Applying RouteNet and LSTM to Achieve Network Automation: An Intent-based Networking Approach

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***Abstract*— The expansion of infrastructure and services in the 5th generation networks resulted in complex configuration management throughout the network lifecycle. To this end, network automation replaces existing traditional manual administrative approaches with software-driven repetitive and reliable applications. Since network expansion is in multiple dimensions, including multi-services, domains, and platforms, it is challenging to resolve such a vast infrastructure through a single automation solution. Hence this paper proposed applying an intent-based solution for achieving automatic orchestration for vastly spreading network services. Intent-based solution not only considers network automation but also performs service assurance throughout the network service lifecycle. The proposed IBN (Intent-Based Networking) solution implements a closed-loop network lifecycle management using a single abstracted software platform. It translates high-level requirements to the infrastructure irrespective of the various underlying platforms and domains, and it includes intelligence-driven monitoring and updates for service assurance. A multi-model machine learning approach is proposed in this work to control the network infrastructure reliably. To this end LSTM (Long Short-Term Memory) algorithm is applied for compute-resource prediction and the Route-Net model for optimized service path routing. The infrastructure includes FlexRAN deployed as the access network controller, OSM (OpenSource MANO) resides at the core, and the KOREN network serves as a high-speed transport network.**

Keywords—IBN, 5G, OSM, KOREN, ML, SDN and Route-Net

I. Introduction

The demands of new services introduced advancements to cater to the requirements. 5th generation of the network is not only about enhancement in terms of bandwidth latency and throughput, but it also includes the provisioning of many new services while considering optimization, efficiency, and advanced features. A variety of new platforms have been developed over the past few years, requiring a specific type of configuration. The standards of 5G recommended distinctive architecture for the development of infrastructures. However, industries and opensource platforms follow many different approaches to implement standards resulting in a complex situation for intercommunication. Similarly, network service orchestration involves multiple domains, and the selection of the control platform depends on the type of service and operator choice. The shift towards SDN (Software Defined Networking) and NFV (Network Function Virtualization) achieved freedom from vendor-specific hardware [1]. However, they resulted in multi-vendor software, requiring specific experts to configure and control the network manually [2].

End-to-End network service orchestration on one side incorporates multiple domains and requires orchestration through numerous layers on various platforms. Infrastructure developers usually follow a disaggregated approach towards the achievement of service provisioning resulting in multi-vendor deployments. Hence requiring vendor or platform-specific experts to control, configure and manage the infrastructure. Many vendor-specific access network platforms are available for operators, including FlexRan, cloudRAN, ORAN, xRAN, etc., requiring distinct experts for configurations. Similarly, various core network orchestrators are available as options for infrastructure managers to orchestrate VNFs, including OSM (OpenSource MANO), OMEC (Open Mobile Evolve Core), ONAP (Open Network Automation Platform) etc. Similarly, multiple cloud controllers and SDN controllers are available for compute resource and networking control. The only requirement is to automate the orchestration across different network domains and while handling various vendor-specific platforms [13-15].

Network automation is proposed as a solution to handle complex network configurations automatically using software applications. It includes planning, development, and optimization of network services. In the current developments, the network automation applications focus on a single problem or handle a single domain. However, a single multi-purpose solution can serve as a solution to more significant issues. Recently, ETSI (European Telecommunications Standards Institute) proposed ZSM (Zero Touch Network and Service Management) for achieving autonomic networks [6]. Similarly, IETF (Internet Engineering Task Force) focused on IBN platforms to achieve network automation [5]. To this end, they considered a closed-loop platform that can translate user requirements into implementable policies and then applies configuration to physical devices. In addition, it includes continuous monitoring and assurance of service at runtime. However, existing solutions either considered domain-specific implementation or have not evolved to achieve the multi-domain and multi-purpose generic solution [1-3].

The ML-driven solutions are fundamental to achieve automation in every walk of technology. The diverse and dynamic requirements in networks demand the incorporation of multiple ML models to achieve network automation. Every network domain has its specific problems and requires a specific intelligent solution to achieve optimization and reliable solutions. ML applications in networks are envisioned in multiple dimensions, including resource prediction and scaling, anomaly detection and mitigation, proactive policy creation and assistance, policy assurance and update, and requirements translation and machine reasoning. Existing works have focused on developing ML-based applications to resolve a singular direction. However, this work considers a multi-model approach to handle network orchestration [4].

This work proposes a generic IBN-based platform for the orchestration of network services autonomously. It is reinforced by multiple machine learning models for optimization, assurance, and reliable service provisioning across different domains [5]. The proposed system includes an IBN platform for orchestrating configurations across multiple domains. Further, it involves central monitoring and analytics system to process and analyze network statistics continuously. Finally, it incorporates machine learning to update, manage, and control network policies based on network statistics. This work utilizes LSTM to handle core network VNF, computes scaling, and uses Route-Net to handle transport network routing.

The manuscript is organized as follows: Section II explains system architecture and working. Section III briefs about configuration test-bed. Section IV illustrates the results. Finally, Section V concludes the paper.

II. SYSTEM ARCHITECHTURE AND WORKING

IBN systems achieve network automation by implementing a closed-loop service lifecycle. It implements an IBN application an abstraction layer on top of multi-X (domain, vendors, and operators) platforms. IBN replaces the legacy manual configuration control with an automated software application to control the underlying distributed infrastructure. It enables the administrators to control and analyze the network using a high-level GUI-based (Graphical User Interface) service orchestration portal. The IBN application translates the service requirements into policies and then generates applicable configurations. The conversion of high-level requirements to policies is done by using a catalog repository. The catalog repository serves as a central database containing blueprints of the overall network. It firstly generates the E2E context-aware service design, and then it generates domain-specific policies. The policies are then translated to each domain as configurations for underlying platforms [6] [11].

In addition to the orchestration of configurations, the IBN system continuously monitors each domain using its monitoring and analytics system. The monitoring system preprocesses the data of each underlying domain and invokes ML and Update mechanism. The lifecycle of intent continuously perceives the system behavior and performs updates to optimize and ensure service availability. The updates engine consists of multiple ML approaches that specifically serve to resolve each domain-specific problem. The components of IBN are detailed as follows.

A. Intent Translation Mechanism

It receives high-level service requirements, and is based on 3GPP network slicing specifications, accepts three types of service requests, including GBR (Guaranteed Bandwidth Rate), non-GBR, and IoT (Internet of Things). The translation mechanism consists of an E2E-Context aware service designing module that, upon receiving intents, registers it to the catalog repository, which in return process the required information and help to create E2E slice templates. It also contains domain-specific policy and configuration generators, including RAN, Core, and Transport network translators.

RAN translators process the RAN slice policies while considering the required bandwidth and E2E context and instantiates multiple slices with required resources. All the configurations are provided to the FlexRAN controller in the form of JSON configuration using the REST interface. Core network translator handles core network slicing templates, including NST (Network Slice Templates), VNFD (virtual Network Function Definition), and NSD (Network Service descriptors). The generated configurations are applied to the OSM orchestrator to configure core network slices, as shown in figure 1. The service configuration from IBN is distributed to the respective domain and location [12].

We have used KOREN as a backhaul Transport network that interconnects multiple edges and service-providing core networks [16]. In this work, we have handled interconnection between multiple computing edges, each containing a compute server, and deployed EPC using OpenSource MANO. Transport Network translation module evokes RoutNet to find the best path between source and destination edges. In addition, it provides a VLAN-based QoS ensured Route between edges and edge and clouds [7].

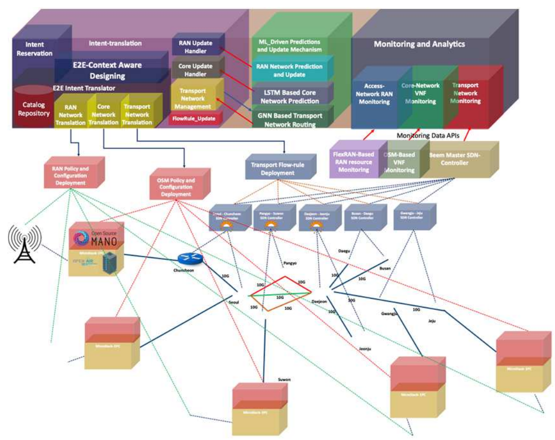

Fig. 1. Overall IBN-Based cloosed loop infrastructure for E2E multi-X (Platforms, Domains and Operators) Orchestration using RouteNet and LSTM.

B. Intent Monitoring and Analytics

There are three analytics modules that collect monitoring information from each of the RAN, Core, and Transport, respectively. The distributed RANs data gets collected from FlexRAN controller and stored and analyzed in the monitoring and analytics module. Similarly, OSM-based VNF monitoring information is exported to Prometheus and visualized using Grafana [12-16]. The transport network is monitored through Restful APIs of the BEEM SDN controller and is stored and visualized, as shown in the Figure 1.

Figure 2 shows that the data of each link is collected through BEEM controller and secondly the data of the compute server at the edges is also collected illustrated as dashed blue lines [15].

In addition, through continuous monitoring, the data is analyzed to check for anomalous behavior, and based on dynamic thresholding, it triggers the ML models to foresee required updates. Hence resulting in closed-loop control of E2E distributed multi-X network infrastructure.

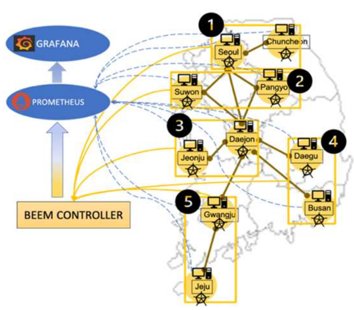

Fig. 2. Monitoring system arcitecture on top KOREN. Ilusstrating the monitoring of edge nodes and KOREN links.

C. *Multi-X network optimization through multiple ML approaches.*

There are multiple problems that are required to address while achieving the automation with service assurance. Hence we have implemented domain-specific DL (Deep Learning Models) to achieve full automation in the distributed and multi-platform-based test-bed. Following two models have been used in this work:

- The first model used in this work is LSTM can also be known as the cloud VNF resource prediction model. Through this ML model, we can predict the future utilization of VNFs based on the current monitored status, and then the IBN system decides whether it requires resource scaling to achieve the service assurance or not. We have used the GWAT-13 Materna dataset for training the model [9]. The dataset consists of matrices collected from three different cloud traces of the German cloud provider, and its parameters include the timestamp, CPU utilization, Memory utilization, and storage utilization.
- The dataset was split into 70-30 training and testing. After that, the LSTM model is trained over 438 epochs, and the MAE (Mean Absolute Error) value 0.1213. The test and train accuracy map is illustrated in Figure 3.

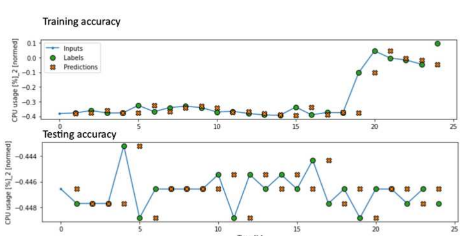

Fig. 3. Illustrates the difference between predicted and actual labels and shows that the training accuracy is higher than testing but the LSTM model is doing good prediction with only few outliers.

- In addition to the LSTM based compute resource scaling in our work, we have applied a RouteNet-driven routing technique to ensure the best services across different edges. The enormous amount of traffic is predicted to be streamed over the next-generation network. The higher bandwidth requires better links to support the flow of traffic with assuring the QoS for the service. To this end, we have implemented RouteNet, a GNN (Graph Neural Network) approach to predict the future link utilization on the KOREN topology. The RouteNet takes topology and routing data as input, and it invokes MSMP (multistage messages passing) on the topology to train GNN on that specific topology [8]. The dataset was collected and preprocessed through the monitoring and analytics module. There are 22 links in the topology, and the dataset of three months period was used to train the RouteNet Model. The network parameter considered includes timestamp, packet transmitted/received and bandwidth. The preprocessing of data is performed to map the links data to path data, and we have used three routing schemes in our approach. From every source to the destination, our model predicts the three best path options with their predicted link utilizations.
- Figure 4 shows the architecture of RouteNet, which takes time series topology data as input and performs MSMP on it. MSMP has three stages. At the first stage, it calculates the relation among links to path relations, and in the second stage, it computes the relation among path to links. As every link utilization is dependent on how many paths traffic is passing through it, and every path utilization is dependent on the link utilization of intermediate links in that path. The final stage is the readout stage which is fully connected NN (Neural Network), which provides the predicted link utilization of all the paths in the topology per applied routing schemes as output.

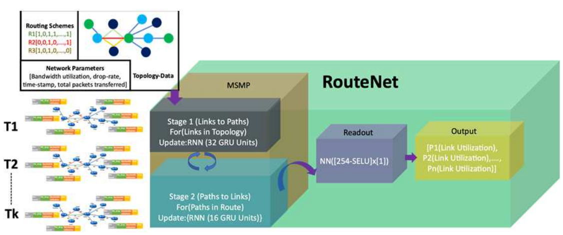

Fig. 4. Illustrates the architecture of RouteNet model that takes Links to Paths data and Routing schemes as input and provides prediction of link utilization of all the paths. In addition it consists of 32 units of GRU activations for both stages of MSMP and fully connected Selu activation for Readout model.

- The training of over 1.6 million iterations resulted in a 0.025 RMSE loss value, as shown in Fig 5. The graph illustrates the difference between actual and predicted values dark orange and faded blue line, respectively, where the dark Blue line shows the RMSE value. It can be observed that over time model accuracy was decreased and reached almost 0.025.

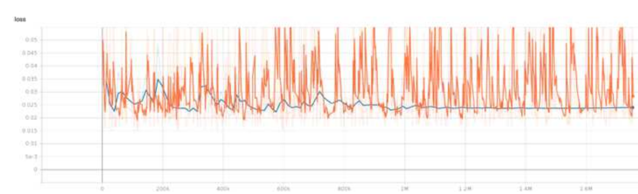

Fig. 5. Illustrates the results of RMSE of training of RouteNet.

D. *Intent Update Mechanism*

There are two update mechanisms firstly, the Routing path update mechanism and secondly, the core network EPC (Evolved Packet Core) VNFs scaling [9-12].

- The RouteNet-driven update mechanism is first invoked when orchestrating the E2E slice in between different edges initially. Whenever RouteNet is invoked, it calculates the best paths using the paths link utilization predictions, and it selects the best from the list of paths. The path update mechanism is invoked periodically based on dynamic thresholding. The thresholds are set in between 70 to 90 percent for links whenever the predicted utilization passes the threshold value, and we update the path which has a low threshold.
- Similarly, the VNF update mechanism gets invoked periodically to scale the VNF resources whenever a certain type of VNFs get overwhelmed with traffic and their utilization crosses the threshold. Hence, reducing the chance of failures and assuring the service availability with optimization.

III. Results

Other than the results of Machine Learning models, this work achieved traffic test results across different domains. Firstly 8k video traffic tests were performed from Daejeon that is being served from Pangyo, and we have successfully achieved 25.69 MiB/s. Secondly, we achieved 4k video streaming tests by setting 4k tests between Daejeon and Suwon simultaneously. The achieved bandwidth was 3.057 MiB/s. The tests were performed using the Iperf tool, and we applied multiple VLANs between all the nodes to stream traffic. Each VLAN serves as a gateway for EPC as shown in Fig 6.

Fig. 6. *8k-video streaming test between Pangyo and Daejeon edges and 4k-video streaming test results between Daejeon and Suwon nodes.*

IV. Conclusion

The increase in complexity of next-generation networks has demanded the shift towards the fully automated network. To this end, the legacy manual, error-prone network configuration approaches were required to be replaced with software-driven automated systems. This work applied IBN based application to resolve End to End orchestration challenge through the application of multiple machine-learning models. It achieved promising results for the training of machine learning models and QoS assurance for End-to-End services. In addition, it illustrated a distributed orchestration approach through which multiple open-source platforms can be orchestrated and controlled. In the future, it is required to apply Machine Learning to the RAN domain, and in addition, we want to apply network anomaly detection approaches to achieve network security.

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