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Al-Shammari, H, Lawey, A orcid.org/0000-0003-3571-4110, Elgorashi, T et al. (1 more author) (2019) Energy Efficient Service Embedding In IoT over PON. In: 2019 21st International Conference on Transparent Optical Networks (ICTON). 2019 21st International Conference on Transparent Optical Networks (ICTON), 09-13 Jul 2019, Angers, France. IEEE . ISBN 978-1-7281-2779-8

https://doi.org/10.1109/ICTON.2019.8840429

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Energy Efficient Service Embedding In IoT over PON

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ABSTRACT

In this paper, we present an energy efficient service embedding framework in Internet of Things (IoT) network using Mixed Integer Linear Programming (MILP). The framework enables an energy efficient smart road paradigm for different simultaneous applications supported by a passive optical network (PON) and wireless communication in the smart city. It optimizes the infrastructure's resources including the access network, IoT, fog and cloud computing. We consider an event-driven paradigm in a Service Oriented Architecture (SOA) in our framework in order to provide service abstraction of basic services which can be composed into complex services and exploited by the upper application layers. The framework results show that it is possible to reduce the power consumption by optimizing the selection of computing nodes and traffic distribution in the network while satisfying the service requirements.

Keywords: IoT, Cloud, PON, Energy Efficiency, MILP, smart city.

I. INTRODUCTION

The popularity of Internet of Things (IoT) is growing due to the reduction in the cost, size and power consumption of IoT devices. However, the limited data processing and storage resources and increasing traffic generated by the IoT devices[1], created a need for integrating IoT with cloud and fog computing to complement their services [2] – [6]. The cloud and fog are considered the main contributors in providing data processing, storage, resource management, service creation, service management for the IoT [7], [8]. The integration paradigm of IoT and Cloud improves the reliability, ubiquity, and scalability of IoT services [9]. The cloud features provide high elasticity and on-demand usage models for efficient and scalable service provisioning [10]. Although cloud computing is an emerging technology for processing content in distributed environments, the property of centralized computing of the cloud comes with a high traffic overhead in terms of capacity and power consumption challenges[11], [12], hence, Fog computing is being developed to meet these requirements [7], [13].

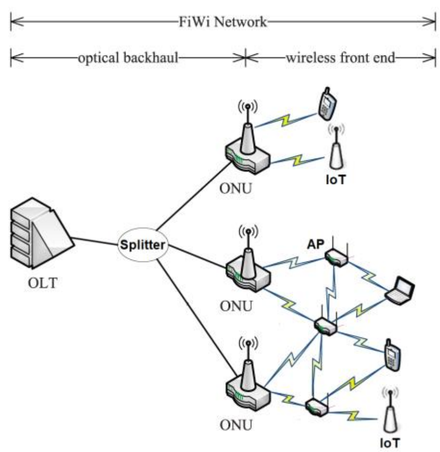

Fig. 1: Schematic access network structure [14].

The IoT, fog and cloud can be integrated over a Fiber-Wireless (FiWi) network [17]. As shown in Fig. 1, FiWi is composed of a Passive Optical-fiber Network (PON) as its backhaul to provide high capacity and reliability [18] – [20]. On the other hand, ubiquitous coverage, connectivity, and mobility can be provided by wireless front end networks such as Wi-Fi, and LTE [14], [27], [28]. The PON provides high link capacity by exploiting multiplexing techniques over the optical fiber networks such as Time Division Multiplexing PON (TDM-PON)[21] – [23], Wavelength Division Multiplexing PON (WDM-PON)[24] – [26].

This paper is organized as follows: In Section II, we introduce our framework of energy efficient IoT-based smart road system. Section III discusses the results of the energy efficient IoT service embedding. Finally, Section IV concludes the paper.

II. ENERGY EFFICIENT IOT-BASED SMART ROAD SYSTEM

In the smart road paradigm, different IoT devices such as cameras, climate sensors (snow sensors, rain sensors, fog sensors and wind sensors), motion sensors are needed to continuously monitor the weather, speed and status of vehicles, parking occupancy and pedestrians crossings lines [29]. To enhance smart road systems, the control system should make decisions and execute different operations with high performance and efficiency to serve different services i.e. traffic lights control, road monitoring, accident alarms and information distribution in an intelligent manner. The aim of this paper is to propose a framework for smart roads by i) embedding the requested service into the physical infrastructure of the smart city setting, ii) optimally placing computing platforms within the IoT network, fog, or cloud, optimizing the overall infrastructure in terms of power consumption, and iii) minimizing the power consumption of embedding due to selection of energy efficient nodes and reducing the processing and network power consumption. The service requests are implemented following the Service Oriented Architecture (SOA) in the workflow form of a business processes (BP) [13], [30]. The BP is considered as the virtual topology that consists of virtual nodes and links. The virtual nodes encapsulate the request processing, location and function requirements such as the requested sensing/actuating functions. The virtual links encapsulate the requests communication requirements such as traffic demands and connections with the neighbors. The framework's objective is to find the optimal set of physical nodes and links and processing platform to embed the requested services into the network with minimum power consumption. The framework is based on a Mixed Integer Linear Programing (MILP) model with the objective of minimizing the power consumption of service embedding in IoT networks. We benefit from our track record in service embedding in IoT networks [31] – [33].

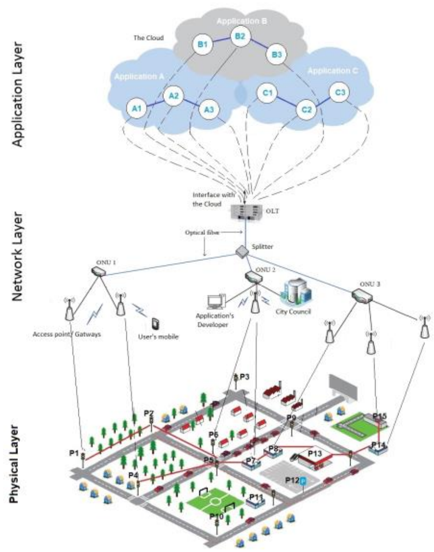

Fig. 2: Architecture of Service embedding in IoT over the PON

The physical layer consists of IoT nodes connected to access points (AP) through Wi-Fi. Each AP is connected to an ONU. The application layer consists of the service requests represented in our framework by a set of BP's. We consider the following in our architecture.

1- The physical layer is composed of:
   - A processing module hosting a CPU and RAM.
   - A network module hosting a Tx/Rx circuit and a Tx power amplifier that provide the link with at least one AP.
   - Function module interfaces to a set of supported sensors and actuators.
2- The network layer consist of network element of AP's, ONU's, splitter, OLT.
3- The application layer represented by a set of BPs, each BP is characterized by:
   - Set of virtual nodes and links
   - A function for each virtual node
   - Virtual nodes processing and memory requirements
   - Virtual nodes zone request
   - Virtual traffic demands for each virtual link

The framework exploits the heterogeneous characteristics of the power consumption of the i) Optical and wireless links ii) Computing module in the selection of cloud, fog or the IoT nodes iii) – Allocation of IoT nodes. A smart city scenario is considered where the physical layer is composed of 30 IoT nodes distributed across a city district of an area 600m × 600m.

The following assumptions are made:

- The network elements and processing nodes capabilities are distributed in the physical network. The processing capabilities are in three levels (Edge, Fog, and Cloud) in term of CPU frequencies (48, 400, 1600, or 2800 MHz) representing IoT nodes, Fog, and Cloud computing [35]. The network elements are considered with their corresponding maximum data rates and power consumption values [36] as shown in Table 1.

Table1: Processing modules power specifications and power consumption in active mode

CPU Type	CPU CLK	MIPS	Idle power	Max Power	Location
MSP432P4	48 MHz	100	1 mW	20 mW	IoT
Cortex-M7	400 MHz	856	1 mW	110 mW	IoT
R710	1.6 GHz	7500	40 W	119 W	Fog
Xeon E5540	2.8 GHz	49360	128 W	247W	Cloud
Optical Line Terminal (Tellabs 1134)				173W	Network
Optical Network Terminal (Zhone GPON 2301)				5 W	Network
Shared Wi-Fi Access Point (Enterasys AP3660)				21 W	Network

- There are 3 sensing functions (Camera, Climate sensor, and motion sensors), one control function and 3 actuation functions (Alarms, display screens, and traffic lights). Each IoT node is capable of providing one function of each type while the virtual node requests one function only.
- The processing and network demand of virtual nodes and links vary from low to high based on the services.
- The IoT nodes are connected to the AP via 10 Mbps transceiver modules with the IEEE 802.11 stack [37].
- There is a set of five geographical zones that represent the sub-districts of the smart city. The IoT nodes are distributed randomly and uniformly over these zones and each virtual node requests a location in one of these five zones.

III. RESULTS AND EVALUATIONS

We evaluated 3 scenarios with 2,3 and 4 BPs. We assumed that each BP is composed of three virtual nodes with a sequential workflow of a sensor, a controller, and an actuator. Two embedding scenarios are considered. The first scenario is an Objectiveless Service Embedding (OSE) scenario. The OSE scenario embeds the virtual nodes of each BP into available IoT nodes, fog or cloud nodes that satisfy the virtual nodes and links requirements without any objective function, while the second scenario, Energy Efficient Service Embedding (EESE), embeds the virtual nodes of each BP into available IoT nodes, fog or cloud that satisfy the virtual nodes and links requirements with an objective function that minimizes the total power consumption. Fig. 3 shows the power consumption OSE and EESE scenarios respectively. The results display high power consumption with the OSE scenario. In the EESE scenario, the traffic is routed through energy efficient routes and the requests are embedded in low processing demands into IoT nodes in order to reduce the overall power consumption. The results display the processing and network power consumption of the EESE scenario under different number of BPs. The results show that most of the power is consumed by the network module in the nodes. The power consumed by the network modules contributes about 64% (on average) of the total power consumption of the network.

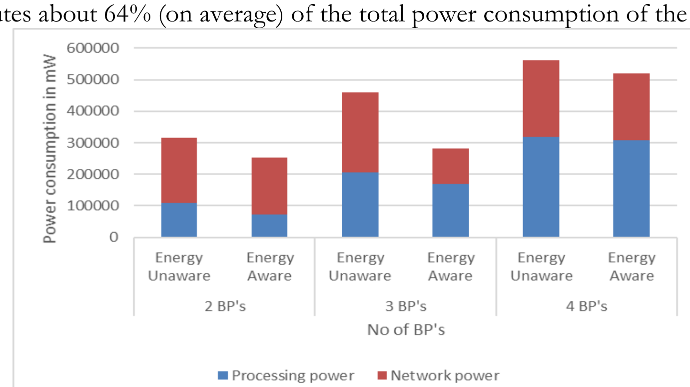

Fig. 3: Power consumption of OSE and EESE.

The EESE results show an average power saving of 30% compared with OSE. This power saving is due to: selecting the possible IoT nodes for embedding the controller node for processing due to low PUE values (i.e. PUE is equal to 1 for the IoT nodes and more than 1 for the cloud and fog), selecting the shortest distance links in the wireless network in order to reduce Tx-amplifier power consumption, minimizing the number of hops in order to reduce the number of relays IoT nodes, utilizing the processing capacity of the selected energy efficient nodes. The framework utilizes the processing in the IoT nodes rather than the fog and cloud, which reduces the network power consumption in addition to processing power consumption.

IV. CONCLUSIONS

This paper has proposed an energy efficient framework for embedding IoT based smart road system applications. We developed a MILP model to optimize the embedding so the power consumption of the processing resources and network are minimized. The services to be embedded are represented by a virtual topology (virtual nodes and links) following business processes workflow of the SOA paradigm. The results show that the energy efficient embedding proposed has resulted in average power saving of 30% compared with the energy unaware embedding.

ACKNOWLEDGMENT

The authors would like to acknowledge funding from the Engineering and Physical Sciences Research Council (EPSRC), INTERNET (EP/H040536/1) and STAR (EP/K016873/1) projects. Mr. Haider Al-Shammari would like to thank the Higher Committee for Education Development (HCED) for funding his scholarship. All data are provided in full in the results section of this paper.

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