Journal of Current Research in Engineering and Science
JCRES
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 6- Issue 1, Paper 20,January 2023

Minimization of Maximum Link Utilization in SDN –A Survey

DevikaSuresh , SwethaR , YuvachandiranR, Vignesh A , Dr.GeethaV,
Dept. of Information TechnologyPuducherry TechnologicalUniversity
Puducherry,India.

***Abstract*—Software-defined networking (SDN) is a newperspectivethatovercomesthebarrierswhicharefacedbyregular or standard networking architecture. The main idea ofSDN is to split the control plane from the data plane. Software-definednetworking(SDN)technologyisbecomingamajortechnique in managing and configuring network and upgradingthenetworkperformance.TheevolutionofSoftwareDefinedNetworking (SDN) enlarges the freedom of routing and gives anefficientapproachtobalancenetworkflows.Duetotheeconomical and scientific challenges in changing to a full SDN-enablednetwork,ahybridSDN,withapartialdistributionofSDNswitchesinaconventionalnetwork,hasbeenaprevailingnetworkarchitecture. As for now, Traffic Engineering (TE) in the hybridSDNhascaptivatedvastattentionsfromindustryandmanyothers. This paper surveys focuses on minimization of maximumlinkutilization forefficient flowof trafficin thenetwork.**

Keywords—Traffic Engineering, Software Defined Networking,Minimizationof MLU.

I.INTRODUCTION

To meet the massive requirements of traffic transmission, InternetService Provider (ISP) has been expanding the investment on thee stablishmentofnetworkinfrastructuretoguaranteetoahighbandwidthandlowlatencynetwork.TrafficEngineeringasanefficient network management toolhelp Internet Service Providers(ISPs)optimizenetworkperformanceandresourceutilizationbyconfiguring the routing across their backbone networks to controltraffic distribution.

The emerging Software Defined Networking (SDN) is a networkingparadigm where the data plane and control plane are decoupled I the SDN switchan dSDN controller,respectively.SDN switchisaprogrammabledevice that is responsible for forwarding network flows according to flow entries from SDN controller. SDN controller is a logically centralized device that supports a globa lview of the network state bycollecting network information from SDN switches.

However, migration from SDN has its own challenges, especially forlarge and expensive Internet Service Provider (ISP) networks. One-step migration from traditional network running IP protocols, likeOSPF, to SDN imposes huge capital expenditure, for replacing all thelegacynetworkinfrastructureswithspecializedSDNequipmentonthenetwork operators. Moreover, it comes with an enormous operationalburden and potential security risks since SDN technology is relativelyimmatureandexistssoftwarevulnerabilitiessubstantially.So,apreferable choice arises out of partial SDN deployment, that is hybridSDN(HSDN).

Recent breakthrough in Reinforcement Learning (RL) have promotedtremendous progress in various fields. Reinforcement Learning (RL)attempttosolvedecisionmakingproblemsthroughcontinuouslearningbyinteractingwiththeenvironmentinatrial-and-errormanner.Duringthelearningprocedure,pastexperiencesaregeneralized to new situations by learning an RL agent. Once themappingisestablished,theefficientdecisionpolicycanbedeterminedrapidly. The integration of RL and Neural Network (NN) can betterdescribe the complex scenarios and exhibit superior performance onrealizing anadaptiveand fastdecision-making.Theadvantages ofRLare its great potential to realize intelligent TE so that the dynamictrafficdemands can behandledtimely inthehybridSDN.

In order to enable a flexible traffic splitting, traffic flows on SDNswitches are forwarded to the next hop according to the flow entriesdispatchedbySDNcontrollers.TheroutingconstraintsforhelegacyroutersandSDNswitchesaredifferent,whichposesagreatchallengetodesignaneffectiveRL-basedapproachtolearnanRLagent.Secondly, the RL agent is gradually trained by repeatedly interactingwith the environment. The flexibility of traffic flows on the SDNswitchesmaycauseunnecessaryroutingloops.Thus,areasonableandcorrect emulation environment should be established for learning theRL agent. Thirdly, to achieve the intelligent and rapid generation ofroutingschemes,the designof the RLagentshouldbe carefullyconsideredtohandlethedynamically-changingtrafficdemandspromptly.

II.MINIMIZINGMAXIMUMLINKUTILIZATION

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Maximumlinkutilization(MLU)isusedtoevaluatethenetworkcongestion.AstheMLUincreasesthecongestionincreases,andasthe MLUdecreasesthecongestionalsodecreases,andwhenthecongestionisdecreasedtheoperationofthenetworkscanbeperformed easily. The minimization of maximum link utilization canbereachedby usingdifferentmethods. They areasfollows:

III. H-PERMISSIBLE PATHS ROUTINGSCHEME (HPRS)

Duetothelimitedspaceofthecostly TCAMResources,theproblemofroutingoptimizationunderthepathcardinalityconstraintsisstudied[1]. Theroutingoptimizationproblemistakenasa MINLPproblem,anapproximationalgorithmHPRSispresentedwithanapproximationratio of $O(logL)$. After conducting evaluations, 2-permissible pathsrouting gives more profit. The MLU under HPRS is near optimal andwhen compared with the optimal routing the number of flow entriesare reduced.But Delay, throughput factors in routing optimizationwerenot observed.

IV.CRITICALFLOWREROUTING-REINFORCEMENTLEARNING

Themainaimofthispaperistominimizethemaximumlinkutilizationand to reduce the disturbance in the network [2]. Here the maximumnumberoftrafficflowscanbeforwardedusingECMP,andredirecting theselectivecriticalflowsusingSDN.Inthis,FirstCFR-RLaReinforcement Learning-based identifies and selects a small set ofcritical flows for each given traffic matrix, and then they have beenreroutedbysolvingasimplelinearprogrammingoptimizationproblem. By rerouting only a limited portion of total traffic, CFR-RLachieves near-optimal performance. The evaluation results show thatCFR-RL is able to generalize to unseen traffic matrices. Some futurework includes minimizing rerouting traffic as one of the goals andexplorethetrade-offbetweenmaximizingperformanceandminimizing reroutingtraffic.

V.ROAR

EarlierstudiesonTEinthehybridSDNare traffic-oblivious or itconsumesalotoftimethiscausesroutingschemestofailinresponding to the dynamically changing traffic [3]. So, to overcomethis, in this paper, a Reinforcement Learning (RL) based method ispresented,itlearnsatraffic-splittingagenttoaddressthedynamically-changing traffic and to attain the link load balancing in the hybridSDN.Afterevaluations,theperformanceofROARmethodontheminimizationofMLUissuperiortotheOSPFmethod,andapproximatestotheWASRTEmethod.ThecalculationtimeofroutinggenerationforaTMhaveexhibitedthepotentialsoftheproposedROARmethodinachievingonlineintelligentrouting.Furtherworkistoevaluatetheproposedmethodintherealproductionnetrks.The real ISP network may adopt different strategies todeploytheSDNdevices,sosomemorestudiescanbeimplementedonevaluating the generalization of our proposed method to the differentstrategies of the SDN deployment and the different topologies ofhybridSDN.

VI. ANEWDECOMPOSITIONTECHNIQUE

It is centered on a scalable traffic engineering scheme for effectivelymapping traffic demands to paths in SDN datacenters [4]. The Trafficflows in data center networks are categorized into elephant flows andmice flows. The elephant flows are scheduled by an optimal solutionbased on LP. A new decomposition technique is proposed that canlimitthesearchspaceoftheoriginalLPproblem.Sincethemiceflowshave the sensitive time requirements, some paths are reserved forimmediatelyforwardingthese.Thepresentedmethodavoidsthenetworkcongestionbyusingtheoptimaldemand-pathmappingwitha tolerabletimecomplexityandat the same time handle the time-sensitivemiceflows.Furtherstudyincludeshowtosaveenergywhenachieve a balanced load in the network, especially for cloud-basedDCNs.

VII.ADISTRIBUTEDALGORITHMDERIVING FROM LANGRAGIAN DECOMPOSITION THEORY

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The main objective of the paper is minimization of maximum linkutilization, and comply with SDN waypoint enforcement and TCAMresource limitation [5]. First form the TE problem as an integer linearprogramming (ILP) model and solve it in a centralized manner. NextdevelopadistributedalgorithmderivingfromLagrangiandecomposition theory to efficiently solve the TE problem. The resultsshows that the when SDN deployment rate approaches 30%, TEDRalgorithm can obtain TE performance comparable to that of full SDN.Thefutureworkis,theTEDRalgorithmpresentedinthispaperworksin static traffic conditions. But in high dynamic traffic conditions, thealgorithmshouldreactfasteraccordingtothechangesandtheresultingroutes should be modified according to the newly calculated SDNwaypoints.

VIII.MILP

Here,anewmixedintegerlinearprogrammingisdesignedtofullysupportadjacencySIDs[6].Tominimizethenumberofvariablesandconstraints inK-MILP,asimplifiedformulationisdesigned.Basedonit, two extensions are made to cap either the number of *K*-segmentpaths used to carry a traffic flow to avoid excessive flow splitting, orthelengthofa*K*-segmentpathtoreducepacketbandwidthconsumption and packet delay. K-LP are not optimal because they donot consider paths involving non-shortest path links. In this paper, anenhancedversionof2-LPtosupportadjacencySIDsistaken.

IX.SEGMENTROUTINGOVERIPv6 NETWORK

Here a novel TE algorithm WA-SRTE is proposed, which takes notonly the SR nodes deployment but also the link weight setting intoconsideration[7].wedivideWA-SRTEintotwophases:offlinenetworkdesignandonlineroutingoptimization.WA-SRTEcanachieve almost same TE performance as in full SR network with 20%to40%SRnodedeployed.Butthereisnecessityofweightadjustmentin hybridIP/Srnetworks.

X.TEIN SD-WAN

Here the performance of baseline TE algorithms is evaluated first [8].Afterwards, we implement different deep Reinforcement Learning(deep-RL)algorithmstoovercome the limitationsofthe baselineapproaches. We implement three kinds of deep-RL algorithms, thatare:Policygradient,TDanddeepQ-learning.Duetopredictivenatureof ML algorithm, TE based algorithms based on RL outperforms allotherdeterministicones interms ofserviceuptime.

XI.DEEPREINFORCEMENT LEARNING

DRL agent learns the interdependency between the traffic loads ofnetwork switches and the network performance [9]. It decides theoptimalsetoflinksweightstomakebalancebetweenend-to-enddelayand packet losses of network. The proposed routing system can solveexplorationissuesbyutilizingthemodellednetwork.Butitisextensivelylonglearningprocess.

XII. QR-SDN

HeretheQR-SDNisevaluatedfirst,aclassicaltabularreinforcementlearningapproachthatdirectlyrepresentstheroutingpathsofindividualflowsinitsstate-actionspace[10].QR-SDNisthefirstreinforcementlearningSDNroutingapproachtoenablemultiplerouting paths between a given source switchdestinationswitchpairwhilepreservingtheflowintegrity.InQRSDN,packetsofagivenflowtakethesameroutingpath,whiledifferentflowswiththesamesource-destinationswitchpairmaytakedifferentroutes. Finally, we implementedQR-SDNinaSoftware-DefinedNetwork (SDN)emulation testbed.

XIII. PROPOSED METHOD

1) A new method has been proposed here. In the Proposed method for solving the TE Problem of the Hybrid SDN contains two

stages: offline Learning stage and online routing stage.

2) At the Offline Learning Stage, given the network topology of Hybrid SDN and traffic information, we first construct a graph to ensure a Hybrid SDN environment with a loop free routing for the interaction of the RL agent. With the constructed graph, a traffic splitting agent is trained to establish a direct relationship between the network environment and the routing schemes by leveraging the RL framework.

3) At the Online routing stage, through deploying the trained traffic splitting agent, an effective routing scheme can be quickly calculated when traffic demand changes.

Fig. 1. Design Diagram of the Proposed Method

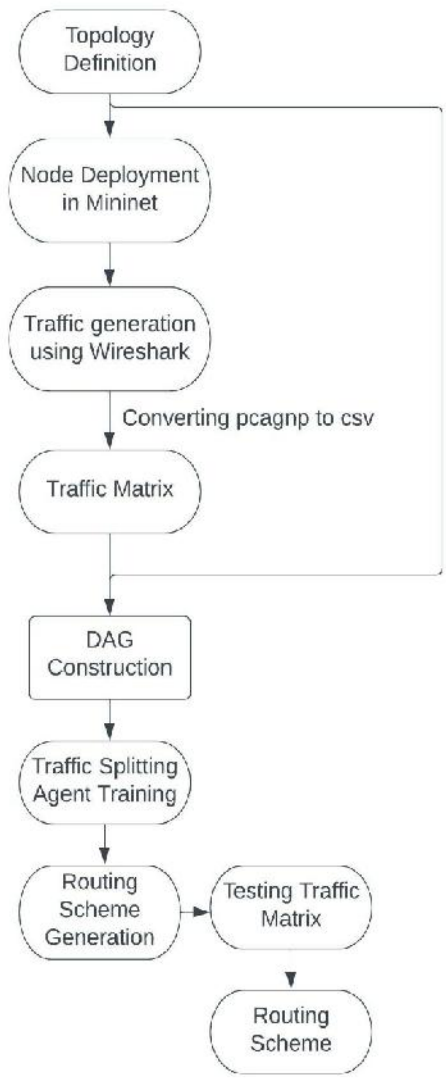

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TABLE 1. Summaries of Different Methods for Minimizing Maximum link Utilization **Ref.**	**Method**	**Summary**
[1]	H-PermissiblePathsRoutingScheme(HPRS).	The problem is taken as a MINLP problem,and an approximation algorithm HPRS withanapproximationratioof$O(logL)$,isproposed.
[2]	Critical Flow Rerouting-ReinforcementLearning.	CFR-RL chooses the critical flows for eachgiven traffic matrix and these flows can beredirectedbysolvingasimplereroutingoptimizationproblem.
[3]	ROAR.	In the ROAR method, a traffic-splitting agentis trained on a set of traffic demands offline,After the traffic-splitting agent is learnt, it isdeployedandwhentrafficdemandsarechanging, it can generate the routing schemeseffectively.
[4]	ANewDecompositionTechnique.	Here,anewdecompositiontechniqueisproposed for limiting the search space basedon the linear programming method to workouttheprobleminreasonabletime.
[5]	A Distributed Algorithm Deriving fromLagrangianDecompositionTheory.	A formulation P is proposed to reduce themaximumlinkutilizationinacentralizedmanner,whichconsidersthewaypointenforcementandthelimitationonTCAMresources.
[6]	MILP	Based on the formulation, they are made tocap either the number of K-segment or thelengthofaK-segmentpathtoreducepacket bandwidthconsumptionandpacketdelay.
[7]	SegmentRoutingOver IPv6Network	TEalgorithmWA-SRTEisproposed,whichtakeslinkweightsettingintoconsideration.

[8]	TEInSD-WAN	Weimplementthreekindsofdeep-RLalgorithms i.e. policy gradient, TD and deepQ-learning to overcome the limitations of thebaselineapproaches
[9]	DeepReinforcementLearning	DRLagentlearnstheinterdependencybetween the traffic loads of network switchesandthenetworkperformanceandmake balancebetweenend-to-enddelayandpacketslossesof network
[10]	QR-SDN	In QR-SDN, packets of a given flow take thesame routing path, while different flows withthesamesource-destinationswitchpairmay takedifferentroutes.

XIV.CONCLUSION

This paper surveys about different routing techniques to minimize the maximumlinkutilizationinTrafficEngineering.A Reinforcement Learning method canbeusedtominimizethemaximumlinkutilization.

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