Topology Discovery Protocol for Software Defined Wireless Sensor Network: Solutions and Open Issues

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***Abstract*— The fusion of the two models Software Defined Network (SDN) and Wireless Sensor Network (WSN), gives rise to a new paradigm called Software defined wireless sensor networks (SDWSN). One of the core concepts of SDN is the separation of the network's control and data planes. Topology Discovery (TD) is a critical component of any SDN architecture. Due the dynamic nature of WSN, the network topology keeps changing due to the mobility of nodes or the running out of the battery energy. Therefore more packets will be sent to the controller to update the topology and flow table. Such an overhead traffic could negatively affect the efficiency of the network resources, such as energy, channel, memory or storage and processing capability. This phenomenon calls for the development of an efficient TD protocol in SDWSN without compromising the performance of the network such as throughput, network lifetime and latency. In this paper, the possibility of how to increase the efficiency and reduce the control traffic overhead through TD in SDWSN has been discussed. Current SDN controllers use the OpenFlow Discovery Protocol (OFDP) as the key protocol for discovering the underlying network topology. OFDP is the protocol used by OpenFlow controllers to discover the underlying topology. However, such discussion on OFDP is not exhaustive and thus a comprehensive survey of the TD for SDWSN becomes necessary.**

Keywords— Topology Discovery, SDN, WSN, OFDP, SDWSN.

I. INTRODUCTION

The capacity of WSNs need has increased due to the development of the Internet of Things (IoT) by managing more of current research in this field. IoT is a network of smart objects attached to a communication medium [1].

WSN is supposed to play a principal role in IoT since the sensor nodes are the principal components of this concept [2]. It is a great platform for low-rate wireless personal area networks and it faces several challenges, such as network management and heterogeneous (diverse) node networks [2], [3]. In the architecture of WSN, we have micro-sensors that control environmental and physical factors such as temperature, humidity, vibrations, motions where the sensor nodes are miniature and fancy and held the development in Micro Electrical Mechanical Systems (MEMS) development [1].

One of the main challenges in WSN is how to enable flexibility on infrastructure, considering that all nodes behave both as forwarding devices and end nodes, there are different routing patterns, different applications being executed by the nodes and yet it should be energy efficient and limit the control traffic [6].

SDN addresses several of the WSN challenges; especially energy which is the source of the network lifespan. Therefore, this leads to infuse SDN with WSN to form SDWSN [3]. It is a network defined for dynamic control of smart devices [3].

SDN is a way to conducts networks that split the control plane from the data plane [4]. The routing/forwarding decisions are made by the SDN controller established on network information received where OpenFlow was the first protocol proposed to establish the communication [5].

A lot of the energy functions are removed from the physical node to a logically centralized controller in SDN. Functions such as routing, major processing and management are handled at the controller or application level [5], [3], [7], however, topology management is needed for the network management.

The need of an efficient TD in SDWSN is because, since the dynamic nature of WSN, there is a change in the network due to the node mobility and more data are sent to the controller to update the topology. Overhead traffic could negatively affect the resources of the network [9]. The topology of the network also plays an essential role in energy. Very few employments of nodes use a great deal of energy because the communication range between nodes is long [1], [10], [11].

TD is a process by which an entity on the network assembles information about the topology of the network itself. It can occur in many ways and at many levels in the network and is strongly tied to the network architectures and protocols used [12]. The topology information helps the controller to have an overview of the entire network [13]. And the TD must follow some of the requirements for the controller.

Some of those requirements are: TD must be error-free; a topology error leads to a wrong routing of flows. The clash can be very catastrophic if the error is in the routing core (core routers and links). The second one is TD must be efficient; a discovery protocol must not flood the controller with unnecessary information and only sends the topology events information when they appear.

The controller is allowed by the topology management to facilitate the applications in the application plane, where the network traffic is routed through the network topology to its destination. The controller discovers a topology through, host discovery, switch discovery and combines links between the switches [13], [9], the controller finds the host by receiving a data-In message from the switch [14]. The switches are discovered during the initial bond process with the controller and combines links between switches are discovered through the OFDP [15], [16], [6].

The rest of this paper is organized as follows: In section II gives a brief background about TD and SDWSN architecture, in section III talks about TD in SDWSN; in section IV, we give the methods of evaluation on TD. Section V, we give the open research issues and we suggest possible solutions to address these issues. And finally, section VI concludes the paper.

A. SDWSN Architecture

The SDWSN model is also envisioned to play a critical role in the rising Internet of Things paradigm. It is a new emerging paradigm for Low-Rate Wireless Personal Area Networks (LR-WPAN) [1]. The solution to support SDN approach LR-WPANs is, in fact, SDWSN [7] where communications in LR-WPANs occur at a low rate by definition. It is extremely important to guarantee low-energy consumption. To reduce energy consumption, SDWSN uses duty cycles by turning the radio off when it is not utilized [7].

There are different implementations of the architecture of SDWSN; they all conform to the fundamentals of SDN decoupling. The Fig. 1 depicts the basic functionalities of SDWSN as applied by various researchers [1].WSN has been conceived to be application-specific, which has probably formed a belief so far [8], [1].

The data plane consists of sensors performing flow-based data forwarding and the control plane consists of one (or possibly more) controller that centralizes all the network intelligence, performing network control such as routing and Quality of service (QoS) control [9]. The whole idea is to make the underlying network (i.e., data plane) programmable by manipulating a user-customizable flow table on each sensor via Sensor Open Flow (SOF) [10], [11].

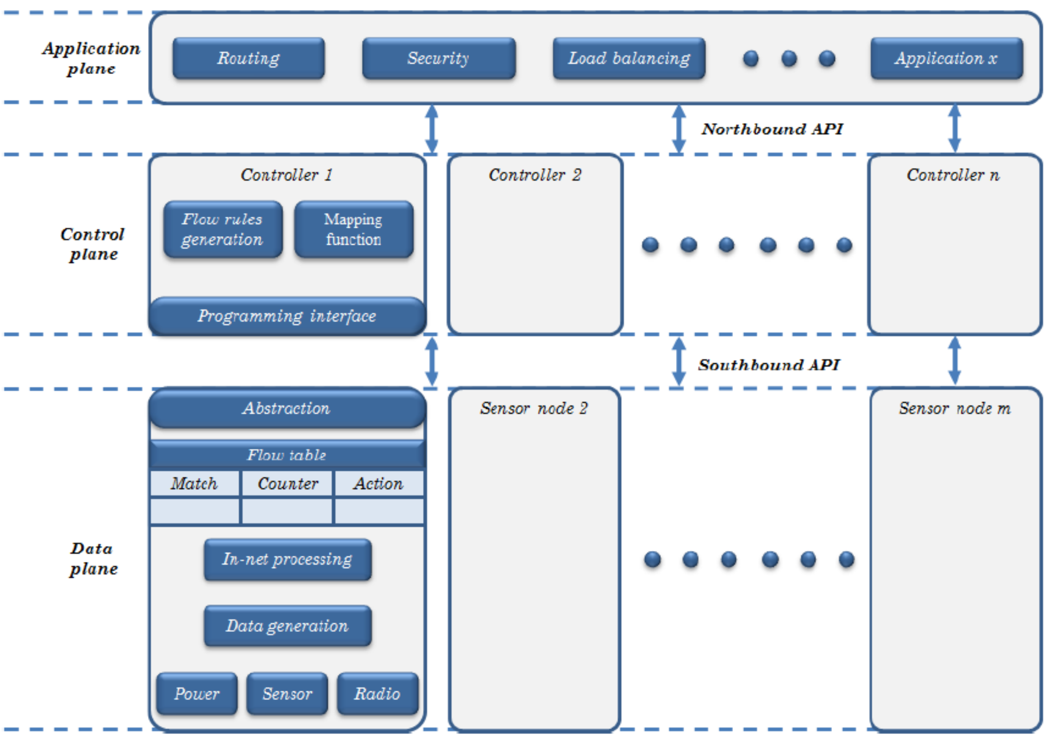

Fig. 1. Basic SDWSN architecture [1].

II. BACKGROUND

Section II gives the background of SDWSN architecture and Topology Management.

A. Topology Management

The topology management is a unique characteristic of SDN as compared to traditional networks. However, TD is a key component supporting the logically centralized network management and control paradigm of SDN and is a service provided by all SDN controller platforms. The decoupling of the control plane from the data plane enables the SDN to have a logically centralized control of the network [12]. To achieve the centralized control, a controller (responsible to control the network centrally) should have a global visibility of the complete network.

A controller incorporates various core modules that assist in executing various SDN applications. Among the core modules, a topology management creates a topology of the entire SDN infrastructure. The topology not only facilitates the controller but also assists the application plane service to perform its operation using the network programmability. The network topology is significant to both the control plane and the application plane because it provides an abstract visibility of the entire network devices.

III. TD IN SDWSN

Section III gives a literature review on TD in SDWSN whether it is centralized, decentralized or distributed TD.

Incorporating SDN in WSN results in moderate control traffic overhead for the sensor Network will not be overloaded. The control traffic overhead is the total number of bits of the packet-out messages sent per second [12]. The reduction in the number of the required control messages in the TD process has a direct impact on the control traffic overhead. The number of Linked Layered Discovery Protocol (LLDP) Packet-In messages received by the controller in a single discovery round depends on the network topology and is simply twice the number of active inter-switch links in the network, one packet for each link direction. The total number of LLDP Packet-Out messages a controller needs to send per OFDP discovery round is the total number of ports in the network [12]. The reduction of the control traffic is achieved by using the improved version OFDPv2 algorithm [12].

The OpenFlow protocol is a guideline approach used for communication between the controller and the OpenFlow switches on the southbound interface of the SDWSN [13]. The southbound interface bares requests and replies to both the controller and the OpenFlow switches [11]. The updated network topology information is significant to the controller in providing efficient control and management of the network. As a result, the efficient TD is considered to be an important characteristic for the controller. Developing a topology of the network requires switch discovery, host discovery and interconnected switches' discovery.

Below we discuss different papers on TD according to their approaches used, strengths, weaknesses and objectives.

A. Centralized TD

A centralized system, all stations depend on a single controller to transmit and receive information. And it is easy to control but has low scalability.

Pakzad *et al.* [12] proposed "Efficient TD in OpenFlow-based Software Defined Networks" by implementing a new TD approach OFDPv2 (OpenFlow discovery protocol version 2) by using POX controller platform. OFDPv2 which has the goal of reducing the overhead of the TD mechanism by reducing the number of control messages that need to be sent by the controller. However, Azzouni *et al.* [14] proposed "sOFTDP: Secure and Efficient TD Protocol for SDN". They have implemented sOFTDP as a TD module which is more secure than OFDP.

Lowekamp et al. [15] proposed "TD for Large Ethernet Networks" by developing two approaches to improve the completeness of their forwarding databases. Their implementation requires access to only one endpoint to perform the queries needed for TD.

Abdolmaleki *et al.* [16] proposed "Fuzzy TD protocol for SDN-based wireless sensor networks". The proposed fuzzy logic based solution, called Fuzzy TD Protocol (FTDP) was implemented to improve the efficiency of SDWSN. This work is designed according to the SDN solution for WSNs. It is one of the first works that uses fuzzy theory in SDWSN. Their proposed solution fuzzy system in the control plan has the objective to increase the delivery rate of packets, reduce the packet loss, and increase the remaining energy of the network in order to improve the performance of SDWSN.

B. Decentralized and Distributed TD

Decentralization is the process of transferring information, through more elements of a network so that no one node can be control. It has moderate scalability. However, different methods on TD were decentralized.

In decentralized method, Bejerano *et al*. in [17] proposed "Physical TD for large multisubnet networks" where their algorithms rely on standard Simple Network Management Protocol (SNMP) Management Information Base (MIB) information that is widely supported in modern IP networks with the main challenges in determining the most complete set of path constraints for each skeleton path and another challenge for heterogeneous Ethernet network is the Complexity for physical TD. Another method that relies on SNMP MIB information is proposed by Breitbart *et al*. in [18] "TD in Heterogeneous IP Networks" by presenting algorithm for discovering physical topology in heterogeneous IP networks in the context of a TD tool with difficulties such as Limited local information and transparency of elements across protocol layers.

A distributed system is very stable and a single failure doesn't do much damage and has a few scalability. It is quite similar with decentralized except that all the information are distributed among them. Below we discuss some of the methods that are distributed TD. Distributed systems are very stable and a single failure doesn't do much damage.

Donnet *et al.* [19] proposed "Efficient Algorithms for Large-Scale TD" by proposing and evaluating Doubletree, an algorithm that reduces redundancy simultaneously on routers and end systems. In another distributed TD method, the authors, RoyChoudhury *et al.* [20] proposed "A Distributed Mechanism for TD in Ad Hoc Wireless Networks Using Mobile Agents" by designing a multi-agent based protocol to make the nodes in the network topology aware; the principal aim of this method is to collect all topology-related information from each node in the network and distribute them periodically to other nodes through mobile agents. They have used a concept of link stability and information aging. Donnet *et al.* in [21] proposed "Improved Algorithms for Network TD" by showing how to improve the communication scaling properties through the use of Bloom filters to encode a probing stop set. An additional benefit comes from reduced communication costs. The problems in [21] from the significantly higher traffic levels it would generate and from the explosion in the data it would collect. Ochoa-Aday *et al.* [22] proposed "Current Trends of TD in OpenFlow-based Software Defined Networks" by addressing the main TD protocol approaches LLDP and BDDP (Broadcast Domain Discovery Protocol) with challenges of supporting the TD functionality.

IV. Methods and Evaluation

Researchers have developed different approaches or algorithms to address TD. Table 1 shows different approaches for different papers with their strengths, weaknesses or challenges and objectives. And it gives a brief description of each section. We have investigated about eleven recent papers on TD.

Table 1: Comparison Table

Methods	**Objectives**	**Approaches used**	**Strengths**	**Weaknesses/ challenges**
Azzouni *et al.* [14].	Implementing sOFTDP as a TD module in Floodlight	LLDP packets	▪ Bidirectional Forwarding Detection. ▪ Hashed LLDP content.	security and efficiency issues of OFDP
Ochoa-Aday *et al.*[22].	Discovering in Open Flow-based network and hybrid network.	LLDP and BDDP	▪ Dynamic configurations and innovations in the network. ▪ Reduction of the controller.	▪ Difficulty to support the functionality of TD. ▪ Difficulty to support for OpenFlow switches.
Lowekamp *et al.* [15].	Designing of an algorithm the physical topology of the Ethernet network.	"spoofed" ICMP-echo packets and The Lucent group	▪ Information mapping combination. ▪ Sufficient data.	▪ No forwarding database. ▪ Dumb switches. ▪ Sufficient traffic. ▪ Incomplete information.
Donnet *et al.* [23].	Reduce intra-monitor redundancy.	Doubletree algorithm	▪ The tree-like structure of routes on the internet. ▪ Doubletree can reduce measurement load.	▪ Lack of consideration of efficiency for internet monitoring system. ▪ The problem of redundancy ▪ bandwidth consumption
Breitbart *et al.* [18].	discovering the up-to-date physical topology of an IP network	MAC addresses	Dealing with incomplete information and VLANs	▪ Limited local information. ▪ Transparency of elements across protocol layers. ▪ Heterogeneity of network elements.
Donnet *et al* [21].	▪ Determining the performance of Doubletree, ▪ Reduce communication overhead and ▪ Increase probing effectiveness	Doubletree algorithm	Reduced communication costs	▪ Higher traffic levels. ▪ Obstacle to Doubletree's implementation. ▪ Inherent scaling problems
RoyChoudhury *et al.* [20].	Topology information collection and distribution the network.	▪ stigmergic communication ▪ Link stability. ▪ Information aging	The use of sensor network in TD	▪ Node mobility ▪ Information convergence ▪ Navigation strategies
Bejerano *et al* [17].	Partial topology information demonstration using SNMP MIB	skeleton-path refinement algorithm	Strong completeness	Complexity for physical TD.
Pakzad *et al* [12].	▪ Reduction of the overhead of the TD. ▪ configure the largest possible network	OFDPv2 (OpenFlow Discovery Protocol Version 2)	▪ higher control traffic overhead ▪ high data rates	Scalability and reliability problems.
Abdolmaleki *et al.* [16].	▪ Improvement of the delivery rate of data, ▪ Reduction of the packet loss, and ▪ Network energy increment.	Fuzzy TD Protocol (FTDP).	▪ Increase the delivery rate of packets, ▪ Reduce the packet loss, ▪ Increase the remaining energy of the network.	▪ Limited energy consumption ▪ Load balancing, dynamic topology and ▪ Node mobility

With the methods mentioned in the table above, researchers have investigated challenges for their proposed methods. To address the challenges of scalability and reliability as discussed in [12], the authors have proposed the OFDPv2 approach. The approach involves the following changes by modifying the controller behaviour and install a new rule on each switch, which specifies that each LLDP packet received from the controller is to be forwarded to all available ports. The strength of the method is to reduce the controller overhead by using the approach mentioned. The scaling problem is also discussed in [21] where the aim is to determine the performance of Doubletree when using Bloom filter with the strength of reducing the communication cost.

The challenges mentioned in [16], such as limited energy consumption was addressed by using FTDP approach. The approach has the strength of improving the performance of SDWSN with the strength of increasing the delivery rate of the data, reducing the data loss and increasing the network energy.

V. OPEN RESEARCH ISSUES

In future research, challenges and directions of TD in SDN are given. The research on TD is still at the beginning. Therefore, plentiful opportunities occur for forthcoming work to reduce the challenges in TD. The following forthcoming directions will benefit researchers to analyze different solutions in making the TD continuous in the SDWSN.

However, combining numerous SDN domains and distributing the network topology amends in the TD can be a very challenging responsibility. These combinations need a standard protocol to efficiently share the control information among the SDN devices. The controller must be regularly improved by adding features. One of the possible solutions after the controller is improved is to save the TD state in the neighbour controller; the process of the TD proceeds from the last registered status. However, when the network topology changes during the improvements, the registers will be poor in the respective topology. To reduce this issue, the controller should be improved at the time when the chance for the topological adjustment in the network is minimized.

For the issue of efficiency, by using OFDP, the controller regularly transmits numerous packets to each switch in the network, which could bring in performance reduction of the data plane. Investigations made on diverse controllers demonstrate from the beginning some network size meaning number of switches, operating only the discovery module results in the meaningful development of the controller's CPU usage and reduction in performance. Scalability is another issue where the OFDP is not scalable since discovery packets might decrease or withheld. Moreover, by using OFDP in a multi-controller SDN network discovery cost gains linearly as more controllers are accumulated.

By using numerous protocols, a complete topology can be discovered. Since one protocol would leave significant gaps since various network blocks and probe data based on a protocol will be employed

The Logical centralization arises in scalability and reliability problems, since the SDN controller would symbolize a point of breakdown. To follow up this issue, researchers have suggested physically distributed SDN controllers, such as the Onix system which is a distributed control platform for large-scale production network.

With SDN controller, also called logically centralized entity, control intelligence is taken out from the forwarding elements such as router and switches and focused to the SDN controller, implemented in software. Given that the controller is generally the performance obstacle of SDWSN, making a principal service such as TD more efficient can have a meaningful shock on the overall network performance and scalability.

The performance based on OpenFlow has the objective to transmit one Packet-Out message to every switch and to transmit the corresponding LLDP packet out on all its ports where the issue is that OpenFlow switches do not support any dedicated performance for TD and the controller has the obligation to realize this service.

VI. CONCLUSION

In this paper, We have discussed different approaches based only on TD. by incorporating SDN in WSN in the TD, results in moderate control traffic overhead for the sensor Network to not be overloaded in the architecture of SDWSN

We have reviewed the currently existing standard OFDP, for SDWSN TD. And we also investigated some of the open research issues based on TD.

Some of the related works discussed in the literature review present the solutions for TD problems in SDWSN. We have also discussed the opportunities applying to SDN and have investigated the solution to the energy consumption problem which is SDWSN must support the duty cycle as a matter of fact, it would occur in topology adjustment which should be acknowledged by the modules that are responsible for network control.

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