Energy management techniques in Software-Define Wireless Sensor Network

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Abstract. Software Defined Wireless Sensor Network (SDWSN) is composed of sensors nodes in which routing processes are entrusted to a controller in a centralized mode. In an SDWSN architecture, the control plane is decoupled from the data plane. Sensor nodes are easily reconfigurable and are even more flexible than in traditional WSNs. Resource management becomes easy. However, this centralized management of routing processes requires a large amount of control messages. This induces additionnal energy consumption. In this paper, first, we analyse different techniques used to face this energy consumption problem and we highlight limits of the used methods. Then, we provide some perspectives.

Keywords: SDWSN, energy consumption, WSN, routing process.

1 Introduction

In recent years, Internet of Things (IoT) has been gaining momentum and has become a major part of our society. Different variants of IoT architecture have emerged, among which we have Wireless Sensor Network

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(WSN). WSNs are networks consisting of multiple sensor nodes that collect information in their deployment environment and send them to a sink node or data collector nodes via multi-hop process. They are widely used in many application areas, including medicine, precision agriculture, military usages. Despite the expansion of WSNs, reconfiguring sensor nodes once deployed remains difficult. A new technology called Software Defined Networking (SDN)has emerged. It allows to decouple the network control plane from the data plane. SDN makes easier to configure and manage WSN nodes through a controller. However, the major challenge with SDN is the massive production of control messages during communication between the controller and WSN nodes. This induces high energy consumption. Researchers have proposed solutions for architectures[1][2], routing protocols[3] and other mechanisms [4] to deal with this energy management problem. In this paper, on the one hand, we highlight various existing works focused on energy management in Software Defined Wireless Sensor Networking(SDWSN). On second hand, we conduct a critical review of these works and identify research perspectives. The rest of this paper is organized as follows. In Section2, we present Software-Define Wireless Sensor Network technology, particularly its architectures and its advantages over the traditional WSN. In section3, we analyse different techniques used to optimize the energy consumption in SDWSN. Then we conduct a critical study of these solutions and we draw some perspectives in section4. Finally, we conclude in Section5.

2 SDN in Wireless Sensor Networks

Software Defined in Wireless Sensor Network (SDWSN)is the technology that allows a separation of the data plane from the control plane in WSN architecture. This paradigm allows a controller to manage the global behavior of the network. Network components such as sensor nodes reside in the data plane and simply transmit data according to streaming instructions supplied by the controller. This method of network management allows global configuration of the network. This approach contrasts with distributed management schemes, which require individual configuration of network equipments to change network behavior. SDN architecture includes application programming interfaces (APIs) that provide a working interface between the application, control, and data planes. The northbound APIs are between the application plane and the control plane, and the southbound APIs are between the controller and the data plane. The southbound APIs facilitates management of flow rules between the controller and the data plane devices. OpenFlow[5] is the standard commonly used as southbound API [5].

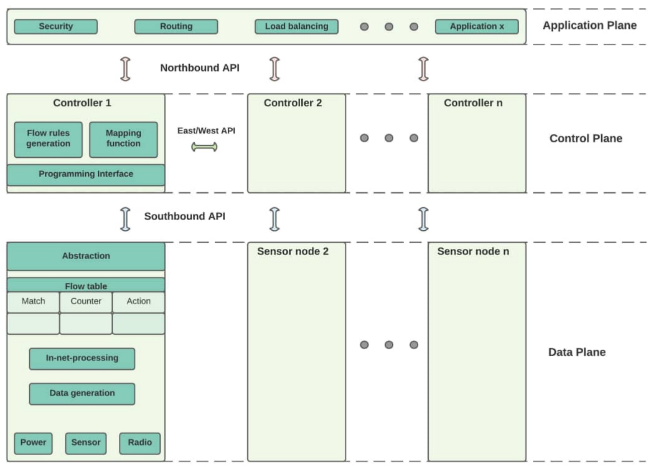

Fig. 1. Architecture d'un SDWSN.

2.1 Contribution of SDN in the WSN

Administration of WSNs is a tedious task for its administrator due to their rigidity for reconfiguration, also WSNs are facing security problems due to decentralized management. SDN will bring several advantages to the management of WSNs namely flexibility in resource management, security of network devices etc. Some advantages of SDN in WSNs have been discussed as Suits:

- At the configuration level: SDN will facilitate the redeployment of applications and increase the flexibility of resource management. Multiple applications can be tested by the administrator without passing from node to node for configuration. Thus, the WSN becomes more efficient in its use as one could switch from one application to another without redeploying new devices. Also, the maintenance or the change of a device is done very easily since the WSN devices do not manage the control plane anymore.

- Energy management: WSN nodes are subject to energy constraints, which requires the use of energy efficient protocols. SDN with its global view of the state of WSN nodes will be able to offer efficient management of WSN energy consumption. Also, appropriate mechanisms can be designed to reduce energy consumption. The control plane functions can manage multiple routing protocols, thus avoiding nodes to be dedicated for a particular application in order to achieve energy efficiency according to usage.

- at the security management level: SDN suffers from the same security problem as WSNs. However, security solutions implemented in a distributed manner in WSNs can be redeployed in a centralised manner at the application layer with SDN. Centralizing security management makes it easier to deploy and configure security systems. This centralisation of security allows a quick response in case of an attack.

2.2 Differents Architectures of SDWSN

In order to improve and facilitate configuration and resource management in SDWSNs, different architectures have been proposed. [6], the Sensor OpenFlow proposal includes two (2) elements: an architecture with a clear distinction between the control plane and the data plane, and a central component that standardizes the communication protocol between these two planes. Sensor OpenFlow not only provides the basic OpenFlow functions, but also allows dynamic assignment of tasks to sensor nodes via the control plane. The authors solve the problem of insufficient resource utilization and performance degradation by promoting the sharing of hardware resources between different applications and the reuse of implemented functionality. SDWN [7] architecture not only includes the basic functions of Sensor OpenFlow, SDWN has other techniques such as data aggregation, duty cycle, rule definition and actions to optimize cross layer communication. This new architecture involves two (2) essential components, namely generic nodes where the flow tables and the sensing applications are located, and the sink node composed of a device managing the communication with the generic nodes and another one being an embedded system combining the tasks of controllers and virtualize. TinySDN[1] is an architecture for defining multiple controllers in a wireless sensor network, unlike most proposals where only one controller is required. It contains two major components: the SDN-enabled sensor node, which contains an SDN switch and an SDN terminal, and the SDN controller, in which the control plane is programmed. The main contributions of their work were the design and implementation of TinySDN. Their results showed that, compared to CTP (Control Tree Protocol), TinySDN does not introduce considerable delay in the routing task, the delay is only seen in the generation of the first packets, which have to wait until the data fluxes are specified on the sensor nodes. SDN-WISE[2] is a new SDWSN solution in which the sink node is a gateway between the sensor nodes and the controller. In order to reduce energy consumption, SDN-WISE uses techniques such as data aggregation, duty cycle. It establishes a stateful approach by encoding different features in the data structure; such as WISE state table accepted identifiers and WISE flow table. However SDN-WISE has limitations related to data collection and interacting with the controller through the same sink node resulting in collisions between data and control messages. Martin Jacobsson et al[8] proposed an architecture where the nodes integrate a local controller that receives and executes commands from the central controller either by modifying the parameters of the functions or by installing new code into the functions through virtual machines for embedded systems. In their work, an application execution environment is defined, for networked processing of sensor data, important for application robustness, energy efficiency and delay reduction, and updating the application code over the air. The controller manages long-term decisions such as which protocol and parameters to use, and the collection of topology and link information for robustness and flexibility. IT-SDN[9] a new SDWSN architecture that contains three (3) parts: the southbound (SB) protocol that defines the communication procedure between the controller and the sensor nodes, the Neighbour Discovery (ND) protocol that maintains the neighbour information of the sensor nodes, and the Controller Discovery (CD) protocol that identifies the next candidate hop to reach the controller. They further described a software architecture based on contiki OS, which in addition to the main components of the general architecture (ND, CD and SB), added four (4) auxiliary components: A Neighbourhood Table providing a common data structure for the ND protocol to write discovered information; Flow Tables that store routing information defined by the controller; RX/TX Queues that correspond to buffers to prevent packet drop in case of network congestion or long packet processing times; and finally a central component that orchestrates all other modules based on events.

Table 1: Recap of SDWSN architectures

3 Energy management in SDWSN

In SDN-based WSN management, a logically centralized controller maintains a global view of the entire network involving large control messages generation. This results in additional energy consumption. To overcome this energy consumption problem, many solutions have been proposed. Different techniques including control message reduction, QoS routing, data aggregation and energy-based cluster head election have been implemented in the control plane level to reduce energy consumption in SDWSNs. In this section, we analyze the effectiveness of these different techniques to optimize energy consumption.

Architecture	Scalability	Implementation and environment	Techniques and	Controller
Sensor OpenFlow[6]	NO	SIMULATION NS3	Support protocol for SDN (API southbound)	Centralisé
SDWN[7]	NO	PROPOSITION	Aggregation Routing Duty cycle	Centralized
TinySDN[1]	YES	PROPOSITION	Multi-controller frame In-band traffic control	Distribute
SDN-WISE[2]	YES	SIMULATION COOJA	Reduction of the overload Aggregation Ease of programming	Distribute
Architecture of Jacobsson[8]	NO	PROPOSITION	Mobility management and location	Centralized
IT-SDN[9]	NON	SIMULATION COOJA	Definition of procedure communication A routing mechanism	Distribute

3.1 Clustering

Clustering in SDWSN is a technique used to reduce network loads. In this type of network architecture, nodes logically join together to form groups called clusters. In each cluster, one node is chosen as the cluster leader, called cluster head, to direct communication. The purpose of cluster formation is to reduce network overhead. This reduces energy consumption and improves the lifetime of the network.

Flauzac et al.[10] proposed to make clusters in the network and assumed that each cluster head is a controller called the SDNCH. each SDNCH manages the nodes of an SDN domain. to do this, the nodes collect information about the environment, process it and send it to the SDNCH. Also, the main controller is a node with superior resources to the other nodes in the cluster. the controller goes through the SDNCHs to have full access to the nodes and even for the injection of flow rules.

In [11], authors investigated the possibility of introducing software-defined networking concepts into wireless sensor networks. They argued that the introduction of SDNs into WSNs could help solve some of the challenging problems of WSNs, such as energy consumption optimization and network management. In their proposed architecture, the controller is integrated with the base station to generate the routing table for the cluster heads. In their work, the simple sensor nodes do the data filtering during the collection according to the rules defined by the controller, the data sent are associated to the state information of the nodes.

Tan et al.[12] proposed QSDN-WISE that is a software-defined hierarchical network architecture for WSNs. It makes the system adaptable and allows complex network management. QSDN-WISE consists of a clustering algorithm, routing and LAN maintenance. The clustering algorithm is based on a dual cluster head, called DCHUC, avoids the power hole phenomenon and reduces the workload of a single cluster head.

WSN-integrated SDN architecture is proposed in [13]. In this routing approach the WSN sink node is replaced by the controller and the cluster head by a flow switch. So, a separation between the routing plane and the control plane is performed. It is required that the sensor nodes, including the head nodes, only have to route the received packets with a single lookup process and do not participate in the routing decision to lead to energy savings. The openflow switch, which acts as the cluster head, has higher energy than the sensor nodes. The rest of the nodes sense the data and send it to the cluster head. The controller is responsible for neighbourhood identification and topology discovery. This proposed architecture optimized energy consumption.

Authors in [14] have proposed a routing decision model for wide area networks called SD-MHC-RPL. To manage a large number of devices, it organises the nodes in a multi-hop cluster scenario. Each cluster is managed by a cluster head node implementing a low energy management protocol.

The principle work in this [15] to advocate a brand new clustering set of rules referred to as EBCA based on SDWSN. The SDWSN controller, redefines the communique radius of every sensor node based on the distance to the sink node and the quantity of neighbouring nodes, and proposes a new clustering method based on the residual energy of the node itself and its neighbours. Nodes select cluster heads based on the distance to the cluster head and the residual energy of the cluster head.

Shen et al.[16] proposed a LEACH-based clustering algorithms called EDSS-LEACH. The latter takes into account neighbours, residual energy and the three jump factors to the sink node. Using a fuzzy logic model, it calculates the scores of each node in each round of dynamic subnetwork expansion. Based on the scores, the algorithm finally obtains a set of well-distributed cluster heads and each cluster head determines its next hop using Dijkstra's algorithm. Simulation results show that the EDSS-LEACH algorithm may extend the network lifetime and improve the energy consumption balance.

3.2 QoS routing

In order to optimize energy consumption in SDWSN, several authors have proposed energy efficient routing protocols. FTDP is a routing solution [3] implemented on the SDN-WISE architecture. It uses the fuzzy system to calculate the cost associated with the neighbouring nodes in order to choose the node with the best cost as the next hop. FTDP based on QOS parameters (the amount of remaining energy of the node, the number of packets in queue wire and the number of neighbours) executes the fuzzy system which consists of fuzzification, inference system and defuzzification to calculate the cost associated to each eligible neighbor node. The node with the highest cost is chosen as the most appropriate intermediate node. Based on simulation results, they were able to prove that FTDP improves the network lifetime and increases the packet loss rate compared to SDN-WISE.

Bello et al.[4] proposed FTS-SDN implementing a routing manager at the SDN-WISE controller. This routing manager is responsible for creating responses to requests from the network. In application layer, the FTS-SDN routing manager software comes to a decision how the soliciting for node should cope with the mismatched packets and sends one or extra drift policies to allow the node to match the contemporary incoming packet with future comparable packets as a consequence reducing the strength intake of the soliciting for nodes.

To improve traffic distribution, Schaerer et al.[17] proposed the dynamic trafic-aware routing protocol DTARP, which considers the centrality and dynamic traffic statistics of nodes when calculating the path. With these informations, the most active and central nodes are recognized and are less eligible for retransmissions. Therefore, routes through less active nodes are chosen even if they have a slightly higher hop count. In addition, it is possible to have multiple short paths with the same length between two alternative energy management techniques were also used in the control plane.

Al-Hubaishi et al.[18] proposed a brand new routing choice approach in which a fuzzy-based totally dijkstra algorithm is used. This technique takes into consideration now not most effective the distances among nodes, however additionally the final energy of the nodes at the route, to increase the life of the network. The results show that the proposed SDN structure with Dijkstra's fuzzy algorithm is more efficient than Dijkstra's ZigBee-based algorithm in terms of energy consumption. Their method provides efficient routing even as extending the lifetime of the network.

Banerjee and al[19] proposed SD-EAR, software-defined energy-aware routing. SD-EAR divides the fully distributed structure of a sensor network into clusters where each controller is responsible for the area. The controllers known the topology of the associated zone, and also keep track of the node links. Outlying nodes in a zone are nodes that have a certain portion of the radio circle outside the zone. One of the goals of SD-EAR is to provide an energy-efficient routing protocol and a watchdog strategy to promote energy conservation in the network.

3.3 Reducing the production of control messages

Hieu and al[20] proposed a new mechanism called Trickle timers, to optimize network performance. The Trickle timer permits sensor nodes in a wireless network to exchange some control packets per hour when the network state remains stable. The Trickle algorithm establishes a density-sensitive local communication primitive with an underlying coherence model that guides when a node transmits. When the network is stable or coherent, Trickle causes nodes to transmit very few control packets (e.g., a few packets per hour) to reduce network overhead. When an inconsistency is detected, the node quickly resolves it by increasing the packet exchange rate. Performance evaluation shows that the SDN-WISE protocol with Trickle timers consumes very little energy, compared to the SDN-WISE protocol.

In [21], Ndiaye et al. proposed a solution called FR-CMQ running on the IT-SDN architecture. This solution reduces the number of 'flow rule request' messages to the controller. It accomplishes this by sending only the first packet request; for the other packets coming from the same source and going to the same destination, they will be queued at the node until it receives an instruction to process them. This prevents duplicate packets and saves the node energy.

In order to reduce the control message overhead problem, Nagarathna et al.[22] propose the mechanism of timeout by an SDN controller. Their objectives are to avoid the overhead problem and get a single response with appropriate information about its adjacent nodes located in the direction of the destination node during the packet forwarding operations.

Buzura et al.[23] implemented a well-informed control component efficiently that can manage a WSN and determine whether the sensors should transmit data or not. In addition, the controller can also decide to proactively transmit data for each sensor. This reduces the amount of data traffic in the WSN layer. In this proposal, for the controller to perform the proposed functions, it implements two components. First, it needs a basic learning component that learns the behaviour of each sensor, i.e., the data transmission frequency for each sensor to determine a pattern. Second, it implements a diffusion mechanism based on the previously established time interval models. Several simulations have been performed on historical weather conditions and the results show a significant decrease in network traffic reducing energy consumption and increasing network lifetime.

3.4 Other energy optimization mechanisms

Zhang et al.[24] advocate an energy-efficient resource allocation algorithm in SDWSNs. This radio useful resource allocation set of rules is controlled through central controllers with processing strength and storage and computation. Inside the latter, they pose an optimisation trouble optimising power use underneath QoS constraint. Then, the preliminary optimisation hassle is modified the usage of a semidefinite relaxation to attain a centralised adaptive bandwidth and energy allocation (CABPA).

Zhang et al.[25] proposed a centralized algorithm based on SDP(a semidefinite programming) for the power consumption issues in SD-WSNs. Because hassle is comfy into an SDP, it serves as a lower certain, which effortlessly achieves an premier power and bandwidth allocation. In addition, the tightness of the lower bound is analysed by two proposed special cases. Also, an alternative distributed approach is developed to provide a performance benchmark of the centralized approach. The simulation results reveal that the proposed centralized algorithm performs better in terms of energy consumption and bandwidth utilization.

Pradeepa[26] proposed the SDNSPIN controller to achieve energy savings by adjusting the power of sending nodes based on the distance between neighbouring nodes. Information about the SDN-enabled sensor network topology is transmitted in two steps: the SDN controller node, through a SPIN protocol, generates the neighbour table, and among these neighbours, the best one is selected based on its voltage level and link quality. In order to distinguish the neighbour, the SDN controller node broadcasts ADV packets and expects request messages from nodes; upon receiving a request, each request sender is included in the added neighbour table with its RSSI and energy level. Based on its neighbourhood table, the best neighbour is suggested to the sensor node to forward the information.

Authors in [27] implemented a traffic monitoring algorithm called SDN-TAP. SDN-TAP notifies the congestion state of affairs by using sending an alarm message to the controller to recreate the go with the flow guidelines for the congested node, the source node(s), and the information transfers. Evaluations have shown that SDN-TAP outperforms traditional routing protocols in reducing packet loss rates and energy consumption.

Table 2: Energy optimization mechanisms in SDWSNs

Solutions	clustering	Aggregation	Reduction of messages contrôle	Duty Cycle	Routing
EDSS-LEACH[16]	YES	YES	YES	NO	YES
SDN-TAP[27]	NO	YES	NO	YES	YES
FR-CMQ[21]	NO	NO	YES	NO	YES
DTARP[17]	NO	YES	NO	YES	YES
QSDN-WISE[12]	YES	YES	YES	YES	YES
FTDP[3]	NO	YES	NO	YES	YES
Integrating Trickle Timing[20]	NO	YES	YES	YES	NO
SD-EAR[19]	YES	NO	YES	YES	YES

4 Discussions and perspectives

Clustering based routing process has several advantages such as data packets aggregation[16] and reduction of control messages[12] in the network. These reduce nodes energy consumption. However, in this local centralized appraoch, cluster heads, which have the same characteristics as regular nodes, are much more solicited. As a result, their energy levels drop faster. Some cluster head change processes are based on residual energy of the members of the cluster. However, these cluster head change processes induce a large number of control messages. If the network is not dense, the cost of these processes may be greater than these benefits. For this reason, we recommend setting a minimum number of nodes for each cluster. The more elements per cluster, the better data aggregation process optimizes energy consumption.

Load balancing techniques [17] are based on node centrality or node traffic statistics as the failover parameter. In many lossy network contexts, these parameters are very volatile (change very quickly). This can cause network instability. We believe that the use of the residual energy of the nodes with a threshold of the difference between the residual energies of the two intermediate candidate nodes may be effective in the network lifetime optimizing.

To increase nodes lifetime, some authors rely on increasing the frequency of control messages transmission. Since these messages are sometimes essential to the proper functioning of the sensor network, in particular in lossy network contexts, we believe that it would be better to focus on the elimination of duplicate packets or to use the same packet for multiple purposes.

5 Conclusion

In this paper, we investigate SDN based techniques used to optimize energy consumption in WSNs. We review different SDWSN architectures and energy management schemes for efficient energy consumption. So, techniques like clustering, load balancing, QoS routing processes ones are analysed. We highlight some limits of these techniques proposed in the literature. We then propose some perspectives including the avoidance of redundant control messages, taking into account level of congestion of nodes in route selection process, for effective energy consumption optimization.

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