Intelligent SDN-Based multi-protocol selector for IoT-enabled NMT networks

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***Abstract*—The popularity of the Internet of Things is increasing and it is being used in many commercial sectors, using customized technologies for specific environments. Applications and protocols, and the unique requirements of each environment, pose a significant challenge for IoT applications, necessitating communication and message exchange support. This paper aims to propose an intelligent SDN-Based multi-protocol selector for IoT-enabled NMT (Non-Motorized Transportation) networks. The main goal of this work is to give the mobile nodes within IoT-enabled NMT networks the flexibility to choose the appropriate wireless communication protocol from several protocols they have to transmit information according to criteria, including battery life, data size and priority of the packet, to pass the most important data first.**

Keywords*— *Software Defined Network (SDN), Internet of Things (IoT), Wireless communication protocols

I. INTRODUCTION

Internet of Things (IoT) has recently received considerable attention due to its capabilities, which can help humanity advance in terms of intelligence, automation, and ease. The IoT is a network of interconnected, internet-linked connected things, actuators, sensors, and other smart technologies that allow people to communicate with each other and objects to communicate with each other. The IoT is an essential component of the Information and Communication Technologies (ICT) infrastructure of smart and sustainable cities as an emerging approach to urban development due to its enormous potential to improve environmental sustainability.

NMT is a form of commuter that relies not on an engine or a motor for movement. NMT comprises bicycle and small-wheeled transport such as kick scooters and skateboards [1]. Integrating NMT into the IoT system provides a high benefit to cities, especially those seeking sustainable development and transforming into smart cities. IoT-enabled NMT could become one of the primary resources for dynamic information such as atmospheric (weather, humidity, or temperature) and air quality information during its movement in/within different parts of the city; besides, it has zero carbon emissions.

However, several challenges facing wireless communications are to be addressed to deliver this information to the destination effectively, including data rate, communication range, energy efficiency, diverse quality-of-service, and selecting the suitable wireless communication protocol. An essential key pillar of an application's success or failure is choosing the appropriate wireless communication protocol in a given situation. This would mostly be effective as unsuitable wireless technology can hamstring critical aspects of the performance of the application, and thus, it becomes unusable. Software-Defined Networking (SDN) emerged as an intelligent networking solution that uses dynamic software programs to make communication management easier and to improve network performance, especially in access networks [2]. The SDN separates the control logic from the sensor nodes, making it a suitable solution for the inflexible management of Wireless Sensor Networks (WSNs).

Several literature works have discussed how to deal with multiprotocol wireless communication in heterogeneous networks. An approach based on fuzzy logic is proposed in [3], where it takes QoS measurements of the trajectories between origin and destination as input parameters and determines the weights of all trajectories. Gao and Chang have introduced in [4] a scalable and flexible communication protocol that serves as a bridge between the Internet and numerous heterogeneous wireless networks. Kang et al. have proposed in [5] a self-configurable gateway that detects and configures smart things in real time over wireless networks. Bonaiuto et al. have presented in [6] a system for elite sports applications based on a wireless sensor network consisting of peripheral nodes (up to eight) that communicate with the user and collect data through a Wi-Fi connection, and a master node. Kim et al. have proposed in [7] an access gateway for the network environment of the Internet of Vehicles (IoV), where it manages the traffic of incoming data to the In-vehicle Network (IVN) and the traffic of outgoing data to the IoV. The gateways suffer difficulties since they are pre-configured, rely on vendor-specific APIs, and are restricted to just authorized devices and policies.

This paper introduces an intelligent SDN-Based multi-protocol selector for IoT-enabled NMT networks. The principal purpose of this work is to give the mobile nodes

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within the IoT-enabled NMT networks the flexibility to choose the appropriate wireless communication protocol from among several protocols they have for transmitting information, according to a set of criteria; such as battery lifetime, data size, and priority of the packet in order for most important data to pass first.

The remainder of the paper is structured as follows: section II describes the architecture, and the characteristics of the wireless communication protocols used, section III describes the system implementation and evaluation, and section IV presents the conclusions.

II. System Architecture of Intelligent SDN-Based Multi-Protocol Selector for IoT-Enabled NMT Networks

The intelligent SDN-Based multi-protocol wireless communication selector aims to give the mobile nodes within the IoT-enabled NMT networks the flexibility to choose the appropriate wireless communication protocol from among several wireless protocol modules that they have for transmitting information, according to a set of criteria, such as bandwidth, energy consumption, and reliability. The mobile node (in our case is IoT-enabled NMT) is equipped with several wireless communication modules, in addition to various types of sensors. Each of them is responsible for collecting data and detecting the changes in the environment, and then responding to some output in the other system. The SDN-Based multi-protocol wireless communication selector organizes the process of sending this data based on a set of rules stored in a knowledge base, which will be used by a fuzzy logic control system. These rules, for example, include prioritizing some data over other data and selecting the appropriate wireless communication protocol that corresponds to the characteristics of that data. Fig. 1 illustrates the presented system architecture.

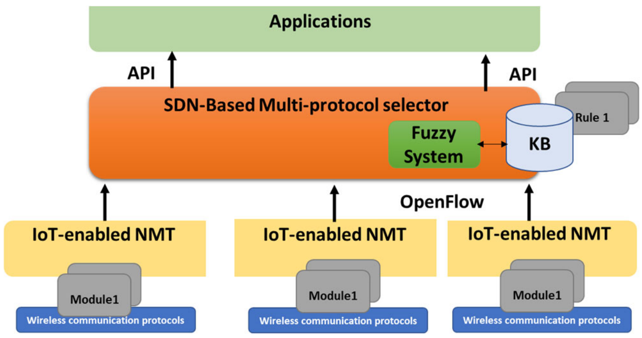

Fig. 1. The Architecture of the proposed System

A. *Criteria for Comparison Wireless Communication Protocols*

This section underlines a group of criteria that are considerable on the process of selecting an appropriate wireless communication protocol. [8][9][10][11][12].

- **Bandwidth**: The increase in bandwidth affects power consumption and reach, making bandwidth an essential consideration when selecting a wireless communication protocol for data transmission.

  Energy Efficiency: One of the crucial aspects of selecting a wireless communication protocol for an IoT node is energy consumption. Minimizing the amount of time that IoT node is active, reducing the transmission time, constant and activity of IoT node has led to significant savings in energy efficiency.

- **Reliability:** It guarantees a successful transfer of data to the destination as quickly as possible. Increased reliability is directly proportional to increased bandwidth, so reliability is an important criterion to consider when selecting a wireless communication protocol.

B. *Types of Wireless Communication Protocols*

The wireless technologies provide devices with the ability to exchange data wirelessly between them, which is the basis for any IoT system [13]. The transmission distance can range from a few centimeters to several hundred km. The main characteristics of wireless communication technologies used in IoT systems are described below [12][13][14][15] [16].

- **Wi-Fi**: Is a wireless networking technology based on the technical standard IEEE 802.11, which can transmit data at high speed and connect computers, smartphones and other devices to the Internet. Wi-Fi networks operate on 2.4 GHz and 5 GHz frequency bands. The appeal of Wi-Fi stems from its simplicity, cost-effectiveness and ease of interaction with other networks and network components.

- **Zigbee**: It is a cost-effective, low-power wireless protocol based on the technical standard IEEE 802.15.4. Zigbee operates on 2.4 GHz, 868 MHz and 900 MHz unlicensed bands. Communication between the Zigbee nodes is organized in a mesh topology. The device's long life is the most well-known feature of the Zigbee network. It is possible to live for ten years or even longer.

- **LoRaWAN:** is an abbreviation for Long Range Wide Area Network, a sort of wireless network and one of the Low Power Wide Area Network (LPWAN) technologies. LoRaWAN transmits data over license-free Megahertz radio frequency bands, in Europe on 868 MHz, and on 915 MHz in North America. LoRaWAN solutions are used in many commercial and industrial settings.

- **Sigfox**: is a private LPWAN network launched in 2009 in the IoT sector. It operates on multiple bands relying on the geographic location. It operates at 868 MHz ISM in Europe, and in North America at 900 MHz ISM. Sigfox offers energy-efficient connectivity and low bit rates over long-range communication.

- **Mobile Networks (3G/4G/ LTE /5G)**: Is a cellular communication network distributed over geographical areas, called “cells”, at least one base transceiver station serves each cell that connects devices in the same or different cells. The first commercial mobile network lunched in 1979 under the appellation First generation (1G). Since then, new cellular network generations (2G, 3G, and 4G) with different transmission modes, high-capacity voice and data communication, and power consumption have evolved. Long-Term Evolution (LTE) and 5G are the most recent mobile technologies, and they are widespread with high-bandwidth smartphones and IoT devices. 5G networks are faster and have more channels than previous-generation networks.

C. Comparative Analysis of Wireless Technologies

The process of designing an IoT network and selecting the appropriate wireless protocol requires comparative analysis to provide insights into the characteristics of each technology. Table 1 compares the current available wireless protocols. [13][12].

TABLE I. WIRELESS TECHNOLOGY COMPARISON

Tech.	Characteristics			
	BW	*Bit Rate*	*latency*	*Power*
Wi-Fi	20 MHz	Up to 7 Gbps	10–50 ms	250 mA
Zigbee	2 Mhz	20 - 250 Kbps	254	52 mA
LoRa	900 MHz <500 kHz	<10 kbps	>1s-	24-44 mA
Sigfox	900 MHz 200 kHz	<100 bps	>1s	27 mA
3G	5 MHz	0.5–5 Mbit/s	25ms	600-700 mA
LTE	1.4-20 Mhz	Up to 100Mbps	15ms	100-490 mA
5G	25 MHz	50Mbps-2Gbps	<30ms	TBD

III. System Implementation

This section briefly introduces the fuzzy logic control system, semantic reasoner and demonstrates how we integrate a system like that into a mobile IoT node for better wireless communication protocol selection. This would lead to better network traffic management to meet QoS requirements for various services.

A. Fuzzy Logic Control System

The fuzzy logic is defined as sort of multivalued logic that is quite similar to human thinking than the traditional logical system. A fuzzy logic control system transforms linguistic control strategies into an expert knowledge-based automatic control technique [17]. Fuzzy logic control system consist of three stages: 1) fuzzification, 2) fuzzy inference, and 3) defuzzification. [3]. There are three functions in the fuzzification phase: a) measurement of the input variable values, b) The transformation of input data into linguistic values that can be used as fuzzy set labels, c) scale mapping of input values in the appropriate universe of discourse. A fuzzy logic controlling system's brain is the fuzzy inference logic phase. This stage models human decision-making based on fuzzy concepts. Fuzzy control is inferred using fuzzy implication and fuzzy logic's inference procedures. In the defuzzification step, a variety of output parameters are translated into a corresponding discourse, and a non-fuzzy control action is generated from a fuzzy control action inferred.

B. Semantic Reasoner

Semantic reasoners are software applications that can response questions or calculate deductions, reasonable consequences using ontologies-based logical knowledge bases [18]. An ontology is a formal description of the application domain's notions, relationships, and individuals [19]. Ontologies are widely used to represent knowledge, emphasis on the integration of information, the reuse of components, and the discovery of latent knowledge, among other things. They are expressed with the standard language OWL 2 [20]. OWL Lite, OWL DL, and OWL Full are three increasingly expressive sublanguages of the OWL [21]. OWL DL is a type of description logic that is extremely expressive with a Resource Description Framework (RDF) syntax. Description Logics (DLs) are a type of knowledge representation formalism that is based on classes (concepts)[22]. One of the reasoners that deal with extensions of classical DLs is fuzzyDL, an extension to classical DLs with the goal of dealing with fuzzy / vague / imprecise concepts [23]. The combination of fuzzy logic with DLs or ontologies makes it possible to represent imprecise knowledge and to perform approximate reasoning.

C. System functionality

The SDN-based multi-protocol selector is responsible for selecting the most appropriate wireless communication protocol for data transmission according to several rules. This considers the type of data, its size, its importance, and the characteristics of each protocol to ensure the fulfillment of specific QoS requirements. The characteristics of each communication protocol listed in Table 1 are preloaded to the SDN-based multi-protocol selector, along with sensory data type, size, sensor reading time interval, and degree of importance. The SDN-based multi-protocol selector receives data for the input parameters and fuzzifies them based on the associated function of the corresponding input variables using the defined fuzzy logic control system.

For instance, information such as videos, audio, and thermal imaging has a massive size and needs a high bandwidth communication protocol for transmitting. Also, with non-motorized transportation, there is no need for real-time processing, as in autonomous vehicles and drones. Therefore, these data will be marked as not important data, and it will be queued until the mobile nod is near a public Wi-Fi hot-spot to transmit them. On the other hand, dynamic information such as atmospheric (weather, humidity, or temperature) and air quality information does not require a high bandwidth communication protocol for transmitting, but this information needs to be transmitted over fixed periods of time, which means a higher rate of energy consumption, due to the need to active (wake) the node. Therefore, the SDN-based multi-protocol selector should choose a communication protocol that has a low energy consumption and at the same time has a low bandwidth. In other cases, such as a fall detected, it requires the SDN-based multi-protocol selector to use all available resources and select the highly reliable communication protocol to transmit the alert message as shown in Fig 2.

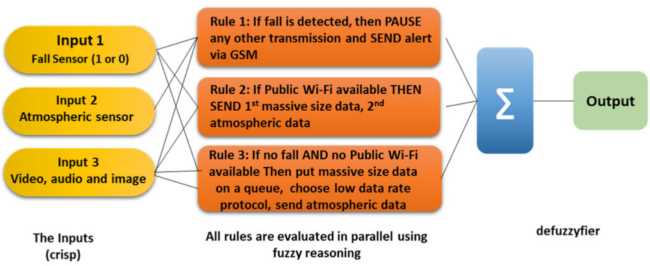

Fig. 2. Fuzzy Inference Process

Semantic technologies are used in this work to describe the context of the IoT-enabled NMT network as well as the mobile node with its characteristics and capacity. The reasoner uses the information available from the characterization of each radio interface and the occupancy levels of each of the QoS queues we have defined (urgent, streaming, irrelevant...). These (crisp) ontologies are stored in a fuzzy knowledge base

(KB). fuzzyDL enables for the importation of OWL Lite queries to make it easy to represent fuzzy KBs. It also uses a fuzzy element to estimate the occupancy of the queues.

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V. CONCLUSIONS

In conclusion, this paper introduces an intelligent SDN-Based multi-protocol selector for IoT-enabled NMT networks. The principal purpose of this work is to give the mobile nodes within the IoT-enabled NMT networks the flexibility to choose the appropriate wireless communication protocol from among several protocols they have for transmitting information, according to a set of criteria, such as battery lifetime, data size, and priority of the packet in order for most important data to pass first. We evaluate the use of fuzzy logic and semantic reasoner techniques to effectively manage network resources and services.

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