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Design, Development and Evaluation of an Intelligent End to End Network Slicing System for Digital Health Applications in 5G and Beyond 5G Networks.

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Introduction

5G will be integrated into everyday life to support a wide range of digital applications and use cases. The traditional one-size-fits-all network architecture is slowly becoming inefficient. The Third Generation Partnership Project (3GPP) has proposed network slicing in 5G as a solution. Network slicing technology assigns logical and virtual network resources to specific services over a shared physical infrastructure. 3GPP has proposed 4 Generic network slice categories enhanced Mobile Broadband (eMBB) and Ultra-Reliable Low-Latency Communication (URLLC) , Massive Internet of Things (MIoT) and Vehicle to Anything (V2X).

The Problem

The generic network slice types by 3GPP are inflexible, cannot meet overlapping and competing demands of various applications and services within networks. Therefore, specialized and custom network slices are needed. However, most existing research neglects the design and planning phases of custom network slice instances, resulting in network slice deployments that fail to meet the quality of service (QoS) and service level agreement (SLA) requirements of specific industry verticals. We see a solution to this owing to the huge amount of data generated by digital applications on the 5G network. In the context of this research, this data will be generated by digital health applications like a Virtual Clinic, Tele-audiology, Tele-haptics, Latent TB Image Transfer App, m-Health App for HIV Management, Adrenaline Auto-Injector App. All these apps are being developed at the University of Cape Town and are in the advanced stages of testing and validation.

Hypothesis

By using unsupervised machine learning techniques to analyse networking data and network flow statistics, it is possible to create custom network slice templates. These templates can then be interpreted and implemented to create personalized network slices instances for specific industries, such as healthcare, that have digital health applications and use cases as slice tenants.

Research Motivation

Network slicing has been successfully implemented in verticals like V2X and IoT services but its implementation in the healthcare vertical is yet to be realized. One of the reasons for this gap could be the lack of real-world test beds to validate such advancements in the healthcare sector. Additionally, there are technical challenges associated with developing and deploying end-to-end network slices tailored to support specific vertical industries that need to be addressed.

Research Aim

To develop an end-to-end 5G network slicing framework that utilizes networking data generated by digital health applications to create custom 5G network slice templates. The framework will follow a 5-step pipeline, incorporating Machine Learning (ML) algorithms to enhance the learning process. The custom network slice templates will be used to implement customized end-to-end network slice instances in the healthcare vertical.

Research Objectives

1. Implement an end-to-end 5G test network and identify network flow data collection tools for collecting networking data and statistics from selected digital health applications.
2. Identify, implement, evaluate, and benchmark data preprocessing, dimensionality reduction, and unsupervised clustering machine learning techniques on the digital health applications network flow dataset.
3. Identify and implement supervised machine learning techniques for classifying test data into the clusters developed in objective 2 and use feature selection techniques to identify attributes that can be used to create custom network slice templates.
4. Design, implement, and evaluate end-to-end resource orchestration, management, and enforcement framework that uses the custom network slice templates to orchestrate the end-to-end network slice instances from the RAN, TN, and CN of a 5G network.

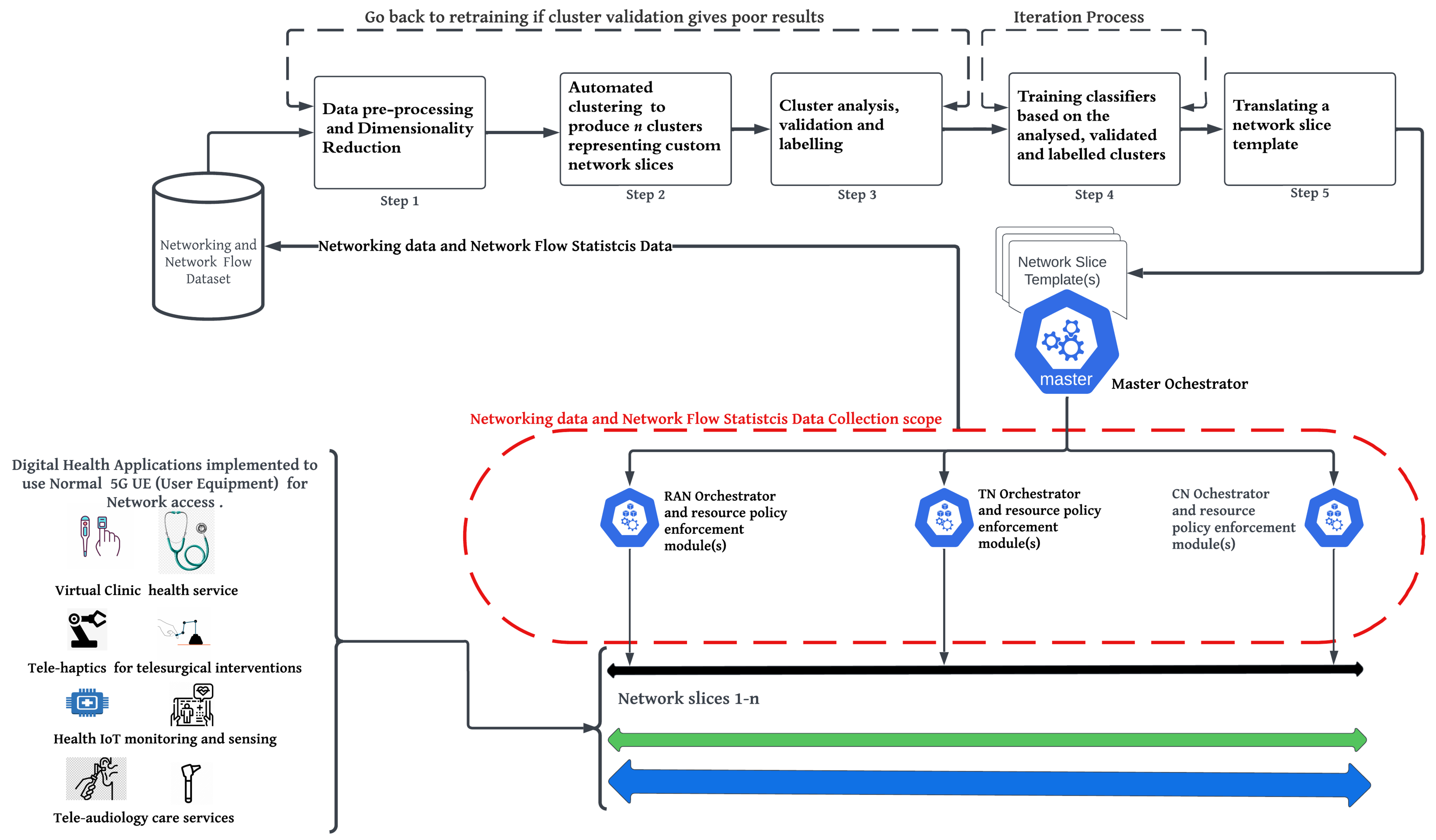

Figure 1: Proposed Solution Architecture.

Insights on The Methodology

1. Categorical features in the network flow dataset like Source.IP, Destination.IP, QoS Flow IDs, and Digital Health App Tag will be encoded using one-hot encoding.
2. The dataset will be non-linear with highly dimensional features and identifiers collected from the RAN, TN and CN domains of the network. Thus, we will benchamark Kernel PCA and Isometric Mapping (Isomap) to reduce the dimension of the dataset.
3. Since the number of clusters is unknown and the datasets is likely be noisy we will benchmark DBSCAN and hierarchical clustering algorithms. The clusters produced will represent distinct and custom network slice categories. With no ground truth to evaluate the quality of the produced clusters, we suggest using internal validation metrics such as the Calinski-Harabasz index, Variance Ratio Criterion, Davies-Bouldin index, and Silhouette Coefficient to evaluate the quality of the clusters.
4. Then, we propose to train classifiers in conjunction with wrapper feature selection algorithms on the labelled clusters produced in 4 to identify most important network flow features that can be translated to network slice template attributes.
5. The resultant network slice templates will be orchestrated by controllers in the different network domains to create network slice instances for the different digital health apps which will be the slice tenants.

Acknowledgements

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