Integration of Network Slice Controller for Enhanced Intent-Based Networking in 5G/6G Networks

Alejandro Muñiz Da Costa
Luis M. Contreras Murillo
alejandro.muniz@telefonica.com
luismiguel.contrerasmurillo@telefonica.com
Telefónica I+D
Madrid, Spain

ABSTRACT

Intent-Based Networking (IBN) has emerged as a transformative paradigm in the dynamic realm of networking, revolutionizing network management by focusing on high-level intents expressed by users. This paper explores the integration of the Network Slice Controller (NSC) in an IBN context further enhances network management by enabling scalable resource requests, outsourcing resource evaluation, and modular operation of intent processing. However, challenges such as addressing the knapsack problem, obtaining sufficient network information without compromising privacy, and optimizing the process without counterproductive overloads need to be tackled. Overall, IBN holds immense potential in revolutionizing network management in the 5G/6G era, paving the way for personalized and efficient connectivity, and the Network Slice Controller can be a key feature to facilitate the integration of IBN with 5G/6G network controllers.

CCS CONCEPTS

• **Networks → Network management**.

KEYWORDS

Intent-Based Networking, Network Slice Controller, NSC, scalable resource requests, resource evaluation, modular operation, intent processing, 5G/6G era, efficient connectivity, integration, network controllers

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1 INTRODUCTION

1.1 Context and motivation

In the dynamic realm of networking, intent-based networking has emerged as a transformative paradigm, revolutionizing network management by leveraging high-level intents expressed by users. This shift in focus from low-level configuration and management tasks to the underlying intent has led to enhanced network agility, automation, and alignment with telecommunications industry objectives. In this paper, we delve into the concept of intent-based management and its importance in the context of network slicing, a key feature of next-generation networks like 5G and forthcoming 6G.

Intent-based management entails a departure from manual configuration of individual network devices to defining network behaviors based on user intents. Users articulate their desired outcomes or intents through high-level policies, abstracted from the intricacies of the underlying network infrastructure. By prioritizing desired outcomes over implementation intricacies, intent-based networks simplify network management and encourage alignment with cutting-edge paradigms such as network slicing and software-defined networks.

Network slicing, a fundamental capability of next-generation networks, enables the partitioning of a physical network into multiple logical networks, each tailored to specific requirements. These slices can be customized to provide diverse applications and user groups with distinct performance characteristics, quality of service, and isolation levels. Intent-based management plays a pivotal role in network slicing by facilitating the creation, deployment, and orchestration of network slices based on user-defined intents. This approach optimizes resource utilization and enhances the quality of user experiences.

By automating the implementation of network slicing intents, intent-based management simplifies the network slices creation process while enabling rapid deployment and dynamic adaptation of slices to changing application demands, network contexts, and technologies. Operators can monitor slice performance, enforce policies, and dynamically allocate network resources based on desired intents. This intent-based approach empowers network operators with a holistic view of the network, aligning network behavior with intended outcomes and delivering superior user experiences.

1.2 Objectives of the article

Our primary objective in this article is to propose the adoption of the Intent-Based Networking (IBN) paradigm for the management of 5G/6G networks. To accomplish this, we leverage the concept of the Network Slice Controller (NSC) as proposed in [1]. Through the utilization of the NSC architecture, our aim is to demonstrate the seamless integration of network access requests within an interoperable and modular framework. Additionally, we intend to evaluate the optimal approach for integrating this architecture either over or under the SDN north bound interface (NBI), carefully analyzing the advantages and disadvantages associated with each alternative. By addressing these objectives, we strive to contribute valuable insights and recommendations for the efficient and effective implementation of IBN in 5G/6G network management.

1.3 Structure of the article

The article provides an application proposal of Intent-Based Networking (IBN) in 5G and 6G networks. We are covering the fundamentals of IBN and its advantages over traditional network management approaches, as well as the challenges and opportunities in 5G and 6G networks for IBN application. The integration of IBN in these networks is discussed, including reference architectures, components, protocols, and design considerations. The article then explores the application of IBN in 5G and 6G networks, focusing on service orchestration, automation, and the role of the Network Slice Controller (NSC), providing our proposed scheme of integration and how it fits within the SDN controller. Evaluation and challenges of IBN implementation in these networks are examined, such as performance evaluation, technical considerations, and security and privacy issues. Finally, we are concluding by summarizing the findings, contributions, and future research opportunities in the application of IBN in 5G and 6G networks.

2 BACKGROUND

2.1 Intent-Based Networking (IBN) fundamentals

Intent-Based Networking (IBN) refers to a network management approach where operational goals and outcomes are expressed as high-level intents, without specifying the implementation details. The concept of intent originated in Autonomic Networks, where it represented abstract, user-defined policies guiding network operations. It allows users to focus on desired outcomes rather than low-level device configurations. However, IBN extends beyond autonomic networks and applies to any network environment. Intent is characterized by a declarative nature, defining operational goals and outcomes while omitting implementation details. In an ideal IBN implementation, the network itself interprets and translates intent into device-specific rules and actions, leveraging distributed algorithms and local device abstractions. However, certain centralized functions may be necessary to provide a conceptual point of interaction and global knowledge of the network. These functions can assist in translating intent into actions and achieving desired outcomes. The implementation and hosting of such functions can be distributed to avoid single points of failure.

IBN represents a network management paradigm where networks are managed based on high-level intents. It enables networks to recognize and adapt to user intent, achieving desired outcomes without requiring explicit technical instructions. This approach offers advantages such as simplified network management, abstraction from low-level details, and the ability to align network behavior with intended outcomes, distinguishing it from traditional network management approaches.

2.2 5G and 6G networks: Challenges and Opportunities

5G and 6G networks represent the next wave of wireless communication systems, promising transformative applications and connectivity enhancements. These networks offer unparalleled speed, low latency, capacity, and connectivity, driving innovation across industries. However, their deployment and operation present significant challenges alongside promising opportunities. Interoperability and integration challenges arise from the coexistence of different network technologies and architectures. Security and privacy concerns are magnified in these networks. Managing network slices, which provide customized network instances, adds further complexity. Orchestrating multiple network slices, allocating resources, and ensuring isolation and performance guarantees are challenging tasks.

Addressing the challenges and harnessing the potential of 5G and 6G networks are crucial for realizing their benefits. Intent-Based Networking serves as a valuable tool for maximizing their capabilities. It enables the direct instantiation of new services and assists in managing network slices and interacting with the network controller. Intent-Based Networking abstracts implementation details, streamlining network management.

2.3 Network Slice Controller (NSC)

The Network Slice Controller (NSC) is a proposed component designed to facilitate the request, realization, and management of IETF Network Slices. Its primary function is to serve as an intermediary between higher-level systems and Network Controllers. Through its North Bound Interface (NBI), the NSC receives customer requests and identifies the necessary resources to actualize the specified network slice. It interacts with Network Controllers via its South Bound Interface (SBI) to effectively realize the requested slice and oversee its lifecycle management. In the context of Intent-Based Networking (IBN), the NSC integrates both the customer's perspective and the provider's viewpoint to ensure alignment between requirements and operations. The NSC comprises two key modules: the IETF Network Slice Mapper, responsible for processing customer requests, and the IETF Network Slice Realizer, which determines the appropriate technologies for achieving the desired network slice. The Mapper maintains the relationships between customer requests and provisioned slices, while the Realizer generates filtered topologies using network information supplied by the Network Controllers. Ultimately, the NSC plays a pivotal role in enabling customized network capabilities and optimizing resource utilization.

3 APPLICATION OF IBN IN 5G/6G NETWORKS

3.1 Service orchestration and automation in 5G/6G networks using IBNs

In this paper we are proposing the Intent-Based Networking (IBN) paradigm with the objective of offering highly personalized and efficient connectivity. This approach combines service orchestration and automation to provide an enhanced network experience.

One of the key aspects of IBN is the ability to request specific network services. In 5G/6G networks, we can request services such as point-to-point or point-to-multipoint connectivity, with an associated quality of service (QoS). This means that we can simply request in a customized way how we connect and the quality of service we expect to receive.

In addition, to meet more specific requirements, we can request particular features for the allocation of an Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC) or a Massive Machine Type Communications (mMTC) slice. These slices are designed to address different needs, such as high-definition video streaming, ultra-reliable communications or the mass connection of IoT devices, respectively.

To achieve a more efficient management of services and resources in 5G/6G networks, we propose the use of Artificial Intelligence (AI) for two specific phases of the process described here: the definition of Network Resource Partitions (NRPs) and the assessment of the feasibility of the request. Regarding the first point, these resource partitions allow a more efficient and flexible allocation of network resources to the different slices, being possible to use AI to optimize the creation and allocation of NRPs, maximizing the use of available resources.

Complementarily, we could also have an AI that intelligently analyzes the requirements of the requested services and performs real-time assessments to determine the feasibility and viability of allocating resources to satisfy those services. This enables automated and accurate decision making, ensuring optimal delivery of services and a better user experience.

3.2 Key components for IBN implementation in 5G/6G networks

To achieve optimal orchestration and automation of 5G and 6G network services, we propose the adaptation of the previously presented NSC architecture by incorporating two additional modules and an optional module:

- Translation Module: The next-generation network ecosystem encompasses various access technologies, necessitating the adaptation of the intent-based networking module to each of these technologies. To facilitate seamless deployment, we require a preliminary adapter to translate the requests into a standardized format (in our case, we propose the [2] data model). This step shifts the complexity from the Mapper and Realizer modules to a smaller, preliminary adapter.
- Planner: In order to reduce the number of requests and suggest better paths, we are working on an AI-driven module equipped with extensive knowledge of the managed network and near-real-time capabilities [3]. Integrating this module allows us to optimize decision-making and subsequently decrease the number of requests sent to the SDN controller.
- Topology Module: To maintain awareness of the network's state, it may be necessary to introduce an additional module. This module manages the updates to

the network's topology, ensuring up-to-date information on the network's status and the most recent view of each topology's NRP (Network Resource Partition). By including this module, we enable the optimization of network resource partition calculations.

The Mapper and Realizer modules have not been included in this list as they have already been defined. With the introduction of the modules explained above, the complexity of these modules is reduced, with the Mapper module managing the workflow of the service and the realizer module evaluating how the slice should be provided.

3.3 Design and deployment considerations for IBN in 5G/6G environments

The process outlined in this section represents our design and deployment proposal, which is one of several possible implementations. In this case, we have sought a standardized approach, assuming that we are working with an SDN controller that provides basic topology information but lacks comprehensive metrics or characteristics. The software described here functions as a plug-in over the SDNc-NBI, but it does have some limitations, which will be discussed in the following section.

To begin the work, we will translate the network connectivity request from the technology or vendor-specific format into a unified format. Since we are deploying and extending a technology proposed by the IETF (Internet Engineering Task Force), our module will utilize the language defined by the IETF data models [2] Once the information has been translated into our language, we need to determine the two (or more) endpoints that require connectivity. Initially, the client will request connectivity from its IP to the destination IP, but since we do not manage local areas, we must identify the IPs of the entry points within our network.

Once we have identified both entry points in our topology map, we need to evaluate the network between these points. Not all networks function in the same manner, and there may be network characteristics (e.g., technology, ownership, protocols, etc.) that can influence the paths. To account for these differences, we rely on a sub-network characterization called the Network Resource Partition (NRP), which divides the network into layers based on these characteristics. If we lack information about different layers, we assume that the entire network is a single layer, resulting in only one NRP. It would be interesting to explore the possibility of implementing an AI-driven decision algorithm in scenarios with numerous potential NRPs. A similar consideration applies to the viability evaluation, where if a segment satisfies the requested capability, the entire path will be able to do so as well.

This solution can further be enhanced by considering additional factors such as privacy policies, user policies, and high-demand services. By incorporating this broader perspective, the comprehensive set of decisions and allocations will strive for an optimal approach, or at the very least, at different levels in real-world scenarios. Taking privacy policies into account allows for a more holistic approach to network management, ensuring that data protection and confidentiality measures are upheld throughout the intent-based networking implementation. By adhering to established user policies, the system can align its operations with user preferences and requirements, enhancing the overall user experience. Furthermore, the inclusion of high-requirement services as a consideration enables the solution to prioritize and allocate resources efficiently, catering to the specific needs of critical applications and ensuring their seamless operation within the network environment. This heightened level of service provisioning ensures that essential services receive the necessary resources and support, preventing potential disruptions and maintaining optimal performance levels.

Continuing with the resource request process, it is necessary to evaluate not only the entry points to the network for each connectivity request but also assess the networks it will traverse and determine if multiple network segments or a single one will be involved. Through this evaluation, partial path estimations can be made to search for the overall optimum. Furthermore, if a request is divided into multiple segments, it is essential to identify which segments constitute the request. If one of them is not instantiable, all segments of that request should be canceled as a unified set, thereby avoiding unnecessary resource reservations and making those resources available for other requests. Similarly, in the case of adapting these resources to new network contexts, it is also necessary to identify how many resources belong to the same connection to prevent incompatible modifications.

When the network controller detects that a connection has expired or needs to be reallocated, the decision will be propagated to the client in case they wish to generate a new request. During the execution of a service, it may be necessary to adapt the path of a connection (modify the slices that form the path) to accommodate other requests optimally. In such cases, the network slice controller should perform this adaptation transparently to the client.

Overall, this entire process should be transparent to the client, with the client only knowing whether it is possible to obtain the requested service between IPa and IPb with the desired characteristics, if it is possible but with inferior characteristics, or if it will not be possible in any way. This process is depicted in the following figure, which presents the activity workflow, where we can visualize the logical sequence of decisions.

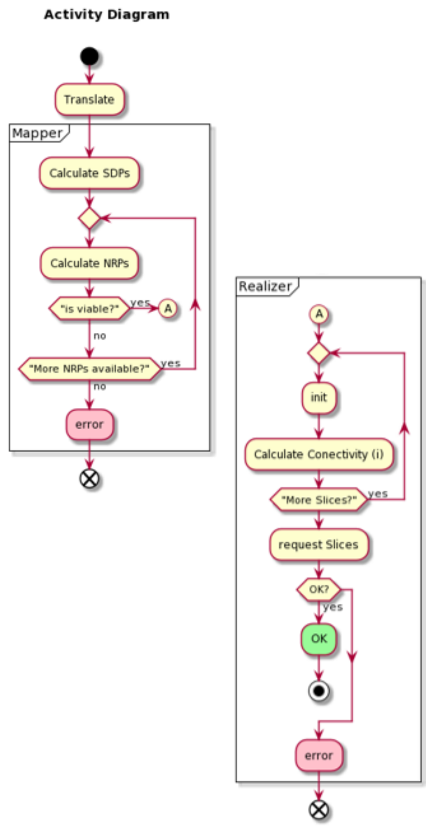

Figure 1: Network Slice Controller activity workflow.

There are also other complementary activities as the creation of the topography map or the identification of the SDPs (Service Demarcation Points), but the realization of these activities will depend on the situation of the component in relation to the network controller: If the NSC works as an external component, it will has an easier integration but counting with a reduced amount of data available, thus decreasing the effectiveness of the solution. Otherwise, if the implementation is integrated within the network controller, it could directly receive information from various network modules, improving the visibility it obtains from the network and therefore offering better slice requests to the network manager, but increasing the complexity of the integration. An intermediate option would involve implementing the planner internally within the controller and the rest of the NSC as an external component to the controller. This way, the drawbacks of the first option are minimized, but it still doesn't require significant modifications to the existing network controller.

3.4 Opportunities and Challenges

In the previous sections of this article we have been able to extract some opportunities that arise in the field of 5G/6G networks with the integration of a Network Slice Controller (NSC) in an Intent Based Networking (IBN) environment. These opportunities allow us to further improve the management of network resources, enabling efficient scaling of resource requests, greater modularity in the processing of intents and the ability to add new functionality to the network controller without increasing internal complexity:

- Network resource request scaling: The use of an NSC provides the ability to scale network resource requests by applications and network nodes. This allows greater flexibility and adaptability in the use of network resources, optimizing their utilization and improving the quality of service offered.
- Outsourcing of resource evaluation: By using an NSC, it is possible to outsource the evaluation of network resources, allowing additional functionalities to be added to the network controller without increasing its internal complexity.
- Modular operation of intent processing: The integration of an NSC in an IBN context allows a more modular operation of intent processing. This implies a clear separation of the network evaluation (mapper) and resource request (realizer) stages. This modularity makes the process easier to understand and manage, improving efficiency and allowing for greater customization in resource allocation.

On the other hand, we have identified also some challenges that we should face to keep improving on this line. These challenges are:

- How to deal with the Knapsack problem: One of the main challenges in integrating an NSC in an IBN context is how to deal with the knapsack problem. This problem refers to optimizing the allocation of limited resources to different resource requests. An efficient and scalable approach is required to ensure that resources are optimally allocated, maximizing their utilization and meeting the needs of applications and network nodes.
- Obtaining sufficient network information without compromising privacy: To perform a complete network visualization and properly assess available resources, it is necessary to obtain sufficient network information. However, this poses the challenge of balancing the need for information with protecting the privacy of network data to avoid data disclosure issues.
- Process optimization without counterproductive overloads: To optimize the evaluation and resource allocation process without falling into counterproductive

overloads it is necessary to find the right balance between efficiency gained and the workload imposed. An overly heavy approach can affect the overall network performance, while an insufficient approach can result in inefficient resource allocation and poor quality of service.

Facing these challenges at the same time that maximizing the opportunities will be key in order to situate the Network Slice Controller and the Intent-Based Networking as leader technologies in the slice management in 5G and 6G networks.

4 CONCLUSIONS AND FUTURE DIRECTIONS

4.1 Findings and contributions

The article focuses on the concept of Intent-Based Networking (IBN) and its application in the context of 5G and 6G networks. It highlights the shift from low-level configuration to high-level intent-based management, which enhances network agility, automation, and alignment with industry objectives. IBN allows users to express their desired outcomes through high-level requests, simplifying network management and encouraging alignment with network slicing and software-defined networks.

Network slicing, a key feature of next-generation networks, partitions a physical network into multiple logical networks tailored to specific requirements. IBN can play a crucial role in network slicing by facilitating the creation, deployment, and orchestration of slices based on user-defined intents. Also, AI is proposed to automate the process, particularly in defining Network Resource Partitions (NRPs) and evaluating the feasibility of requests, optimizing resource utilization and enhancing user experiences.

The article proposes the Network Slice Controller (NSC) as a key component for managing network slices, facilitating requests, realization, and lifecycle management. The NSC integrates the customer's perspective and the provider's viewpoint, ensuring alignment between requirements and operations. This article also focuses on the internal structure of the NSC, upgrading the architecture proposed in [1] and showing a way to manage internal communications and evaluating the possible challenges that arise depending on how the integration of this module is carried out.

Design and deployment considerations are also discussed, highlighting the importance of standardized approaches, translation of requests into a unified format and the evaluation of network characteristics. The article emphasizes the seamless integration of IBN in 5G/6G networks, providing personalized and efficient connectivity while simplifying network management.

In conclusion, in this paper we propose the adoption of IBN in 5G/6G network management, showcasing its potential in service orchestration, automation, and network slicing. The utilization of AI and the NSC architecture offers valuable insights and recommendations for the implementation of IBN, contributing to the efficient and effective management of next-generation networks.

4.2 Future works

As we move into the future of next generation networks, exciting opportunities are opening up to further extend and enhance the integration of the Network Slice Controller (NSC) in an Intent Based Networking (IBN) environment. Some of the promising future work includes the development of intelligent modules for the two points evaluated so far: the definition of Network Resource Partitions (NRPs) and the feasibility assessment method in the network planner. The implementation of artificial intelligence and machine learning algorithms in these modules would allow for more accurate and efficient decision making, optimising resource allocation and further improving the quality of network services.

Furthermore, another important aspect for future research is the extension of the concept to other types of access networks. This implies improving the capabilities of the translator used for the integration of different technologies and expanding the range of technologies where this approach can be applied. By extending the scope of this concept to access networks such as Wi-Fi networks, sensor networks or satellite networks, new possibilities for customisation and adaptability of network services in various environments and scenarios would be opened up. This challenge will require a multidisciplinary and collaborative approach to develop innovative solutions that address the specificities and challenges of each type of access network.

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