and monitoring network were also shown. There are many challenges faced in SDN paradigm when attempting to design enabled devices in SDWN thus, a review paper conducted by Kobo *et al.* [17]is best that point out the issues and proposed design requirements that must be put in mind when attempting to design SDWSN. These problems range from energy, communication, routing, configuration, and security. One of the challenges faced in SDWSN is limited routing strategy hence Galluccio *et al.* [18] proposed a flow splitting optimization (FSO) algorithm for solving the issues of traffic load.

SDWN also rely on the decoupling of forwarding (Switch) devices from the control logic similar to the SDN paradigm. Both hardware (power unit, sensing unit, and radio) and software components are included in sensor nodes of the data plane. The functionalities of IEEE 802.15.4 are performed by the hardware which is on the physical layer when combining with the MAC layer. The two nodes consisted in SDWSN are the generic node which has three layers (PHY. Layer, MAC layer & NOS) and sink node contains two parts; the generic node and the controller.

According to Kobo *et al.*[19], Controller is one of the significant components in SDWSN since it controls the whole behavior of the network through it is programming interface installed in it. in addition, it is the key component where new policies are added and even generates flow plus shifting flow specifications to the sink node in the data plane. The controller can be distributed [20] or centralized depending on the usage.

III. SDN-Enabled Sensor Node

With the increase proposals to deploy SDN paradigm to different applications such as datacenters, IoT, carrier networks unfold questions on how a large number of sensor nodes and end devices used for collection of raw data and transmission be handled to meet all processes.

Recently SDN had been proposed in [21], [22] to be employed in WSNs and cater solutions on the challenges such as an inability to adapt to new changes, sensor nodes being used for specific applications, management of networks and energy consumption. SDN architecture is composed of three planes; application, control, and data plane. Decoupling of data plane from control plane carry benefits of management of network configuration and resource management in the data plane. The combination of SDN with WSN allow us to improve the operation of SDN switches and end devices in what we call SDN enabled node by making nodes reprogrammable through wireless communication. Programmable nodes are so significant because they enable transmission of data from data plane and be used in application plane. in addition, they are applicable to different applications and allowing functions of different processes within the WSN to run efficiently and reduce the costs, improving energy efficiency, scalability and render a system with multiple of functional sensor nodes.

Hence, interest of this paper is focused on design and implementation of SDN enabled sensor node, without SDN enabled sensor node systems/models of SDN and SDWSN cannot be able to operate efficiently and reduce complication of network configurations and management so SDN enabled node is a component that enables SDN paradigm to transfer data from their source in the data plane and be utilized for different purposes in application layers. Many SDN sensor nodes are found in the data plane of the SDN architecture which decouples SDN control plane from data plane and the need to investigate, improve nodes enable these models to transmit information without loss of resources. The sensor nodes comprise of both hardware and software, where hardware consists of a power unit, sensing unit, transceiver, processor, radio, etc. and software node normally consists of flow table, sensing element and in-network processing, where the SDN controller prescribe rules which are stored in flow tables and be utilized by the sensor node in the data plane, the sensor module is able to generate traffic which is sent to the processor while data aggression happen at the sink node and data fusion on sensor node.

According to Ding and Shen [23], there is a component that runs on sensor nodes as end devices for detecting of responses of the environment and forwarding of collected data in the data plane of SDN paradigm, this is called SDN-enabled sensor node/ Programmable node. Thus, SDN enabled sensor node is a type of node that plays both roles: SDN switch and SDN end device. In addition, interesting features like node and resource management could be achieved through SDN enabled sensor node in WSN. Although different node names such as programmable nodes [23-25] and SDN enabled sensor nodes [26] are utilized by different researchers, their purpose is the same hence they can all be referred as SDN enabled nodes.

Techniques in [27] on the design SDN enabled sensor node are emerging with the focus on resource management, topology, Quality of Service (QoS) and energy control by making sensor nodes programmable through wireless communication. In [25] flow-based programmable nodes in software-defined sensor networks were designed by applying SDN and OpenFlow protocol into WSNs. OpenFlow [7] is a type of network protocol based on SDN, it is the most common used southbound interface in recent years. The design and implementation of these programmable nodes were set to achieve different functions such as topology discovery, sensor data acquisition, and processing. And they composed of a sensor module, programmable data transceiver module, and Programmable sensor nodes. According to Lan *et al.* the sensor nodes designed can change their functions and characteristics by means of real-time loading programmed according to the configuration files issued by the controller. They deal with configuration of files as well as other real-time requests to achieve the purpose of data transmission and network information collection. Hence three types of nodes were designed in the data plane, these include:

- Dump node, responsible for data acquisition such as light intensity, temperature, humidity and battery voltage. It is made up of sensor module (which include sensor group and ADC), CC2530 module (which include processor and communication module) and power management module. With three of these modules, processing, sensing and networking can be achieved, and environment information collection is reached. Employing CC2530 module which has processor and communication module enables in network data processing, data storage as well as online programming to be carried.
- Mobile nodes, responsible for all works in the network except for the one occupied by the dump node, it can also move to any position of the network with the instruction of the controller. Furthermore, Mobility is also realized by the mobile nodes.
- Sink node, this serves as a local controller, which is composed of a CC2530 module, power management module, and Nanopi module. According to the author, sink node acts as a coordinator responsible for receiving of information from the controller of control plane and delivering requests and commands to other nodes.it has functions of real-time information collection network. The sink node is designed to be reconfigurable through wireless communication and variability is realized by it. The communication of the sink node with the controller in control plane is through the serial connection and it can communicate with dump nodes and mobile nodes through wireless links, plus the distance of neighboring nodes is determined by the RSSI.

In [15], the features of the three layers SDN-based WASN frameworks is presented by the control plane between the data plane and application plane. In the control plane, the SDN controller instead of the distributed WSAN nodes make decisions for controlling packet forwarding. There are three types of nodes that were included in WSAN, which are sink node, sensor node, and actor nodes and all these nodes reside in the data plane.

- Sink node oversees message collection and data fusion. Based on its protocol set and interface set, the whole WSAN is divided into many communication clusters.
- Senor node, the node resides in the data plane. The functions of the nodes include sensing of the states of task execution and environment as well as forwarding of state messages to relevant actor nodes.
- Actor node, this is the node that does the receiving of state information from sensor nodes, executing cooperatively or independently and returning the execution results to the upper layers.

A hardware independent TinySDN system based on TinyOS architecture was designed and implemented to enable multiple SDN controllers in SDWSN networking. It consisted of SDN enabled sensor nodes, which is divided into three parts; TinyOS application, TinySdnP and ActiveMessageC for data collection & forwarding and SDN controller node, for receiving and controlling data from the data plane. Results from their experiment conducted in COOJA simulator showed no delay in the SDN enabled sensor node for forwarding of data, and the only delay observed was on the first generated data packets, that must wait until data flows are specified on sensor nodes. Each SDN enabled sensor node is designed to find the SDN controller node and receive flow specifications and perform flow request when necessary. Another solution for enabled nodes was presented [21] in SDSN to combine SDN with the existing WSNs and comprised of SDSN programmable controller node and SDSN programmable sensor node (similar with SDN enabled sensor node in TinySDN [8]. SDSN programmable nodes are configured for network control and SDSN

programmable sensor nodes for handling and transmission of data in the data plane. The programmable nodes were reconfigured using wireless communication and designed using NanoPi and CC2530 modules. In the sensor node, several modules like packet generating, CPU, flow table and communication module are contained to do the sensing and forwarding of the data packet in the data plane. CPU is the main component of sensor nodes that determine if the data packet received matches the flow table or not and performs the related action and integrating the data packets from other sensor nodes with data packet generated by its own. SDN enabled sensor node proposed in SDNSPIN [27] addressed issues on energy consumption, higher communication latency, and host level

Security in sensor nodes of SDWSN. Results concerning the above challenges were achieved using CONTIKI simulator [25]. The same principle as of TinyOS framework [6] was used for enabling multiple SDN controllers in SDNSPIN. The distance between a sending node and neighboring sensor nodes is a key parameter used to achieve energy savings and Security is also achieved in host level nodes by the controller; where nodes cannot receive or forward any messages without the knowledge of controller. Create a node as an attacker and DoS flood attacks are identified and are avoided by the host.

TABLE I. SDN ENABLED DEVICES FEATURES

Architecture	Focus	Module used	Nodes developed	Routing protocol	Advantages	Disadvantages
SDWSN [5]	Node mobility Energy management Data aggression Flexibility definition for rules Scalabilities Security	N/A	Sensor node Controller Node	OpenFlow protocol	Node mobility Energy management Scalabilities Security issues were addressed.	Communication delay. Compact packet size
SDWASN [15]	Node mobility Energy consumption Topology Scalability Reliability maintenance	N/A	Sensor nodes Actor nodes Sink node	SDN-based protocol stack	Reliability maintenance. Scalability Node mobility	
TinySDN [8]	Resource management flexibility and memory footprint SDSN enabled sensor node &SDN controller node Energy consumption	Radio module Sensor mote module Controller server module	SDN-enabled sensor nodes SDN controller node	Collection Tree protocol	Node resource management. Flexibility and memory footprint was achieved.	Security is not addressed.
SDN-WISE [18]	Energy management Data aggression Flexibility Performance Simplicity in network programming Topology discovery	CC2530 module	SDN-enabled sensor nodes	SDN-WISE protocol stack	Energy management. Flexibility	Security not addressed. Energy consumption in nodes was not addressed
SDSN [23]	Data aggression Flexibility Scalability Data acquisition and transmission SDSN programmable sensor nodes SDSN programmable controller node	NanoPi module CC2530 module	SDSN programmable sensor nodes SDSN programmable Controller node	Zigbee stack protocol	Greater feasibility in the node. Scalability was achieved.	Security is not addressed.
SDNSPIN [27]	Security Routing protocol Energy efficient Transmission delay latency	TinyOS module	SDN-enabled sensor node	SDNSPIN protocol SPIN protocol CTP protocol	Security was achieved Energy efficiency was reached in SDN enabled node	Using SPIN does not guarantee packed forwarded to be received.
SDSN [25]	OpenFlow protocol SDSN programmable sensor nodes SDSN programmable controller node	NanoPi module Sensor module Data programmable transceiver module	Dump nodes Mobile node Sink node	OpenFlow protocol	Data plane based on flow table forwarding has lower packet loss Energy is monitored in real-time by controller Network can be repaired efficiently	Security is not addressed.

IV. Comparison and Discussion

There are many techniques and requirements to be considered during the design and implementation of SDN enabled sensor nodes in Software-Defined Wireless Sensor Networks. TABLE I presents some of the significant features that must be employed in the design of SDWSN such as the module to be used, routing protocol, aims and nodes to be developed. Deciding which routing protocol to use is very important since it determines which route the data must be transmitted from the data plane to the control plane without loss of information, furthermore, different routing protocols offer different features like energy management, security, scalability, flexibility, etc. OpenFlow protocol utilized in [17], [7] and [25] was the first protocol to be employed in SDN for wireless sensor networks.

Due to the increase proposals of SDN to be employed in WSNS other protocols such as Collection Tree Protocol (CTP), Zigbee stack protocol, SDNSPIN were employed in [15], [20] and [28] were used in the implementation of SDWSN. Implementing hardware based SDN enabled sensor node requires different types of modules to be coupled to do the sensing, communication and manage the energy in the system., the commonly used modules are the CC2530 module, NanoPi module, radio module and data programmable transceiver module used in the implementation of the programmable nodes in TABLE I

For the past years, since SDN emerged few programmable wireless nodes/SDN-enabled sensor nodes have been developed even though they are so vital that they collect data and transmit it for end-user purposes. Most of the papers reviewed only employed sensor nodes which they didn't design themselves with a risk that the SDWSN system they are employing them might not work or the system could consume a lot of energy, prone to attacks and not all sensor nodes can work, even lead to loss of information during the transmission of data, thus, SDN-enabled sensor node must be implemented with care. SDN-enabled sensor node designed in [5], [23], [27] and [[25] are the best that can be employed in SDN paradigm based on WSNs to cater solutions on sensing and forwarding of information in the systems. the main advantages of SDN enabled sensor node are that energy in nodes can be monitored in real-time by the controller hence energy management in sensor nodes is achieved when the controller decides the best route to be used when transferring of data from the data plane. Additionally, other features like scalability, node mobility, flexibility, and reliability can be easily being introduced by the use of a centralized controller node and SDN enabled sensor nodes

The common challenge faced in the SDN-enabled node is security, most of the nodes designed don't address this issue living sensor nodes to prone attacks which cannot be easily countered leading to information loss. Security is included in the design and implementation of nodes by using protocols that can detect malicious threats. Some protocols employed don't guarantee information being delivered to the controller. Another challenge is on the communication of the node with its neighboring nodes, where parameters such as distance and speed are taken into consideration for nodes to exchange data. Some solutions concerning common challenges are highlighted, for example Since sensor nodes in data plane are normally powered by battery hence papers like[8, 15, 17, 18, 27] have focused on ways to reduce the energy consumption in SDN enabled sensor nodes, for example setting them into sleeping mode when they are not in use.

In [17] features like node mobility, energy management, data aggression, flexibility definition for rules, scalabilities, security were discussed. Even though SDWSN is still in its infancy stage, it appears to tackle some inherent WSN issues such as security which was omitted for many in SDN discussions for the past years. Security is one of the mentioned challenges with SDN in WSN but a few papers [17, 27] aim to tackle this issue. Since SDN controller is centralized, it is easily exposed to threats and the whole network can collapse since it controls the whole behavior of the network.

Meanwhile, other papers [8], [18], [15] presented some features like topology discovery, memory footprint, data acquisition, and transmission. Positive results were achieved. Routing protocols were also presented in SDNSPIN. Routing protocols are so important that they improve system operations and applications. Routing protocols like MAC, SPIN, Ad hoc on-demand and many more are used for different purposed. in addition to SDNSPIN transmission delay latency was also addressed.

V. Conclusion

This paper highlights the challenges faced in WSN and SDN and their solutions. solutions provided by the emerging SDN paradigm for wireless sensor networks were discussed. This paper is presented to provide a review based on SDN programmable nodes/SDN-enabled nodes for information collection and transmission in the data plane. Discussions of techniques to be considered when attempting to design of SDN-enabled sensor node for Software-Defined Wireless Sensor Node were provided, in addition, different SDN enabled nodes designed in the past few years were discussed, the discussion extended on SDWSN, where highlights on SDN enabled sensor nodes which are vital for information collection and transmission were presented. Energy consumption in sensor nodes was found to be efficient, most of the papers have tackled this problem meanwhile security remains a concern, hence the aim future design of this paper will include security solutions in SDN enabled sensor nodes. Different SDN enabled sensor nodes are designed using different techniques, therefore, in our implementation of SDN enabled nodes will make use of combinations of these techniques which cater best solutions for nodes in the SDN paradigm.

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