JÖNKÖPING UNIVERSITY
School of Engineering

Exploring Software-Defined Networking Challenges in Sweden

IT Team Knowledge and Skills Gap

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Abstract

Software-Defined Networking (SDN) is a new evolving approach within the networking domain. The concept is based on decoupling and abstracting the control and data plane of the traditional network devices. This separation facilitates the network operations with many benefits such as faster delivery, better segmentation, scalability, programmability, enhancing the quality of service and the quality of experience. Despite all the benefits, SDN has its own set of challenges.

The purpose of this study is to explore the main challenges in adopting SDN architecture in Swedish organizations. The focus is on the skills gap as one of the main challenges and how Swedish organizations were able to manage it.

A qualitative approach has been chosen to conduct this research using semi-structured interviews to collect the data from seven different organizations, using a mixture of a purposive and snowball sampling selection. A thematic approach was then used to generate categories and themes from the collected data.

The results are consistent with previous studies when it comes to technical, financial and security challenges. The technical challenges, however, were fewer in comparison with previous studies. A new way of working was presented as a new challenge when implementing SDN solutions. Furthermore, the knowledge gap was mentioned as a key challenge within Swedish organizations when implementing/operating SDN.

Finally, clear recommendations were made to overcome the knowledge gap challenge, from consulting a third-party expert, having a detailed plan, employing a multiphase process for SDN implementation, to having an online learning platform available to the IT team.

Keywords

Automation, Centralized Controller, DevOps, Knowledge gap, Programmable Networks, SDN, SDN Challenges

Sammanfattning

Software-Defined Networking (SDN) är en framväxande teknik inom nätverksdomänen. Konceptet är baserat på att frikoppla och abstrahera kontrollplan och dataplan för de traditionella nätverksenheterna. Separationen underlättar nätverksdrift och ger många fördelar såsom, snabbare leverans, bättre segmentering, skalbarhet, förbättrade kvalitet på tjänsten och kvalitet på upplevelsen. Trots många fördelar har SDN också utmaningar.

Syftet med denna studie är att utforska de största utmaningarna med att implementera SDN-arkitektur i svenska organisationer. Fokus ligger på kunskapsklyftan som är en av de tidigare identifierade huvudutmaningarna, och hur svenska organisationer har hanterat dessa.

En kvalitativ metod har valts för att genomföra denna studie med hjälp av semistrukturerade intervjuer för att samla in data från sju olika organisationer, med hjälp av en blandning av målinriktat och snöbollsurval. En tematisk metod användes sedan för att generera kategorier och teman från den insamlade datan.

Resultaten överensstämmer med tidigare studier när det gäller tekniska, ekonomiska och säkerhetsmässiga utmaningar. De tekniska utmaningarna var dock färre jämfört med tidigare studier. Ett nytt arbetssätt presenterades som en ny utmaning vid implementering av en SDN-lösning. Dessutom, nämndes kunskapsklyftan som en central utmaning inom svenska organisationer vid implementering och drift av SDN. Slutligen presenterades tydliga rekommendationer för att övervinna utmaningen med kunskapsgapet, från att konsultera en tredje part, att ha en tydlig plan, använda en flerfasprocess för SDN-implementering samt att ha en digital utbildningsplattform tillgänglig för IT-teamet.

Nyckelord

Automation, Centraliserad Kontroller, DevOps, Kunskapsklyfta, Programmerbara Nätverk, SDN, SDN Utmaningar

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1 Introduction

Modern organizations rely heavily on network technologies to support their information and communications technology (ICT) infrastructure. Network technology is an important part of modern technologies, such as cloud computing, Internet of things (IoT) and big data, that are becoming increasingly crucial to organizations (Horvatha, Nedbala, & Stieningera, 2015). Large enterprises such as Google, eBay, Facebook, and Microsoft use large data centers that generate a substantial amount of data. Those datacenters rely heavily on virtualization technologies which in turn rely on the concept of adaptability within the network infrastructure providing the different resources needed (Alsmadi, AlAzzam, & Akour, 2016). The amount of network traffic has increased due to the Internet's ability to support an ever-increasing range of devices. Therefore, the networking technologies must enable a dynamic design in order to effectively support this (Varghese & Buyya, 2018). Software Defined Network (SDN) architecture separates the control plane logic from the forwarding plane logic, providing a unique approach to network programmability presenting a way to control, change and manage network behavior dynamically (Baktir, Ozgovde, & Ersoy, 2017; Varghese & Buyya, 2018).

SDN has gained traction in recent years promising a centralized way to manage a complex network (Cox, Chung, Donavan, Ivey, & Clark, 2017). That said, SDN comes with its own set of challenges which hindered its expected spread among organizations. Among those challenges is the lack of know-how among the IT teams/administrators, can contribute to other challenges or issues, such as security or performance issues (Horvatha, Nedbala, & Stieningera, 2015; Adrian, Kurniawan, Faza, Maulina, & Shihab, 2020). As mentioned above one important advantage of SDN is its unique approach to network programmability, which also presents a challenge. Programmability means that the technology relies heavily on software, which requires a set of skills that can be considered outside the scope of network-oriented skills present in the network staff/team (Contreras, Doolan, Lonsethagen, & Lopez, 2015).

1.1 Problem formulation

In recent years, the key skills required for a network engineer have changed dramatically, the dominating trends are toward building a more programmable and automated network infrastructure (Cisco, 2017) . Through this concept, network devices can be managed seamlessly by a centralized controller (Jefia, Popoola, & Atayero, 2018) . Recent research related to network technologies trends showed that adopting SDN architecture improved the efficiency of network infrastructure utilization by 25%-30%, reducing the costs by 30% and taking the security to a higher level by incorporating new security features that are not presented by the traditional network infrastructure (Syuntyurenkoa & Gilyarevskii, 2021). SDN changes the daily life of a

network engineer. The configuration, troubleshooting and even the designing phase can be accomplished in diverse ways, and new concepts have been presented such as network programmability and automation (Pfitzer & Coté, 2017). SDN is considered to be a solution to the shortcomings of the traditional network architectures while supporting the concept of application-driven networks (Sezer, et al., 2013). SDN simplifies network design, provides better resources utilization, decreases the level of consumed energy, while presenting superior quality of service (QoS) strategies (Bhaumik, et al., 2014). The new emerged architecture facilitates self-service providing and on-demand resource allocation efficiently by cloud services providers (Hakiri, 2014).

Alongside the opportunities that come with adopting an SDN architecture, several concerns and challenges need to be addressed: Performance, security, flexibility, scalability, and interoperability are considered key challenges posed by SDN (Jefia, Popoola, & Atayero, 2018). SDN solutions rely on the idea of having a centralized controller which manages, monitors, and operates all network services. The failure of the controller can cause a failure in the whole network which presents the reliability of the SDN controller as a challenge (Rana, Chamoli, & Dhondiyal, 2019). Additionally, to the controller reliability challenge, control placement in the network appears as another challenge, the number of required controllers and suitable physical locations in the network need to be considered (Jammal, Singh, Shami, Asal, & Li, 2014). The consistency appears as another challenge in the distributed SDN solutions, the controllers need to exchange information about the network state in a way that ensures the consistency without affecting the performance (Bannour, Souihi, & Mellouk, 2018). Massive financial resources can be required to upgrade the infrastructure which are considered as an additional challenge (Binlun, Chin, Kwang, Yusoff, & Kaspin, 2018).

Furthermore, adopting SDN means that network engineers need to adapt to the new evolving technologies by gaining the required skills and competences to meet the needs for the SDN-based solutions, the employees learning/developing, and adaptability are additional challenges in adopting SDN solutions (Adrian, Kurniawan, Faza, Maulina, & Shihab, 2020). The shortage of skills in ICT prohibits the companies finding the right employees which can cause a delay in projects, limit the innovation, and reduce the market growth (Kolding, et al., 2018). The concept of personal skills and know-how appears as a part of the organizational challenges when implementing and managing SDN solutions (Contreras, Doolan, Lonsethagen, & Lopez, 2015).

To the best of our knowledge no other research has focused on researching SDN challenges within the Swedish region, specifically focusing on the organizational aspect of the challenges. This paper aims to explore the current challenges associated with adopting SDN architecture within Sweden focusing on the organizational aspect specifically the knowledge gap. During the literature survey process, it was observed

that the knowledge gap was mentioned in passing only. Furthermore, it was observed that no other research has focused on investigating how it was remedied and what skills that are missing. Although earlier studies have undertaken the effect of the skills gap on adopting SDN architectures. This paper will dive deeper into this challenge and how the companies/organizations adapt their strategies to respond to this challenge in the Swedish context.

The potential audience for this research expected to be organizations that have SDN implemented or planning on migrating to SDN architecture, as well as researchers aiming to further investigate SDN challenges.

1.2 Purpose

The aim of this research is to explore the main challenges in adopting SDN in Swedish organizations and how it may differ from previous studies. The focus will be on the skills gap as one of the main challenges and how Swedish organizations were able to remedy it.

1.3 Research Questions

To the best of our knowledge, similar studies focusing on SDN challenges were mostly done on an international scale, therefore the first question will focus on the Swedish market investigating if there are new challenges specific to the Swedish market that are not mentioned in previous studies. Moreover, previous studies have shown that the knowledge gap is one of the main challenges when adopting an SDN based solution, therefore, the second question aims to investigate how Swedish organizations/companies handled this issue and what knowledge needed to be developed.

The research will seek to accomplish the mentioned purpose by attempting to answer and discuss the following questions:

The first question aims to discover the current challenges when adopting an SDN solution within Swedish organizations/companies to get an overview in the Swedish context.

Q1. What are possible new challenges when adopting an SDN solution within the Swedish companies/organizations as compared to previous international studies?

Based on the results of the first question illustrating if the skills gap is one of the main challenges in Swedish organizations. The second question will attempt to identify the methods used to either avoid or manage this challenge.

Q2. How did Swedish organizations bridge the skills gap between the IT team and the SDN technology?

1.4 Delimitations

The scope of this research is limited to the organizations that have an SDN in place or at least the infrastructure with an implementation plan in mind. Therefore, an important limitation of this research is the limited number of organizations that adopted or plan to adopt the emerging technology. The organizations that have intention to adopt SDN without a plan in place, are out of the scope for this research. Furthermore, the limited population sample can be considered a limitation as it can affect the reliability of the results. Finally, the method of choice conducting the research which is a qualitative approach. Unlike the quantitative approach, this lacks the possibility of producing reliable statistical base to rely on.

1.5 Disposition

The remainder of this work is structured as the following: *Chapter 2* illustrates the method used for both data analysis and collection. *Chapter 3* presents relevant background information about SDN architecture, applications, and benefits. The related work and what has been done previously in the field of study is presented in this chapter as well. *Chapter 4* presents the collected data and the analysis. *Chapter 5* discusses the results and the method. Finally in *Chapter 6* the conclusions are presented alongside suggestions for future work.

2 Research Method

A qualitative approach has been chosen as the main approach with the goal of examining the challenges encountered by IT teams when adopting an SDN based solution. The qualitative approach was chosen for its ability to explore the challenges associated with adopting an SDN solution from the individual perspective. This approach provides a complex and detailed look at the problem (Creswell & Poth, 2018), which is needed in this case to be able to explore the issues within this research.

Using the qualitative approach, this research aims to explain the phenomenon for a deeper understanding as well as reach a set of recommendations (Mohajan, 2018). This aims to reach an explanation knowledge level, as well as reach the prescriptive/normative knowledge level through the recommendations. The generated recommendations and best-practices aim to serve as a basis to overcome the SDN knowledge gap as a challenge.

The downside of using a qualitative method, would be that it can be time consuming if one is using a large enough sample, but it more than makes up for that by providing a deep dive into the subject even with a smaller sample (Rahman, 2016). A quantitative approach was considered to provide a large enough sample, but it would only give a snapshot of the issue and it would be near impossible to gain the required insight into the issue using only this approach (Rahman, 2016).

2.1 Data Collection

Semi-structured interviews are the method of choice for this study. The interview questions are formulated using the knowledge acquired from the literature survey in chapter 3, to keep the questions unified across all interviews and achieve reliability. The questions follow an open-ended approach to provide the participants the freedom to share their experiences with as much details as possible. This is one of the main reasons semi-structured interviews were chosen, to provide the flexibility needed.

Using semi-structured interviews provides the flexibility of having open-ended questions as well as theory driven questions, which allows for a deeper understanding of the subject based on answers grounded in the subject own experience (Galletta & Cross, 2013).

2.2 Interview Guide and Selection

2.2.1 Selection

The study aims to explore the challenges of adopting SDN solutions within a Swedish context (Swedish companies / organizations) as mentioned in section 1.2. A mixture between a purposive or judgmental selection method and snowball method was used as sampling method. Qualitative approach allows the researcher to explore and understand

the meaning of a phenomenon from the individual perspective. A purposive sampling method allows the researcher to have a sample from which the most can be learned, and therefore it directly facilitates a deeper understanding of the phenomenon (Merriam & Grenier, 2019). A sample was chosen to offer the most information to help achieving the purpose of the study, using the criteria below:

- Companies/organizations chosen should have an SDN solution already in place or at least the infrastructure in place with an implementation plan ready.
- Employees picked within the organizations should have worked directly with the SDN solution to be able to draw from their personal experiences.
- To be a member of the network/IT team or IT managers to get the team perspective as well as the management's.
- Companies/organizations should be in Sweden

A list of companies/organizations in Sweden that might have an SDN solution implemented or an IT consultancy that implement SDN was made, and an email was sent inquiring about their willingness to participate (see *Appendix 2*). The other sampling method used was snowball, which is to ask the participants to nominate others to participate in the study (Gill, 2020).

2.2.2 Interview Guide

The semi-structured interview is a flexible method that can offer multi-dimensional streams of data, providing approach that can start from a theoretical grounded place moving to more open-ended questions allowing the participants to venture beyond the current literature tapping into the participant own experiences (Galletta & Cross, 2013). Additionally, this approach provides a space for the researcher to ask follow-up questions that were not thought of originally to further clarify or build on the participant answers, which allows for a deeper understanding of the subject (Galletta & Cross, 2013).

In planning the interviews, the preliminary part or the open segment is very important as it allows the participants to share their stories which give the interview the depth and direction needed, before having a more theoretical based question (Galletta & Cross, 2013). The following steps or guidelines help to facilitate a well thought out interview (Galletta & Cross, 2013):

- Establish a level of comfort and ensure understanding of participant rights
- Move into broad questions that create openings for participant to begin to speak from her or his experience
- When necessary, probe for clarification

- Mentally note meaningful junctures in participant's story to which you'll return later in the interview for greater exploration and depth
- Support the flow of the narrative with probes that guide its direction as it relates to your research topic

An interview guide was developed as a base keeping to the recommendations listed above to keep the interview questions transparent as well as relevant and informative.

Below are the steps included:

- Presenting the interviewers as well as the purpose behind the study and what types of questions to be expected.
    - In this step we will present ourselves and the purpose of the study (studying the challenges associated with adopting SDN solutions within Sweden focusing on the knowledge gap).
    - Participants are to be informed of the types of questions asked, such as their position in the company and educational background to establish their knowledge extent in the subject, as well as their experiences implementing or planning the SDN solution implementation.
- Participants are to be informed that their data will remain confidential, and they can drop out of the study at any time and their data should be deleted upon request. Furthermore, participants are to be informed of their right to refuse to answer certain questions should they choose to.

Included categories in the interview:

- Job title in the company
- Educational background
- Their definition of SDN and an SDN solution
- Their role in the SDN implementation process
- Their experience when implementing the SDN solution
- Their perspective of the management involvement in the implementation
- Issues rising during implementation
- Solutions or workaround done to overcome those issues
- Types of training implemented before the implementation process
- Ways to improve the process

All interviews were conducted via Microsoft Teams, and recorded with the participant consent, and deleted once it has been fully transcribed. See *Appendix* 1 for the detailed interview questions.

2.3 Data Analysis

A thematic approach was chosen to conduct the data analysis for the study. The main reason for choosing this approach is its flexibility. Even though broad themes are identified to some degree beforehand from previous research, this study is aiming to find a new perspective on the issue, and therefore the coding is done through analyzing the data looking for patterns to generate categories and themes. This is an inductive or bottom-up approach which is known for its flexibility (Braun & Clarke, 2006).

Thematic analysis much like the grounded theory relies on the researcher being able to discover and interpret implicit and explicit patterns and ideas from the data (Guest, MacQueen, & Namey, 2014).

Thematic analysis makes it easy to generate themes based on a small amount of evidence (Braun & Clarke, 2006). To maintain credibility the themes were created using obvious patterns that were repeated across the data.

A five-phased cycle shows the process of the analysis, the process follows the phases previewed as: (1) Compiling, (2) Disassembling, (3) Reassembling, (4) Interpreting, and (5) Concluding (Yin, 2015).

In order to process the data in a systematic approach, *NVivo* software was used to assist in analyzing the qualitative data for more efficiency and deeper insights through the participants' thoughts and experiences related to SDN.

The research analysis process is aligned with the mentioned five-phased cycle and processed using the mentioned software. The compiling phase presents a database of the transcripts files in a format of Microsoft Word document. Each interview has a separate transcript file including with both the questions and the answers. Disassembling phase is used to break down the compiled database into segments and assign codes. Reassembling phase is based on disassembling phase by rearrange the presented codes into main categories which are presented in the section 4.2 *Collected Data*. The interpreting and concluding phases are more related to the discussion section and are basis for the research conclusion.

2.4 Credibility

The study is designed to explore the current challenges when adopting an SDN solution within Swedish organizations/companies with a focus on the knowledge gap. To get a fair representation of the issue, seven organizations/companies were chosen. Within each organization/company members from the IT team were chosen to participate in the study. All participants must have been involved in an aspect of the SDN implementation/operation process.

During the interviews the questions were open-ended as to not lead the participant towards a specific path and leave room for them to answer from their own experiences,

giving them the chance to affect the study. Additionally, upon request, all transcribed data were sent to the participant once it's done to get final approval before adding it to the empirical data, to ensure the data integrity.

The data is then collected and analyzed using the thematic approach, determining themes within the data based on commonality and emerging patterns. As mentioned above (see section 2.2 data analysis). The results are then checked against previous literature to establish validity.

In this research the terms descriptive, interpretive, theoretical, internal, and external validity are used as well as reliability to determine the credibility of the research. The terms descriptive, interpretive, and theoretical validity are the most relevant to qualitative research (Johnson, 1997).

2.4.1 Descriptive validity

This refers to the factual accuracy of the reported data, in other words, is what's being told accurate? (Johnson, 1997). To achieve descriptive validity all interviews were recorded and attended by both authors to get different perspectives. Afterwards, the interviews were transcribed by both authors.

2.4.2 Interpretive validity

This refers to the interpretation of the fact and opinions of the participant (Johnson, 1997). Qualitative research relies on interpreting the participants' statements and observation (Johnson, 1997). To achieve interpretive validity a strategy called *Participant feedback* or *member check* was used. This simply means that when a conclusion or an interpretation of a statement was reached by the researcher, the participant was asked for the confirmation and feedback (Johnson, 1997). This was done during the interviews by asking the participants to confirm a certain interpretation of their answer.

2.4.3 Theoretical validity

Theoretical validity is the ability to produce theoretical explanation of the data (Johnson, 1997). Due to the small sample of population, this could not be fully achieved.

2.4.4 Internal validity

Internal validity is the extent which the data represents reality and not the results of external factors (Brink, 1993). There are different factors that can affect the internal validity of a research, such as *Maturation* and *Selection* for example (Runeson, et al., 2012). The *Maturation* threat refers to the participant reacts differently by the passing of time, boredom and tiredness are examples of this (Runeson, et al., 2012). To avoid this, the interviews time was almost always under 40 minutes except for one interview

that lasted 60 minutes. The *Selection* threat simply means that the participants do not represent the population or don't have the relevant knowledge (Runeson, et al., 2012). To avoid this the participants were chosen based on their participation in the SDN implementation or operation process. Furthermore, all organizations selected used a form of SDN and were chosen from organizations that uses SDN internally and IT consultancy companies that implement this technology and thus have extensive knowledge on the subject. This was to get different perspectives on the technology from both a company that uses one SDN solution internally perspective as well as a consultant perspective.

2.4.5 External validity

External validity is the degree to which this reality or representation of reality can be applied across groups (Brink, 1993). To be able to achieve this, the participants were chosen with relevant knowledge in SDN. Furthermore, the study included companies/organizations that had an SDN solution implemented internally as well as consultancy companies that implemented this solution within other companies. Choosing to include consultancy companies in the sample, added more variation as they implement SDN within different organizations, and therefore each consultant brings different experiences related to SDN implementation and operation. With that said, having a bigger population sample would have helped to fully achieve external validity.

2.4.6 Reliability

The term Reliability refers to the consistency of the research, meaning the ability to replicate the results or a similar result at least using the same circumstances (Brink, 1993; Malardalen University, 2022). To achieve reliability the interview questions were unified for all interviews and asked in the same order to all participants (see *Appendix* 1). Having said that, the results can vary to a small degree in a duplicate study depending on the selection process.

2.5 Ethical Considerations

According to the *Swedish Research Council*, there are four basic principles to be kept in mind when implementing a humanities-social science research (Swedish Research Council, 2002) :

- The information condition: This principle stipulate that all participants must be informed of the purpose behind the stud
- The consent condition: This principle dictates that all research participants must give their consent beforehand
- The confidentiality condition: To fulfil this principle, all collected data should be treated as confidential and not to be shared outside the study parameters

- The utilization condition: This principle dictates that all collected data can only be used for research purposes and not for any other purpose

To adhere to those conditions or principles, the study was designed around those rules and the following was implemented: All participants are informed of the purpose behind the study before hand and consent are requested before conducting the interviews. Furthermore, participants are informed of their right to drop out of the study at any point should they choose to. The data collected is used only to serve the purpose of the study and it shall remain confidential. Additionally, the participants were anonymous when included in the research paper. The interviews are conducted online through Microsoft Teams, to facilitate a simpler way of recording the interviews with the participants consent of-course, stipulating that the recorded interviews along with the transcripts are to be deleted after concluding the study. Finally, any collected data can and will be deleted upon the participant request.

3 Theoretical Framework

3.1 Traditional Architecture

In traditional data communication networks, the capabilities of network devices can be categorized in specific planes. Three planes are mostly used: Data plane, control plane and management plane (see figure 1). Data plane forwards the traffic between network devices (routing and switching) (Odom, 2020). Control plane manages the traffic forwarding and represents the logic and intelligence of the network device, in this plane the decision of how and where to send the traffic in the data plane is taken (Coughlin, 2014). Control plane is considered the brain of the network device (Tanwar, Gohil, & Tanwar, 2016). Management plane includes the protocols that allow network engineers to manage the device using a form of network management systems. (Göransson, Black, & Culver, 2017). Traditional network devices use a distributed control plane and a distributed data plane, the functions of the data and control plane are located within each device (Jefia, Popoola, & Atayero, 2018).

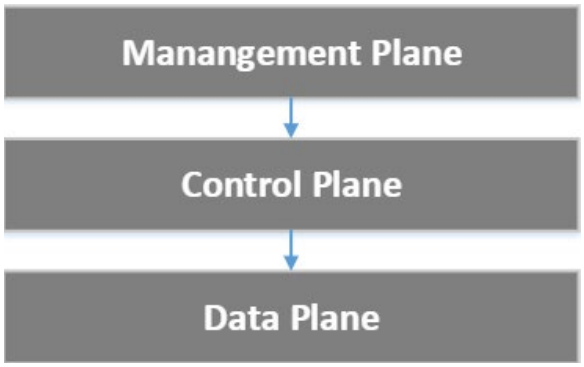

Figure 1. Planes of the Traditional Network Architecture (So, 2016)

3.2 SDN Architecture

Software-defined networking (SDN) is an emerging network approach that separates the control plane from the data plane of a network, centralizes the management logic of the whole network in an SDN controller (Binlun, Chin, Kwang, Yusoff, & Kaspin, 2018). The controller is the main component of the SDN network and represents the center of intelligence where the control plane functions are performed (Coughlin, 2014).

The implementation of SDN can be applied in various environments, regardless of the size or the requirements of the network the SDN can be a solution to improve the network characteristics and provide additional functions (Jefia, Popoola, & Atayero, 2018). Datacenters, enterprise networks, optical networks and even the small office/home office networks can be targets to SDN applications (Jefia, Popoola, & Atayero, 2018). SDN solutions support implementation scenarios where both legacy

and programmable devices are used, this type of implementation is identified as hybrid SDN (Ahmad & Mir, 2020).

As shown in figure 2, SDN architecture has three main planes including data, control, and application plane (Nguyen, Tran, Fowler, & Souihi, 2021). Traditionally, a management plane has been identified to monitor, configure, and maintain the network devices. This plane is usually centralized with an aim to have a holistic view for the network and manage the distributed control plane (Odom, 2020). In the SDN context, the controller eliminated the differentiation between the control plane and the management plane, and the role of the management plane has been considered out-of-scope for the SDN architecture and can be ignored. (Halepildis, et al., 2015).

The new abstracted application plane is added to the network architecture to manage the management functions and the control logic. Application plane communicates with the controller through northbound application programming interfaces (SDN northbound APIs), and the southbound APIs enable the communication between the controller and the network devices (Amin, Reisslein, & Shah, 2018). The terms northbound and southbound are used to distinguish whether the interface interacts with the application or with network devices (Göransson, Black, & Culver, 2017).

SDN architecture can be implemented in a distributed modality by extending the control plane between multiple controllers, this application is primarily used in the datacenters and by service providers. This model the communication between the controllers uses the east-west APIs (Benamrane, Ben mamoun, & Benaini, 2016).

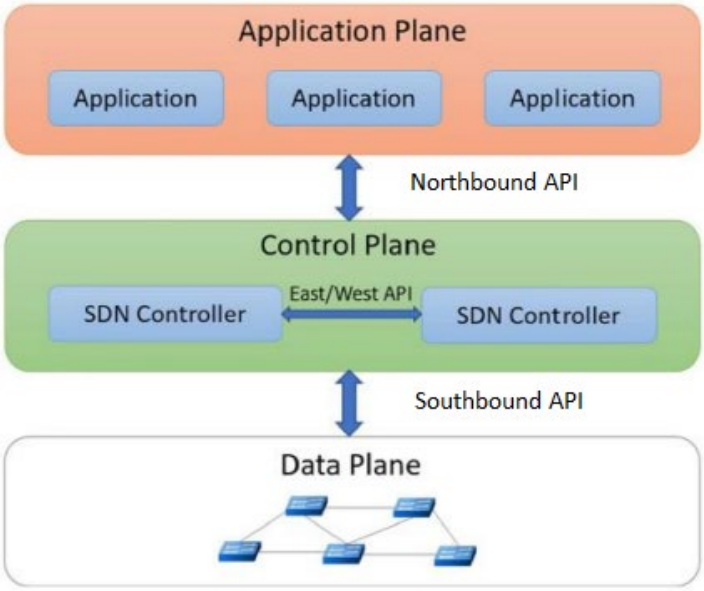

Figure 2. General Architecture of software-defined networking (Nguyen, Tran, Fowler, & Souihi, 2021)

The abstraction that is provided by the SDN facilitates creating virtual network architectures by separating the services which are provided by the network, from the

physical network (Göransson, Black, & Culver, 2017). SDN utilizes the concept of virtual networks to create overlays built on the physical network and managed by the controller (Cox, Chung, Donavan, Ivey, & Clark, 2017).

Going forward, SDN does not require using the command line interface to interact with each single device during the configuration phase. SDN controller provides two main types of APIs to interact with both the network devices and the applications (Cisco, 2017).

Southbound Interface or API

The communication between the distributed data plane on each network device and the centralized control plane on the controller is established using this interface, the controller uses this interface to apply forwarding rules and policies, OpenFlow is commonly used southbound interface (Ahmad & Mir, 2020).

Northbound Interface or API

This interface links the controller with the applications in the abstracted application plane, applications can accomplish the complex network tasks like QoS, security policies, load balancing, delay and jitter management, topology discovery and much more using this API, representational state transfer (REST) API is a common northbound API (Cox, Chung, Donavan, Ivey, & Clark, 2017).

Automation Tools

Network automation increases the configuration efficiency within the network devices by using automated scripts rather than the traditional methods for the configuration (Fuzi, Abdullah, Abd Halim, & Ruslan, 2021).

3.3 SDN Applications

The SDN technologies are applicable in a wide range of communication and networking scopes, some of the key applications of SDN are: Wireless Communication, Data Centers and Cloud Environments, Campus, and High-Speed Networks (Bakhshi, 2017)

Software-Defined Wide Area Networking (SD-WAN) is the application of the SDN concept in the WAN architectures (Moser, 2021). This technology allows the organization to connect to sites over large distances and eliminates the disadvantages of the traditional WAN technologies such as high cost and lack of Quality of Service (QoS) (Moser, 2021).

3.4 SDN Benefits

The concept of decoupling the control plane and data plane offers many benefits such as faster delivery, easier scalability, and centralized network provisioning (Adrian, Kurniawan, Faza, Maulina, & Shihab, 2020). Programmable network services reduce

the management cost and higher innovation rates can be considered as additional benefits (Cox, Chung, Donavan, Ivey, & Clark, 2017). Saving energy is mentioned as a benefit of SDN architecture, the ability to power down or put in an energy saving state all the links and devices that are not in use has a significant effect on energy consuming in datacenters (Sherwin & Sreenan , 2021). SDN is agile and considered the next generation network (Ahmad & Mir, 2020). Furthermore, enhancing the quality-of-service (QoS), and the quality of experience (QoE) are mentioned as advantages of SDN over the traditional networks (Deb & Roy, 2022).

Network segmentation which is defined as an approach to divide the network into multiple segments with an aim to improve security monitoring and network control, this approach has been mentioned as a key benefit of SDN (Moser, 2021).

3.5 SDN Challenges

Despite the benefits of adopting SDN, some potential challenges that face SDN architectures have been identified in the literature. Decoupling of the data plane and control plane functions raises challenges some are related to the security, scalability, and reliability (Nguyen, Tran, Fowler, & Souihi, 2021).

In the following section, the SDN challenges are categorized in *security*, *technical*, *financial* and the *knowledge and skills gap challenges*. A literature review is presented below with a focus on the knowledge gap challenges.

3.5.1 Security Challenges

SDN has special characteristics which are important to mention in order to understand the new security threats in this technology (Sahoo, Sahoo, & Mishra, 2022). These characteristics can be categorized as: The presence of a centrally controlled network, the presence of open programmable interfaces, the use of switch management protocols, flexibility for third-party network services, virtualized local network and the presence of centralized monitor units (Sahoo, Sahoo, & Mishra, 2022) .The combination between the SDN characteristics and the new provided features through SDN introduces new security challenges (Sahoo, Sahoo, & Mishra, 2022). SDN architectures are exposed to a complex set of security challenges, these challenges are directed to the data plane and the control plane (Bakhshi, 2017). The controller is the main target to security threats in SDN architectures (Jefia, Popoola, & Atayero, 2018). OpenFlow has some security related issues as well, and since it is commonly used by many SDN controllers, these controllers inherit these security threats (Cox, Chung, Donavan, Ivey, & Clark, 2017).

Furthermore, there are additional security threats within the SDN distributed architectures in terms of having secure authentication methods between the SDN controllers and securing the information exchange between these controllers (Ahmad & Mir, 2020).

3.5.2 Technical Challenges

Controller-Related Challenges

SDN raises some challenges related to its nature of having a centralized control plane (Karakusa & Durresia, 2017). Below are some of these challenges.

Scalability

The scalability as a challenge is not unique to SDN, the problem related to how to scale up the network infrastructure to meet the requirements for the new added functions has affected the traditional network implementations for decades (Cox, Chung, Donavan, Ivey, & Clark, 2017). SDN scalability is an important challenge to the control plane (controller) in SDN, the problem arises due to the centralized nature of SDN (Karakusa & Durresia, 2017). The scalability challenge is caused by the latency that occurs in responding to many network devices by a single SDN controller. Another cause is the communication channels between the controllers through the east-west APIs when a distributed SDN implementation is chosen (Cox, Chung, Donavan, Ivey, & Clark, 2017).

Reliability

Having a reliable SDN architecture is basically the ability to perform network functions seamlessly even in a case of a controller failure (Ahmad & Mir, 2020). The reliability requirements are increasing with the expansion of the information and communication systems. As the controller is the brain of the network, therefore any disruption in it will lead to loss of communication and the inability of the network to serve its basic functions (Netes & Kusakina, 2019). Reliability is considered as a performance metric to measure the percentage of the control path loss (Wang, Zhao, Huang, & Wang, 2017).

Availability

Availability as a concept is closely connected to reliability, in the centralized SDN implementation the controller may have redundant modules which facilitate adding or removing hot-swap parts without interrupting the services (Tanyingyong, 2021). In the distributed SDN implementations preserving the availability can occur by having a physical distribution for the control plane through implementing multiple controllers while keeping a logical centralization (Cox, Chung, Donavan, Ivey, & Clark, 2017)

Controller placement

The main objectives of controller placement approaches are to maximize the reliability and reach the minimum controller latency among the controllers or between the controller and network devices (Wang, Zhao, Huang, & Wang, 2017). A major concern when designing SDN networks is related to the controller placement problem (CPP), this challenge has a significant effect on the performance metrics like availability,

latency, and reliability, this challenge arises especially within the multi-controllers' implementations (Singh & Srivastava, 2018).

Troubleshooting

Adopting SDN solutions can increase the complexity of the network, which makes the troubleshooting process to pinpoint the cause of the failure is challenging (Manzalini, Steinert, Sharma, & Marchetto, 2015)

Application-Related Challenges

Another emerging category of the challenges that faces SDN architectures is based on the potential interference between the applications that use the SDN network to provide the network services. (Haas, Culver, & Sarac, 2021) summarized the challenges related to the applications as the following: Possibly conflicting interactions among multiple SDN applications, potentially unauthorized behavior exhibited by SDN applications, applications running outside of the SDN controller execution environment and potential security threats introduced by SDN applications interacting with remote third-party data and information sources (Haas, Culver, & Sarac, 2021).

Consistency - Distributed Architecture

To handle the scalability and availability challenges in the centralized SDN architectures, multiple controllers can be implemented in a distributed architecture (Benamrane, Ben mamoun, & Benaini, 2016). The concept of having multiple SDN controllers has been debated in the literature, distributed architecture raises the consistency as a major challenge (Alsmadi, AlAzzam, & Akour, 2016). As mentioned before the east-west APIs are used in the distributed architectures, eastbound is used to exchange the information between the controllers, and the westbound is used to exchange the information with the traditional architectures, legacy distributed control plane (Ahmad & Mir, 2020). Implementing multiple controllers eliminates the availability as a challenge by load balancing and avoiding the single point of failure. On the other hand, having a consistence general view of the network and replicating it between the controllers can be complicated (Karakusa & Durresia, 2017).

3.5.3 Financial Challenges

The total cost of the network can be a concern, this cost consists fundamentally of the initial deployment as well as the energy-related costs such as energy consumption (Wang, Zhao, Huang, & Wang, 2017). After deploying an SDN solution, additional financial resources are required to train the technical team to operate the network (Amin, Reisslein, & Shah, 2018). SDN Deployment usually comes with substantial budget investment requirements, which a lot of organizations cannot afford (Sandhya, Sinha, & Haribabu, 2017).

Applying reliable SDN architecture alongside with an optimal financial policy which pledges the best-use of the financial resources can be a challenge during SDN implementation. A research study from *International Data Corporation* (IDC) shows that 80% increase in IT management cost in the data centers can be linked to adopting virtualization and SDN technologies (Nadeau & Gray, 2013). The core concept of the SDN is based on the separation between the data plane and the control plane (Moser, 2021), this separation increases the complexity of the centralized control plane to meet the needs of the new architecture which in turn increases the pressure on the hardware to respond to this complexity, an increased cost in the development is predicted due to the cost of the upgrading the hardware component (Göransson, Black, & Culver, 2017).

3.5.4 Knowledge and Skills Gap

The need for the foundational knowledge in networking is not going anywhere, but the way it is managed is changing and evolving to a more centralized and automated approach (Cisco, 2017). Network engineers have worked mostly with CLI's which is according to Gartner's research vice president Andrew Lerner prediction that less than 30% of network operation teams will rely on CLI as the main interface (Cisco, 2017).

An SDN based network topology is a complex process that requires deep knowledge to be able to implement it while keeping in mind different aspects such as: Controller placement, scalability, performance, security etc. ensuring optimal performance (Shamugam, Murray, Leong, & Amandeep , 2016). Therefore, a lack of knowledge can cause numerous performance and security issues (Horvatha, Nedbala, & Stieningera, 2015).

According to (Horvatha, Nedbala, & Stieningera, 2015), the know-how in Software Defined Networking within data centers represents an important challenge. The article mentions that integrating an SDN solution into enterprises needs a well formulated plan that pays attention to SDN specific details such as the number of controllers and their placement according to the topology for example. This, if done by unskilled staff, can lead to very high security risks (Horvatha, Nedbala, & Stieningera, 2015).

Programmability is a big advantage of the SDN approach, it does however represent a gap in the network engineer knowledge as it is in a way outside the knowledge scope of a traditional network engineer (Contreras, Doolan, Lonsethagen, & Lopez, 2015).

The term DevOps (Developers and Operators) is a combination between the development team and the operation team to bridge the knowledge gap between the two teams to meet the requirements of the advancing technologies (Wang & Liu, 2018). The connection between SDN and DevOps is based on that the SDN facilitates the ability to apply DevOps methods on the network (Stubbs, 2016). Moving to use the DevOps is fundamental to simplify and automate the processes within the SDN (Manzalini, Steinert, Sharma, & Marchetto, 2015).

Recruiting staff with the right technical skills or up-skilling the current staff can be challenging to the organization when adopting DevOps (Senapathi, Buchan, & Osman, 2018).

4 Results and Analysis

In this chapter, the obtained results of the qualitative research are reported. For clarity, section 4.1 *Participants* introduces the participants anonymously according to section 2.5 *Ethical Considerations.* In section 4.2 *Collected Data*, the data that has been gathered is presented. Section 4.3 *Data Analysis* presents the finding of the qualitative analysis performed on the collected data and based on a thematic analysis approach.

4.1 Participants

To answer the study questions, seven participants were interviewed from various Swedish organizations and companies.

Three companies are IT consultancy companies that helped customers plan and implement SDN solutions. Four companies/organizations have a form of SDN solution within their IT infrastructure. All participants were involved in either SDN implementation or operation. This chapter presents all participants briefly highlighting their work title as well as their previous experience in relation to SDN. The participants are labeled and shall be referred to as participant One to Seven throughout the study to comply with the ethical guidelines mentioned in section 2.5, keeping the participant identity anonymous. See table 1 for a brief introduction to the participants.

Table 1. Research's Participants- Overview

Participant	Role in the organization	Organization type	SDN experience field
Participant One	IT Architect	Government agency	Virtualization platforms
Participant Two	Senior Solution Architect	IT consultancy company	Cisco SD-WAN
Participant Three	Consulting Manager/Senior Solution Architect	IT consultancy company	Cisco ACI Cisco SD-WAN
Participant Four	Service Owner	IT consultancy company	Cisco ACI
Participant Five	IT Architect	Service Provider	Cisco ACI
Participant Six (Group of three)	One Unit Manager and two Network Administrators	Government agency	Cisco ACI
Participant Seven	Network and Security Engineer	IT consultancy company	Cisco ACI Fortinet SD-WAN

Participants One

Participant One occupies the position of IT architect in the organization. This is a Swedish organization with more than 600 employees. The organization employs a type of virtualized infrastructure that utilizes the concepts of SDN at its core.

Below, participant One mentions their previous experience in relation to SDN.

> Since 2012 we have been working towards virtualizing all of our infrastructure and by 2016, we were able to virtualize all our infrastructure.

Participant Two

Participant Two holds the position of senior solution architect. This is a Swedish IT consultancy company that specializes in IT and network infrastructure with more than 650 employees.

Below, participant Two talks about their job description as well as previous experience with SDN.

> I actually do everything from requirements collection, design work to some part of the implementation. Usually, we hand over to a customer after.
>
> I have implemented Cisco SDN, especially what is called SDA. I worked 13 years at the company. Then I also worked with some SD-WAN.

Participant Three

Participant Three holds the position of consulting manager and senior network architect. This is a Swedish IT consultancy company that specializes in IT and network infrastructure with more than 22 employees.

Below, participant Three mentions their job title as well as previous experience with SDN.

> I have a lot of experience with SDN. We were actually the second in the world and first in Europe to implement Cisco ACI. The only one before us was a university in Abu Dhabi. I was responsible for implementing all new customers, we worked as an outsourcing provider, and after that we were specialized in SD-WAN, and it is a form of SDN as well. And there I have worked with many brands.

Participant Four

Participant Four holds the position of service owner in an international consultancy company that specializes in technologies from IT and network infrastructure to cyber security and data analysis. The company has 12000 employees in 25 countries including 600 employees in the Swedish branch.

Below, participant Four talks about their job description within the company, as well as previous experience.

> Service owner for the network. At present, this means that I am responsible for the development and management of all network services.

> I did not have previous SDN experience before working with this SDN solution. I did however have 15, 17 years of traditional routing and switching experience before working with SDN.

The participant works within the Swedish branch and was interviewed regarding the in-house SDN solution implemented within the company.

Participant Five

Participant Five occupies the position of IT architect in the company. The company is a Swedish service provider that specializes in providing fiber connection to companies.

Below, the participant talks about their previous experience with SDN.

> […] We have done proof of concept or pilot; you can say before implementing.
>
> […] We also run the municipality's network, we have implemented SDN for the municipality […] and we run Cisco SDA

Participant Six

Participant Six is a group of three participants that participated in the same interview answering questions with a unified answer (One answered for the whole group). Their job titles are (one Unit manager and two network administrators). This is a Swedish organization that have over 6000 employees with an implemented SDN solution within the participants IT department.

Below, the participants talk about their job description and previous experience.

Unit manager:

> I'm the unit manager for the unit called the data center.
>
> Our unit is responsible for both the infrastructure on the IT side, so storage networks and everything that makes things work.
>
> The skills are, as I said, network technicians, server technicians, a little database administrator. The service side is divided into 2 teams on one for Windows server for Linux / open source.

Network administrators:

> […] network administrators all here. Simply system technicians, but we handle the network administration, so to take care of our entire Core network where Access network and type router, switches, firewalls switches, some load balancers and other security products.

Participant Seven

Participant Seven holds the job title as a network and security engineer. This is a Swedish IT consultancy company specializes in network security.

Below, the participant mentions their previous experience in relation to SDN

> […] I've been looking at SD-WAN, and then been in one company looking at evaluating different vendors and solutions. […] now I'm also in another customer. We're actually starting to roll out another SD-WAN solution, so we have done all the proof-of-concept technical pre studies and now we're starting to do the low-level design and the implementation plan.
>
> […] for another customer worked with a data center, migrations, and consolidations. So, we actually built an ACI network infrastructure in one of the data centers.

4.2 Collected Data

In this section the collected data is presented based on the interviews' transcripts. The section gives examples of how the participants have answered the interview questions according to the categories which are presented in section 2.2 *Interview Guide and Selection*. As a result of the interviews' collected data which could be aligned with the literature review presented in chapter 3 *Theoretical Framework (see table 2)*. The data was coded initially into the following main themes: *SDN Architecture*, *SDN Adoption*, *SDN Security Challenges*, *SDN Technical Challenges*, *SDN Financial Challenges*, *SDN Knowledge Gap* and *Lessons learned*.

Table 2. Collected Data – Themes

Theme	Deduced from the Theoretical Framework	Deduced from the Collected Data
SDN Architecture	✓	✓
SDN Adoption		✓
SDN Security Challenges	✓	✓
SDN Technical Challenges		✓
SDN Financial Challenges	✓	✓
SDN Knowledge Gap	✓	✓
Lessons learned		✓

4.2.1 SDN Architecture

In this section the participants describe their understanding for the SDN as a technique.

SDN Definition

Participant One

Participant One defined the SDN generally and linked the SDN concept with the virtualization in his organization.

> […] it stands of software defined network, and we in the organization have been working with virtualization since 2006 […]. And until 2012 we have basically virtualized everything except our large platform […]

Participant Two

Participant Two defined the SDN based on Cisco's definition and mentioned that the concept based on having a controller to manage the network instead of the traditional management tools.

> Before, you had management tools, but now it will be a controller instead, and if you look to Cisco's definition, intent-based network is that I have meaning with my network, I don't need to know exactly to do it, but the system will translate the configurations to the different network modules and devices.

Participant Three

Participant Three mentioned that the SDN is a wide concept based on the context but simply it means to use the traditional technologies but in a centralized form.

> SDN has become a very wide concept, there is SDN in the data center, on the WAN, and in the virtualization environments. There are SDNs on many different layers, but I would say, what they all have in common is that you use classic techniques and technologies, but all have a central orchestrator and overly layer on the top

Participant Four

Participant Four defined the SDN as combination between the hardware and platform or software which can be modified using programing technologies, the participant based the definition on Cisco's perspective

> So, my definition of SDN is what Cisco has taught me […] you are no longer a pure network engineer because you need to understand the technology from the systems perspective to be able to use it […]. So, my definition is hat SDN, for me, is a hardware and platform or software that can be modified using programming.

Participant Five

Participant Five defined the SDN briefly as a policy in the network

> SDN in some way is the policy that governs the network instead, that you set up a framework for how you want the network to operate

Participant Six

Participant Six linked the SDN with the easiness concept, by allowing to implement the network functions in an easier way, and confirmed the policy concept of the SDN

> I would say that SDN is an easier way to implement the old technologies such as VXLAN and access lists within larger virtual environments. There is nothing that has

> not been possible to do before, but it was a lot of work to do and with SDN it will be policy-based and much easier

Participant Seven

Participant Seven presented their understanding to the SDN technologies as overly technologies built on traditional technologies

> I would say it's an overly technology building on the basic network functions in our SD-WAN as overlay for traditional WAN circuits, so and also if you look at the ACI and all this, it's also the overlay and NSX6, so it's all overlay techniques, more or less.

4.2.2 SDN Adoption

In this section the participants showed their attitude to the technology. Furthermore, argued about the benefits of the SDN applications and the presence of an implementation plan. The examples mentioned below from both companies that are considered a customer (a company that will buy the SDN solution) as well as the IT consultancy perspective.

SDN Acceptance

Participant One

Participant One attitude to the SDN was related to the organization need to adopt SDN

> […] I have looked at NSX both in their previous variant and the new one, but we could not find like a business case that needs to be solved by adopting this solution and the network guys are comfortable with […]. And we don't need new stuff all the time […]. I would rather say not being able to, but it is more that we have no seen that we really need it.

Participant Two

Participant Two explained from IT consultancy perspective that the trend in the campus network architectures still towards the traditional way of implementation

> […] it has usually been the case that you are quite traditional, as you should dare to make these changes, so many has set up this new technology as a basis and not gone all the way […].

Participant Three

Participant Three mentioned that the need to obtain programming skills can be a barrier in order to accept the SDN by IT team

> […] many in the operation department must start learning to code, at least very basic, and that is not always received very well.

Participant Four

Participant Four mentioned that the stability of the product can affect the attitude towards the solution.

> It took at least two years before the entire platform was stable. There were a lot of service window software upgrades and so on for the first two years. But now it's good. It took two years before it was stable, quite simply.

Participant Five

Participant Five confirmed the choice of the same solution if that needed

> […] yes, the solution itself, we have been using Cisco since before, so we will not change

Participant Six

Participant Six confirmed the choose of the same solution if that needed

> The ACI environment has worked fantastically well, so it would probably feel natural right now to choose it, we don't have much experience in NSX

Participant Seven

Participant Seven discussed why the SDN is not so common yet

> It's a big work effort, there's lots of training and a lot of pre studying and work to do. I think it's maybe hard for business to take that next step within a network. So maybe in a big customer, for the smaller ones, maybe don't see the benefits, they will keep it simple […] they don't have that many different resources and knowledge types.
>
> For large organization, you can have specialists for DevOps, for network engineers, you know for service and storage, smaller businesses have more generalists? They do everything, so I think that's harder for them. […] maturity or knowledge gap.

SDN Benefits

Participant One

Participant One mentioned the load balancing and automation as examples of the SDN benefits

> Clearly, there are tasteful things in NSX, to introduce load balancing features, they have sensible firewall […]. For these new requirements that are like Kubernetes comes with, an SDN solution could mean that we do not have to touch the physical network, SDN solution can be used above it.

Participant Two

Participant Two mentioned the benefits of the SDN from IT consultancy perspective

> If we look at SD-WAN then as we talked before, the user experience got better immediately, and we could save money on a couple of sites […]

Participant Three

Participant Three mentioned the benefits of the SDN from IT consultancy perspective

> […] I would say that it is very easy to sell SDN because there are many theoretical advantages, especially on the WAN. […] technicians are happy with the technology because it makes it a lot easier.

Participant Four

Participant Four mentioned that SDN could make the automation and monitoring processes easier and faster

> It was easier to automate on the platform and even after automation you could get changes faster in the platform. […] when we think about the network operations and network delivery, so we could monitor more, and the process was faster.

Participant Five

Participant Five mentioned the QoS and the efficiency in applying the network policy as key benefits of the SDN

> […] following the policy and how it should work by assigning who should access what and control that from the top (controller). […] it was a problem to us how to prioritize applications over others, it was quiet technically difficult, but when we used Cisco ACI, we could prioritize per application […].

Participant Six

Participant Six mentioned that SDN can provide faster network implementation as well increase the stability of the network.

> We see that something like setting up a new network or subnet is much easier and faster to be done with SDN. […] I would say that the network is incredibly stable, and we didn't have any operational interruptions

Participant Seven

Participant Seven mentioned the cost, build smarter networks, security, segmentation and zero touch provisioning as the main benefits for implementing SDN solutions

> Well, I think for SD-WAN, as usually you can buy cheaper circuits and you can build smarter network where the policy-based application routing. […] and obviously that would get a lot of benefits for the end customers getting better access to Internet, so that's usually the drivers for as the SD-WAN.
>
> I think for ACI that could be more like you want to have a segmentation and security, […] if you look at the API and SDN, it's going to be the segmentation similar to what you have in in the cloud environments.
>
> […] zero touch provisioning, because I think that's one of the big benefits for us for the SD-WAN we would like to ship all the equipment on site you just plug them in and then we're gonna onboard it in our central management platforms.

Implementation/Migration Plan

Participant One

Participant One mentioned, with no details, the presence of a migration plan since 2008.

> We had a plan when we moved in 2008 and we have kept this plan and filled in as we needed, needs for more environments and so on.

Participant Two

Participant Two, from their perspective (IT consultancy company), confirmed having a customized plan with a common basis

> The plan is quite different, so it is not usually the same plan […] we have basic plan from previous implementations that we can reuse it […] we in the organization are very dynamic, we check each customer and what they exactly want.

Participant Three

Participant Three, from their perspective (IT consultancy company), confirmed having a three phases plan to implement SDN

> You have three phases in such a plan, first phase called CMO current mode of operation, then you move to the next phase called IMO intermediate mode of operation, where both the old network and the new network exist at the same time […]. Then you have FMO future mode of operation, and this phase of the plan is the one you sell to the customer

Participant Four

Participant Four mentioned that the organization had a plan

> Yes, maybe we had, but I don't know much about the plans, but what I can say that the organization didn't expect too much

Participant Five

Participant Five mentioned that the organization had fundamental plan to implement SDN, which was as a response to a technical problem

> […] we had technical problems, we planned but it went very fast and usually you will not implement in that speed in normal ways

Participant Six

Participant Six mentioned that the organization has partnership with a consultancy firm in order to implement the solution

> We did a pretty big job together with the consulting company, the supplier that we use when the concept was developed […] it was a lot of work by the supplier and us to prepare for the implementation.

Participant Seven

Participant Seven mentioned the presence of a plan regarding the SDN implementation

> We have a plan, so we have to creating the implementation plan for that's SD-WAN that roll out at the moment.
>
> […] for ACI, if looking at obviously we worked with a partner at that time, and they had a kind of a runbook or a Template […] we just fill in all the different information that needs to be because there's a lot of similar or the same setup […]so they have a good run book that we used as a template.

> And obviously you need to do some tweaking, but you can have a framework, a standard framework that you know the basic infrastructure and then you need to work with your customer to get you know the customization.

4.2.3 SDN Security Challenges

This section presents the participants opinions regarding the SDN security challenges. The examples mentioned below from both companies that are considered a customer (a company that will buy the SDN solution) as well as the IT consultancy perspective.

Participant One

Participant One mentioned the security as a challenge in the SDN, especially when merging the SDN with other systems

> It is challenging if you have an IDS, security system, logging system and so on […] and we don't have either staff or competence to establish an external security operation center.

Participant Two

Participant Two confirmed that the security is a key challenge in SDN

> […] I will say that that's what I'm most worried about […]

Participant Three

Participant Three mentioned the security as a challenge in SDN

> […] a big challenge in terms of security, if you make a mistake in SDN it will spread to all your network devices, the small mistake can become a huge one, that is a major security challenge.

Participant Four

Participant Four confirmed the security challenges in the SDN

> There were initially restrictions on how to implement the security in Cisco ACI

Participant Five

Participant Five confirmed the security challenge in the SDN

> You have more functions which means more code and more bugs […] What a big challenge is the disadvantage with the security

Participant Six

Participant Six confirmed the security challenge and that they chose to keep their firewalls after implementing the SDN

> […] SDN supplier said that you no longer need a firewall, but we still chose to keep our firewall […]

Participant Seven

Participant Seven discussed that understanding the new security requirements can be challenging within the SDN

> […] well, it can be challenging because you need to know all the traffic patterns within the data center, as I said before, you can do segmentation and security rules within the same network within the same subnet, and obviously you've never seen that traffic before even if you had a firewall. […] now obviously you need to put up security rules and access rules in between servers and you don't know what kind of ports and the patterns that needs to be open […] if you ask the system owners or developers, they don't know. So that's a challenge in that way to understand the security, to set it up the security policy

4.2.4 SDN Technical Challenges

This section presents the participants opinions regarding the SDN technical challenges. The examples mentioned below from both companies that are considered a customer (a company that will buy the SDN solution) as well as the IT consultancy perspective.

Participant One

According to participant One, the troubleshooting is considered as a technical challenge when adopting an SDN solution.

> […] you have become very dependent on infrastructure, but when you start troubleshooting, you do not have much. You have to trust that it works, and you rely on an SDN environment on that.
>
> […] so, what do you do if you suspect that it is disturbing? here you need something? But now it's driving outside of this and see how it works so the purely traditional troubleshooting.

Participant Two

Participant Two added that availability and new way of working as main technical challenges

> The availability, if we speak traditionally, if you misconfigured something so it had been done on one switch and you probably notice that. […] its quiet big difference in the amount of time, the number of errors can also differ.

Participant Three

Participant Three mentioned the security and troubleshooting as main technical challenges

> I would say that there is a big challenge in terms of security […]. Another challenge is related to the troubleshooting, you many do not know how the solution really works. […] if something goes wrong, it can be very difficult to know why, because everything is automated, you only have one GUI.

Participant Four

Besides the security, participant Four mentioned the complexity as a technical challenge.

> […] there is always a bug opportunity, so it becomes complex […] you have more functions which means more bugs as well

Participant Five

Participant Five mentioned the concept as new way of working and troubleshooting as main technical challenges

> You must think network 2.0 in some way […] it doesn't really work as one is used to with networking
>
> You may have more tools to troubleshoot, but it is also perhaps more difficult to troubleshoot, so I think that troubleshooting will be done in a new way

Participant Six

Participant Six mentioned the concept of new way of working as a main technical challenge.

> Personally, personal challenge has been that SDN is a very new way of working, […] the thing that you don't have the same control anymore, a lot is happening in the background […]

Participant Seven

Participant Seven confirmed that the complexity and the troubleshooting are main technical challenges within the SDN

> […] there are so many layers that you need to understand that you need to troubleshoot. And if you look at the ACI, you don't have layer two anymore, it's all layer 3
>
> […] so, you have to learn another 3 or 4 levels of the stack to understand it fully so yes, it's challenging.

4.2.5 SDN Financial Challenges

This section presents the participants opinions regarding SDN challenges from a financial perspective. The examples mentioned below are being told from both the perspective of companies that are considered a consumer (a company that has an SDN solution implemented in-house) as well as the IT consultancy perspective.

Participant One

Participant One discussed the license cost of a specific SDN solution and how it can be too much in comparison to the benefit expected from the product. The participant represented their view from a client perspective (the company that buys the solution) and not an IT consultancy.

> Just the NSX that VMware wants to sell now. So, the license cost is really expensive, you have to say. If you look at the money compared to what added value it gives us, perhaps in terms of security versus what the need is.

Participant Two

Participant Two talked about the challenge of adopting new technique because the added cost it brings with it. Furthermore, the participant talked about the financial benefits of adopting SDN specifically SD-WAN from an IT consultancy perspective.

> Organizationally, it's difficult enough to get management and also the technicians to understand the benefits of this […]. It is often the case when new technology comes along, it may entail increased costs.
>
> […] looking at SD-WAN as we talked about from the beginning. The experience gets better immediately, and we save money on a couple of sites, thus the investment cost is met.

Participant Three

Participant Three discussed the financial aspects of SDN solutions both positive and negative from their perspective (IT consultancy company).

> […] yes. I would say that the biggest reason why you choose SDN, is to reduce the operating costs a great deal.
>
> I would say, if you go on the WAN side of SDN, there I would say that you save money almost immediately. [...] both because you can run on internet links instead of MPLS and you earn a lot if you choose a solution that runs Zero Touch Deploy because then you do not have to bounce all equipment via some configuration place before you send out everything at once instead.

Participant Four

Participant Four didn't mention any financial challenges related to SDN

Participant Five

Participant Five didn't mention any financial challenges related to SDN

Participant Six

Participant Six briefly mentioned the challenge of the initial investment in SDN from a client perspective.

> It is always a challenge to try. It also entails an investment cost, so it was probably one.

Participant Seven

According to participant Seven, the organization can reduce the costs by adopting an SDN based solution.

> It could be cheaper because obviously you get this if you look at the ACI, you get these orchestrations, if you do a lot of orchestration in the platforms. So, if you look at the operational part and operational costs for your operations teams, I think maybe you can save money in the long run for operations.

4.2.6 SDN Knowledge Gap

The participants' answers regarding SDN knowledge gap are presented in this section.

Participant One

Participant One discussed the knowledge gap issue when adopting an SDN solution. The participant highlighted that the knowledge gap as an important factor in choosing the technology stack.

> If we are talking SDN, there is another flavor, which is the NSX. [...] With this you have a limited number of staff, and they have a limited number of time and competences that will suffice to a certain level. [...] to say the team will have full-stack knowledge is not realistic [...].

Participant Two

The participant talked about the missing knowledge within IT teams when dealing with SDN solutions. Participant Two categorized them into deep knowledge of routing protocols as well as programming and automation knowledge. The participant argued more regarding that automation and programming are not used by everyone, so for those programming knowledge is not an issue.

> The problem is that if you look at the SDN solution today, it is quite advanced. A lot of protocols involved. There are a lot of different virtualizing things, and if you look in general [...], most people who are out today [...]. They have an understanding of Spanning tree, VLAN and IP networks and these pieces, but maybe not so much routing protocols and in these solutions relies heavily on routing protocols and quite advanced [...], so it becomes a pretty big knowledge issue.
>
> At the same time, you can ask yourself the question then. Traditionally I had to know these techniques to be able to configure this stuff. Talking SDN, one should not really need to know these things theoretically.
>
> But when it malfunctions, you must investigate what went wrong, you still have to go in and look now and then. Then the technicians should do what you have done before [...]. There it is a balancing act [...] so that they can handle and understand all this that happens under the hood [...].
>
> […] automation there are many who talk about it, some who do, but the vast majority do not. [...] you have two categories if you think about it. The ones who want to do everything themselves set up described python and all workbooks and playbooks.
>
> Then we have the customers who do not want to spend time on it, rather buy ready-made SDN box that has a lot of features in it that we can use and then we are willing to pay for that box instead of paying a team and developing all these pieces.

Participant Three

Participant Three highlighted the aspects of SDN that present a challenge when it comes to the IT team knowledge.

> Then you must have a staff that must be able to work with APIs or certain programming languages and so on, and you may not be able to. One of the big challenges.
>
> A lot of the operation department must start learning to code a little, I would say at least the basics and it is not always received very well.

> Another has a bit to do with this is troubleshooting. You may or may not really know how the solution works properly. But it requires deep knowledge.
>
> Because to understand exactly how it works then build something that you do not really know how it works, I would say. It is not so secure. You must know how it works to build it properly[…]
>
> Because SDN is often based on very classic technologies. SD-WAN build almost on BGP for example. I would say most SDN solutions have BGP somewhere under the hood. If you do not know it properly, it is difficult to understand how it works.
>
> If we look at the data center level; then there are even more advanced technologies like MP-BGP with EVPN VXLAN. All those pieces. If you do not understand the technologies from the beginning, it is very difficult to get acquainted with the SDN solution. [...]

Additionally, the participant stated that the knowledge gap can even be the root cause of other challenges.

> it effects both security, operation, and implementation.

Participant Four

Participant Four discussed the different knowledge aspects desired in someone working with SDN.

> No, there were not a lot of knowledge gaps. The people who implemented this and we who took over we had very good understanding precisely from those perspectives. So, we had a lot of staff with Python and automation knowledge. [...] and advanced routing switching but there was completely new terminology in the solution itself which you had to learn. How things worked in this architecture [...] before you could apply your knowledge.
>
> We had a team of technicians. Network technicians, service technicians to some extent also automation technicians who worked with this and I think it was very effective in that they learned the environment and architecture very quickly. But it was not so good at the same time.
>
> So, it was more efficient to have dedicated staff who worked with it. But when they then disappeared or when they were no longer dedicated. So, it placed higher demands on the rest and that was another learning journey again for the rest of the staff.
>
> A traditional network technician. If they work with us, it will be a long journey to understand our environment. On the other hand, will they have attended a 2-year pre-vocational DevOps training. So, it will be pretty easy for them to fit in.

Participant Five

When the participant was asked if network automation and programming can be considered as one of the main knowledge gaps, the participant confirmed stating that this maybe outside the skill scope of a network technician.

> I absolutely agree with that, where it is not really this normal […] not really have that competence in network people, as it is.

Participant Six

Participant Six talked about the organizational challenges focusing on knowledge as an important challenge. The participant raised the point that not only the network team that needs to be aware and understand this but everyone that is in the IT and the infrastructure team because SDN imposes a new way of working and designing, even outside the network team.

> At an organizational level, the big challenge has been to get everyone talking to understand the benefits of segmenting things. Why should they need to move this server somewhere?
>
> Like understand how it works? A lot of that sort of thing. It will still be you on the network side saying that now you will need to work more. And then those who are going to work must understand why they need to do this. This has been a challenge.
>
> [...] Ansible which is a new thing, especially for my colleagues. It feels like it has been the biggest challenge to have to script things. To build a lot of playbook and so on. It's nothing we've needed before.
>
> advanced routing, so it is more complicated in ACI than it is traditionally.

Participant Seven

Participant Seven discussed the knowledge gap within SDN. The participant mentioned that server and storage knowledge is important and not just networking. Furthermore, the participant talked about the possibility of custom automation and that programming knowledge for example is not a problem with ready solutions such as ACI as they come with their own set of automated tasks built into a graphical user interface (GUI).

> “There is a big knowledge gap. […] Well, I think you have to have a wide understanding is not just networking. You also need to understand all the the virtual servers and all the storage. So, you can’t just focus on on networking.”
>
> “You can do a lot of scripting with SDN if you want to, but you know at least with the Cisco ACI platform for example, you don't have to do any scripting out of the box.2

4.2.7 Lessons Learned

This section presents the data drawn from each participant experience with SDN. What went right and wrong? As well as how would they have done it differently?

Participant One

Participant One talked about the importance of testing the solution as a whole before rolling into production, as one thing they would have done differently.

> "[…] is that we have not tested it as often as we should have afterwards in its."

Participant Two

Participant Two discussed the importance of the planning and design phase in SDN. The participant highlighted that it can be a lengthy process to be done right.

Furthermore, the participant talked about the type of education or on-boarding process they offer as a consulting company to the clients to get the IT team ready.

> […] in SDN cases, and that has to do with the fact that there is a lot more automation. It is that the planning and design phases are usually much longer than you are used to.
>
> Often, I would say that is probably the case, that we hold such courses in scenarios that we set up this network and then we go through or develop a number of scenarios[...]. We will do a number of such scenarios that we see may come. Then we set up guidelines for them on how to handle them. Maybe even a workshop and educate through these pieces what it should look like then or what the system should look like. Some could take it further, there may be some training also within Cisco that you can go and so on.

Participant Three

Participant Three discussed three different aspects that can improve both the implementation and operation process. First, they mentioned how the design can ease the day-to-day operation. Secondly, the guideline, they as a consultancy company use as a template plan for SDN implementation. Thirdly, a consult firm that specializes in this technology can be invaluable in the implementation process. Furthermore, the participant highlighted the importance of getting help from an external expert to narrow the knowledge gap and ease the transition.

Finally, the participant mentioned that they encourage their employees to take industry standard certificates to stay current.

> An important thing is that when you work with SDN, often, the architecture will look in such a way that you would want to make most things look quite similar. [...] Because with SDN you do not want to have so much individual configuration in different locations for different tasks [..] but much of SDN is about having a design mindset where you think like this: how can we do this in one way so that we can easily automate so that I can with the click of a button get it a change that goes all over [...]
>
> You have 3 phases in all such plans. First phase goes over the current and it is called CMO current mode of operation. [...] the next phase called IMO intermediate mode of operation, where both the old network and new networks exist together. [...] then you have a future plan that is the FMO Future Mode of operation, where you ask, where will I be when this project is finished?
>
> That would probably be my absolute best tip now when I think about everything. Find out how things actually work in a current network and get help from an external partner
>
> […] I always say this for example, we have a standard that everyone who starts with us should always take a CCNP […].

Participant Four

Participant Four mentioned multiple points that needed improvement on their part, as well as their recommendations. Having dedicated teams for different aspects of SDN was a double-edged sword. It made life easier bridging the knowledge gap, but it made it difficult when they were no longer dedicated to the project. Another point is spreading

SDN knowledge or awareness across all the IT teams and not just the network team, as this technology affects the way IT teams work in general. Finally, the participant stressed the importance of the design phase.

> We had a team of technicians. Network technicians, service technicians to some extent also automation technicians who worked with this and I think it was very effective in that they learned the environment and architecture very quickly. But it was not so good at the same time. […] But when they then disappeared or when they were no longer dedicated. So, it placed higher demands on the rest and that was another learning journey […].
>
> [...] We have different types of architects, we have network architects, but we also have, server and applications architects or system architects. We could have probably trained them a little more and spread SDN awareness in the rest of the company. Because there are a lot of things in SDN that can affect not only pure network technologies [...] but they can affect those who write applications, and those who set up other types of systems that require a network.
>
> […] Evaluate your decision quite deeply [...] and then plan and structure the design in the beginning. Spend a lot of time.

When asked if having the service provider (Cisco) there every step of the way was another part of their success, the participant confirmed it. "Yes, absolutely".

Participant Five

Participant Five discussed the lessons learned during the implementation and operation of SDN as well as their recommendations. The importance of an outside consultant if the required skills are not available, is their first recommendation. This will help providing a well thought out implementation as well as a knowledge source for the staff to learn from. Another advice was to spend time on the high-level design first, in the form of segmentations and policies then move on to more detailed configurations. Finally, the participant highlighted the importance of testing before moving to production, similar to previous participants.

> We take in people to help us set things up. Sure, there will be consultant [...] Absolutely, we use consultants all the time [...].
>
> It can be a requirement I think to have someone who has done this before. [...] then you get education and so on [...] this way the consultant can be support [...]. The goal is to know the system yourself later, best practice […].
>
> You must start from the top and put these segments, in terms of policy from the top. That's where you must start. And then you come down to the bits and pieces.
>
> Before moving into the site, we could have tested everything first.

Participant Six

Participant Six discussed the importance of a consultancy firm, as well as other recommendations and mistakes during the implementation and operation of SDN.

> We did a pretty big job together with the consulting company, the supplier that we use when the concept was developed […] it was a lot of work by the supplier and us to prepare for the implementation.
>
> [...] to bring external expert help. It was very important to implement, and even after the implementation to have someone to be able to ask questions [...]
>
> There was an increased dialogue [..] It can be a different way of working [...] there is a lot more dialogue about what structure should look like as they want it to be and so on.
>
> that planning was scattered, it was spotless. What should have been taken into account [...] and a plan on how we migrate over the existing systems, also inside ACI. It's easy to get complacent.

When the participant was asked about the best technical decision they had during the implementation, having a separate firewall was their answer.

> When we heard all the presentations about SDN, all the SDN suppliers said that you no longer need a firewall. We still chose to keep our firewall.

Participant Seven

Participant Seven talked about the importance of having a well-thought-out low-level plan when moving to SDN. Furthermore, the participant mentioned having a company wide access to a tech online learning platform as a solution to narrow the SDN knowledge gap and keep the staff up to date.

> You know, there's a lot of online training that you can do. We use plural site.
>
> So, they got the enterprise agreement. So, everybody in the organization could do training.
>
> Uh, they focused obviously. And regarding a cloud data center network, DevOps. So you know everybody could pretty much do this online training. I think that was a good approach was […] education plan for all the engineers and all, all the people, and this could fit anybody. Really. You can go in an entry class.
>
> To do a really good low-level design to go through it with all you know, all stakeholders.

4.3 Data Analysis

A thematic analysis approach has been applied to identify data codes, categories then themes based on common patterns in the data to answer the research questions.

4.3.1 SDN Architecture

The collected data from the interviews shows that the participants have different definitions for the SDN, based on their understanding of the technology.

Participant One defined SDN based on the virtualizing concept, as a technology to virtualize the network, the definition mentioned by (Göransson, Black, & Culver, 2017) in section 3.2 *SDN Architecture.*

The concept of a centralized control plane to facilitate the centralization of the management logic, which is mentioned in the section 3.2 *SDN Architecture* by (Binlun, Chin, Kwang, Yusoff, & Kaspin, 2018) is confirmed by participants Two, Three and Four. All three participants are IT consultancy companies, and they defined SDN by having a centralized controller to manage the network instead of using the traditional management tools.

Participants Five and Six defined SDN as an efficient approach to apply network policies. Additionally, participant Six mentioned the ease concept, which is closely related to SDN, as the concept is mentioned in section 3.4 *SDN Benefits* by (Adrian, Kurniawan, Faza, Maulina, & Shihab, 2020).

Participant Seven defined the SDN as new overlay technologies based on traditional technologies, the same concept is mentioned by (Cox, Chung, Donavan, Ivey, & Clark, 2017) in section 3.2 *SDN Architecture*.

4.3.2 SDN Adoption

Participant One named automation and load balancing as key benefits of SDN. Participants Two and Three mentioned the quality of experience (QoE) as one of the main benefits of SDN. Additionally, the efficiency is a key benefit according to participant Five. These benefits are confirmed by (Deb & Roy, 2022) in section 3.4 *SDN Benefits* when the authors stated that enhancing the QoS and the QoE are advantages of the SDN. From an IT consultancy company's perspective, participants Two, Three and Four mentioned the economy benefits of the SDN, by considering the SDN solution as a desirable service they could provide to their customers. What was mentioned by participants Four and Six regarding the faster delivery and easier scalability is confirmed by (Adrian, Kurniawan, Faza, Maulina, & Shihab, 2020) in the section 3.4 *SDN Benefits*. Improving the monitoring which is mentioned by participant Four is confirmed by (Moser, 2021) in the same section.

The acceptance of the SDN as technology varies between the participants. Participant One has a negative attitude from a specific SDN platform when the solution does not respond to the required business needs. Participants Two, Three and Seven mentioned that adopting the SDN within the Swedish organizations is still in the early stages, participant Two stated that the knowledge gap can be a barrier in the way to adopt an SDN architecture, the level of maturity and knowledge in the organization is discussed by participant Seven in relation to SDN adoption, more about that will be discussed later in section 4.3.6 *SDN Knowledge Gap.* Participants Three and Four showed their acceptance and a positive attitude regarding the SDN as a technology as well the adopted solution.

The presence of an implementation plan is confirmed by all participants, the level of complexity and details varies based on the type of the implementation, more about planning will be discussed further in the section 4.3.7 *Lessons Learned.*

4.3.3 SDN Security Challenges

The security was mentioned by all participants as a major challenge in the SDN, this idea is discussed and confirmed in the section 3.5.1 *Security Challenges.* Participant One highlighted the security challenges when integrating the SDN with other implemented systems. Participant Three stated that the security challenges can have serious consequences caused by the misconfigurations from the centralized controller. Participant Four named the product-related security challenges in the form of firmware bugs, which the organization experienced by the chosen SDN solution. Participant Five briefly stated that the SDN, in general, provides more functions which means more code which causes more potential security threats. Participant Six mentioned that the organization chose to preserve their traditional security solution aligned with the implemented SDN solution as a measure to respond to the security challenges. Participant Seven stated that understanding the new security needs within the SDN can be challenging.

4.3.4 SDN Technical Challenges

In addition to the security challenge which is named by the participants in the section 4.3.3 *SDN Security Challenges* and confirmed by the section 3.5.1 *Security Challenges,* the participants mentioned various technical challenges based on their experience with the chosen SDN solution. Participant Two added the availability as a technical challenge in the SDN, availability is mentioned by the literature as a controller-related challenge in the section 3.5.2 *Technical Challenges*. Participants One, Three, Five and Seven mentioned the troubleshooting as a challenge in the SDN and participants Four and Seven mentioned the complexity, these challenges are confirmed by (Manzalini, Steinert, Sharma, & Marchetto, 2015) in the section 3.5.2 *Technical Challenges.* Participants Two, Five and Six mentioned that adopting SDN can rise an emerging challenge in terms of new way to work which could change the day-to-day operations for the IT-team.

4.3.5 SDN Financial Challenges

SDN deployment can cause a big strain on the organization budget (Sandhya, Sinha, & Haribabu, 2017) as mentioned in chapter 3 *Theoretical Framework*. The data collected presents two contrasting opinions on the financial aspect of SDN. On the one hand, multiple participants that are using an SDN in-house solution pointed out from a consumer perspective that the initial investment is a challenge, and a reason for pause even. On the other hand, IT consultancy companies presented the financial aspect as an advantage of SDN, as it saves money in the long run.

Participant One named this as one of the main challenges when considering adopting SDN, which can cause a pause in the decision. Participant Six confirmed the financial aspect as a challenge as well. Participants Two and Three talked about this from an IT consultancy firm perspective. They both named the financial aspect as an advantage as it saves money in the long run. Participant Two however, named it as a challenge from the perspective of getting the client/consumer to see that the benefits outweigh the initial cost.

4.3.6 SDN Knowledge Gap

As mentioned in chapter 3 *Theoretical Framework*, the know-how represents a big challenge in software defined networking (Horvatha, Nedbala, & Stieningera, 2015). According to research, programmability is named as one of the main knowledge gaps when it comes to traditional network engineers (Contreras, Doolan, Lonsethagen, & Lopez, 2015).

It is evident from the data presented in section 4.2.6 of the *Collected Data* chapter 4.2 that the knowledge gap or the know-how represents a challenge according to the participants. The knowledge gaps were categorized by multiple participants into two categories: Programming/automation knowledge is the first gap, which was identified and clearly mentioned by participants Two, Three, Five and Six. It was mentioned by participant Seven that ready solutions such as Cisco *Application Centric Infrastructure* (ACI) comes with its own set of automation tasks, and therefore programming and custom automation is not really needed.

Even though, participant Six uses ACI which has its own automation tools and does not require programming knowledge as mentioned by multiple participants, the participant did mention a programming knowledge gap that is closely tied to the use of Ansible (configuration management system) with association to SDN. Another gap is advanced routing or deep knowledge of routing protocols, this was identified by participants Two, Three and Six. Participant Three even highlighted the negative effect of the SDN knowledge gap on the security, operation, and implementation of SDN.

Participant Four however did not confirm having a knowledge gap within the team since there were dedicated teams (automation technicians and system administrators) to handle the aspects of SDN that is not familiar to the network teams. The participant then highlighted the learning journey after those teams were no longer available, which does indicate a knowledge gap at that time. Finally, the participant pointed out that a DevOps engineer or even a programmer with basic network understanding would be a better candidate for their organization to work with SDN, than a traditional network engineer. Table 3 presents an overview of SDN challenges as they were mentioned by the participants.

Table 3. SDN Challenges – Overview

Participant	Security Challenges	Technical Challenges	Financial Challenges	Knowledge Gap Challenge
Participant One	Mentioned with no details	Troubleshooting	Additional cost (License)	Mentioned with no details
Participant Two	Mentioned with no details	Availability, New Way of Working	Additional cost (advantage from the provider perspective)	Programming, automation knowledge, Advanced routing
Participant Three	Mentioned with no details	Troubleshooting	Additional cost (advantage from the provider perspective)	Programming, automation knowledge, Advanced routing
Participant Four	Mentioned with no details	Complexity	Not mentioned	Mentioned /Not relevant to the company
Participant Five	Mentioned with no details	New Way of Working, Troubleshooting	Not mentioned	Programming, automation knowledge
Participant Six (Group of three)	Mentioned with no details	New Way of Working	Mentioned with no details	Programming, automation knowledge, Advanced routing
Participant Seven	Mentioned with no details	Complexity, Troubleshooting	Not mentioned as a challenge (advantage from the provider perspective)	Mentioned with no details

4.3.7 Lessons Learned

The data collected from the interviews presents multiple lessons learned addressing multiple challenges. This can be categorized into three categories: *Knowledge Gap, Process Phases and Security*.

Knowledge Gap

The data shows different approaches that are taken by Swedish companies to remedy or overcome the knowledge gap challenge.

Participant Two and Three as consultancy companies do offer workshops to their client when implementing an SDN solution to get their IT team ready to this new way of working. Participant Three encourages their own employees to take IT industry standard certificates to stay current on the latest technologies to remedy this issue.

Participant Four mentioned the use of dedicated teams (automation and system admins) to narrow the knowledge gap within the network team. Furthermore, they recommend having IT organization wide education to spread SDN awareness as it affects the entire IT team way of working, from server infrastructure to application design. This point was also discussed by participant Six, as they mentioned having an SDN increased interdepartmental dialogue.

Participant Seven mentioned the use of online learning platforms such as Pluralsight to narrow the knowledge gap within their organization.

Finally, participants Three, Four, Five and Six stress the importance of external expert help to narrow the knowledge gap during the implementation and initial operation.

Process Phases

All participants agreed on the importance of the planning, designing, and testing phases in the process regarding implementing SDN.

Participant One stressed the importance of testing the whole environment. Participant Three presented a template plan they use as a starting point for SDN implementation. This plan consists of three phases. CMO current mode of operation, which goes over the current state of your network. IMO intermediate mode of operation is the second phase to study both the SDN and current network. FMO future mode of operation, which goes over the future plan and the end goal. Participants Four and Five stressed the importance of a well thought out planning and designing phase. Participant Seven stressed the importance of having a good low-level plan before starting the implementation or the migration to SDN. Finally, participant Six stressed the same point, especially if you are migrating a current infrastructure and not starting new.

Security

Having a separate firewall outside of the SDN solution is one recommendation that was presented in the interview data. This was agreed upon by participants Four and Six as one of the best security decisions taken during the implementation.

5 Discussion

The following chapter discusses the results presented in chapter 4 *Results and Analysis, as* well as the applied research method presented in chapter 2 *Research Method* and used to obtain these results.

5.1 Result Discussion

The purpose of this study is to explore the main challenges in adopting SDN in Swedish organizations as mentioned in section 1.2 *Purpose*. The results are then compared to previous international studies which are mentioned in chapter 3 *Theoretical Framework.* An additional objective to this study is to investigate how Swedish organizations have bridged or attempted to bridge the SDN related knowledge gap.

The results from the analysis of the collected data are discussed below according to the problem formulation and the research questions.

- ***Q1: What are possible new challenges when adopting an SDN solution within the Swedish companies/organizations as compared to the previous international studies?***

The results in the previous chapter were in line with what was expected based on previous studies. The results in this research pinpoint the major challenges in adopting SDN in Swedish organizations. These challenges could be categorized as: *Security*, *Technical Challenges, Financial Challenges and Knowledge Gap*.

We chose to align the classifications presented for the SDN challenges with previous studies which facilitates the comparison. Security as a challenge could be classified under the technical challenges, but it was added as an independent category due to its importance as it was recognized as a key challenge by all participants. *Availability, Troubleshooting, Complexity, and New Way of Working* are parts of the technical challenges category. The *Financial Challenges* are argued based on the provider (IT consultancy) perspective as well as the consumer perspective. The *Knowledge Gap* as a challenge is mentioned and confirmed.

The ***Security*** was recognized as a challenge with a high concern by the participants, this has been revealed by the literature review earlier.

The ***Technical Challenges*** based on the collected data, list the *Availability*, *Troubleshooting* and *Complexity,* all these challenges are mentioned in previous studies and were expected. Additionally, the concept of *New Way of Working* is mentioned as a new technical challenge in comparison to the previous studies. This can be closely tied to the knowledge gap as a direct result. This can be a lack of knowledge to a specific SDN solution or a way of working. In comparison with the previous studies, the absence of various technical challenges within the SDN implementations in the Swedish context

is noticed. The participants didn't mention any *Application-related Challenges* or *Consistency- distributed Architecture Challenges,* the *Controller-related Challenges* were limited to the *Troubleshooting* and *Availability*. This can be argued as a result to the lack of SDN related knowledge or awareness, where the tendency within the Swedish organizations is still towards the traditional network solutions to avoid SDN complexity, without the need for additional customizations, which eliminates previously mentioned challenges according to section 3.5.2 *Technical Challenges*.

The ***Financial Challenges*** in terms of additional costs are mentioned by the participants as well by the earlier studies, the thing that distinguishes this study is having these challenges argued from two different point of views. The provider of the SDN solution which is an IT consulting company as well as the consumer of this technology. The IT consultancy presents SDN as a solution for network expense as it does save on operation cost in the long run. The consumer, however, sees the initial cost as the biggest financial hurdle.

The ***Knowledge Gap*** as a challenge is mentioned by the participants, it is evident from the data collected that SDN solutions such as Cisco Application Centric Infrastructure (ACI) come with its own set of automation tools that require no programming knowledge. Programming and custom automation was still mentioned as a requirement from multiple participants. This indicates that SDN imposes a certain mindset or a way of working that transcends just the network. An example of this is configuration/ orchestration management tools such as Ansible was mentioned as one of the SDN knowledge gaps by participant Six, which is tied closely to programming. This was mentioned from organizations that use Cisco ACI, which does not require Ansible or any third-party tool for automation. This new way of working does require that SDN knowledge or awareness to be transferred to all members of the IT team and not just the network team. This includes the server, storage, and development team, among others.

The results indicate that the participants have different understanding of SDN as an architecture. This in turns influences their acceptance of the technology. Furthermore, it was observed that the acceptance and attitude towards SDN as a technology were influenced by the level of knowledge regarding the SDN.

An important finding in this research is that SDN as a technology is still in the early stages in Swedish organizations. This can to a big degree be attributed to the knowledge gap challenge, where the competences to implement/operate SDN solutions are lacking. This was mentioned by three participants (Two, Three and Seven), the three participants are IT consultancy companies with a deep experience in the Swedish market. The participants relate this phenomenon mainly to the knowledge and competence gap which has been considered earlier as a key challenge. Finally, it was observed that the

knowledge gap can be considered as one of the main contributors to many of the mentioned challenges, both technical and security.

- ***Q2: How did Swedish organizations bridge the skills gap between the IT team and the SDN technology?***

As per the empirical data presented in chapter 4 *Results and Analysis*, it is evident that the knowledge gap within the IT team is one of the main challenges when adopting SDN architecture. This was evident in both the interviews data as well as from previous research. SDN presents more than just a new architecture for the network, but it is a new way of working within the IT and infrastructure team. This was mentioned multiple times by the participants. SDN relies on automation, and that presented as a major advantage of the emerging technology which saves precious time for the operation team.

Programming, automation, and advanced routing knowledge were named as the main skillsets that are required within the network team. The mentioned skills according to the participants, especially the consultancy companies specializing in IT infrastructure, pose the biggest problem when leaving the SDN solution in the hand of the client's IT teams.

There were multiple lessons learned as well as recommendations as to how to overcome the knowledge gap issue. The first recommendations were to use an outside consultant to ensure smooth implementation as well as to give a learning opportunity to the organization's staff to shadow SDN experts and get answers when needed. Another approach was to have dedicated teams from other IT specialties working with your IT team to fill the gap. This was a doubled edged sword when used by participant Four. This can be more of a temporary solution in our opinion if there was no plan to transfer this knowledge during the process. However, if this was used as both help and as an educational mean, it would have made the transition period back to the network team seamless. Finally, having a multiphase process (plan, design, and test) during the implementation process is very important to eliminate any guess work as well as have a well-tested environment before pushing to production.

5.2 Method Discussion

A qualitative approach was used to conduct this research with semi-structured interviews as the data collection method. The interview questions were designed to be open-ended to avoid steering the participants answers. A copy of the interview questions is included in *Appendix 1*. The qualitative approach facilitated a deeper understanding with a wider image of the issues introduced in this study, this was accomplished through using the open-ended questions which allowed the participants

to tell their story in relation to the issue at hand, venturing beyond the current literature (Galletta & Cross, 2013).

Furthermore, through follow up questions, which are adapted to the participants answers, a deeper understanding and a broader picture were made clear. That said, a combination of qualitative and quantitative method would have produced a much larger and clearer result. Using a sequential explanatory strategy to be more specific would allow for a deeper understanding of the phenomenon. This uses a quantitative approach to start with, followed by a qualitative approach taking a closer look and further explaining the issue (Creswell, 2009). The downside to this approach is the lengthy and time-consuming data collection process (Creswell, 2009), which would require a bigger time frame than what is available for this thesis.

Selection is a threat to the internal validity of the research. This simply means that the selected participants do not represent the population or do not have relevant knowledge (Runeson, et al., 2012). A mixed purposive and snowball sampling method was used in the sampling process, with the purposive approach as the dominant one to ensure the participants possess the required knowledge. All participants were chosen based on the purposive method, with the exception of participant Four, which was recommended by participant Three.

Furthermore, having participants that are IT consultancy firms as well as organizations that use an in-house SDN solution, did add contrast to the results through getting answers from IT teams that are new to the technology as well as experts.

Another threat to internal validity is *Maturity*, which basically means that the participant can become bored (Runeson, et al., 2012).Therefore, the interviews were kept as brief as possible approximately 30 to 60 minutes per participant, which was sufficient to be able to have clear and specific answers.

The ethical guidelines were presented at the beginning of all interviews, followed by the interview questions under each category (See *Appendix 1*). Concluding all interviews, the participants were given the chance to assess the questions and add or adjust to their answers. Both authors were present in all interviews which provided a full contribution and understanding for the dialog. After each interview, the data was transcribed, and the recordings were deleted as per agreement with the participants. Furthermore, the participants agreed for the transcribed data to be deleted, once the research is concluded.

6 Conclusion and Recommendations

This chapter presents the conclusion as well as provides answers to the research questions. Furthermore, recommendations for practical and scientific implications are presented. Finally, potential future work is discussed based on the findings.

Q1. *What are possible new challenges when adopting an SDN solution within the Swedish companies/organizations as compared to the previous international studies*?

The study demonstrates that security is considered a key challenge in adopting SDN solutions within Swedish organizations. Based on the findings presented above, the technical challenges mentioned in this research were limited in comparison with previous studies. This could be explained by the limited spread of SDN solutions within Swedish organizations. The concept of new way of working is mentioned as a new technical challenge in comparison with previous studies. The financial challenges in terms of additional initial costs are confirmed to be a challenge by previous research. This research presents the financial challenge from both an IT consultancy perspective and the consumer perspective. On the one hand the IT consultancy companies present the financial aspect as an advantage, while on the other hand it is presented as a challenge specifically the initial cost from the consumer perspective. The knowledge gap confirmed to be a key challenge when adopting SDN and can be considered a major contributor for the limited spread of SDN technology. Finally, the only challenge that can be considered new compared to previous studies is *The New Way of Working* challenge.

Q2. *How did Swedish organizations bridge the skills gap between the IT team and the SDN technology*?

According to the results the knowledge gap consists of the following aspects. A lack of programming and automation knowledge as well as advanced routing knowledge. The research presented clear recommendations to overcome this challenge based on the experiences of the participating organizations. Using a third-party IT consultant was mentioned as one of the main recommendations when lacking SDN knowledge. Having a clear implementation and operation process is the second recommendation for most of the challenges and not just the knowledge gap. This eliminates personal interpretation and provides clear pathway for the staff to follow. A multiphase process was recommended by the participants (planning, designing, and testing). Having an online learning platform that is available to the entire organization was one of the recommendations to narrow the knowledge gap. An in-house workshop with technology experts is another recommendation. Finally, SDN architecture transcends the network team, as it affects most aspects of IT, and therefore spreading SDN awareness across IT teams is very important. Furthermore, cross team collaboration is

an extension of this to minimize any negative impacts on the rest of the infrastructure as a result of adopting an SDN architecture.

6.1 Practical implications

The study presents recommendations that can be used by organizations that are implementing SDN solutions or planning to migrate their network infrastructure to an SDN based architecture. Below are clear recommendations from organizations that went through the SDN implementation and operation process, presenting the challenges they went through and how they overcame some of the challenges, especially the SDN knowledge gap.

- The use of third-party IT consultant
- Having clear implementation and operation plan
- Using a multiphase process to implement SDN
- Having an online learning platform available to the IT team
- Encourage cross-team collaboration and knowledge exchange

6.2 Scientific implications

This research contributes scientifically by providing an updated snapshot of the current challenges associated with implementing SDN within Sweden. Furthermore, this study contributes by providing recommendations to overcome the knowledge gap as a challenge. This was missing from previous studies, as the knowledge gap was not researched in depth.

6.3 Future Work

This research can serve as a starting point to understand the current challenges associated with SDN implementations and how Swedish organizations have dealt with that. Future research can explore the phenomenon further, exploring each challenge in a deeper and more extensive manner providing a clear framework to overcome each challenge. Due to the limited time frame and population sample the phenomenon could not be explored deeper. Having a larger population sample and using a mixed method between both a qualitative and quantitative methods are recommended for more reliable picture, as well as developing a clear theory to generalize to the population. Therefore, this would be the first recommendation for future research.

The security aspect is mentioned as a challenge from several participants but with no specific details. Therefore, deeper research into the details of this challenge within the Swedish context is recommended for future research as well.

Finally, it is evident that there is a knowledge gap among IT teams when it comes to SDN implementation and operation. Therefore, a comprehensive study in network

engineering education is recommended to discover what is lacking and what aspects that can be improve.

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8 Appendices

Appendix 1: SDN Interview Questions

Ethical guideline:

- Interviews will only be recorded upon participant consent.
- The participants will have final review rights of the interview material.
- All participants shall remain anonymous.
- All recorded interviews are to be deleted upon completion of the study, or upon request from the participant.
- The participant has the right to refuse answering any question, as well as retract their answer.
- The participants have the right to back out of the study at any time, should they choose to.

Categories to be included in the interview:

- Participant – related questions
    - What is your job title within the company?
    - What does that entail?
    - What is your educational background?
    - What is your previous technical experience in SDN?
    - Were you involved in an SDN implementation previously?
- SDN definition and understanding
    - How would you briefly define SDN architecture?
    - What is the SDN solution that is implemented or to be implemented in the company?
    - What business goals motivated the move to SDN architecture?
    - Were those businesses goals achieved?
- SDN implementation challenges and experiences questions
    - What was your role in the SDN implementation process?
    - What challenges did you personally as well as on an organization level encountered during the migration/implementation process?
    - According to research knowledge gap is one of the main challenges when implementing SDN. In your opinion, was this true and to what degree?

- If there was a knowledge gap, what were the steps taken by the organization to remedy this?
- Did you have an implementation plan and if yes, what was it and can you describe the planning phase in terms of the used resources?
- To which degree was the management involved the planning phase?
- How realistic was the plan after the implementation?
- What were your expectations and fears prior to the implementation process?
- How did the day-to-day operation differ after implementing the SDN solution in comparison to the traditional way?

- Ways to improve the process
  - In your opinion, how would the implementation plan be improved now that you have went through the process?
  - Was there a specific process set in place by the organization to deal with implementation challenges? If yes, was it effective and why in your opinion?
  - In your opinion what was the best technical and organizational decision taken during the implementation process?
  - If you can give one piece of advice to other organizations attempting to implement the same solution, what would that be?

Appendix 2: SDN interview invitation via E-mail

Subject: Möjligheten för examensarbete intervju

Content:

Hej!

Vi är två studenter (Ahmed Abdelhadi och Mohammed Raoof Fadda) som studerar tredje året på IT-infrastruktur och nätverksdesign vid Tekniska högskolan i Jönköping (JTH). Vi skriver just nu vårt examensarbete om de utmaningarna vid implementering av SDN lösningar inom svenska företag. Vi fokuserar specifikt på kunskapsklyftan mellan en traditionell nätverkslösning jämfört med SDN-lösning som en av huvudutmaningarna.

Inom kort kommer vi att börja genomföra intervjuer, och vi tycker att det skulle vara fantastiskt om er organisation var en av deltagarna, om ni använder eller planerar att använda en SDN-lösning för er nätverksarkitektur. Alla intervjuer kommer att genomföras online via Zoom eller MS-Teams för att göra det enkelt för dig som deltagare. Intervjuerna kommer att genomföras med de som har varit inblandade i beslutet eller implementationen av SDN-lösningen.

Intervjuerna kommer att vara ca 30–60 minuter, per deltagare om det är möjligt.

Om ni har ytterligare frågor, tveka inte att kontakta oss.

Vi ser fram emot att höra från er snart.

Med vänliga hälsningar,

Ahmed & Mohammed