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# Virtualization Framework for Energy Efficient IoT Networks

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**Abstract—**In this paper, we introduce a Mixed Integer Linear Programming (MILP) model to design an energy efficient cloud computing platform for Internet of Things (IoT) networks. In our model, the IoT network consisted of four layers. The first (lowest) layer consisted of IoT devices, e.g. temperature sensors. The networking elements (relays, coordinators and gateways) are located within the upper three layers, respectively. These networking elements perform the tasks of data aggregation and processing of the traffic produced by IoT devices. The processing of IoT traffic is handled by Virtual Machines (VMs) hosted by distributed mini clouds and located within the IoT networking elements. We optimized the number of mini clouds, their location and the placement of VMs to reduce the total power consumption induced by traffic aggregation and processing. Our results showed that the optimal distribution of mini clouds in the IoT network could yield a total power savings of up to 36% compared to processing IoT data in a single mini cloud located at the gateway layer.

**Keywords — IoT; cloud computing; virtualization; energy efficiency**

## I. INTRODUCTION

The Internet of Things (IoT) represents a major evolution in legacy data communication. Its ultimate purpose is to connect all physical objects in our world to the Internet. IoT networks provide these objects with the means to interact with each other to achieve higher efficiency in performing their designed objectives. The number of Internet connected devices is forecast to reach 25 billion by 2015 [1]. Having such a large number of connected devices opens the door toward smart applications in healthcare, transportation and smart grids, etc. [2]. IoT deployment faces several key challenges, such as security, scalability, interoperability and reliability [3]. Energy efficiency is another challenge that has to be confronted by IoT architects [3]. Building energy efficient networks is a technological trend that has resulted from efforts to address environmental, capital and operational costs in the Information and Communications Technology (ICT) sector. Therefore, the IoT is expected to benefit from the wide spectrum of proposed energy efficient network solutions.

Cloud computing is one of the main approaches investigated to lower data center and network power consumption [4]-[8].

In this work, we introduce a Mixed Integer Linear Programming (MILP) model to address the energy efficiency in IoT networks supported by cloud computing. Due to space limitations, we omit the MILP equations and reserve them for the poster that accompanies this paper. Therefore, we only explain the MILP framework and discuss its results in this paper.

The remainder of this paper is organized as follows: in Section II we briefly review the IoT architecture and the integration of cloud computing with IoT networks. Section III introduces our energy efficient IoT model. In Section IV, we discuss the model results. Then, Section V concludes the paper.

## II. IOT AND CLOUD COMPUTING

A general IoT layered architecture is shown in Fig. 1. The first lowest layer (Perception Layer) is constructed from the physical objects, e.g. sensors [9]. The second layer (Network Layer) aggregates data sent by IoT objects [10]. The third layer (Service Layer) is responsible for storing and processing the information aggregated by the Network Layer and making decisions based on the outcome of the data processing [3]. These outcomes play a significant role in specifying user applications. Management of the implementation of these applications is performed by the fourth Application Layer [3].

The fifth layer (Business Layer) manages the four lower layers. It is responsible for building the IoT business models and designing future business strategies based on the information received from the Application Layer [3].

Cloud computing relies on sharing storage, network and computing resources among users in the form of Virtual Machines (VMs). Abstracting physical resources enables the clouds to fulfill users' requirements and maximize resource utilization concurrently [11]. The study in [11] lists several advantages of merging clouds and IoT systems. For instance, service heterogeneity of the connected IoT objects can be efficiently supported by the cloud [11]. In addition, having elastic clouds capable of dynamic resource allocation can help to smooth IoT scaling [11]. However, the combination of IoT and cloud computing also faces some challenges, such as unique identification, resource provisioning, energy efficiency [12], security and privacy [13].

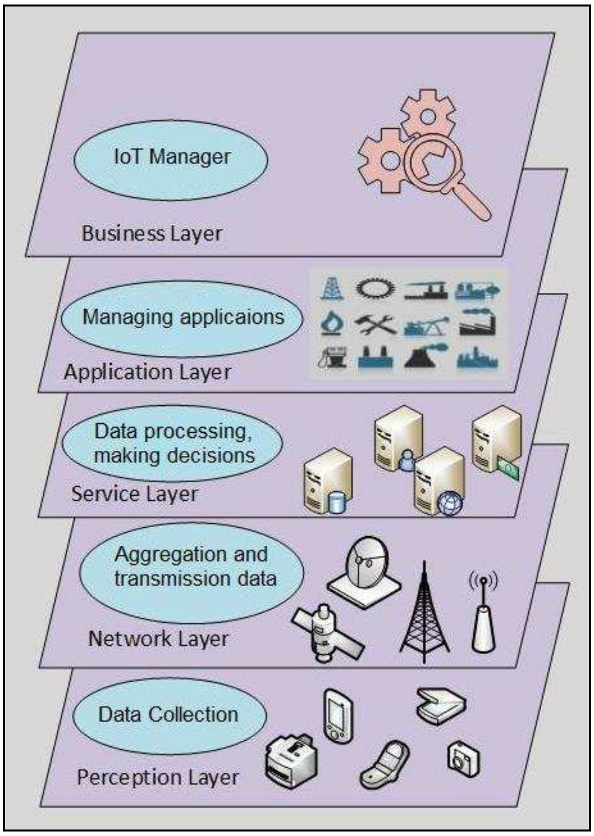


Fig. 1. General IoT architecture.

### III. ENERGY EFFICIENT MILP FOR IOT WITH VMS

Our MILP model considered the architecture shown in Fig. 2. This architecture consisted of four typical layers. The first lowest layer was constructed from IoT objects. The second layer hosted the relay elements that aggregate traffic from IoT objects. The third layer hosted one coordinator element that aggregated the relay traffic. Finally, the fourth layer hosted one gateway element that aggregated the coordinator traffic. In our framework, each element in the three upper layers was capable of hosting VMs that could process the traffic aggregated at that element. VMs process IoT data to extract a particular form of useful knowledge depending on the VM type, e.g. temperature gradient trends. The extracted knowledge traffic has a lower data rate compared to the original un-processed traffic. This reduced-traffic conveying knowledge is sent to the gateway at the fourth layer. The gateway provides a means to connect the IoT network to the Internet. Each IoT object specializes in performing a single task only; therefore, it is assigned to a single corresponding VM type.

The MILP objective was the minimization of the total power consumption. The total power consumption is composed of the traffic-induced power consumption in the four layers plus the processing-induced power consumption of the VMs located in the networking elements at the upper three layers.

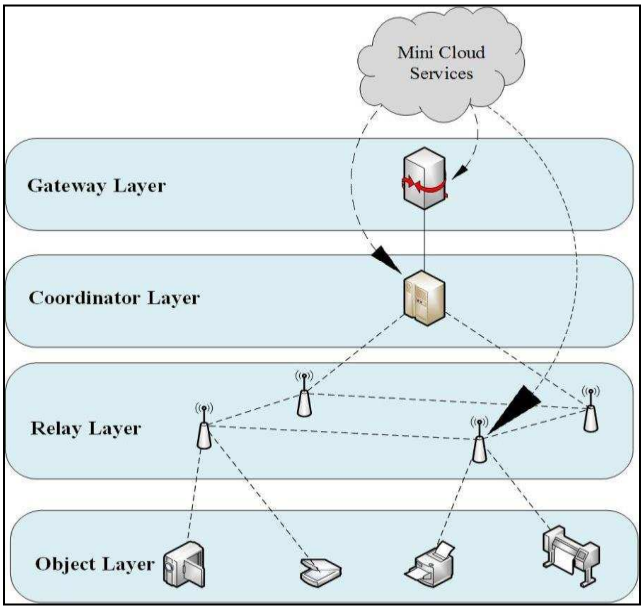


Fig. 2. The evaluated architecture

The MILP was subject to certain constraints that controlled the placement of the VMs, their capacity in terms of number of served IoT objects, locations of mini clouds and flow conservation for the IoT original and reduced traffic. In the case of capacitated VMs, the model optimized the number of replicas of each VM. Capacitated VMs can serve a limited number of IoT objects.

### IV. RESULTS

Fig. 3 shows the distribution of IoT objects, relays and coordinator elements within an area of 30m×30m. The gateway, not shown in Fig. 3, was 100m away from the coordinator. We considered 50 IoT objects, 25 relays, one coordinator and one gateway. The IoT objects are randomly and uniformly distributed and a relay element is placed every 6m. We have considered the receiving and transmitting power consumption (including propagation losses and the power amplification) for IoT objects and the networking elements [14]. Devices in the four layers communicated using the ZigBee protocol. Each CPU in the networking elements consumed an average 5.5 W [15].

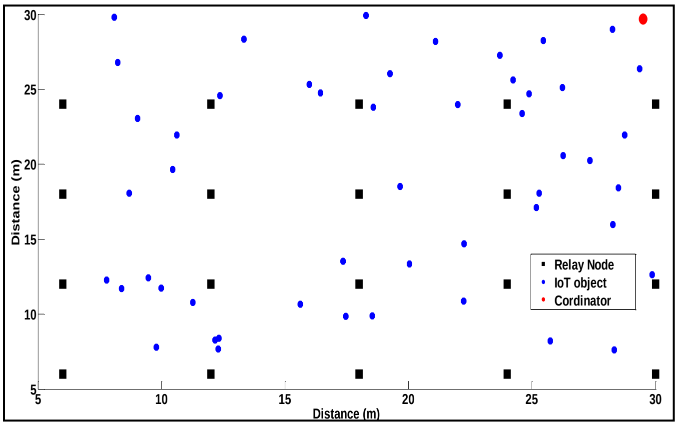


Fig. 3. Distribution area of IoT.

We considered two scenarios. The first scenario, referred to as Gateway Placement Scenario (GPS), restricted VM hosting at the gateway element only, so that IoT data were aggregated and processed by one mini cloud at the gateway. The second scenario, referred to as Optimal Placement Scenario (OPS), allowed full flexible VM placement at relays, the coordinator or the gateway elements. Both scenarios evaluated four different types of VMs. The VMs' CPU utilization depended on the VM type only and was not a function of the number of served IoT objects, i.e. constant serving rate. The VMs' CPU utilization is also assumed to be independent of the traffic reduction percentage. This is because the same VM processing power can be assigned to tasks that can produce high traffic reduction such as temperature differential, or to image compression tasks that might not achieve large data reduction.

The total power consumption for the two scenarios is shown in Fig. 4. The x axis represents different considered traffic reduction percentages. Fig. 4 divides the total power consumption into its two components: traffic-induced and processing-induced power consumption. The results show that GPS had a higher total power consumption compared to OPS. This was mainly due to the higher number of hops crossed by the IoT-to-VM traffic in the IoT network as all VMs were located in the upper fourth layer. In addition, GPS total power consumption was not affected by the different traffic reduction percentages considered in Fig. 4. The reason was that the gateway used to host the VMs represented the last layer in traffic aggregation and processing.

Hence, the extracted knowledge was locally hosted by the gateway and not sent to the upper layers. Therefore, the traffic-induced power consumption for GPS comes only from the non-reduced traffic received from the lower layers, which was not affected by the different reduction percentages. In future work we will consider the optical core layer where large data centers receive the extracted knowledge traffic from the IoT network gateway(s).

On the other hand, OPS managed to reduce the total power consumption compared to GPS. This was due to OPS' optimal VMs placement that reduced the number of hops between the VMs and IoT objects.

The results also indicated that lower total power consumption was feasible with higher traffic reduction percentages for OPS. This was because the reduced "knowledge" traffic required a lower number of components in the IoT network elements, e.g. lower number of ports. Reducing the number of networking elements and/or their components allows them to be powered off, which achieves power efficiency. The average total and network power savings for the OPS were 36% and 46%, respectively, compared to the GPS.

Note that GPS and OPS consumed the same processing-induced power, due to two reasons. First, VMs in both scenarios had similar total CPU utilizations as both scenarios served similar input demands. Second, the VMs' power consumption was independent of the VMs' placement as the IoT networking elements were assumed to be equipped with similar CPUs.

Both scenarios powered-on one VM copy for each VM type. This decision was influenced by the fact that the VMs considered were un-capacitated in terms of the maximum number of served IoT objects. Therefore, each VM type could serve all its objects using one VM copy only for both scenarios.

Fig. 5 shows the total power consumption of the OPS considering capacitated VMs. We specified the capacity of the VMs to serve 5, 10 or 15 objects.

Fig. 5 shows that the power consumption increased with a decreasing number of objects per VM. The increase in power consumption is due to the need for more VM copies that have to be created for each VM type. This increased the CPU utilization of the networking elements, and therefore, more power was consumed.

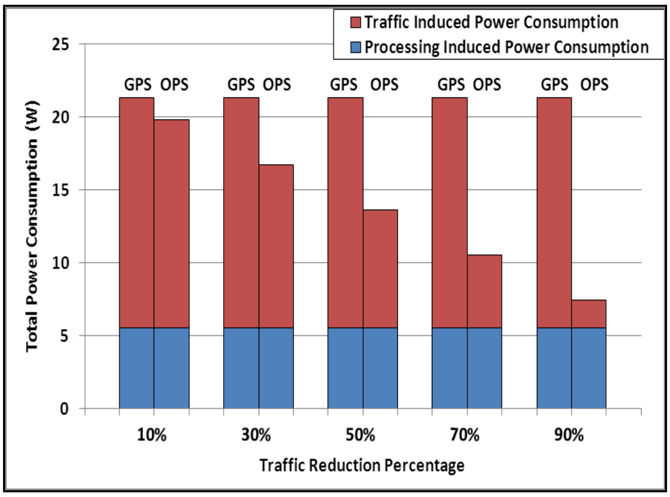


Fig. 4. Total power consumption for GPS and OPS.

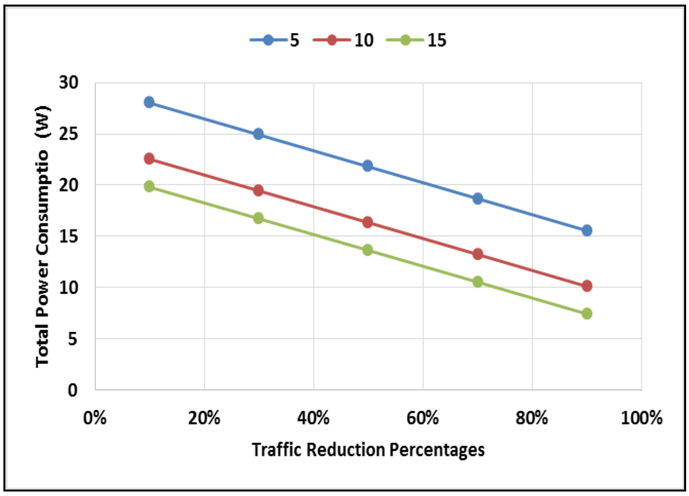


Fig. 5. Power consumption considering capacitated VMs.

## V. CONCLUSIONS

This paper introduced an energy efficient IoT model that considered building mini clouds at relays, coordinator and gateway devices in an IoT network. We demonstrated the feasibility to save up to 36% of the total power consumption, given our set of input parameters, by optimally placing VMs in the IoT network. Energy savings came from a reduced number of hops in the network as well as a reduced number of components being employed by the networking elements as traffic was progressively processed and reduced through the network. We also investigated the impact of capacitated VMs on total power consumption. The larger the number of served IoT objects per VM, the lower the number of powered on networking elements, and hence, there was better energy efficiency. For future work, we will consider scalability and run time performance for proposed approach.


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