A Cooperative Energy Saving Scheme for NG-PON2-based 5G X-Haul

Luca Valcarenghi(1), Andrea Marotta(2), Carlo Centofanti(2), Fabio Graziosi(2), Koteswararao Kondepu(3)

(1) Scuola Superiore Sant'Anna, 56127 Pisa, Italy luca.valcarenghi@santannapisa.it
(2) University of L'Aquila, 67100 L'Aquila, Italy
(3) Indian Institute of Technology Dharwad, Dharwad, India

Abstract *To reduce the energy consumption of the optical access network supporting the x-haul, this paper proposes a Software Defined Network (SDN) approach that coordinates the 5G TDD pattern and the downstream x-haul transmission for turning ON and OFF selected power-hungry Optical Network Unit (ONU) elements. ©2023 The Author(s)*

Introduction

NG-PON2 (i.e., Time and Wavelength Division Multiplexed PONs) have been considered for supporting x-haul interfaces (e.g., fronthaul, midhaul, and backhaul)[1]. However, to meet the sometimes (e.g., split option 5 and lower-layer split options) strict fronthaul latency requirements[1],[2], solutions based on Cooperative DBA (CO DBA) have been proposed[3],[4].

CO DBA exploits the Time Division Duplexing (TDD) utilized in 5G[5]. Indeed, CO DBA defines an interface for an Optical Line Terminal (OLT), to which the DU is connected, to receive wireless scheduling. Thus, the OLT can estimate the amount and arrival timing of the fronthaul (FH) signal to an ONT and schedule upstream transmission in advance to reduce the uplink latency.

5G TDD can be also exploited for reducing NG-PON2-based x-haul energy consumption but this aspect has not been thoroughly investigated yet. In the recent past, energy efficient Time Division Multiplexed Passive Optical Network (TDM-PON) schemes were proposed and adopted in the standards to extend the lifetime of an Optical Network Terminal (ONT) during main power failures, as a primary target, and to reduce average power consumption at all times, as a secondary target, while not sacrificing service quality or availability[6],[7]. However, they were not considered in an integrated wired-wireless scenario (i.e., FiWi).

The software programmability and openness of software defined mobile networks and, in particular, of Open RAN (O-RAN) paves the way towards the cooperation between RAN and optical transport network infrastructures, which has been shown to offer advantages in terms of network efficiency and of savings in cost of ownership for operators[8]. In parallel, the introduction of Software Defined Optical Access Networks (SDOANs) allows to implement flexible strategies for bandwidth allocation and energy efficiency in a dynamic and programmable way[9].

This paper proposes a collaborative approach, inspired by the CO DBA, that leverages the programmability of O-RAN and SDOANs and the 5G TDD utilized in the 5G physical layer for reducing the NG-PON2-based x-haul energy consumption. The method combines the cyclic sleep mode defined in[7] with the possibility for the NG-PON2 to receive wireless scheduling. Selected ONT receiver components are turned OFF when 5G New Radio (NR) slots or symbols are dedicated to uplink transmission. The method is so general that can be applied to different x-haul interfaces (i.e., fronthaul, midhaul, backhaul) with different next generation NodeB (gNB) splits or none.

System Model

We consider the reference architecture shown in Fig. 1 where a gNB (or alternatively a RU or RU+DU) is connected to the core network (or DU+CU/CU, and core network) through a NG-PON2. In this paper, we focus on the scenario where the x-haul interface is carried by a single wavelength of the NG-PON2, thus it is equivalent to a TDM-PON. At the wireless side TDD is adopted as duplexing mechanism.

The gNB (RU/RU+DU) is equipped with an ONT while DU (DU+CU) is deployed at the OLT side. The PON can be configured according to the adopted mobile configuration. When a RU is deployed at the ONT side, the PON acts as fronthaul infrastructure and ad-hoc resource allocation strategies are implemented to offer very low latency to fulfill fronthaul latency requirements. When RU+DU or gNB are deployed at ONT side, the PON acts as midhaul or backhaul infrastructure and DBA strategies are adopted based on

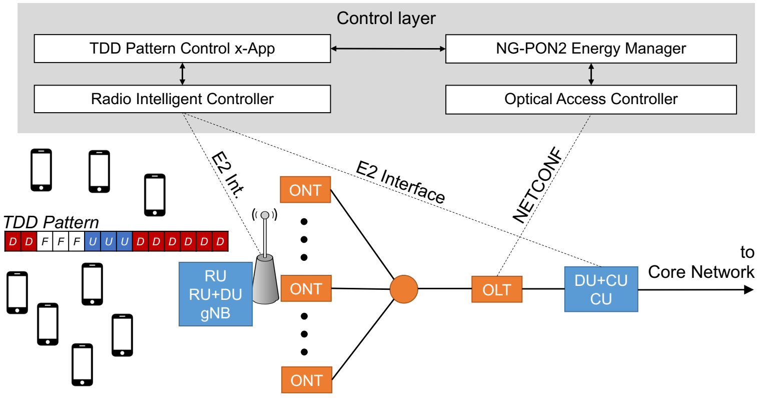


Fig. 1: System Model

specific end-to-end services' requirements.

The PON is managed by an Optical Access Controller (OAC) which interacts with an agent placed at the OLT using NETCONF protocol[10]. The OAC is responsible to enforce policies at the OLT for the management of quality of service, bandwidth allocation strategies, and energy efficiency. Moreover, it exposes northbound Application Programming Interfaces (APIs) to allow operators or any other third party to implement desired software defined control.

The Radio Access Network (RAN) is managed by a Radio Intelligent Controller (RIC). In O-RAN, two RICs are defined: Near Real Time (Near-RT) RIC, which is responsible to apply decisions and perform monitoring on a millisecond time scale, interacts with a Non-RT RIC which provides policies with a time scale ≥ 1s. On top of the Near-RT RIC, custom-built applications called xApps implement the control logic desired by the network operator via APIs exposed by the Near-RT RIC.

Proposed Cooperative Sleep Technique

In 5G New Radio (NR), as specified in[5], the slots and the symbols within slots during a downlink-uplink (DL-UL) period can be configured in various ways: uplink (U), downlink (D) or flexible (F). The configuration is achieved through the exchange between gNB and UE of the *tdd-UL-DL-ConfigurationCommon* message. The UE can be provided also with another configuration message, namely the *tdd-UL-DL-ConfigurationDedicated*, that overrides only flexible symbols per slot over the number of slots as provided by the *tdd-UL-DL-ConfigurationCommon*. Some slot formats with symbol configuration (i.e., 56 indexed from 0 to 55) are predefined in[5]. Some examples are provided in Fig. 2.

The proposed cooperative sleep technique, CO-SLEEP for short, is based on the directionality of the TDD pattern: when the UE is transmitting uplink (U), downstream transmission from the OLT to the ONT is absent (or minimal) in the PON; when the gNB is transmitting downlink (D), upstream transmission is absent (or minimal). Thus in the former case selected receiver subsystems of the ONT can be turned temporarily OFF and in the latter case selected transmitter subsystems of the ONT can be turned temporarily OFF.

CO-SLEEP leverages two applications (depicted in Fig. 1), realized on the top of the network controllers (i.e., RIC and OAC), to achieve energy saving in the PON x-haul: the *TDD Pattern Monitor* x-App and the *NG-PON2 Energy Manager*. Once the gNB (or RU, RU/DU) has exchanged the slot/symbol configuration messages with the UE, the TDD Pattern Monitor xApp sends the configuration to the NG-PON2 Energy Manager. The NG-PON2 Energy Manager interacts with the OAC that, in turn, selects a sleep time for the ONT. Such sleep time is communicated to the ONT as in formerly devised cyclic sleep schemes[6]. Specifically, in this paper, CO-SLEEP puts the Clock and Data Recovery (CDR) ONT in sleep mode when no traffic is transmitted downlink in the air interface (i.e., during the U slot-

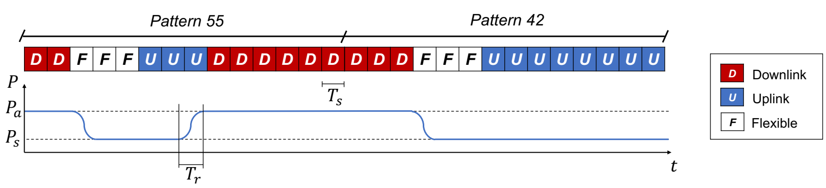
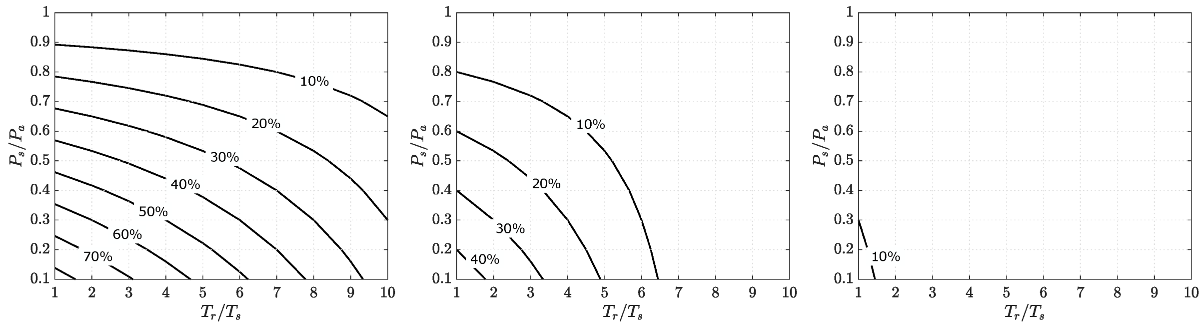


Fig. 2: CDR activation and deactivation



(a) Energy saving percentage with pattern 0 **(b)** Energy saving percentage with pattern 42 **(c)** Energy saving percentage with pattern 55

Fig. 3: Energy savings for different TDD patterns as a function of T_s/T_r and P_s/P_a

s/symbols), thus no (or minimal) traffic is directed downstream towards the ONT.

Results

An initial evaluation of the proposed scheme is performed through a MATLAB numerical evaluation. The considered scenario features a single gNB connected to the NG-PON2. The gNB is assumed to adopt a cell-specific TDD slot format configuration (*dd-UL-DL-ConfigurationCommon* in[5]). Thus, the same TDD pattern is adopted by all the UEs.

We define P_a as the power consumed by the CDR in *active* state and P_s as the power consumed during the *sleep* state. T_s is the symbol time in the mobile network and T_r is the *recovery* time needed by the CDR circuit to transit from the *sleep* to the *active* state.

Fig. 3 shows the percentage of energy saved by CO-SLEEP with respect to keep on the CDR always ON as a function of the ratios P_s/P_a and T_r/T_s for different TDD patterns. Comparing different patterns, shows that higher energy saving can be achieved with patterns where the number of uplink symbols (U) is higher. In particular for Pattern 0, where only uplink symbols are allocated, we can obtain up to 80% saving.

The amount of time required for the CDR recovery strongly impacts the energy saving. This appears evident by observing Fig. 3c. Indeed, Pattern 55 presents 3 symbols over 14 allotted for the uplink transmission (U). However, the need to recover from the *sleep* state at the 9-th symbol strongly limits the advantages achievable by the proposed technique, which is able to obtain 10% saving only. As expected the longer is the recovery time T_r the lower is the amount of time spent in the *sleep* state and the energy saving. Please note that we assume all the flexible symbols (F) to be allotted for downlink transmission to consider worst case conditions.

Another relevant aspect is represented by the time required for the communication between the control layer and the OLT and the application of the policies transmitted via NETCONF protocol. We experimentally measured such time by utilizing the commercially available Calix Axos E7-2 NG-PON2. The delay measured for the application of general scheduling policies of variable length (i.e., number of XML lines) transmitted via NETCONF varies between 100ms and 200ms. This highlights that ML-based forecast techniques for the prediction of the adopted TDD patterns may be needed to avoid to enforce not updated policies at the ONT due to the delay in the application of NETCONF rules.

Conclusion

This paper proposed a novel method exploiting 5G TDD and programmability of Open Radio Access Network (O-RAN) and Software Defined Optical Access Networks (SDOANs) for x-haul energy efficiency.

The proposed method consists in turning OFF part of the ONT receiver when the air interface TDD pattern features upstream slots/symbols.

Preliminary results show that energy savings up to 80% can be achieved for patterns featuring long uplink transmission symbols. However, the energy saving depends not only on the residual ONT power consumption but also on the time to recover from sleep mode and on the time to reconfigure the PON when the traffic pattern changes.

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