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Green Saudi National Fibre Network (SNFN)

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Abstract—In 2015, there were more than 21 million active users of the Internet in Saudi Arabia. In the present paper, we consider minimizing the power consumption of the Saudi National Fibre Network (SNFN) by formulating the problem as a mixed integer linear programming (MILP) model. Firstly, we optimize the location of single or multiple data centres in the SNFN under a traffic profile based on a gravity model where the production rate and attractiveness of each node is proportional to the population of that node. We evaluate the network power consumption considering three scenarios of data centre locations. The MILP model results show that identifying the optimum data centre locations can save up to 53% of the network power consumption compared to the random data centre locations. Secondly, we optimize the SNFN physical topology considering different data centers locations. The model results show that optimizing the network physical topology can save up to 76% of the total power consumption compared to the current topology.

Keywords—IP over WDM networks, MILP, Data centre, Energy efficiency, Physical topology, SNFN.

I. INTRODUCTION

Year after year, the number of connected devices to the Internet has been increasing dramatically. By the end of 2015, there were more than 21 million active users of the Internet in Saudi Arabia[1]. This number is expected to soar in the coming years calling for new measures to ensure efficient resource utilization and energy consumption. Minimizing the power consumption of the network will lead to reducing the carbon footprint as well as the running cost.

Nowadays, greening the Internet has attracted many research efforts [2], [3]. The authors in [4] developed a MILP model to minimize the power consumption of the IP/WDM fiber network by optimizing the virtual topology. Also, Dong et al. in [5] and [6] built a MILP model to examine the IP/WDM NSFNET network with the data center's power consumption as well as optimize its physical topology. Moreover, Lawey et al. in [7] developed a MILP model to introduce a framework for designing energy efficient cloud computing services over non-bypass IP/WDM core networks. In this paper, we evaluate the power consumption of the Saudi optical network's backbone (SNFN). We optimise the location of data centres as well as the physical topology using the MILP models developed in [5] and [6].

The remainder of this paper is organised as follows. Section II briefly reviews the IP over WDM network architecture and the data centre architecture. In Section III, we introduce the MILP model used to optimise the location of data centres and present the results of optimizing data centre locations in the SNFN network. In Section IV, we introduce the MILP model used to optimise the physical topology. Also, we present the results of optimizing the physical topology of the SNFN. Finally, section V concludes the paper

II. IP/WDM NETWORK AND DATA CENTRE ARCHITECTURE

IP over WDM network is composite of two main layers: IP and the optical layer. On the IP layer, the IP router is connected to an optical switch in each node. The IP router aggregate the traffic from access network. Meanwhile, the optical layer provides a large capacity for data communication between the IP routers. Optical switch nodes are connected to physical fibre links. The transponders provide optical-electronic-optical (OEO) processing for full wavelength conversion in each node. To enable the optical signals to make a transmission in a long distance, the erbium-doped fiber amplifiers (EDFAs) are used to amplify optical signals in the fiber links. In case of longer transmission, the regenerators are used if the link's length exceeds 2500 km [4], [8].

Multiprotocol Lambda Switching protocol over wavelength division multiplexing (MPLS over WDM) is the routing protocol on IP over WDM optical core networks that route the data packets from source to destination nodes through the shortest path with a connection-oriented service. Using MPLS, the IP over WDM-routed traffic can be implemented by either bypass or non-bypass light paths. In the case of bypass, the packets intermediate nodes will not process the packets. The packets will take a cut through into the destination node. Meanwhile, on a non-bypass path, the packets will be processed by every intermediate node during the journey from the source to the destination. Implementing a bypass light path can significantly reduce the power consumption of the network. However, a non-bypass light path allows for scanning, inspecting, and monitoring packets to check for any security threats [9], [10] .

A traditional data centre consists of a multiple racks which host the servers. The servers deliver different services (such as content, storage or processing capacity) to the end-users with critical infrastructure characteristics. These data centres can provide a resource of web servers, storage, databases or even processing capacity to the users [3]. Usually, the data centre is built close to the core network node so as to take advantage of the large bandwidth. Figure 1 illustrates the basic architecture of an IP/WDM network connecting to a data centre.

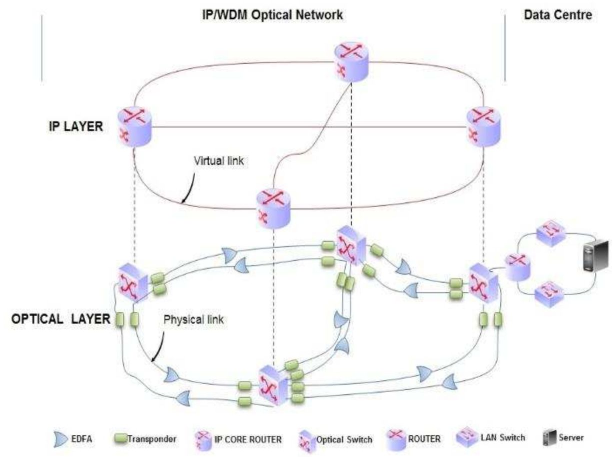

Figure 1: IP/WDM optical network architecture with data centre.

III. THE OPTIMISATION OF DATA CENTRES LOCATION IN SNFN

A. MILP MODEL

In this section, we re-introduce the MILP model developed in [5] to optimize the data centre locations in IP over WDM networks for completeness.

Parameters and variables of MILP model are defined as following:

Core Network Parameters

N	Set of nodes (cities) in IP over WDM network.
$Nm_{\{N\}}$	Set of neighbours' nodes of node N.
Nodes	Total number of nodes in IP over WDM network.
Erp	Power consumption of router port.
Et	Power consumption of transponders.
Ee	Power consumption of EDFA.
Eo	Power consumption of optical switch in IP/WDM core network.
Erg	Power consumption of regenerator.
W	Number of fibre's wavelength in IP over WDM network.
B	Total bandwidth of wavelength.
S	Maximum distance between the pair of EDFAs on IP over WDM network.
A_{mn}	Total number of EDFA on the path between nodes pair m and n.
PUE_n	Fixed number that represents the power effectiveness of the network [cooling, lighting …etc.].

Core Network Variables:

L_{sd}	The traffic demand between the sender node s and receiver node d of IP/WDM network.
C_{ij}	Number of wavelength used on the virtual link between node i and node j.
W_{mn}	Total number of wavelengths per physical connection between node m and node n.
$AggPort_i$	Total number of aggregation ports on router i that communicate with other network parts.
F_{mn}	Total number of fibres between node m and node n.
L_{sd}^{ij}	Total traffic demand between the sending node s and receiver node d, which pass through a virtual path from node i to node j.
W_{ij}^{mn}	Total number of wavelength used on the connection between node i and node j that pass through physical path between node m and node n.
RG_{mn}	RG_{mn} = 1 if there is a regenerator within the link between node m and node n, otherwise RG_{mn} = 0.
R_{sd}	Total non-data centre traffic from node s to node d.

Under the non-bypass routing, the IP over WDM network power consumption is composed of:

1) The total power consumption of routers ports:

$$PUE\_n \cdot \left(\sum_{i \in N} Erp \cdot AggrPort_i + \sum_{m \in N} \sum_{n \in Nm: n \neq Nm} Erp \cdot W_{mn} \right)$$

2) The total power consumption of transponders:

$$PUE\_n \cdot \left(\sum_{m \in N} \sum_{n \in Nm} Et \cdot W_{mn} \right)$$

3) The total power consumption of EDFAs:

$$PUE\_n \cdot \left(\sum_{m \in N} \sum_{n \in Nm} Ee \cdot F_{mn} \cdot A_{mn} \right)$$

4) The total power consumption of optical switches:

$$PUE\_n \cdot \left(\sum_{i \in N} Eo_i \right)$$

5) The total power consumption of regenerator:

$$PUE\_n \cdot \left(\sum_{m \in N} \sum_{n \in Nm} Erg \cdot RG_{mn} \cdot W_{mn} \right)$$

Data centre is represented by the following parameters and variables

Data centre parameters

DLrate	Download rate per user = 5 Mbps.
L	Large number.

Data centre variables

D_{sdv}	Traffic demand of data centre v located in node s destined to users in node d.

DClocation$_s$ DClocation$_s$ = 1, if there is a data centre in node s, otherwise DClocations = 0.

The model is defined as follows:

Objective:

Minimize

$$PUE\_n \, . \Bigg(\sum_{s\in N} Erp \, . \, AggrPort_s + \sum_{m\in N} \sum_{n\in Nm: n\neq m} Erp \, . \, W_{mn} + \sum_{m\in N} \sum_{n\in Nm: n\neq m} Et \, . \, W_{mn} + \sum_{m\in N} \sum_{n\in Nm: n\neq m} Ee \, . \, F_{mn} \, . \, A_{mn} + \sum_{i\in N} Eo + \sum_{m\in N} \sum_{n\in Nm: n\neq m} Erg \, . RG_{mn} \, . \, W_{mn} \Bigg) \quad (1)$$

Subject to:

1) Flow conservation constraint:

$$\sum_{j\in N: i\neq j} L_{sd}^{ij} - \sum_{j\in N: i\neq j} L_{sd}^{ji} = \begin{cases} Lsd & i = s \\ -Lsd & i = d \\ 0 & otherwise \end{cases}$$

$$\forall \, s, d, i \in N : s \neq d \quad (2)$$

Constraint (2) represents the flow conservation constraint of the traffic flows on the IP/WDM network. It ensures that the total incoming traffic equal the total outgoing traffic to the network; excluding the source and destination nodes.

2) WDM capacity constraint:

$$\sum_{N\in Nm} W_{ij}^{mn} - \sum_{N\in Nm} W_{ij}^{nm} = \begin{cases} Cij & m = i \\ -Cij & m = j \\ 0 & otherwise \end{cases}$$

$$\forall \, i, j, m \in N : i \neq j \quad (3)$$

Constraint (3) represent the optical layer's flow conservation constraint. It ensures that the total number of incoming wavelengths in a virtual link exactly equal the outgoing wavelengths in a virtual link node excluding the source and destination nodes of the virtual link.

3) IP traffic capacity constraint:

$$\sum_{s\in N} \sum_{d\in N: s\neq d} L_{sd}^{ij} \leq C_{ij} \, . \, B$$

$$\forall \, i, j \in N : s \neq d \quad (4)$$

Constraint (4) represents capacity of virtual link. It ensures that transmitting traffic through virtual links does not exceed its maximum allocated capacity.

4) WDM capacity constraints:

$$\sum_{i\in N} \sum_{j\in N: i\neq j} W_{ij}^{mn} \leq W \, . \, F_{mn}$$

$$\forall \, i, j \in N \quad (5)$$

$$\sum_{i\in N} \sum_{j\in N: i\neq j} W_{ij}^{mn} = W_{mn}$$

$$\forall \, i, j \in N \quad (6)$$

Constraint (5) and (6) represent the capacity of the physical link. Constraint (5) ensures that the number of wavelengths channels in virtual links transmitting through the physical link does not exceed maximum capacity of fibres. Constraint (6) ensures that the number of wavelengths channel in virtual links, which transmitting through the physical link is equal to the number of wavelengths in that physical link.

5) Total number of aggregation ports :

$$AggrPort_s = \frac{1}{B} \sum_{d\in N: s\neq d} L_{sd}$$

$$\forall \, s \in N \quad (7)$$

Constraint (7) calculates the total number of aggregation ports in IP/WDM core router.

6) Total demand on core network:

$$L_{sd} = \sum_{v\in DataCentre} D_{sdv} + R_{sd}$$

$$\forall \, s, d \in N : s \neq d \quad (8)$$

Constraint (8) represent the data centre traffic and regular traffic on the network.

7) Data centre location:

$$\sum_{v\in DataCentre} \delta_{sv} \geq DClocation_s$$

$$\forall \, s \in N \quad (9)$$

$$\sum_{v\in DataCentre} \delta_{sv} \leq L \, . \, DClocation_s$$

$$\forall \, s \in N \quad (10)$$

Constraint (9) and (10) ensure there is a data centre v will be placed on node s, which has more than zero originating demand traffic where L is a large number.

B. THE MODEL RESULT

Considering the Saudi National Fibre Network (SNFN) [11][12][13] of 28 nodes and 40 links, depicted in Figure 1, we optimised the location of a single data centre and multiple data centres considering asymmetric data traffic between the users and data centres as well as the traffic between regular nodes. The asymmetric traffic volumes, depicted in Figure 3, have been assumed depending on different cities population The cities populations and information about which had been collected by the Saudi General Authority of Statistics in 2010 [14].

In general, the user-data centre traffic dominates the total traffic of the Internet. On our model, we assumed that the user-data centre traffic is 80% and regular traffic is 20% on the network. In our evaluation, the total number of users in the network varies throughout the day between 200K at 6 A.M. and 1.4 million users at 10 P.M. as shown in Fig. 4. The single users-data centre download rate is assumed to be at 5 Mbps. Moreover, we assumed that the regular traffic between the nodes fluctuated depending on the time, between 40 Gbps at 6 A.M. and 400 Gbps at 10 P.M. The user-data centre traffic, as well as the regular traffic volume, is distributed among the nodes depending on the different cities' populations, which are depicted in Figure 3. Table 1 shows the model input parameters of IP/WDM network. The MILP model was solved using AMPL/CPLEX software on Xeon, 3.5GHz server with 64GB memory.

After running the MILP model, we found that the most power-efficient location in which to place a single data centre is in Riyadh. The location has been chosen by the model due to its highest population and central location on the network (minimum hop count to other nodes). Optimising the locations of two data centres in the SNFN yeilds Riyadh and Jeddah as the optimum locations. Jeddah is selected as it has the second-highest population as well as its central location between the nodes in the western region of the country. then, we ran the model to optimise the locations of three data centres. Dammam was chosen as the third optimum location, in addition to Jeddah and Riyadh. In the case of five data centres, Makkah and Jizan were chosen to host the replicated content data centres due to their having the fourth- and fifth-highest populations.

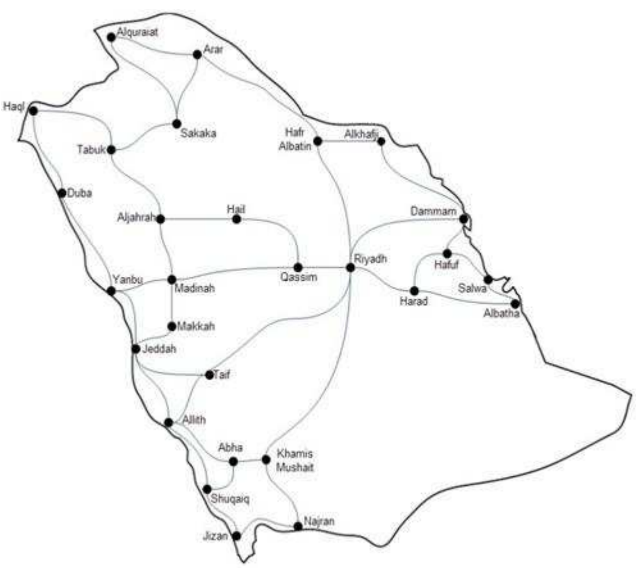

Figure 2: The SNFN Topology

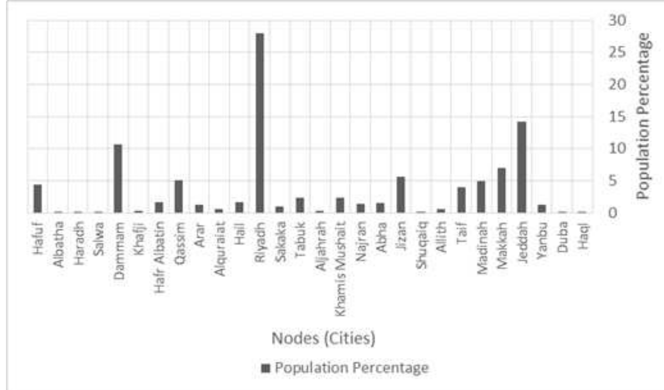

Figure 3: the percentage of each node population.

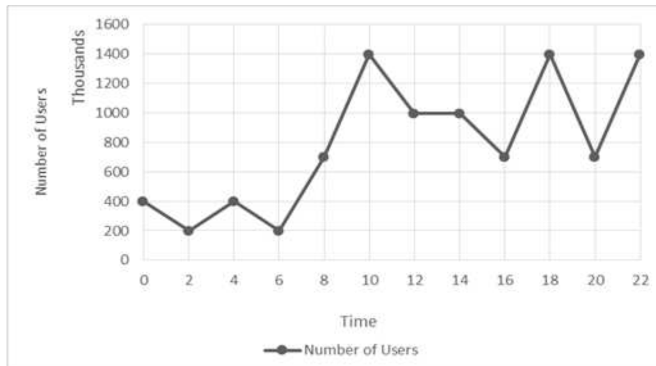

Figure 4: Number of users during the different time of the day.

Table-1 Input Parameter of the Model

Router port average power consumption (Erp)	825 W [8]
40 Gbps transponder power consumption (Et)	167 W, reach 2500 KM [8]
40 Gbps regenerator power consumption (Erg)	334 W, reach 2500 KM [8]
EDFA power consumption (Ee)	55 W [8]
IP/WDM switch power consumption (Eo)	85 W [8]
Number of wavelengths in a fibre (W)	16
Bit rate of each wavelength (B)	40 Gbps
Span distance between two EDFAs (S)	80 km
User download rate (DLrate)	5 Mbps
Network power usage effectiveness (PUE_n)	1.5 [15]
Total number of users (Clients)	200K, 400K, 700K, 1M and 1.4M

Figure 5 shows the total power consumption of the SNFN with different data centre locations at different time of the day. Compared to the randomly chosen data centre location (in Yanbu), the optimised single data centre location in Riyadh saves 47% of the total network power consumption. Also, compared to three randomly chosen data centres locations (in Yanbu and Tabuk and madina), the three optimised data centre locations in Riyadh and Jeddah and dammam saves 51% of the total network power consumption. Moreover, compared to five randomly chosen data centres location (in Yanbu, Tabuk, Madina, Qassim and Abha), the five optimised data centre locations in Riyadh, Jeddah, Dammam, Makkah and Jizan saves 53% of the total network power consumption.

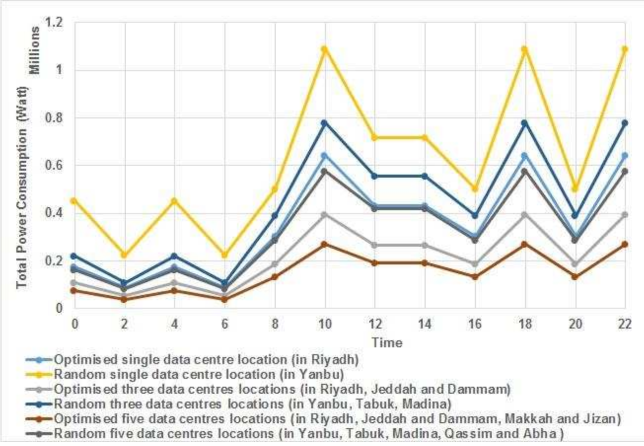

Figure 5: Total SNFN Network power consumption.

IV. THE OPTIMISATION OF SNFN PHYSICAL TOPOLOGY

A. MILP MODEL

Given the nodes locations (cities) of the SNFN, we optimize the physical links connecting them so the network power consumption is minimized.

We re-introduce the MILP model developed in [6] for completeness. In addition to the sets, parameters, variables and constraints defined in the previous section, we define the following:

Node connection parameters

NodalDegree	Minimum number of links connecting a node.
NOfLinks	Total number of network links.

Node connection Variable

$Link_{mn}$	$Link_{mn} = 1$ if there is a link connection between node m and node n, otherwise $Link_{mn} = 0$.

The model is defined as follows: Objective:

Minimize:

$$PUE\_n \,.\Big(\sum_{s\in N} Erp \,.\, AggrPort_s + \sum_{m\in N}\sum_{n\in N: n\neq m} Erp \,.\, Wmn + \sum_{m\in N}\sum_{n\in N} Et \,.\, W_{mn} + \sum_{m\in N}\sum_{n\in N} Ee \,.\, F_{mn} \,.\, A_{mn} + \sum_{i\in N} Eo + \sum_{m\in N}\sum_{n\in N} Erg \,.\, RG_{mn} \,.\, W_{mn}\Big) \quad (11)$$

Subject to:

1) Physical link capacity constraint

$$\sum_{i\in N}\sum_{j\in N: i\neq j} W_{mn}^{ij} \leq W \,.\, Link_{mn} \qquad \forall\, i,j \in N \quad (12)$$

Constraint (12) represents physical link's capacity constraint. It ensures that the total number of wavelength in virtual links traversing a physical link does not exceeded the maximum capacity of fibres in the physical link if the physical link exists.

2) The minumum Nodal Degree

$$\sum_{n\in N: m\neq n} Link_{mn} \geq NodalDegree \qquad \forall\, m \in N \quad (13)$$

Constraint (13) represent the minimum nodal degree.

3) Total number of network links

$$\sum_{m\in N}\sum_{n\in N: m\neq n} Link_{mn} = NOfLinks \quad (14)$$

Constraint (14) represents the total number of links in the network.

4) Node's Links

$$Link_{mn} = Link_{nm} \qquad \forall\, m,n \in N \quad (15)$$

Constraint (15) ensures that there are a bidirectional link between node n and node m.

B. THE MODEL RESULT

We redesign the physical topology of the SNFN network considering the same number of links of the current topology (40 links). In order to optimize the physical topology, we obtained the geographic distance between the set of 28 nodes using Google Maps [16]. The minimum nodal degree is set to be either 1 or 2. However, having a node connected to the network with a single link is not desirable. In the case of link failure, this node will be totally isolated from the network. Then, we investigated the optimized physical topology by assuming the same traffic pattern of the previous section.

The MILP model is solved using AMPL/CPLEX software on University of Leeds high performance computer (Polaris) using 16 nodes (256 cores) with 16 GByte of RAM per core. Each node comprises two eight cores of the Intel 2.6 GHz Sandy Bridge E5-2670 processors [16].

We optimized the physical topology using three data centre locations scenarios. Under the non-bypass approach, the optimized topology of SNFN with a minimum nodal degree of 1 and 2 is depicted in Fig. 6 for (a) a single data centre in Riyadh, (b) two data centers in Riyadh and Jeddah with replicated content, and (c) three different data centers locations in Riyadh, Jeddah, and Dammam with replicated content. In general, since the majority of the traffic is users-datacenter based, the optimized topology shows that for the model, we chose to build a direct link between the nodes and their closest node hosting a data centre. In addition to saving on total network power consumption, the topology will reduce the delay in accessing the data centre. Compared to the current topology depicted in Figure 2, our optimized topology will minimize the hop count by establishing a direct link connection between the users' nodes and data centre's node.

Figure 7 illustrates the power consumption of the different SNFN topologies in Figure 6. Significant power savings are achieved through optimizing the physical topology compared to the original SNFN topology. With a single data centre, as shown in Figure 7 (a), optimizing the physical topology has saved 76% of the total power consumption on nodal degree = 1 and nodal degree = 2, compared to the original one. Then, as shown in Figure 7 (b), the optimised physical topology with two data centres has resulted in saving of 72% of the total power consumption in both nodal degree cases compared to the original topology. After that, with three data centres, as shown in Figure 7 (c), the optimised topology has achieved power saving by 70% in the both cases.

In the three scenarios, the second link in nodal degree = 2 is set but not used. Because of that the both nodal degree cases show identical power saving. The data centre traffic will be sent through a direct link. While, if the two communicated nodes are not hosting a data centre, the non-data centre traffic will be groomed through an intermediate node instead of a direct link.

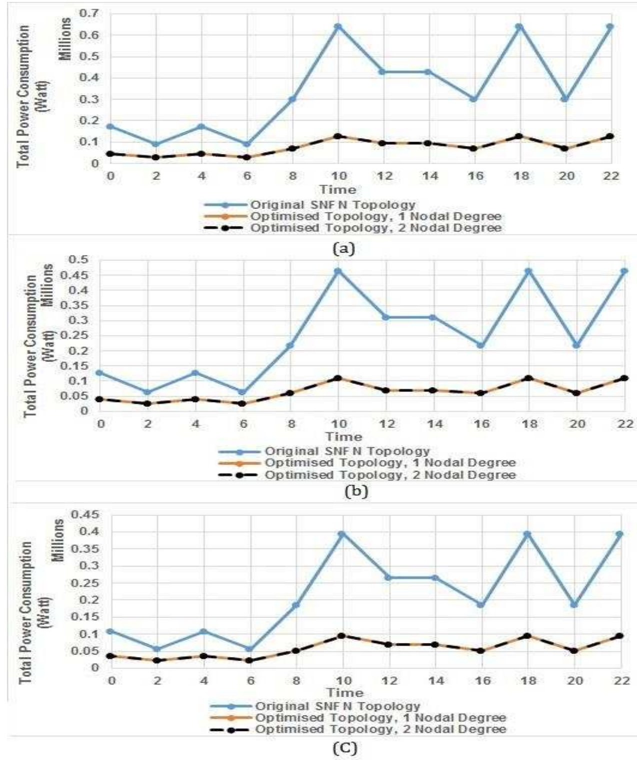

Figure 7: a) SNFN with Riyadh serving as data centre with different physical topologies. b) SNFN with Riyadh and Jeddah serving as data centres with different physical topologies. c) SNFN with Riyadh, Jeddah and Dammam serving as data centres with different physical topologies.

Figure 6: (a) The optimised physical topology of SNFN with Riyadh hosting data centre. (b) The optimised physical topology of SNFN with Riyadh and Jeddah hosting data centres. (c) The optimised physical topology of SNFN with Riyadh, Jeddah and Dammam hosting data centres.

V. CONCLUSION

In the present paper, we investigated the Saudi National Fibre Network (SNFN) power consumption by formulating the problem as a mixed integer linear programming (MILP) model. The SNFN was evaluated under different volumes of users' data centre traffic and regular traffic at different times of the day. Firstly, we optimized the data centre locations in the SNFN. The MILP result showed that the most energy-efficient location for one data centre is in Riyadh. Also, we found that the optimum locations for two data centres with replicated content are in Riyadh and Jeddah, three data centres with replicated content are in Riyadh, Jeddah and Dammam and five data centres with replicated content are in Riyadh, Jeddah, Dammam, Makkah and Jizan. Moreover, the results showed that we can save up to 53% of the network power consumption by finding the optimum data centre locations compared to the random ones. Secondly, we redesigned the SNFN network physical topology with energy-efficiency awareness. The network nodal degree was set to be either one or two. On the model result, we found that there was a large margin in which savings could be made to minimise the SNFN power consumption. By applying energy-efficient topology, the model results showed that we can save up to 76% of the power consumption compared to the current physical topology.

VI. ACKNOWLEDGMENT

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REFERENCES

[1] "The Communications and Information technology Commission (CITC)." [Online]. Available: http://www.internet.gov.sa/en/. [Accessed: 20-Apr-2016].

[2] R. Bolla, R. Bruschi, F. Davoli, and S. Member, "Energy Efficiency in the Future Internet : A Survey of Existing Approaches and Trends in Energy-Aware Fixed Network Infrastructures," IEEE Commun. Surv. TUTORIALS, VOL. 13, NO. 2, vol. 13, no. 2, pp. 223–244, 2011.

[3] H. Hu, Y. Wen, T. S. Chua, and X. Li, "Toward scalable systems for big data analytics: A technology tutorial," IEEE Access, 2014.

[4] G. S. G. Shen and R. S. Tucker, "Energy-Minimized Design for IP Over WDM Networks," IEEE/OSA J. Opt. Commun. Netw., vol. 1, no. 1, pp. 176–186, 2009.

[5] X. Dong, T. El-Gorashi, and J. M. H. Elmirghani, "Green IP over WDM networks with data centers," J. Light. Technol., vol. 29, no. 12, pp. 1861–1880, 2011.

[6] X. Dong, T. El-gorashi, and J. M. H. Elmirghani, "On the energy efficiency of physical topology design for IP over WDM networks," J. Light. Technol., vol. 30, no. 12, pp. 1931–1942, 2012.

[7] A. Q. Lawey, T. E. H. El-Gorashi, and J. M. H. Elmirghani, "Distributed energy efficient clouds over core networks," J. Light. Technol., 2014.

[8] "GreenTouch Green Meter Research Study : Reducing the Net Energy Consumption in Communications Networks by up to 90 % by 2020," pp. 1–25, 2013.

[9] K. Zhu, S. Member, and B. Mukherjee, "Traffic Grooming in an Optical WDM Mesh Network," vol. 20, no. 1, pp. 122–133, 2002.

[10] Jun Zheng; Hussein T. Mouftah, Optical WDM Networks:Concepts and Design Principles, 1st ed. Wiley-IEEE Press, 2004.

[11] "ITC NETWORK CAPACITY - Existing Infrastructure." [Online]. Available: http://www.itc.sa/capacity. [Accessed: 13-Apr-2016].

[12] "National Fiber Network." [Online]. Available: http://www.mobily.com.sa/portalu/wps/portal/mobile/m-carriers/m-mobily-capabilities/m-national/m-saudi-national-fiber-network-snfn. [Accessed: 13-Apr-2016].

[13] "Saudi National Fiber Network Awards Cisco Multi-year Managed Services Contract." [Online]. Available: http://www.cisco.com/web/ME/about/news/2015/210915.html. [Accessed: 13-Apr-2016].

[14] "'General Authority Of Statistics'. Stats.gov.sa. N.p., 2016. Web. 11 Apr. 2016."

[15] J. Baliga, R. Ayre, K. Hinton, and R. Tucker, "Energy consumption in wired and wireless access networks," IEEE Commun. Mag., vol. 49, no. June, pp. 70–77, 2011.

[16] "Google Maps I Saudi Arabia." [Online]. Available: https://www.google.co.uk/maps/place/Saudi+Arabia. [Accessed: 11-Apr-2016].