Study on Coupling of Software-Defined Networking and Wireless Sensor Networks

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***Abstract*—Typically, wireless sensor networks (WSNs) provide application-specific networking schemes based on restricted resources. For the reasons, WSN-based routing algorithms can be variously designed for applications. Even if two different WSN applications (e.g., target tracking and temperature monitoring) coexist in a network, the two applications can use different routing algorithms, running simultaneously on the same sensor nodes and network. However, the sensor nodes can efficiently spend their restrict resources (e.g., battery power) unless the two algorithms need to run simultaneously. There are a few research tries to deal with this problems by combining sensor networks with basic concepts of software-defined networking (SDN). However, performance of such a combination needs to be fully evaluated because the basic concept of SDN could not always give a positive effects to WSNs. Thus, this paper gives a try to analyze coupling of SDN and WSNs.**

Keywords—wireless sensor networks, software-defined networking, software-defined sensor networking, programmable sensor networking

I. Introduction & Motivation

For the time being, a few key words (e.g., machine to machine (M2M), Internet of Things (IoT)), which bring up the image of next generation networks, have been mentioned as a hot potato; at the same time, a concept, "*software-defined networking (SDN)*," has been focused as a hot research item. According to [1], the SDN is an emerging network architecture where network control is decoupled from forwarding and is directly programmable. Of course, a few research tries, related to WSNs, also has begun to combine SDN with technology of sensor networks [2][3]. They insist necessary of such a combination to overcome shortcomings of WSNs; for instance, versatile, flexible, and easy to manage. However, anyone cannot say conclusively so far that the SDN concept always give positive effects to WSNs. Hence, this short would like to evaluate the combination SDN and WSNs from the various viewpoints.

The next section introduces how possibly SDN can be combined with WSNs and analyzes system requirements of such a combination before evaluating its performance in the further section.

II. Coupling of Software-Defined Networking and Wireless Sensor Networks

The general concept of SDN is a networking method where control plane and data plane are decoupled, so the control plane is managed by a dependent device, named "controller," and the data plane is managed by SDN switches (or called, "SDN devices") with flow tables. A network operator can remotely set up required networking mechanisms to the controller, and the controller designs routing policies. Then the controller delivers this routing policies to the SDN switches in real-time process through a specific communication channel (e.g., openflow[4]). The SDN switches sets up their forwarding tables. Whenever the SDN switches receive packet, they route the packet to a next hop according to the forwarding tables.

Therefore, this paper carefully defines a brand-new conceptual keyword, "*Software-Defined Sensor Networking (SDSN)*," as one way of sensor networking, which the basic concept of SDN is applied to like Fig.1. Another keyword, "*Programmable Sensor Networking*" has a similar meaning.

Then there could be a couple of remaining questions, "how can SDN concept be combined with WSNs and how outstanding performance can SDSN demonstrate?" Even though SDSN is designed to overcome several shortcomings of WSNs, it is not easy to give concrete answers in fact. So far, the existing studies on SDN do not stay at the mature or perfect stage, and also researches on coupling of SDN and WSNs has just stepped in the beginning stage via a few tries [2][3].

A. System Architectures

So far, SDSN stays at a concept stage for a new paradigm

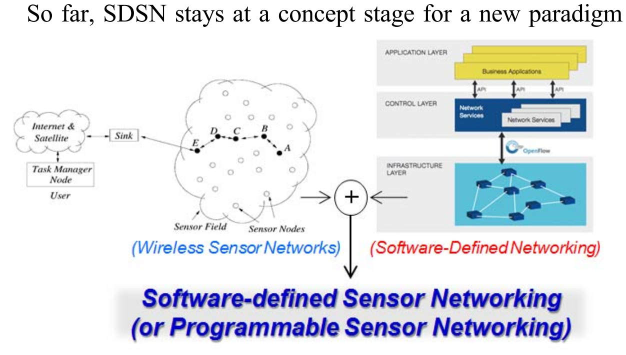

Fig. 1. A fundamental concept of coupling Wireless Sensor Network [5] with Software-defined Networking [1]

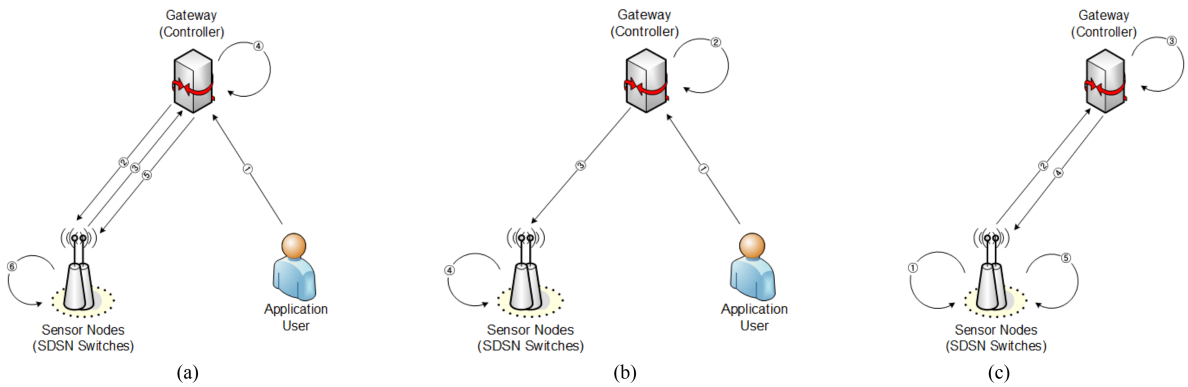

Fig. 2. Network control scenarios: (a) initial procedure, (b) on-demand procedure, (c) event-driven procedure

of sensor networking, so it is not easy to give a perfect solutions or answer if someone concretely asks what architectures SDSN have. Nevertheless, we carefully think of a possible architecture for SDSN.

First of all, nothing is different between physical network topology for SDSN and legacy sensor networks. Only different thing is that gateways have controller functions, and sensor nodes have functions of SDN switches. The functional components (e.g., network operating in gateway and data forwarding in sensor nodes) for SDSN would additionally be required into sensor nodes and gateways. This other components are the same as the legacy sensor networks. In other words, all of sensor nodes and gateways in legacy sensor networking have to do something for both of control plane and data plane. However, gateways in SDSN have a role of control plane (e.g., computing routes and network topology, and sensor nodes in SDSN do data plane (e.g., only packet forwarding).

For to accomplish roles of a controller, a gateway in a sensor network should initially require information of all local sensor nodes; for instance, geographical information (X, Y, & Z coordinates), remaining energy, and so on. Then such information is used by the gateway to figure out optimal routing paths. This routing information is delivered to all the local sensor nodes with their tasks. The sensor nodes send sensing data as the given routing information. So, next section concretely explains how to accomplish control plane and data plane separately.

B. Control Plane

There can be a lot of application service fields, such as temperature, humidity, air pollution, and target tracking. According to characteristics of the applications, three procedure types can conduct network control; an initial procedure for network configuration, an on-demand procedure for application requirements, and an event-driven procedure for network change. Figure 2 shows the procedures among a gateway, sensor nodes, and applications in details. The sequential numbers in Fig.2 indicates an operation order of the procedures for control plane like bellows.

In the initial procedure, application user requests necessary data to the gateway, and the gateway collects related node information and computes network topology, routing paths, tasks, and so on. This information is delivered to the related sensor nodes, and the sensor nodes set up the task and forwarding information. After completing this procedure, the sensor nodes send sensing data according to the given forwarding rules.

The on-demand procedure is required to modify the network control patterns by demands on application users. For example, when the user wants to change a temperature monitoring pattern from getting the highest temperature to average temp., the user immediately requests the task changes to the gateway. And then the gateway re-computes network topology and routing paths and delivers them to related sensor nodes. The sensor nodes modify the setup of their own forwarding tables and tasks.

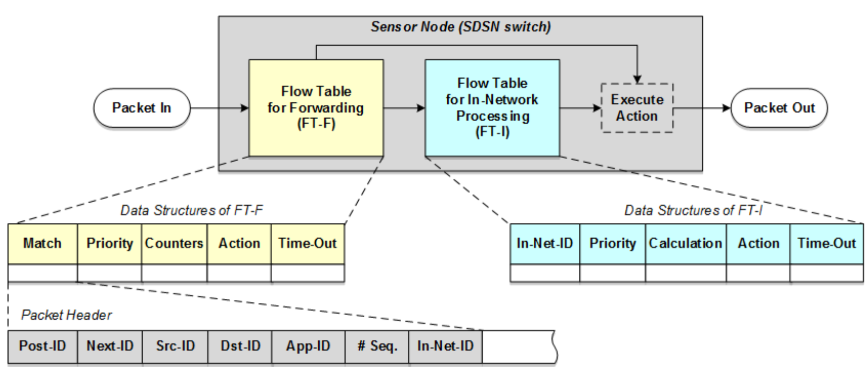

Fig. 3. Data structures for data forwarding in a sensor node

Lastly, event-driven procedure is required to reflect unexpected changes of network topology, such as network failures, node movement, and so on. For instance, when a sensor node runs out of its energy, the node sends its energy status to the gateway. The gateway re-computes network topology and routing paths and delivers them to related sensor nodes. The sensor nodes modify the setup of their own forwarding tables and tasks.

C. Data Plane

After the initial procedure done, all sensor nodes and gateway are ready for data delivery, and data plane is started. Data plane in SDSN is relatively simple. That is, sensor nodes (SDSN switches) only have a role of packet forwarding according to forwarding rules of flow tables, which are similar to routing tables used in routers. The SDSN switches require two flow tables, such a flow table for forwarding (FT-F) and in-network processing (FT-I). Figure 4 shows data structures of the two tables.

III. System Requirements & Analysis

This section evaluates the combination of SDN and WSNs with pros and cons from the viewpoints of architectures and performance.

A. Programmable sensor networking

"*Programmable networking*" (or "*software-defined sensor networking*") is the key function of SDN. If sensor networking is also programmable, more various application services are simultaneously available in a deployed sensor network field. This is a major reason of such a combination. On the contrary, if not programmable, to offer various different application services, a sensor network should be plied on another in a field because sensor networking is typically application-specific.

B. Decoupling control plane with data plane

WSNs are application-specific because they have restricted resources and computing capability. For this reasons, WSNs are not recommended to keep layered approaches based on TCP/IP protocols [5]. In other words, control and data plane should be considered to reduce overheads when an application is designed in WSNs.

C. Communication channel for control plane

To support the control plane of SDN, a communication channel between a controller and SDN switches is necessarily required. However, guarantee of such a channel between a gateway and each sensor node is practically difficult in WSNs. This is one of the most technical challenges. The well-known channel, Openflow [4] is currently based on TCP/IP connectivity. Then sensor nodes should equip full protocol stack of TCP/IP for the channel. However, sensor nodes typically have restricted resources and computing capability, so such a full protocol stacks must be critical and controversial.

D. Overhead for control plane

As another critical technical challenge, overhead for control plane leads to energy problems. Each sensor node should sustain connectivity with the gateway relatively. If so, a bottleneck will happen to sensor nodes around the gateway. This leads to shorten lifetime of the sensor network. In WSNs, energy management is the most crucial issue.

E. In-network processing support

For supporting in-network processing, the sensor node should keep the data in cache, generate new data with previous data, or route new generated data to a designated outgoing interface according to situation. Actually, this is not consider in SDN.

F. Security considerations

SDN can be exposed to various security threat vectors, such as forged or faked traffic flows, attacks on vulnerabilities in SDN switches and controllers, attacks on control plane communications, lack of mechanisms to ensure trust between the controller and management applications, and so on [6].

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V. Concluding Remarks and Further Works

This short paper provides overview of combining SDN with WSNs and then evaluates whether SDN can be harmonized with WSNs or not through five pros and cons. So far, it is not easy to make a right conclusion and answer about such a combination. The plain fact is that the SDN concept can be one of the innovative solutions to effectively utilize restrict network resources (especially, WSNs) for future networks. The technical challenges, mentioned in section III, are expected to be possibly improved via further researches. As a consequence, this paper believes that it is certainly worth coupling SDN with WSNs. The further work has a plan to provide a solution of programmable sensor networking, which improves the challenges.

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