Migration cost optimization for service provider legacy network migration to Software-defined IPv6 network

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Funding information
- NTNU-EnPE-MSESSD program – Norway
- UGC - NP, Grant ID: FRG/74_75/Engg-1
- NAST
- ERASMUS+ KA107
- U.S. NSF CNS 1650831 and HRD 1828811

Summary

This paper studies a problem for seamless migration of legacy networks of Internet service providers to a Software-defined networking (SDN) based architecture along with the transition to the full adoption of the Internet protocol version 6 (IPv6) connectivity. Migration of currently running legacy IPv4 networks into such new approaches require either upgrades or replacement of existing networking devices and technologies that are actively operating. The joint migration to SDN and IPv6 network is considered to be vital in terms of migration cost optimization, skilled human resource management and other critical factors. In this work, we first present the approaches of SDN and IPv6 migration in service providers' networks. Then, we present the common concerns of IPv6 and SDN migration with joint transition strategies so that the cost associated with joint migration is minimized to lower than that of the individual migration. For the incremental adoption of software defined IPv6 (SoDIP6) network with optimum migration cost, a greedy algorithm is proposed based on optimal path and the customer priority. Simulation and empirical analysis show that a unified transition planning to SoDIP6 network results in lower migration cost.

KEYWORDS

Legacy network, SDN, SoDIP6, ISP network migration, migration approaches, migration cost optimization

1 | INTRODUCTION

The 128 bits length IPv6 addressing was introduced[1] in the decade of early 1990's due to the rapid growth of internet users forecasted and depletion of 32 bits IPv4 addressing. The exponential growth of the number of connected devices to the internet, leading to the Internet of things (IoT), wireless sensor networks (WSN) towards smart communities and smart cities leads to increase in the service provider network size, makes the existing system more complex in operation and management. IPv6 network migration world-wide is in progress. After the exhaustion of IPv4 addresses as announced by IANA[2], adoption of IPv6 addressing is becoming compulsory for service providers. Few developed countries have a satisfactory level of IPv6 network deployment, but on average the worldwide IPv6 capability has just crossed 25%[3]. This figure is mostly led by the migration status of developed countries, while the IPv6 adoption rate of developing countries is still below 1%[3,4]. In the meantime, the emerging Software-defined networking (SDN) provides superior network management and controlling features compared to legacy networking systems[5,6]. SDN implementation on data center networks is growing[7], while its implementation in Internet service provider (ISP) and Telecom (Telco) networks is still in early stages[8,9]. IPv6 deals with addressing and routing at the network layer, while SDN deals with the overall network management and control by segregating control plane and data plane of network device; making the network more flexible and programmable. Being interrelated technologies, the migration process towards their adoption have common concerns from various perspectives like lack of skilled human resource, security, quality of service, protocol supports and many more[10]. An IPv6 network fully controlled and managed over an SDN environment is referred to an Software-defined IPv6 (SoDIP6) network[11].

Network migration refers to the transformation of existing networking systems into operable next generation network technologies, either by replacing the existing networking devices/infrastructure or upgrade of hardware/firmware so that operational efficiency can be enhanced. The lack of backward compatibility in both SDN and IPv6 networking paradigms creates a challenging situation for service providers wiling to perform "real-time" migration of their legacy IPv4 networks[12,13]. Migration to new technologies is becoming mandatory for service providers to adapt to global competition and provide efficient services to the users. However, immediate service provisioning of newer technologies might not be practical, due to the need of high investment in network migration to replace or upgrade network devices, transformations in software systems and related services along with lack of skilled human resources (HR) to operate and support the newer networking systems[10,11,14,15]. Hence, for the fairly sustained internet service providers, it is more important to develop the strategic plan for joint migration and optimize the total cost of migration for their future sustainability.

In this paper, in light of SoIP6 network migration, we address the following research questions: (a) what are the steps and strategy for SoDIP6 network migration for service providers? And (b) how does one optimize the overall network migration cost for service providers?

After choosing the best method for gradual migration to SDN and IPv6 networks for service providers, we develop the necessary steps and strategies of joint network migration by considering customer priority and optimal path in the ISP networks as a use case. Then, we develop migration cost optimization model and greedy algorithm for the joint network migration implementation. The proposed approach is evaluated through simulation and empirical analysis. In addition with literature study, in this article, we consider interviews conducted with more than ten technical heads of Nepalese enterprises and service providers to define the joint migration steps and assumptions on migration cost modeling. Overall, this paper has following contributions in joint network migration planning and migration cost optimization.

- Individual migration approaches to IPv6 and SDN are briefly presented. Their interrelationships are identified via joint migration considerations.
- A greedy algorithm is proposed based on customer priority and optimal path for phase-wise service provider network migration with available budget constraints.
- Mathematical modeling and analysis are provided for migration cost estimation and percentage of cost optimization by introducing shared cost coefficient and correlation strength between two paradigms (i.e. SDN and IPv6).
- It is verified that the joint migration to SoDIP6 network optimizes the total migration cost for service providers.

Rest of the paper is organized as follows. Section 2 summarizes the individual migration approaches for IPv6 and SDN with joint migration considerations and related works. Section 3 presents a use case with joint migration strategies as suitable migration approach. Section 4 presents the common cost parameters of both networking paradigms for migration cost modeling and optimization with a greedy algorithm for optimum migration planning. Section 5 demonstrates the simulation results and performs formal analysis with proposed cost optimization model. Section 6 presents the discussions and future works, while section 7 concludes the paper.

2 | LITERATURE REVIEW

The rapid growth of the number of Internet users world-wide with increasing network size has been adding complexities in existing network operation and management[5]. Furthermore, recent advancement on networking and communication technologies raise the adaptability and sustainability issues for network service providers. The ultimate source of economic growth of an organization is the timely implementation of newer technologies for efficient and reliable services that, in fact, changed during the country's economic growth[16]. Customers always demand for efficient and reliable services with reduced costs. Hence, adoption to newer technologies for service providers with their future sustainability are the major concerns. The multiple challenges of control and operations of existing network and lack of sufficient IP addresses limit the growth of network for service providers. IPv6 is regarded as a solution to solve the existing problems associated with limited public IPv4 address space and the other associated issues like network address translations (NAT) proliferation, security, and quality of service. Similarly, the separation of control and data planes in SDN enhances the efficiency of network management enabling programmable, scalable, flexible and more robust network with ease of configuration.

To meet the service standards according to changes in technologies and address customer demands of newer technologies, network migration is one of the best options. Similarly, newer technologies developed are obviously efficient on any aspects like optimization in operational expenditure (OpEX), energy efficiency, operation and control friendliness etc. Less customer demand for IPv6 based services is the major reason that delays network migration world-wide[17]. Similarly, SDN implementation is independent of customer endpoints. It deals with network management that the service provider needs to consider for their service improvement. Hence, SDN in service provider networks takes longer period, same as that for IPv6 adoption world-wide. The lack of several features in vertically integrated legacy IPv4 systems can be avoided by the implementation of fully featured SoDIP6 network[10,11,18,19].

2.1 | Overview of IPv6 network migration approaches

Adoption of IPv6 in real practice not only depends on the status of individual organizations, but also on what others are doing with their interconnected networks[20]. Network migration of an individual ISP could depend on the status of external interconnected networks that influence the speed of migration in the chain[10,21]. Different methods are in practice for migration to an IPv6 network. Tunneling, dual stack, and translations are the three broad categories of IPv6 transition methods.

In tunneling, one packet is encapsulated into the payload of another packet and the encapsulated packet is sent through the public network infrastructure. It ensures the communication between two or more IPv6 only sites located at a far distance over the IPv4 infrastructure, by establishing tunnel end points between IPv6 hosts and the routers[22,23]. In the existing legacy IPv4 networking, IPv6 communication between two IPv6 sites can be achieved using tunneling. In the pre-migration phase, encapsulation of IPv6 packet over IPv4 payload provides a solution to communicate between IPv6 only sites over IPv4-only networks, while the reverse is applicable in post-migration when IPv4 traffic will be encapsulated into IPv6 payload to communicate between IPv4 sites within IPv6 networks. Tunneling methods include configured and automatic tunneling. In configured tunneling, a network administrator configures the tunnel end point routers, and fixes the traffic to route to the proper destination network[22]. In automatic tunneling, a router automatically tunnels the packets according to their destination address to forward the traffic to the destination network. Several techniques are available to implement automatic tunneling of IPv6 packets over IPv4 payload. For example, tunnel broker with tunnel setup protocol[24], TEREDO[25], 4to6[26] as a reverse scenario of 6to4[27], 6over4[28], public 4over6[29] and lightweight 4over6[30], ISATAP[31], DS Lite[32], MAP-E[33,34], 6RD as a rapid deployment approach[35], and IPv4 residual deployment[36] are some tunneling approaches developed for transition.

The dual stack (DS) method is a simple and straight-forward solution for service providers to enable smooth transition of legacy IPv4 network into IPv6 only network. In this approach, every device should be able to process both IPv4 and IPv6 packets[37]. Either only one stack can be enabled at a time in the network, or both stacks can be activated based on the requirements. Migration to a DS network is a safe and comfortable approach for service providers to provide reliable and uninterrupted services to customers of their choice.

Translation enables conversion of IPv4 headers into IPv6 headers and vice versa. All the IP/ICMP headers are translated at the border between the IPv4 and IPv6 sites[38]. Different translation techniques are defined and implemented for transition of service provider networks. For example, IVI (stateful and stateless)[39], NAT64[40] with DNS64[41], NAT46[42], 464XLAT[43], CGNAT[44], NAT444[45], double NAT64 (also known as NAT464)[46], and MAP-T[47] are translation approaches developed for transition.

Details about IPv6 migration methods with their benefits and drawbacks are discussed at different literature[2,48]. Tunneling approaches do not encourage for the network migration. Because, tunneling simply provides the route for tunneled IPv6 traffic over legacy IPv4 infrastructure from source to customer endpoints. Tunnel endpoint router has performance bottleneck. It gives short term solution to provide IPv6 based services to customers, while ISP networks still operate with legacy IPv4 networking system. Similarly, translation mechanisms are also short-term solutions and applicable until the interconnected ISP networks are not migrated to IPv6 operable networks. Boarder routers that perform translations have performance bottleneck as well as this approach does not support advance applications for end-to-end communications. Dual stack approach provides the long term solutions that every device operates on IPv4 and IPv6 networking. ISPs can decide suitable time to switch-off the legacy IPv4 and operate over IPv6 only network. The drawback of dual stack is that every device runs dual systems that create device performance issues. Additionally, this approach is not applicable to expand new network because of depletion of public IPv4 address. But for the migration of existing network devices, dual stack is considered as the smooth and safe transition method for service providers. Both stacks will operate during the transition periods only, while to avoid the dual stack network operation costs, service providers can switch-off the IPv4 stack after complete migration to IPv6-only network. Hence, in this article, we considered dual stack approach for migration.

2.2 | Overview of SDN migration approaches

The removal of the control plane from each switch/router and integration into a single controller that manages and controls the data planes devices is the approach endorsed by the SDN. The decoupling of control and data plane avoids the operational complexities of vertically integrated legacy IPv4 networking system. The superior features of SDN such as better control of the network with optimized OpEX enables service providers to migrate their legacy networks into SDN[49,50]. But, same as IPv6 migration, immediate migration to SDN is not viable. Three approaches of legacy network migration to SDN proposed by ON.LAB[51] are: (a) Legacy to Greenfield (L2G), (b) Legacy to Mixed (L2M), and (c) Legacy to Hybrid (L2H).

The L2G approach is applicable when creating a new network or expanding a network that involve a completely new SDN based infrastructure. L2G prefers replacement of existing legacy devices with SDN enabled devices. However, complete replacement of network devices at once is not viable for service providers due to higher costs. Service providers can implement this approach for a pilot test and experimentation as well as for expansion of new networks.

The L2M approach enables a gradual migration of an existing network. The set of routers/switches in a single autonomous system (AS) might have a mix of legacy and OpenFlow enabled devices. In this approach, an interoperability between legacy and OpenFlow devices has to be ensured. SDN-IP implementation over ONOS provides the mixed types of communication in the multi-domain routing environment[50,52,53].

The L2H approach requires both legacy routing table and OpenFlow table to be maintained by a single router. This is in fact, a dual stack approach like dual stack IPv6. The decision to activate legacy or OpenFlow communication is based on where the traffic to be destined. Experiment by ON.LAB[51] and studies by different authors[54–58] indicates that migration to a hybrid network is viable. The L2M approach is also treated as L2H approach in some literature[15,59]. During the incremental deployment, the target network will have mix of both legacy and SDN enabled devices until the network is completely migrated to SDN and the network handles both legacy and OpenFlow traffic during migration. Note that OpenFlow is the south-bound API of SDN that defines the way the controller should interact with the forwarding plane, as we are dealing with the migration of data plane devices which is more related to support of OpenFlow protocol to operate over SDN environment. The terms 'SDN' and 'OpenFlow' are used synonymously in this article.

SDN increases automation in network management and operation with less human intervention that can help to reduce capital and operational expenditures (CapEX/OpEX) of the organizations[49,60,61]. Hence, it encourages service providers to search for better options and attraction towards SDN. Besides implementation challenges[57,62], the SDN standard is promising for efficient network management because it solves existing issues of legacy networks and creates highly flexible, visible, programmable, scalable, modular, open interface and abstraction-based networks[51,63]. Migration to SDN for data center networks is popularly endorsed[56,64,65]. Similarly, practices[51,65–71] of ISP/Telco and data center networks migration to SDN and IPv6 encourage service providers to migrate their legacy networks in a phase-wise manner. For smooth and cost effective transitioning, the L2H approach is more suitable for service providers[15,72]. In this article, we consider L2H as a suitable method for migration of legacy networks into SDN.

2.3 | SDN and IPv6 network joint migration considerations

In section 2, we went through a brief review on IPv6 and SDN migration approaches separately. In this section, we discuss the interrelationship and common concerns between IPv6 and SDN so that our assumption on joint migration cost modeling will be more justifiable.

The sufficiency of IP addresses provisioned by IPv6 allow for the evolution of IoT and WSN. Similarly, the programmable networking features of SDN help to introduce smart behaviors on every device. Figure 1 shows the amalgamation of networking paradigms and their operations with services into layers. IPv6 and SDN are interrelated because IPv6 deals with routing and addressing in the IP layer, while SDN deals with the controlling of networking operations as a networking management layer. Those technologies that are recognized in the network operation layer are operated by service providers. The customer services to be provided by ISPs and Telcos are service layer activities.

FIGURE 1 Layered view of SoDIP6 network

Existing network operators are migrating their networks into IPv6 operable networks. Meanwhile, the emergence of SDN has created additional challenges for network operators to migrate their networks to SDN environment. Both being underlying network layer paradigms, some common issues can be clearly seen between IPv6 and SDN. These include security, quality of service, migration cost, skilled human resources, protocols and application supports, suitable planning and strategies for migration, service continuity and many more[11]. With all those concerns, total cost of investment become the major issue for every service provider. Because the cost involved hardware/software upgrade, device replacement, technical HR development and even to develop the security appliances with service continuity as a part of CapEX and OpEX. In this regard, considering migration planning of two paradigms as a joint migration would help to reduce the organizational costs. Hence, we introduce a cost modeling and optimization approach for joint migration to SDN and IPv6 operable networks in section 4.

Different transition approaches discussed in previous sub-sections 2.1 and 2.2 for IPv6 and SDN are not mutually exclusive. Most of the approaches are adapted by different organizations worldwide[8,73,74]. Implementation of transition mechanisms depends on the current status of the ISP and its interconnection with other interconnecting ISPs. After investigating through different transition approaches for SDN and IPv6 both, in this article, we consider joint migration to dual stack IPv6 and hybrid SDN[67] known as dual stack SoDIP6 network, in joint migration modeling and cost optimization for smooth transition.

2.4 | Related works in SDN and IPv6 network migration cost optimization

In this section, we first present related work on techno-economic aspects of SDN and IPv6 network migration. Then, we focus on related work on SoDIP6 network migration cost optimization.

Technically viable and economically feasible solutions should be adapted while considering technology migration. Hence, cost of migration plays vital role together with the readiness parameters in terms of applications, protocol supports, and technical human resources. Some papers[75,76] discuss the economic aspects of IPv6 network migration, where some cost benefit analysis are presented for different stakeholders, considering the fundamental principle of Probit model, that adaptation to newer technologies are viable if revenue exceeds expenditure. This applies to all kinds of networks, internet and content service providers for their sustainability. Measuring the tangible benefits of SoDIP6 network migration is fairly complex because of its focus on efficiency of network operation, management, security and quality of service, where direct measurement as a source of revenue is difficult. But, the benefits of SoDIP6 network include major contributions in organizational CapEX/OpEX optimization[49,77] that are notably considered.

NIST[78] has presented an economic impact analysis of IPv6 network surveying stakeholders including service providers, and hardware and software vendors. Csikor L et al[58] presented a cost-effective solution with respect to hardware appliance upgrade in SDN migration. Some researchers[79–81] have presented the techno-economic aspects of SDN migration.

Backbone network migration with better resource utilization using heuristic solutions including different genetic algorithms (GA) are presented by Türk S et al[82]. The authors simulate the scenario for a period of five years over ISP backbone networks and claim that a crowded DPGA gives better result for optimum cost and resource utilization. Additionally, Türk S et al[83,84] present studies based on network migration optimization using meta-heuristics and optimization of network migration cost using memetic algorithm[85]. This study provides solutions to network service providers about when to migrate a network router in terms of CapEX, OpEX and ImpEX optimization. Shayani D et al[86,87] presented a service migration cost model using queuing theory and hill-climbing optimization for reduced operation cost and optimization of human resource allocation to migrate traditional telecommunication networks into next generation networks. A study from the perspective of techno-economic analysis to reduce CapEX/OpEX via SDN and NFV in mobile network operation is presented by Naudts B et al[88]. Lähteenmäki J et al[89] discussed an activity based cost modeling for network service provider cloud platform, in which cost is considered with respect to activities that generally does not address administrative cost. This is not also the case presented from the perspectives of network migration and it lacks incremental costs during incremental deployment of network devices in the long run.

Most of the earlier studies related to cost optimization were focused either on single technology migration or on different telecommunication networks. Das T et al[80] presented the multi-technology migration using an agent-based modeling technique that joint migration is more beneficial than single technology migration in terms of cost optimization. A preliminary analysis with economic model[90] of SoDIP6 network migration and continuity to detail formal analysis for migration decision to be taken with suitable strategy at proper time for nationwide interconnected ISPs to migrate their legacy networks into SoDIP6 networks from the evolutionary gaming approach was presented in our previous work[10]. To the best of our knowledge, there are limited studies on ISP network migration cost optimization considering different technologies. We are the first to propose feasible approach for joint migration planning of SDN and IPv6 in service provider networks.

ISP networks are generally heterogeneous in nature with dynamic characteristics of network devices. Due to the complexity of cost metrics identification for joint technology migration and the lack of real dataset, we apply a mathematical method in this article to design an optimal system[91]. Hence, we choose an optimal path calculation as a critical path method to find optimum number of routers to be migrated and implement an integer linear program (ILP) to optimize total migration cost. This article is focused to present a techno-economic aspects of joint migration to SoDIP6 network with suitable migration strategy and cost optimization in service provider networks.

3 | OUR SODIP6 NETWORK MIGRATION STRATEGY

In this section, we develop the strategy with basic migration steps by considering a use case of a migrant network by considering customer priority and the optimal path that the service provider needs to follow for migration planning. We also present permissible states and feasible transition paths to migrate legacy network into operable SoDIP6 network.

Up to date information management of network devices is the pre-requisite for service providers to gain detail knowledge of existing network devices so that proper migration planning can be achieved. The inventory of hardware and software details help to identify whether any network device can be upgraded or should be replaced with new one to make it capable to operate with newer technologies. Device status identification, budget estimation, plan for upgrade or replacement, and implementation of the plan are the major steps for network migration. The plan requires service providers to maintain an inventory of network devices and infrastructure to monitor the status using suitable management tools[92–94]. The overall steps for network migration are depicted in Figure 2. Service providers first identify the detail router status, and then identify whether the running routers are to be replaced or its firmware/hardware upgrade is sufficient for migration. In the status identification step, total number of routers to be replaced or upgraded is identified, and then assessment of technical HR with total cost of network migration is identified. Hardware upgrades generally means increase of memory, processing and input/output capacity of the router. For the inter-network operating system (IoS)/firmware upgrades, it is required to ensure support for IPv6 routing and forwarding as well as OpenFlow supports in SDN environment, security and quality of service policy, applications and protocol supports by the upgraded device. Although Figure 2 looks generic in nature for any kind of technology upgrades that service providers could follow, at a deeper level, the steps are followed by ensuring IPv6 and SDN supports based on this joint network migration. Our study in this article is objectively focused on the router upgrades or replacement cost optimization, because migration cost identification and optimization is considered one of the major tasks in the migration steps for service providers to be executed before deployment. To evaluate this task, we consider the ISP network scenario of Figure 3 as a research use case.

FIGURE 2 Network migration steps for service providers

As a use case, we consider a local ISP network that provides different services to its clients. ISPs provide the services to customers based on service level agreement (SLA). They also maintain the priority of customers according to services provided as per the SLA. ISP maintains information to answer the questions such as "who are the prioritized customers that need SoIDP6 based services, and how many routers in the optimal paths are to be migrated?" The service provider network is considered as an Autonomous System (AS) in which the ISP is planning to migrate this network into SDN enabled IPv6 network. We assume the legacy to hybrid approach to migration so that each router, once migrated, is able to operate with legacy and SDN/OpenFlow standards as well as to operate with both IPv4 and IPv6 addressing as a dual stack router. The end routers connected to customer endpoints are the customer edge (CE) routers and the border router connected with foreign network is called a gateway router. For example, in Figure 3, routers E, L, K and J are CE routers and router A is a gateway router.

FIGURE 3 Use case scenario of customer priority and optimal path routing based ISP network migration scenario

In the initial migration planning phase, suppose 'Bank' is the first priority customer to whom the ISP should provide SoDIP6 based services. In this case, the CE router is L. Hence, the set of routers in the shortest path from L to A is identified with their statuses and optimum cost of migration is estimated. Suppose that, in Figure 3, router L to A has the shortest path identified as [L,F,C,A]. Based on the available migration budget, these routers are migrated to SoDIP6 network and the SDN controller is activated with this migration. In the next phase of migration, another priority customer (e.g. 'University') is set. In this phase, routers in the shortest path from CE router 'K' to gateway router 'A' are [K,G,C,A] in which, routers C & A are already migrated and only two routers K and G are to be migrated. In this phase of network migration, total routers to be migrated are fewer than the total routers in the identified shortest path. Additionally, the routers that are not migrated in the previous phase will be migrated in the next phase migration, because the number of routers to be migrated in the shortest path will be in decreasing order. This approach of migration planning according to budget constraints, customer priority and shortest path encourage for phase-wise smooth transitioning to SoDIP6 networks for service providers. Quality of service with respect to traffic engineering and budget constraints are the major factors in making migration decisions[81,95,96].

After complete migration, with the better efficiency and operational control over the migrated network, the legacy IPv4 stack is smoothly disabled from the quad stack (IPv4, IPv6, Legacy & SDN) routers based on the availability of SDN and IPv6 only network and services with interconnecting external networks. The existing legacy network routers in ISP networks are heterogeneous in nature with different device characteristics like different product versions, firmware, vendor specific configuration etc. Hence, migration cost identification is fairly complex and challenging. We simplify the cost estimation approach by considering set of parameters to fit into our model and apply integer linear programming. The model developed is for legacy to SoDIP6 network migration, where the network routers once migrated are able to operate with quad stack i.e. IPv4 routing (I4), IPv6 routing (I6), legacy or traditional network (TN) and the SDN (SD). The possible transition steps from legacy to quad stack SoDIP6 and finally to DS (IPv6 and SDN only) SoDIP6 network is presented in Figure 4 with list of permissible states as transition state matrix in (a) and a transition state diagram in the form of an acyclic graph in (b).

At the beginning, an ISP network is in the early stage operating in the state of legacy IPv4, indicated by the starting state in Figure 4 (b). In this case, in the binary representation, the flag for I4 and TN is 'ON' and hence, the initial state of [I4, TN, I6, and SD] is '1100'. Similarly intermediate state '1111' has complete SoDIP6 network at which, all technology flags (I4, TN, I6, SD) are 'ON'. Final state (0011) is the complete migration to SDN and IPv6 only network at which, TN and I4 are switched off. For the transition planning from initial state (1100) to intermediate state (1111) and then to final state(0011), there are several paths, where the transition costs varies accordingly based on the choice of available paths during migration. The practice of SoDIP6 migration depends on the choice of path of transition by ISPs according to possible paths presented in Figure 4(b). For the joint migration planning, service provider has to choose states like [1100, 1111, 0011], [1100, 1111, 1011, 0011] and [1100, 1111, 0111, 0011], while other optional paths provide the individual migration sequence. Transitioning from initial state '1100' to state '1111' gives the joint migration approach, while the disabling of legacy/IPv4 stacks to reach to final state could be any optional paths as indicated in Figure 4(b). For example, if an ISP choose the migration paths [1100, 1111, 1011, 0011], the migration actions are (i) enable IPv6 and OpenFlow towards quad stack network at state '1111', (ii) turn off legacy networking management to state '1011' and (iii) turn off legacy IPv4 to reach to final state '0011'. The data plane devices at state '1111' is enabled with legacy IPv4/IPv6 routing features for recovery purpose[97]. With the defined transition strategies stated as joint transition paths as shown in Figure 4, we present a greedy algorithm for phase-wise network migration with mathematical model for joint migration cost optimization in section 4.

FIGURE 4 Permissible transitions (a) list of state matrix (b) feasible transition paths (acyclic graph)

4 | MIGRATION MODELING AND COST OPTIMIZATION

This section formalizes the migration strategy discussed in section 3 as a mathematical model with an ILP formulation and presents a greedy algorithm for migration cost optimization.

Some of the research studies[79,80,98] show that joint transition to correlated technologies is more beneficial than individual migration. Hence, we expect that joint migration to SDN and IPv6 network is more cost effective than the individual migration. We justify our expectation by introducing parameters like shared cost coefficient (μ) and strength of correlation ($\in$) between SDN and IPv6. The Shared cost coefficient measures the optimum cost of joint migration. For example, hiring skilled human resources (HRs) to operate and manage newer technologies incurs higher cost. If a technical HR is trained for SDN operation then the same HR can be assigned to IPv6 network operation, if resources for both technologies are shared during training. This means, instead of running separate training programs for HR development to handle SDN and IPv6 network, a combined training can be conducted because, the HR of network operation team as a whole looks after all the operational and managerial issues of addressing, routing, control and troubleshooting. OpenFlow version 1.3 and beyond supports IPv6[99]. This helps to have joint migration to SoDIP6 networks. Under the different categories of cost metrics defined in different literature[49,60,100], we consider cost metrics associated to technology migration, while most of these are obtained from interviews with technical head of enterprises and internet service providers. The cost metrics and their symbolic notations are defined in Table 1. We have adapted those cost metrics and mathematical models from our previous preliminary work[101].

TABLE 1 Cost metrics and their symbolic notation for individual and joint migration to SDN and IPv6

It is viable to upgrade the IoS/Firmware of existing legacy network devices[15,102]. But, lack of IoS/Firmware upgrade leads to the decision for hardware replacement. A decision coefficient $x_{\alpha_i} \in [0,1]$ for IPv6 and

$x_{\alpha_s} \in [0,1]$ for SDN is separately defined for IoS/Firmware upgrade, while joint decision coefficient $'x_\alpha'$ is introduced as:

$$x_\alpha = x_{\alpha_i} \wedge x_{\alpha_s}$$

Similarly, if x_{β_i} and x_{β_s} are the decision coefficients for hardware replacement for IPv6 and SDN, then the decision coefficient for SoDIP6 $'x_\beta'$ for hardware replacement is defined as:

$$x_\beta = x_{\beta_i} \vee x_{\beta_s}$$

This joint migration decision coefficient is derived from the individual migration such that IoS/Firmware upgrade for both technologies should be true, while the hardware upgrade is common for both. Hence, for individual and joint migration, every network router is upgradable or replaceable, is defined by:

$$x_{\alpha_i}, x_{\alpha_s}, x_\alpha = \begin{cases} 1, & if\ upgrade\ is\ true\ and\ upgrade\ cost < replacement\ cost \\ 0, & else\ (replacement) \end{cases}$$

Due to dynamic device characteristics, upgrade or replacement cost estimation of individual network router is a complex task. Hence, we simplify the total cost estimation based on the individual router migration cost. Total cost estimation is generalized in terms of number of routers set to be migrated in a phase. Here, total migration cost towards IPv6 network of N routers is:

$$\tau_i^r = f(cost\ entities)_{IPv6} = \sum_{i=1}^{N} \{x_{\alpha_i}(\alpha_i + x_{\beta_i} \cdot \beta_i) + \neg x_{\alpha_i} \cdot \theta_i + \gamma_i + \delta_i + \sigma_i\} \quad (1)$$

Total router migration cost for SDN of N router is given by:

$$\tau_s^r = f(cost\ entities)_{SDN} = \sum_{s=1}^{N} \{x_{\alpha_s}(\alpha_s + x_{\beta_s} \cdot \beta_s) + \neg x_{\alpha_s} \cdot \theta_s + \gamma_s + \delta_s + \sigma_s\} \quad (2)$$

If the number of routers to be migrated in an ISP network are homogenous based on their device characteristics and vendor support provided, in the worst case, if two technologies are independent, then total cost of migration would double the cost of individual migration.

Total cost of migration$(\tau_{si}^r) \leq$ [cost of IPv6 migration (τ_i^r) + cost of SDN migration (τ_s^r)]

By considering interrelated technologies [98,101], for joint migration, we introduce shared cost coefficient(μ), known as optimization variable which provides the coupling between SDN & IPv6 and strength of correlation (ϵ).

I.e. minimize $\left(\frac{1}{\mu}\right)^{\epsilon} (\tau_i^r + \tau_s^r)$, subject to $1 \leq \mu \leq 2$ & $0 \leq \epsilon \leq 1$ (3)

The interpretations of two optimization variables viz. shared cost coefficient (μ) and strength of correlation (ϵ) are provided at Table 2.

TABLE 2 Interpretations of μ and ϵ with their different combination of values.

From a migration perspective, considering different cost metrics, SDN and IPv6 are not mutually exclusive. They are correlated so that the shared cost coefficient 'μ' lies between 1 and 2, while strength of correlation lies between 0 and 1. Hence, in normal scenario, $\tau_{si}^{r} < 2\tau$ holds true. Based on equation (3), the individual cost entities can also be modeled as follows:

$\gamma \leq (\gamma_i + \gamma_s) \cong \left(\frac{1}{\mu}\right)^{\epsilon} (\gamma_i + \gamma_s),$

$\delta \leq (\delta_i + \delta_s) \cong \left(\frac{1}{\mu}\right)^{\epsilon} (\delta_i + \delta_s),$

$\sigma \leq (\sigma_i + \sigma_s) \cong \left(\frac{1}{\mu}\right)^{\epsilon} (\sigma_i + \sigma_s)$, and

$\alpha \leq (\alpha_i + \alpha_s) \cong \left(\frac{1}{\mu}\right)^{\epsilon} (\alpha_i + \alpha_s),\ subject\ to\ 1 \leq \mu \leq 2$

For $\beta_i = \beta_s = \beta$ (hardware upgrade cost for both technologies is considered as single upgrade). Hence, from the derivation of individual cost metric, equation (3) can be revised as shown in equation (4).

$$\forall[\alpha, \beta, \gamma, \delta, \sigma] \geq 0, minimize\ \left(\frac{1}{\mu}\right)^{\epsilon} (\alpha + \beta + \gamma + \delta + \sigma), \text{ Subject to } 1 \leq \mu \leq 2 \quad (4)$$

Router replacement cost indicates the purchase of new router. If replacement is true, then the hardware and software upgrade cost is set to false. Hence, $\neg x_\alpha$ is represented as the complement of x_α. The total joint migration cost is the function of six tuples $(\alpha, \beta, \theta, \gamma, \delta, \sigma)$ presented in equation 5.

$$\tau = f(\alpha, \beta, \theta, \gamma, \delta, \sigma) = \sum_{k=1}^{N} \{x_\alpha (\alpha + x_\beta \cdot \beta) + \neg x_\alpha \cdot \theta + \gamma + \delta + \sigma\}_k \quad (5)$$

Hence, for the homogenous network devices, total optimized cost of N routers migration based on equation (3), (4) and (5) is calculated as:

$$\tau = \sum_N \left(\frac{1}{\mu}\right)^{\epsilon} \{(x_\alpha \cdot \alpha + \gamma + \delta + \sigma) + x_\alpha \cdot x_\beta \cdot \beta + \neg x_\alpha \cdot \theta\}, \text{ subject to } 1 \leq \mu \leq 2 \quad (6)$$

Equation (6) provides the optimization in joint migration to migrate N routers. Due to budget constraints, migration of all N routers at a time might not be viable for service providers. Our criteria for migration planning is the phase-wise migration based on shortest path and customer priority. Equation (6) is modified to fit into the criteria that K numbers of shortest paths are identified based on customer priority. Hence, the entire network can be migrated over K number of phases. If N_i is the number of routers to be migrated in the i^{th} migration phase of K shortest paths, the optimization in total migration cost is provided by equation (7)

$$\tau = \sum_{i=1}^{K} \sum_{j=1}^{N_i} \left(\frac{1}{\mu}\right)^{\epsilon} \{(x_\alpha \cdot \alpha + \gamma + \delta + \sigma) + x_\alpha \cdot x_\beta \cdot \beta + \neg x_\alpha \cdot \theta\}_j, \text{ subject to } 1 \leq \mu \leq 2 \quad (7)$$

By considering the optimum migration cost as formulated in equation (7), Algorithm 1 presents the overall steps of ISP network migration, while Table 3 presents the list of notations used in Algorithm 1.

TABLE 3 Notations used for Algorithm 1

Algorithm 1 Greedy algorithm for phase-wise migration to SoDIP6 networks

5 | SIMULATIONS AND ANALYSIS

A complete simulation environment has been created using Python programming language. The network is visualized using Python NetwokX and Matplotlib modules. The system architecture simulation setup is as shown in Figure 5.

Network graphs in the form of CSV or GML file can be loaded in to the system. The device SNMP details are stored in JSON file format and the data are mapped randomly to each routers. To identify the router status, whether it is upgradable or replaceable, is not in the scope of this paper. Hence, status of routers are also randomly assigned. Similarly, details of customer records available in the CSV format are mapped only to the CE routers. The priority routers list is generated and fetched in a sequence for shortest path calculation. List of routers in the shortest path between the highest priority customer-end router and ISP gateway router has been identified. Cost profile generator module selects the value of shared cost coefficient and strength of correlation with value for each cost metric defined. Total cost of migration in the shortest path is then calculated and compared with available organizational budget for migration. The algorithm then runs for the next shortest path with next priority customer and estimates the migration cost with optimization accordingly.

FIGURE 5 System model simulation environment

5.1 | Data preparation for simulations

Based on the cost metrics identified for the unified migration to SoDIP6 network, the cost of networking device (such as router) migrations are first determined by acquiring the domain knowledge obtained by surveying with internet/telecom service providers. We assume that one human resource can handle ten routers for its operation/management including server systems management with latest technologies. HR development to operate the internal networks, product development as well as internet service provisioning costs are comparatively higher than other costs. IoS/firmware upgrade cost is comparatively less and negligible because of vendor neutral solutions available with SDN. However, to upgrade the proprietary products like CISCO/JUNIPER switches and routers, per license IoS upgrade or features addition cost is considered. We also referred other literature[88,89,103] to identify the cost metrics and assumed the cost for each metric defined as shown in Table 4. These are the shared cost considering both networking paradigms.

TABLE 4 Individual router migration cost assumption for defined cost metrics

The algorithm was tested by extensive simulations with four types of network topologies, while three standard network topologies were downloaded from internet topology zoo (www.topology-zoo.org). The first topology has 8 nodes and 13 links randomly generated by python script using NetworkX module in Mininet. The second network topology is the Abilene network having 11 nodes and 14 links. The third topology is the Xeex network having 24 nodes and 34 links and finally, fourth topology is the BtAsiapac Network having 20 nodes and 31 links. Appendix 1 provides the customer priority database, prepared for simulation based on the given network topologies.

5.2 | Results and analysis

Our simulation results show that the migration cost optimization varies with respect to different combinational values of shared cost coefficient (μ) and the strength of correlation (ϵ) as shown in Figure 6. Smaller values of ϵ, for example, ϵ at 0.2 gives less correlation meaning that total joint migration cost is almost equal to the sum of individual migration costs. For higher values, e.g. ϵ at 1.0 with $\mu = 2$ for two technologies, joint migration cost is almost equal to the migration cost of a single technology. Optimum migration cost can be achieved at $\mu = 2$ and $\epsilon = 1.0$ at which the total joint migration cost is optimized by 50% as shown in Figure 7. But, this is an ideal situation, where IPv6 and SDN are fully correlated/coupled and treated as a single technology. All the cost estimations in this results are plotted at $\mu = 2$ for the two technologies (SDN & IPv6). Setting the correlation strength (ϵ) value from 0.4 to 0.7 gives more realistic estimations in practice. Hence, at $\epsilon = [0.4, 0.5, 0.6, 0.7]$, total joint migration cost optimization of 12.94%, 29.29%, 34.02% and 38.44% respectively can be achieved.

This approach is also suitable for budget planning in a phase-wise migration and hence, service providers can schedule the migration with their available budget constraints. The graphs of Figure 8 (a) shows that 8 routers in random network are migrated in 3 phases in which, 3 routers are identified to be migrated in the first phase shortest path. Similarly, list of other routers to be migrated in the second and third phases are identified. Further, Figures 8(a), 9(a), 10(a) and 11(a) show the number of routers to be migrated in the set of corresponding phases and its shortest path, while Figures 8(b), 9(b), 10(b) and 11(b) show the distributions of budget required to migrate those routers with percentage of total cost expected to be optimized in the joint migration. It also shows that the migration cost per phase migration are generally found to be decreasing. This creates a favorable situation for ISPs according to budget constraints in the migration planning. 11 routers in Abilene, 24 routers in XeeX and 20 routers in BtAsiapac networks are set to be migrated at 4, 13 & 14 phases respectively. The number of routers to be migrated in a phase depends upon the choice of ISP gateway router. Similarly, the number of phases identified are based on the customer numbers with their priorities. Changing the gateway changes the shortest path from CE router to the gateway. Hence, it directly affects the number of phases at which the network is to be migrated. We assumed '*Chicago*' '*Chicago*' and '*Singapore'* as the gateway routers on Abilene, Xeex and BtAsiapac network respectively.

FIGURE 6 Migration cost profiles with respect to shared cost coefficient (μ) and strength of correlation (ϵ)

FIGURE 7 Percentage of total joint migration cost optimized at μ = 2 (SDN + IPv6)

FIGURE 8 Number of routers identified to be migrated per phase shortest path – (a), and optimum cost of migration per phase shortest path – (b) for Random Network (8 nodes 11 links)

FIGURE 9 Number of routers identified to be migrated per phase shortest path – (a), and optimum cost of migration per phase shortest path – (b) for Abilene Network (11 nodes, 14 links)

FIGURE 10 Number of routers identified to be migrated per phase shortest path – (a), and optimum cost of migration per phase shortest path – (b) for XeeX Network (24 nodes, 34 links)

FIGURE 11 Number of routers identified to be migrated per phase shortest path – (a), and optimum cost of migration per phase shortest path – (b) for BtAisapac Network (20 nodes, 31 links)

Due to random assignment in the simulations, some routers are set as upgradable, while some are set as replaceable. Hence, cost of migration in the initial phases might be high because a higher number of routers could be identified for migration. On the other hand, the graphs (Figure 8b, 9b, 10b & 11b) of optimum migration cost show that each phase migration budget might be different even if the number of routers to be migrated are same. For example, in Figure 10(a), the number of migrant routers in 9^{th} and 12^{th} phase shortest paths are the same, but Figure 10(b) shows that 12^{th} phase migration incurs lower cost as compared to 9^{th} phase migration cost against same number of routers are set to be migrated. This indicates that routers in the 12^{th} phase migration are identified as upgradable. Similarly, in Figure 11, 5^{th} and 11^{th} phase routers are identified as upgradable so that the cost of migration in the graph of Figure 11(b) is less as compared to others in the subsequent migration phases. According to Table 4, upgrade cost is less than replacement cost and hence, estimated costs will be fluctuated on every new execution of the simulation due to random assignment of router status. The fact that upgrade cost is less than the replacement may create decision space for service providers to encourage themselves to apply another strategy that all the upgradable routers shall be transformed to SoDIP6 capable routers first and then replace remaining routers with the remaining budget. Because with the available budget, more routers can be upgraded instead of replacement.

6 | DISCUSSION AND FUTURE WORK

The increasing number of internet users and the infrastructures world-wide have created challenges to service providers to maintain and operate their networks with increasing complexities and higher cost of operation. SDN and IPv6 are the two well-known emerging networking paradigms currently under deployment for which service providers need to migrate their existing legacy networks into such operable new networking paradigms. The layered view of SoDIP6 network depicted in Figure 1 shows the interrelationship between SDN and IPv6, with brief discussions on different transition techniques for IPv6 and SDN in section 2. This motivated the need for joint network migration in terms of proper migration planning and cost optimization. Figure 2 depicts the basic steps in network migration to be considered by ISPs followed by permissible transition paths presented in Figure 4 including phase-wise migration process presented in Algorithm-1. This provides the guideline for ISPs to proceed for joint network migration planning. The choice of our migration strategy is governed by customer's demand, organization budget constraints, and optimal path with migration cost optimization in the joint migration.

There are some studies planning migration based on time constraints and budget[104], link utilization minimization and upgrade budget as resource constraints[59], hybrid SDN migration consideration and energy optimization using genetic algorithm[105], and incremental deployment based on least cost path and budget constraints[79]. In the above studies, basically budget constraints and traffic engineering considerations like link utilization and least cost path were considered to replace legacy router to migrate to SDN. None has provided actionable approaches and steps for migration implementation with estimated cost required for transitions. Additionally, all are limited to single technology migration. Following the joint technology migration, we considered not only the replacement of routers but also focused on possible hardware/firmware upgrades for migration cost optimization. We used priority customers with their service demands as a base line strategy for migration planning with least cost path considering traffic engineering and budget constraints. Further, our approach is not limited to time constraints. As the service providers can plan the migration setting time constraints on which link to migrate first and when, based on customer demand. Thus, links related to highly prioritized customers can be chosen for migration in the first year and consequently to other secondary priority customers in the following years. After the migration steps are defined, cost estimation and optimization model in section 5 with result and analysis in section 6 presented the percentage of cost optimized in joint migration. The steps in migration are briefly summarized below.

(a) ISP Maintains the network inventory system that contains specification details of the network device in operation.
(b) Prioritize the customers to whom the SoDIP6 network based services are to be provided.
(c) Identify the optimal path and set of nodes in the optimal path from customer end gateway to ISP gateway router.
(d) Find the status of every un-migrated node in the optimal path whether it is upgradeable or replaceable.
(e) Calculate the optimum upgrade cost or replacement cost based on the device status and associated cost metrics.
(f) Migrate routers in the optimal path based on available budget constraints.
(g) Repeat the migration procedure with next priority customer until all the nodes in the network are migrated.
(h) Evaluate the functional operation of network with new technologies implemented.
(i) Fix the issues if any and continue expanding the network as regular maintenance and business expansion plan.

The progress status of IPv6 network migration in ISP and Telco networks world-wide shows that the application and protocol supports for IPv6 network operations are maturing, while adopting SDN in service provider networks is gaining momentum[8,57,106]. We believe that, our work as an addition of a brick with the ongoing research, experimentation, testing and implementation practices[8,57,58,95,107] of SDN would enable towards incremental deployment of SoDIP6 network in the service provider networks. The summary of research works carried out in this study is depicted in Figure 12. Starting from the legacy networks, migration steps and strategies for migration to SoDIP6 networks were defined and performed joint migration modeling and analysis for migration cost optimization.

FIGURE 12 Summary of research works

Finding suitable cost metrics for migration cost estimation and optimization was a major challenge of this research. In the case of availability of real dataset related to different cost metrics of ISP network migration, other machine learning methods like ant-colony optimization, particle swarm optimization and genetic algorithm etc. can be applicable for cost optimization. These are considered as future works. We have randomly set the router status for upgrade or replacement in the simulation and analysis. This leads to variation in per phase migration cost estimation on every cycle of simulation execution. However, this does not change the percentage of cost optimized. Implementation of an intelligent approach to find the status of a particular router whether it is upgradable or replaceable is considered as future works. Being the first approach to address joint migration problem, this research is particularly scoped to customer demand and optimal-path based migration scheduling for cost optimization in joint network migration via ILP formulation. However, there are some implementation complexities that need to be ensured before implementation. For example, we consider migration to dual stack SoDIP6 network in the hybrid SDN, so that failure of a link could be avoided by routing the SDN/non-SDN traffic from alternate paths. This require further research and experimental tests. For small enterprise networks, single SDN controller is sufficient, but for large ISP networks having large number of network devices, there are limited studies on controller placement and controller load balancing problems during incremental deployment of SoDIP6 network[108,109]. These need to be further investigated.

The need of legacy to SoDIP6 network migration including different migration approaches of IPv6 and SDN in brief is presented in section 2 following joint network migration consideration in section 3 and joint migration strategies in section 4. This addresses the first research question. Migration modeling with cost optimization approach presented in section 5 with experimental results and analysis on migration cost optimization in section 6 justify the second research question laid out in this article.

7 | CONCLUSION

In this paper, we have presented the need of joint network (IPv6 and SDN) migration based on their common concerns for organizational OpEX and CapEX optimization. The basic steps and strategies for joint network migration to new networking paradigms like SDN and IPv6 have been discussed. For the service providers worldwide, being in the early stage of SDN and IPv6 network migration, joint migration based on SoDIP6 network results to lower total migration cost. We have introduced the shared cost coefficient and strength of correlation between SDN and IPv6, and formulated the ILP problem for joint migration. The proposed approach is suitable for migration scheduling so that significant percentage of cost optimization can be achieved by following joint migration to SoDIP6 network. The simulation results and formal analysis have shown that joint migration approach is more beneficial than the individual migration. Proposed greedy algorithm provides the optimum solution for phase-wise network migration based on customer priority and available budget constraints so that fairly sustained service providers can smoothly schedule for their network migration tasks.

ACKNOWLEDGMENT

We acknowledge following organizations for this research support. University Grant Commission (UGC)-Nepal (grant id: FRG/74_75/Engg-1), NTNU (Norwegian University of Science and Technology) under Sustainable Engineering Education Project (SEEP) financed by EnPe, Nepal Academy of Science and Technology (NAST), ERASMUS+ KA107 and U.S. National Science Foundation (NSF). The work of Dr. Danda B Rawat was partly supported by the U.S. National Science Foundation (NSF) under grants CNS 1650831 and HRD 1828811. Any opinion, finding, and conclusions or recommendations expressed in this article are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied of the NSF.

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TABLE 1 Cost metrics and their symbolic notation for individual and joint migration to SDN and IPv6

Cost metrics	IPv6 migration	SDN migration	Joint migration (SoDIP6)
Cost of IoS/Firmware upgrade	α_i	α_s	α
Cost of hardware upgrade	β_i	β_s	β
Cost of hardware/router replacement	θ_i	θ_s	θ
Vendor support Cost	γ_i	γ_s	γ
HR development Cost	δ_i	δ_s	δ
Total cost of migration	τ_i^r	τ_s^r	τ
Decision Coefficient(x) for IoS upgrade, hardware upgrade	$x_{\alpha_i}, x_{\beta_i}$	$x_{\alpha_s}, x_{\beta_s}$	x_α, x_β
Miscellaneous Cost	σ_i	σ_s	σ

TABLE 2 Interpretations of μ and ϵ with their different combination of values.

Shared cost coefficient $(\boldsymbol{\mu})$	Strength of correlation $(\boldsymbol{\epsilon})$	Interpretations	Remarks
Any value within the defined limit	0	SDN and IPv6 are independent with no correlation. So, $\tau = 2\tau^r (= \tau_i^r + \tau_s^r)$ is true.	This is not applicable. The literature study demonstrates that SDN and IPv6 are not totally independent.
1	Any value within the defined limit	SDN and IPv6 are not coupled. So, $\tau = 2\tau^r (= \tau_i^r + \tau_s^r)$ is true.	This is not applicable. The literature study demonstrates that SDN and IPv6 are not totally decoupled.
> 1 & < 2	> 0 & < 1	SDN and IPv6 are coupled and correlated technologies where $\tau < 2\tau^r (= \tau_i^r + \tau_s^r)$ is ture. This gives the optimization in total migration cost.	This is the most favorable and applicable case for joint migration modeling.
2	1	SDN and IPv6 are fully coupled and correlated technologies, and $\tau_i^r = \tau_s^r$, where joint migration cost, $\tau = \frac{2\tau^r (= \tau_i^r + \tau_s^r)}{2}$ The total cost is half, meaning that total cost of migration is equivalent to the cost of migration of a single technology.	This is also not an applicable scenario, because SDN and IPv6 are not a single paradigm and are not fully coupled & correlated.

TABLE 3 Notations used for Algorithm-1

Parameters/Variables	Descriptions (Meaning)
$V \in G$	Number of nodes as vertex, 'V' (router/switch) in the network (G).
$e \in E_v$	End router, 'e' (edge router) in the set of customer priority vector (E_v).
$p \in P_e$	Optimal path, 'p' in the set of alternate paths (P) between the key node pairs (e,S), where 'S' is the ISP gateway router.
$u_k^e \in U_p^e$	Optimum migration cost of a router 'k' in the set of all routers (U_p^e) within defined optimal path p.
ρ_k^e	Router 'k' identified in the optimal path (the router status is either replace$\leftarrow$ 0 or upgrade$\leftarrow 1$).
σ_k^e	Set of cost metrics defined in Table 1 for each router (k) in the optimal path.

TABLE 4 Individual router migration cost assumption for defined cost metrics

Description of cost metrics	SoDIP6 capability per router (USD)	Descriptions
IoS Upgrade Cost	$275	Average per router IoS upgrade license cost
Hardware Upgrade Cost	$700	Addition of memory or extra ports
Router Replacement Cost	$7,000	Average purchase price of SoDIP6 capable L2/L3 device
Support Cost	$140	Vendor support per router license cost
HR Development Cost	$250	Assume cost is $2500 per HR, where one person handles/manages 10 routers with server systems.
Miscellaneous Cost	$75	Extra cost per router during the migration. This may include configuration, testing, verification, transportation etc.