SDN Controller Placement Design for Large Scale Production Network

Muhammad Zen Effendy
zenzest@students.telkomuniversity.ac.id

Rendy Munadi
rendymunadi@telkomuniversity.ac.id

Sofia Naning H
sofiananing16@gmail.com

Faculty of Electrical Engineering
Telkom University
Bandung, Indonesia

Abstract— Software-Defined Network (SDN) architecture offers many advantages related to flexibility, higher network programmability and simplicity of application service development. On the other hand, this architecture leaves a number of issues related to scalability, reliability and performance (such as delay and control communication overhead) to be applied to large-scale networks such as the Service Provider / Wide Area Networks (WAN).

This researchpropose design solutions of controller placement on well-established traditional existing legacy network with a large number of nodes, million of users and various services. SDN design topology created by taking into consideration the configuration of traditional existing network to ensure reliability, the design begins by setting a 'candidate' where to place the controller selected based router/switch with high processing bandwidth on a legacy network and taking into account the maximum propagation delay and other parameters of POCO framework and load of the controller to ensure that every controller load on the network can not exceed the capacity of the controller itself.

Controller placement design that taking into account controller candidate with high procesing bandwidth gives more optimal placement when desingning SDN Network, The simulation results give better controller load balancing and resiliency.

Keywords—; SDN, Controller placement, Controller Load

I. INTRODUCTION

Controller design placement depends with the resilience and performance aspects required, there is usually no single best placement solution but the trade-off between some selected parameters [2]. POCO framework provides a Pareto-optimal placement of data on the resilience aspect of the design is based Controller failure parameter, controller placement disruption, Load imbalance and Inter-controller latency. Another important parameter when determining the controller placement is the load controller (load of the controller), where the load of each controller on the network can not exceed the capacity of the controller itself [3].

This research was made to solve the problem of controller placement if the location of the controller determined in advance (legacy network -given, as a 'candidate', based on the location of the main router on the existing network): whether they will be optimum placement? And if not, how many and where were the additional controller should be installed? to obtain the optimum design.

The main objective of this research is to determine the Optimal placement Controller Schematic Design which meets the requirements of resilience network parameters, controller imbalance and maximum controller load..

The paper is organized as follows. An overview of the related experimental work on SDN Controller placement isgiven in Section II. The network model is described in detail in Section III. The placement design issues together with an SDN-controlled MAN design example are examined in Section IV. Section V presents conclusions and future work.

II. SDN CONTROLLER PLACEMENT PROBLEM

Controller placement design depends upon the resilience and performance aspects of placement, usually no single solution will be found but the best placement is a placement Controller among multiple selected parameters [2]. Some algorithms design and studies have been done to optimize the design of SDN controller placement this, Heller [1] discusses the optimization of the propagation latency by using k-median (average case latency) and k-center (worst case latency) using an algorithm facility location optimization problem. Hock et. al [2] create a resilient framework-based Pareto Optimal placement Controller (POCO) for parameter optimization analysis that takes into account failure Controller, Controller placement Disruption, Load imbalance and Inter-controller Latency. Gung Yao [3] defines Capacitated Controller Placement Problem that takes into account the load of the controller in algorithm design.

Controller failures Tolerance

Proper placement of many controllers design can reduce the maximum latency between nodes and the controller and increasing the failure-tolerance against possible outage of one or more controllers. So if the main-controller down, all nodes connected to the same controller assigned to the nearest controller on the network.

To increase resiliency, optimization of controller placement should take into account the worst case latencies aspect to this controller failures. When an outage happen on a controller, assign multiple nodes in the other controller could increasing latency.

To calculate the latency in the Controller placement, maxsimum node-to-controller-latencies $\pi^{\text{max latency}}$ are calculated based on a matrix $d_{v,w}$ which is the shortest distance between nodes v and w in V.

Node-to-controller maximum latency plcement number controller $\mathcal{P} \in 2^{\mathcal{V}}$ is defined by:

$$\pi^{\text{max latency}}(\mathcal{P}) = \max_{(v\in\mathcal{V})} \min_{(p\in\mathcal{P})} d_{v,p} \quad (1)$$

Calculation of latency to the possibility of down controller can be obtained by the following approach:

Maximum latency when no controller down denoted as $\pi_{\emptyset}^{\text{max latency}}$.

Maximum number of total latency of all possible C of combination possibilities controller failure up to k - 1 is denoted as:

$$\pi_{\mathcal{C}}^{\text{max latency}}(\mathcal{P}) = \max_{(s\in\mathcal{C})} \pi_{s}^{\text{max latency}}(\mathcal{P}) \quad (2)$$

Load Imbalance

The more numbers of nodes connected to the controller, the higher the load controller which causes the addition of queuing delay on the controller.

Load Balancing Controller is required to avoid overload on a controller while the other controller deficient load.

With $\pi^{\text{imbalance}}$ the difference between the highest node number who served a controller with the fewest number of nodes served by another controller.

Obtained by the formula:

$$\pi_{\emptyset}^{\text{imbalance}}(\mathcal{P}) = \max_{(p\in\mathcal{P})} n_p^{\emptyset} - \min_{(p\in\mathcal{P})} n_p^{\emptyset}$$

$$\pi_{\mathcal{X}}^{\text{imbalance}}(\mathcal{P}) = \max_{(s\in\mathcal{X})} \left(\max_{(p\in\mathcal{P})} n_p^{s} - \min_{(p\in\mathcal{P})} n_p^{s} \right) \quad (3)$$

Inter-Controller Latency

Depend on the frequency synchronization between the controller, Latency between the controller becomes an important parameter to maintain the stability of the network.

Inter-controller latency is defined as the greatest latency between two controllers on placement P :

$$\pi^{\text{controller-latency}}(\mathcal{P}) = \max_{(p_1,p_2\in\mathcal{P})} d_{p_1,p_2} \quad (4)$$

Maximum Latency

In this study, network delays that used as constraint parameter is the propagation delay, with a maximum latency requirements refer to the IP Backbone SLA TELKOM is 20 ms.

Maximum Propagation delay is calculated based on the propagation delay at fiber optic by the formula [4]:

$$\textit{propagation delay} = \frac{\textit{Link length (mile)} \times 1.609 \left(\frac{km}{mile}\right) \times 1000 \left(\frac{m}{km}\right)}{2 \times 10^{8} \left(\frac{m}{s}\right)} \quad (5)$$

(* Wave velocity in the fiber optic = 2x108 m / s)

Maximum latency is to be used as a constraint to determine the network design.

Controller Capacity

SDN Controller load on the network is influencing by four main components: (1) processing of messages and the delivery PACKET_IN; (2) the maintenance of a local view of the network; (3) the communication process with another controller to maintain the global view; (4) the installation process the application rules.

Depending on the design of the network, the amount of these components can be very different, but in general the processing load PACKET_IN is the biggest contributor total load of the controller [3].

In this study, to determine the number of controller (n) needed on the design, use the formula:

n = The maximum capacity of the controller / switch capacity of processing,

In this study, analysis and evaluation of the design is using the controller capacity in previous studies [7].

III. The Network Model

Network Topology

PT Telkom's network topology consists of a 3 Tier of Network Infrastructure: Access Network (all customers connect here), Metro E Network (IP & regional based transport) and IP MPLS Network (service creation & the backbone).

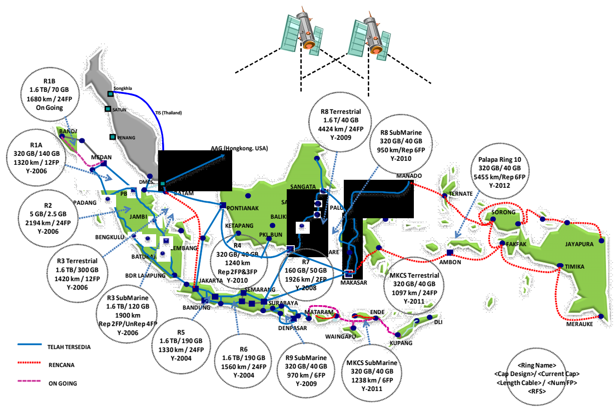

Fig 3.1 Network Topology illustration of PT Telkom Indonesia.

Divided into Antonomous System (AS) Regions, Regional network is using Metro Ethernet network and divided into several sub-region boundary with links between metro nodes with a capacity of 1G and 10G on its Regional backbone link.In this research, we will analyze one of the Region (AS) Metro Ethernet, East Java.

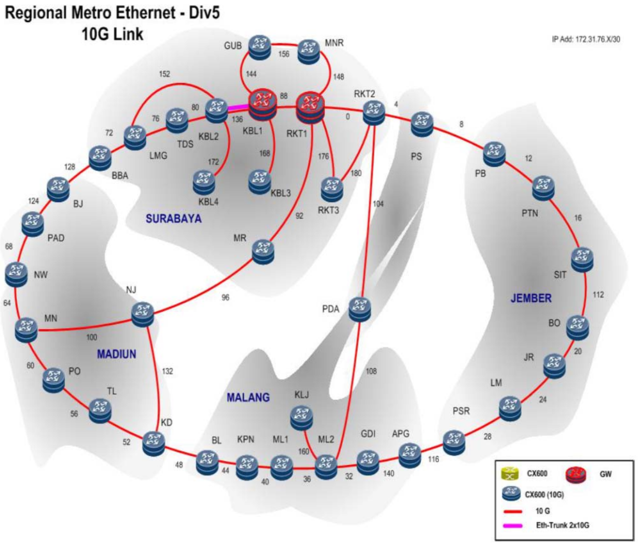

Fig 3.2 Java Regional Metro Ethernet Backbone Link.

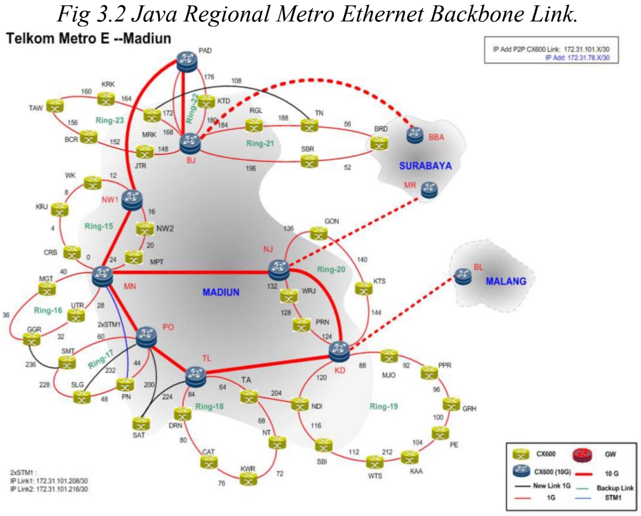

Fig 3.3 Metro Ethernet Network East Java, Madiun Ring: Aggregator Link.

Design Model

In this study, we will discuss the best controller location to be placed on the network topology for the implementation of SDN Network, assuming:

- Controller location placed on the existing nodes location.
- Interconnection between physical nodes using the existing transport network
- Traffic flow is calculated as the existing traffic demand, as one of the design parameters.
- Backbone metro node used as a candidat placement, with the first priority starting from the node with the highest bandwith processing.
– Latency Constraint calculated in this study is the propagation latency.

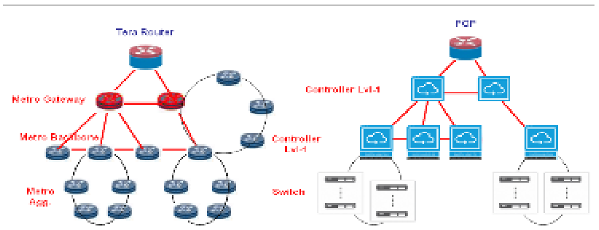

Fig. 3.4 Abstraction, Existing vs Next Topology

IV. DESIGN AND SIMULATION

Proposed Method

The proposed method includes the steps of: determining the design constraint, definng the number of controllers required and then calculate the value of the design parameters of various scenarios.

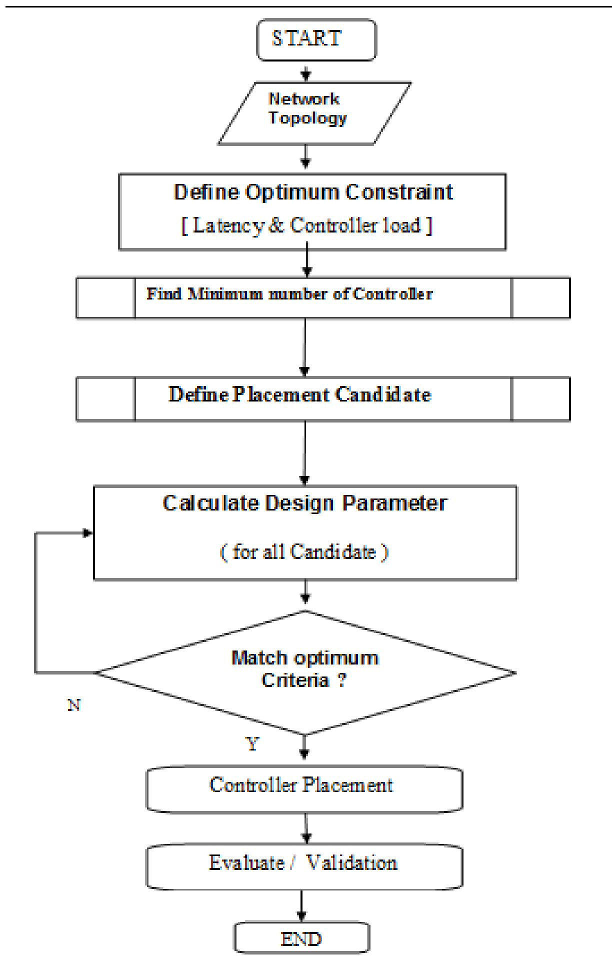

Fig. 4.1Proposed Method

A.1 Determining the Design Constraint

The design must meets the requirements of maximum 20ms Latency [11] and the minimum number of controllers to to handle all flow within the network.

A.2 Calculating the number of Controller

Controller processing performance depends on parameters such as: processor speed, RAM, number of Switch that connected, the number of flow table etc. The controller capacity is the the ability of processing flow per second (packet-in). There are a various available controller capacity, this research used Controller with a capacity of 1.75 Mpps. [11]

In this research, the Controller hierarchy base on the existing hierarchical network topology. The number and location of Controller backbone (Level-1) will be determined based on the capacity of the existing backbone traffic flows to be served, the number and location aggregator Controller (Level-2) following the topology Metro-aggregator existing boundary.

A.2.1 Determining the Number Controller Level-1.

Traffic flow at backbone network of the existing Regional Jatim metro to the gateway is shown at the table below:

Table 4.1Total number of backbone-Metro East Java packet going to the Metro Gateway (Flow per second)

NODE	candidat	lat	long	BW	Switching Cap	Port Cap.	Fwd perf.	Packet Flow (K pps)
ME-D5-KBL2	KBL	-7,2315	112,744972	40	**2.56 Tbps**	**1.28 Tbps**	**1600 Mpps**	300
ME-D5-KBL4	KBL	-7,2315	112,744972	40	**2.56 Tbps**	**1.28 Tbps**	**1600 Mpps**	300
ME-D5-PSR	JR	-8,2135	113,114556	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-PS	RKT	-7,65138889	112,901333	10	640 Gbps	320 Gbps	400 Mpps	139
ME-D5-MNR	RKT	-7,28505556	112,781444	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-RKT4	RKT	-7,32777778	112,776278	40	**2.56 Tbps**	**1.28 Tbps**	**1600 Mpps**	300
ME-D5-RKT3	RKT	-7,32858333	112,745417	40	640 Gbps	320 Gbps	400 Mpps	300
ME-D5-TL	MN	-8,07893	111,694651	10	640 Gbps	320 Gbps	400 Mpps	139
ME-D5-PAD	MN	-7,172432	111,661084	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-MN1	MN	-7,62722222	111,520056	20	640 Gbps	320 Gbps	400 Mpps	155
ME-D5-MN2	MN	-7,62722222	111,520056	20	640 Gbps	320 Gbps	400 Mpps	155
ME-D5-NW	MN	-7,40361111	111,446861	10	640 Gbps	320 Gbps	400 Mpps	139
ME-D5-PO	MN	-7,867808	111,474745	10	640 Gbps	320 Gbps	400 Mpps	139
ME-D5-SIT	JR	-7,70302778	114,012806	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-BO	JR	-7,91527778	113,822611	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-JR	JR	-8,17486111	113,693556	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-PTN	JR	-7,71861111	113,530556	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-LM	JR	-8,13319444	113,223167	2	640 Gbps	320 Gbps	400 Mpps	29
ME-D5-PB	JR	-7,747649	113,215168	10	640 Gbps	320 Gbps	400 Mpps	139
			TOTAL	**385**				**3.832**

obtaining the total amount of flow per second: 3,832 Mpps, so the minimum number of required controller are 3 controllers.

A.2.2 Determining the Number of Controller Level-2

From the existing metro-agregrator flow with the assumption that packet flow from a node forwarding to the controller, giving a total FPS of: 7,150 Mpps, so the minimum required controller is 5 controller.

Table 4.2 Total number of Metro-aggregator Java packet out (Flow per second)

NODE	lat	long	BW	Switching Cap	Port Cap.	Fwd perf.	Packet Flow (K pps)
ME-D5-KBL2	-7,2315	112,744972	40	**2.56 Tbps**	**1.28 Tbps**	**1600 Mpps**	150
ME-D5-KBL4	-7,2315	112,744972	40	**2.56 Tbps**	**1.28 Tbps**	**1600 Mpps**	150
ME-D5-PSR	-8,2135	113,114556	1	640 Gbps	320 Gbps	400 Mpps	12
ME-D5-TMP	-8,2135	113,114556	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-TGS	-7,731325	113,106629	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-TJB	-6,89361111	113,077222	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-BLG	-7,12055556	113,069444	1	640 Gbps	320 Gbps	400 Mpps	23
NEW ME-D5-SKP	-7,88472222	113,050833	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-GRA	-7,70805556	112,999778	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-PS	-7,65138889	112,901333	10	640 Gbps	320 Gbps	400 Mpps	70
ME-D5-APG	-8,23638889	112,876389	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-ARB	-6,94752778	112,841	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-KJR	-7,25138889	112,791222	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-LEC	-7,83416667	113,2275	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-LM	-8,13319444	113,223167	2	640 Gbps	320 Gbps	400 Mpps	15
ME-D5-PB	-7,747649	113,215168	10	640 Gbps	320 Gbps	400 Mpps	70
ME-D5-TPH	-8,204601	113,174945	1	640 Gbps	320 Gbps	400 Mpps	23
ME-D5-GEM	-7,54777778	112,696639	1	640 Gbps	320 Gbps	400 Mpps	23
		TOTAL	**761**				**7.150**

A.3 Determining the location of Candidates

Placement of the controller defined by the maximum capacity of the controller so that the overall flow of Node / Switch that is connected to the controller can be served by a controller.

A.3.1 Location Candidates for Controller Level-1

Controller level-1 will be placed at the location of the metro backbone to hadle the flow of traffic passing through the network backbone as seen in Fig. 3.3, the candidate location selecting base on Node with high bandwidth processing, which is a regional transport backbone.

From any locations of the backbone nodes, controller placement candidates are: KBL, CTR, ML, MN, KD, JR.

Table 4.3 Metro Ethernet Backbone Regional Jatim, sort by Packet Flow at descending order.

NODE	lat	long	BW	Packet Flow (K pps)
ME-D5-KBL2	-7,2315	112,744972	40	300
ME-D5-KBL4	-7,2315	112,744972	40	300
ME-D5-RKT4	-7,32777778	112,776278	40	300
ME-D5-RKT3	-7,32858333	112,745417	40	300
ME-D5-ML1	-7,98044444	112,629694	20	155
ME-D5-ML2	-7,98044444	112,629694	20	155
ME-D5-KD	-7,8145	112,017333	20	155
ME-D5-MN1	-7,62722222	111,520056	20	155
ME-D5-MN2	-7,62722222	111,520056	20	155
ME-D5-JR	-8,17486111	113,693556	20	140
ME-D5-PS	-7,65138889	112,901333	10	139
ME-D5-GUB	-7,28916667	112,735861	10	139

A.3.2 Placement Design of Level-1 Contoller.

A.3.2.1 Determining Controller Candidates

a. Calculate the load of each controller

The load of each controller is calculated based on the boundary of the existing infrastructure. Calculations in the previous chapter obtaining minimal of 3 Controller, so possible scenario of candidates to determine the controller placement are:

Table 4.4 Controller placement candidate and Scenario based on existing traffic flow.

Scenario-1			Scenario-2			Scenario-3		
Candidate	Packet Flow	% Load	Candidate	Packet Flow	% Load	Candidate	Packet Flow	% Load
MN	1322	75,54%	**MN**	1322	75,54%	**MN**	1322	75,54%
KBL+MN	1326	75,77%	**KBL**	901	51,49%	**KBL**	901	51,49%
RKT+JR	1184	67,66%	**RKT**	901	51,49%	**RKT**	901	51,49%
			ML-JR	708	40,46%	**ML**	425	24,29%
						JR	283	16,17%
	Avg	**72,99%**		**Avg**	**54,74%**		**Avg**	**43,79%**

b. Defining the number of controllers required

Considering Resiliency parametr network with 1 unit controller down, the controller load obtained as follows:

Table 4.5Resiliency scenario

Scenario-2			Scenario-1		
Candidate	Packet Flow	% Load	Candidate	Packet Flow	% Load
MN	1322	0,00%	**MN**	1322	0,00%
KBL	901	70,37%	**KBL+MN**	1609	110,83%
RKT	901	70,37%	**RKT+JR**	901	70,37%
ML-JR	708	59,34%			
	Avg	**50,02%**		**Avg**	**90,60%**

So in this study, the placement scenario evaluated using 4 controller with possible placement : MN, KBL, RKT, ML and MN, KBL, RKT, JR.

B. Simulation

This section analyze some scenario of placement and the parameter results using POCO framework for the placement candidates of metro traffic that handles regional backbone.

B.1 Placement ***Scenario 1****: RKT (1), KBL (3), MN (9) and ML(6)*

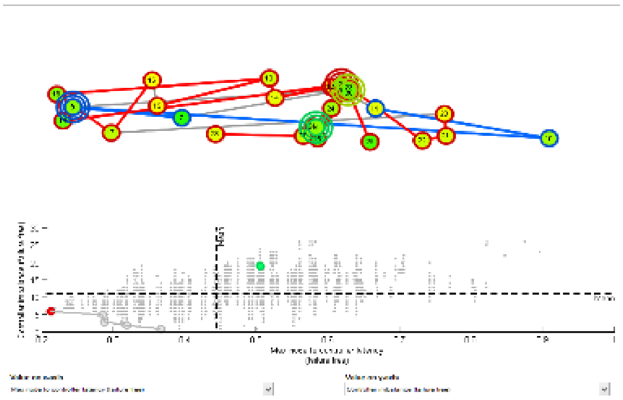

Fig 4.2 Latency and Controller imbalance for RKT, KBL, MN, ML.

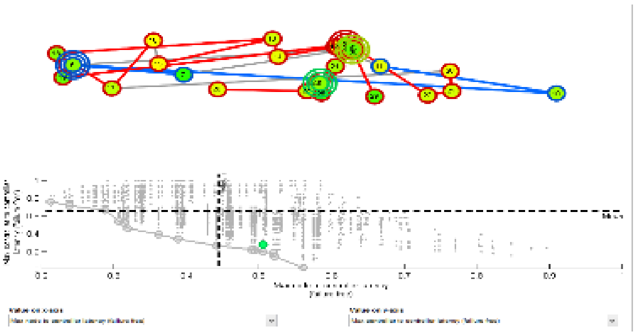

Fig 4.3 Node to Controller / Controller Latency for RKT, KBL, MN, ML

B.2 Placement **Scenario 2**: RKT, KBL, MN, JR

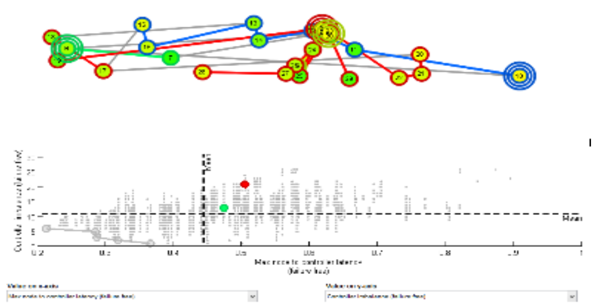

Fig 4.4 Latency and Controller imbalance for RKT, KBL, MN, JR

C. Analysis

Fig 4.3 to 4.6 shows that in the first scenario, latency Node Controller to be at 0,51, max Controller to controller latency at 0.3 and the controller controller imbalance is 18 nodes. In the second scenario: latency Node Controller to be at 0,48, max Controller to controller latency at 0.5 and controller imbalance is 11 nodes. From the calculation formula in the previous chapter, resulting the maximum propagation latency of scenario-1 0.7781105254 ms and using a scenario-2 resulting propagation at 1.311215983 ms maximum latency.

Scenario-1 gives more balance for the controller load and give smaller intra controller latency, and because intra controller flow between controller are higher than controller to node, the second scenario chosen because it provides lower latency values than the first scenario.

C.1 Placement Design for Level-2 Contoller.

Placement scenarios analyze by using POCO framework for placement controller which handles traffic metro-aggregator. With 7 controller of existing boundary, flow that must be served by each controller on the boundary as follows:

Table 4.5 Flow packet / s of each Metro-aggregator boundary.

Boundary	Packet Flow
JR	1395
KBL	1133
KD	792
ML	1131
MN	930
MR	445
RKT	884

Because the maximum capacity of the controller (if using a controller with a similar capacity at all controller level-2), another scenario that can be selected is 5 controller, by combining the two adjacent boundary serviced by a single controller, obtaining candidate placement with possible scenario : JR, KBL, ML, MN-KD and RKT-MR.

C.2 Latency Analysis

Propagation latency selected scenarios simulated by POCO framework.

POCO Framework best placement Failure-free scenario, with number of controller = 1 (k = 1), obtained max controller to node latency is around 0.525.

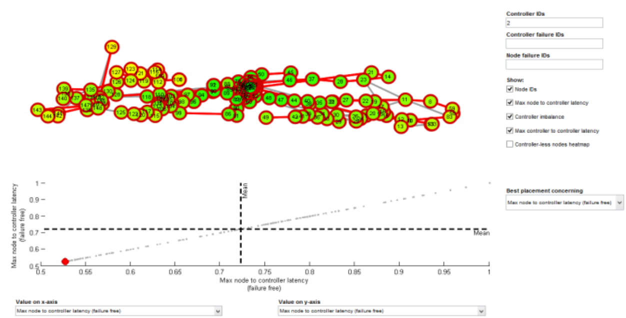

Fig 4.5 Best placement, k=1, POCO failure-free scenario.

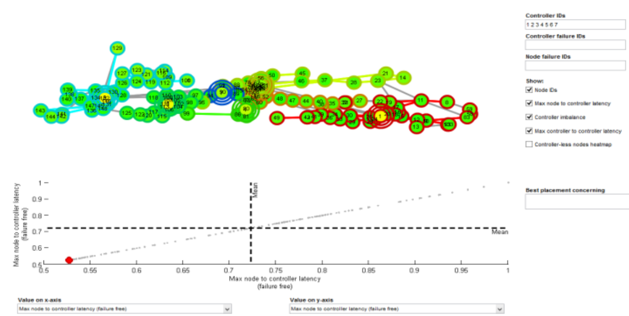

Fig 4.6 Best placement, 7 controllers scenario.

With 7 Controller scenario, resulting latency at 0.525, which means have the maximum latency scenarios as same as optimum placement in the network.

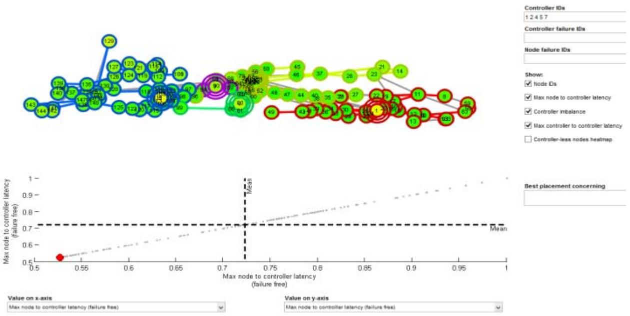

Fig 4.7 Best placement, 5 controllers scenario.

At the second scenario: using the 5 controllers, latency obtained at: 0.525, resulting in an average propagation latency node-to-controller similar to the first scenario.

C.3. Analysis of Load Balancing

Total packet flow to handle by each controller is as follows:

Table 4.6 The load of each Controller Lvl-2

Scenario-1			Scenario-2		
Boundary	Packet Flow	% Load	Boundary	Packet Flow	% Load
JR	1395	79,71%	JR	1395	79,71%
KBL	1133	64,74%	KBL	1133	64,74%
KD	792	45,26%	ML	1131	64,63%
ML	1131	64,63%			
MN	930	53,14%	MN-KD	1722	98,40%
MR	445	25,43%	RKT-MR	1329	75,94%
RKT	884	50,51%			
	Avg	54,78%			76,69%

By using the same controller capacity, the more controller placed on the network, give more less average load on the network controller.

C.4. Analysis of Resilience

Resilience parameters taken into consideration to ensure network flow can still be handled by the controller if one or more of the controller to experience an outage.

Table 4.7 Resiliency scenario

Scenario-1			Scenario-2		
Boundary	Packet Flow	% Load	Boundary	Packet Flow	% Load
JR	0	0,00%	JR	0	0,00%
KBL	1365,5	78,03%	KBL	1598	91,31%
KD	1024,5	58,54%	ML	1596	91,20%
ML	1363,5	77,91%			
MN	1162,5	66,43%	MN-KD	1722	98,40%
MR	677,5	38,71%	RKT-MR	1794	102,51%
RKT	1116,5	63,80%			
	Avg	63,90%		Avg	95,86%

From the table seen by using the appropriate boundary of the existing controller, network remained stable for the flow of traffic in the network.

V. CONCLUSIONS AND FUTURE WORKS

Controller design placement by determining the location of candidate controller that takes into account the load controller parameters and resilience resulting in better design on the controller processing load and increasing resiliency while meet the controller to node latency requirement.

Detailed traffic flow analysis have to be ensured to have the best placement design.

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