Toward high-capacity and energy-efficient optical networks

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***Abstract*—The growth of traffic demand induces network operators to extend network capacity. Multi band is an attractive solution to support traffic increase. In parallel, climate change imposes to explore solutions to reduce and make scalable the network energy consumption, especially because energy consumption increases with traffic. This paper discusses network migration to multi band while accounting for energy efficiency.**

***Index Terms*—Energy efficiency, energy saving, energy consumption, multi band.**

I. Introduction

Information and Communication Technology (ICT) contributes for 5-9% of electricity use [1] and for around 3% of CO_2 emissions. Typically, the energy requirements increase with traffic, which intensifies with an annual growth above 20% [2]. Because of this continuous growing, operators and research community in general are evaluating solutions to increase network capacity, such as space division multiplexing (SDM) [3] and multi band [4]. The former solution requires the installation of new fibers (parallel fibers or multi-core or multi-mode fibers) [5]. The latter one permits to extend the life of already deployed fibers, by exploiting unused portions of spectrum: e.g., S- and E-bands. However, given the serious climate change issues, the support of traffic growth in network infrastructures cannot be the only scope. Infrastructures should support the increasing traffic with adequate network functionalities, while being energy sustainable. Reducing ICT energy consumption and make it scalable with traffic should be nowadays obligatory.

Research community is investigating energy consumption and working on energy-efficient solutions such as *sleep mode* [6], i.e. to set idle devices in a state ("sleep") at negligible power consumption; such devices should be promptly re-waken up when needed. Avoiding electronic terminations, through optical by-pass, is another way for reducing energy consumption. Recently, digital sub-carrier multiplexing (DSCM) has been investigated to reduce energy at traffic aggregation nodes [7]. Indeed, DSCM permits to aggregate sub-carriers (thus traffic) all-optically, avoiding energy-hungry interfaces and electronic processing. In general, in optical networks, a relevant contribution to the energy requirements is given by transponders. As an example, transponders equipped with 600G transceiver cards may consume around 300 W [8], [9], with a contribution of 120 W due to the transponder board with inactive cards. Indeed, transponders include energy-hungry ASIC performing electronic processing, e.g. for equalization (linear dispersion compensation) and symbol decision. Actions in the transceiver components are required to reduce the energy consumption in optical networks. Recently, pluggable transceivers are penetrating the market. Pluggables permit to avoid transponders since they are directly installed in Layer-3 interfaces (e.g., routers). Moreover, their standardization is targeting low power consumption: e.g. 400ZR has a target maximum power consumption of 15 W, while 400ZR+ of 25 W. The main drawback of pluggables is the limited optical reach which can be in the order of 500 km. Moreover, to best of our knowledge, current pluggables operate in C-band only and they should be explored for other bands.

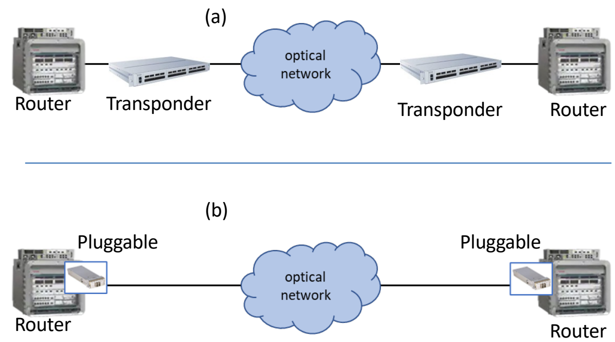

Fig. 1: (a) Optical network including transponders; (b) Optical network including pluggable transceivers

In this paper, we carry on an analysis on the power consumption of networks equipped with pluggable transceivers, considering migration scenario to multi band and limited optical reach. Simulation results show how pluggable transceivers can strongly reduce the energy consumption of optical networks while traffic increases.

II. Optical network equipped with pluggables

In traditional optical networks, routers are connected to transponders equipped with transceivers, as shown in Fig. 1a. On the contrary, pluggable transceivers are directly installed into routers (or Ethernet switches), thus avoiding the transponder (Fig. 1b). As mentioned above, given the target maximum power of pluggables, their main limitation is a shorter optical reach. According to these considerations, the following allocation strategy for pluggables or transponders is proposed with the aim of maximizing the use of pluggables while

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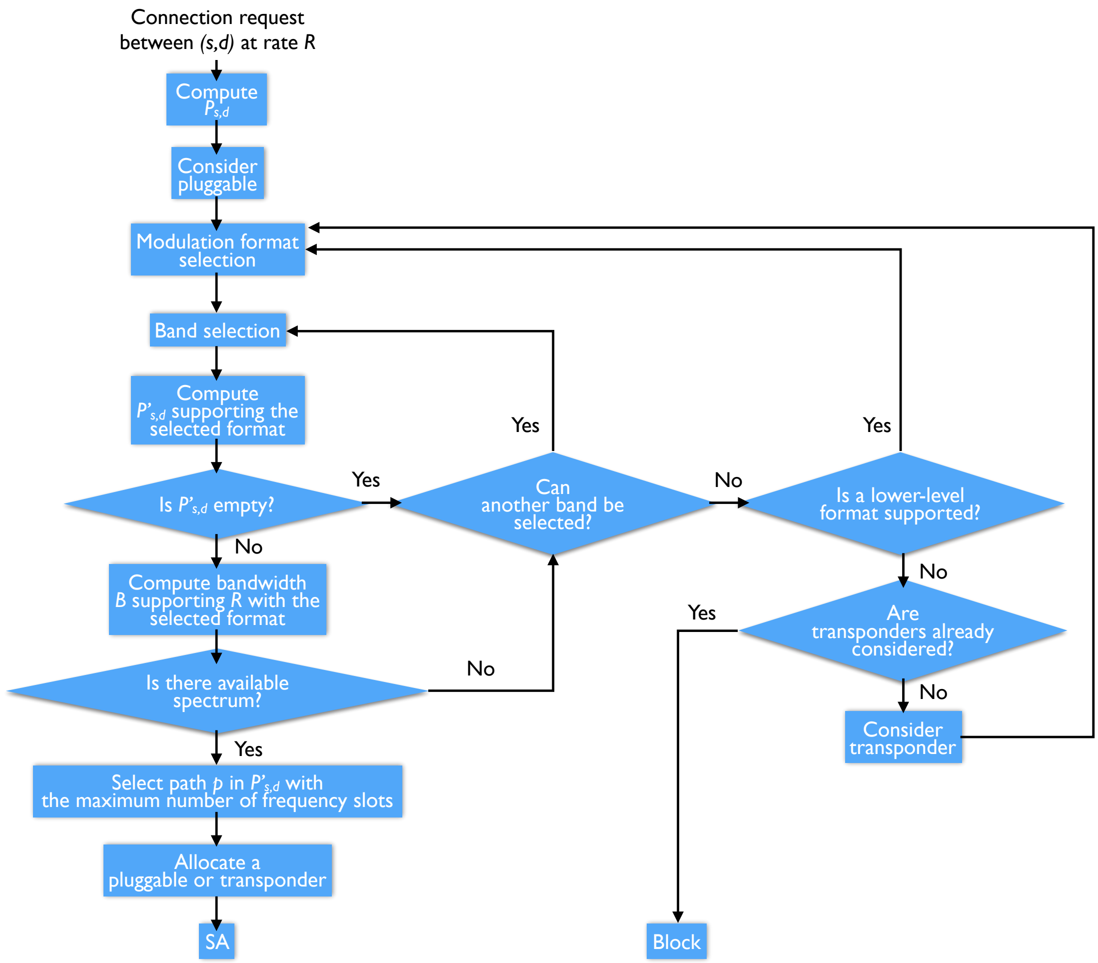

Fig. 2: Flow chart of the proposed allocation strategy

guaranteeing the proper network connectivity. The proposed allocation strategy is summarized in Fig. 2.

A connection request at rate R between nodes pair (s, d) is assumed. The set of paths $P_{s,d}$ connecting (s,d) is computed (or, if pre-computed, is considered). The use of pluggables is preferred than the use of transponders. Then, the highest-level modulation format supported by the pluggable is assumed (e.g., DP-16QAM). After that, a band is selected; preference is given to the C-band, then to L-band, and finally to the S-band. Note that the bands present different transmission performance (e.g., due to different amplification technologies). Within $P_{s,d}$, the set $P'_{s,d}$ of paths supporting the maximum optical reach for that modulation format in the assumed band with the pluggable is computed. If $P'_{s,d}$ is empty, another band is attempted; if all the bands have been attempted, a lower-level modulation format is considered; if all the supported formats have been attempted, it means that (s,d) requires a longer optical reach to be connected and transponders are considered. If $P'_{s,d}$ is not empty, the bandwidth B required to meet the requested rate R with the selected modulation format is computed and the path in $P'_{s,d}$ maximizing the number of frequency slots satisfying the continuity constraints is selected. Note that for frequency slot we mean a portion of spectrum of the ITU-T flex-grid including B. Finally, spectrum assignment (SA) is performed.

In the case there is no available spectrum in $P'_{s,d}$, another band is attempted. Otherwise, the use of transponders may increase the number of paths in $P'_{s,d}$, given a larger optical reach supported. A connection is blocked when there is no available spectrum and all the supported modulation formats and bands are considered with both pluggables and transponders.

III. Simulation Analysis

A custom built event-driven C++ simulator has been used to evaluate the power consumption (due to transmitter and receiver sides) and the blocking probability of a network equipped with pluggables ("Pluggable preferred") and a network equipped with transponders only ("with Transponders"). Two multi-band scenarios are investigated: C+L and C+L+S with available spectrum as in [4]. We tested the proposed scheme on a reference Spanish transport network with 30 nodes and 55 bi-directional links. The inter-arrival process of 200 Gb/s connection requests is assumed to be Poissonian. Requests are served with one DP-16QAM channel switched in 37.5 GHz, or with two DP-QPSK channels in 75 GHz. Inter-arrival and holding times are exponentially distributed

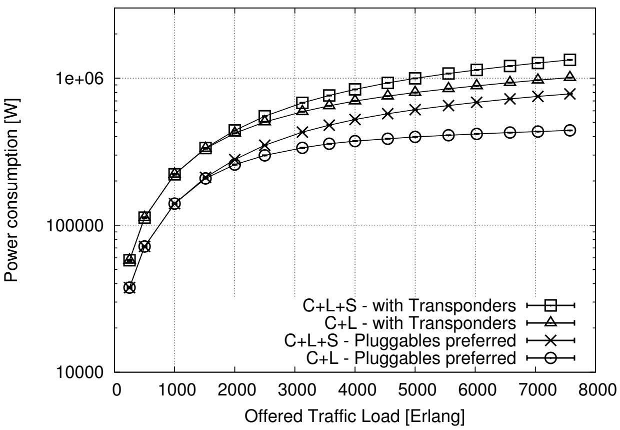

Fig. 3: Power consumtpion vs. traffic load

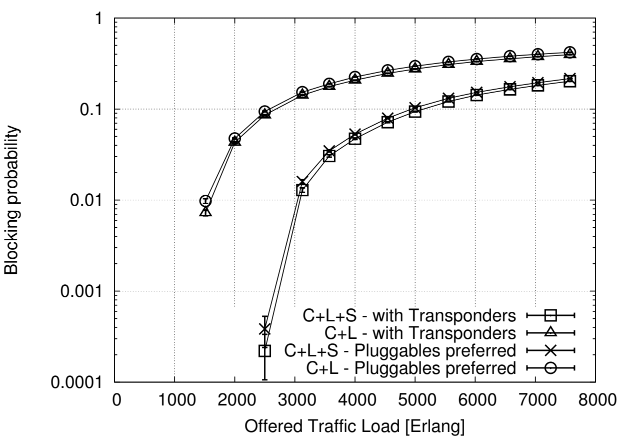

Fig. 4: Blocking probability vs. traffic load

with an average of $1/\lambda$ and $1/\mu$ = 500 s, respectively, with the connection requests uniformly distributed among all node pairs. Traffic load is expressed as λ/μ. $P_{s,d}$ is composed of shortest paths in terms of hops. The reach of pluggables in C+L with DP-16QAM and DP-QPSK is assumed 250 and 500 km, respectively, while in S-band it is assumed to be the half (e.g., 250 km for DP-QPSK). The reach of transponders is retrieved observing simulations of [10]: with DP-16QAM it is 350 km in C+L and 235 in S, while DP-QPSK is assumed to connect each source-destination pair in the assumed topology.

Fig. 3 shows the power consumption at varying the traffic load. As expected, power increases with traffic load given that an higher number of pluggables or transponders is required. The use of pluggables strongly decreases the power consumption on both C+L and C+L+S, thanks to source-destination pairs supporting the optical reach of pluggables. In general, in the C+L+S scenario, power consumption is higher than in the C+L scenario, because the availability of more spectrum permits to setup more connections activating more pluggables or transponders. As an example, focusing on "Pluggable preferred", the curves in C+L and C+L+S start to diverge around 1500 Erlang, which is a traffic load with non-zero blocking probability in C+L, thus where the S band starts to be exploited. The adoption of pluggables permits to reduce power consumption by around 50%.

Fig. 4 shows the blocking probability at varying the traffic load. As stated above, at 1500 Erlang, blocking probability of C+L is non zero, thus at that traffic load the S-band starts to be exploited in the C+L+S system. In general, the introduction of S strongly reduces blocking. Comparing "Pluggable preferred" with "with Transponders", the former experiences a slightly higher blocking probability. This is due to the shorter optical reach supported, thus shorter paths are more frequently used, limiting more the load balancing of routing and resulting in a faster saturation of shorter links/paths.

IV. Conclusion

The benefits of pluggable transceivers are investigated in multi-band scenarios. Pluggables permit to avoid energy-hungry interfaces as transponders, thus reducing the power consumption of the network. However, the use of pluggables is limited by a shorter optical reach. Especially in a multi-band scenario, where bands present different transmission performance (e.g., different amplification technologies), and where the S band may present poorer performance (e.g., than C), it is fundamental to advance with this technology (still while limiting its power consumption to 15-25 W) so that even in the S band pluggables can be used for longer distances.

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