School of Electronic and Electrical Engineering

FACULTY OF ENGINEERING

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Interim Progress Report

CO2 Emissions minimized VM (Virtual Machines) Placement in a Cloud-Fog Network Architecture by Employing Renewable Energy Sources

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Project Objective

The principle focus of this Individual Engineering Project is to reduce the overall carbon dioxide emissions in the cloud to flog layers by employing renewable energy sources in different nodes. This is achieved via the utilisation of mathematical modelling and heuristics. Given that a model and heuristics has been developed, a practical solution involving the development of an application in which users can manipulate the topology variables and constraints will be pursued.

Introduction to the Technical Background and Motivation

Motivation

The primary subject of the related literature is the extent of the supersedence brought forth by cloud and fog computing in comparison to other models. Lately, there has been a growing interest in trying to minimize the energy consumption, however there has been limited emphasis placed on trying to reduce emissions by employing appropriate renewable energy sources in each cloud-fog topology. There is always going to be a minimum energy requirement that is needed to fulfil the data centres as well as the overhead. The total energy expenditure of typical data centres not only include the computing equipment, which are usually virtualized, but the overhead equipment that are needed for the machinery to run. Conventionally, the power usage effectiveness (PUE) is used as a variable to indicate how efficient a data centre is.

Employing renewable energy sources such as solar power and wind energy, to provide power by placing it within transport network nodes would significantly reduce overall emissions. However, questions occur on whether it would be profitable to place renewable energy sources in nodes with low processing capability, such as edge servers, given the initial cost in setting up renewable energy on-site. Another factor to consider is the sporadic nature of renewables, where overproduction of energy in one site would prove to be useful to utilize the complementary energy in another node. By developing an MILP (Mixed Integer Linear Programming) model, renewable energy sources will be placed appropriately such as that it would maximise the routing of power within different nodes that need it via simulations. Energy storage devices (ESD) are used to store excess energy produced. The model ensures that nodes do not consume more than what the renewable energy source can produce. In addition, energy is within the limits of the available energy stored in the ESD.

Cloud Computing Overview

Cloud computing has been a primary factor in supplementing individuals and organizations with economies of scale, savings, and efficiency. The primary selling point of cloud computing is its ability to accommodate for exponential growth in voluminous data and provide entities to host functions by providing access, seemingly boundless, to a continuum of computing recourses such as processing, data storage, and networking functions. As a result of the ever-increasing demand for cloud computing, strain has been imposed on cloud data centres and the energy utilized from the equipment needed to maintain the computing equipment is increasing. As an attempt to alleviate the linearly increasing energy expenditure and the strain imposed on data centres brought by traffic, fog computing is a paradigm that makes available computing components that are closer to the traffic producing sources. The fog layer brings forth functionality such as filtering, in which voluminous traffic can be filtered in the fog layer without having redundant data be sent to the cloud layer, thus saving bandwidth. This saves power consumption, thus emissions, that would have been brought from the usage of the transport network. It is worth noting that fog computing was not introduced solely for its potential to save power, but to provide users with increased quality of service and low latency by offloading services on fog nodes whenever appropriate.

Cloud Computing Services and Virtualization

Cloud computing provides services that are in the form of Infrastructure-as-a-Service (IaaS), allowing users access to processors, routers, data storage through means of virtualization techniques that allows for data replication, log access, and machinery health. Platform-as-a-Service (PaaS) provides users with an operating system, development tools, and business analytics, that can be accessed through manufacturer-specific API calls. Software-as-a-Service (SaaS) are applications that can be accessed remotely via the internet, otherwise known as a web-based software. The functions of the three different services mentioned is shown in *Figure 1.* Virtualization is a technique that provides customers with the mentioned services, by virtualizing underlying computing resources, such as CPU, data storage, and networking tools, of physical hardware to the extent the customer specifies. For example, customers can control the number of cores and the size of memory. Virtualization provides interfaces of variety hardware-specific applications to run on different platforms. This comes to use in networking, where clusters containing various platforms and functionality can be accessed simultaneously by customers through means of a virtual machine. Virtualization allows for entire core network service functionalities to be placed in edge servers, within the proximity of a subscriber, through means of a virtual machine copy, this, however, comes at the expense of increased computing power, therefore increased emission. In contrast, placing a virtual machine in a core server node comes at the expense of transport network processing cost. This paper will explore the optimum placement of virtual machines and renewable energy such that these factors are considered. One might wonder, to what extent running a virtual machine on a host machine would affect power consumption compared to running it on native hardware. The difference in power consumption is minuscule, therefore negligent. This is because many of the virtualized services, such as the operating system and functionality, can directly processed by the underlying host.

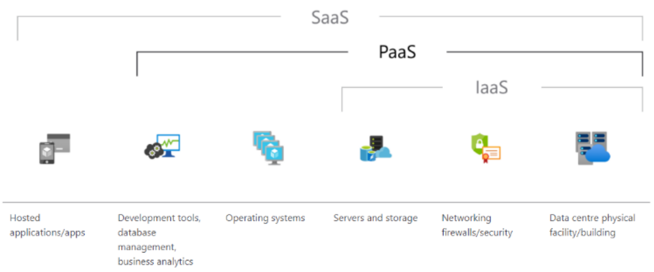

***Figure 1* – [1] Obtained from Microsoft Azure, different cloud services that are virtualized by Virtual Machines**

Cloud-fog and IP over WDM architecture

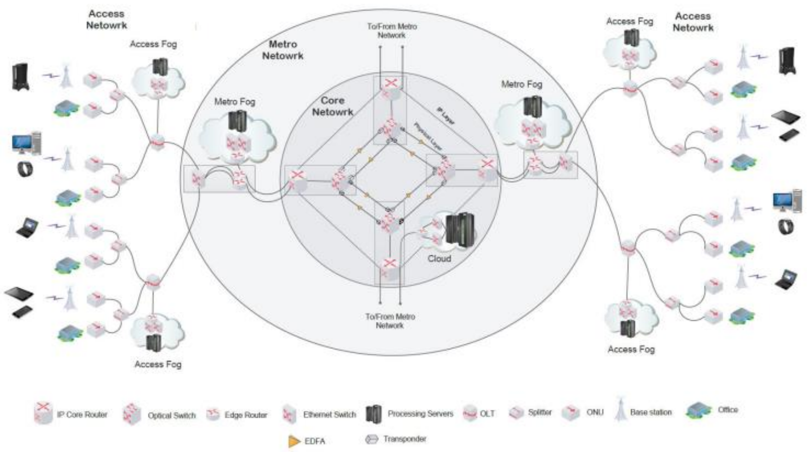

***Figure 2* – [4] Cloud to Fog Architecture that shows the access, metro, and core networks**

The cloud-fog network is composed of multiple layers, as indicated in *Figure 3*, the top being the core network, traversing down to the metro network, and finally to the access network. The core network is based on the light path bypass IP over WDM network, that connects different access networks. It has two layers, the IP layer, containing core IP routers that provide maximum bandwidth to optimise routing to destination and group data packets based on common traits obtained from low end edge routers, and an optical layer. Each core IP router is connected to an optical switch, which connects to an optical cross connect, that divides optical bandwidth into multiple wavelengths, via an associated transponder into a multiplexer, that sends light-data using a single fibre optic, amplified by an EDFA for longer distance traversal. A transponder's main job in IP over WDM is to convert the signal received from an IP router into the desired WDM wavelength, and vice-versa at the demultiplexer end. A core network can be composed of several points of presence. A metro network serves as an aggregation layer that connects access network to the core network. The access network connects subscribers to the core telecommunication network, it is considered the first point of access.

The ever-increasing traffic imposed on transport networks, from core to access networks, leads to an increasing power expenditure. Power, conventionally, is sourced from non-renewables, leading to an increase in CO_2 emissions.

Summary Of Related Background Literature

This project is inspired from the paper, [4] *Energy Efficient VM Placement Over Cloud-Fog Architecture*, where an MILP model was developed to place virtualized machine (VM) services in different nodes in the cloud-fog architecture for optimum energy efficiency given several factors. These include the minimum VM workload requirement, the VM popularity, and data rate. The network layers, the core, metro, and access networks, stemmed a set of parameters that where inputted to the MILP model. In the access network, optical network units are connected to the optical line terminal, this derives a set of parameters such as the total average energy consumption from the amount of components present in a node. In the metro network, the edge switches, and routers parameters such as their average energy consumption, bit rate, and number has been accounted. In the core network, parameters stemmed from the IP and Optical layer components in which the average energy consumption and the number of the components where inputted to the MILP model. The MILP model's main objective is to minimize the total power consumption summed from all the power expenditure mentioned. The model was subject to constraints, which includes the VM constraints, flow conversation constraint in the virtual and physical topology, and physical constraints such as link capacity or number of routers at a node. The VM services were placed at either nodes in the topology needed to satisfy the traffic imposed. In addition, VM services workload was considered in both a linear and constant profile, in a way that satisfies the minimum quality of service.

This project also builds on the concept highlighted in,[2] *Energy-minimized design for IP Over WDM Networks*, in which the paper produces an MILP model that simulates a backbone core IP network design that serves all incoming traffic demand, contains a limited amount of IP routers at a given node, and has a maximum amount of wavelengths to a single optical fibre cord. Power consumption that is utilized from the IP routers, optical switches, optical cross connects, transponders, and EDFAs are summed as part of the objective, which aims to minimise the total energy consumption stemmed from the components. The model ensures that the flow conservation law is satisfied such that the total outgoing flow of data packets is equal to the total incoming flow if the node, or the point of presence, is an intermediate node. [5] If it is a source node, then the total output flow subtracted by the total input flow must be equal to the traffic demand between the node pair. [5] If it is a destination node then the total incoming flow minus the output flow is equal to the traffic demand between the node pair. This law ensures that data packets can be diverged throughout multiple nodes, in both the virtual and physical topologies. Virtual topology consists of a set of light paths that sits on top of the physical layer, this ensures that if a physical node is malfunctioning, then packets are still able to be routed appropriately. The model ensures that sufficient wavelength capacity is available in both the physical and virtual topologies.

```
########## Objective
minimize EC:

#direct bypass
#compare to non bypass
sum{i in N} Erp*(Aggrp[i]+sum{j in N:i<>j} Cij[i,j])+

sum{m in N}(sum{n in Nm[m]}Et*Wmn[m,n])+

sum{m in N}(sum{n in Nm[m]}Ee*Amn[m,n]*Fmn[m,n]);

############Constrains

##########flow conservation in IP layer...Ref (2)
s.t. Cons2{s in N, d in N, i in N:s<>d}:
sum{j in N:i<>j}Lsd_ij[s,d,i,j] - sum{j in N:i<>j}Lsd_ij[s,d,j,i]=
if i=s then Lsd[s,d] else if i=d then -Lsd[s,d] else 0;

#####accumilated demands portions on a virtual link does not exceed its capacity..(3)
s.t. Cons3{i in N, j in N:i<>j}:
sum{s in N}(sum {d in N:s<>d} Lsd_ij[s,d,i,j])<=Cij[i,j]*B;

##### total No. of ports does not exceed the limit..(4)
s.t. Cons4{i in N}:sum{j in N:i<>j}Cij[i,j]+Aggrp[i]<=rpMax[i];

#####total No. of ports does not exceed the limit..(5)
s.t. Cons5{j in N}:sum{i in N:i<>j}Cij[i,j]+Aggrp[j]<=rpMax[j];

#####flow conservation in WDM layer...(6)
s.t. Cons6{i in N, j in N, m in N:i<>j}:sum{n in Nm[m]}Wij_mn[i,j,m,n]-sum{n in Nm[m]}Wij_mn[i,j,n,m]=
if m=i then Cij[i,j] else if m=j then -Cij[i,j] else 0;
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***Figure 3* – [2] IP Over WDM MILP model code**

A Description of the Work Done in the First Term

1. Literature in relation to WDM networks, networking, routers, switches, virtual and physical topology, packets, and other related concepts have been studied
2. Related papers completed by the supervisor have been studied
3. The first three chapters, of *Routing, Flow, and Capacity Design in Communication and Computer Networks*, where studied to understand the concept behind flow conservation model and virtual topology
    a. Understanding the concept behind flow conservation model and virtual topology
4. CPLEX program has been installed on my machine, and the supplementary book, *AMPL: A Modelling Language for Mathematical Programming*, was followed, in addition to simple examples being implemented
5. *Energy-minimized IP over WDM Network*, paper has been studied, and the MILP model simulations have been conducted, the results from the paper have been emulated
6. *Energy Efficient VM Placement Over Cloud-Fog Architecture*, paper has been extensively studied, the objective and the constraints have been understood, the MILP model has been developed, and the results have been emulated.
    a. Both papers mentioned will have a lot of similarities, in terms of constraints, to my current paper,
7. Constraints for renewable energy sources and energy storage device has been studied, however, further research will be conducted for the upcoming term

A Reflection of Progress and any Project Management Issues

Overall, the progress in the first couple of weeks consisted of familiarizing myself with overall research methodologies and looking briefly into different pieces of literature to gain outlook in how to go about the research project. As I was not previously exposed to the related literature before, I found myself doing extensive work to familiarize with concepts. Luckily, my distributed systems module has provided me with a lot of help as a lot of concepts overlapped with my project. I would say in the coming term, I would create a specified agenda of what is needed to be achieved in the beginning of the week, and would work towards those goals on a day to day basis. At the end of the week, a meeting with a supervisor would be useful to discuss the progress made, and the agenda for next week. In terms of progress, I personally believe that the development of the MILP model for both papers, VM Placement and IP over WDM, should have been done earlier than Christmas, and the initial development of the MILP model of the current research topic should have been initiated before Christmas. However, with my acquired knowledge of the concepts, I am confident that progress will be made on deadline targets.

A Description of Next Semester Plans

The next semester's agenda would go as follows:

1. Further research will be conducted on optimal placement of renewable energy, different renewable energy sources will be studied, their energy output based on average figures, plausibility of placing it in different nodes, and constraints
2. Due to the sporadic production of energy, research on energy device storage and feasibility of placement within nodes will be conducted, the average amount of energy storage figures will be obtained
3. Several papers in relation to the research project will be studied to identify further gaps that can be filled within the current research conducted
4. An MILP model will be developed in relation with my paper to find the optimal placement of virtual machines, renewable energy sources, and energy storage devices in order minimize CO2 emissions
    a. An objective, parameters, constraints, and related equations will be developed
5. Heuristics will be developed for a practical approach that provides real-time calculations based on the MILP model
    a. A flowchart will be developed
6. If time allows, an application will be developed with a user interface that extends the heuristics.

References

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[3] Ciena, "What is WDM or DWDM?," 2022. [Online]. Available: https://www.ciena.com/insights/what-is/What-Is-WDM.html. [Accessed 5 January 2022].

[4] T. E. H. E. HATEM A. ALHARBI, "Energy Efficient Virtual Machines Placement Over Cloud-Fog Network Architecture," IEEE, 2020.

[5] M. Pioro, "Node-Link Formulation," in *Routing, Flow, and Capacity Design*, El Sevier, pp. 43-45.