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A power consumption sensitivity analysis of circuit-switched versus packet-switched backbone networks ☆

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ABSTRACT

While telecommunication networks have historically been dominated by a circuit-switched paradigm, the last decades have seen a clear trend towards packet-switched networks. In this paper we evaluate how both paradigms (which have also been referred to as optical bypass and non-bypass, respectively) perform in optical backbone networks from a power consumption point of view, and whether the general agreement of circuit switching being more power-efficient holds. We consider artificially generated topologies of various sizes, mesh degrees and – not yet previously explored in this context – transport linerates. We cross-validate our findings with a number of realistic topologies.

Our results show that circuit switching is preferable when the average node-to-node demands are higher than half the transport linerates. However, packet switching can become preferable when the traffic demands are lower than half the transport linerate. We find that an increase in the network node count does not consistently increase the energy savings of circuit switching over packet switching, but the savings are heavily influenced by the mesh degree and (to a minor extent) by the average link length. Our results are consistent for uniform traffic demands and realistic traffic demands.

A key take-away message for other research on power saving solutions in backbone networks is that the ratio between the average demand and the demand bitrate has considerable effect on the overall efficiency, and should be taken into account.

1. Introduction

Electricity consumption in telecommunication networks is an important issue – The worldwide electricity consumption of telecommunication networks (which includes operator networks, office network equipment, and customer premises network access equipment) has been estimated to be 330 TW h in 2012, accounting for 1.7% of the total worldwide electricity consumption in the same year [2]. While it can be argued that this number in itself is relatively small, it is non-negligible and increasing at a rate of 10% per year. Moreover, its relative contribution to the

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total worldwide electricity consumption is increasing as well (from 1.3% in 2007 to 1.7% in 2012). With the foreseen traffic growth in communication networks [3], this trend is not likely to halt soon. As such, the interest to improve the energy-efficiency of telecommunication networks is a hot research topic, and is of importance for economic (reducing the energy cost), technical (reducing the associated heat dissipation) and environmental (reducing the carbon footprint) reasons.

The electricity consumption in backbone networks is expected to rise considerably – The major part of the power consumption in the telecommunication operator networks is currently attributed to the wired aggregation & access networks and mobile radio networks. The backbone networks, in contrast, are estimated to account (in 2012) for only about 8% of the total operator network consumption (which includes the wired aggregation & access, mobile radio and backbone networks) [4]. However, the energy consumption in wired access networks is proportional to the number of connected subscribers, while the consumption in the backbone network is proportional to the traffic volume [4]. With the expected increase of traffic volume, high growth rates in the backbone's energy consumption are expected (potentially even overtaking the access networks' consumption [5]). For this reason, it is important to react timely to the energy issue of backbone networks.

Circuit switching has been identified, so far, as more energy-efficient than packet switching – In response, there is a growing body of research literature on reducing the energy consumption in backbone networks. Among the approaches proposed are the introduction of sleep modes, energy-aware routing protocols, energy-aware network design, optical bypassing of power-hungry Internet Protocol (IP) routers, and dynamic rate adaptation. A thorough survey is available in [6]. However, in the last decades, the telecommunication industry has seen a shift from circuit-switched networks to packet-switched networks. There has been some earlier research into the power consumption of circuit switching versus packet switching (briefly discussed in Section 2). The general agreement seems to be that circuit switching has a lower power consumption than packet switching.

However, we think that the picture is not so clear-cut – Most works point out the benefits of circuit switching over packet switching in terms of power consumption. These benefits depend however on the investigated network scenario. For example, looking at Fig. 4 of [7], the *x*-axis depicting "Average of random traffic demand" starts from 20 Gbps/node pair, while the capacity of a single Wavelength Division Multiplexing (WDM) channel is set to 40 Gbps. The missing range 0–20 Gbps/node is expected to show that the packet-switched networks can be less power consuming than the circuit-switched networks, as preliminarily indicated in our earlier work [8] and by Bianco et al. in [9].

Contributions of this paper – In this paper we extensively compare the circuit and packet-switched IP-over-WDM networks with respect to their power efficiency. We consider circuit switching in the context of optical circuits, in contrast to the more traditional opto-electronic circuit switching such as in SONET/SDH and OTN. We focus on the comparison of circuit switching and packet switching in terms of inverse power efficiency (W/Gbps), leaving the more complex hybrid solutions aside. The inverse power efficiency is the power (in Watt) required to transport a uniform demand of 1 Gbps (lower values indicate more efficient operation). Note that circuit switching and packet switching in this context has also been referred to as optical bypass (or transparent switching) and non-bypass (or opaque switching) respectively. The four key contributions of our paper with respect to the existing body of research are as follows.

- In addition to considering the mesh degree and network size (in terms of the number of nodes and average physical link length), we evaluate the influence of the channel linerate on the power efficiency of circuit switching versus packet switching, a parameter which to our knowledge has previously not been assessed.
- We particularly look at network scenarios where packet switching is preferable from a power consumption point of view. This aspect has to the best of our knowledge not been addressed in the previous literature (cf. [7], as mentioned above).
- We study the (inverse) power efficiency of both switching paradigms under increasing traffic demand. We show that the power efficiency of packet switching in sparsely-connected networks is almost independent of the traffic demand, whereas for circuit switching the power efficiency improves with increasing traffic.
- We find that a higher node count does not necessarily make circuit switching more preferable. In highly meshed networks the node count does not influence the relative savings of circuit switching over packet switching at all. Our results show that the mesh degree, the demand/linerate ratio and the physical link length are critical parameters.

All in all, our results provide a better insight into the trade-off of the power efficiency of circuit switching versus packet switching.

Organization of this paper – We briefly discuss related work in Section 2. After outlining the network architecture (Section 3) we provide details on our methodology for calculating the network power consumption (Section 4). In Section 5 we introduce the different set of topologies, traffic matrices and transport linerates that we will consider. Using the result from our dimensioning tool, we show in Section 6 that (a) indeed packet switching can be the preferable option with respect to power consumption below certain traffic demand bitrates, (b) that this crossover point is essentially determined by the ratio of the traffic demand over the linerate, and (c) to a minor extent also by the mesh degree.

This paper is an extended version of our earlier work [1]. It includes a more elaborate introduction (Section 1) and related work (Section 2), a more formal description of our dimensioning algorithm (Section 4.2), a validation of our results with demands based on actual traffic measurements from the Abilene topology (Section 6.5), an assessment of plausible real-life demand/linerate ratios (Section 6.2), a short cross-validation with the results from Shen and