

Improving the Efficiency of Cooling in the Headend

A Technical Paper prepared for SCTE/ISBE by

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1. Introduction

Headends and hubs are getting more sophisticated, with more video options, much more data handling, and telephone soft switches. With this increased sophistication comes more power consumption, which can cause problems to arise. Some electronic equipment is rated for long-term operation at a maximum temperature as low as about 100 degrees Fahrenheit. As switches, servers, and other equipment have evolved, the pressures on cooling have gotten much more severe. A one-rack-unit (1RU) edge QAM chassis, for example, may be rated to consume about 200 watts. Imagine two 100 watt incandescent light bulbs in this 1RU (1.75 inch) rack – that’s a lot of heat! Stand behind a “big iron” (high port count) cable modem termination system (CMTS) loaded to maximum capacity and feel the air exhaust temperature.

Cooling of a headend is not unlike cooling of a data center except there is a plethora of different types of equipment with different cooling strategies. Also, while many data centers have raised floors through which they can channel cooled air to each rack, most headends tend to use overhead cabling (a trend in data centers, too), with less capability for handling airflow. While data centers also experience expansion with time, many headends and hubs were built in a different era when power density was not nearly so high, and cooling was easier. Air conditioning was deployed that matched the amount of power being consumed and the cooling problem was averted. Today every cooling dollar needs to work as hard as every other dollar spent on infrastructure.

Let’s see if lessons can be learned from data centers, and see how we might apply them to headends and hubs (we’ll just say headend, but obviously we are including hubs that have similar cooling requirements). According to IDC, up to 60 percent of downtime can be directly attributed to electronic failures due to excessive heat, so addressing heat loads has very beneficial effects. In this paper, we will zero in on a few key issues.

2. Organizing to Save Energy

Energy savings opportunities are in a number of places; however the greatest energy savings happens with the involvement and support of top management. Many successful programs (SCTE 234 or ISO 50001 for example) have been implemented by energy teams who report directly to the board of directors or a high-ranking officer of the company. Management needs to put a priority on efficient cooling, including guidance to the energy team as to what type of payback period is expected. A reasonable criterion might be a 3-year payback for an investment in energy savings. When considering the payback period, don’t forget the cost of heat removal (air conditioning) as well as heat generation. Depending on local power costs and the air conditioning efficiency, removing the heat may cost more than generating it in the first place. As a general rule, the EPA says that for every unit of electronics power, an equal unit is required for cooling. Some references state even more power is required for cooling.

3. The Top 12

According to the EPA Energy Star Program, the top 12 opportunities to save energy and hence money in a data center are¹:

1. Server virtualization (*This is big: virtualization results in higher server utilization, more process power, and fewer servers.*)
2. Decommissioning of unused servers
3. Consolidation of lightly utilized servers
4. Better management of data storage
5. Purchasing more energy-efficient servers, UPSs, and PDUs
6. Hot aisle/cold aisle layout
7. Containment/enclosures
8. Variable-speed fan drives (*general airflow issues*)
9. Properly deployed airflow management devices
10. Server inlet temperature and humidity adjustments
11. Air-side economizer
12. Water-side economizer

In this paper, we will concentrate on opportunities 5-8. The website referenced (end note 1) has many resources to get you thinking about how to save energy and hence money. Some of these opportunities will possibly not apply to your headend, but others will. A lot can be learned from studying the experiences in data centers. The applicability of certain measures may also depend on location: the issues are different in a dry desert climate than in a humid seaside resort, but saving energy/money is a universal goal.

4. Technologies that Save You Energy (Opportunity 5)

Example: You have a few servers and switches in your headend, maybe not as many as in a large data center, but some. Ask, how old they are, and how do they stack up in terms of energy efficiency with newer products? Is there a way you can let some go to sleep during off hours, when your subscribers are demanding fewer server-based services? Some operating systems allow for running the processors at a slower speed when the demand on them is not great, resulting in lower power dissipation. Some can consolidate functions on a fraction of the processor cores available, putting the unused cores to sleep when they are not needed.

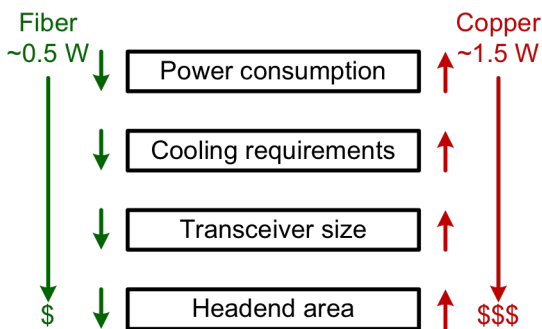


Figure 1. 10 Gb/s Operating Cost, Fiber vs Copper

consumption, which not only saves money in operating the equipment, but saves a similar amount in cooling costs.

There are choices, in many cases, of interconnecting equipment with either fiber or copper cabling. We'll have more to say later about the merits of each, but right now let's talk about the relative merits of the transmitters and receivers in the routers, servers, and CMTSs. Figure 1 indicates an estimate of the power draw of each technology based on a single 10 Gb/s link. Fiber transceivers are lower in power

Opportunity: There are certainly potential savings in UPSs and power distribution units (PDUs). It is common to use battery-based uninterruptible power supplies to bridge the time between a power failure and when the generator can start then carry the load. Have you looked recently to see if there are more efficient units on the market? If you are in the market for UPSs, are you comparing the total operating cost (which includes efficiency) of the candidate UPSs? You have probably added a lot more equipment to your headend in the years since you purchased your last UPS. Is it capable of handling the load you would present to it today? Same for your generator: if you need it, will it be capable of handling today's load?

Opportunity: Some PDUs step down voltage for distribution to rack-based power distribution units. How efficient are the transformers? How efficient are the rectifiers where AC is converted to DC? How efficient are the voltage regulators? When you get to 48 vdc distribution, you are dealing with a LOT of current. Is your wiring sufficiently sized to handle the current without creating power-robbing voltage drop? These issues can develop over years, as more equipment is added. You have probably experienced the same thing at home: you are using more power than you did maybe 20 years ago, even though equipment has gotten more efficient. This is simply because you have more equipment. And much of that equipment consumes so-called "phantom power," using power even when turned off. To an extent, the same goes for your headend. In particular, UPSs use some power when not in use, to keep the battery float charged and to monitor power, to be ready to start when needed.

5. The Cost of Removing Heat

Several anecdotal reports place the cost of removing heat from a data center or headend, at nearly the same as the cost of operating the equipment. This is a sufficient cost to persuade companies to explore unconventional heat removal techniques. For example, IEEE recently reported that Microsoft has built an experimental underwater data center, which drives the heat removal cost down from maybe 90 percent of the server powering cost to about 3 percent.ⁱⁱ

6. Some Numerical Examples

Table 1. Example Annual Costs of Power, Not Including Heat Removal

# connections:	100		200		300	
	10 Gb/s links		10 Gb/s links		10 Gb/s links	
	Copper	Fiber	Copper	Fiber	Copper	Fiber
\$0.070	\$184	\$61	\$368	\$123	\$552	\$184
\$0.075	\$197	\$66	\$394	\$131	\$592	\$197
\$0.080	\$210	\$70	\$421	\$140	\$631	\$210
\$0.085	\$224	\$75	\$447	\$149	\$671	\$224
\$0.090	\$237	\$79	\$473	\$158	\$710	\$237
\$0.095	\$250	\$83	\$500	\$167	\$749	\$250
\$0.100	\$263	\$88	\$526	\$175	\$789	\$263
\$0.105	\$276	\$92	\$552	\$184	\$828	\$276
\$0.110	\$289	\$96	\$579	\$193	\$868	\$289
\$0.115	\$302	\$101	\$605	\$202	\$907	\$302
\$0.120	\$316	\$105	\$631	\$210	\$947	\$316
\$0.125	\$329	\$110	\$657	\$219	\$986	\$329
\$0.130	\$342	\$114	\$684	\$228	\$1,026	\$342

We can estimate the cost of transferring data on copper or fiber cables by looking at some scenarios involving the number of links you have and the cost of power in your area. Table 1 illustrates the cost of simply operating either *fiber* (utilizing lightwaves) or *copper* (utilizing electron flow) interfaces, without regard for the cost of power supply inefficiency, the cost of heat removal, or the cost of additional

blockage of moving air due to cable blockage. Table 2 assumes a rule-of-thumb air conditioning cost of 100 percent of the power consumed by the equipment. Heat generated by fiber interfaces are lower than the heat generated by copper interfaces. As of December 2016 the average commercial power cost in the US was about 10.5 cents per kWh.ⁱⁱⁱ The cost ranged from about 0.5 to 12 cents per kWh, depending on location.^{iv}

Table 2. Example Annual Costs of Power, Including Heat Removal

# connections:	100		200		300	
	10 Gb/s links		10 Gb/s links		10 Gb/s links	
	Copper	Fiber	Copper	Fiber	Copper	Fiber
\$0.070	\$368	\$123	\$736	\$245	\$1,105	\$368
\$0.075	\$394	\$131	\$789	\$263	\$1,183	\$394
\$0.080	\$421	\$140	\$842	\$281	\$1,262	\$421
\$0.085	\$447	\$149	\$894	\$298	\$1,341	\$447
\$0.090	\$473	\$158	\$947	\$316	\$1,420	\$473
\$0.095	\$500	\$167	\$999	\$333	\$1,499	\$500
\$0.100	\$526	\$175	\$1,052	\$351	\$1,578	\$526
\$0.105	\$552	\$184	\$1,105	\$368	\$1,657	\$552
\$0.110	\$579	\$193	\$1,157	\$386	\$1,736	\$579
\$0.115	\$605	\$202	\$1,210	\$403	\$1,815	\$605
\$0.120	\$631	\$210	\$1,262	\$421	\$1,893	\$631
\$0.125	\$657	\$219	\$1,315	\$438	\$1,972	\$657
\$0.130	\$684	\$228	\$1,367	\$456	\$2,051	\$684

7. Moving Heat to the Node

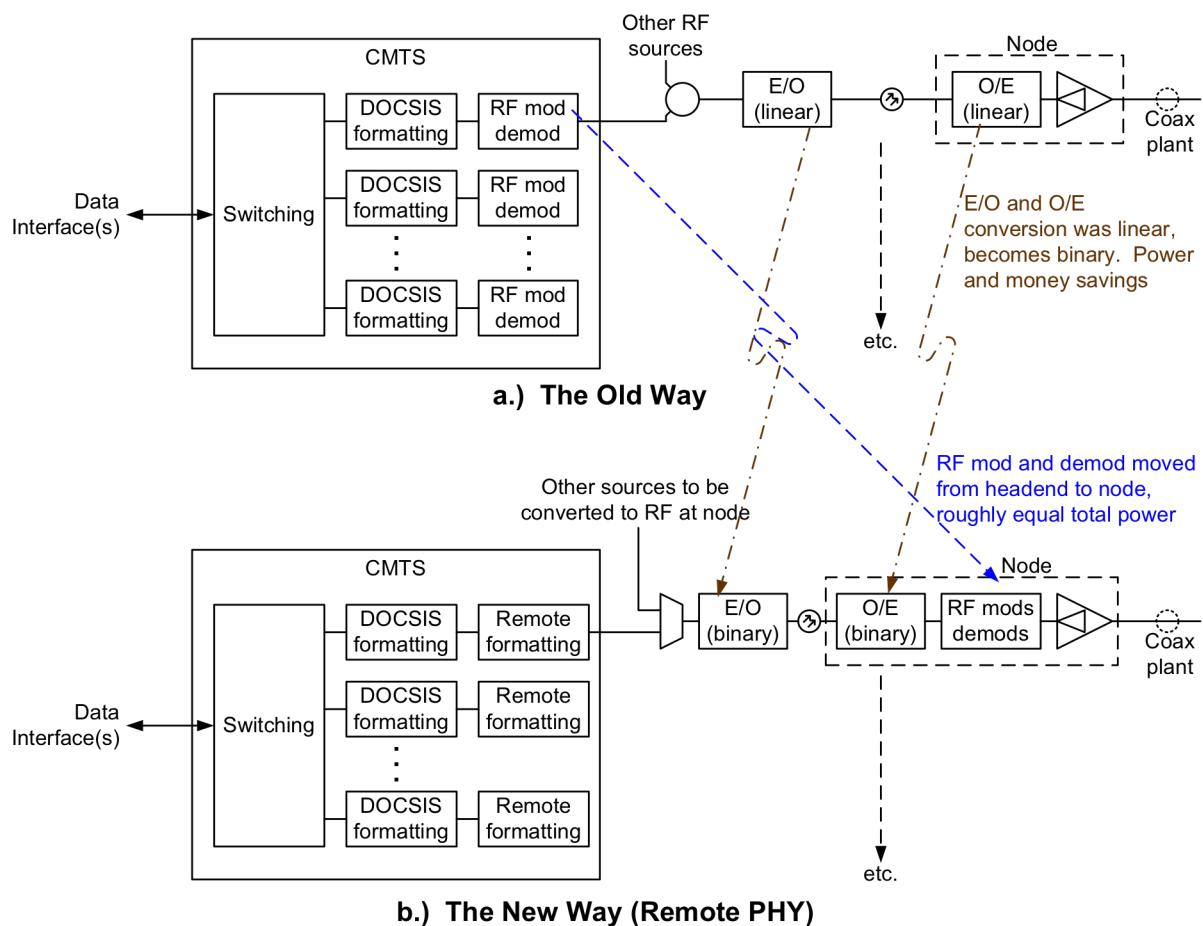


Figure 2. Moving RF Modulators and Demodulators to the Node (only modulation shown for simplicity)

There has been a lot of interest in moving the QAM modulators to the node, particularly but not totally applied to modem systems. This *Remote PHY* (for *remote physical layer*) has advantages in terms of cost and some overall power savings, as well as removing some power-hungry equipment from the headend and making some incremental improvement in the quality of signals delivered to the coax plant. However, to an extent you are moving heat from a headend, where you have active heat removal equipment, to a node, where you have only passive heat removal and a more hostile temperature environment.

Figure 2a illustrates the old way, with RF modulation and demodulation in the CMTS (and in other equipment). What is desired is to move the modulators to the node. While not primarily seen as a power saving feature (the overall savings are minimal), it does reduce power demand somewhat in the headend by moving out the relatively power-hungry modulation and demodulation processes, and exchanging the linear electrical-to-optical and optical-to-electrical conversion processes to lower power and cheaper binary processes. The downside is more heat moves to the node, which has traditionally been a problem

to keep cool, and the timing issues involved in separating the RF from other CMTS functions has created a number of headaches for equipment designers.

Proposals are available that move even more heat-producing circuitry out of the headend, but so far as we know, they are not under active development at time of publication.

8. Hot Aisle/Cold Aisle Layout (Opportunity 6)

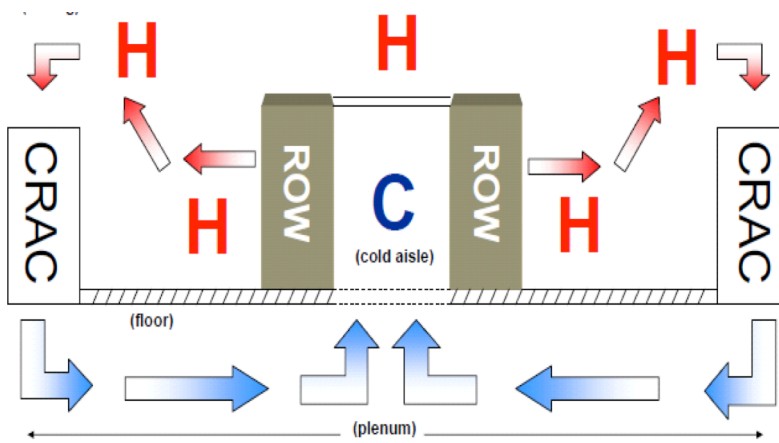


Figure 3. Hot Aisle/Cold Aisle Concept

Most equipment needing active cooling takes air in from one side and expels it to the other side of the equipment. It is common for equipment to take in air from the front side and expel it to the rear. This leads to the concept of hot aisle/cold aisle, as illustrated in Figure 3. A cold aisle is formed between rows of equipment racks by forcing cold air from the air conditioning system (computer room air conditioning or CRAC)

between the rows. Equipment is installed such that it always draws air in from the cold aisle(s) and expels it to the hot aisle(s) on the other side, where it is returned to the CRAC. This improves the efficiency of the air conditioning by making sure that the cold air goes where it does the most good. In some cases containment (of either hot or cold air) is employed to prevent the cold and hot air from mixing, reducing the efficiency of the process.

The figure assumes a raised floor, which can act as a duct for the cold air. We call such an arrangement a *plenum*. If you don't have a raised floor, there are other ways to get cold air to the cold aisle. You can use conventional overhead ducting to get the cold air to the cold aisle. There are also CRAC units that fit in a row of racks as just another rack, taking air in from the hot side and expelling the cooled air to the cold aisle.

If equipment, such as many "big iron" CMTSs, takes in air in front and expels it to the rear, then the front side will face the cold aisle. If you have a piece of gear that pulls in air from the rear and expels it to the front, then of course the opposite mounting is employed. We have seen equipment that takes air in on one side and expels it on the other. In this case, baffles will need to be used to direct the air properly.

Some older and less power-dense equipment may use passive cooling rather than active (fan) cooling. Such equipment may locate most heat-producing components near the rear, but it may not. Since such equipment does not produce as much heat for its size, it is probably less important to orient it correctly for cooling purposes.

9. Containment/Enclosures (Opportunity 7)

In order to prevent the cold and hot air from mixing, it is obviously important to enclose the racks so that air cannot get around the equipment in the rack. This runs counter to an old philosophy that says remove back and side panels from a rack to let air circulate more freely. This might have been a good philosophy when equipment was passively cooled, but with the density of modern gear, and the use of fans to move air, putting side panels on racks is a good approach. You may want to go even further to prevent cold and hot air from mixing, sealing leaks in the racks.

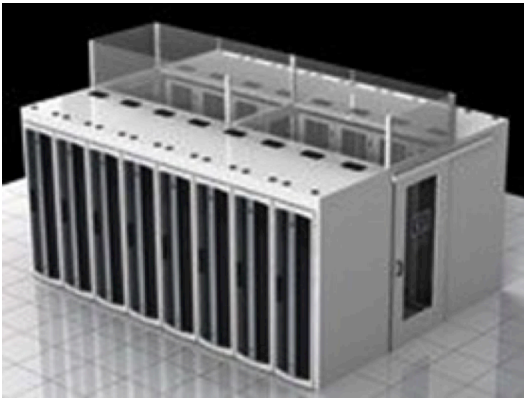


Figure 4. Hot Air Containment System (Chatsworth)

In some cases it will be beneficial to add walls or baffles to keep the hot and cold air apart. Figure 4 illustrates a hot air containment system, which can return the hot air to the intake of the CRAC. We want the cold air to do as much work for us as possible, and it will not do that if it is warmed by the hot air – it should be warmed by passing through the equipment needing to be cooled.

Sometimes the ends of the aisle will be closed off by doors in order to prevent cold and hot air from mixing. Doing so can increase your power density (watts dissipated per cubic foot of space) by up to four times, and can increase your cooling efficiency up to three times.^v This increase in power density is due to more

efficient direction of the cold air. The increase in cooling efficiency is due to the greater temperature

difference between the hot and cold air.

(Note that the efficiency of cooling the *air* increases with a greater difference in hot and cold temperatures, but air that is too hot will not cool *equipment* efficiently.)

Depending on power densities, enclosing either hot or cold air aisles may or may not be deemed necessary. Your CRAC vendor will be able to advise you on the best approach in your situation.



Figure 5. Enclosed non-heat-producing equipment helps prevent air leakage

There will be some non-heat-producing equipment, such as fiber management, in your headend, as in Figure 5. It should be covered such that it does not let cold air

leak into the hot aisle. Some operators go as far as sealing small leaks between the hot and cold aisles in order to prevent air mixing.

10. Variable Speed Fan Drives (general airflow issues) (Opportunity 8)

In this section general airflow issues are reviewed, though the referenced listing (endnote 1) refers to variable speed fan drives. Even many home heating and air conditioning units use variable speed air handling, because it does improve the efficiency of heating and cooling. When less cooling is needed, fan speeds are reduced. This improves the efficacy and efficiency of cooling because it keeps the air moving at all times, improving the consistency of air temperature and reducing the losses associated with air blockages (more on this later).

11. Effect of Reducing Cooling Air Speed

We can illustrate the effect of reducing cooling air speed by referring to an analogy with electrical systems. The volume of air passing a certain point is analogous to current in an electrical circuit. The moving air encounters resistance from turns it must make and from obstructions it encounters, such as grating and cables it must flow around. Finally, the pressure differential between air at the output of a blower and at the input is analogous to voltage. Thus, we have an equivalent of Ohm's law that says $\text{pressure} = (\text{air flow}) * (\text{resistance})$. The power required to move the air is $(\text{power}) = (\text{air flow})^2 * (\text{resistance})$. This is the power required to move the air in a circuit consisting of the blower, the cooling apparatus, and the air path in the headend. You can see that the power required moving the air is proportional to the square of the air speed. (There are some non-linear effects in air flow that can cause the resistance to be a function of air speed, thereby exacerbating the effect described here.) Thus, the slower the airflow, the less it costs to pump it through the headend. On the other hand, the slower the air is moved, the less effective it is at removing heat. Hence the advantage of variable speed fan drives, which can slow down airflow when heat removal needs are lower and speed it up when required.

12. Reducing the Resistance to Airflow

Besides slowing the airflow when it is not required to be faster, we can reduce the resistance to airflow by eliminating or reducing as many impediments to airflow as possible. The fewer times the air must change directions as it goes through your headend, the better. Where it enters or exits from grates, the more open the grate the less resistance the air will encounter. Often the air handling is combined with cable raceways, as in the air plenum of Figure 3 above, where it is common to put the cable raceways in the plenum. This may happen in overhead environments too.

Let's consider options in certain wiring, to use fiber or copper cabling. If the air handling is shared with cabling, it will be more efficient to use fiber, as illustrated in Figure 6, where 48 CAT6A cables are required to serve the same number of ports as is a single 0.58-inch cable

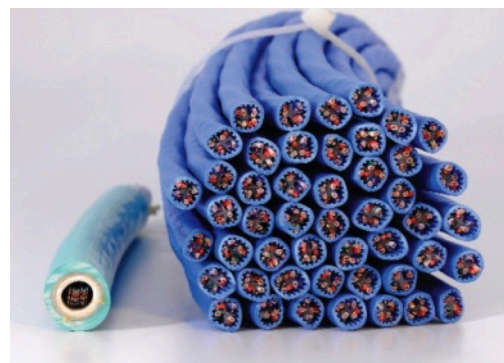


Figure 6. Size comparison of fiber and reduced-size CAT6A bundles

bundle of fibers. The benefit of the smaller size of the fiber cabling is shown in Figure 6, but the savings can also be illustrated using a simulation of airflow around the fiber and copper cabling.

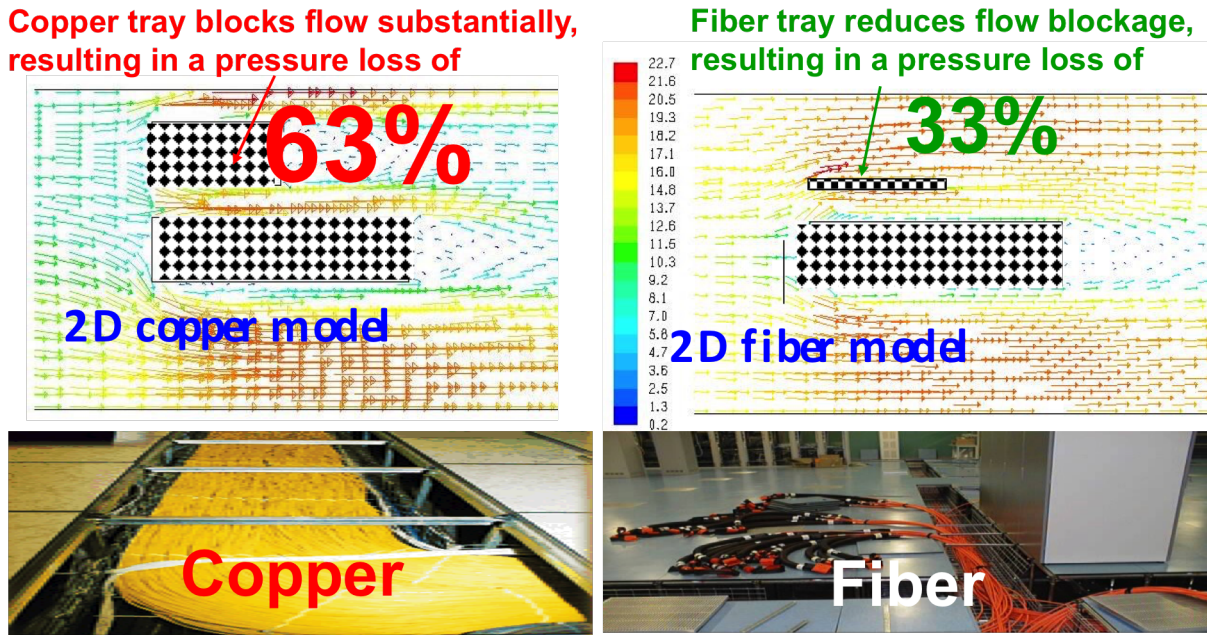


Figure 7. Simulation of airflow around copper and fiber cabling

Figure 7 illustrates two dimensional simulations of air flow around copper and fiber interconnections. The pressure loss is another way of expressing the resistance the air is encountering. The simulation shows a pressure loss of 63 percent for the copper model and only 33 percent for the fiber model, making the point that the smaller the size of the cabling the less energy it is going to take to move air passed it.

13. Advantages of Fiber in the Headend

Fiber offers a number of advantages over copper (CAT 5/6) cabling in the headend, some of which have been alluded to above. The size of the fiber bundle needed to move a given amount of data is smaller than the size of the bundle of copper wiring needed to move the same amount of data. This smaller fiber bundle obviously impedes airflow less, as illustrated above in Figure 7. It can also make cabling the headend easier, as both the size and weight of cabling is reduced.

In many cases, multimode fiber can be used in the headend. It is not intended to transport signals long distances, but it may work in the headend. Multimode fiber can be preferable over single-mode fiber for several reasons. First, connector attachment with multimode fiber is faster than connector attachment for either single-mode fiber or for CAT 5/6 cable, with less chance for error. Another reason is that the light is visible, making signal tracing easier and drastically reducing the potential of eye damage from inadvertently looking into an active fiber.

As illustrated in Figure 1, fiber transceivers dissipate about one-third the power dissipated by copper transceivers operating at the same data rate. Finally, those who have worked around CATV RF components will really appreciate this last advantage, held in common with fiber optic cable in the plant: there is no possibility of RF pick-up or radiation from fiber optic interconnects, and no possibility of it introducing ground loops.

14. Conclusions

As we strive to get more performance from inside plant, with fewer dollars allocated to get that performance, ultimately our attention falls on the efficacy and efficiency of the cooling in headends and hubs. The better job done in cooling, the better (and cheaper) our plant will perform. For a major renovation or new build, it is likely advantageous to bring in a cooling expert who can define the optimum ways to cool, given your equipment mix and climate.

15. Appendix: The Difference Between Headends and Hubs^{vi}

Those from a telephone background call the point where signals are assembled to go to subscribers, a *central office*, or *CO*. Those from a cable TV background call it a *headend*. Either way, it is the point at which communications of all types are assembled for transmission to the customer.

Telco people might call a field-mounted terminal which converts signal formats and sends them the last distance to a home a *digital subscriber line access multiplexer*, or *DSLAM*. Cable telecommunications people call it a *hub* (maybe a *node* would also fit that description, we shall define both below).

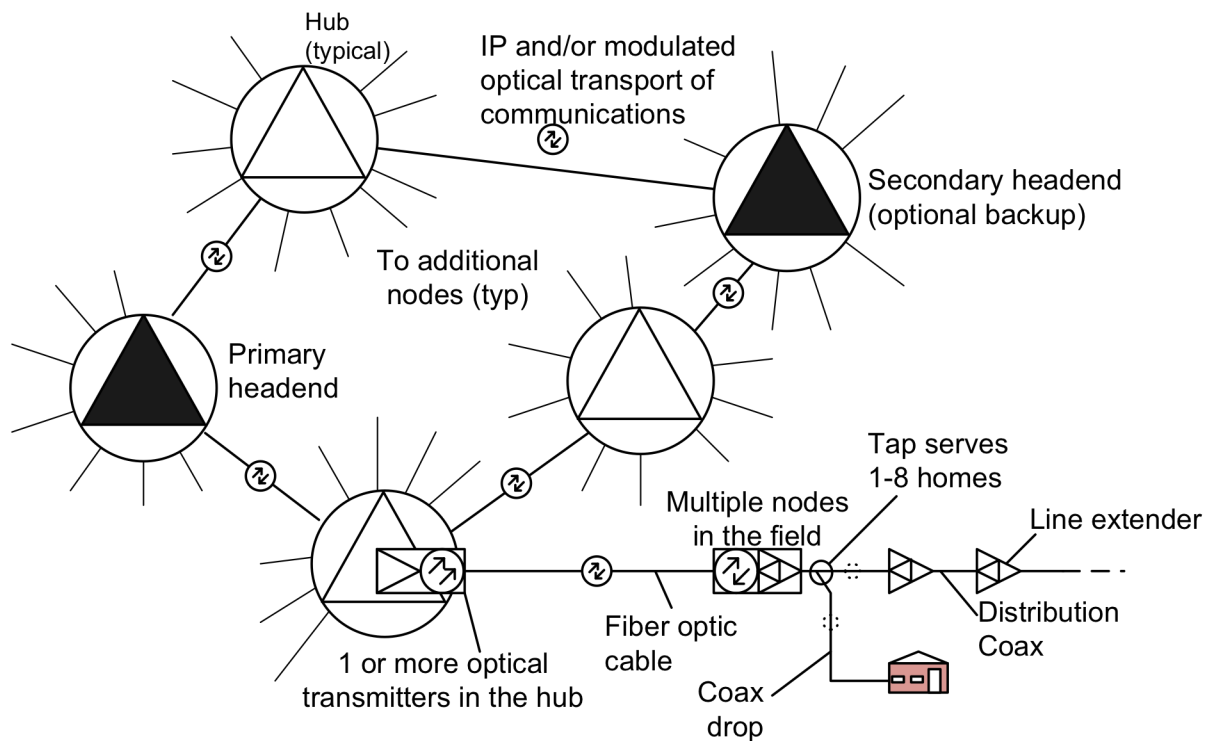


Figure 8. Headends and Hubs in Cable TV Plant

Figure 8 illustrates a high-level HFC system as it might be applied in a large metropolitan area. A primary headend gathers most or all TV content, and may be the interface point for data and voice services. An optional secondary headend, which mirrors the functions of the primary headend, may be placed in a geographically different part of the metropolitan area, so that if a disaster, such as a fire, occurs at the primary headend, the secondary headend can take over. The headend(s) are linked using fiber optic cables, to hubs, which may serve 10,000 to 20,000 customers. The hub may include certain data and maybe voice equipment and will typically convert signals to the RF modulated format needed on the coaxial cable. The RF signals are in turn modulated onto optical carriers in optical transmitters. The output of these transmitters differs from that which you may have experience with for transmitting data. Rather than transmitting a digital signal, represented by light ON for a binary 1 and OFF for a binary 0 (or vice versa), the optical transmitter of Figure 8 is a linear (analog) transmitter capable of transmitting a wide spectrum of RF signals (typically from 54 MHz to 1,002 MHz or more in North America), each RF signal carrying one of several types of content: one 6 MHz (8 MHz in many parts of the world) channel may carry one analog video signal (declining in use), or multiple digital TV signals, or time-division-multiplexed data including voice. These signals are assigned a frequency band, and many such signals can coexist at one time on one fiber optic transmitter.

The optical transmitter puts signals described above onto a fiber optic cable, which traverses most of the distance to a neighborhood to be served. At the neighborhood, a *node* demodulates the optical signal, turning it back into the RF modulated carriers which went into the optical transmitter. From here, the signals are transported to homes through coaxial cable. RF amplifiers are usually needed to overcome signal loss, which loss may be attributed to two mechanisms. Each time a tap is used remove some signal

power to serve one or more homes, conservation of energy dictates that less power is available to go further downstream to other homes. The second mechanism is loss in the coaxial cable itself, which can be significant. If the signal level gets too low, then analog channels get noisy (“snow” in the picture). If digital signals get too low in amplitude, the picture or data disappears, with just a small signal level range where the picture breaks up.

Upstream signals are all RF-modulated carriers, returned over the coax by using lower frequencies on the coax (typically 5 to 42 MHz in North America). At the node they are modulated onto an optical carrier by an upstream transmitter, and then transmitted to the hub, usually on a dedicated fiber. Sometimes the same fiber used for downstream transmission will also be used for upstream transmission, using a different wavelength.

Many areas of the world use other transmission standards. In many locations, RF channels are 8 MHz wide rather than the 6 MHz used in North America, and carry upstream signal at frequencies up to about 65 MHz, with downstream signals being carried from about 85 MHz up. For many years there has been talk in North America about changing our split between upstream and downstream frequencies, but momentum and the market are hard things to overcome.

16. References

ⁱ https://www.energystar.gov/products/low_carbon_it_campaign/12_ways_save_energy_data_center

ⁱⁱ Ben Cutler, Spencer Fowers, Jeffrey Kramer and Eric Peterson, *Want an Energy-Efficient Data Center? Build It Underwater*, IEEE Spectrum Special Report, Feb. 21, 2017, <http://spectrum.ieee.org/computing/hardware/want-an-energyefficient-data-center-build-it-underwater>

ⁱⁱⁱ <https://www.eia.gov/electricity/monthly/pdf/epm.pdf>, Table 5.3, "Average Price of Electricity to Ultimate Consumers." Use "Commercial" column.

^{iv} https://www.eia.gov/electricity/monthly/update/wholesale_markets.cfm, "Electricity Monthly Update" using data for December 2016.

^v Chris Jagers and Travis North, *Airflow Containment: The Road to Data Center Efficiency*, *BICSI News Magazine*, May/June 2010. See http://www.nxtbook.com/nxtbooks/bicsi/news_20100506/index.php

^{vi} Adapted from Farmer et. al., *FTTx Networks: Technology Implementation and Operation*, 2017, Elsevier, Inc.