Improve Energy-Efficiency of Hybrid Fiber-Coaxial Networks with Traffic-Aware Design

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ABSTRACT

We propose an advanced algorithm to achieve coordinated CMTS-side energy-saving in a HFC network supporting DOCSIS 3.0 standard. Based on traffic information, the algorithm grooms as many as cable modems (CMs) on a minimal number of CMTS ports as possible, and put the rest of its ports to sleep for energy-saving. With network simulations using a realistic CM traffic model, we demonstrate over 31.5% saving on the ON-time for CMTS ports. We also investigate the tradeoff between the energy-saving and the number of CM change operations, and the results show that the algorithm can control the number of CM changes with a preset readjustment threshold.

Keywords: Hybrid fiber-coaxial (HFC) networks, cable access networks, DOCSIS 3.0, traffic-aware design, green networks.

1. INTRODUCTION

Recently, improving energy-efficiency has become one of the biggest challenges in Information and Communication Technology (ICT). It is shown that the operation of access networks is one of the major contributors to the carbon emission of ICT [1]. New technologies in Hybrid Fiber-Coaxial (HFC) networks, such as channel bonding released in Data over Cable Service Interface Specification (DOCSIS) 3.0 [2], can boost access bandwidth and user experience. However, they could also increase the power consumption on both the Cable Modem Termination Systems (CMTS) and Cable Modems (CM). On the CM side, multiple transceivers are normally turned on to accommodate upstream (US) and downstream (DS) bonding. On the CMTS side, equipment vendors have to develop linecards with increased number of US/DS ports, which results in additional power consumption.

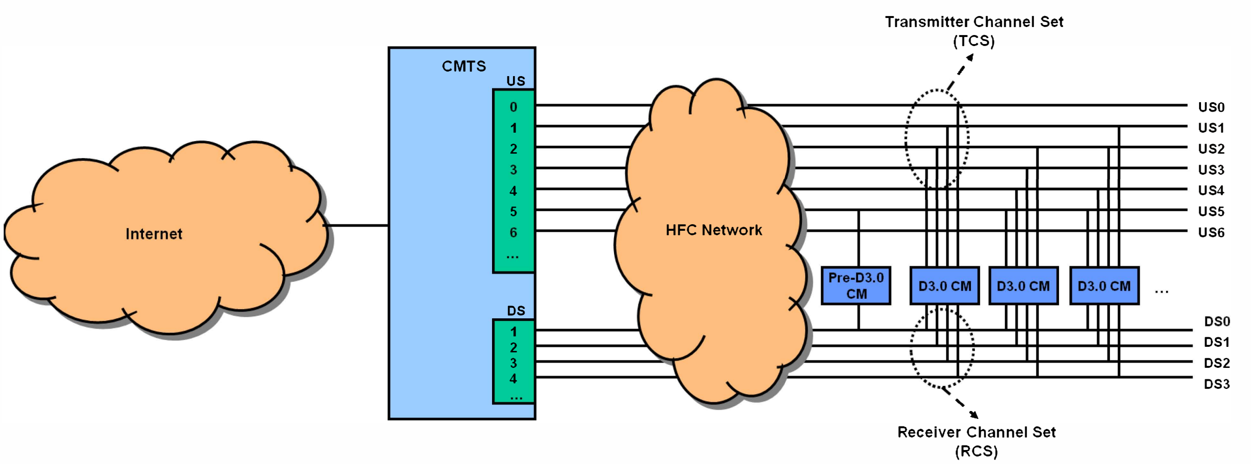

Fig. 1 Infrastructure of HFC network supporting DOCSIS 3.0 standard, CMTS: Cable Modem Termination System, HFC Network: Hybrid Fiber Coaxial Network, D3.0: DOCSIS 3.0, CM: Cable Modem, US: upstream, DS: Downstream

Fig. 1 illustrates a typical HFC network infrastructure that supports DOCSIS 3.0 standard. The DOCSIS 3.0 wideband CM equips with multiple transceivers, and can connect to multiple US/DS channels from the CMTS for high-speed data transmission. The traffic on a HFC network comes directly from the customers, and it is well known that the traffic load has daily fluctuations due to the life cycle of human beings [3]. In [4], we have proposed and

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demonstrated that the CM energy consumption can be effectively reduced with a traffic-aware algorithm that selectively shuts down CMs' transceivers, and adjusts their connections to the CMTS on the fly. In addition to CM-side energy-saving, CMTS-side energy-saving can be achieved with a coordinated approach. Specifically, The CMTS grooms as many as CMs on a minimal number of ports as possible, and put the rest of its ports to sleep mode for energy-saving. In this paper, we propose an efficient CMTS-side energy-saving algorithm that only makes minimal changes based on the current connection states, and avoids intensive CM moving-around on the CMTS. With network simulations, we demonstrate effective network-wide energy-saving, and investigate the tradeoff between the energy-saving and the number of CM change operations.

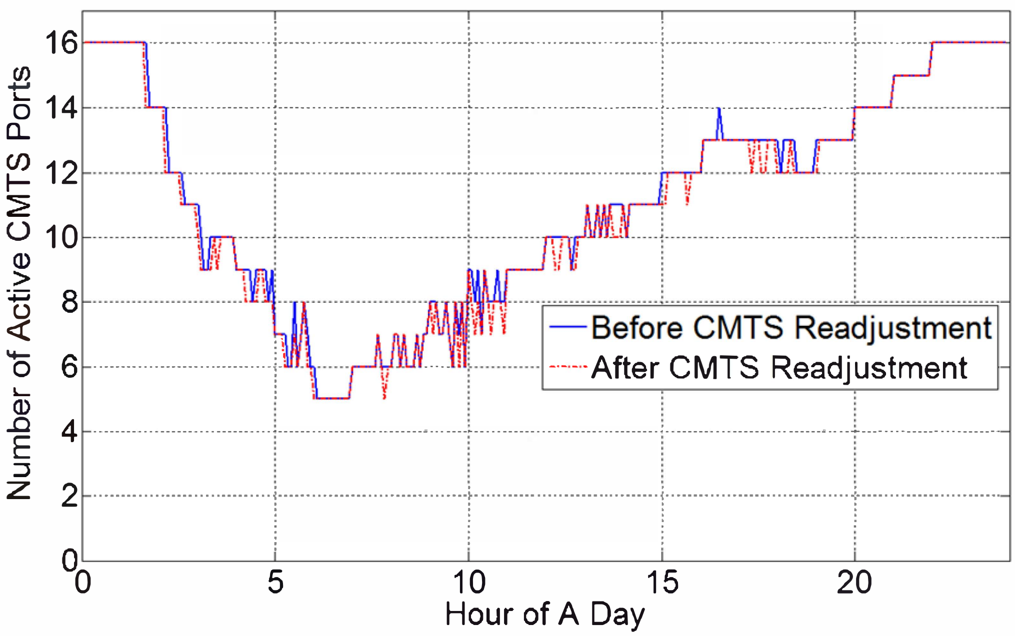

Fig. 2 Number of active CMTS ports for $T_{load} = 5\%$.

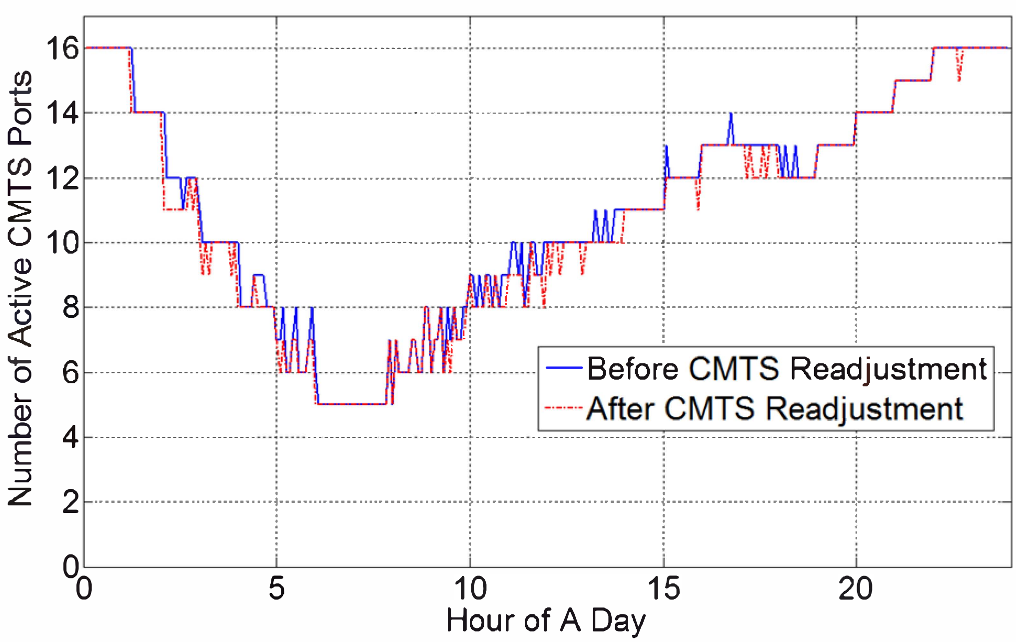

Fig. 3 Number of active CMTS ports for $T_{load} = 20\%$.

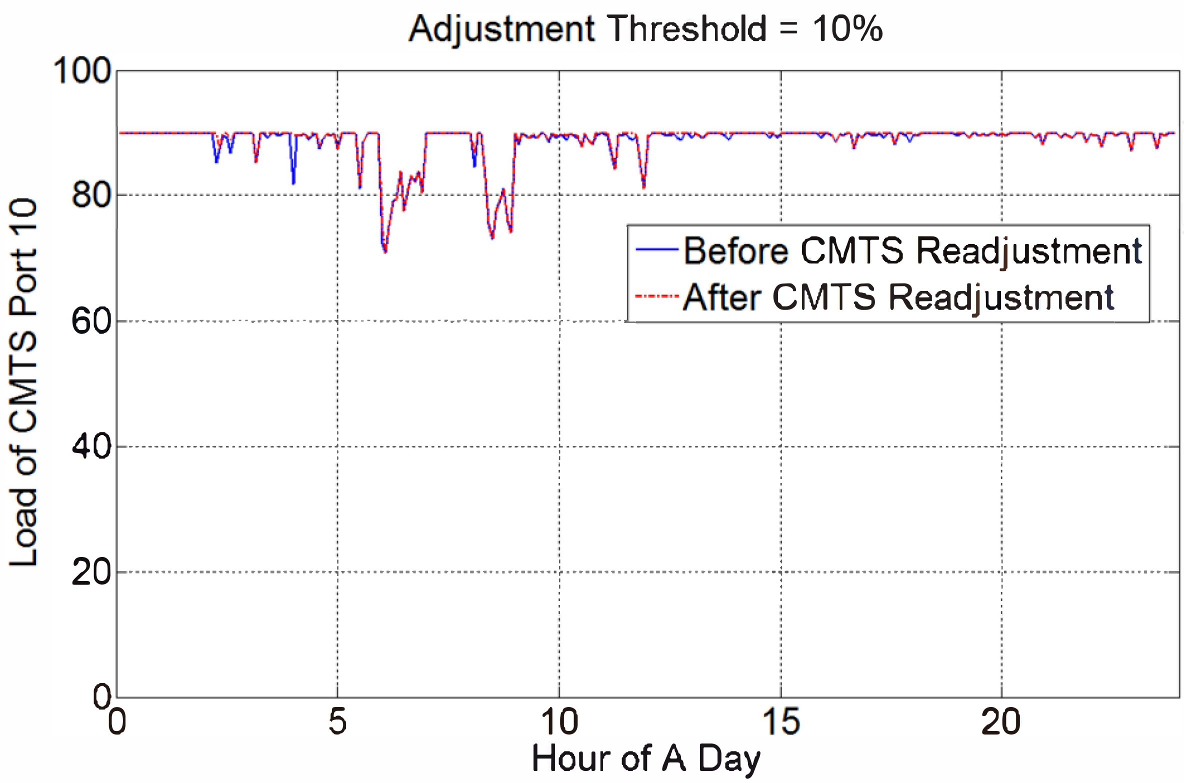

Fig. 4 Load of CMTS port in terms of CM connections changing with time, for port 10, when the readjustment threshold is 10%.

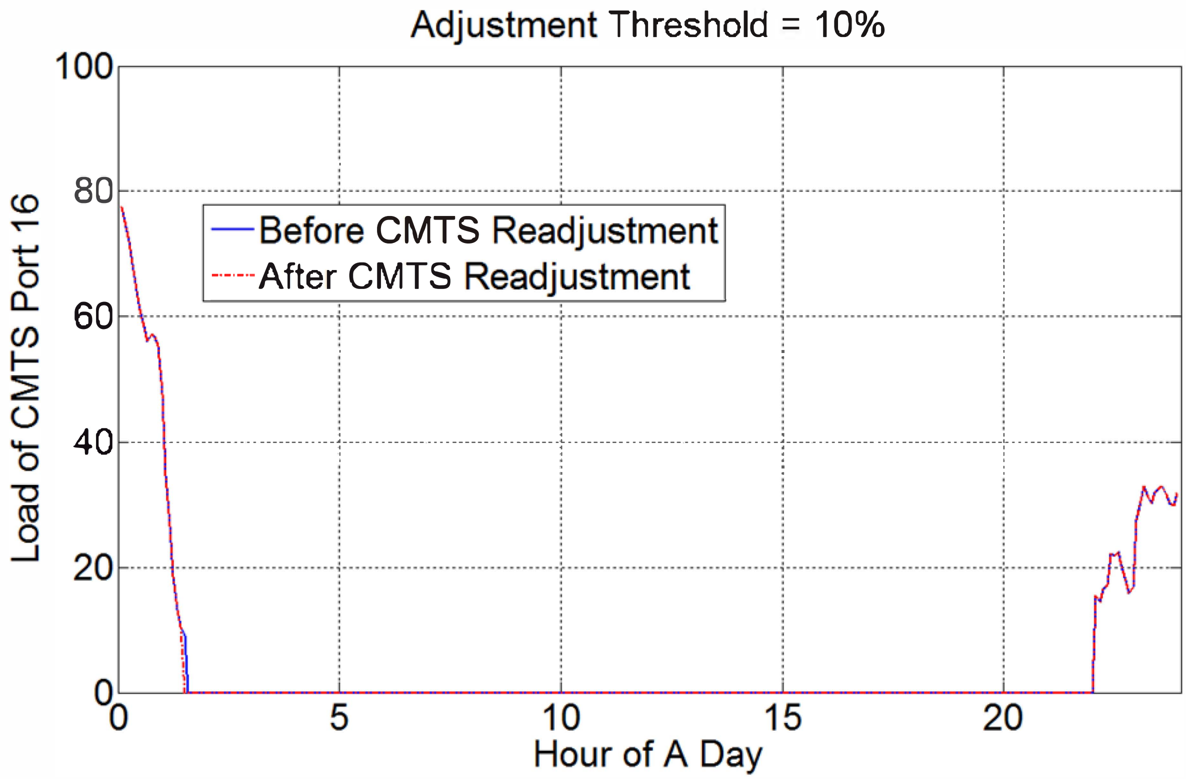

Fig. 5 Load of CMTS port in terms of CM connections changing with time, for port 16, when the readjustment threshold is 10%.

2. CMTS-SIDE ENERGY SAVING ALGORITHM

Given a MAC domain of HFC network, we define $U = \{U_1, U_2, ..., U_N\}$ and $D = \{D_1, D_2, ..., D_N\}$ as the sets of N US and N DS ports that the CMs can access, respectively. We assume the sets of US and DS ports have the same size. $L_u(i,t)$ and $L_d(i,t)$ are the US/DS port loads in terms of connected CMs for *i-th* port at sampling time t. Each CM has M transceivers that make US and DS connections to CMTS ports, as $U_{cm}^{(k)} = \{U_{cm,1}^{(k)}, U_{cm,2}^{(k)}, ..., U_{cm,M}^{(k)}\}$ and $D_{cm}^{(k)} = \{D_{cm,1}^{(k)}, D_{cm,2}^{(k)}, ..., D_{cm,M}^{(k)}\}$. Here, k is the id of the CM in the MAC domain. For simplicity, we assume the US traffic load fluctuation mimics that of DS, which is usually the case in a practical HFC network [3]. When the asymmetry of DS and US traffic has to be addressed, a more sophisticated algorithm can be developed to treat the DS and US separately with the similar logic. In [4], we have already shown that by proactively monitoring the instant and average CM traffic load and adjusting CM's connections ($U_{cm}^{(k)}$ and $D_{cm}^{(k)}$) to CMTS ports accordingly, we can achieve effective energy-saving on the CM-side. The CMTS-side energy-saving algorithm works as the second phase. Basically, at each sampling time t, we sort CMTS ports according to their loads $L_u(i,t)$ or $L_d(i,t)$. When we have to increase a CM's connection set, we direct the new connections to the available CMTS ports that are busiest. While for decreasing a CM's connection set, we take off connections that are from the lightest CMTS ports. After these operations are done, we readjust the CM-CMTS connections based on a preset load threshold T_{load}. Specifically, for all of the CMTS ports, when $L_u(i,t)$ or $L_d(i,t)$ is less than T_{load}, we try to redistribute the CMs on that port to other ports. By adjusting T_{load}, we can control the number of CM change (or dynamic bonding change (DBC)) operations, and avoid intensive CM moving-around. Then, we put all CMTS ports that are not connected to any CM to sleep mode, for energy saving.

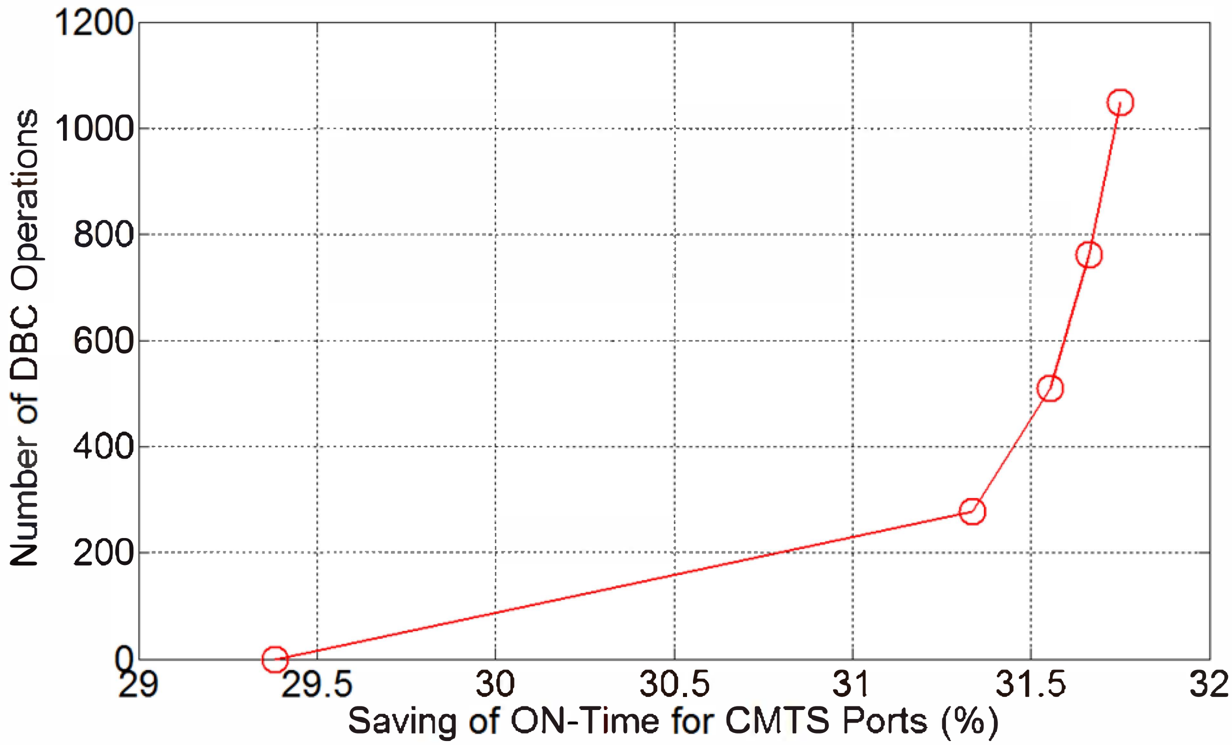

Fig. 6 Number of DBC operations vs. Saving of ON-time for CMTS ports,

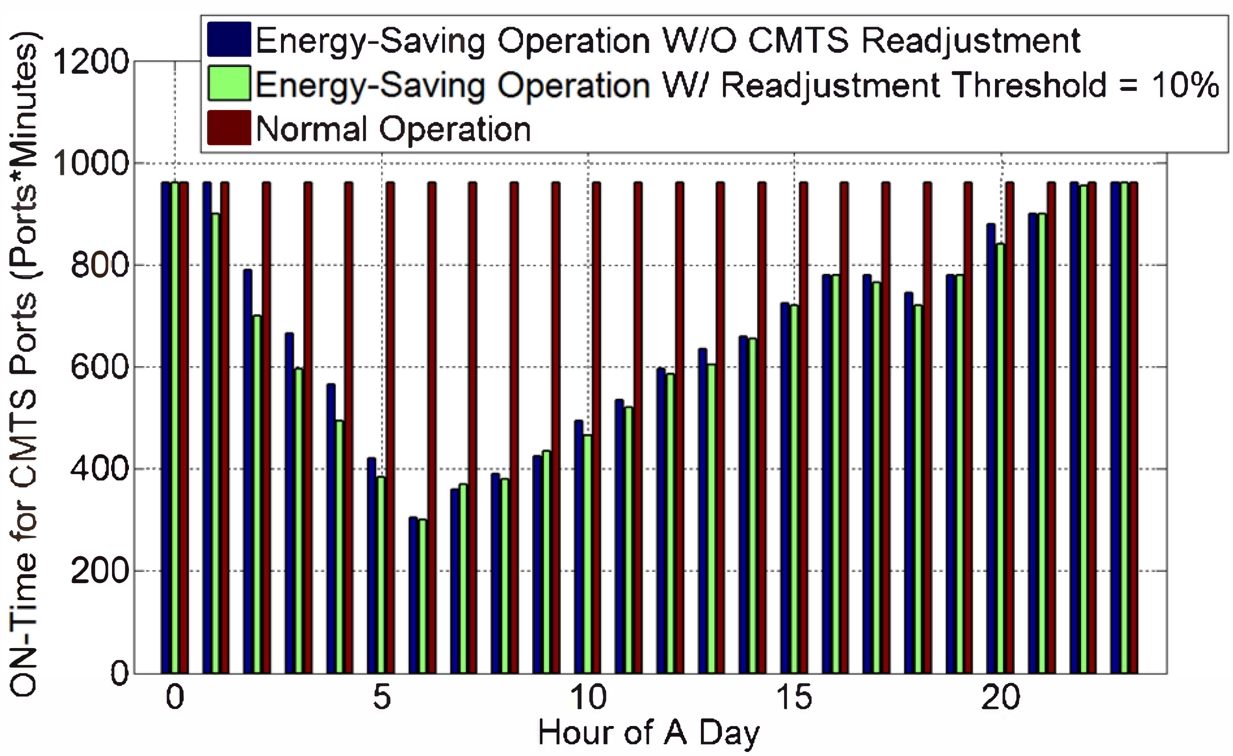

Fig. 7 Comparisons of ON-time for CMTS ports.

3. SIMULATION RESULTS

To evaluate the proposed CMTS-side energy-saving algorithm, we design a simulation with N = 16 ports on a CMTS linecard and 1000 CMs. Each CMTS ports can accommodate 256 CM connections as 90% load (reserve 10% load for performance margin). Each CM has 4 transceivers, and it carries traffic that follows a realistic HFC model with self-similarity [3,4]. For simplicity, we assume the US traffic load fluctuation mimics that of DS, and only considers DS traffic and ports. The CM's connection set size can be set as 1, 2, or 4, for low-power, moderate-power, and high-power modes, respectively. CM instant traffic load is sampled every 5 minutes, and the average load is taken over a duration of 10 minutes. The high-working (HW) and low-working (LW) thresholds for CM traffic are set as 50% and 25%. Fig. 2 and 3 compare the number of active CMTS ports changing with time for $T_{load} = 5\%$, and $T_{load} = 20\%$. The blue solid line is the number before CMTS readjustment, and the red dash line is that after CMTS readjustment. As we can see, the CMTS readjustment can further reduce the number of active CMTS ports, and when the preset load threshold for readjustment is higher, more active ports can be saved with the cost of increased number of DBC operations. Fig. 4 and 5 show the load of CMTS port in terms of CM connections changing with time, for ports 10 and 16, when the readjustment threshold is 10%. The load on ports 10 and 16 is imbalanced, and the readjustment increases the load on port 10 while decreases that on port 16. Therefore, the CM connections are groomed with minimal number ports to save energy. Fig. 6 shows the trade-off between the energy-saving and the number of CM DBC operations, and over 31.5% saving on the ON-time of CMTS ports can be achieved with around 500 DBC operations. The comparisons of ON-time for CMTS ports are plotted in Fig. 7 for three scenarios, and the energy saving operation with readjustment achieves the best performance.

4. SUMMARY

We proposed an advanced algorithm to achieve coordinated CMTS-side energy-saving in a HFC network supporting DOCSIS 3.0 standard. A case study on the effectiveness of the algorithm has been performed with simulations of 1000 CMs on a 16-port CMTS linecard over a 24-hour period. With a realistic CM traffic model, we demonstrated over 31.5% saving on the ON-time for CMTS ports. The tradeoff between the energy-saving and the number of CM DBC operations has also been studied, and the results showed that with our algorithm and a preset readjustment threshold, the number of DBC can be well controlled.

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