Teaching Case

Understanding Wi-Fi

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Abstract

Connecting our devices wirelessly has become ubiquitous. The typical response to network problems is either to shrug our shoulders or to gripe about the state of the network. This case presents a short history of Ethernet and then continues with an explanation of how a Wi-Fi network works and why it slows down periodically.

Keywords: Ethernet, Wi-Fi, Network Topology, Network Communications

1. Wi-Fi PROBLEMS

It is time for the FIFA World Cup Final, Wales vs Tunisia. Jordan was trying to stream the match when Taylor burst into the room, complaining that the dorm's Wi-Fi is acting up again and wanting to know if Jordan is having any better luck watching the game.

Both are moaning about how the campus network seems to break down at the worst possible moment. Jordan's roommate, Logan, had been trying to sleep. However, with all of the noise Logan woke up and said, "I've told you before, just plug your laptop into the network jack on the wall," then promptly fell back onto the pillow.

Jordan was dubious that this would work but connected the laptop to the network jack anyway. After a moment or two the video stopped breaking up, and the two of them were able to watch. Logan, on the other hand, couldn't get back to sleep due to Taylor yelling at the screen.

2. A BRIEF HISTORY OF ETHERNET

The 1960s saw the beginning of the proliferation of electronic computers and a need to access and interconnect those computers. Each computer company, such as IBM, Honeywell, and Burroughs, had their own proprietary way to interconnect their own computers. This made it very difficult for people on one brand of computer to access or share resources on a different brand of computer. This was not a significant problem for most companies since they typically would standardize on one computer brand. However, the United States government, and especially its military, employed computers from many different computer companies.

The Pentagon's Advanced Research Projects Agency funded research into ways to interconnect disparate computer systems. One of these projects was Alohanet, which connected computing resources across the Hawaiian Islands using two-way radios starting in 1971 (Abramson, 1970, Abramson, 1985).

As a graduate student at Harvard, Robert Metcalfe based his doctoral dissertation on improvements to Alohanet (Griffin, 2001). During this time, he was working at Xero's Palo Alto Research Center (PARC). He was tasked with developing a way to connect Xero Altos (an early personal computer) together. Taking his analysis of Alohanet as a starting point, he led a team that developed a new way to connect the Altos together using coax cables instead of two-way radios called Ethernet (Metcalfe & Boggs, 1976). This original form of Ethernet (10Base-5) ran at 10Mbps and used a very thick coax that was hard to work with. In 1983, Ethernet was accepted as a standard by IEEE as 802.3 (IEEE, 2022). By

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1985 a more flexible coax was adopted for use with Ethernet (10Base-2) (Quine, 2021).

A few years later, saw the introduction of twisted pair wring for Ethernet (10Base-T) in 1990. While it still ran at 10Mbps, it was easier to run and enabled the ability to add notes without having to disrupt the network. In 1995 a faster form of Ethernet was released running at 100Mbps. It ran on both twisted pair wiring (100Base-TX) and on fiber optic cables (100Base-FX). 1Gbps Ethernet over twisted pair (1000Base-T) and fiber (1000Base-SX and 1000BaseMx) was released in 1998. 10Gbps Ethernet running over fiber (10GbE) came out in 2002.

About twenty different Wi-Fi standards have been developed. The following describes several of the more popular ones. The wireless version of Ethernet (802.11) was initially released in 1997 running at 2Mbps on an unregulated frequency at 2.4Ghz. 802.11a runs a regulated frequency near 5GHz and was released in 1999. The use of higher frequencies allowed a bandwidth increase up to 54Mbps. 802.11b was also released in 1999. It used the 2.4Ghz spectrum and improved bandwidth up to 11Mbps.

In 2003, 802.11g was released. It used the original 2.4Ghz spectrum but changed the signaling method in order to improve bandwidth. It was backwards comparable with 802.11b by slowing all devices down to match any 802.11b devices on the network.

The 802.11n standard was released in 2009. It allowed for the use of both the 2.4GHz and the 5GHz frequencies as well as multiple antennae. 802.11n has a theoretical maximum bandwidth of 600Mbps.

In 2013, 802.11ac (not to be confused with 802.11a) was released. It runs on the 5GHz spectrum. By using multiple antennae and improved signaling methods it is able to attain a bandwidth as high as 1730Mbps.

One of the most recent versions of Wi-Fi, 802.11ax, has a theoretical maximum bandwidth of up to 9608Mbps. The improvement in bandwidth is due to a combination of multiple antennae, improved signaling methods, and the addition of the 6GHz radio spectrum.

3. COMMUNICATION CHANNEL

After the match (a 4-2 victory for Tunisia), a disappointed Jordan asked Logan why plugging the laptop into the network jack let them stream the game without any problems. "Aren't both the dorm's Wi-Fi and the network jack on the same network?"

"They are and they aren't," replied Logan. "They are both using the Ethernet protocol. From your perspective, they seem to be the same since you needed to register your laptop with the school's IT department to use them and since you can get to the same places on the internet with either one. However, they use different media."

"Media? What does the media have to do with this?" asked Jordan. "Is this an example of fake news?"

Taking a deep breath, Logan explained, "Not that type of media. For computers and other communication devices, it is the substance that the signal travels through. It could be copper wires like the wired network, fiber optic cables, or radio waves like the ones used by Wi-Fi. In order to communicate, you need a transmitter to send the message, a medium that carries the messages, and a receiver to get the message. This is called a communication channel. For example, when I talk, my vocal cords vibrate the air, which carries that sound to your ears. There are three different approaches that you can set up a communication channel.

"The first is called Simplex. This is a communication channel that sends information in just one direction. The second is called Half-Duplex. This is a communication channel that allows both sides to send and receive messages over the same medium, but not at the same time. They have to take turns; each one has to wait until the other is done before sending their own message. The third approach is called Full-Duplex. This approach allows both sides to send and receive messages over the same medium at the same time. Let me draw it for you" (see Figure 1).

Task 1
We want to help Jordan to understand the differences between Simplex, Half-Duplex, and Full-Duplex. Provide examples of each and explain why they fit into the given category.

4. COLLISIONS

"Wait," said Jordan, "I still don't see why plugging into the wired network fixed the problem. I get that Wi-Fi is Half-Duplex, but I was only trying to watch the game. I wasn't sending anything."

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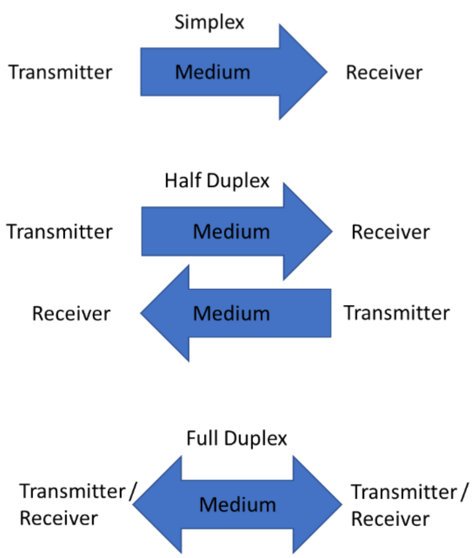

Figure 1 Communication Channel Configuration

Smiling, Logan replied "Do you think that anyone else was trying to stream the match?"

"Of course. Lots of people were watching from their rooms," said Jordan.

"Exactly," continued Logan, "Wi-Fi is a shared medium. It's kind of like everyone was in one room. If you and a friend were on opposite sides of a room and wanted to talk, other than speaking loudly, you wouldn't have a problem having a conversation. If another couple of people enter the room, you would still be able to have a conversation, but with a few interruptions due to the other conversation. Let's change it up a bit. What if you had 30 conversations going on in that room? What would happen?"

"Well, 30 conversations would make it hard for me to talk to my friend," said Jordan. "I get that you are saying that the dorm's Wi-Fi is like a large room with everyone talking at the same time, and that would cause problems with being able to watch the match. But that's an analogy. Computers sending data are much faster than people talking are. Couldn't each computer just wait until nothing was being sent before sending their data?"

Logan was happy that Jordan was catching on and replied, "That's exactly what Wi-Fi does. Each device on a network, which we refer to as a node, listens to see if anyone else is sending before they send their data. The thing to remember is that even though we think of communication happening instantaneously. It actually takes a finite amount of time for the data to get from point A to point B and since more than one bit is being sent, there is time between the first data bit and the last data bit. Because of this, data can collide resulting in the message not being received. I know that you didn't care for my other analogy, but let's try this one. Imagine a railroad that had just one train track and four stations that we'll label A to D (figure 2a). Any station can send out a train, but first they have to make sure that no one else is using the tracks. We refer to this as Carrier Sense Multiple Access (Kleinrock & Tobagi, 1975, Metcalf & Boggs, 1976).

"Let's say that A has something to send to C, and D has something to send to B. Both A and D look to see if there is anything on the track, and not seeing anything send their trains on the way. The train from station A is halfway past C just as the train from D collides with it (figure 2b). Think of this as C having received part of the data coming from A before it was interrupted by the data

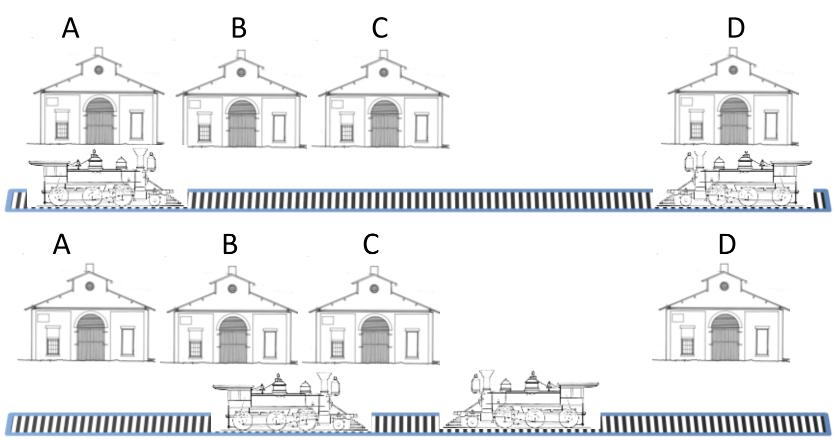

Figure 2a (top) and 2b (bottom) Delay between sending and collision.

coming from D. In addition, none of the data coming from D ever gets to B (Molle, Sohraby, & Venetsanopoulos, 1987). After the collision, the data still needs to get through. Each node will then resend its data."

"Hold on a moment, Logan," said Jordan. "That feels like you are setting things up for repeated collisions. What is going to prevent the resent data from colliding?"

"You're right," replied Logan. "We need to avoid repeated collisions. It turns out that in a wireless environment nodes cannot always detect if a collision occurred. So, in addition to listening for no one else to be transmitting before sending data, the sender also waits for an acknowledgement from the receiver. If an acknowledgement is not received, the sender assumes that there was a collision and waits a random amount of time before trying to resend the data. Since both sending nodes that collided will wait a random amount of time, the chance of the resent data colliding is reduced. If another collision occurs, the nodes then will wait a new random amount of time that can be up to double the prior maximum wait time. This is called exponential backoff."

Task 2

Given what you have learned about Wi-Fi, what other approaches could nodes take to ensure that collisions will not occur on shared media?

5. ETHERNET SWITCHING

"Now that you understand why you had problems watching the match using Wi-Fi, you are probably wondering why plugging your laptop into the building network resolved your problem," said Logan. "In most cases, wired Ethernet directly connects a single computer (node) to a centrally located networking device called a switch. A switch listens to all of the traffic, learns where each node is connected, and sends the data out to just the recipient node. Unlike shared media where everyone can see all of the data, the sender and receiver are the only ones that can see the data being sent. Using our prior example, this would allow A to send a message to C at the same time that D sends a message to B. Each 'conversation' has its own channel and would not have the ability to collide.

"This works the same way as a telephone system. When you make a call, it connects to just the person you dialed. No other telephones ring. No other telephones can hear your conversation. In addition, when someone else makes a call, you cannot hear their conversation. Does all this make sense?" Logan prompted. "I get it now. This is way cool.

Do you think that I should sign up for a networking course?" asked Jordan.

"I don't see why not!"

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Figure 2 stations extracted from https://commons.wikimedia.org/wiki/File:Central_of_Georgia_Railway,_Savannah_Repair_Shops_and_Terminal_Facilities,_Bounded_by_West_Broad,_Jones,_West_Boundary_and_Hull_Streets,_Savannah,_Chatham_County_HAER_GA,26-SAV,55-_%28sheet_16_of_17%29.png a work by the US National Park Service which places it in the public domain.

Figure 2 locomotives https://commons.wikimedia.org/wiki/File:2-6-0.png are from The Steam Engine, published 1890 by Blackie & Son, London which is in the public domain.

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