# Stimulating green FTTH networks using home router virtualization

Julio Montalvo, Koen Casier, Bart Lannoo

*Abstract*— **Telecom networks consume a considerable amount of electrical energy and according to the environmental guidelines, just as other businesses, telecom should aim at continuously lowering this consumption. Still in a telecom network a lot of the energy consumption is hidden under the radar, as a large part of the energy consumption is caused by the customer premises equipment (CPE), often installed by the network operator. As this equipment is consuming energy from the customer's side, the telecom operator is not confronted with the energy consumption of this equipment. This also means that the operator gains by any reduction in the cost of the CPE, regardless of whether this involves the installation of less energy efficient equipment. In this paper we investigate the use of a bridged CPE solution and a home router virtualization network solution, in which part of the functionality of a CPE is moved into the network operator equipment and as such reduce the energy consumption by equipment aggregation and specialization. In this paper, we show that this will at the same time reduce costs and as such could be a positive action for the operator, simultaneously reducing the power consumption of the CPE. On top of this bridged CPE, the incentives required to stimulate operators to introduce more energy efficient CPE equipment faster in the network are estimated. Finally, by means of game theory, we propose a method to investigate how the incentives should be placed in order to stimulate green FTTH massive deployments.**

*Index Terms*—**Energy-efficiency, FTTH (Fibre to the Home), Home Router, Gateway, Incentives, Regulation, Virtualization**

## I. Introduction

ENERGY-EFFICIENCY in the industry of Information and Communication Technologies (ICT) has the potential to significantly reduce the operational expenses (OPEX) of service providers and network operators, while having a positive environmental impact by reducing the energy consumption and carbon emissions at the same time.

On the other hand, the adoption of internet for business and the penetration of broadband technologies with high access speed even above 100 Mb/s per user is being pushed in several countries worldwide during the last years, in order to increase business efficiency, attract innovative start-up companies and create new employments, eventually increasing the Gross Domestic Product (GDP).

As an example, the Digital Agenda for Europe targets broadband access speeds above 30 Mbps for all Europeans by 2020, with at least 50% of the connections with speeds higher or equal to 100 Mb/s. In order to achieve these targets, massive broadband deployments with fibre optics in the access network are playing a relevant role. The Fibre to the Home (FTTH) Council Europe reported 63 million homes passed, i.e. with fibre access infrastructure ready for customer subscription, and 16.2 million subscribers in Fibre to the Home/Building (FTTH/B) networks in Europe at the end of 2012. The reported values of Compound Annual Growth Rates (CAGR) of subscribers and homes passed equal 40% and 50% between years 2009 and 2012 [1].

Among the different fixed access technologies using optical fibre, the final picture ends in the deployment of fibre from the network operator Central Office (CO) up to the user premises, forming the so-called FTTH networks. A generic FTTH architecture is shown in Fig. 1.

A FTTH network is formed by an Optical Line Terminal (OLT) in a CO of the network operator, which provides broadband access to a number of customers. The CPE connects the home devices (Personal Computers, Smartphones, Tablets, Set-Top-Boxes, etc.) to the OLT using the optical fibre deployed in the optical distribution network (ODN).

Inside customer premises, an Optical Network Terminal (ONT) acts as optical-to-electronic (OE) signal converter from the operator network to the customer premises, and vice versa. Within the same device than the ONT or in another one, a typical gateway (GW) provides interfaces to the user Local Area Network (LAN) and manages the user traffic. When the GW device includes Layer 3 functionalities, it can be referred to as home router, see Fig. 1(a).

The access network (OLT, ONT, GW) consumes around 85% of the energy of wire line networks, with about 10 W per user related to the CPE (considering 2010 technology) [2]. As a consequence, achieving energy efficiency in the CPE devices is a relevant way of reducing the overall power consumption of access networks.

Stimulating energy efficiency in access networks, as well as at the customer premises, is a difficult task, especially as energy consumption generates problems and costs which are not directly transferred to the operator, but often occur down the

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line (pollution), are charged to someone else (to the customer) or are actually enforced upon the customer (CPE consumption).

In this paper, we focus on a network innovation approach, the home router virtualization. In section II, the description of the architectures and technologies for home router virtualization in FTTH networks are described. In Section III, we provide estimations of the impact of home router virtualization in a realistic FTTH scenario in the city of Gent, by analyzing the Total Cost of Ownership (TCO) for the network operator as well as the power consumption per user, including CPE. Section IV estimates the incentives required to stimulate home router virtualization in FTTH networks. Section V presents a game theoretical model that can be used in future work to investigate the impact that the regulator policies and incentives could have on the speed of adoption of energy efficient CPEs by FTTH network operators. Finally, the paper concludes in Section VI.

## II. HOME ROUTER VIRTUALIZATION IN FTTH NETWORKS

Network functions virtualization aims to achieve a wide variety of advantages, such as reducing equipment cost and power consumption or increasing speed of time to market, by changing the architectural approaches of network operators [3]. While the classical network architecture approach is using fragmented non-commodity hardware, such as OLTs, routers, firewalls, carrier grade Network Address Translation (NAT) or Broadband Remote Access Servers (BRAS), the network virtualization approach consists of the consolidation of many of the former network equipment types onto industry standard high volume servers, switches and storage. Industry standard high volume servers are servers built using standardised Information Technology (IT) components (such as x86 architecture) and sold in the millions. Software implementing network functions can run on a range of industry standard server hardware, exploiting the economies of scale of the IT industry.

In the context of this paper, virtualization refers to the generic concept of a technological framework developed to reduce the complexity of CPE devices, in this case the GW device used to provide FTTH access, and perform the higher layer network functionalities of the home GW (IP routing, firewall, Dynamic Host Control Protocol [DHCP], Digital Living Network Alliance [DLNA]) within the service provider network, thus obtaining increased efficiency due to statistical gain as well as other operational advantages.

Recently, the power savings in a FTTH-PON using Layer 2 bridges as GW, thus shifting Layer 3 functionalities to the network operator, keeping a Layer 2 customer network, see Fig. 1(b), were estimated between 30% and 60% depending on the LAN interfaces [4, 5]. According to the GreenTouch Consortium, the virtualization of the GW functions can be a medium term approach to achieve a fivefold energy efficiency gain factor with regards to the power consumption of the GW processor in the customer premises [6]. Different network approaches to achieve this shift of the GW functions from the customer premises to the network operator premises can be found in [7].

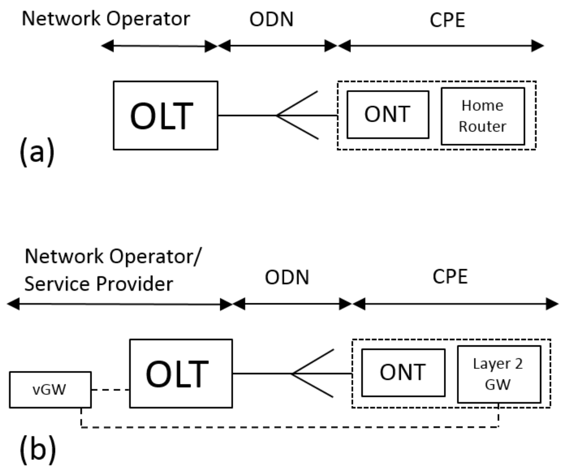



Fig. 1. General schematic of a FTTH network with a home router (a) and a layer 2 GW (b). CO: Central Office; OLT: Optical Line Terminal; ODN: Optical Distribution Network; CPE: Customer Premises Equipmen; ONT: Optical Network Terminal; GW: Gateway.

We distinguish between different nodal approaches for network functions virtualization of the higher level network functionalities of the home GW:

- vGW implemented in additional IT equipment. In this case, GW functions can be performed by commodity hardware running the virtual gateway (vGW) functions, such as high volume computing servers located in a datacenter or between the Access Node and the IP edge. The efficiency and flexibility of this approach can be increased by running, in the same physical machine, several Virtual Machines (VM) able to implement network functions via software in a single server platform. An example of a high speed packet processing function implementation using a personal computer platform is shown in [8].
- vGW fully implemented in existing network equipment. In this case, vGW functions may be added to existing network equipment such as the Access Node or the IP edge. A lack of software flexibility can be expected with regards to the vGW implementation in new IT equipment.
- Hybrid approaches for vGW implementation. In this case, vGW functionalities are split and performed in different parts of the network. In this approach, the data plane can be kept in existing network equipment, while adding control plane functions in additional IT equipment, so that the vGW functionality is implemented in a distributed way.

Among all options, smooth migration from home router GW to vGW, as well as scalability, flexibility, cost and energy consumption are key aspects to be considered by network operators and service providers.

## III. TOTAL COST OF OWNERSHIP OF FTTH NETWORKS WITH HOME ROUTER VIRTUALIZATION

To indicate the potential of home router virtualization, we performed a Total Cost of Ownership (TCO) calculation for an illustrative example scenario in the city of Ghent, Belgium. A modular in-house calculation toolset has been used to perform the analysis of the TCO of FTTH deployments. We use the same hierarchical techno-economic model described in [9], considering a Passive Optical Network (PON) deployment and considering the Capital and Operational Expenditures (CAPEX, OPEX) of different CPE operator strategies, see Table I and Table II, respectively.

TABLE I. CAPEX MODEL FOR CPE VIRTUALIZATION

| Cost [a] | | |
|---|---|---|
| ***Device*** | ***CPE strategy*** | |
| | Home router GW | Layer 2 GW (vGW) |
| CPE | 1.4 | 1.1 |
| Virtual GW | 0.0 | 0.1/subscriber |

a. Normalized values with regards the cost of an ONT.

TABLE II. OPEX MODEL FOR CPE VIRTUALIZATION

| ***Parameter*** | ***CPE strategy*** | |
|---|---|---|
| | Home router GW | Layer 2 GW (vGW) |
| CPE energy consumption | 15.8 W | 12.7 W |
| Virtual GW | 0.0 W | 0.16W/subscriber |
| CPE MTBF[a] | 55,000 h | 65,000 h |
| Virtual GW MTBF | Infinite | 200,000 h |
| Labour cost per CPE failure[b] | 0.004 | 0.0033 |
| Material cost per CPE failure[b] | 0.45 | 0.45 |
| Labour cost per Virtual GW network device failure[b] | 0.0 | 600 |
| Material cost per Virtual GW network device failure[b] | 0.0 | 6 |

a. Mean Time Between Failures

b. Normalized values with regards the cost of an ONT.

The goal is to illustrate a case in which TCO reduction and energy efficiency are in line. Two different CPEs are considered for this study:

- Regular CPE (rCPE): TCO for a FTTH deployment using a regular CPE (home router GW) as a Business as Usual (BAU) operator strategy. The device cost, power consumption and OPEX (especially installation cost and maintenance) values of a rCPE are estimated and integrated in a TCO model for FTTH networks.
- Energy efficient CPE + network solution (EE CPE): TCO for a FTTH deployment using a bridged CPE (L2 GW) and vGW in the network as an innovative operator strategy. The new network equipment required for vGW has been modelled as new OLT cards, which are included in the TCO model, as well as the power consumption and the OPEX (especially installation cost, maintenance) of the new OLT cards, together with the new CPE (L2 GW).

## A. *Greenfield scenarios*

Fig. 2 shows the first results for a GPON deployment in a city environment with 22k users connected after 10 years, following an S-shaped adoption curve. Two greenfield deployment scenarios are considered, one with the home router CPE strategy (routed CPE) and a more energy efficient strategy using home router virtualization (Bridged CPE). The results predict a 20% reduction in the energy costs after 10 years together with an important reduction in the considered operator costs (i.e. CPE device cost, installation cost and maintenance).

From these estimations, it is concluded that an operator can have an important advantage to choose the home router virtualization technology for a greenfield rollout, as soon as the technology is mature enough for a commercial deployment.

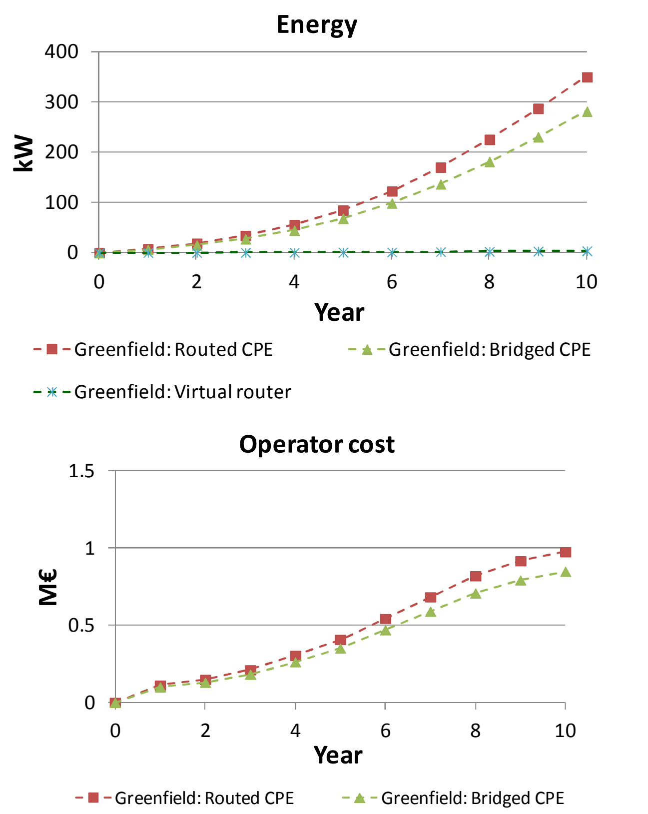
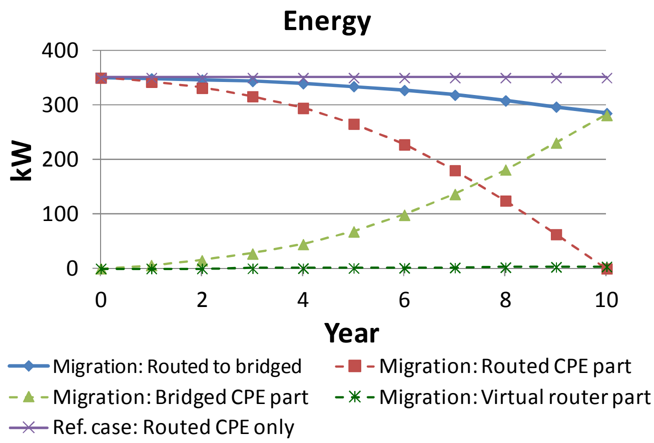



Fig. 2. Energy consumption and operator costs for routed and bridged CPE in a GPON deployment in a city environment with 22k users connected after 10 years.

## B. *Brownfield scenarios*

Several operators, however, already started with FTTH rollouts and we can assume that their technology is corresponding to a home router CPE technology. To verify the feasibility of a bridged CPE technology, it is important to calculate the energy consumption and operator costs in a migration scenario from routed to bridged CPEs. Fig. 3 and Fig. 4 show the results for a slow (spread over 10 years) and faster (spread over 5 years) migration scenario. The migration results are further split between the portion of routed and bridged CPEs together with a common part corresponding to unchanged CO equipment. To estimate the additional costs and energy savings, the migration scenario is also compared to a reference case where the routed CPE technology is not upgraded to a bridged

CPE technology. Once the migration is finished, a 20% energy reduction is reached as could be expected from the Greenfield results. However, an additional operator cost is required during the migration phase, which is during the migration years much higher for the fast scenario, To put all these numbers in a broader perspective, Table III compares the TCO and energy consumption figures for the different evaluated deployment scenarios. It shows that in a Brownfield scenario, a faster migration is even better in the cumulated extra TCO with regards to keeping a routed CPE scenario, 3.95% in 5 years versus 4.6% in 10 years. Nevertheless, a higher financial effort with a maximum of 38.7% TCO annual increase is required to achieve a faster migration, versus a maximum of 9.7% TCO annual increase for the slower migration. Energy savings are in 5 years very close (12%) to the maximum achievable in Greenfield (18.6%).



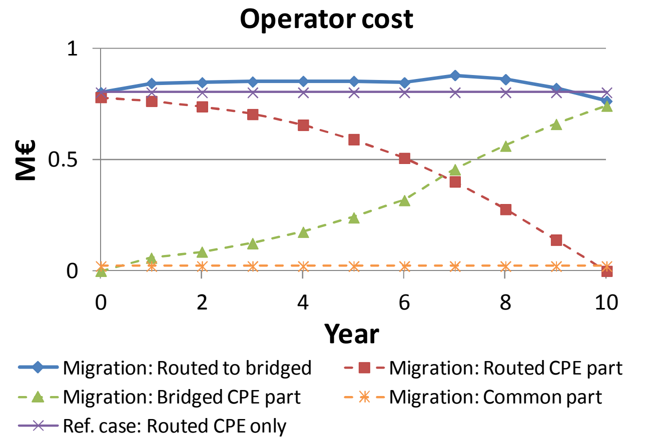




Fig. 3. Energy consumption and operator costs for a migration scenario from routed to bridged CPEs in a time frame of 10 years, in a GPON deployment in a city environment with 22k users connected from year 0.

## IV. INCENTIVES FOR ENERGY EFFICIENCY

As shown in the previous section, using an EE CPE is a typical use case in which standardization on network solutions and research/innovation can be more important than regulation to lower the energy consumption in FTTH networks.

Based on this work, we propose a model for the analysis of TCO considering different operator strategies on the deployment of energy efficient CPEs in already existing FTTH deployments.

Depending on the network operator and service provider strategy, bridged CPEs could be installed in case of new FTTH subscribers and the already existing routed CPEs would be replaced by bridged CPEs at a certain speed. As the energy consumption of bridged CPEs is lower, significant energy savings would be achieved.

Depending on the migration speed, only bridged CPEs would be present in the network after a certain amount of years. Nevertheless, the cost of achieving this situation for the network operator can be a limiting factor, because of the cost of CPE replacement and service migration from a routed to a bridged CPE scenario.

Energy efficiency targets, such as the Code of Conduct (COC) for Broadband Equipment in Europe [10], establish general guidelines to energy efficient devices in the customer premises with broadband access. Nevertheless, incentives for energy efficiency could also be enforced by regulation authorities in order to push energy savings and influence the energy consumption of telecom networks and operator decisions.

We propose a model to analyse the impact of incentives for energy efficiency and network operator decisions in FTTH broadband deployments. As incentives could be positive or negative, the TCO will be dependent on the energy efficiency strategy adopted by the network operator. As a consequence, depending on the incentive scheme, the operator can take the decision of increasing the energy efficiency of CPEs at a different speed, depending on cost issues.

Table III provides quantitative results of how energy efficiency can impact a FTTH GPON network TCO.

In this case study, we show that in a greenfield FTTH-GPON deployment, a TCO reduction higher than 10% and power savings in the CPE side close to 20% can be simultaneously achieved with home router virtualization architectures. If the GPON network is already in operation with home routers in the customer premises, a fast migration (5 years) to the home router virtualization scenario is more energy efficient and requires less TCO effort in a 10 year timescale.

The presented model and the quantitative analysis can serve as guidelines for possible scenarios in the future, where home router virtualization, as a mature and standardized technology, could be stimulated by public policies or regulators.

TABLE III. COMPARISON BETWEEEN THE DIFFERENT DEPLOYMENT SCENARIOS

| Scenario | Cumulated extra TCO | Maximum annual extra cost | Cumulated power savings |
|---|---|---|---|
| Greenfield | -13.4 % | N/A | 18.6 % |
| Migration (5 years) | 3.95 % | 38.7 % | 12.2 % |
| Migration (10 years) | 4.6 % | 9.7 % | 6.5 % |

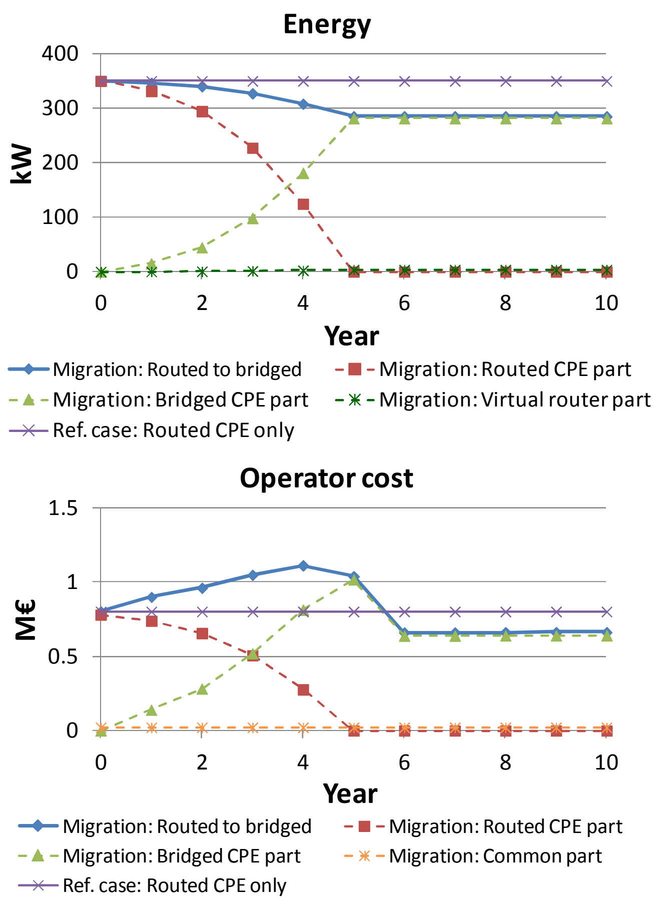



Fig. 4. Energy consumption and operator costs for a migration scenario from routed to bridged CPEs in a time frame of 5 years, in a GPON deployment in a city environment with 22k users connected from year 0.

In the presented case study, we can conclude that a likely successful public policy could be to, at least partially, fund the migration to energy efficient bridged CPEs scenarios in FTTH networks. The incentives required to achieve that in 5 years are estimated around 5% of TCO in FTTH-GPON deployments, achieving in ten years a 12.2% total power saving in the CPE side and around 20% power savings in the long-term. Another public strategy could be to use negative incentives (penalties) to force FTTH network migration to home router virtualization; nevertheless, this approach may have a negative impact, especially in competitive scenarios where speed of deployment can be a critical issue for a FTTH network operator in order to guarantee the profitability of the investment.

## V. Game Theoretical Model for Future Evaluations

Finally, we propose a game theoretic model that can be used in future evaluations to analyse the energy efficiency achieved in a FTTH deployment, combining the energy and TCO model from section III with the impact of theoretical incentives to energy efficient CPEs of a regulator authority, as described in section IV. In such a way the most likely reaction of both operator and regulator could be quantified. Therefore we model the effect a new incentive might have on the uptake and proactive introduction of new and more energy efficient equipment (CPE) in the FTTH network.

The strategies an operator can take in this are:

1. The operator could stick with a routed CPE network approach for the coming years
2. The operator could also switch gradually to a vGW solution in the network, by replacing legacy subscribers at a predefined speed. As a part of the strategy the operator can choose the speed of replacement of this equipment.

In both cases, the operator can additionally choose to install at a certain speed more energy efficient devices, either home routers (strategy 1) or bridges (strategy 2) achieved with BAU technology improvements to new subscribers, and as such stay closer to the COC.

The strategies the regulator can take in this are:

1. Define the expected energy efficiency and boundaries for low and high energy efficiency. This will of course be linked to the COC.
2. Set a positive and or negative incentive-scheme for good or bad energy efficiency. A positive incentive would allow operators to get additional funding or subsidies when installing newer equipment and as such be clearly in line with the recommendations given in the previous section. A negative incentive would be in line with the currently existing greenhouse gas emissions taxation, and push for more energy efficient installations.

A calculation approach comparable to that mentioned in section III should be used for calculating the TCO of the operator for all strategies it might choose. The energy consumption (per user) of every solution should be calculated at the same time, and linked to the total incentives or penalties that are added to the TCO of the operator. This TCO + incentives – penalties is the payoff or outcome in the game matrix for the operator. The payoff of the regulator should be calculated according to a weighted index consisting of the (inverse) energy consumption per customer and the (inverse) total TCO of the operator. Both having a lower value is a better outcome, as lower energy consumption is clearly beneficial and as there is a correlation between TCO and customer subscription prices and as such an inverse correlation between TCO and customer surplus.

Fig. 5 gives an overview of the expected evaluation space of the game theory, where the strategies of the regulator have been split between rewarding, in terms of incentives when doing better than good energy efficiency, and penalizing, in terms of penalties when doing worse than bad energy efficiency. It should be noted that additional approaches could be integrated as well.

All game theory evaluations will be based on a game theory matrix which is able to work with discrete calculation steps as is the case with both the TCO as the incentive calculation. In Fig. 5 there are also two example Nash Equilibria (NE) indicated by means of a circle (A and B). In case the NE of the game would be point A, this would mean that a high rewarding regulator combined with a not as much penalizing regulator strategy would have a high positive impact on the energy efficiency of the operator. In case the NE of the game would be point B, this would mean that the impact of the regulator on the operator is small and rather gained by penalizing and only lightly rewarding strategies.

## VI. Conclusions

In this paper, the Total Cost of Ownership (TCO) and total energy consumption of routed and virtual gateways in the customer premises equipment of a massive FTTH-GPON deployment have been estimated.

Our results show that home router virtualization can achieve a 20% energy consumption reduction in CPEs as well as significantly reduce the deployment cost for the network operator in a greenfield deployment. In brownfield scenarios, however, an additional cost is required to migrate towards a home router virtualization technology. A faster migration is better than a slow migration from an energy consumption and TCO point of view, but it requires a huge additional investment by the network operator during the migration phase. Therefore, we also discussed potential incentives and/or penalties that e.g. a regulator could define towards the network operator to enforce an energy efficient strategy.

A model based on game theory has also been proposed to study the influence between the TCO of the FTTH network and a regulation enforcing energy efficiency. Based on the outcomes of the evaluation, the selection of the dominant strategies and the relation these strategies have to actual interaction between the operator and the regulator, it should be feasible to answer the following questions:

- What is the best strategy (or direction) for the operator?
- What is the Net Present Value (NPV) reduction and business uncertainty suffered by the operator due to the regulator policy? Does it guarantee the investment and competitiveness of the FTTH network?

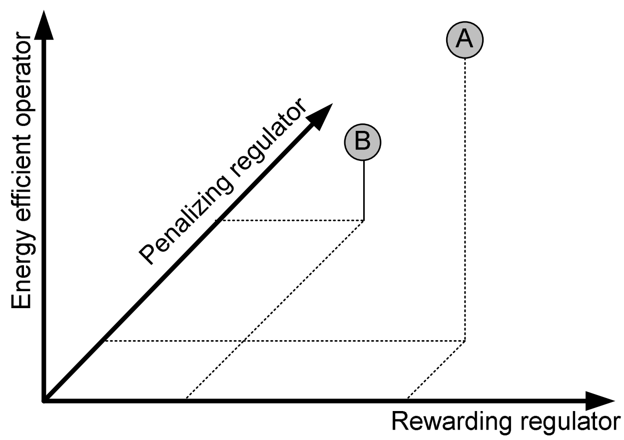



Fig. 5. Game theory visualization with two examplary Nash equilibria.

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