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Fuzzy topology discovery protocol for SDN-based wireless sensor networks

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ABSTRACT

The growing trend in pervasive systems forces traditional wireless sensor networks to deal with new challenges, such as dynamic application requirements and heterogeneous networks. One of the latest paradigms in this area is *software defined wireless sensor network*. According to the paradigm, the networks take care of managing topological information and forwarding decisions using a bipartite architecture in which a control plane decides the forwarding policies and the data plane (i.e. ordinary sensor nodes) executes them. Unfortunately, in highly dynamic networks, this approach generates an overhead of control packet exchange between the ordinary nodes and the control plane, that leads to additional energy consumptions. This paper proposes a fuzzy logic based solution, called *Fuzzy Topology Discovery Protocol* (FTDP), to improve the efficiency of software defined wireless sensor networks. This work is designed according to the *Software Defined Networking solution for WIreless SEnsor networks* (SDN-WISE), which is an open source solution for software defined wireless sensor networks. The proposed work is one of the first attempts to use fuzzy theory in software defined based wireless sensor networks. The simulation results show that our approach can increase the lifetime of the network by 45% and decreases the packet loss ratio by 50% compared to the basic SDN-WISE solution.

1. Introduction

Wireless Sensor Networks (WSNs) are becoming a fundamental part of our lives. These networks are composed of sensor nodes that cooperatively monitor the physical environment [1] and track events [2]. Unlike traditional networks, WSN nodes are resource constrained in terms of energy, communication range, bandwidth, processing power, and memory [3]. Additionally, a WSN has to deal with a great variety of applications that require different network structures [4,5], and may exploit mobile nodes [6,7]. Numerous solutions have tried to optimize the performance of these networks by introducing new design principles as well as establishing new protocols and algorithms. In recent years, a new paradigm, which is called *Software Defined Networking* (SDN), is introduced that allows the network administrators to dynamically manage their net-

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works. The decoupling of the forwarding devices (data plane) from the control logic (control plane), eases the change in the behavior logics without being affected by the heterogeneity in the underlying forwarding hardware. For instance, the controller can determine the best routing decisions to transfer data to the base station, and reduces the overhead of route selection task from other nodes even if the topology changes [8]. This idea is used in WSNs which leads to energy efficiency [9,10]. Given the constraints of sensor networks and the difficulties related to planning and designing nodes for different applications, the use of SDN concepts in WSNs is gaining attention. Wireless sensor network needs adaptive methods and techniques that are compatible with different applications and requirements [11]. Many researches [12–16] took advantages of SDN features to improve topology discovery as well as increasing flexibility, and scalability. One of their goals is to reduce the task deployment time, avoid the cost of node reboot, and deleting measurement tasks at runtime. For example, the technical challenges required to apply OpenFlow in WSN are investigated in [14]. Furthermore, SDN based sensor nodes need a reliable link with the controller to exchange network information that can be used by a network topology discovery algorithm for further enhancement of the routing decisions made by the controller [9]. According to the inherent constraints related to WSNs such as limited energy consumption, load balancing, dynamic topology and node mobility [17], it is vital to design an appropriate routing protocol that considers all these requirements and reduces control traffic between the nodes and the controller.

The main objective of this work is to improve the performance of software defined wireless sensor networks, by proposing a novel fuzzy logic based controller. We used fuzzy theory in topology discovery and routing decision modules. Each sensor node has to provide the required information containing the energy, the length of queue, the list of neighbors and the cost of each node. Therefore, a fuzzy logic based controller can consider several properties of the network nodes, such as the number of neighbors, the ongoing traffic, the workload level, and the remaining energy, to choose the best forwarding node and improving the performance of the network. This approach is implemented based on *Software Defined Networking solution for WIreless SEnsor networks* (SDN-WISE)[16], which provides a comprehensive architecture for software defined wireless sensor networks. Simulation results show that our approach can increase the lifetime of the network and decrease the number of lost packets.

The rest of the paper is organized as follows: In Section 2, the related works are surveyed. Then, in Section 3, a brief description of SDN-WISE is provided as the background of our work. Section 4 explains the implementation details. Simulations and performance analysis are presented in Section 5, and finally, in Section 6, we draw the conclusion.

2. Related works

Software Defined Networking is an emerging topic of research, which emphasizes on facilitating network management and increasing the scalability [18]. In these networks, there is a clear separation between the forwarding (data) plane and the control plane. In other words, the traditional forwarding logic is defined in the control plane and then implemented in the network devices. Therefore, the controller is in charge of taking forwarding decisions and sending them to the network nodes that converts the ordinary nodes into simple forwarding devices.

In [12] the authors focused on reviewing the enabling technologies used in SDN based sensor networks. For instance, *Over-the-Air-Programming* (OTAP) enhances the nodes in flexibility issues of the assigned tasks by dynamically reprogramming them, while the network has to be able to adapt to the new requirements of the newly deployed applications. These particular networks that are called *Software Defined Sensor Networks* (SDSN), rely on a *Sensor Controller Server* that is responsible for assigning the appropriate role to each node in the network. Another work that concentrated on programming aspects is the research published in [19]. The authors identified three main layers of abstraction for programming APIs, which are 1) Monitor network state, 2) Implement packet forwarding policies, and 3) Maintain a connection with the network node. In [20] *Tiny Software Defined Measurement* (SDM) is introduced. Tiny SDM is a software defined measurement architecture for WSNs that provides a C-like language, called *Tiny Code Language* (TCL), which separates the measurement logic from the remaining code. Tiny SDM supports easy customization of different measurement tasks, as well as fast and efficient deployment of a new measurement task by only transmitting the binary code.

OpenFlow [21–24] is one of the distinguished implementations of SDN solutions. The network nodes in OpenFlow treat incoming packets according to the rules, which are stored in *Flow Tables*. The flow table determines the type of operation to be performed on packets. These tables are filled, maintained, and updated in the nodes by the control plane.

The authors in [10] introduced a general WSN framework based, where the controller is using OpenFlow protocol. The main goal of the work is to tackling the energy efficiency issues of WSNs. They analyzed the advantages of using SDN in WSNs in resolving traffic issues, such as data forwarding, data aggregation, and failure of path and energy consumption.

Similar to OpenFlow, *Sensor Open Flow* (SOF) [14] supports closed internal network processing. It also provides *Software-Defined WSN* (SD-WSN) architecture that clearly separates the data and control planes. SOF is the central part of SD-WSN, which is a standard communication protocol between the two planes. The improvements addressed in SD-WSN are in three areas of resource underutilization, counter-productivity, and restrict management. In fact, SD-WSN makes the underlying network programmable by manipulating a user-customizable flow table on each sensor using SOF.

Tiny SDN [15] is a solution that enables *Tiny Operating System* (TinyOS) nodes to behave as the nodes of software-defined WSN. Each SDN-enabled sensor node recognizes its neighbors and sends information to the SDN-controller node through the *Collection Tree Protocol*. One of the main features of this solution is the collection of topology information. SDN-enable sensor nodes send beacon packets and wait for a response. After receiving the response, the sender's information, including