République Algérienne Démocratique et Populaire

Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

Ecole Supérieure en Informatique
-08 Mai 1945- Sidi Bel Abbes

Mémoire de Fin d'Etudes

Pour l'obtention du diplôme **d'Ingènieur d'Etat**

Filière: **Informatique**

Spécialité: **Ingénierie des Systèmes Informatiques(ISI)**

Thème

Optimal Service Placement for In-Network Computing Services in P4

Présenté par:

Ines Guerziz

Soutenu le : **21 Septembre 2023** Devant le jury composé de :

- Fayçal Bendaouad	Docteur	Président
- Mohamed Azza	Docteur	Examinateur
- Alaa Eddine BELFEDHAL	Docteur	Encadrant
- Yacine GHAMRI-DOUDANE	Professeur	Co-Encadrant

Promotion : 2022/2023

Acknowledgment

Above all, I begin by expressing our deep gratitude to the Almighty, **ALLAH**, for bestowing upon us the strength, blessings, and good health required to undertake and complete this significant endeavor. The achievement of this thesis stands as a testament to the unwavering support and assistance received from numerous individuals, to whom I extend my sincere thanks.

Reflecting on this remarkable journey, I am overwhelmed with gratitude for the unwavering support and sacrifices made by my parents, **BELFERRAGUI BADIAA** and **GUERZIZ ABDELOUAHEB**. Their boundless love, prayers, care, and dedication to providing us with an education have not only made this momentous achievement possible but have also set the foundation for my future endeavors. I extend my heartfelt appreciation to my dear sister, **BOUCHRA**, and my brothers, **ILYES** and **AHMED**, for being pillars of support, sharing in our joys and challenges, and contributing tirelessly to the successful culmination of this thesis. I would like to express my heartfelt gratitude to my beloved grandmother, as well as to my uncles and aunts, for their generous support and love.

My profound gratitude extends to the entire **ESI-SBA** community, where I have had the privilege of spending enriching years. I would like to express a special acknowledgment to my advisor, **ALAA EDDINE BELFEDHAL**, whose guidance and mentorship have been instrumental in shaping my academic trajectory.

Additionally, I am deeply thankful to my advisor at La Rochelle University, **YACINE GHAMRI-DOUDANE**, for providing me with the remarkable opportunity to join the L3i and explore new horizons and discoveries.

As I look ahead to the future, I am filled with excitement and determination to apply the knowledge and experiences gained during this thesis to new endeavors. It is with profound appreciation for the past and hope for the future that I extend my heartfelt thanks to all my friends and classmates who have shared this journey with me. Your camaraderie and support have been invaluable, and I wish each one of you the very best in your new journeys and endeavors.

Abstract

In the ever-evolving landscape of computing, recent years have seen the integration of cloud and edge computing, fundamentally reshaping the deployment of applications and the delivery of services. However, a groundbreaking player has emerged on this stage: 6G technology. As the sixth generation of wireless technology, 6G promises revolutionary advancements in connectivity and computation, propelling us into a new era of technological possibilities.

But alongside 6G's rise, in-network computing has become a pivotal concept. This approach capitalizes on the computational prowess of network devices, effectively erasing the line that traditionally separated networking from computing. Within this dynamic evolution, the optimization of service placement takes center stage. It plays a vital role in ensuring peak system performance and efficient resource utilization.

This thesis embarks on a comprehensive exploration of the intricate interplay between service placement and the paradigm of in-network computing, with a particular focus on how 6G technology is poised to transform this landscape. By rigorously analyzing the challenges and formulating innovative strategies, we unveil how service placement seamlessly aligns with this emerging paradigm. This research not only bridges the gap between established knowledge and novel requirements but also serves as a visionary roadmap for the future of distributed systems, where 6G technology is set to drive unprecedented levels of efficiency and innovation.

Keywords:

In-Network Computing, Service Placement Optimization, 6G Technology, P4 Programming Language.

Résumé

Dans le paysage constamment en évolution de l'informatique, ces dernières années ont vu l'intégration de l'informatique en nuage et de l'informatique de périphérie, remodelant fondamentalement le déploiement des applications et la prestation de services. Cependant, un acteur révolutionnaire a émergé sur cette scène : la technologie 6G. En tant que sixième génération de technologie sans fil, la 6G promet des avancées révolutionnaires en matière de connectivité et de calcul, nous propulsant dans une nouvelle ère de possibilités technologiques.

Mais parallèlement à l'essor de la 6G, l'informatique en réseau est devenue un concept essentiel. Cette approche capitalise sur les compétences de calcul des dispositifs réseau, effaçant efficacement la frontière qui séparait traditionnellement le réseau de l'informatique. Au sein de cette évolution dynamique, l'optimisation du placement des services prend une place centrale. Elle joue un rôle vital dans la garantie des performances optimales du système et de l'utilisation efficace des ressources.

Cette thèse entreprend une exploration approfondie de l'interaction complexe entre le placement des services et le paradigme de l'informatique en réseau, en mettant particulièrement l'accent sur la manière dont la technologie 6G est sur le point de transformer ce paysage. En analysant rigoureusement les défis et en élaborant des stratégies innovantes, nous dévoilons comment le placement des services s'aligne parfaitement avec ce paradigme émergent. Cette recherche comble non seulement l'écart entre les connaissances établies et les exigences nouvelles, mais sert également de feuille de route visionnaire pour l'avenir des systèmes distribués, où la technologie 6G est destinée à stimuler des niveaux d'efficacité et d'innovation sans précédent.

Mots-clés :

In-Network Computing, Optimisation du Placement des Services, Technologie 6G, Langage de Programmation P4.

Abbreviations and Notations

INC	In - Net Work Computing
MC	Mist Computing
FC	Fog Computing
DC	Data Centers
QOS	Quality Of Service
FPGAs	Field Programmable Gate Arrays
NICs	Network Interface Cards
NFV	Network Function Virtualization
SDN	Soft Ward - Defined Networking
APIs	Application Programming Interfaces
VMs	Virtual Machines
PISA	Protocol Independent Switch Architecture
PHVs	Packet Header Vectors
TCAM	Ternary Content Addressable Memory
ALUs	Arithmetic Logic Units
FPGA	Field-Programmable Gate Arrays
CLBs	Compute Logic Blocks
WGs	Working Groups
ICN	Information-Centric Networking
ULL	Ultra-Low-Latency
NDN	Named Data Networking
BYOD	Bring Your Own Device
RAN	Radio Access Network
COIN	Computing In The Network
VR	Virtual Reality
AR	Augmented Reality
PLCs	Programmable Logic Controllers
CFAAs	Compute-Fabric-as-a Service
AI	Artificial Intelligence
PNDs	Personal Network devices

SPP	Service Placement Problem
VMs	Virtual Machines
DAGs	Directed Acyclic Graphs
CR	Resource Constraints
CN	Network Constraints
QOE	Quality Of Experience
ILP	Integer Linear Programming
INLP	Integer Non Linear Programming
MILP	Mixed Integer Linear Programming
MINLP	Mixed integer Non Linear Programming
MIQP	Mixed Integer Quadratic Programming
MDP	Markov Decision Process
PEC	Pervasive Edge Computing
EC	Edge Computing
MEC	Mobile Edge Computing
WDs	Wireless Devices
BS	Base Station
PTPNs	Priced Timed Petri Nets
DRL	Deep Reinforcement Learning
DDPG	Deep Deterministic Policy Gradients
SlAs	Service Level Agreement
RRU	Remote Radio Head
SDN	Software Defined Networking
SLA	Service Level Agreement
TN	Transport Network
URLLC	Ultra Reliable Low Latency Communication
V-CRAN	virtualized Cloud Radio Access Network
VIM	Virtual Infrastructure Manager
VM	Virtual Machine
VNF	Virtual Network Function