The Physical Layer

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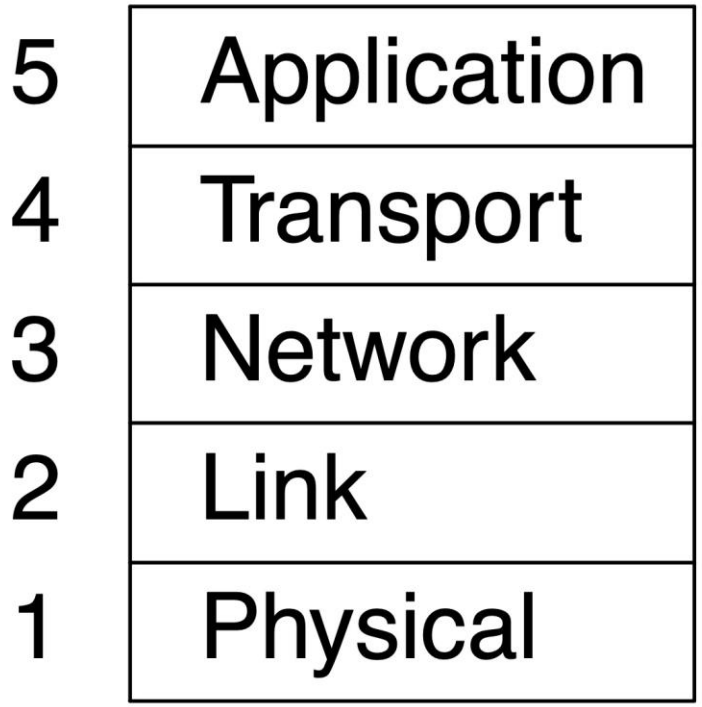
Today we start at the bottom of our reference model

- Problem: get data from one link to another
- Question: How does the data (bits) get transmitted over wire, radio, or light?
- Answer: let's find out



We'll start with guided transmission media

- It is guided because there is a physical "wire thing" that the data goes "through"

- This may be
  - Persistent storage
  - Twisted pair
  - Coaxial cable
  - Power lines
  - Fibre optics

Persistent storage is weird but still relevant

- Do you want to transmit lots of data quickly? Don't use the Internet!
- With USPS, you can ship anywhere in the US in 24 hours
  - If you ship a 30 TB drive
  - That's roughly 86,400 bits/second or over 70 Gbps (assuming 24 hours)
  - If you're only 1 hr away, that turns into 1700 Gpbs
  - In terms of cost, that is half a penny per gigabyte
- *Lesson: Never underestimate the bandwidth of a station wagon filled with tape drives hurtling down the highway*
- Real world
  - My work – we hand off back up drives off site, swapping them weekly
  - Amazon SnowMobile is…

Amazon snowmobile is an actual truck load of data

- Just incase your company needs to be an exabyte of data into the cloud
  - (for real though)

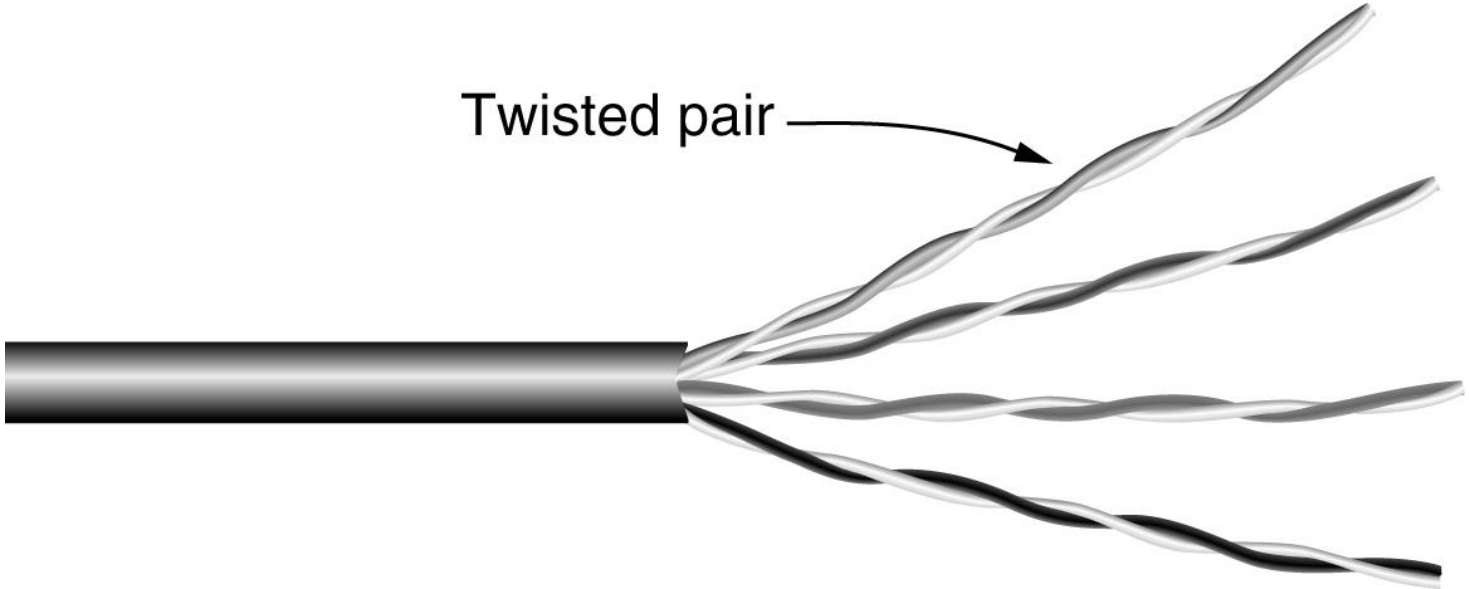
There is a Microsoft Data Box that is used for people who are not uploading a truckload of data

Twisted pairs of cables

- Persistent storage is great, but clearly we don't do that very often
  - Transfer times are measured in hours/days
  - Twisted pairs however can transmit data in milliseconds
    - Think: latency, lag, ping time, etc.
- Definition
  - Two insulated copper wires
  - About 1mm thick
  - Twisted so that the waves emitted cancel out
  - Data is transmitted via a difference in voltage (rather than absolute voltage)
- Where are twisted pairs used?
  - Telephone
  - Cat 5e

Twisted pairs will be around for a long time

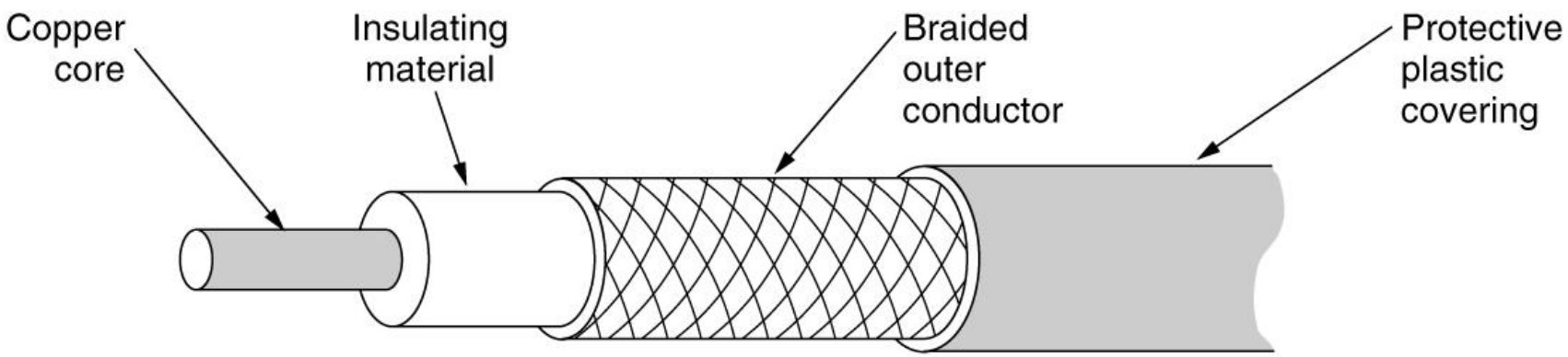
- Performance is “fine”, about 500 Mbps
- Telephone infrastructure originally used
  - It already existed (remember dial-up connections? DON’T ANSWER THE PHONE!)
  - ADSL ran over this infrastructure
- Cat 5e cables have 4 twisted pairs
  - If 100 Mbps, then only 2 of the pairs are used



Coaxial cables are everywhere thanks to television

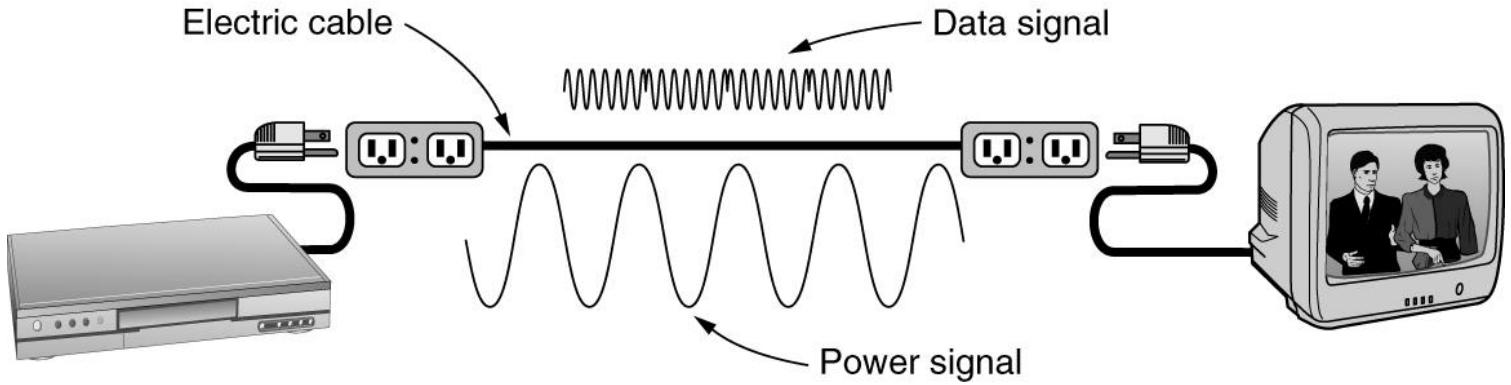
- Much of the infrastructure is already in place for TV
- Stiff copper core (does not like to be bent)
  - Very insulated, works well with long distance
  - Very high bandwidth

- (This is why your cables don't like to be bent)



It turns out, power lines can also transmit data (and power…)

- It is possible to transmit data over power lines on the same “hot” wires as the power



- Most electronics need power, so it makes sense to try and do it anyway
- Unpractical everywhere but a small home, where it could actually work well
- Originally used by power companies to send metering information

Fibre optics is the future

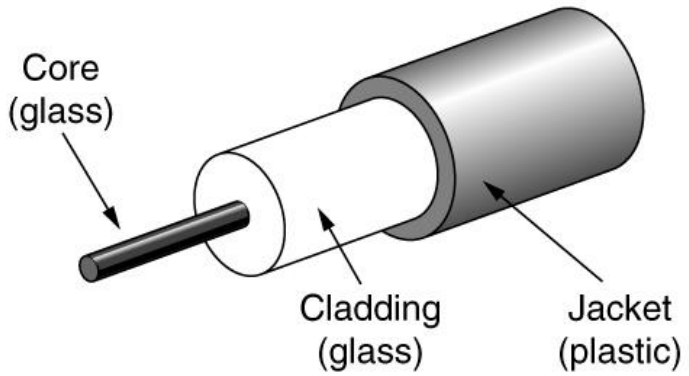
- Communication technology has increased with Moore's law in about the same way computational technology has
- In that we have seen a performance increase of a factor of 2,000
  - With error rates down to almost 0
- The issue with fibre optics is "the last mile problem"
  - It is very expensive to replace the coaxial infrastructure that exists between your house and the ISPs infrastructure
  - Networking is limited by the worst connection in the entire system
  - (draw on board)
- Who uses fibre?
  - Internet backbone
  - Data centers
  - Eventually, everybody

So what makes fibre so great?

- It’s made of glass
  - We have known how to make glass since Ancient Egyptian times
  - Glass is made of sand, which is basically free
  - Modern production can make class incredibly transparent
  - For instance, if the ocean were made of modern glass, you could see the ocean floor from an airplane
- It is lightweight
  - 1000 copper lines of 1km in length weigh 8000 kg
  - The same in fibre weighs only 100 kg
- Light does not leak from the cables
  - So you can’t wiretap them (maybe?)
- Works very well over long distances

How does the light travel through the glass?

- The glass core is about as thick as a human hair
- Light is emitted from an LED or Laser
- A photodiode reads the light at the end of the line
  - (this is what slows down the process)
  - You can transmit at the speed of light, but can you read that fast?



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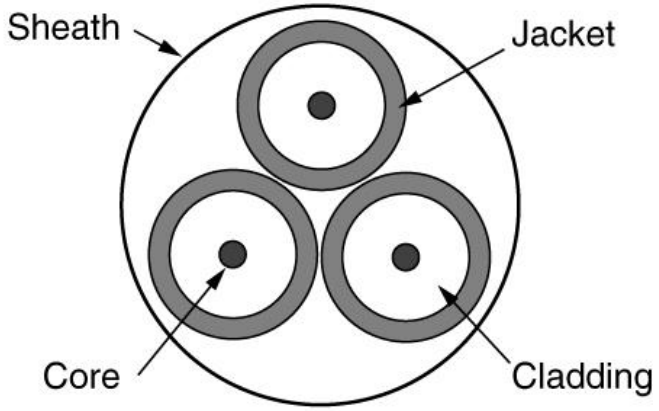

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Comparison of LED and Semiconductor Laser

Item	LED	Semiconductor laser
Data rate	Low	High
Fiber type	Multi-mode	Multi-mode or single-mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

Fibre Optics vs. Coaxial Cables

- Fibre Pros
  - High bandwidth
  - Not affected by power surges, EM interference, power failures, chemicals
  - Thin/lightweight
  - Does not leak light
  - Difficult to tap
- Problems
  - Requires specific engineering skills to manage
  - Fibres can be damaged by being bent too much

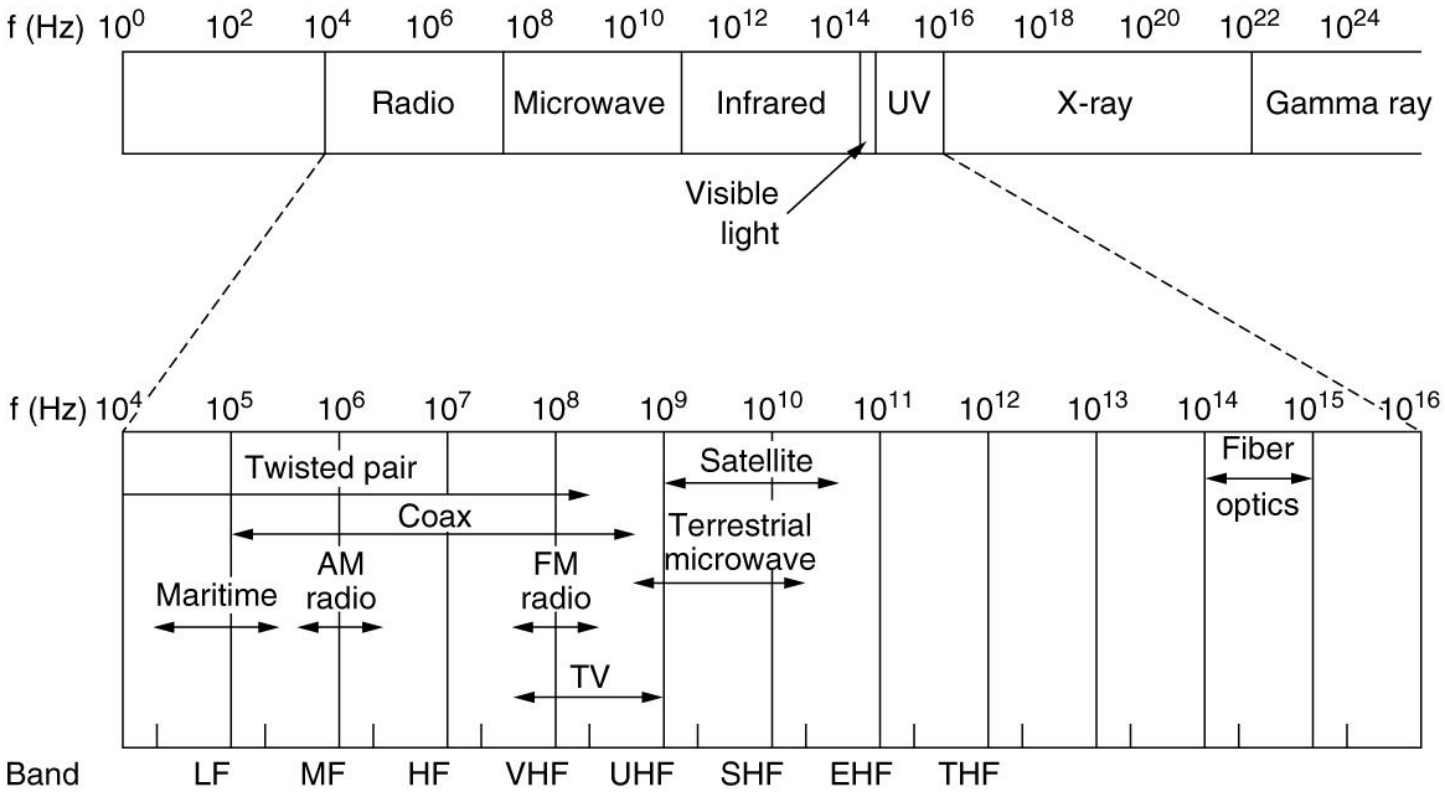
Next up is wireless transmission

- We generally think about wireless transmission as WiFi

- But there are many other uses
  - Long distance microwaves
  - Omnidirectional radio waves
  - Infrared light beams
  - Laser beams of information

Let’s take a look at where these waves/light exists on the electromagnetic spectrum

- We know that UV/X-ray/and Gamma rays are harmful
- So most things exist between Radio and Ultraviolet
- It’s a good thing we can only see that tiny spectrum of visible light



The frequency hopping spectrum has a fun history

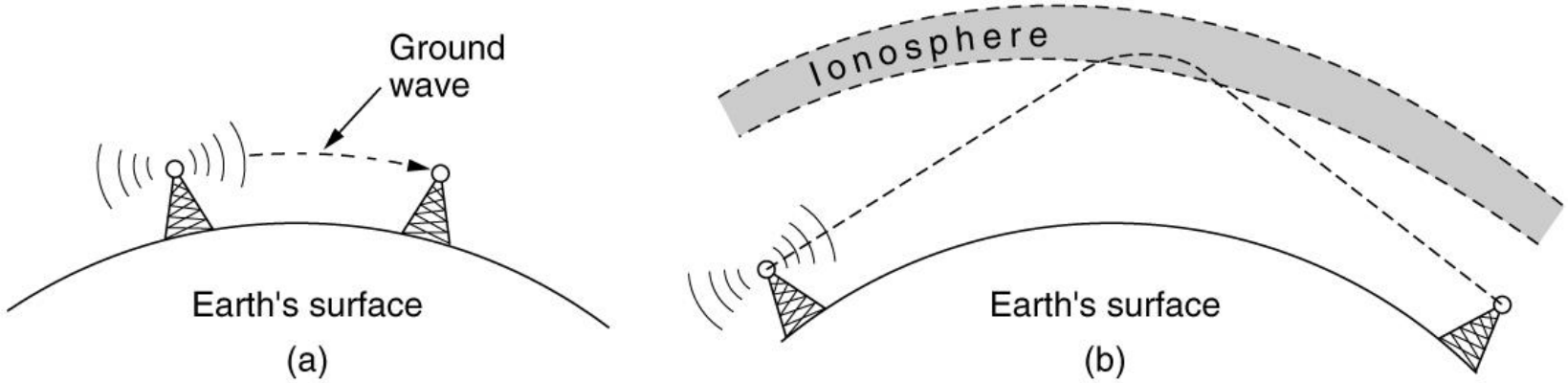
- The idea is to hop between different frequencies, say 100 times per second
  - The military likes this idea because it is difficult to track/jam
- Invented by an Australian actress/musician Hedy Kiesler
  - She was inspired by her husband's work who said it was easy to jam a torpedo's control radio because it was always on one frequency
  - She discovered he was selling weapons to Hitler so fled to America
  - In her free time, she invented frequency hopping over 88 different frequencies to help the Allied war effort
  - Received no royalties nor did the Navy care
- Until… her patent expired
  - Modern use: Bluetooth

Radio transmission is great because it goes through buildings

- Radio transmission are omnidirectional (ALL directions)
- *This is not always a good thing*
- GM made a new Cadillac with computer controlled ABS
  - The cars would go crazy in exactly one situation
  - Ohio, when highway patrol was watching
  - It turns out, the wiring created an accidental antenna that picked up the exact frequency of the Ohio High Patrol Radio
- Radio waves can interfere with each other
  - Constructive
  - Deconstructive
  - This is why your Hot Pockets have pockets of frozen meat and pockets of fire meat

Some waves follow the curvature of the earth, others can bounce off of the Ionosphere

- It is possible to communicate very long distances over radio waves
- HAM operators can talk to each other across the country (given certain conditions (like being high on a hill))
- There's also some very weird/creepy things on radio
  - https://en.wikipedia.org/wiki/Numbers_station
  - Just some person reading off seemingly random numbers on short wave radio (travels across the Earth)



Microwaves travel in a straight line

- But do not pass through walls very well
- Therefore, requires a line of sight
- However, this is a relatively inexpensive way of transmitting data long distances
  - One can buy a small patch of land every 50 km or so and build a directional tower
  - Much cheaper than laying cable through a city/streets/sewers/everything else that can get in the way
- MCI (Microwave Communications Inc.) built an entire business off this idea
  - Eventually got merged into Verizon
  - Had long distance communication before AT&T did by using microwaves

SPRINT involves the railroad for some reason

- Well a very smart reason
- The South Pacific Railroad owned thousands of miles of LAND
- *Idea: bury communication cables on the land next to the railroad that is already owned*
- And even has a track to ship stuff with already in place

- **S**outh **P**acific **R**ailroad **I**nternal **N**etworking **T**elephony
  - Now they are owned by T-mobile?

Infrared transmission is more light than radio

- Does not go through walls, therefore licensing from the government isn’t necessary

- Most remote controllers are infrared
  - Anyone ever take advantage of the bounce when the TV doesn’t receive the signal from the controller?

- Game Boy Color had infrared
  - Gotta trade those pokemon

- A network transmission we do not often think about, but probably have used recently

Transmission via light is obscure

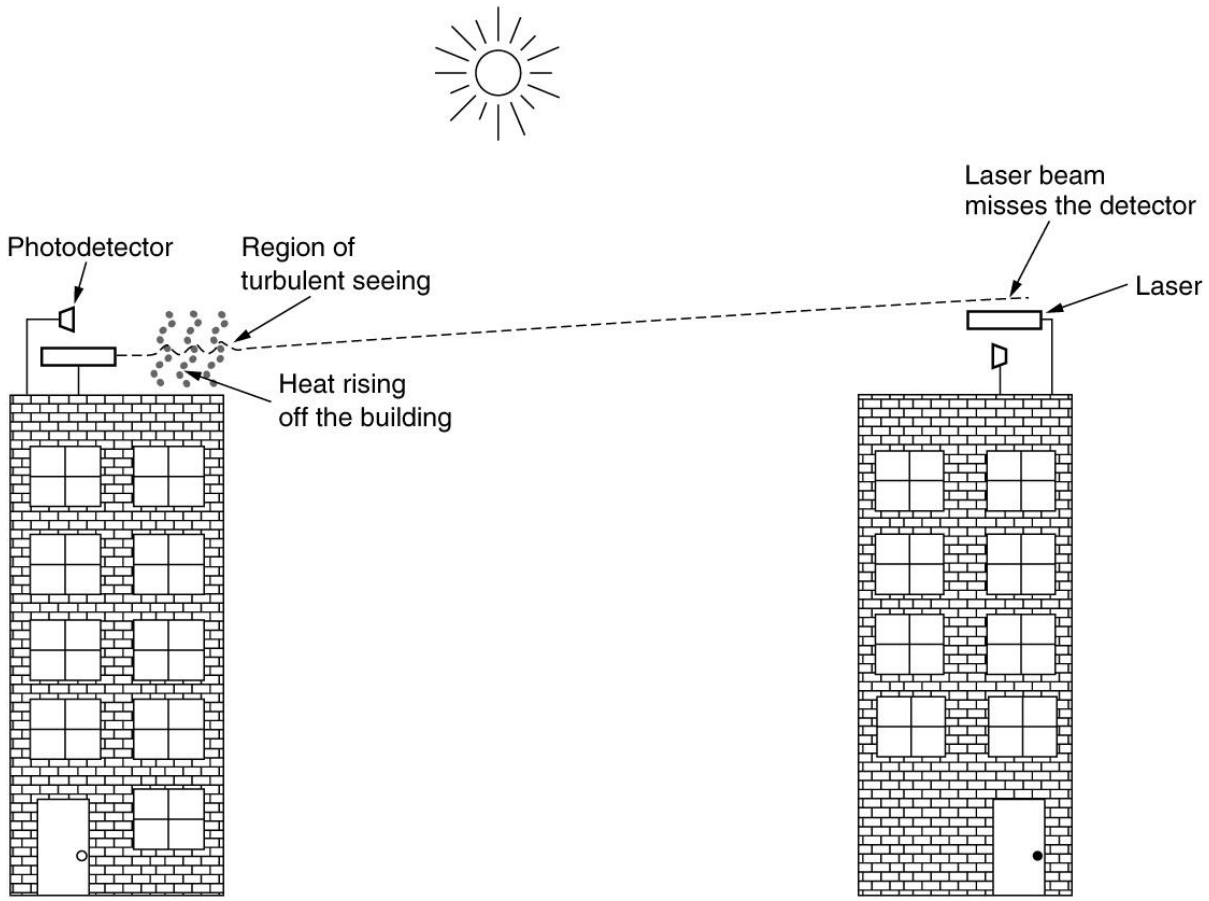
- But it is possible we will see this in in the future

- Why?
  - We have so many light emitting devices, all you need is something to read the light
    - Phones, watches, car lights, sirens on emergency vehicles
    - Weird futuristic light up t-shirts? Who knows

- A traffic signal could potentially read embedded information from an ambulance light and control the traffic
- Maybe weird futuristic ads? Everything is always ads

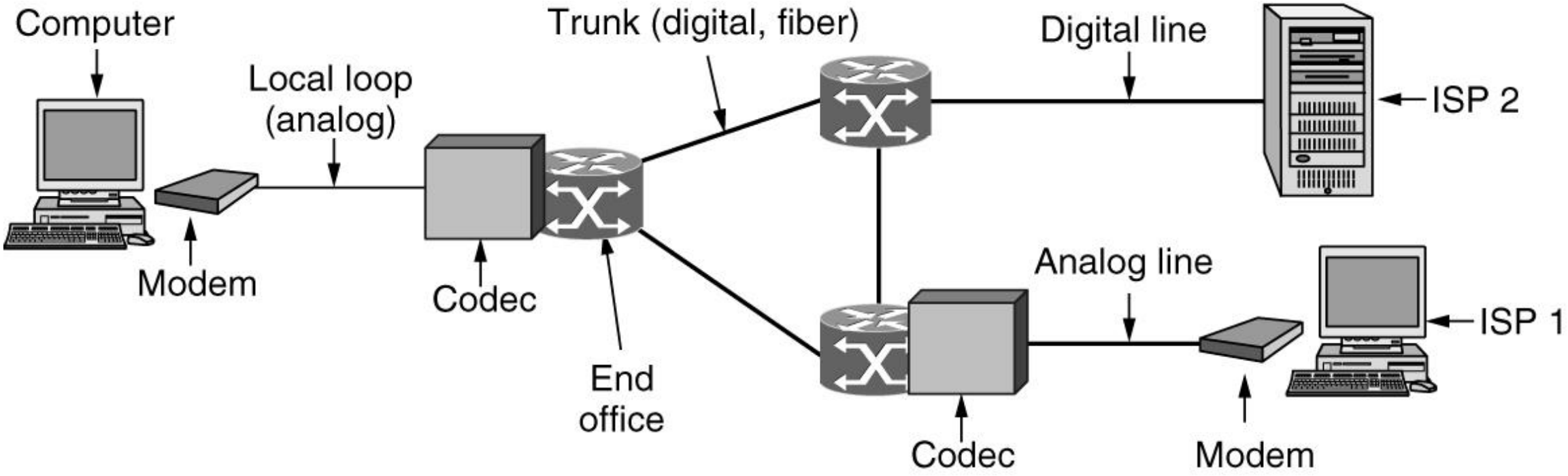
There are issues with light that need to be resolved

- There was a system that worked perfectly at night, was tested, and then deployed the next day when customers showed up
- Nothing worked because the heat rising off of the building was causing the light to bend
- *(not to be confused with fibre optics, ie. light travelling through a glass tube)*



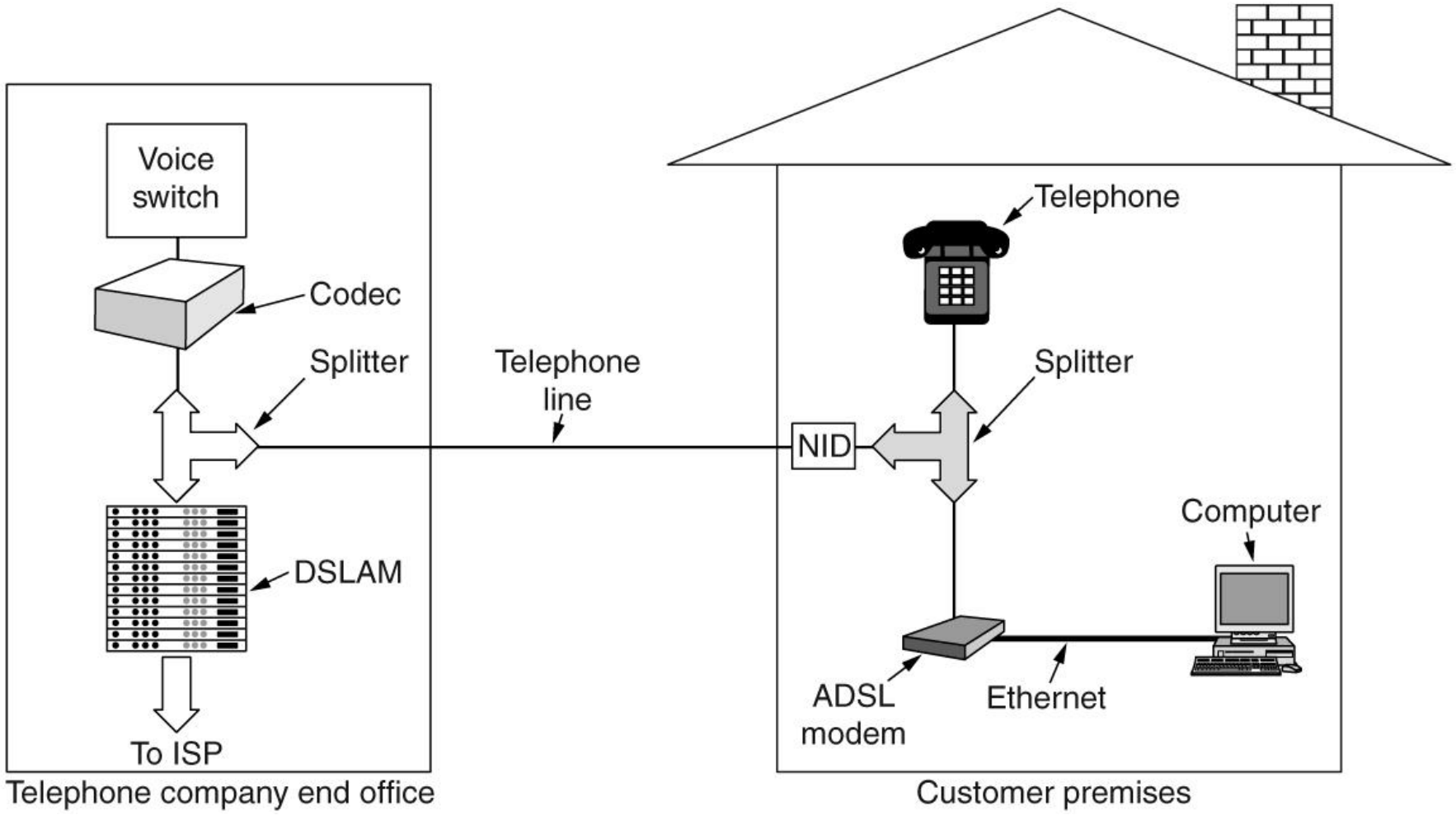
Telephone Modems (briefly)

- Uses both analog and digital transmission for computer-to-computer conversations



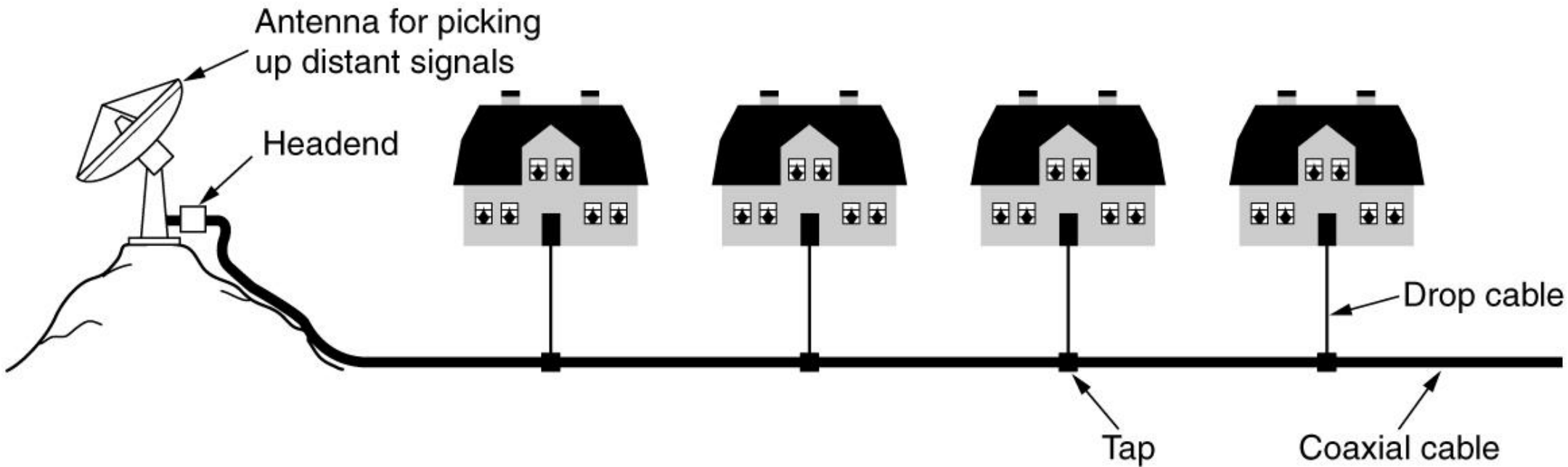
DSL Subscriber Lines

- Phone separated from the network
- Digital Subscriber Line



Cable Networks

- Independently operated early cable television network
- CATV (Community Antenna Television)
- Local electrician could setup a CATV system for their neighborhood
- By 1970, there were thousands of these in operation



Then came HBO

- 1974, Time Inc. started a new channel
  - Home Box Office
  - A cable on subscription channel that focused entirely on movies

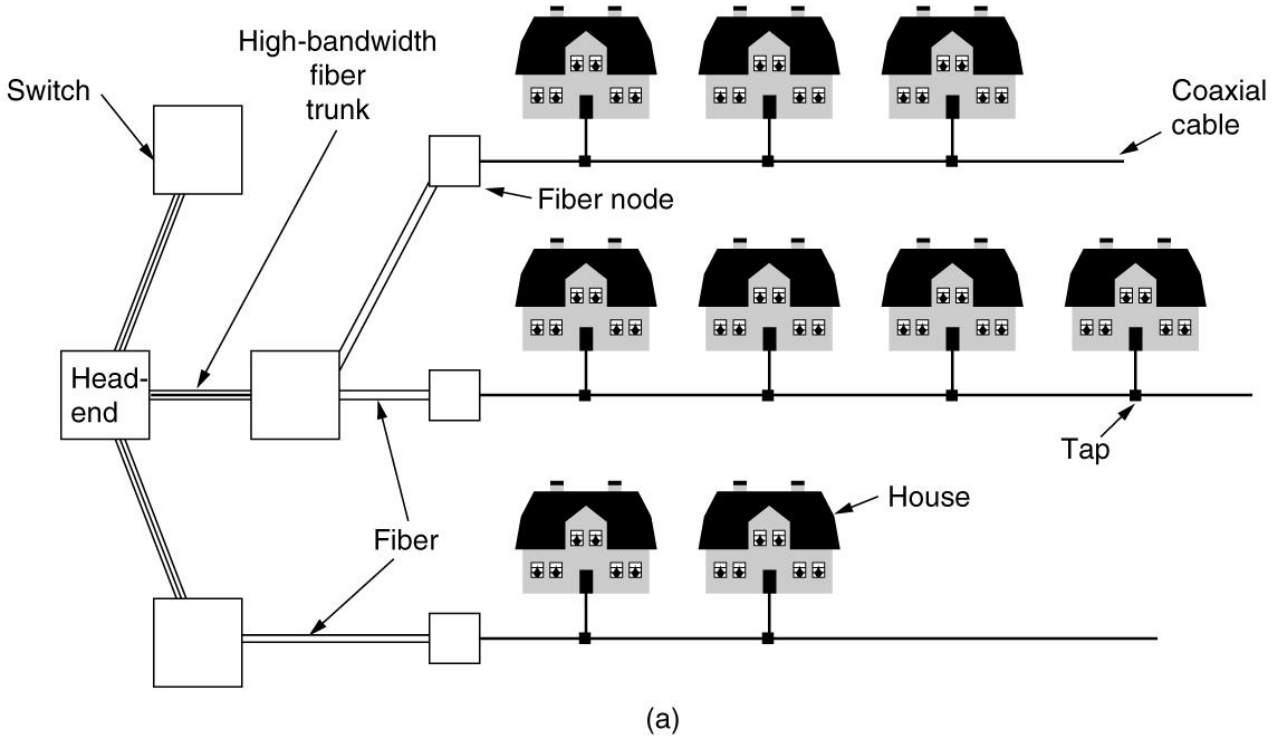
- Other corporations followed suit and started making channels specific to topics: sports, cooking, kids, etc.

- This caused two big changes:
  - Large companies began buying up the smaller existing infrastructure and expanding their own systems (get more paying subscribers)
  - Created the need to connect many systems into one, potentially connecting systems that are very far away
  - (roughly the same thing that happened to the telephone)

Comparing of Internet access over cable (HFC networks)

- The trend has to been to bring fiber optics closer and closer to the home

- HFC – Hybrid Fiber Coax



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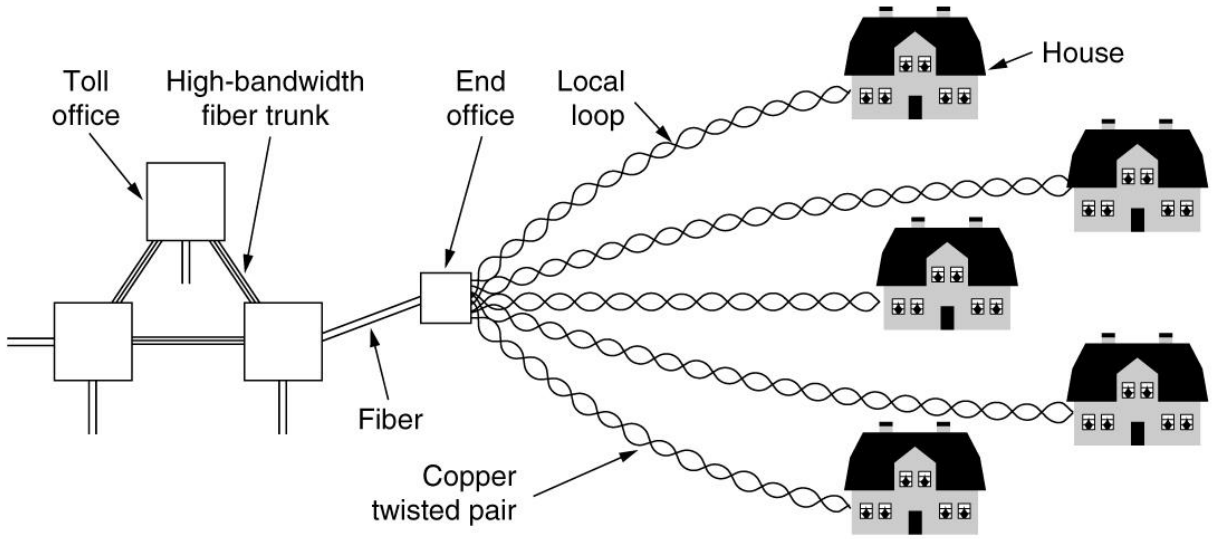

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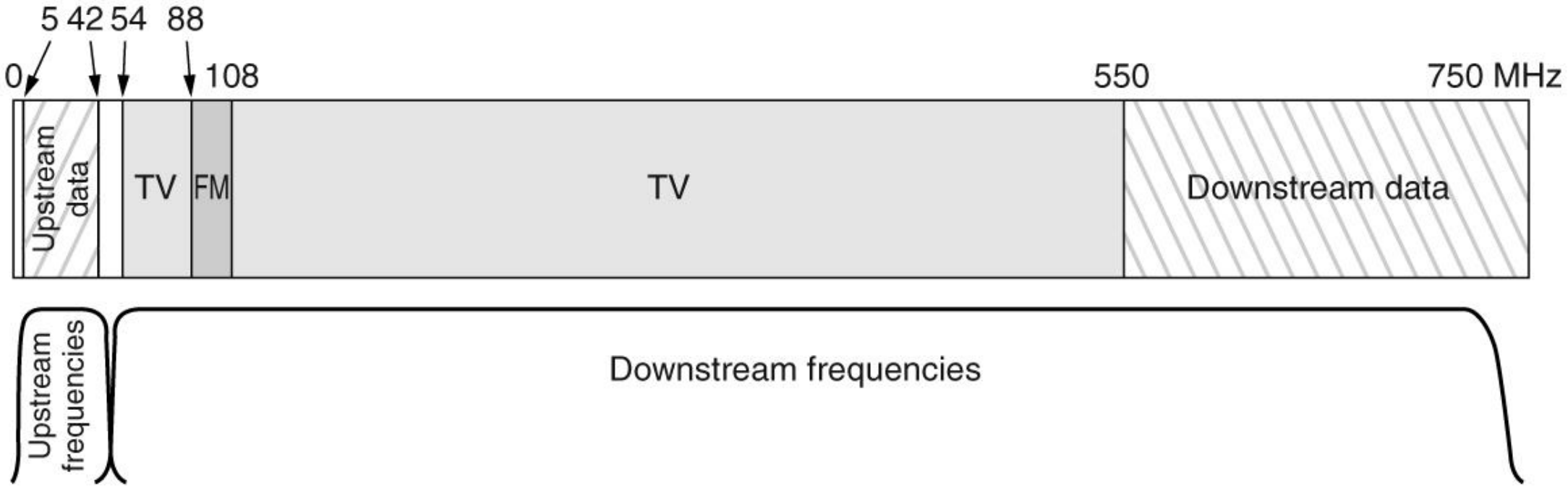
Where the Internet lives on a coax cable

- Frequencies for TV will not go away any time soon
  - Older customers who have no yet “cut the cord” would be very upset
- Demonstrates why up speed is often so much slower than down speed (though it shouldn’t be these days)



DOCSIS

- The standard widely deployed across US, Canada, and Europe
- Developed in 1997 by CableLabs
- 1.0 (1997)
  - Provided 38 Mbps downstream, 9 Mbps upstream
- 2.0 (2001)
  - Tripled upstream by utilizing the upstream of the TV spectrum (TV is purely downstream)
- 3.1 (2013)
  - 1 Gbps downstream achieved

Cable Modem

- Every house needs a cable modem to connect the LAN to the ISP network