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Joint Cost Estimation Approach for Service Provider Legacy Network Migration to Unified Software Defined IPv6 Network

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Abstract

Service providers world-wide are facing challenges of network operations, management, security, quality of service and address deficiency problem while the current world network still run with the existing legacy system. The issues of address shortage including the problems of legacy IPv4 address have been resolved with the advancement on IPv6 addresses. Similarly the increasing complexities of networking management have also been addressed by the advancement on Software Defined Network (SDN). For the future sustainability, service providers have to migrate their existing network to newer technologies. This requires upgrades on or replacement of existing networking devices that are operating on real time. But the lack of sufficient cost, technical human resources and suitable migration plan are becoming the major challenges for the fairly sustained service providers to migrate their existing network into next generation programmable network. SDN and IPv6 are the two new paradigms in networking operation and management that jointly after migration addresses all the existing issues of current networking system. In this paper, we present a greedy algorithm to identify the migration cost of network devices in the optimal path based on customer demand for incremental adoption of SDN enabled IPv6 network. We justify that a unified migration approach to SDN and IPv6 network would help to reduce the total cost of migration. We also verify that sequence of migration considering customer demand and cost constraints give the good estimation for unified migration to Software Defined IPv6 (SoDIP6) network.

Keywords: SDN, IPv6, Joint Migration, Strategies, Service Providers, Migration Cost

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1. INTRODUCTION

The 128 bits length IPv6 addressing scheme is standardized after the prediction of IPv4 address depletion during the decade of 1990s. The growth of internet connected smart devices is exponential with the advancement on technologies shifting the society into smart cities and smart communities. This leads to the increased network infrastructure and exhaustion of IPv4 address finally making the existing IPv4 networking infrastructure more complex in management and operation. However decoupling of controller from data plane is not new, the separation of data and control pane as a concept of Software Defined Network is recently gaining momentum with the opportunity to have efficient and flexible network management and operation. After successful implementation of Software Defined Network (SDN) over data center network, its research and innovation towards migration of service provider network take a major attraction for researchers world-wide. From the technical perspectives, IPv6 and SDN are not directly correlated but from the migration perspectives considering of security, quality of service, migration cost, requirement of technical human resources, technology & application supports and migration plan, these are inter-related entities. Both are the underlying network layer technologies where IPv6 deals with addressing and routing at network layer while SDN deals with the operation and management of network layer devices including interfacing with application software and data plane devices. Both IPv6 and SDN are not backward compatible with legacy IPv4 networking system. Hence, migration of legacy networking systems into operable Software Defined IPv6 (SoDIP6) network has certain challenges to service providers. The major challenges are the cost of migration, technical human resources, and trust on uninterruptible services including security, protocols and application supports. Looking into the global IPv6 migration status [1], the world's IPv6 capability has just crossed 16%. Asia IPv6 capability is crossing 16.26%. Similarly the google IPv6 user access status is 23.85% [2]. Google reported to have 37 countries have exceeded 5% IPv6 traffic. Akamai reported to have 7 countries exceeded 15% of IPv6 traffic. IPv6 adoption of developing countries is still less than 1%. Different migration approaches are defined and adapted by the service providers' world-wide [3]. But current deployment status shows that the service providers of developing countries are still lacking in the migration. The requirement of huge cost for migration and low customer demand enables service providers in the context of wait and see mode regarding IPv6 migration. In the meantime, the emergence of SDN and its opportunities has put the pressure to service providers to migrate their network into such a newer and efficient technologies. SDN is emerging and its migration in the service provider network is in the early stage.

Migration is inevitable besides its challenges. Sustainability is the major issue in terms of costs associated with technology migration for the service providers of developing nations. In this paper we present a greedy algorithm for legacy network migration cost estimation and present the joint migration approach so that the total migration cost considering joint technologies like IPv6 and SDN can be optimized.

This paper is organized as follows. We present the background and related works on IPv6 and SDN migration from the techno-economic perspectives in section 2. SDN and IPv6 joint transition strategies are discussed in section 3. Section 4 presents our proposed greedy algorithm and mathematical model for individual and joint migration cost estimation. Simulation results and performance analysis have been discussed in section 5. Section 6 concludes the paper.

2. BACKGROUND AND RELATED WORKS

2.1 Need of Network Migration

Technology adoption and the future sustainability are the major requirements for every service provider to provide services to customer equipped with newer technologies. Network migration is defined as the upgrades or replacement of hardware/software according to service needs to meet the standards with newer technologies. Internet Service Providers (ISPs) are bounded by the Service Level Agreement (SLA) with the customer to provide service with pre-defined service quality against the cost they charge for the services. With the increase of users, network size increases leading challenges to management, operations and increase capital/operational expenditures (CapEX/OpEX) of the organization. Migration of network sometimes depend upon the customer demand and so service providers act accordingly. Like for example, IPv6 migration is delaying because there is not the customer demand. Network migration is for the better efficiency and manageability of service providers themselves that help to reduce organizational CapEX/OpEX. The exhaustion of IPv4 address with its associated problems in the network operation and management are the major causes to migrate legacy network into next generation network technologies like IPv6 and SDN.

2.2 IPv6 Network Migration

The process of IPv6 migration started since 1998 after its standardization. Within the last two decades, different migration techniques have been developed under the broad category of tunneling, dual stack and translation mechanisms for the smooth transition of existing IPv4 network into operable IPv6 network and co-existence with IPv4 as well. Since the year 2015, the IPv6 network migration world-wide is rapidly increasing as seen on the google statistics [2]. However service providers worldwide are in rush of migration, the IPv6 user penetration rate of most of the countries are below 1%. The rate of IPv6 user penetration of the most of the developed countries [1] is as low as below 10%. The bigger ISPs [4] like Comcast (66.30%), SoftBank (33.77%), ATT (65.95%), Verizon Wireless (85.51%), Deutsche Telekom (56.04%) and KDDI (41.96%) have significant progress on IPv6 deployment. Service providers of developing nations are still in the early stage of their network migration to IPv6. It is realized that a sustainable solution with an optimum planning and cost estimation of network migration for service providers of developing countries are required. Our work of transition planning and cost optimization approach on this paper will attract to those fairly sustained tier-3 service providers for their network migration.

Authors in [5] and [6] present the economic aspect of IPv6 migration. Basic cost/benefit analysis were discussed from the dimensions of infrastructure vendor, wireline/wireless internet service providers, mobile services providers, content providers, enterprises and consumer end users with the basic principle of well-known Probit Model indicating that revenue should exceed the expenditure to adapt new technologies. It means new technology is implementable only when the benefit exceeds the cost of adoption. It is fairly hard to decide for service providers to adapt new technologies without the guarantee of return on investment. Measuring the benefit in a tangible way is somehow uncertain in IPv6 and SDN migration because it is a network layer activity and is independent of customer. It mostly focused with the security, quality of service and performance of network which the service providers are more concerned with. NIST report [7] has also performed the cost/benefit analysis of IPv6 network migration in terms of security, hardware and software services.

2.3 SDN Migration

The operation of legacy IPv4 network is vertically integrated leading to complexity in configuration and management. SDN centralized the control plane and provides vendor neutral solution for device configuration with flexibility and programmability in the network. SDN brings revolution in the efficient network management with optimized OpEX [8, 9] for service providers. ON.LAB [10] proposed three approaches for SDN migration. these are i) Legacy to Greenfield, ii) Mixed and iii) Hybrid Network. First approach implies the complete replacement of legacy devices with OpenFlow enabled device. There are several constrains that existing network can’t be migrated to Greenfield at once. This is applicable only if someone is expanding new network with OpenFlow enabled devices. Mixed approach enables for gradual migration in which some of the devices run with legacy standards while some devices operate with OpenFlow standards. In this approach, legacy and OpenFlow device should be interoperable. This viability should be analyzed form the perspectives of traffic engineering. In hybrid approach, every device maintains routing table by the legacy system and also maintains the flow table obtained from SDN controller. In this paper, we consider cost estimation for the hybrid approach in which every device is able to operate with legacy and OpenFlow technology both. This migration experiment was applied by ON.LAB to migrate Stanford Campus Network. Panopticon [11], Fibbing [12] and HARMLESS [13] are some of the approaches proposed to upgrade existing legacy devices to SDN capable hybrid devices.

Data Centers world-wide are migrating to SDN [14-15]. Its successful deployment in the data center network encourages internet and telecom service providers to migrate their legacy network into programmable next generation network. The application and protocol support for OpenFlow enabled network is not yet matured in the ISP network. However phase wise migration is abruptly gaining the progress. AT&T announced to migrate its existing network into its future generation networking system fully equipped with SDN and NFV in 2014 with the name "User-Defined Network Cloud" [16].

To the best of our knowledge, moreover technical approaches of individual migration to SDN and IPv6 have been studied. This is our first work regarding techno-economic analysis on joint migration to SDN enabled IPv6 network with cost estimation based on SLA. Summary of related works regarding network migration from the different perspectives are presented in Table I.

Operators, who are still thinking for IPv6 migration have to think for SDN migration jointly to optimize the migration cost. The major stakeholders like Stanford Campus Network, Google Data Center, NTT communication and AT & T [20-23] have already deployed the prototypes and implementing SDN with the migration in a phase. This encourages other service providers to decide for the migration.

3. JOINT TRANSITION STRATEGIES

In this section we present the correlation between SDN and IPv6 in terms of migration and their associated costs. We also identify the best transition path to verify that unified migration to SoDIP6 network would help to reduce the total migration cost.

We consider the migration based on customer demand as per Service Level Agreement (SLA). Service provider maintains the customer priority list with associated end access routers to provide internet services. Figure 1 provides the scenario of migration sequence. If bank, university, home users and government office are in the priority of first, second, third and fourth, then bank as a first priority customer will be chosen. Suppose the shortest path form router *h* to ISP gateway router *a* is identified as [h,e,d,a], then total migration cost of those routers in the shortest path will be identified. The routers in the shorted path are migrated first with the available budget constraints. Then in the next phase of migration, the un-migrated routers due to budget constraints in the previous phase and set of routers in the shortest path of second priority customer (eg. University) will be chosen. Figure 1(ii) shows that when university is chosen as second priority customer, the shortest path is [g,e,d,a] in which only g is the un-migrated node, will be migrated in addition with previously un-migrated routers. Similarly other routers according to customer priority will be migrated. This approach would help manage the budget for migration. The routers after migration are quad stack (IPv4, IPv6, Legacy and SDN) routers. The legacy IPv4 stack will be disabled to make the network SDN and IPv6 only in a phase according to the customer traffic availability on IPv4 and with national/international transit connections.

We assume that service providers are in the early stage of their network migration to SDN and IPv6. Migration cost estimation is complex and challenging due to dynamic nature of the device characteristics and varying network size of different operators. We develop the simple mathematical model and implement an algorithm of cost estimation using integer linear programming. Our model is for the purpose of legacy to quad stack SoDIP6 network migration.

The starting network is the legacy IPv4 network and the targeted network is the Software Defined IPv6 (SoDIP6) network. We assume that the legacy router supports IPv4 only with traditional routing features. This legacy network is to be migrated such that it will be able to operate with IPv4 and IPv6 packet processing and forwarding as well as support OpenFlow in addition with legacy routing during the transition period. The legacy routing feature is enabled on the data plane device for the recovery purpose [24]. The IoS/Firmware is upgraded such that it is enabled with IPv6 in the legacy routing and the forwarding engine acts as a data plane. This could be activated from the command line configuration. We represent the transition by the transition Table II and directed acyclic graph as the state transition diagram shown in Figure 2. Only valid transitions are represented by the binary representation as to switch on or off the technology as per requirement. Like for example, we can migrate legacy IPv4 network into IPv6 and then to SDN, i.e. transitioning from state a to states b, c or d is possible. But transitions directly form state *a* to state *g, h, i, e* and *f* are not possible. Because migration is a gradual process and the real operating network devices can’t be switched on the fly from IPv4 to IPv6 and legacy to SDN. Most of the researches on SDN migration have been performed with respect to budget constraints and traffic engineering [19], [25-26].

Considering Figure 2, the ultimate objective of every ISP is to move form state *a* to state *i*. The cost of transition depends upon the choice of path in the transition diagram. Paths [a,c,i], [a,c,e,i] and [a,c,h,i] indicate the unified migration. At node c, the network reaches the quad stack SoDIP6. The other paths [a,b,h,i], [a,b,c,i], [a,b,g,h,i], [a,b,c,h,i], [a,b,c,e,i], [a,d,f,e,i], [a,d,c,i] and [a,d,c,e,i] show the individual migration to IPv6 and SDN. The choice of path defines the migration sequence. Like an ISP choose path [a,b,g,h,i], the sequence is i) enable IPv6, network becomes dual stack at node *b* ii) turn off IPv4 stack at node *g* iii) enable OpenFlow in the legacy IPv6 network at node *h* and iv) turn off legacy network management at the targeted node *i.*

Service providers shall have different optional paths available for the migration but from the traffic engineering perspectives, optimal path has to be considered with budget constraints for the migration. Transition link 2 in Figure 2 indicates the joint migration while link paths (1, 4), (3, 5), (1, 6, 12, 13) and (3, 10, 11, 14) indicate the separate migration of current network into SoDIP6. In the next section we develop an algorithm with mathematical model for cost estimation of individual and joint migration considering the transition paths stated in Figure 2.

4. ALGORITHM AND MATHEMATICAL MODEL

Das T. et al [18] analyzed the case of network migration with two technologies viz. IEEE-PCE and SDN. Their study verifies that joint migration is more benefitted than the individual itself. Following the same assumption, we expect that network upgrades will be more cost effective in joint migration of SDN and IPv6. To justify our assumption, we consider the separate migration scenarios first and then develop a simple mathematical model for joint migration. IPv6 and SDN are not the complementary technologies, however being both under the network layer technologies, we can find the common concerns between them while considering cost of migration.

For the unified migration to multiple technologies, we need to know the shared metrics that help to reduce the migration cost. Like for example if a technical person is trained for the SDN configuration then the same person can do the IPv6 configuration if resources are shared during training. The network team as a whole look after all the addressing, routing, operation and management issues. Here the training cost is shared between SDN and IPv6. Similarly OpenFlow 1.3 and beyond supports IPv6. If IoS (Internetwork Operating System) of a router is upgraded to SDN then it automatically supports IPv6. From our preliminary survey with real internet service providers, we identify the important cost metrics associated with technology migration. Figure 3 shows the cost metrics in which some parameters can be shared between SDN and IPv6 during migration.

We consider the network of teir-3 ISPs that they maintain the customer priority list based on service needs. The shortest path in the network towards the customer of highest priority will be chosen for migration. The number of routers in the priority path will be migrated first. If some of the routers are migrated then consequently there might have more alternate paths available for next migration. Similarly in the next phase of migration, other routers in the next optimum path according to customer priority will be migrated. Algorithm 1 presents the cost estimation and migration steps.

Generally IoS/Firmware upgrade is viable [27]. However for older routing devices, hardware upgrade is not significant if the software upgrade is not possible. This means, if support for IPv6 and/or SDN is not possible via IoS/firmware upgrade then device replacement is required. Hardware upgrade concerns with the performance of the device once it is migrated to targeted technologies. Hence, we introduce the decision coefficient of IoS/firmware upgrade and hardware upgrade cost. Let $x_{\alpha_i} \in [0,1]$ and $x_{\alpha_s} \in [0,1]$ be the decision coefficient that holds either true or false for every router IoS/Firmware upgrade to IPv6 and SDN separately. Similarly, $x_{\beta_i} \in [0,1]$ belongs to the decision coefficient for hardware upgrade. Table IV provides the list of symbols used for the total migration cost estimation.

Every router whether upgradable or replaceable is identified by the IoS/Firmware upgrade decision coefficient.

$$x_{\alpha_i}, x_{\alpha_s}, x_{\alpha_{si}} = \begin{cases} 1, & if\ upgrade\ is\ true \\ 0, & else\ (replacement) \end{cases}$$

Upgrade decision can be taken only if, Upgrade Cost (T_u) < Replacement Cost (T_r)

The cost of replacement associated with the purchase of new hardware capable of operating the targeted technologies also include the support, human resource and miscellaneous costs. Human resource (HR) development mostly related to the training cost to make resource ready for operation. The total cost of a node migration is calculated as the function of the individual cost entity associated with the costs of migration. Identifying the HR training, support and miscellaneous costs is an np-hard problem. We generalize those costs in terms of number of routers that are to be migrated. i.e.

Total node migration cost for IPv6 of N nodes:

$$\tau_i^r = f(cost\ entities)_{IPv6}$$

$$= \sum_{i=1}^{N} \{x_{\alpha_i}(\alpha_i + x_{\beta_i}.\beta_i) + \overline{x_{\alpha_i}}.\theta_i + \gamma_i + \delta_i + \sigma_i\} \quad (1)$$

Where x_{α_i} and $\overline{x_{\alpha_i}}$ are complement of each other. If $x_{\alpha_i} = 1$ then $\overline{x_{\alpha_i}} = 0$.

We assume that, the cost metrics that affects the cost of migrating a backbone router to IPv6 is almost same with the migration to SDN. Total node migration cost for SDN of N nodes: $\tau_s^r = f(cost\ entities)_{SDN}$

$$\tau_s^r = \sum_{s=1}^{N}\{x_{\alpha_s}(\alpha_s + x_{\beta_s}.\beta_s) + \overline{x_{\alpha_s}}.\theta_s + \gamma_s + \delta_i + \sigma_s\} \quad (2)$$

For the heterogeneous network device, it is obvious that the exact cost on each topic varies with each node due to the dynamic characteristics of device and the vendor support available. Assuming that all the nodes are of same type based on configuration and support, in the worst case, the total migration cost following separate migration would double the costs if migration cost for both the technologies are considered same for each router. Total migration cost considering individual migration: $T(R_n)\ (= \tau_{si}^r) \leq (\tau_i^r + \tau_s^r)$. For joint migration, we introduce the optimization variable μ such that:

$$minimize\ \frac{1}{\mu}.(\tau_i^r + \tau_s^r), \text{ s.t. } 1 \leq \mu \leq 2$$

Here the variable μ is called *shared cost coefficient*. If the shared cost coefficient is two, the total cost of simultaneous migration will be almost half of the sum of individual migration. This cost is almost equal to the migration of one technology. Like for example SDN migration has automatically integrated IPv6 migration into dual stack SoDIP6 network. When the coefficient value is one, the total migration cost is the sum of cost for individual migration to SDN and IPv6. Hence μ gives the coupling [27] between the two interrelated technologies. We introduce another coefficient ϵ to measure the strength of effect of correlation related to cost saving [28] between SDN and IPv6 such that optimum migration cost can be achieved.

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

From Equation 3, we draw that if two technologies are independent of cost regarding migration i.e. $\epsilon = 0$ then total cost of migration is the sum of individual migration i.e. $\tau_{si}^r = 2\tau(= \tau_i^r + \tau_s^r)$ otherwise $\tau_{si}^r < 2\tau$ holds true. Hence for individual cost entities,

$$\gamma_{si} \leq (\gamma_i + \gamma_{s)} \cong \left(\frac{1}{\mu}\right)^{\epsilon}.(\gamma_i + \gamma_s)$$

$$\delta_{si} \leq (\delta_i + \delta_{s)} \cong \left(\frac{1}{\mu}\right)^{\epsilon}.(\delta_i + \delta_s)$$

$$\sigma_{si} \leq (\sigma_i + \sigma_s) \cong \left(\frac{1}{\mu}\right)^{\epsilon}.(\sigma_i + \sigma_s)$$

$$\alpha_{si} \leq (\alpha_i + \alpha_{s)} \cong \left(\frac{1}{\mu}\right)^{\epsilon}.(\alpha_i + \alpha_s), s.t. 1 \leq \mu \leq 2$$

$\beta_i = \beta_s = \beta$ (Assuming that hardware replacement is common for both technologies). Above representations can be written as:

$$\gamma_{si}, \delta_{si}, \sigma_{si}, \alpha_{si} \leq \left(\frac{1}{\mu}\right)^{\epsilon}[\gamma, \delta, \sigma, \alpha]$$

s.t. $1 \leq \mu \leq 2$ and $\gamma, \delta, \sigma, \alpha \geq 0, \beta \geq 0$ (4)

The decision coefficient for joint migration is derived from the decision coefficient on separate migration. The IoS/Firmware upgrade for the both technologies should be true while the hardware upgrade is common for both. Hence,

$$x_{\alpha_{si}} = x_{\alpha_i} \wedge x_{\alpha_s} \equiv x_{\alpha}$$

$$x_{\beta_{si}} = x_{\beta_i} \vee x_{\beta_s} \equiv x_{\beta}$$

The total joint migration cost is identified as

$$\tau_{si}^{r} = f(\alpha, \beta, \theta, \gamma, \delta, \sigma)_{si}$$

$$= \sum_{si=1}^{N} \{x_{\alpha_{si}}(\alpha_{si} + x_{\beta_{si}}.\beta_{si}) + \overline{x_{\alpha_{si}}}.\theta_{si} + \gamma_{si} + \delta_i + \sigma_{si}\} \quad (5)$$

Hence, considering the individual cost entities are equal for both the migrations, then from equation (3), (4) and (5) we get equation 6 for total migration cost estimation.

$$\tau_{si}^{r} = \sum_{si=1}^{N} \left\{ \left(\frac{1}{\mu}\right)^{\in} (x_{\alpha}.\alpha + \gamma + \delta_i + \sigma) + x_{\alpha}.x_{\beta}.\beta + \overline{x_{\alpha}}.\theta \right\}$$

$$\text{S.t. } 1 \leq \mu \leq 2 \; and \; \alpha, \beta, \gamma, \theta, \delta, \sigma \geq 0 \quad (6)$$

5. RESULTS AND ANALYSIS

Equation 6 provides total cost estimation for simultaneous migration with respect to shared cost coefficient and the strength of correlation between SDN and IPv6. The relationship between the shared cost coefficient and the factor of migration cost is calculated at different strength of correlation (ϵ). Figure 4 (left) shows the cost profiles at different values of strength of correlation with varying shared cost coefficient. At $\epsilon = 0.2$, it is shown that two technologies are less correlated and the total cost of migration is almost equal to the sum of individual migration cost. At $\epsilon = 1.0$, with varying μ from one to two, the total cost of simultaneous migration is almost reduced to half. Figure 4 (right) shows the migration cost variances at $\mu = 1.5$ with number of routers to be migrated.

The total cost of migration is the sum of cost for routers to be upgraded and replaced. When upgrade cost is less then replacement cost, then more number of routers in the optimal path will be upgraded than replacement for the budget allocated at that step for network migration. Because of less cost, routers are to be upgraded first and remaining budget can be used for replacement.

We implemented our algorithm using python with three types of network topology. These are (a) random network (8 nodes, 13 links), (b) Abilene network (11 nodes 14 edges) and (c) Xeex network (24 nodes, 34 links). Random network is generated by python script with NetworkX module. Abilene and Xeex networks are standard backbone and customer end network dataset obtained from internet topology zoo (topology-zoo.org). Customer priorities are randomly generated and assigned to end access routers. Then the routers in the optimal path with highest order priority customer are migrated first. Figure 4 presents the routers migration status with customer priority as a phased migration sequence. This approach is suitable for budget planning in a phase. The graphs of Figure 5 shows that 8 nodes in random network are migrated in 3 phases, while 11 nodes in Abilene and 24 nodes in Xeex networks are migrated at 5 and 14 phases respectively. Service providers can schedule the migration with budget constraints. Initial migration budget might be comparatively high. But once the routers are migrated, the number of routers to be migrated in the next phase shortest path will be reduced because some of the routers in the path would already be migrated in the previous migration phase. This leads to less amount of budget will be allocated in the subsequent next phases of migration.

6. CONCLUSION

IPv6 adoption worldwide is increasing while the SDN migration in the ISP and Telcos network is emerging. Network migration leads to higher cost with respect to human resource development, security, quality of services, development & deployment, testing and verification. Tier 3 ISPs of developing nations are still in the early stage of IPv6 network migration. SDN deployment is in the beginning stage with research and development. The proposed greedy algorithm in this paper identifies the joint migration cost for the backbone and access network towards unified software defined IPv6 network based on customer demand as per SLA. The correlation between SDN and IPv6 are identified based on shared cost coefficient and strength of correlation so that migration cost profile will be applicable to minimize the total cost of migration. Migration scheduling is optimized in a phase with customer priority considering budget constraints in which service providers can run number of phases irrespective of time defined for the migration. It is observed that joint migration would reduce the total cost of migration with optimized CapEX and OpEX for service providers. Similarly, migration cost will be in decreasing order in the subsequent number of migrations that helps to fairly sustained service providers to migrate their existing legacy IPv4 network into SDN enabled IPv6 network within allocated budget constraints.

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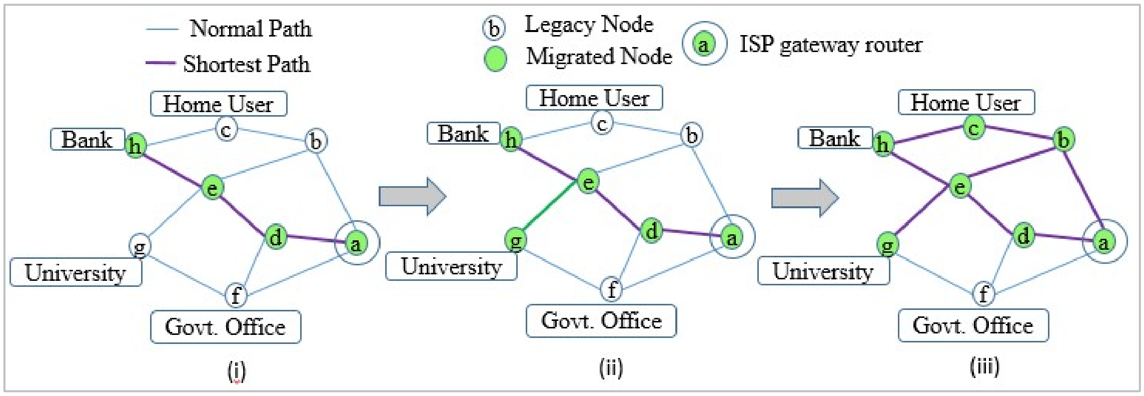

Figure 1 Migration sequence of nodes based on customer priority

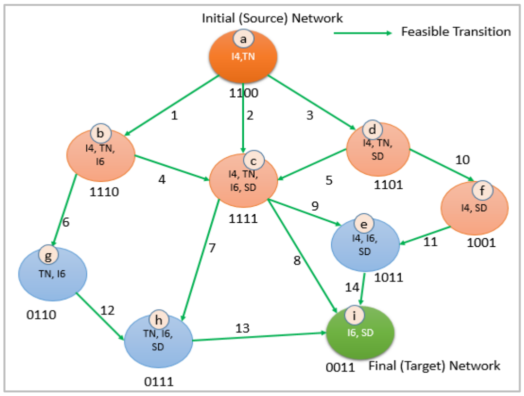

Figure 2. Network migration state diagram

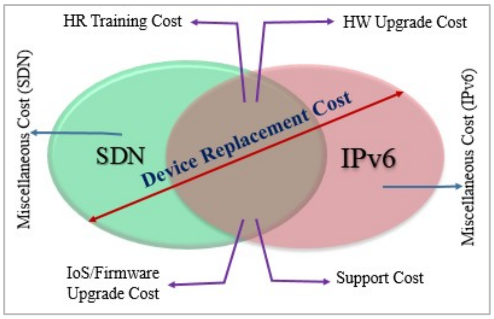

Figure 3. Migration cost metrics

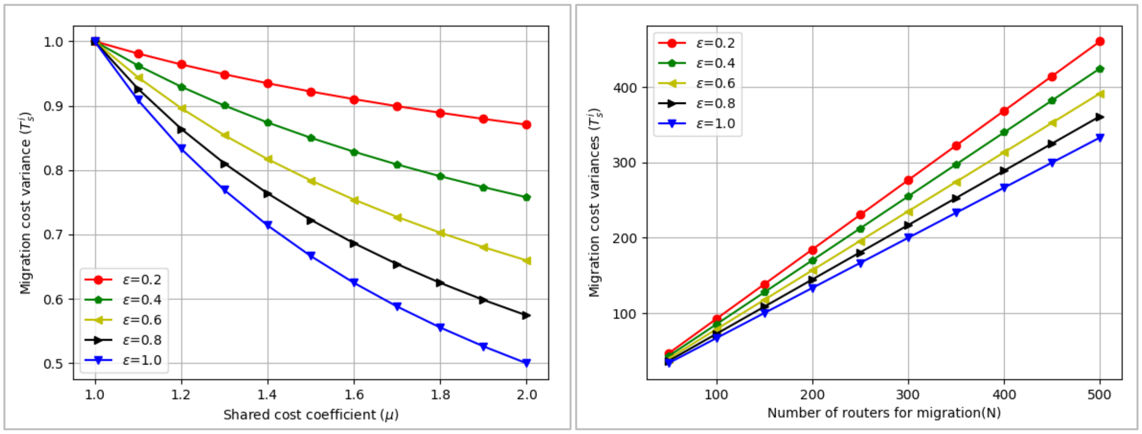

Figure 4 Migration cost variances with shared cost coefficient and correlation strength (left), Migration cost variances with number of router migrations (right) at $\mu = 1.5$

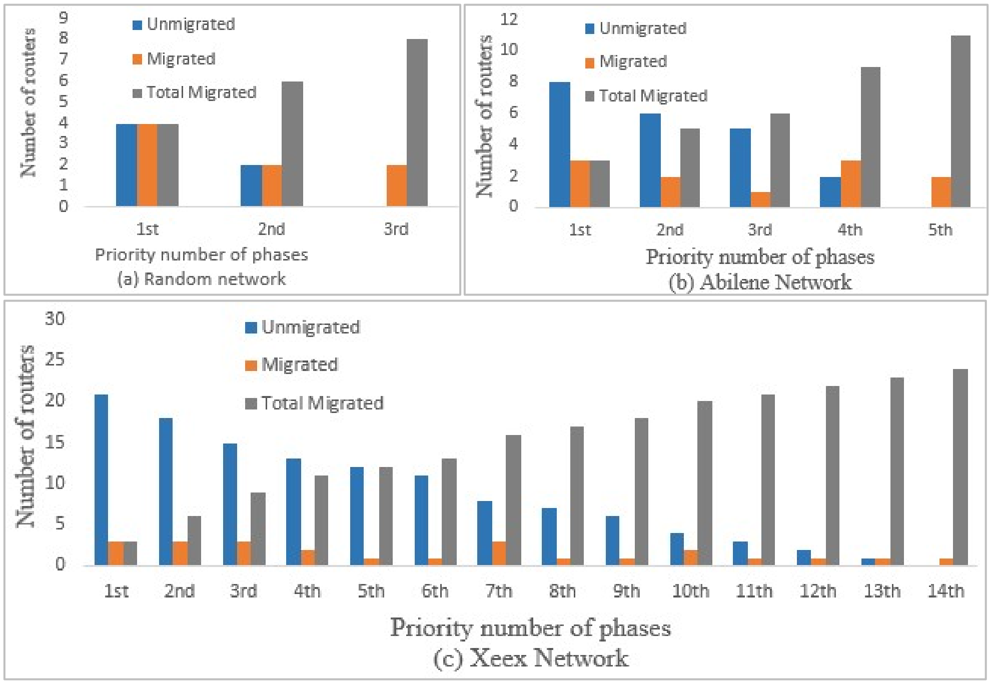

Figure 5 Phase-wise router migration sequence with customer priority

TABLE I. RELATED WORKS AND MIGRATION APPROACHES

Authors	**Technology Migration**	**Migration Perspective**	**Approach**
OECD report [6]	IPv6	Economic	Study on economic effects of migration
Gallaher M. et al [7]	IPv6	Economic	Impact analysis via survey with service providers, software & hardware vendors
Das T. et al [17]	SDN	Techno-economic	Greedy algorithm applied for migration scheduling
Das T. et al [18]	IEEE-PCE + SDN	Techno-economic	Agent based modeling & simulations
Yuan T. et al [19]	SDN	Traffic Engineering	Customer based migration scheduling

TABLE II. TRANSITION STEPS FORM TRADITIONAL (LEGACY) TO SOFTWARE DEFINED IPV6 NETWORK.

SN	IPv4 (I4)	Traditional Network (TN)	IPv6 (I6)	SDN (SD)	Descriptions	State
1	✓	✓			IPv4 Only, Traditional Network	Initial state
2	✓	✓	✓		Dual Stack IPv4 & IPv6, Traditional Network	Transit/Transition
3	✓	✓		✓	IPv4 Only, Traditional & SDN	Transit/Transition
4	✓			✓	IPv4 Only, SDN	Transit/Transition
5	✓	✓	✓	✓	Quad Stack Network	Transit/Transition
6	✓		✓	✓	SDN with Dual Stack IPv4 and IPv6 Network	Transit/Transition
7		✓	✓		IPv6 Only, Traditional Network	Transit/Transition
8		✓	✓	✓	Traditional & SoDIP6 Network	Transit/Transition
9			✓	✓	SoDIP6 only Network	Target Network

TABLE III. NOTATIONS FOR ALGORITHM 1

Parameters	Description (Meaning)
$V \in G$	Number of Nodes (Router/Switch) in the network (G)
$e \in E_v$	End Device (Router/Switch) in the set of Customer Priority Vector (E_v)
$p \in P_e$	Optimal Path in the set of alternate paths between the key node pairs (e,S), where S is the central gateway router at the Service Provider Network Operation Center (SP NOC)
$u_n^e \in U_p^e$	Migration cost of a node in the set of all nodes in the optimal path p
ρ_n^e	Identified value of node n in the optimal path (the value is either Replace← 0 or Upgrade← 1)
σ_n^e	List of cost metrics for each device in the optimal path

TABLE IV. NOTATIONS FOR MATHEMATICAL MODELING OF MIGRATION COST ESTIMATION

Description of Cost Entities	Notations for IPv6	Notations for SDN	Notations for SDN & IPv6
IoS/Firmware Upgrade Cost (R_{ios})	α_i	α_s	$\alpha_{si}\ (or\ \alpha)$
Hardware Upgrade Cost (R_{hw})	β_i	β_s	$\beta_{si}(or\ \beta)$
Device Replacement Cost (R_r)	θ_i	θ_s	$\theta_{si}\ (or\ \theta)$
Support Cost (R_s)	γ_i	γ_s	$\gamma_{si}(or\ \gamma)$
Human Resource Development Cost (R_h)	δ_i	δ_s	$\delta_{si}\ (or\ \delta)$
Miscellaneous Cost (R_m)	σ_i	σ_s	$\sigma_{si}(or\ \sigma)$
Total Cost of Router Migration (T_R)	τ_i^r	τ_s^r	$\tau_{si}^r(or\ \tau)$
Decision Coefficient(x) (IoS, Hardware Upgrade)	$x_{\alpha_i}, x_{\beta_i}$	$x_{\alpha_s}, x_{\beta_s}$	$x_{\alpha_{si}}(or\ x_\alpha), x_{\beta_{si}}(or\ x_\beta)$

ALGORITHM 1. GREEDY ALGORITHM FOR COST ESTIMATION OF NETWORK MIGRATION

```
(V, Ed ∈ G)←input vertices (v) and links (Ed) in network graph G
$\forall e \in E_v : \partial_c = Customer\ Priority\ Value\ (highest)$
$\boldsymbol{for}\ i \leftarrow 1\ to\ N \mid P_e$
  $\boldsymbol{if} opimal(P_i)\ \boldsymbol{then}$
    $p \leftarrow P_i$
$input \leftarrow n \mid p$          /* n is the number of un-migrated nodes in the optimal path p */
$\forall u_n^e : u_n^e = NULL;$      /* migration cost for each device */
$\tau_i^s = \mathrm{NULL}$           /* initialize total migration cost */
$\boldsymbol{for}\ k \leftarrow 1\ to\ n \mid p$
  $\tau_i^s += u_k^e(= \mathrm{migration\_cost}(\sigma_k^e, \rho_k^e))$
If ($\tau_i^s < B^e$) Migrate(n)     /* migrate all nodes (n) in the optimal path p if phase budget $B^e$ is sufficient) */
Else    Migrate (m)                  /* migrate m ($< n$) number of nodes in the optimal path p */
Repeat algorithm until all routers in the network attached to all customers are migrated
```