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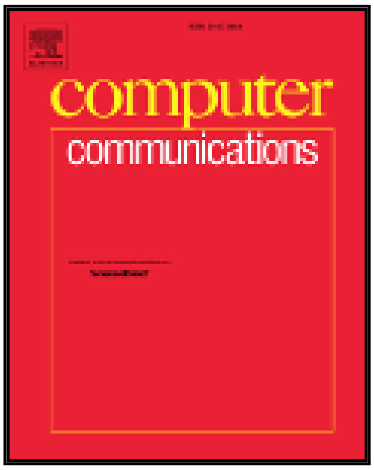

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Efficient Virtual Network Function Placement Strategies for Cloud Radio Access Networks

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***Abstract*—The new generation of 5G mobile services place stringent requirements for cellular network operators in terms of latency and costs. The latest trend in radio access networks (RANs) is to pool the baseband units (BBUs) of multiple radio base stations and to install them in a centralized infrastructure, such as a cloud, for statistical multiplexing gains. The technology is known as Cloud Radio Access Network (CRAN). Since cloud computing is gaining significant traction and virtualized data centers are becoming popular as a cost-effective infrastructure in the telecommunication industry, CRAN is being heralded as a candidate technology to meet the expectations of radio access networks for 5G. In CRANs, low energy base stations (BSs) are deployed over a small geographical location and are connected to a cloud via finite capacity backhaul links. Baseband processing unit (BBU) functions are implemented on the virtual machines (VMs) in the cloud over commodity hardware. Such functions, built in software, are termed as virtual functions (VFs). The optimized placement of VFs is necessary to reduce the total delays and minimize the overall costs to operate CRANs. Our study considers the problem of optimal VF placement over distributed virtual resources spread across multiple clouds, creating a centralized BBU cloud. We propose a combinatorial optimization model and the use of two heuristic approaches, which are, branch-and-bound (BnB) and simulated annealing (SA) for the proposed optimal placement. In addition, we propose enhancements to the standard BnB heuristic and compare the results with standard BnB and SA approaches. The proposed enhancements improve the quality of the solution in terms of latency and cost as well as reduce the execution complexity significantly. We also determine the optimal number of clouds, which need to be deployed so that the total links delays, as well as the service migration delays, are minimized, while the total cloud deployment cost is within the acceptable limits.**

***Index Terms*—Cloud Radio Access Network; Network Function Virtualization; Software Defined Networking; Virtual Network Function Placement.**

I. INTRODUCTION

Recently, because of the explosion in the number of mobile devices, demand for new online services and consequently the data traffic has grown rapidly. With the proliferation of mobile technology, there has been a burst in the traffic originating from IoT devices, video on demand (VoD), online gaming, healthcare, and many other applications. Millions of new sensing devices and online services exchanging data have significantly contributed to this trend. It is expected that the volume of mobile data will be 1000X higher than today, and the number of connected devices will be between 10X to 100X by 2020 [3]. According to Wireless World Research Forum (WWRF), the number of connected wireless devices is expected to be 100 billion by 2025 [2]. The unprecedented growth in online services, mobile devices, as well as the data has exerted tremendous pressure on the cellular network operators to provide the connectivity to their end-users while maintaining the quality of service (QoS).

To accommodate this growth, network operators have to deploy more and more base stations to offload traffic from congested cells. Increasing the number of base stations to meet the growing user demand increases the capital expenditure (CAPEX) and operational expenditure (OPEX) for cellular network operators. More specifically, CAPEX increases as base stations are the most expensive components of a wireless network infrastructure, while OPEX increases as cell sites demand a considerable amount of power and resources to operate. However, revenues for the operators are still flat [1]. The aforementioned problem will be aggravated by the introduction of 5G networks. 5G networks will incorporate different types of heterogeneous traffic and 5G operators will be confronted with the major challenge to support a number of diverse vertical industry applications in order to expand the wireless market. Table 1 provides a summary of typical examples of such services, which illustrate the wide diversity of their associated requirements.

TABLE 1. NETWORK SERVICES AND DEMANDS

Case	Application	Requirements
Broadband access in dense areas	Events, games, etc.	High traffic volume, ms latency
Mobile users	Trains, vehicles, drones	Connectivity at high speed
Massive IoT	Sensors, smart devices, wearables	Low power, around 1 million connections per km^2
Time sensitive	Health, smart grid, etc.	Redundancy, ms latency

A novel mobile network architecture that minimizes the operational cost for network operators while accommodating such increasing heterogeneous user demands and satisfying the QoS has become a necessity. Cellular operators have started to experiment with novel networking paradigms, new ways to leverage existing equipment in new deployments, and more flexible resource planning and network managing tools. Cloud radio access network (CRAN) is a novel mobile network architecture, which has the potential to meet the above-mentioned challenges. It is based on a concept proposed by Lin et al. [8], which allows cellular network operators to share the