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Fog-assisted Caching Employing Solar Renewable Energy for Delivering Video on Demand Service

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ABSTRACT

This paper examines the reduction in brown power consumption of transport networks and data centres achieved by caching Video-on-Demand (VoD) contents in solar-powered fog data centres with Energy Storage Devices (ESDs). A Mixed Integer Linear Programming (MILP) model was utilized to optimize the delivery from cloud or fog data centres. The results reveal that for brown-powered cloud and fog data centres with same Power Usage Effectiveness (PUE), a saving by up to 77% in transport network power consumption can be achieved by delivering VoD demands from fog data centres. With fully renewable-powered cloud data centres and partially solar-powered fog data centres, savings of up to 26% can be achieved when considering 250 m² solar cells. Additional saving by up to 14% can be achieved with ESDs of 50 kWh capacity.

Keywords: Video-on-Demand (VoD), IP over WDM networks, Cloud Data Centres, Fog Data Centres, Renewable Energy, Energy Efficiency, Energy Storage Device (ESD), Mixed Integer Linear Programming (MILP).

1. INTRODUCTION

The video traffic is estimated to have a Compound Annual Growth Rate (CAGR) of 54% from 2016 to 2021 [1]. As a result, the power consumption of transport networks linking cloud data centres and end users is expected to massively increase. As these systems are typically brown-powered, this also leads to steep rise in CO₂ emission and operational costs due to high utilization and cooling requirements against thermal dissipation [2]. To overcome both issues, several greening approaches were considered in the last decade such as improving the hardware, optimizing the routing and workload scheduling, and using renewable power sources [3]. The authors of [2] considered lightpath bypassing in IP over WDM core networks to reduce the power consumption of the non-bypass approach. As part of the outcomes of GreenTouch, a leading Information and Communication Technology (ICT) research consortium with 50 industrial and academic collaborators, the work in [4]-[16] investigated a combination of greening approaches for IP over WDM networks. Those included optical bypassing, topology optimizations, Mixed Line Rates (MLRs), efficient protection and sleep modes, in addition to considering two improvement schemes for hardware which are the Business-As-Usual (BAU) improvement in equipment due to CMOS technology advances, and BAU with further GreenTouch improvements. The former indicated 4.23× energy efficiency improvements compared to 2010 networks while the later indicated 20× improvements.

Optimizing the workloads and content placement to reduce the traffic and hence the power consumption was also considered to green core networks as in [17]-[19]. In [17], the authors focused on data centre and popular contents placement strategies and found that placing the data centres at the centre of the network and replicating the contents on multiple data centres according to popularity minimized the power consumption by 28%. In [18] and [19], the caching of Video-on-Demand (VoD) contents is optimized to reduce storage and transport energy consumption while considering sizes of the caches, contents popularity at different hours and dynamic cache contents replacement. To reduce the CO₂ emission coupled with the rise in brown power consumption, the use of renewable resources was considered to power different networking and data centre elements [20]-[23].

Different implementations such as Mobile Edge Computing (MEC), Fog Computing (FC), and cloudlet Computing (CC) were recently introduced to reduce the latency of cloud computing [24] and improve the energy efficiency of transport networks [25]-[28]. Nano Data Centres (NaDa) were introduced in [29] as a Peer-to-peer (P2P) computing and storage infrastructure and energy consumption reductions by 20-30% were obtained. Using fog data centres for smart cities was discussed in [30] to reduce core networks power consumption. The performance and power consumption tradeoffs of using different data centre topologies for big data computations in fog environments was discussed in [31]. In [32], the concept of integrating micro data centre (Micro-DC) into Optical Line Terminals (OLTs) of Passive Optical Networks (PONs) was discussed to partially reduce core networks traffic. To enhance the use of interrupted renewable sources such as solar power for data centres, optimizing the use of Energy Storage Devices (ESDs) was suggested [33].

This work utilizes a MILP model to reduce the brown power consumption of transport networks when delivering VoD contents by maximizing the use of solar energy in fog data centres with ESDs in the access network. The rest of this paper is organized as the following: Section 2 elaborates on the system model and the parameters used in the MILP model. The results are presented in Section 3, while, the conclusions and future work are given in Section 4.

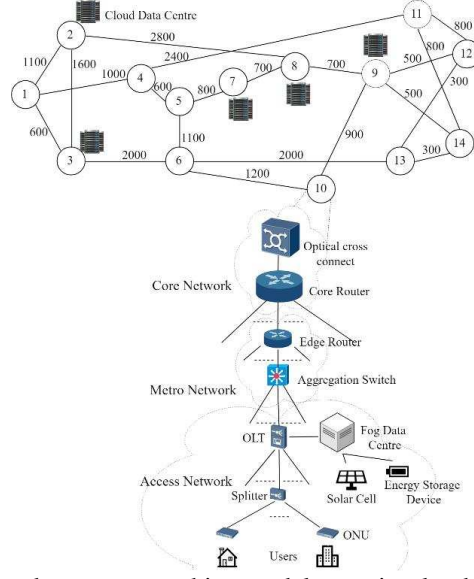


Figure 1: Fog data centre caching model to assist cloud VoD services.

2. SYSTEM MODEL FOR OPTIMIZING VOD DELIVERY FROM CLOUD OR FOG DATA CENTRES

An IP over WDM network with NSFNET topology was utilized for the core network as shown in Figure 1. Core nodes are equipped with MLR IP router and transponder ports and the links have adequate EDFAs and regenerators. All devices have power consumption values taken from [5] for 2020 equipment. Cloud data centers (CDCs) are pre-located in nodes 2, 3, 7, 8, and 9. In each core node, a metro network, composed of edge routers and Ethernet switches (C9500-32QC [34]), is utilized to provide connection to the access networks. The access network is composed of OLTs [35] connecting the metro network with Fog Data Centres (FDCs), in addition to splitters and ONUs connecting to end users. For CDCs and FDCs, networking equipment power consumption is assumed to be 30% of the servers' power [36]. The content server in [23] which has a maximum capacity of 1.8 Gbps was considered, which allows FDCs to maximally provide 160 Gbps via about 88 servers. We considered solar renewable energy for its suitability in fog environments within cities. The solar irradiance values in all 14 nodes were collected from [37] and an efficiency of 26.3% was considered [38]. Each FDC is powered by brown sources, and directly by solar cells with areas between 50 and 250 m², or additionally by stored solar energy in an ESD (e.g. Li-ion battery) with capacities between 20 and 50 kWh [39]. Power Usage Effectiveness (PUE) values between 1.25 and 1.1 for FDCs and of 1.1 for CDCs were considered. Consumer video traffic based on Cisco Visual Network Index (VNI) forecast [5] was considered for the demands.

Table 1. Key Parameters for the MILP Model.

Power consumption of a metro Ethernet switch 40 Gbps port [34]	50 W
Power consumption of a content server per Gbps [23]	221.1 W
Capacity of a content server [23]	1.8 Gbps
PUE of cloud data centre (PUE_c)	1.1
PUE of fog data centre (PUE_f)	1.25 to 1.1
Ratio to account for networking equipment power consumption [36]	1.3
Power consumption of an OLT [35]	904 W
Total capacity of links between OLT and metro network	160 Gbps
Total capacity of links between OLT and fog data center	160 Gbps
Size of solar cell per OLT (SSC)	50, 100, 150, 200, 250 m ²
Battery maximum capacity (E_{max}) [39]	20-50 kWh
Charging percentage per hour and Discharging percentage per hour [33]	72.25%, and 90.25%
Self-discharging per day [33]	3%

3. RESULTS

A. Power consumption with brown-powered data centres:

We start by evaluating the brown power consumption (PC_b) required to optimally deliver VoD demands in terms of power consumption efficiency from brown-powered CDCs and FDCs. Figure 2 shows the total PC_b per day for different PUE_f values. The results show that for PUE_f of 1.25, delivering fully from CDCs is the most efficient. As PUE_f improve, the model starts to deliver partially from FDCs. When PUE_f is equivalent to PUE_c , it becomes more efficient to fully stream from FDCs as the required power consumption to deliver from FDCs and CDCs will be equivalent, and the transport network consumption will be the factor determining the differences in PC_b .

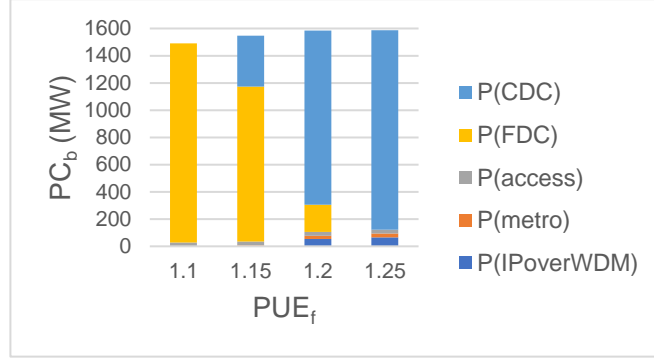


Figure 2: PC_b under different PUE_f values.

B. Power consumption with fully renewable-powered CDCs and renewable-powered FDCs:

We now consider fully renewable-powered CDCs and FDCs with PUE_f of 1.1 and solar cells. Figure 3a shows the total PC_b per day when considering different sizes for the solar cells (i.e. SSC). The results indicate that savings by up to 26% can be achieved in the transport network relative to case A when fully delivering from the CDCs.

C. Power consumption with fully renewable-powered CDCs and caching in renewable-powered FDCs with ESDs:

In this case we consider optimizing the streaming of VoD from cloud or fog data centers with PUE_f of 1.1 and SSC of $250 m^2$ while optimizing ESDs usage. Figure 3b shows the total PC_b per day when considering different capacities for Li-ion batteries. The results indicate that additional savings by up to 14% can be achieved in the transport network relative to case B for solar cell size of $250 m^2$. The increase in power savings values is due to optimizing the direct use of solar power in the FDC or charging the ESD for the use when it is not available.

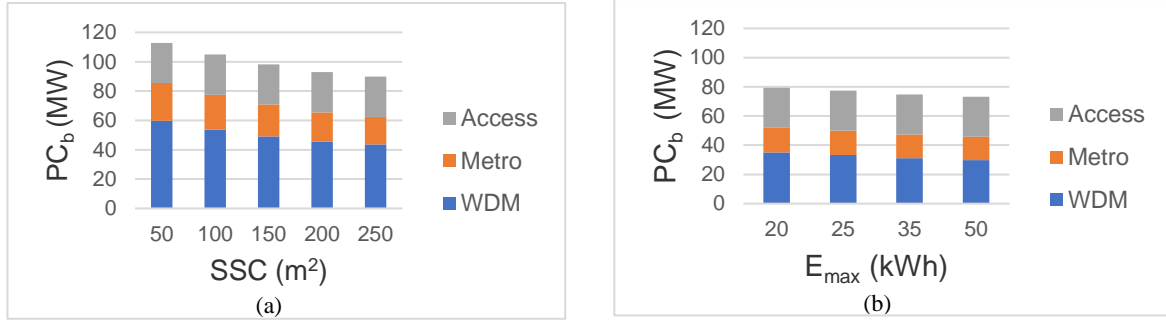


Figure 3: (a) PC_b with renewable-powered CDCs and partially solar-powered FDCs with different SSC values, (b) PC_b with renewable-powered CDCs and partially solar-powered FDCs with ESDs.

4. CONCLUSIONS AND FUTURE WORK

This paper addressed the optimization of delivering VoD services from cloud or fog data centres with solar cells and ESDs. With brown-powered data centres, the results indicate that with PUE_f higher than PUE_c , it is more energy efficient to deliver partially or fully from CDCs. When PUE_f is equivalent to PUE_c , it is more efficient to deliver from FDCs. As many cloud providers utilize renewable power, we also examined the optimization when CDCs are fully renewable powered and the FDCs are partially solar powered. Savings by up to 26% can be achieved when considering $250 m^2$ solar cells and additional saving by up to 14% can be achieved when also considering ESDs with capacity of 50 kWh. Future work includes considering the actual networking power consumption of different topologies for FDCs, and the storage requirements and popularity of VoD contents.

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