UNIVERSITI PUTRA MALAYSIA

CONTROLLER PLACEMENT PROBLEM IN THE OPTIMIZATION OF 5G BASED SDN AND NFV ARCHITECTURE

ABEER ABDALLA ZAKARIA IBRAHIM

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By

ABEER ABDALLA ZAKARIA IBRAHIM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

October 2021

DEDICATION

I owe tremendous and special gratitude to my lovely family for their continued and unfailing love, support and understanding during the pursuit of my Ph.D. studies that made the completion of the thesis possible.

Dedicated to

My Parents,
My caring Husband, Dr. Saber Mohammed Elnour Fadul
My caring Son: Hussam, and
My beautiful Daughters: Yomna and Leena
My teachers, who provided me with the best education,
All the people in my life who touch my heart.

......With Love……

Abeer A. Z. Ibrahim
October 2021

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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October 2021

Chairman : Associate Professor Fazirulhisyam Hashim, PhD
Faculty : Engineering

The fast rise in data traffic and the vast range of services and applications accessible in 5G networks must be addressed effectively. Integrating Software Defined Networking (SDN) with Network Function Virtualization (NFV) is a low-cost way to build a reconfigurable network, reduce operating costs, and optimize network performance. The separation of control functionality from forwarding devices brings orchestration and management to enable 5G network programmability. Although centralized control facilitated orchestration and administration of 5G services and applications, it could not handle massive and varied data volumes. 5G networks can avoid performance degradation, enable diverse network traffic management, and create a flexible and scalable design by adopting and deploying multi-controllers in the network control layer. However, for optimum 5G core design and cost-effectiveness, a group of controllers must be appropriately mapped.

A distributed 5G-SDN-NFV-based network architecture uses the controller placement problem (CPP) to manage controller placement and number. A heuristic called dynamic mapping and multi-stage CPP algorithm (DMMCPP) was developed to solve CPP as resource allocation in a distributed 5G-SDN-NFV-based network. This thesis divides CPP solutions into three groups based on three objectives: (i) scalability and load balancing, (ii) reliability and resilience, and (iii) efficient routing for energy-aware design. First, a dynamic allocation and mapping CPP (DAMCP) is developed to solve network dynamic resource location problems. It demonstrates a trade-off between locating a minimum number of controllers and network traffic to maximize resources and achieve load balancing at minimum costs. Second, the increasing demand for controllers exposes the network to control planes and connection failures, which are the most frequent problems in SDN networks. If the control plane fails to improve system resilience quality, A reliable RAMCP is formulated as an optimal solution for fault tolerance. Furthermore, the approach is extended with a Particle Swarm Algorithm (PSO) and presented as a hybrid RASCP to validate the optimal location and number of

controllers. Third, the considered traffic paths across backup nodes and redundancy lengthen, increasing latency and power consumption in a network. The proposed energy-aware routing algorithm (EARMCP) implements efficient flow routing mechanisms for network traffic to minimize the number of active links and 5G-DC devices. Extensive computations utilizing MATLAB 2018a on the Intel Core i7/Gen 10 processor and 16 GB of RAM are used to evaluate the algorithm efficacy.

According to the blueprint of our heuristic method, the allocation and the optimum number of controllers under an effective decentralized policy could achieve higher efficiency. The selected control number is picked with a higher efficiency before the rescheduling is approximately 80 % for optimized controllers up to 90 % of resource management than other comparable algorithms in such a densified network. In addition, energy savings of up to 70% are achieved compared to the proposed Dijkstra-based energy-aware algorithms.
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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

MASALAH PENEMPATAN PENGAWAL DALAM PENGOPTIMUMAN SENIBINA SDN DAN NFV BERASASKAN 5G

Oleh

ABEER ABDALLA ZAKARIA IBRAHIM

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Peningkatan pantas dalam trafik data dan rangkaian luas perkhidmatan serta aplikasi yang boleh diakses dalam rangkaian 5G mesti ditangani dengan berkesan. Mengintegrasikan Rangkaian Tertakrif Perisian (SDN) dengan Virtualisasi Fungsi Rangkaian (NFV) ialah cara kos rendah untuk membina rangkaian boleh dikonfigurasikan semula, mengurangkan kos operasi dan mengoptimumkan prestasi rangkaian. Pengasingan fungsi kawalan daripada peranti pemajuan membawa orkestrasi dan pengurusan untuk membolehkan kebolehprograman rangkaian 5G. Walaupun kawalan terpusat memudahkan orkestrasi dan pentadbiran perkhidmatan dan aplikasi 5G, ia tidak dapat mengendalikan volum data yang besar dan pelbagai. Rangkaian 5G boleh mengelakkan kemerosotan prestasi, mendayakan pengurusan trafik rangkaian yang pelbagai, dan mencipta reka bentuk yang fleksibel dan berskala dengan mengguna pakai dan menggunakan berbilang pengawal dalam lapisan kawalan rangkaian. Walau bagaimanapun, untuk reka bentuk teras 5G yang optimum dan keberkesanan kos, sekumpulan pengawal mesti dipetakan dengan sewajarnya.

Seni bina rangkaian berasaskan 5G-SDN-NFV yang diedarkan menggunakan masalah peletakan pengawal (CPP) untuk mengurus peletakan dan nombor pengawal. Heuristik yang dipanggil pemetaan dinamik dan algoritma CPP berbilang peringkat (DMMCPP) telah dibangunkan untuk menyelesaikan CPP sebagai peruntukan sumber dalam rangkaian berasaskan 5G-SDN-NFV yang diedarkan. Tesis ini membahagikan penyelesaian CPP kepada tiga kumpulan berdasarkan tiga objektif: (i) skalabiliti dan pengimbangan beban, (ii) kebolehpercayaan dan daya tahan, dan (iii) penghalaan yang cekap untuk reka bentuk sedar tenaga. Pertama, peruntukan dinamik dan CPP pemetaan (DAMCP) dibangunkan untuk menyelesaikan masalah lokasi sumber dinamik rangkaian. Ia menunjukkan pertukaran antara mencari bilangan minimum pengawal dan trafik rangkaian untuk memaksimumkan sumber dan mencapai pengimbangan beban pada kos minimum. Kedua, peningkatan permintaan untuk pengawal mendedahkan rangkaian untuk mengawal pesawat dan kegagalan sambungan, yang merupakan

masalah paling kerap dalam rangkaian SDN. Jika satah kawalan gagal meningkatkan kualiti daya tahan sistem, RAMCP yang boleh dipercayai dirumuskan sebagai penyelesaian optimum untuk toleransi kesalahan. Tambahan pula, pendekatan ini dilanjutkan dengan Algoritma Swarm Partikel (PSO) dan dibentangkan sebagai RASCP hibrid untuk mengesahkan lokasi optimum dan bilangan pengawal. Ketiga, laluan trafik yang dipertimbangkan merentasi nod sandaran dan redundansi dipanjangkan, meningkatkan kependaman dan penggunaan kuasa dalam rangkaian. Algoritma penghalaan sedar tenaga (EARMCP) yang dicadangkan melaksanakan mekanisme penghalaan aliran yang cekap untuk trafik rangkaian untuk meminimumkan bilangan pautan aktif dan peranti 5G-DC. Pengiraan yang meluas menggunakan MATLAB 2018a pada pemproses Intel Core i7/Gen 10 dan 16 GB RAM digunakan untuk menilai keberkesanan algoritma.

Mengikut pelan tindakan kaedah heuristik kami, peruntukan dan bilangan optimum pengawal di bawah dasar terpencar yang berkesan boleh mencapai kecekapan yang lebih tinggi. Nombor kawalan yang dipilih dipilih dengan kecekapan yang lebih tinggi sebelum penjadualan semula adalah kira-kira 80 % untuk pengawal yang dioptimumkan sehingga 90 % daripada pengurusan sumber daripada algoritma setanding lain dalam rangkaian yang padat sedemikian. Di samping itu, penjimatan tenaga sehingga 70% dicapai berbanding algoritma sedar tenaga berasaskan Dijkstra yang dicadangkan.

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Date: 14 April 2022

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$C_{Assignment}$	Cost of assignment of switches
$C_{D_{ij}}^{\lambda_{ij}}$	Flow cost between $(i.j)$
C_j	Set of controllers or servers in a network
C_K	Set of active controllers in a service region
$C_{R(y,r)}$	Cost of reliable network
C_{UtiK}	Cost of locating the controller
$C_{\Re}$	Number of backup controllers
D_{ij}	Distance between controller j and NE i
d_j	Number of demands at the controller
e_{ij}	The decision for link-state
E_{ij}	Set of network links
$f_C(d_j)$	Flow traffic of control plane
$f_{NF}(G)$	Overall network flow
$f_r(d_i)$	Flow requested demand by nodes
$L_C(C_j)$	Controller load
N_{NE}	Set of network nodes
P_{ij}	Path failure probability
P_j	Controller failure
P_r	Control failure probability
R	Reliability of the system
r	Backup or redundant path
$r_{r,f}$	Decision for a path selection to routing traffic to the next domain
T_{Nw}	Average network latency

τ_{ij}	Propagation delay
τ_{pi}	Packet sending delay
$\tau_{Threshold}$	Network threshold latency
γ_j	Processing latency
λ_i	Flow rate requested by switch i
λ_{ij}	Traffic flow between i and j
ζ_C	Controller processing capacity
ζ_E	Link capacity
$\rho_{e,f}$	Decision for path selection between *i* and *j*
U_{Budget}^{C}	Controller utilization budget
U_j^C	Decision if controller located and utilize at *j*
U_ρ	Controller utilization
$\chi_{ij}^{C,S}$	Decision variable for whether switches are assigned to the corresponding controller
$x_{S,C}^{U}$	Decision indicates that the node state is forming ON/OFF
$\eta_{resource}$	Efficiency of resource scheduling for control plane
Z_{jr}	Decision for the selection of the next controller

LIST OF ABBREVIATIONS

4G	Fourth-generation
5G	Fifth-generation
6G	Six- generation
BS	Base Station
BSS	Business support system
C-RAN	Cloud radio access Network
CAPEX	Capital Expenditure
CCP	Capacitated Controller Placement
CCPP	Capacitated Controller Placement Problem
CLEP	Cluster Leading Election Issue
CPP	Controller Placement Problem
DAMCP	Dynamic Allocation and Mapping Controller Placement
DC	Data Center
DMMCPP	Dynamic Mapping and Multi-stage Controller Placement Problem
DWN	Dense Wireless Network
GA	Genetic Algorithm
GRS	Greedy Randomized Search
E2E	End to end
EA	Evolutionary Algorithm
EAR	Energy-aware Routing
EARMCP	Energy-aware Routing Mapping Controller Placement
EB	Exabytes
ESS	Energy Storage System

HetNet	Heterogeneous Network
IP	Internet protocol
ICT	Information Communication Technology
IoE	Internet of Everything
IoT	Internet of Things
IT	Information Technology
ITU	International Telecommunication Union
LP	Linear Programming
M2M	Machine to Machine
MEC	Mobile Edge Computing
MILP	Mixed-integer Linear programming
MOCPP	Multi-Objective Controller Placement Problem
MOEA	Multi-Objective Evolutionary Algorithm
MOO	Multi-Objective Optimization
MOOP	Multi-Objective Optimization Problem
MPLS	Multi-protocol Label Swapping
NF	Network Function
NFV	Network Function Virtualization
NGW	Next-generation mobile Network
NP	Nondeterministic Polynomial time
NWN	Next-generation Wireless Network
OPEX	Operating Expenses
ONF	Open Network Foundation
OSPF	Open Shortest Path First
OSS	Operation Support System

PM	Physical Machine
PSO	Particle Swarm Optimization
RAN	Radio Access Network
RAT	Radio Access Technology
RIP	Routing Information Protocol
QoS	Quality of Service
SA	Simulated Annealing
SDN	Software Defined Networking
SFC	Service Function Chain
SP	Service Provider
SSOA	Salp Swarm Optimization Algorithm
TCAM	Ternary Content Addressable Memory
UE	User Equipment
VC	Virtual Core
VM	Virtual Machine
VN	Virtual Network
VNF	Network Function Virtualization
vSDN	virtualized SDN

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

It was seen in 2020; the world entered a period of the Internet of Everything (IoE) age. A concept that brings together people, data, things, and processes. As a result, the data flow becomes much more valuable and vaster. Traditional hardware-based networks face challenges such as inadequate capacity and poor resilience. They can still not accommodate or operate with the increased traffic, service and applications created by modern technology and meet the emerging digital world's emerging demands [1].

On the other hand, the densified networks, such as fifth-generation (5G) and sixth-generation (6G), undergo a massive paradigm shift due to all emerging innovations that can elevate lifestyle to a brand new level [2]. They are versatile concepts with a broad range of applications and services in potential network planning of future communication, including but not limited to IoT, internet social network, home automation, military equipment, mobile communications, automobile driving, health facilities, and smart cities. Therefore, the advent of 5G and beyond releases till 6G promises high-speed communication and control over greater distances; however, the assurance of flexibility, scalability, reliability, and security has to be highly considered [3]. **Figure 1.1** shows the demand for 5G infrastructure, software, and services for devices, applications, and services beyond 5G.

The 5G derived more intelligent management structures from coordinating numerous networks, typically in control management and complexity [4]. Thus, the arrival of 5G releases aims to provide new opportunities for service providers to increase revenues while decreasing costs and latency. The expansion to much higher carrier frequencies and network radio is crucial because of the continuing demand for increasing traffic, faster consumer data rates, and the associated need for additional spectrum and broader transmission bandwidths. It also enhances network energy performance and reduces interference, while interworking and LTE coexistence will make it possible to utilize existing cellular networks. These features are regarded as major challenges for future mobile communication networks compared to previous cellular communications networks and standards beyond fourth-generation (4G) technologies [5].

Fortunately, the architecture of next-generation wireless networks (NWNs) and 5G necessitates openness to build and manage the massive increase in data traffic hierarchically for optimal network design and planning ideas [6]. Due to the density and diversity of random network topologies, 5G release technologies address the architecture-supporting mechanisms. A key technological advance in network reconfigurations is virtualization and network Softwarization. They enforce the primary 5G network drivers and provide the architectural flexibility necessary to overcome network complexity [7]. Thus virtualization and programmability of 5G core functional modules enable sharing of physical network resources and function chaining among different sections [8].

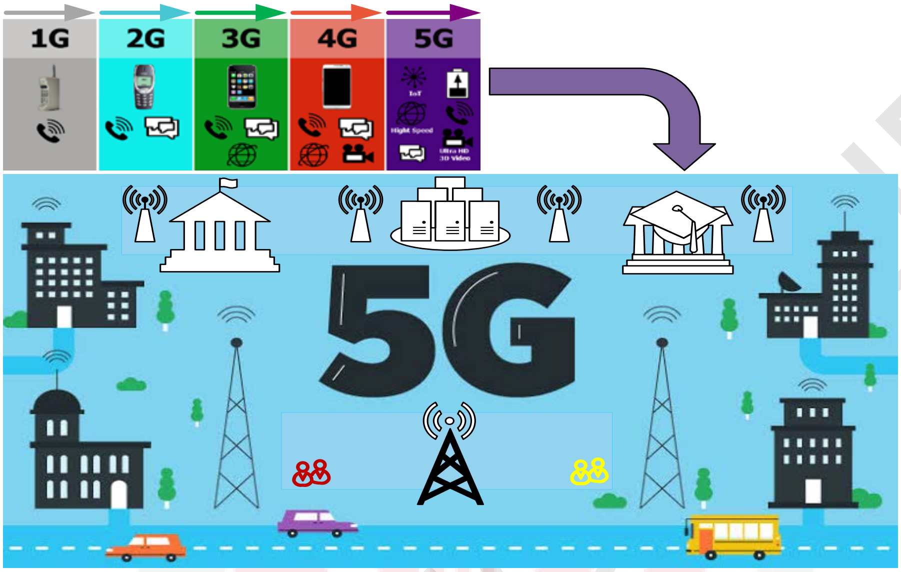

Figure 1.1: The 5G vision and beyond the architecture of wireless technologies

Software-Defined Networking (SDN) and Network Function Virtualization (NFV) are technology enablers that are focused on defining fine-grained network quality of service (QoS) over the network architecture. SDN creates operational intelligence by decoupling network control functions from data layer devices to support advanced automation from a centralized controller [1]. At the same time, NFV provides an adequate abstraction of network services' functionalities and a new infrastructure scalable management to accommodate a wide range of network functions [9].

The integration of 5G with SDN and NFV takes advantage of the software programmability of the 5G core network architecture [10]. This integration runs in a cloud-based architecture paradigm, improves and facilitates reliance on network resources, helps in the unification of state network distribution, and provides an adjustable configuration technique for transparently managing any network [11]. However, when it comes to a softwarized network, a platform is ready to support flexible robustness, resilience, and flexibility and network policy configuration to meet an architecture-supporting mechanism for a diverse 5G service requirement from an architectural standpoint [12].

Making wise decisions to allocate sufficient resources to fulfil all network architecture requirements and context information accomplished by a network control layer is a significant task network resource control (allocation) in 5G networks is challenging [13]. This is attainable by supporting all network traffic functions carried out through the centralized control plane components in 5G cloud-based architecture [11]. The centralized control plane makes these networks particularly vulnerable to upgrades and modifications. Besides that, network hardware-based control platforms are difficult to update, cope or work with the elevated traffic caused by big data demands. Thus, the wireless network's underpinning configuration results in a lack of significant awareness of network infrastructure, making network-wide cohesive policies challenging to deploy. This process considers determining the location of data centers (DCs) and cloud, estimating the volume of the subnetwork or service area network in terms of coverage and capacity. Also, assigning the demands and analyzing the propagation media and latencies requested to set up the networks before implementing any new technology [14].

Therefore, the adoption and utilization of multiple controllers in the control layer architectures for 5G networks tackle the lack of performance degradation to achieve a flexible and scalable architecture [15]. This distributed management control approach has been proposed as a way of facilitating network evolution. An interface between the SDN control plane and current centralized Network Management Systems (NMSs) can help the overall network efficiency.

Nevertheless, there is a research gap in 5G-based SDN and NFV network design and optimization, as well as potential traffic monitoring behavior existing management schemes may not be sufficient. The network resource location problem in the distributed multi-control architecture of SDN-WAN is among the most critical and strategic issues requiring proper planning and optimization of both the control plane and the physical infrastructure layer [16]. Also, future wireless networks can face a significant challenge in efficiently fulfilling the increased network capacity and bandwidth utilization as the spectrum resources remain limited. Many optimization models for communication networks and traffic routing have been investigated; however, relatively few optimization strategies for NPM have been proposed.

On the other side, significant consideration should be provided to connections and node failures, the most frequent failures in SDN networks. Network reliability is essential to achieve a scalable and robust link between controllers and physical network components or associated servers (VMs). Although these redundancies significantly improve network stability, they can increase energy consumption when all network equipment is turned on at maximum capacity. Hence, improving energy sustainability is becoming increasingly essential as global energy consumption has environmental and economic issues [17].

The information and Communication Technologies (ICTs) sector consumes between 10% to 12% of global energy; however, network components consume about 2% of the ICT sector's energy consumption [18]. Consequently, the current and future ICT sectors are based on significant improvements in today's efficiency while using minimal power consumption compared to the old ICT market. Hence, several energy-saving approaches during off-peak hours may be feasible without impacting network performance and stability. This performance enhancement is useful for management and control decisions to prepare the required demand for traffic volume and service request control tools [19].

The following proposals are among particular works used in the thesis: a deep study on the control plane in potential 5G core infrastructure capable of delivering intelligent control functions. Furthermore, based on such an SDN-based framework, a control plane planning and optimization mechanism is specified and addressed to optimally distribute the potential utilization and load balances management process of control load between multiple control planes in 5G core networks. On the other side, by incorporating fault tolerance strategies, this study introduces an optimization method for the reliability and resiliency of the control layer's failure.

The expanded usage of the wireless network can continue to grow in the future due to the increase of wireless device capacity. Therefore, this study explores the potential of integrating SDN and NFV to allow a distributed control plane to fulfil the traffic demands of different applications and services. However, the integration provides the ability to utilize diversity in the 5G core network by efficiently distributing resources at runtime to its multi-network control.

To realize the above objectives, the thesis implements a heuristic method for tackling the problem of optimization. We investigate the applicability of a specific management allocation algorithm to solve the controller placement in distributed 5G core network by developing an optimization multi-objective optimization model. One of the key contributions is to examine controllers positioning for dynamic traffic flows based on the number of controllers mapping for switch-to-controller assignment applied to different average traffic situations within the network.

Our proposed algorithm attempts to answer the questions of the following sub-problems of the Controller Placement Problem (CPP) in terms of: 'How to measure the load imbalance of controllers and determine whether to perform switch migration'; and 'How to make a trade-off between location cost, assignment of switches and fault tolerance costs.'

An in-depth investigation of mathematic evaluation is carried out on distributed configurations under different parameter settings in a reliable manner to assist in choosing the best network architecture. The study aims to let the algorithm adapt an entire system based on the historical data, ensuring that the 5G network can fully realize the system variables and adjust their values optimally to achieve an exemplary network configuration.

Calculating the accurate number of controllers is needed for a specific service area, such as ultra-dense networking and 5G stringent requirements. Although the linear optimization formulation makes the algorithm solvable by any available solving techniques, the task complexity increases abruptly for such scalability criteria. Hence, the execution times and computational resources needed to increase as well. Considering this, a heuristic method based on the CPP algorithm was developed for the placement strategy with Particle Swarm Optimization (PSO). In our research, a hybrid PSO algorithm that incorporates a heuristic assignment procedure is proposed to optimize a proposed Multi-objective Optimization Problem.

1.2 Significance of the Study

The classic network architectures are complex to implement and manage many applications such as cloud networking environments data centers. They are comparatively stagnant, rigid, and challenging to enable modern innovation improvements. The proprietary systems in such designs depend on manual configuration, which is bulky, time-consuming, and erroneous.

Many approaches have been developed to optimize and plan the 5G network based on SDN and NFV. However, specific vital issues must also be tackled to enhance resource management and provisioning in the 5G core. Current management plans could not be adequate among the latest developments of 5G rather than the other iteration of mobile networking technologies; 5G can cover a wide variety of usage cases. Consequently, scalable and programmable network management is needed to maintain the coherent policy and global management through complex access networks. To verify the advantages of controller scalability, processing latency, and energy consumption, SDN/NFV network performance must be modelled, analyzed, and tested.

So far, among them, the integration of SDN into 5G based on distributed network design has gained popularity. The control plane is comprised of a series of dedicated controllers that perform as the key of the SDN, whereas the data plane is formed of several basic packet forwarding switches. This decoupling allows the network to become fully programmable, which has many advantages, such as simplifying network operations, improving network performance quality, and enabling advanced network management.

The significant element is to propose a strategy for describing a distributed system that is compatible with the mapping of controllers in the large-scale implementation of SDN and NFV in core 5G networks. An optimization algorithm is often used to find the best network parameters that can match the simulation results with performance metrics parameters. Such a method is based on optimization and a mathematical traffic engineering model that simulates system behavior under normal and failure conditions when fed system performance degradation. Also, the model provides low latency and high energy awareness, resulting in a qualitative network.

On the other hand, the CPP is the most critical SDN challenge that can significantly impact the overall network efficiency. However, the CPP topic and its challenge have not been thoroughly well reviewed and appropriately discussed in any other studies.

The network performance can suffer because of an ineffective controller positioning strategy. Poor controller distribution may have unexpected effects, such as a lengthy recovery period after a failure, scalability, and energy efficiency aware design.

Therefore, this study presents a detailed analysis of many optimized controller positioning problem algorithms in SDN that are NP-hard or recognized as facility position problems, usually involving the numbers and location of controllers in a network. So, the heuristic and evolutionary algorithm also provided efficient techniques for CPP as a resource location problem. However, most of the previous works dealt with the CPP in a single domain and single parameters. Some of them concentrated on load balancing without calculating the exact number of controllers under the network traffic load and evaluating resource management's assignment efficiency. Moreover, these methods do not tackle network traffic flows to reduce efficiency and the number of controllers to reduce the cost.

1.3 Problem Statement

The introduction of 5G networks and beyond promises high-speed networking and control over longer distances; however, flexibility, scalability, reliability, and security must be considered carefully [15].

Although 5G has benefited from SDN, deploying SDN in 5G core still poses many architectural challenges [20][21]. Nonetheless, with such a massive and dense 5G network and the data flow variations demand, the centralized network control is insufficient to accommodate all network traffic. The diversity of services, devices, and significant traffic flow growth accompanied by the implementation of dynamic policies make it difficult for networks to run without overload. Therefore, the adoption and utilization of multiple controllers in the control layer architectures for 5G networks tackle the lack of performance degradation to achieve a proper allocation of resource and control plane management [22][23][24][25]. The fundamental concept behind the distributed architecture is to break down the sizeable wide-area network into small subnetworks and deploy a single controller for each area to enable unified management. However, proper planning and optimization of the control plane as well as user-plane traffic management are major problems in distributed network architecture [26]. Choosing an approach requires maintaining a group of controllers be correctly mapped to improve flexibility, scalability, and reliability to achieve an optimal cost-effectiveness design for 5G core resource management [27][28]. This is known as a controller Placement Problem (CPP) [29].

Therefore, controller positioning has emerged as a critical design challenge that affects SDN's southbound performance due to the significant influence of propagation latency (switch to controller latency). Moreover, control tasks such as data plane monitoring must be accomplished to keep state information current to optimize the southbound interface. In summary, the following problems have been identified and will be addressed in this thesis:

i. The unpredictable network demands and signaling overhead generated between the far distributed gateway and centralized control plane may overload the controllers due to queuing at the controller system. Similarly, assigning switches to their corresponding controllers without planning will result in the controller's failure to meet the diverse requirements of a large-scale network, resulting in scalability issues. However, due to a commodity server's limitations and the controller's bandwidth constraint, each sub-controller should manage and serve a limited number of switches within their capacity range [30]. Therefore, a dynamic mapping scheme should be configured to find the best location for the number of controllers to achieve optimal resource scheduling and maintain load balancing.

ii. The increased demand for a single controller has contributed to the entire network failure, owing to limited resources that appear insufficient for the controller to handle all network traffic generated by 5G via multiple alternate signaling routes. Thus, it is essential to provide a reasonable balance between a certain level of redundancy and fault-tolerance strategy is required to be utilized under which the control plane is subjected to failure [31]. The locations and number of controllers be allocated to achieve a reliable connection between the controllers and the network's physical components and avoid overloading any controllers [26]. This approach is intended for resilience mechanisms that can be applied to improve network reliability in controller faults, where facility capacity is often fixed. To ensure control plane state reliability, controllers must proactively redirect packets from a failed link to an alternate path [32].

iii. The redundancy lengthens the considered traffic paths across the backup nodes, increasing latency and power consumption in a network. Consequently, it becomes a challenge on the DC where the underlying mapping of network services (switches and routers) is not used efficiently during heavy data traffic, resulting in a high marginal cost of energy consumption. Therefore, a certain level of redundancy-based policies and re-routing traffic mechanism must find. The goal is to identify routes between network components that use the fewest active links scheme using the network's power-saving mode [33]. Besides that, the location of these controllers must be optimized to meet the network energy-aware and user requirements constraints [20][34].

Therefore, the overall concern that must be addressed is how many SDN controllers are required for a completely accurate 5G-based SDN/NFV for WAN and where they should be placed to optimize user-defined specifications and constraints while maintaining acceptable runtime and accuracy. To that end, this thesis investigates a variety of 5G network planning and optimization models. Besides, it proposes efficient heuristic multi-objective optimization formulation mechanisms for large-scale networks of the 5G core. Since the algorithm is an NP-hard problem, efficient algorithms that solve network problems in theoretical and realistic ways are also proposed to find the exact solution for every model. However, the issues listed above must be addressed during the early stages of SDN planning.

1.4 Research Objectives

The main objective of this research is to propose, design, and develop a heuristic multi-objective optimization algorithm for controller placement problems as dynamic resource allocation scheduling in the 5G core-based multi-control SDN-NFV architecture. The research strategy is to determine the optimum location and the number of controllers as well as the assignment cost of switches to their controllers to achieve the best network performance in terms of scalability, reliability, and energy efficiency. To attain the main objective, the following research activities are proposed:

1. To develop the dynamic allocation and mapping controller placement problem (DAMCP) algorithm to solve the dynamic mapping and assignment of the switch-to-controller to achieve load balancing.

2. To develop a reliable (RAMCP) to set a mechanism for overload scenario and fault-tolerance of control plane under failure to maximize control plane reliability and robustness.

3. To develop a novel energy-aware routing mechanism (EARMCP) focusing on finding optimal network traffic routes between the control plane and the data plane that reduces the end-to-end latency and ensures load balancing to increase network power efficiency.

1.5 Scopes and Limitations of the Research

This thesis discusses the concept, design, and implementation of the dynamic allocation multi-level and multi-objective controller placement problem (DMMCP) based on the *K*-center algorithm, Graph Theory, and a Greedy Randomized Search (GRS) algorithm. The algorithm is implemented in MATLAB. It can be applied to classes of densified networks such as 5G in wireless communication systems, where network protocols, including OpenFlow, are implemented.

Many approaches have been developed to design and optimize a 5G network based on SDN and NFV. The integration of SDN and NFV into 5G or distributed network design has gained prominence due to its advantages of low latency, relatively easy flexibility, scalability, and reliability. The scope of the study is highlighted as shown in **Figure 1.2**. Note that the traffic is presented as a network resource instead of channel parameters such as bandwidth or throughput.

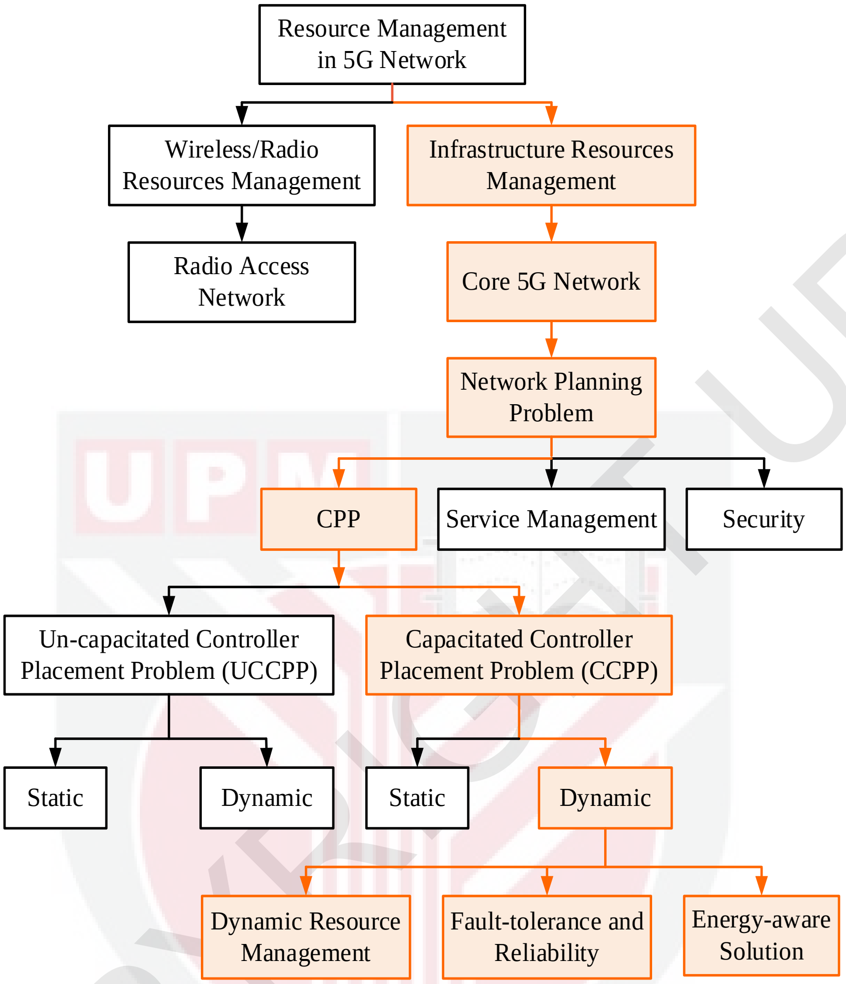

Figure 1.2 : The scope of the study

A significant aspect of this work that directly affects the research methodology for the design of the CPP is the selection of number and placement of controllers in a network, availability, resiliency, and reliability investigated. Within the scope of this research, it focuses on cost and delay for the control plane environment.

The designed algorithm uses the distributed multi-control-based SDN and NFV reference frame architecture. The proposed algorithm simulates the system behavior under normal and faults conditions when its fed system performance degradation. Also, this research focuses on the design and development of the energy-efficient network associated with the routing algorithm and vector control. Therefore, the optimization algorithm used in this study finds a near-optimal solution for the CPP and the trade-off between network parameters that balance the simulation results with output metrics parameters.

1.6 Thesis Contributions

The main contributions of this thesis are listed below:

i. The thesis contributes by analyzing the challenges and future direction of a distributed network architecture concept for a 5G core network based on SDN and NFV in Chapter 3. Their solutions for the enabling technologies of 5G, such as SDN, cloud technologies, and VNFs. The importance is to enable SDN and NFV integration benefits, such as efficient resource allocation and energy-efficient network design.

ii. The model captures the main performance for resource allocation scheduling optimization in terms of CPP and load balancing.

iii. A reliable and robust network design of a novel control plane is provided. A reliable optimization strategy is developed to provide a reasonable balance between fault tolerance requirements and the cost-effective configuration of the network.

iv. Finally, the energy-saving design is presented to accomplish the overall network performance.

Our model results are then utilized to conduct a detailed investigation of control plane performance under realistic data center traffic loads. Our model can be used to forecast network performance and provide the necessary number of servers/controllers to meet network performance requirements.

1.7 Thesis Outline

This thesis comprises seven chapters covering the comprehensive states of the research as depicted in **Figure 1.3**.

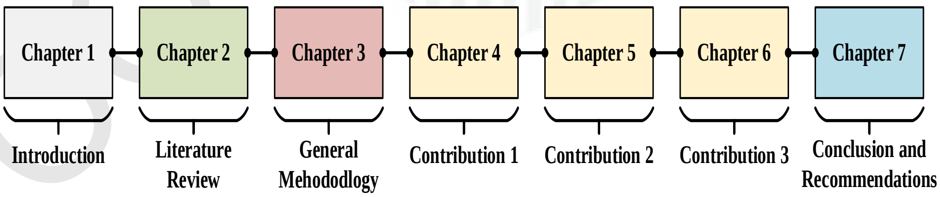

Figure 1.3 : Thesis outline

Firstly**, Chapter 1** comprises seven sections, beginning with the background of the study, which introduced and described the perspective of addressing the 5G network evaluation and planning for future direction. This chapter identifies the main thesis problem statement, objective, scope, and contribution. Secondly, **Chapter 2** covers the critical literature review and related studies on 5G core architecture and enabling technologies. Also, the existing techniques for solving the proposed approaches, ensuring performance and accuracy in large-scale networks. The general methodology and the detailed proposed methods (algorithms), and their performance evaluation and associated results are provided in chapters three, four, five, and six.

So, thirdly, **Chapter 3** presents a general thesis methodology and focuses on the steps for developing the algorithm design steps of the proposed architecture outline to tackle the DWN and CPP. It displays the main principles of the mathematical background of the presented problem and developed models. It also details all the performance metrics used to attain the objectives of the problem and the proposed design of the algorithm configuration.

Fourthly, **Chapter 4** outlines the mechanisms of the proposed heuristic dynamic resource allocation algorithm (DAMCP) and related formulation algorithm design. Fifthly, **Chapter 5** resolves the issue of reliable and fault tolerance network design. This chapter gives the reliability algorithms alongside their evaluation using PSO. Sixthly, **Chapter 6** outlines the Energy-aware Routing CCP (EARMCP) problem and algorithm formulation to minimize and find the routing cost for optimum energy-saving network design. **Chapter 7** presents the general conclusion of the study, along with a summary of the results and contributions that the study made. The recommendations for future research are also presented for the information and use of future researchers.

Finally, the references, appendices, biodata of the author, and the list of publications are given at the end of the thesis.

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