A Data Analysis Methodology for Obtaining Network Slices Towards 5G Cellular Networks

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***Abstract*—Mobile Network Operators (MNOs) are investigating new business opportunities and planning to launch new revenue generating services in the context of 5G deployments. In order to achieve this, MNOs are willing to open up new services and applications to end users as well as vertical industries such as automotive, health, entertainment in order to obtain new revenues. Thanks to recent advances in virtualization technologies, network slicing is one promising approach that can be utilized by MNOs for generating new services and applications that are tailored to demands of end users and vertical industries. Although there have been many works on network slicing applied to mobile network infrastructure, data analytic approach using real world network dataset that investigates how many network slices are needed for each MNOs is still missing. In this paper, we propose a methodology to extract the number of network slices specific to each MNOs via applying clustering on Key Parameter Indicators (KPIs) of major telecommunication operators. Our large scale data analysis results indicate that the number of network slices may differ depending on network quality of MNOs. For some MNOs up to five different network slices can be obtained which correspond to launching different services and applications on each selected network slice.**

***Index Terms*—clustering, mobile operator, KPI, 5G, network slicing.**

I. Introduction

Telecommunication providers are already generating vast amounts of data. In order to gain insights into user experience or the network quality, this data needs to be collected in data lakes and analyzed for proper operation. At the same time, next generation applications & services are expected to be flexible, automated and agile thanks to new infrastructure with network slicing concept utilizing network virtualization technologies with Software Defined Networking (SDN) and Network Function Virtualization (NFV) in 5G. Fast service instantiating infrastructure will enable Mobile Network Operators (MNOs) to offer customized services and deploy new services such as Massive Machine Type Communications (mMTC) in order to boost revenues. Therefore, network slicing and gaining insights via data analytics is slowly shaping the future of telecommunication.

5G era is starting to revise the business models as well as network architecture of future communication of MNOs. 5G is expected to impact every sector such as automotive, e-health, media & entertainment, energy and factories of future [1]. At the same time, for real deployments, MNOs are looking for the most optimized path towards 5G. It is a well know fact that each MNO's strategy will be different based on their policies, key triggers, drivers and use cases. Most of the time, MNOs have different target architectures and deployment plans in future. For example, some MNOs may want to leverage their fixed line incumbency and infrastructure while others may rely on their previous Long Term Evolution (LTE) investments or already deployed small cell or Internet of Things (IoT) network infrastructures. On the other hand, in order to increase revenue, MNOs also want to have early time-to-market advantage for embracing incremental revenue with new business models, creating new value opportunities and utilizing the cost per bit advantage of 5G systems. Therefore, it is important to know a priory how to drive business as well as network strategy towards implementation of 5G.

End-to-end (e2e) network quality becomes important when MNOs open up new services and applications for their subscribers in 5G networks. Network quality of a MNO depends on radio, transport and core network performances. In order to accommodate some of the networking requirements of certain applications, e.g. Ultra reliability and low latency communication (URLLC) mission critical services, each MNO should have the required network upgrades and capacity for enabling connectivity of service equipments (UEs). Considering the fact that there exists wide range of applications/services that can cover different use cases, it is necessary to know how to extend the network slicing concept and address how many slices need be initiated. However, there exists a gap in identifying the required number of network slices to be launched for increasing e2e network quality of MNOs. In the literature, there have been numerous works on network slicing in the context of mobile networks [2]–[4]. Similarly, utilizing data analytics together with network key performance indicator (KPI) performances have also been studied in previous works such as [5], [6]. However, combining real network data and analytical techniques with benefits of network slicing concept for mobile networks is still an open research area.

A. Our Contributions

Although there have been different works that concentrate on concept of network slicing for MNOs and emphasizing the importance of network slicing for MNOs in general, no prior efforts have concentrated on comprehensive data analysis over KPI of major MNOs using long duration and nationwide real data measurement in order to determine an appropriate number of network slices. Different than previous works, in this work we perform data analysis using Machine Learning

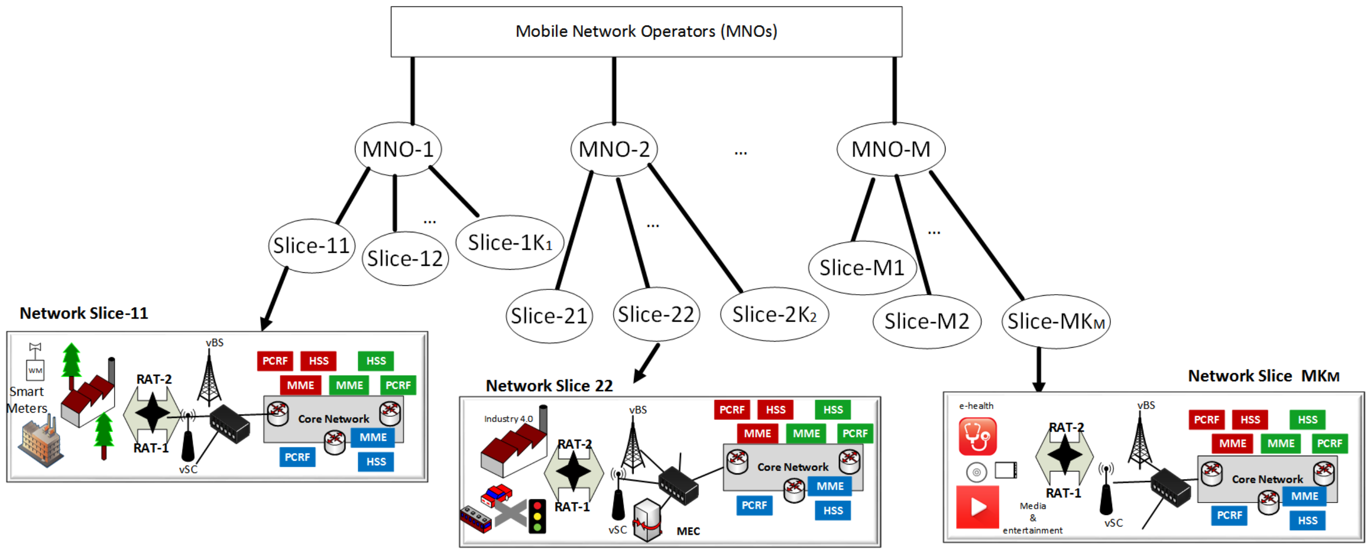

Fig. 1: Network slicing for multiple MNOs having different services and applications.

(ML) algorithms over the KPIs collected from UEs that yield the end-to-end network performance of three MNOs collected over 18 months period. Our analysis is utilized to gain insights into obtaining appropriate number of network slices that can accommodate various application and services for different MNOs . Our contributions in this paper can be summarized as follows: (i) We utilize end-to-end network performance of three MNOs in Turkey using location area code (LAC) based geographical and temporal properties of real data set of 4G cellular networks. (ii) We utilize a clustering method for obtaining insights into potential number of network slices that can be launched for each MNOs. (iii) We find out that depending on the KPI performances of each MNOs, the number of network slices of each MNO can significantly differ where some MNO KPI performances allow higher number of network slices, while others may have low number of network slices due to each MNOs subscribers' data utilization and network infrastructure characteristics.

II. System Model and Architecture

In this section, we investigate the network slicing architecture, system concepts and some of the prominent 5G use cases.

A. Network Slicing: Concept and Architecture

In present mobile infrastructures, MNOs are configuring Access Point Names (APNs) in order to allocate network resources for each service that they provide. However, this is both inefficient and time demanding operation where each device's configuration should be performed across many network elements. This solution is also not providing fine-grained network resource control. This problem puts limitations on proper network operation which greatly reduces the net income of MNOs as network utilization increases. A feasible approach in terms of increasing network flexibility is to make it easy for MNOs to build network slices across whole network. In order to meet the specific demand of a service, MNOs need the control and flexibility of assigning network resources to each service or application. This can ensure MNOs to deliver high quality-of-experience (QoE) with differentiated services for their UEs. By exploiting the recent advances in virtualization technologies such as NFV and SDN, resources can be isolated into programmable sets of slices in order to enable certain network functions and services.

Fig. 1 shows an architectural diagram of the network slicing concept applied for multiple MNOs. Each MNO is assumed to have different number of slices where each slice may serve to different applications and services of MNO. For example, connected vehicles service which can be launched by a MNO can utilize one or multiple slices underneath. Formally, we assume that in our system there are M MNOs and each MNO has K_m total number of network slices. We denote the MNO set $\mathcal{M} = \{1, 2, \ldots, M\}$ and network slice set $\mathcal{K}_m = \{1, 2, \ldots, K_m\}$. Each MNO is assumed to have S_m LACs with LAC set $\mathcal{S}_m = \{1, 2, \ldots, S_m\}$. Note that inside each LAC-s $\in \mathcal{S}_m$, there are many Base Stations (BSs) of MNO-m $\in \mathcal{M}$. Our focus in this paper is on investigating the performance KPIs of MNOs operating nationwide in different regions or cities to extract the potential number of network slice that each MNO can provide. Focusing on LAC-based KPI measurements, we identify the impact of KPI on number of network slices for each MNOs' performance.

B. 5G Application Use Cases

5G offers different capabilities to distinct use cases. The most important three main categories of 5G are based on differentiation on latency, throughput and reliability. 5G Infrastructure Public Private Partnership (5G-PPP) has identified three main use cases for 5G network slices [7]: (i) URLLC, (ii) enhanced Mobile Broadband (eMBB), (iii) mMTC.

(i) **URLLC applications:** URLLC is one generic mode of Machine Type Communications (MTC) where it can be used for mission-critical applications and is driven by requirements of fast and reliable interactions. Some examples are reliable remote robotic actions, real time remote surgery or coordination among vehicles, factory automation, smart grids, reliable emergency systems, self-driving. Some of the requirements are: less than 10 Mbps average throughput, 99.999% reliability, 1-10 ms latency, subscriber densities up to 1,000 devices per square km and mobility support (up to 200 kmph).

(ii) **eMBB applications:** This slice type is expected to provide high data rate and high traffic densities (capacity) and is driven by video and Virtual Reality (VR) requirements. Typical applications are in high resolution video streaming, real time work in cloud environment, Augmented Reality (AR)/VR immersive games, 3D holographic presence. Some of the requirements are: less than 1-10 Gbps peak throughput and 50-100 Mbps average throughput, 50-100 ms latency, subscriber densities up to 150,000 devices per square km and mobility support (up to 120 kmph).

(iii) **mMTC applications:** mMTC investigates challenges for ubiquitous coverage, massive connection support for delay-tolerant traffic and is driven by ability to scale and ensure efficient signalling traffic control. Some of the requirements are: less than 1 Mbps average throughput, 50-100 ms latency, subscriber densities up to 1 million devices per square km and mobility on demand and 10 years of battery lifetime.

III. Clustering Algorithm for Network Slicing

In this section, we perform clustering on existing 4G cellular network data in order to extract insights into potential number of slice that each MNO can offer to their subscribers on the path towards 5G.

A. *Silhouette Method based K-means Clustering*

In order to obtain the number of clusters from the data, we utilize silhouette method of [8]. The method of silhouette works as follows: First, for each point l representing latency and Download (DL) speed in x and y axis of a MNO respectively, we find the average distance between l and all other points inside the cluster, which is a measure of cohesion, denoted by A. Second, we find the average distance between point l and all other points in the nearest cluster, which is a measure of separation, denoted by B. Then, the silhouette coefficient ρ_l for l is calculated as,

$$\rho_l = \frac{A - B}{max(A, B)} \tag{1}$$

Then, the cluster coefficient of each point ρ_l is calculated and averaged in order to obtain "overall" cluster coefficient ρ.

B. *Proposed Methodology to Obtain Network Slices*

The details of the utilized K-means clustering with silhouette method customized for the utilized dataset is given in Algorithm 1. We assume that we obtain K_m number of clusters after silhouette method based K-means clustering for a given MNO-m. As input to Algorithm 1, we provide nationwide latency and DL speed values of each measurements performed by MNOs' UEs. The output is K_m together with LAC-s $\in \mathcal{S}_k$ and its corresponding cluster index for all MNOs. In Algorithm 1, $\mathbf{P}_m$ denotes the MNO-m'th matrix with rows representing LAC-s $\in S_m$ and columns representing average latency and DL speeds. $\mathbf{P}$ represents the matrix formed by concatenating $\mathbf{P}_m$, $\forall m \in \mathcal{M}$ in rows.

Algorithm 1 Utilized K-means clustering with silhouette method

procedure K-MEANS(Latency, DL Speed)
    for each MNO-m $\in \mathcal{M}$ **do**
        for each LAC-s $\in \mathcal{S}_m$ **do**
            Group latency, DL speeds based on LAC-s
            Calculate mean of latency and DL speed
            Construct matrix $\mathbf{P}_m$.
        end for
    end for
    Construct matrix $\mathbf{P}$ and normalize.
    for each MNO-m $\in \mathcal{M}$ **do**
        Run K-means with silhouette on $\mathbf{P}_m$ of $\mathbf{P}$
        Return K_m with highest score
        Return all *LAC*-s $\in S_m$ and its cluster index;
    end for
end procedure

IV. Performance Evaluations

For evaluation results, anonymous data is collected offline on daily basis and transferred into the database for a period of 18 months ranging from January 2016 to June 2017 of MNOs operating nationwide in Turkey. The statistical distributions of the observed test data are given in Table I for all MNOs which yield a relatively large sample size for fair evaluations. Moreover, Table II shows the Coefficient of Variation (CoV) (= stdv/mean) value comparisons of some KPIs, i.e. DL, Upload (UL) and latency nationwide. The total number of LACs is 689, 770 and 556 for MNO-1, MNO-2 and MNO-3 respectively. In our analysis, we utilize latency and DL speed KPIs from our data set for performing our data analysis. As a matter of fact, combining latency and DL speed can release important new set of applications and use cases that can provide new and unseen opportunities for MNOs. These can include low latency and low throughput applications such as system control, low latency and high throughput applications such as AR/VR, high latency and low throughput applications such as IoT and sensor devices and high latency and high throughput applications such as video.

In Fig. 2, we plot the silhouette analysis for K-means clustering on MNO-1 data where $K_1 = 5$ is selected as cluster number yielding largest silhouette coefficient score of $\rho = 0.4861$. We can select $K_1 = 5$ as the number of network slices that MNO-1 can offer based on the existing data analysis of LTE networks. We run K-means algorithm using average

TABLE I: Nationwide 4G Test Speed Data Statistics.

# of measurements	462,638	# of cities	81
# of districts	940	DL (average, Mbps)	42.766
# of neighborhoods	13,163	UL (average, Mbps)	16.891
# of MNOs	3	Latency (average, msec)	31.606
Obser. Duration	18 months	Total # of test UEs	117,059

TABLE II: Comparisons of CoV values of observed KPIs for 4G nationwide.

CoV	**MNO-1**	**MNO-2**	**MNO-3**
DL speed (Mbps)	0.8610	1.2078	0.7609
UL speed (Mbps)	0.7578	0.6566	0.8363
Latency (ms)	0.9802	1.0376	1.0938

DL speed data and latency values over LACs of MNO-1 as input. Fig. 3 shows the distribution of DL speed and latency distributions on x and y-axis respectively. Fig. 3 also marks the corresponding cluster IDs of all LACs. As can be observed from this figure, MNO-1 has wide range of latency and DL speed values which corresponds to different number of clusters (i.e. network slices) in the network. One key observation is that average latency and DL speed performance vary significantly nationwide based on the KPIs on each LAC and MNO-1 can offer variety of services to its subscribers. As a starting point for deploying next generation 5G cellular networks, based on the existing data analysis, it's obvious that MNO-1 can start to offer five different slices with corresponding latency and DL speed values serving various applications and services across nation. For example, according to Fig. 3, MNO-1's existing infrastructure is suitable to provide five different network slices with 1-) medium throughput-low latency, 2-) low throughput-low latency, 3- high throughput-low latency, 4-) low throughput- high latency and 5) low throughput-medium latency demanding applications and services.

In Fig. 4, we demonstrate the MNO-2's average silhouette score distribution over different number of clusters. Based on these values, for MNO-2, $K_2 = 2$ is selected to be the highest scoring cluster number with of $\rho = 0.6788$. Similarly, Fig. 5 shows the latency and DL speed distribution among the selected two clusters. Based on these results, MNO-2's slices are divided based on the latency distributions. Therefore, it can provide both high and low latency services to its subscribers.

Finally, Fig. 6 shows the average score distribution based on number of clusters where $K_3 = 3$ is selected to be highest scoring number of clusters of $\rho = 0.4325$. Fig. 7 plots the corresponding latency and DL speed distribution among the selected $K_3 = 3$ clusters. Based on the data analysis results of Fig. 7, MNO-3 can provide three network slices with 1-) low throughput -low latency, 2-) high throughput-low latency and 3-) high latency-low throughput demanding applications and services.

V. Conclusions

In this paper, we have performed a data analysis over a large sample of collected data indicating the KPI performance of major MNOs in Turkey. Our evaluation results are utilized to answer a key observation of how many number of network slices are needed for a specific MNO based on its network traffic characteristics and end-to-end network performance. Our evaluation results indicate that based on the existing 4G

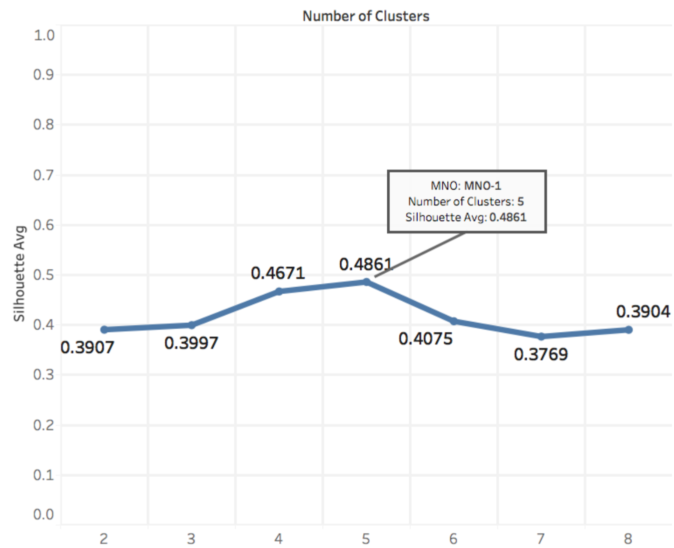

Fig. 2: Determining the number of clusters using silhouette analysis for K-means clustering on MNO-1 data.

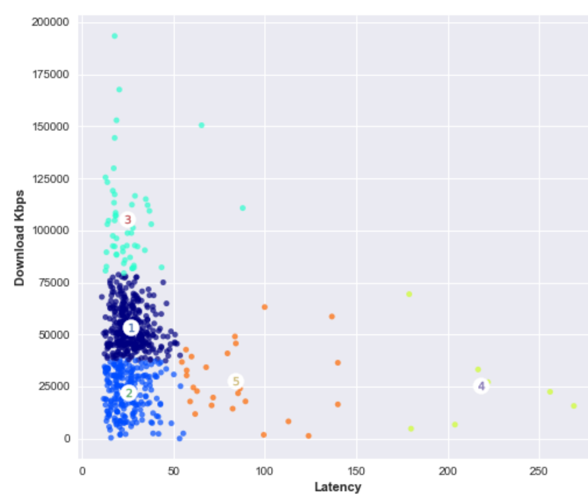

Fig. 3: K-means clustering on MNO-1 data where $K_1 = 5$.

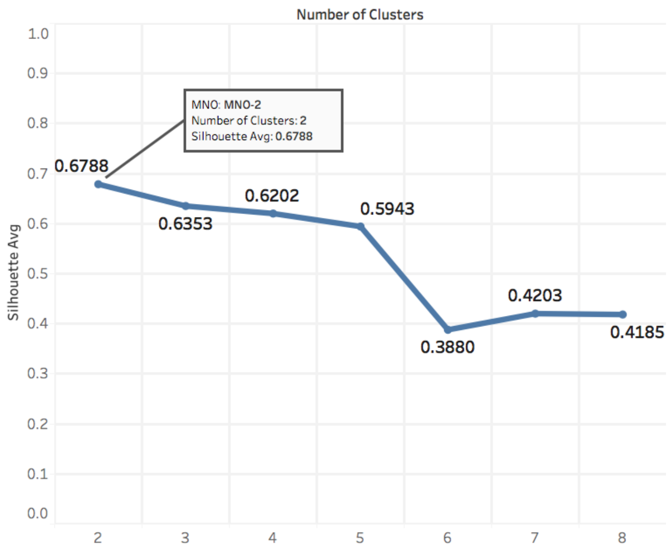

Fig. 4: Determining the number of clusters using silhouette analysis for K-means clustering on MNO-2 data.

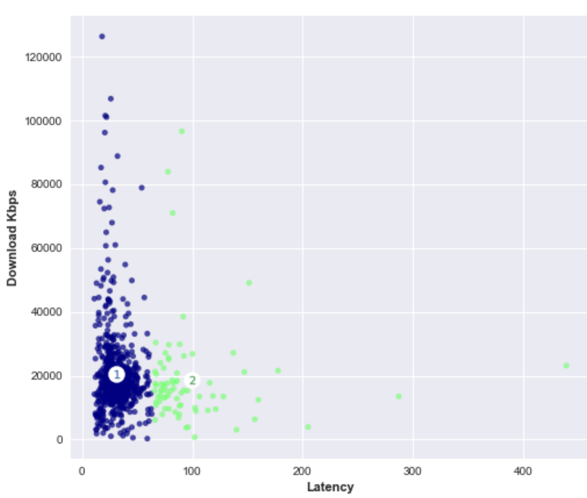

Fig. 5: K-means clustering on MNO-2 data where $K_2 = 2$.

KPI data, each MNOs need to launch different number of network slices nationwide in order to accommodate various services for their subscribers.

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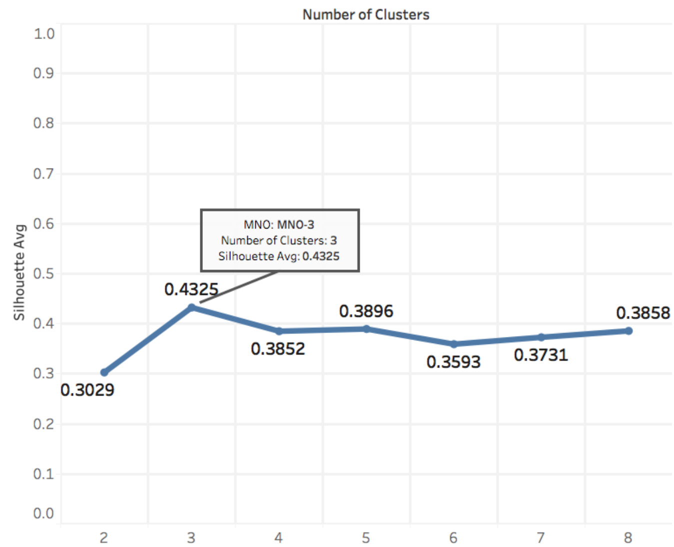

Fig. 6: Determining the number of clusters using silhouette analysis for K-means clustering on MNO-3 data.

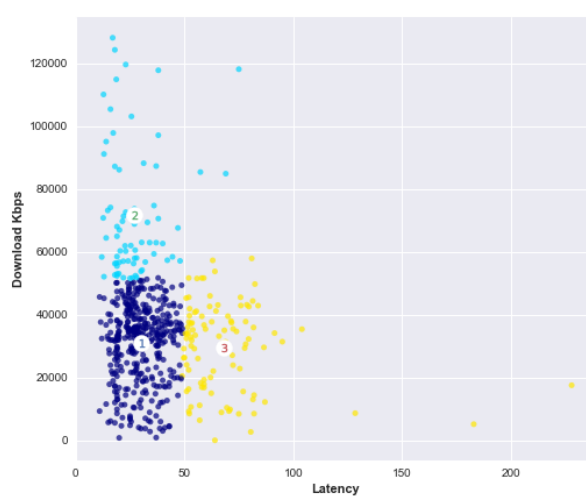

Fig. 7: K-means clustering on MNO-3 data where $K_3 = 3$.

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