

# Architecting Green Broadband Cable Access Network: Energy-Delay Trade-off

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**Abstract:** We propose and investigate an energy-saving algorithm for DOCSIS-3.0 cable access networks. Numerical simulations indicate a possible 17.4% energy-saving for 8000 cable modems, but also reveal a fundamental trade-off between energy and delay.

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## 1. Introduction

Lately, reducing the energy cost has become one of the daunting challenges in Information and Communication Technology (ICT). It is estimated that 37% of the ICT carbon emission is due to operating the Telecom infrastructure and equipments, especially in the access networks [1]. Driven by this trend, effective energy-saving strategies are being sought to architect “Green” broadband cable access networks.

While new technologies in cable access network boost their performance, it could also result in higher energy consumption. One example is the channel bonding technology, which was released in Data over Cable Service Interface Specification (DOCSIS) 3.0 [2]. It achieves over 100 Mbps speed for both downstream and upstream data transmissions. Specifically, multiple 6 or 8 MHz channels are combined into a “bonding group”, which works as one virtual channel for high-speed data transmission. However, channel bonding could increase the power consumption on both the Cable Modem Termination Systems (CMTS) and Cable Modems (CM). On the CM side, multiple (usually 4) transceivers are normally turned on to accommodate  $4 \times 4$  (“# of upstreams”  $\times$  “# of downstreams”) upstream and downstream bonding. On the CMTS side, equipment vendors have to develop CMTS linecards with increased number of upstream/downstream ports, which results in additional power consumption.

In this work, we develop an adaptive, traffic-aware, coordinated energy-saving technology to reduce the power consumption in cable networks. By proactively monitoring traffic load, the proposed technology achieves network-wide energy saving by re-adjusting CM’s bonding groups and shutting down under-utilized upstream/downstream ports on the CMTS side. In parallel of this energy-saving configuration, we will also investigate its performance impact, specially the packet queuing delay. Our analytical and numerical results indicate a fundamental trade-off between the energy saving and the queuing delay.

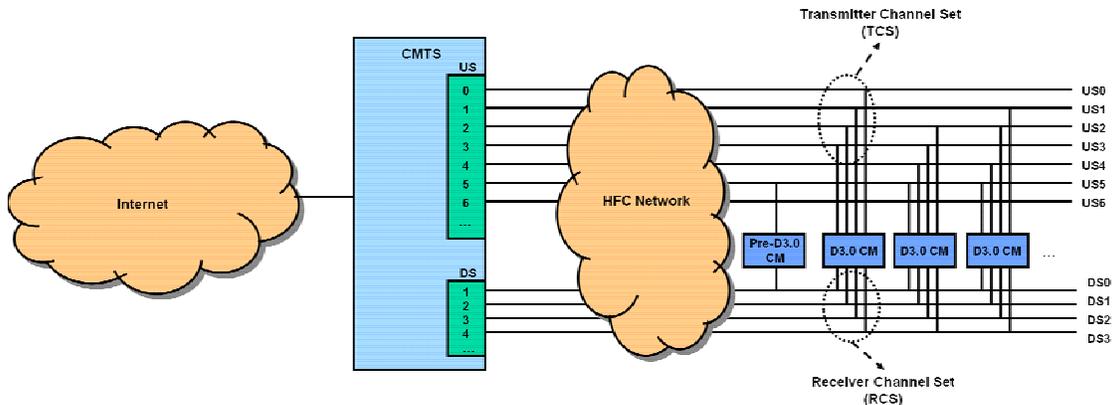


Fig. 1 Infrastructure of DOCSIS 3.0 Network, CMTS: Cable Modem Termination System, HFC Network: Hybrid Fiber Coaxial Network, D3.0: DOCSIS 3.0, CM: Cable Modem, US: upstream, DS: Downstream

## 2. Green DOCSIS 3.0 Network

Fig. 1 illustrates a typical DOCSIS 3.0 network. The DOCSIS 3.0 wideband CM has multiple transceivers, and can connect to multiple upstream/downstream channels from the CMTS for high-speed data transmission. In DOCSIS 3.0 standard, there is a MAC-layer operation called dynamic bonding change (DBC). With DBC, the CMTS can add, delete and replace one or more upstream/downstream channels in a CM’s transmitter channel set (TCS) and/or

receiver channel set (RCS). During DBC transaction, the CM will not go offline or experience significant traffic interruption [2]. The traffic on a DOCSIS network comes directly from the customers, and it is well known that the traffic load has daily fluctuations due to the life styles of human beings [3]. This fact suggests that certain network elements in a DOCSIS 3.0 network may be underutilized during the low-traffic hours, such as from 4:00 to 7:00 am. Thus, if we selectively shut down those elements when the traffic flowing through them is lower than a predefined threshold, the network-wide energy consumption can be reduced. The power-saving algorithm we propose in this work has a two-step operation. The first step is for the CM side, and the second is for the CMTS side.

In a DOCSIS 3.0 network, shrinking a CM's TCS and/or RCS with DBC can reduce its power consumption. For example, changing a CM from  $4 \times 4$  to  $1 \times 1$  can turn off three RF transceivers to save power. In the power-saving algorithm, we define three CM operation modes based on the numbers of upstream and downstream channels it connected to: 1) high-power mode with a  $4 \times 4$  configuration, 2) moderate-power mode with a  $2 \times 2$  configuration; and 3) low-power mode with a  $1 \times 1$  configuration. Note that the  $n \times n$  configuration here means the CM connecting to  $n$  downstream and  $n$  upstream channels. For simplicity, we assume the upstream traffic load fluctuation mimics that of the downstream, which is usually the case in a real cable network [3]. Then, the CMTS maintains two downstream traffic-load thresholds: high-working (HW) and low-working (LW). Fig. 2 shows the state-machine of the CM side power-saving algorithm. For each CM, the CMTS keeps two variables, the current traffic load  $L_{current}(t, m)$  and the average traffic load  $L_{average}(m)$ , where  $t$  is the sampling time and  $m$  is the ID of the CM. Every a few minutes, the CMTS determines the downstream traffic load  $L_{current}(t, m)$  of CMs by measuring the length of corresponding input queues. The CMTS then averages the traffic load with  $N-1$  last data samples to get the average traffic load  $L_{average}(m)$ . The CMTS only shrinks CM's TCS&RCS when the average load is below the thresholds, while the CM's TCS&RCS get restored immediately when the current traffic load is above the thresholds. Thus, there will be minimal impact to the CM's legacy traffic.

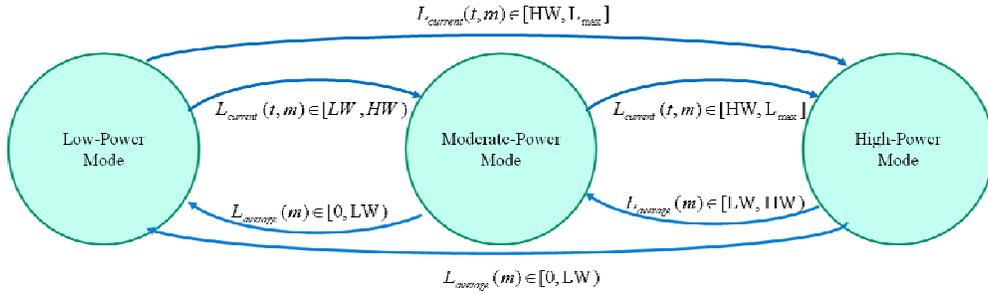


Fig. 2 State-machine of CM side power saving algorithm

The power-saving algorithm in the CMTS side can be considered as a traffic grooming operation based on the traffic load or the CM count on each upstream/downstream port. The CMTS grooms as many as CMs on minimal number of ports as possible, and shut down the rest of the ports to save power. To enable operation efficiency and avoid intensive CM moving-around on a CMTS linecard, the CMTS will not reshuffle all the CMs' connection states in each grooming operation. Instead, the operation will base on the current connection states and only make minimal changes. The detail of the energy-saving algorithm for the CMTS side is omitted due to space limit.

### 3. Theoretical Analysis

We assume the power consumption of a CM follows the expression of:

$$P_m(t) = P_{0,m} + N_m(t)P_{c,m} \quad (1)$$

where  $P_{0,m}$  is the static power consumption of the CM,  $N_m(t)$  is the number of the transceivers the CM is on at moment  $t$ , and  $P_{c,m}$  is the dynamic power consumption for one transceiver. In the normal operation,  $N_m(t)$  is a constant and its value is usually 4; while in our power-saving operation,  $N_m(t)$  follows the state diagrams in Fig. 2 and is a function of  $L_{current}(t, m)$  and  $L_{average}(m)$ . The energy saved on the CM side can be written as:

$$\Delta E = \int_0^T \Delta P(t) dt = \int_0^T \left[ \sum_{m=1}^M (P_{c,m} (4 - N_m(L_{current}(t, m), L_{average}(m)))) \right] dt \quad (2)$$

where  $M$  is the total number of DOCSIS 3.0 CMs, and  $T$  is the total time period of the operation. Our proposed algorithm is verified via numerical simulations based on a realistic CM traffic model [3]. We assume that  $P_{0,m} = 5W$ ,  $P_{c,m} = 1W$ ,  $HW = 50\%$ ,  $LW = 25\%$ , and traffic is sampled every 5 minutes and the average load is taken over a duration of 10 minutes. Fig. 3(a) shows the traffic load fluctuations of a CM in the simulation. 8000 CMs are simulated. Note that each CM has independent traffic inputs in the simulation, but follows a similar trend between each other. Fig. 3(b) shows the power saved in a CM over the day, and Fig. 3(c) shows the total energy consumed by all the CMs for two configurations (one with normal operation, and the other with our proposed algorithm). Within a day, the total energy consumption with the normal operation mode is 1728 kW-h, while the energy-saving mode consumes only 1426.6 kW-h, which translates into a 17.4% energy saving.

Since the power-saving mode can shrink the channel capacity of a CM, we expect that it will increase the upstream queuing delay on the CM. Adopting an M/M/1 queuing model, we can approximate the queuing delay as:

$$T_m(t) = \frac{S_{avg}}{C_{max}} \frac{1}{(N_m(t)/4 - L_{current}(t,m))} \quad (3)$$

where  $S_{avg}$  is the average packet size in bits, and  $C_{max}$  is the channel capacity in bits/sec. We adopt  $S_{avg}$  as 273 bytes, and assume  $C_{max}$  as 30 Mb/s for a 4-channel bonding. In our simulation, we vary the traffic thresholds (i.e., HW and LW) to investigate the relationship between energy-saving and queuing delay, illustrated in Fig. 4 for 8000 CMs. In Fig. 4(a) we can see the maximum average queuing delay is around 1 msec when the HW and LW is 50% and 25%, respectively. Fig. 4(b) shows the tradeoff between the energy saving and the queuing delay. In particular, as the amount of the energy saving increases, the queuing delay the packets experience increases as well.

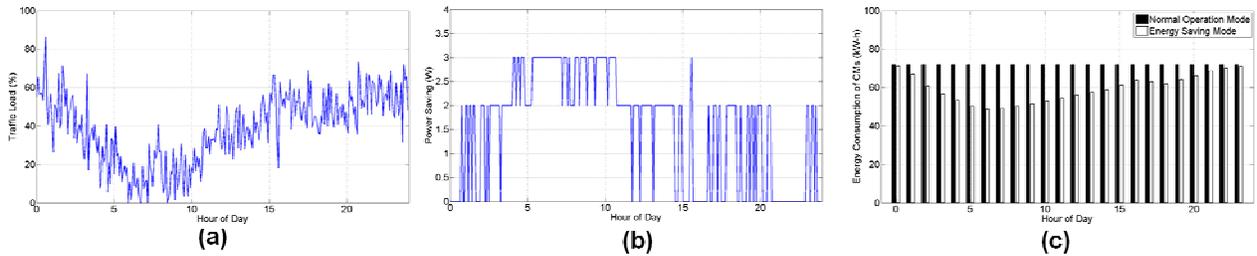


Fig. 3 Simulation results for, (a) A CM's traffic load variation, (b) Power saving achieved on a CM, and (c) Total energy consumption comparison

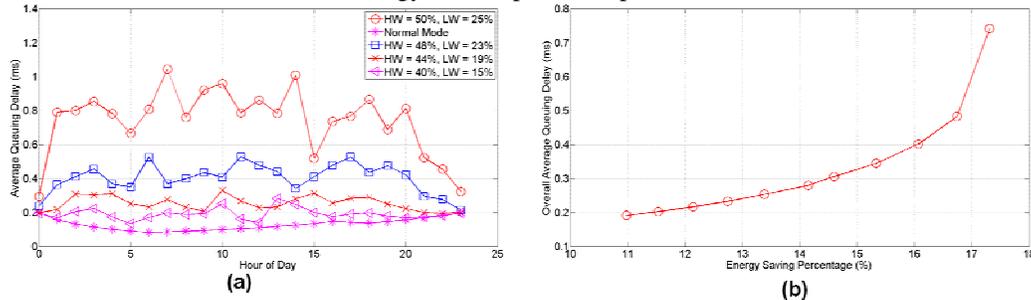


Fig. 4 Simulation results for, (a) Average queuing delay on CMs (hourly), (b) Overall average queuing delay (daily) versus Energy saving

#### 4. Summary

We proposed an advanced algorithm to achieve coordinated energy saving in a DOCSIS 3.0 cable access network. A case study on the effectiveness of CM-side algorithm has been performed with simulation of 8000 CMs over a 24-hour period. With a realistic CM traffic model is, we demonstrate a possible 17.4% energy saving. We then analyze the tradeoff between the energy saving and the queuing delay on the CM by varying the traffic load thresholds. A maximum queuing delay of 1 msec has been obtained at the highest energy saving. As a next step, we will investigate that the energy-saving algorithm on the CMTS side, with an objective to identify the optimal numbers of upstream/downstream ports on the CMTS to support a given amount of CM load.

#### 5. References

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