
BARCELONA – How It Works: Internet Networking
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ALAIN DURAND:

Now that you want also to use red on the same fiber, this is going to be a mess, because Carlos wants to use red. Okay? So what we need to have is essentially somebody in the middle that is going to assign colors. So I will be here and decide on this fiber, you want to use red, I'm sorry, sir, can't. But if you want to use green, that will be okay. Are you fine with that? Yes or no? Yes? Perfect, fine. If you're not fine, well, too bad. But that's how we're going to solve this problem. It will be an arbiter that owns the fiber and that says, "You can use red. You can use red. No, conflict, please use green." Okay?

So there are quite a lot of different colors. Each color is characterized by a wavelength. Color is a wave, you can measure the frequency of a light, it's a wavelength, essentially. And that's how you do this. But this is point to point. This is to go from here all the way there. This is not going to go from here to, let's say, Washington D.C.

So, how do we go from here to Washington D.C.? Well, the easiest solution is that we can create a new fiber that goes from, let's say, my office in Washington D.C. all the way to here. We can get a boat laying fiber across the ocean, and maybe six months later, we will have a fiber here.

Six months might be a long time, and it's quite expensive to get this boat to operate. Maybe I will not do that. Maybe I want to reuse fiber

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that are already there. But to your point, there might be way too many people that want to use the same colors. It's a little bit unmanageable.

So the way to do that is to break down the fiber into small segments. For example, from here to the computer over there, from there to a central office in Barcelona, from Barcelona to someplace in the UK where there is a head office for transatlantic cables, then across the ocean to, let's say, New York, then another cable from New York to Washington, and another fiber from Washington to my office in Washington.

So if you count, it's about ten or so different portions. On each of them, the traffic will be shared among different customers. It may not be the same on the different segments. So there's going to be an operator who operates all those different fibers who is going to decide, on this segment, what will be this color assigned to a customer.

On this other segment next to it, I cannot use red because red has already been assigned. I'm going to switch the color. What I receive on red, I decide I'm going to send it on green on the other side. When it goes to the next stop, green may be transformed into orange, transformed into yellow.

So as long as we have a map that says, "Here , this color is to this customer, here, that color is to that other customer," all the way to the end, I can construct what we call a fiber path from one point to another, simply by putting together those different pieces of fiber. You may not have the same color all the way, you will switch color, but that's okay as long as somebody maintained a map of all those colors.

So, I talked a little bit about speed of fibers. A long time ago, 1 gigabit per second was supposed to be fast, was considered fast, and then we went to 10 gigabit, and then things slowed down a little bit. We got 25 gigabit, 40 gigabit in datacenter, but ten years ago, we started playing with 100 gigabit for providers, but the line card and the router of a [inaudible] 100 gigabit was like \$1 million. It was really expensive.

Now, the prices for 100 gigabit are coming way down, and only ten years later, we're starting to see 400 gigabit. I listened to some presentation about 400 gigabit per second last week at the RIPE meeting, and that's great, but we only have multiplied by four in eight years, and that's maybe not enough. People would like to go to terabit per second, like ten times faster, and they want it about yesterday, not in ten years from now.

So we have a bit of a problem where the speed at which bandwidth increase on those fibers is not fast enough. The industry that produces the fibers and routers that support it is not developing as fast as the industry that is consuming bandwidth, the service provider. And that's a bit of an issue.

So in the meantime, what is happening is simply more fibers. So if we cannot send the traffic over one fiber, we will send it over two fiber or five fiber or ten fibers or 20 fibers. There's more and more fibers. Yes.

UNIDENTIFIED MALE: I want to know how to increase the speed? Is to upgrade the device [inaudible] router or the wireless device or something like this? How to increase the speed?

ALAIN DURAND: So the speed, you have to go back to the point I made earlier. I use lasers, right? I need a faster laser. And on the other side, I'm going to need also a faster laser. But we are now talking about lasers that operate at 100 gigabit per second, at extraordinarily high frequency. This is electronic that is unbelievably expensive, very difficult to build. And going ten times faster becomes even more difficult each time we want to go ten times faster. That's why it is a difficult proposition.

People told me we could build things that will go at terabit per second, but nobody will be able to buy them. It will be too expensive. So keep this in mind. We'll talk about this later. If it's too expensive, it doesn't work. But to your point, you need to change the lasers on both side of a fiber. And if it's a fiber path, on every single element, you need to change the laser. So it becomes quite expensive.

So now that we have fiber path, we need to create networks with all of that. And the idea of creating networks is to say, "I have my network, you have your network, and we're going to interconnect. My network, my rules, your network, your rules. You do whatever you want in your network, I do what I want in my network." Only thing we have to do is to agree on what we are going to exchange.

And maybe I have my network, maybe Mehrzad has his network, but we don't communicate together. Maybe we need to go through Dan, because you have a connection with Dan and I may have a connection with Dan, Dan knows us all, so that's fine. Then I can talk to you through Dan.

Maybe we don't have a connection in common. Maybe Dan talks to Indira and Indira talks to Alexandra, and I know Alexandra, so there is a path here that we can connect to each other. That's how it's going to work. Remember one thing. My network, my rules. [inaudible] we do networking. And then we interconnect all those things together.

So when we talk about Internet, Internet spells with capital I, not with lower case i. Why? Because it means a network of networks. That's really what this is. My network, my rule. The Internet is different. Not my rule, not your rules, it's everybody's rule, because it's a network of networks.

So there is a protocol to communicate on the Internet. It's called IP, for Internet Protocol. So if you believe that IP stands for intellectual property, that might be fine, but in this room today, it stands for Internet Protocol. If you really want to talk about intellectual property, actually, you should talk about intellectual property rights, IPR, not just IP.

So, IP today, internet protocol. Okay, now, we have a connection. We have explained if I want to talk to somebody, I may have to go through a bunch of different people. Let's say I want to talk to Cathy. Cathy, we

are going to exchange some data. Okay? And I'm going to send you a file in some small chunks. I want to make sure that you receive it.

So we're doing a little variation today. First, I'm going to send you a bunch of things. [inaudible] my file and I'm taking it into ten blocks. Cathy, I'm going to send you block one, two, three, four, five, six seven, eight, nine, ten. Did you receive anything? I don't know. Maybe she did, maybe she did not. I have no clue at this point, I just sent the data.

We need to have a way for her to tell me, "Yes, I have received this data." Okay? Acknowledgement. Yes. So, the basic protocol on the Internet is called UDP, for User Datagram Protocol. It simply send always data like I just did. Block one, two, three, four, five, six seven, eight, nine, ten, and then that's it. She received that file, she did not, who cares? Not a very reliable protocol, but there's some usage for that. We'll [inaudible] about it later.

The to her protocol is called TCP for Transmission Control Protocol, which means that we are trying to control the communication and make sure she receives it. So the first thing is to make sure for me that she can hear me. Because if she cannot hear me – and I want to make sure that I can hear her. And she has to make sure that I can hear her. So it has to go all directions.

So first up, we are going to establish what's called a three-way handshake. I'm going to say, "Hello."

CATHY PETERSEN:

Ack.

ALAIN DURAND: Ack. What just happened here? I sent the message, she received it. She said, “Ack.” “Ack” went over the air and I heard “Ack.” When I heard “Ack” coming from Cathy, it means that, first off, she has received my message. Second, she was able to send it back, and I could hear it. Okay? At this point, I know that she can hear me, I know that I can hear her. She knows she can hear me, she has received my message. Right? But she doesn’t know if I can hear her. So I have to send another message to her saying, “Ack. I have received the fact that you can hear me.”

So let’s try it again. Hello.

CATHY PETERSEN: Ack.

ALAIN DURAND: Ack. By doing this three ways, three times, one, two, three, both of us know that we can hear each other. This is what is called three-way handshake in TCP. There's no way to do any faster. If you really want to know that the other person is there and you want to know that the other person can hear you too, that’s what you have to do.

Now we are going to send data. So instead of sending my ten different packets, I'm going to send one packet. Cathy, this is packet number one.

CATHY PETERSEN: Ack.

ALAIN DURAND: This is packet number two.

CATHY PETERSEN: Ack.

ALAIN DURAND: Packet number three. So, I've heard this "Ack" for the first two packets, I know the first two have arrived. I haven't heard anything about the third one. So, what happened? Does anybody have any idea what has happened? Maybe –

UNIDENTIFIED FEMALE: Packet lost.

ALAIN DURAND: Packet lost. Where?

UNIDENTIFIED MALE: [I don't know.]

ALAIN DURAND: You don't know. I don't know either.

UNIDENTIFIED FEMALE: We don't care.

ALAIN DURAND: And you're absolutely right, it doesn't matter. It really doesn't matter. All that matters is that she has not received the packet. So what do I do?

UNIDENTIFIED FEMALE: Send again.

ALAIN DURAND: Bingo. Packet number three.

CATHY PETERSEN: Ack.

ALAIN DURAND: Good. Now I know that she has received my packet. Why was the packet lost? What are the possible reasons that he packet got lost? Any idea? Rudolph.

RUDOLPH DANIEL: Maybe it is not her color.

ALAIN DURAND: Yes. It could be a misconfiguration in the network, wrong color, packet gets sent somewhere else. That's one possibility. Another suggestion.

UNIDENTIFIED MALE: Hardware issue or collision.

ALAIN DURAND: So, hardware issue, yes. Router [inaudible] fiber, something like that. That's possible.

UNIDENTIFIED MALE: [inaudible]

ALAIN DURAND: Yes. Another idea?

UNIDENTIFIED MALE: Virus?

ALAIN DURAND: Virus?

UNIDENTIFIED MALE: Yeah, block the transmission.

ALAIN DURAND: Oh, firewall, yes. But I just sent two packets before. Okay? And they made it. So it's not a firewall. Unless somebody just switched a firewall in a microsecond just after. Not very likely. I don't think that's a reasonable explanation. It's possible, but a little bit unlikely.

What could happen more likely would be, oh, the network was all configured and something happened in the middle and sent the traffic somewhere else. Which is very similar to what you were suggesting, like wrong colors, something happened in the middle. Another idea of what could have happened?

UNIDENTIFIED MALE: Maybe –

UNIDENTIFIED FEMALE: [inaudible]

ALAIN DURAND: Please speak into the microphone.

UNIDENTIFIED FEMALE: Because of the media, like there's some problem.

ALAIN DURAND: Yes. Media error.

UNIDENTIFIED FEMALE: Interference in the media.

ALAIN DURAND: Yes. Media error. For example, in this cable here, it's not fiber, it could very well be that the copper is bad quality, and somebody was, I don't

know, putting some metal object next to it and influencing the signal. Or it could be that, oh, there was this wireless network and some big truck just rolled by and created perturbation in the signal. That's absolutely possible. Yes?

UNIDENTIFIED MALE: Or maybe someone unplugged the cable. That is possible.

ALAIN DURAND: Yes. Exactly. I have a story of a rabbit, and it's a true story. The research center where I used to work back in France many years ago. In the middle of a winter, it was getting called. There are rabbits over there, there are many rabbits. We were next to a forest. They were trying to get warm. They wanted to get inside of the building.

How did they get inside of the building? Well, they found one of the conduits with the fibers, and they went in there. And they were hungry. And you know what? Wildlife loves plastics. I don't understand why, but this is what it is. Fish love plastic beads and rabbits love plastic cables. And the rabbits started to munch on the plastic cable.

At first it was okay, and then two of the fibers got squeezed, and then three of the fibers were squeezed. And after a while, enough fibers were squeezed that communication couldn't go through. We had to find the rabbit.

A few months later, we had the same problem, but not with a rabbit, but with a tractor, with a backhoe. They were digging a hole somewhere

on the campus, and what did they do? They just broke the fiber. Those things happen all the time.

So, somebody talked about collisions or – congestion, that can also happen. Too much traffic. When you have two pipes coming in one place and one coming out, well, it's the same thing as water. You have two water pipes, about like this diameter going to one place, and coming out in the same diameter. Well, if there's not much water coming in, that's fine. If the two big pipes are full, that's physics, they cannot get through, so it will back up and you have water backing up the pipes.

Same thing with networking. We have two gigabit pipes coming in, one gigabit pipe coming out, not enough bandwidth. Doesn't work. So all of those are possibilities why we can lose packets. So, the whole idea of TCP is to say we have to try again. So packet number three.

CATHY PETERSEN: Ack.

ALAIN DURAND: Most of the time, studies have shown that the reason why you lose packets is not because of a rabbit, not because of a tractor, not because of misconfiguration, it's because the network is too busy. So, when you want to reduce this problem, what you had to do is to tell everybody to back off and slow down in the transition.

So instead of simply sending packets as fast as you can, like packet one

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CATHY PETERSEN: Ack.

ALAIN DURAND: Packet two. Packet three. Lost. We are going to slow down. So after a packet was lost, I'm going to interpret this as a sign that most likely, it was not the rabbit, most likely, it was not a backhoe tractor, it was congestion. I'm going to slow down. So I'm going to say, packet four. Wait.

CATHY PETERSEN: Ack.

ALAIN DURAND: Okay. And at that point, it works. Why? Because of that slowdown, and everybody else is going to be the same, receiving packet loss and everybody slowing down. So it's the same as cars in the city. All of a sudden, there's an accident, everybody slows down.

But I'm not going to talk like this forever. Next one, I'm going to try to go a little faster. A little faster.

CATHY PETERSEN: Ack.

ALAIN DURAND: More faster.

CATHY PETERSEN: Ack.

ALAIN DURAND: Faster.

CATHY PETERSEN: Ack.

ALAIN DURAND: Faster.

CATHY PETERSEN: Ack.

ALAIN DURAND: That's how we're going to do this. We're going to increase the speed until – faster. No, that's too much. Okay? Now I need to back off. That's how we're going to do this thing. And if everyone does the same thing, then we will find the optimal transmission speed for everybody.

The curious thing is back in 1990s, people said, "This is never going to work, people are not going to be polite. People are simply going to go

fast, and if you slow down, you simply make them go faster and you slow down.”

But that’s not what happened. Everybody got polite on the network. Everybody implemented this. This is one of the few cases I know of in the network where people did actually the right thing, not for their benefit but for the benefit of the entire community. It worked.

So next layer is about session, it’s about describing what you are going to send. For example, we can send video, and you want to describe this is going to be a video feed and this is the speed of the movie. This is the type of encoding and all of that.

How do you actually describe this? With what’s called the presentation layer. So at first, we had a bunch of formats. Now, people have something like this. This is a menu, it’s called a dictionary, where we can describe all the different elements and add things to it.

So the cool thing that people are using, that kids are using now is called JSON. Years ago, the cool thing was XML. Another ten years before that, it was ASN1. So every ten years or so, there’s a new thing that kids are using. So if you tell me which one you’re using, I can tell you how long you have been doing networking.

But essentially, absolutely none of this matters until you have somebody who is sitting on his bed and browsing the web. Because at the end of the day, that’s what users want. If I talk to my son who is 14, 15 years old almost, he doesn’t care about any of the stuff I just described. All he cares about is sending his picture over Instagram, him

goofing up and doing all kinds of crazy, stupid things. That's what he wants to do. Right?

So, application is what matter, and today, there's one major application on the Internet. It's called the web. The web is not the Internet. The web is one application of the Internet. There are many others, like DNS is one application of the Internet, e-mail is one application of the Internet, instant messaging is one application of the Internet. The one that has been the most popular until a few years ago is the web.

Now we can discuss about is it more important to have web access, mail access, or instant messaging? When I started to do tutorials like this many years ago, my example was e-mail. I was saying, "If web doesn't work, yeah, who cares? But if e-mail doesn't work, people are going to call me in the research center where I was working and being in charge of those things and say, 'Go fix it immediately.'"

Now, e-mail, nobody cares. What matters is instant messaging, things like WhatsApp, Telegram and all those things. If those things go down for five minutes, people will notice it. It changes all the time, but those are the applications that people really care about. And they pay for it, one way or another.

Sometimes, they pay simply because they buy applications. Sometimes, they pay because it's a subscription model. Sometimes, they pay because it looks free, but their data is used by the company that offers the service to sell something else. At the end of the day, everybody pays, one way or another.

And that money is what is used to build the system. Sometimes, people say everything should be free. Yeah, fine, but who is going to pay for the fibers? Who's going to pay for maintaining the stable of different colors? Who's going to pay for paying the bill for the lasers? Somebody has to.

So there has to be some kind of money. And the different systems that work today are either subscription for the users, for example you pay 10, 20, 50, 100 euro, dollars, whatever your currency is a month to your service provider to get connectivity. But you don't pay Google or you don't pay Facebook. Actually, you do pay, through data that you're providing them, and they sell this data. That's how they make money. If they would not sell that data, they will not be able to give you free service.

So, we used to say that if you don't pay for the service, it means that you are the service, and somebody else is using you and your data to actually finance the network. That's how those things work. So that's the financial layer, and on top of that, there is a political layer. Political in the right sense of the word.

Political layer means how do we get together to make decisions, how does a community come to some kind of a consensus to make decisions and decide? So there are different systems that work. One is the community says nothing, there is a king somewhere, and the king decides everything. That's one system.

Another system is there's an election. Every time there is a decision, there is an election, and whoever has the most votes decides. That's one system. Another system is we all get together, we talk, and then

when you're tired of talking and somebody is still standing up and talking, everybody has stopped talking, then that person wins. There are many ways to do that.

At ICANN, this is called the multi-stakeholder model. So you choose where that one fits. But everybody has a voice in the process. That's why we are all here this week, essentially, to participate to this political layer, which is, how do we make those decisions together?

So, I spent a lot of time. How much time do you have left, Cathy?

CATHY PETERSEN:

[inaudible].

ALAIN DURAND:

Oh, perfect. Good. So that was my introduction, [inaudible] to talk about the different technologies, and now we are going to talk really about naming, addressing and routing.

So, this whole thing started many years ago when we were in another city, and I just joined ICANN. First thing I had to do was go to an ICANN meeting. The flight was not so good, and I had some problem before, but I arrived and I had a raging toothache. I needed a dentist.

So, morning arrived, and today I can't talk, but that other day, it was really in pain. I went to see Cathy, and Cathy, I need to make this tutorial tomorrow morning and I'm not going to be able to do that, it's too painful. I need to find a doctor. I know you lived in this city a few years ago. Do you know a good doctor, a good dentist here?

CATHY PETERSEN: Is, I do know a good dentist.

ALAIN DURAND: What's the name of the dentist that you know?

CATHY PETERSEN: My dentist here is Dr. Johnny Walker.

ALAIN DURAND: Dr. Johnny Walker? Alright. I think this guy has some good medicine for me. I don't know if it will be red, blue or black. Black? Okay. So let's find this Dr. Johnny Walker. I just asked Cathy what is the name of her dentist.

So, name. What is a name? Well, when I don't know something, my favorite exercise is to go to the dictionary, open the dictionary, and try to find the definition of it. So, in the dictionary, it says a name is a word by which a person, an animal, a place or a thing is known, addressed or referred to.

So there are two things important here. The word by which somebody is known or something is known or referred to. She knows Dr. Johnny Walker. She referred Dr. Johnny Walker to me. So we are having a conversation about Johnny Walker, about this dentist.

Dr. Johnny Walker, I don't know where he is, but when I will find him eventually and he will help me fix my tooth, I can have a conversation

with him. But right now, I'm having conversation about Dr. Johnny Walker with Cathy. Okay? There are two things we can do with a name. Talking to, talking about.

So, this is the first thing I would like you to remember from this tutorial. Forget all my layer nine, zero to nine, my ten layers. Forget about all that. Forget about this handshake, TCP, rabbit in the hole and everything.

First thing I want you to remember is if I know your name, I know who you are. Okay? So, let me ask, if I know your name –

ALEXANDRA PAGLIARO: Alexandra.

ALAIN DURAND: Alexandra. I know who you are. Okay? Now I can talk about Alexandra to somebody else in the room. Okay? Have you heard about Alexandra?

UNIDENTIFIED MALE: Just now.

ALAIN DURAND: Just now. We can have this conversation with you. Alexandra, what is your favorite color?

ALEXANDRA PAGLIARO: Blue.

ALAIN DURAND:

Blue. Now, I can have a conversation with you or about you. You see? That's what a name is about. So, that's what we just talked about. We can pass the name as a referral. Now, your name is Alexandra, my name is Alain, or Alain in French.

When I was a kid in school, Alain was a very popular name. We were about 30-something in school. There were six kids named Alain. That's fine. Except that we had one teacher, and she always called us, and when she was angry, she would call us again. And one day, she was quite angry, and she said, "Alain, come to the blackboard now."

And I suppose one of us had made something stupid. And what happened right then is the six of us were looking at each other, "Who is she talking about? Who should go to the blackboard and be punished?" And because we couldn't decide, none of us went there. So that made her even more mad at us. "Alain, please come now to the whiteboard." And we just couldn't decide.

So, in the end, she realized that we were confused, and when she put the name of the actual kid who had made some stupid thing and he had to go there. So, the point I'm trying to illustrate here is sometimes when you just have a name or a first name, this is not enough to have a conversation. I'm sure there are many of Alexandra here in Barcelona, this is a fairly common name in Spain, like Alain was in France. So we need to have a full name. May I have your full name please?

ALEXANDRA PAGLIARO: Pagliaro.

ALAIN DURAND: Pagliaro. Not just Pagliaro, because you have like brothers and sisters, you may have friends, uncles, aunts. You need to get the full name. so the full name is –

ALEXANDRA PAGLIARO: Alexandra Gisele Velez Pagliaro.

ALAIN DURAND: Thank you very much. That's a very nice name. So, now we have something that is unique to her, not to your family, not to brothers, not to friends, this is you. Okay. Now, I know this Dr. Johnny Walker, and I need to go find him, right? If I have the name of somebody in a town that I don't know, this is not going to help me very much. What I need is to find an address. So, Cathy, excuse me to come back here, I forgot to ask you. What is the address of Dr. Johnny Walker?

CATHY PETERSEN: His address is 125 Root Canal Drive.

ALAIN DURAND: 125 Root Canal Drive. I think that's a very good address. How did you remember that? Did you have to go through an address book or something?

CATHY PETERSEN: Yes, I did.

ALAIN DURAND: So, what she did actually is look for her address book, which is kind of a Rolodex, I think, and she looked up Johnny Walker, and somewhere, she found a file and the address was written in there. Okay? So this process is called name resolution.

If you have been to the tutorial on DNS this morning, well, DNS is very often used to map a name to an IP address. This is what they're talking about, name resolution, transforming a name into an address. Okay?

So, now we're talking about addressing. Addressing is about answering the question, "Where is it?" I know the name of the thing, I can talk about the thing, I don't know where it is.

So, same thing, let's go to the dictionary. An address of a particular other place or particular of someone. So the name helps me to talk about something, the address tells me where it is. So that's the second thing I would like you to remember.

So, you remember, what is the first thing I want you to remember? If I know your name –

ALEXANDRA PAGLIARO: Alexandra. I know who you are.

ALAIN DURAND: Second thing is I know your address.

ALEXANDRA PAGLIARO: You know where I am.

ALAIN DURAND: Yes. Remember those movies where they say, “I know where you live?” Exactly. That’s what it is. I know where you are. So, let’s make a little bit detour talking about something funny or not so funny depending on perspective.

So I said that my office is in Washington D.C. In Washington D.C., not far from the office, like one street away, one block away, there's a small house painted in white, and it’s fairly famous. Every four years, people are competing to live in there. They don’t pay rent there, so they like to live there. A nice location, centrally located perfectly. So there's competition to get inside.

So, the address of this place is 1600 Pennsylvania Avenue – this thing is not really working – Northwest Washington D.C., 20500-003, U.S.A. That’s the full address of the White House. If you were to send a letter there, it will arrive. I don't know if anybody will read it, that's a different story, but the full address.

This address has as structure, and you have to read it from the end to the beginning. First is U.S.A, that’s the country. We’re not talking about the White House in Belgrade, in Romania, in Turkey, in South Africa, in China. We’re talking about United States of America.

Let's forget the numbers here for a second. D.C. is the Dissect of Columbia. So, in the U.S., you have states everywhere, the 50 states, except the District of Columbia, because when they wrote the constitution and they decided a few years later where the capital was going to be, they didn't want the capital to be in any state, because that will be giving too much favor to a particular state.

So they decided to carve out a little bit of land and said, "This is not going to be in any state, it will be special for the capital city," and they called it the District of Columbia. But from an addressing perspective, it is exactly the same as if it was a state, just the local structure of government is different.

Then, Washington is divided into four quadrant. You have northwest, southwest, northeast, and southeast. This is in the northwest quadrant. Then the name of the street is Pennsylvania Avenue, and then the most specific is 1600. So if I give all those elements, I know exactly the address of this house, I know exactly where it is on the map.

Now, when you have addresses, they are not always geographically structured. There are many different structures that could be put in place. One example is a phone number. In the U.S., if a phone number starts with 1-800, it means it's a tollfree number, you can call, you don't pay. Whoever is on the other side pays.

But you have no idea where the number is. It could be anywhere in the state or it could even be rerouted somewhere else, like in India. Or simply my cell phone. My cell phone number starts with 703, which is area code for Northern Virginia next to Washington, but I'm here now in

Barcelona. So if you look at my number, you cannot say where I am. It's not enough.

IP addresses don't have a geographical structure attached to them. If you look at an IP address, the first part tells you who is the network provider, but doesn't tell you where it is in the world. There is another table that you can look up for that, but simply looking at an IP address without any external information, you have no idea where things are.

Now, people are very interested to know where you are, if only to send you advertisement, so they spend a lot of time and lot of energy, lot of money, to build a database that associates every single IP address in the world to a particular location. This is called geolocation.

Some of those services are free, like MaxMind, and the quality of the data is more or less good. Some of those services are much more expensive because the quality of the data they have is really good.

But addresses also have scopes. Just like my name has scope. I said there were six Alains in my class. The city of Paris is probably the most well-known city in France. In the U.S., there are 29 cities that have the name Paris.

So one day, my son was visiting me in Washington, and I said, okay, let's go for lunch in Paris. And he started to laugh, "We're not going to take a plane back to Paris." I said, "No, we're going to drive." "Oh, you're kidding me, we're not driving to Paris." "Yes, we are." And we just drove for 45 minutes and we arrived to a small city called Paris just outside of Washington D.C.

So if I simply say Paris, it means absolutely nothing. If I say Paris, Virginia, it will mean something. Or if I say Paris, France, it means something.

There was a very famous movie in the mid-'80s called Paris, Texas. For those who remember [inaudible]. And that was also a special Paris, not any Paris. So those things are quite important to specify completely the address.

If in Washington, you say 1600 Pennsylvania Avenue, everybody knows that this is the White House, that's fine. But if you simply say New York Avenue, New York Avenue goes from essentially to the northwest to the northeast. If you don't specify, if you say 2000 New York Avenue and you don't specify which side it is, you may be 4 kilometers away from where you think you need to be. So it's important to specify those things.

Okay. So, the same as names, you can use the name directly or as a referral, addresses are the same. I can use the address directly, and for example, write 1600 Pennsylvania Avenue Northwest Washington D.C., U.S.A, and send a postcard to the White House. That's a direct usage of the address. Or I can punch this into the GPS.

Or I can do like Cathy just did, use her Rolodex and tell me that Dr. Johnny Walker lives in Root Canal Drive. So it's passing as a reference. That address is not enough. We are in a city that I have never been to, having this pain in my tooth here. How do I go to 125 Root Canal Drive? How do I get there? What are my options?

Taxi is an option, yes. Taxi is a very good routing system. Other options? Anybody has an idea how to go to a specific address when you don't know in the city?

UNIDENTIFIED FEMALE: Google Maps.

ALAIN DURAND: Google Maps, yes, or any other maps, actually. A paper map would work also. Thank you. You need external information. Okay? Either you depend on a taxi, externality, or you depend on a map, or you can look at the signs. If there was a sign saying, oh, "Root Canal Drive, go this way," and then I go to a roundabout, "Root Canal Drive, go that way."

Sometimes in cities, you have a sign that says for the main directions, please go left or right, and that will be good enough. I can find my directions. If I'm by myself and I have no external help, it doesn't work. Okay?

So, same thing, let's say that I write this famous postcard, we write it together and we all sign, and we send it to 1600 Pennsylvania Avenue Northwest Washington D.C., U.S.A. In a few days, postcard will arrive there. How? Why? What is the system underlying that will make it arrive there?

It will work because I will give it to the local post office, Spanish post office, and the Spanish post office may have an agreement with maybe the UK post office, and they say, "Oh, for anything that we want to send

to the U.S., please ship it to us in London, and then we have a flight that goes every day from London to Washington or wherever, and we can send this.”

It works because there is a collaboration between the different post offices. So a couple years ago, I went to Vietnam, and I went to visit a museum in Hanoi where one of the most famous prisoners was John McCain. And the prisoners there during the Vietnam war were still receiving packages from their family.

And I was wondering, it’s wartime, people are killing each other, how can they receive packages from their family as prisoners? And the answer was, well, the war was between Vietnam and America. Vietnam was not at war with other countries. In particular, they were not at war with the Soviet Union. There was a cold war with the Soviet Union and America, but not real war.

So, it was actually possible to send packages from the U.S. to Russia, the Soviet Union, and then those packages will be able to go from Soviet Union to Vietnam to Hanoi. So, there was a nonintuitive way to connect all those things together.

In Internet, it’ll be exactly the same thing. It’s not because you cannot talk to each other directly, but you cannot talk through some kind of a remote way.

Which gets us back to routing. Remember my two first questions, okay?
If I know your name –

ALEXANDRA PAGLIARO: I know who you are.

ALAIN DURAND: Exactly. If I know your name, I know who you are, Alexandra. If I know your address –

ALEXANDRA PAGLIARO: You know where am I.

ALAIN DURAND: I know where you live. Third thing is routing. Routing is how do you get there. It is the way or the course taken to get from point A to point B. That's the definition from the dictionary. So maybe first, as this package story was telling you about, go to Russia, then go to Vietnam. That will be the route. Or go to the main intersection, first roundabout, take the second exit, second roundabout, take the third exit, and then go straight. That could be the route. That's what is routing is all about.

So, that's the third thing I want you to remember. What is the third thing I want you to remember?

UNIDENTIFIED FEMALE: If I have a route, I know how to get to you.

ALAIN DURAND: Exactly. Remember that. I know your name, I know who you are, Alexandra. I know your address, I know where you live. I have a route

for you, I know how to get there. Those are the three things I want you to remember today. So, how do you build routes on the Internet?

Well, this is all about putting those signs I was telling you about. First round about, first exit goes where, second exit goes where, third exit goes somewhere else. Okay? We have to build those things.

But like any infrastructure, you have to build the signs before you can start sending traffic. If you start sending traffic and you have a brand new system of routes and roustabouts and there's not a single sign there, there's not a single map, Google doesn't know about it, [inaudible] nowhere.

So first, you have to build all those signs. The way we are going to do that is to start from the destination all the way to the source. So, let's say this is the destination, and I am the service provider connecting the destination. I know how to get to the destination. Okay? And I'm going to tell all my friends, service provider, I know how to get there.

Okay? So, let me pick on you for a second. What is your name? Oksana? Oksana. You're my customer. And I'm going to tell everybody, all my friends – I'm going to Carlos. Carlos, if you want to talk to Oksana, talk to me. Okay. Perfect.

Going to tell you, [inaudible], if you want to talk to Oksana, come talk to me. Okay? And I'm going to tell you also. What is your name again?

RUDOLPH DANIEL:

Rudy.

ALAIN DURAND: Rudy. If you want to talk to Oksana – alright? Now, those guys know how to talk to Oksana, but nobody else does. What are you guys going to do? You’re going to tell your friends exactly the same thing. Please tell your friends behind you that if they want to talk to Oksana, they should talk to you because you know that I know how to talk to Oksana. Please go tell your friends. Exactly. [inaudible] tell the same thing. Alright. Rudy, tell your friends. Exactly. Okay. Now, Sanja, you know how to talk to Oksana, right? How do you talk to Oksana?

SANJA SIMONOVA: [I'll talk to you.]

ALAIN DURAND: Yeah, but you don’t have a connection with me, so you will talk to him. Now, please tell your friends. Alright. Now, Alexandra, do you know how to talk to Oksana? How do you talk to her? So, you talk to her, and essentially, you trust her to do the job. You think she's going to do the job? Yes, you hope so, you trust her, everything is fine. Okay, please tell all your friends and neighbors. Please. Indira, do you know Oksana?

INDIRA KOZHASSOVA: No.

ALAIN DURAND: No.

INDIRA KOZHASSOVA: But I know how to talk to her.

ALAIN DURAND: How are you going to talk to her?

INDIRA KOZHASSOVA: [inaudible].

ALAIN DURAND: And you trust him?

INDIRA KOZHASSOVA: Maybe not him.

ALAIN DURAND: Maybe not, maybe yes, but that's the only information you have, so you have no choice.

INDIRA KOZHASSOVA: No choice.

ALAIN DURAND: No choice, so we'll talk to Alexandra. Okay? And we're going to propagate this. And when you have friends and friends of friends and friends of friends, eventually, you reach everybody. So this is all about "I know somebody. I know somebody who knows how to get there." You

know, it's those old movies again. "I know somebody who knows somebody."

This is what this is about. And the point about trust is really important. Here in this room, we're all friends, we can trust each other. In the Internet, that's the same way. All the service providers, they know each other and they trust each other. They all have some kind of a commercial connection.

For example, [through your] service providers, you are paying for the interconnect, you have a contract in place, you have a business relationship. You trust each other. You're not going to lie, there's no point. That's part of the contract. Same thing for all of you.

So, there's essentially a trust issue while we are trusting somebody to do the right job. And it works because there is a collaboration and a cooperation between all those different service provider to do the right thing. Internet is entirely built on this notion that we trust the other parties to do the right thing.

And the most surprising thing is they actually do the right thing. Most of the time. So, now that I have built this map and we want to send packet, let's say that Mohamed, you want to send traffic to Oksana, and Indira is your service provider. What do you do? You give a packet to Indira. Indira, what do you do?

INDIRA KOZHASSOVA: [Send it to Alexandra.]

ALAIN DURAND: Perfect. Alexandra, what do you do?

ALEXANDRA PAGLIARO: [inaudible].

ALAIN DURAND: Sanja, what do you do?

SANJA SIMONOVA: [I send it to you.]

ALAIN DURAND: You send it to me. Right? This is called hot potato routing. You have some information, you have somebody who knows better than you, you just pass it around. And then you hope that it will work. You take no further responsibility. Once a packet is sent, done, gone.

Remember my layer eight, financial? You don't want to keep the data with you, you want to send it to somebody else. If not, you're paying for it. you don't want to pay for it. Pass it along. It's very simple.

UNIDENTIFIED MALE: Why hot potato? Is it like you don't want to hold it for too long?

ALAIN DURAND: Yes, exactly, because the potato is hot and is burning your hand. It's like you're spending money every time you keep it, right? In your network, because from one router to the next, it's taking memory, fiber space and laser space and all of that. You want to give it to someone else. And when the potato arrives to somebody, it's still hot. It's going to be hot for quite a while, so you want to pass it as quickly as possible so that it eventually arrives to Oksana. Okay?

UNIDENTIFIED MALE: Maybe the analogy is keeping your desk then, having a clear desk, instead of having all these –

ALAIN DURAND: Yes. Exactly.

UNIDENTIFIED MALE: So you're not a lawyer.

ALAIN DURAND: Yeah, exactly. That works too. So, when you pass this data to me, Oksana, I am your service provider, there is somebody over there, his name so Mohamed, he's asked all of us to give you this piece of data. It is for you.

So then you can have a conversation with him and we simply reverse this entire path. We can have this three-way handshake that I played

with Cathy. You can play exactly the same thing here. And you can send your data.

So let's try it. For example, let's say ack to start the communication.

UNIDENTIFIED FEMALE: Ack.

ALAIN DURAND: Okay, I've heard "Ack." Hey. I have a message from Mohamed. Ack. Pass it along. You know now that she has received your communication. You have to remember, three way, you have to send it again.

UNIDENTIFIED MALE: Ack.

UNIDENTIFIED FEMALE: Ack.

UNIDENTIFIED MALE: Ack.

ALAIN DURAND: Ack. Okay, so now we have this communication. You have all these parties here in the middle, we are playing this game and being paid for it so that you and Mohamed can have this conversation. This is what the Internet is all about. And that way, I have arrived, I have seen Dr. Johnny Walker, he gave me some of his black medicine, and my tooth is feeling

much better. Thank you very much for coming with me on this journey to see Dr. Johnny Walker. If you have any question, now is the time. How much time do we have?

CATHY PETERSEN:

If you – oh, we still have 20 minutes for questions and comments. Please, just a reminder, give your name and affiliation before your question. Thanks.

MOHAMED ABUABED:

Mohamed Abuabed from fellowship program. We used to play something similar to this when we were a kid called broken phone, where we select a word and try to send it to as much people possible. And then at the other end, we see what is the word. And usually, it's not the same. Okay? And try to figure out where was the breaking point. So, my question here in the Internet world, if we have a broken router or someone manipulating the data, how we can isolate this?

ALAIN DURAND:

Okay. So, let's play this. What we are going to do is you are going to send a message to Oksana, okay? But you're going to add a specific option. The option is how many people are allowed to forward it. So, if you say zero, then nobody's going to receive it, right? So you start with one. Okay, let's start the game. Start with one, say, "I have this message for Oksana, one person maximum."

MOHAMED ABUABED: I have this message to Oksana, one relay only.

ALAIN DURAND: So, Indira, you have received this message. He says one relay. You are one relay. That's fine. You can pass it along. So, send a message to your neighbor.

INDIRA KOZHASSOVA: I have a message for Oksana, one person. One.

ALAIN DURAND: It was one relay, but you are a relay, so you have to remove one, so now it's zero relay.

INDIRA KOZHASSOVA: Now it's zero.

ALAIN DURAND: So you pass it, and you receive it.

UNIDENTIFIED MALE: I'm not Oksana, I get back not received.

ALAIN DURAND: So the message only arrives here, it does not know what to do with it, drops the message, and he sends an error message saying, "I couldn't do anything." So you send the error message back to Indira.

UNIDENTIFIED MALE: Indira, [inaudible] this error message.

INDIRA KOZHASSOVA: Send it back to Mohamed.

ALAIN DURAND: Okay. Now you start again, but instead of putting relay one, you set relay two. Let's play it.

MOHAMED ABUABED: Okay. I have this message to two relays to Oksana. Two relays.

ALAIN DURAND: Okay.

INDIRA KOZHASSOVA: Passing message.

ALAIN DURAND: How many relays?

INDIRA KOZHASSOVA: One relay left.

UNIDENTIFIED MALE: Message to Oksana, zero relays.

UNIDENTIFIED FEMALE: I'm not Oksana, so the message is going back.

ALAIN DURAND: Exactly. Okay, message going back, going back, going back. And that way, you can figure out how many hops it goes through. And let's say for a second I am the one who doesn't receive – we're going to mess up with it. Okay? So, two relays, you arrive to him. You arrive there. Three relays, you will arrive here. Four relays, you will arrive to me, and you don't receive anything after that. You know I am the one that has a problem.

This technique is called traceroute, so you can figure out who is dropping the packets. Another question. Alexander.

ALEXANDER TIMOSHENKO: Alexander Timoshenko from Google. The question is about timeouts. At what stages timeout can be configurable during the whole chain of sending a message?

ALAIN DURAND: So, there are no exact timeouts per se, but there is a maximum hop count. So you were sending the message with zero, then one and two. The maximum can be sent to whatever people want. The maximum of the maximum is 255. It's an 8-bit value, so can put up to maximum 255.

Most of the time, people put 64. And this number, that is the maximum number of relays that you have to go from one point to another. Has been over the years growing, then shrinking, then growing, then shrinking. At some point, it was about 10, then it went to 20, 30, 40, and then things got more interconnected and it went down, went back up. But typically, people put 64 these days.

So it's not measured in milliseconds or in seconds, it's measured in the number of hops. Next question?

UNIDENTIFIED MALE:

Talking about timeouts, what kind of applications where you would want to specify or configure timeouts to a certain – are there applications where you'd specifically want to say, "Well, okay, maximum hops always to be X?"

ALAIN DURAND:

So, when we have diagnostic tools, like the one we just used with Mohamed, it's very convenient for the application to be able to say, "I want this number of counts, but no more." For regular application, most of the time, they just don't care. They just put whatever is the default and put 64 and be done.

The reason we put this hop count is to avoid loop. Imagine now that you have a misconfiguration. Instead of sending the traffic for Oksana to Rudy, you send it back to Alexander. Let's play how it will work. So you send it with the maximum count of 64. Okay? Send your message.

UNIDENTIFIED MALE: [inaudible] Oksana, maximum hops is 64.

SANJA SIMONOVA: Passing [by and] 63 left.

ALAIN DURAND: Okay. Alexander?

ALEXANDER TIMOSHENKO: Message to Oksana, relays, 62.

SANJA SIMONOVA: Message to Oksana, 61.

ALEXANDER TIMOSHENKO: Message to Oksana, 60 relays.

ALAIN DURAND: Who are you sending it to?

ALEXANDER TIMOSHENKO: To Oksana.

ALAIN DURAND: Yeah, but [inaudible]

ALEXANDER TIMOSHENKO: Ah [inaudible] to Sanja.

ALAIN DURAND: To Sonja.

SANJA SIMONOVA: Message to Oksana, 59.

ALAIN DURAND: So it's going to ping pong all the way – 60 times, essentially, all the way to zero. And at some point, one of you, let's say [inaudible] zero. What do you do?

ALEXANDER TIMOSHENKO: Just error message, it's not received.

ALAIN DURAND: [Exactly.] But if I don't put this maximum count, then it will be forever going between those two guys. The fact that I have a maximum count at 64 means that if there is a loop like this, it will be dropped. Another question?

UNIDENTIFIED MALE: When we talk about the Internet networking, I usually hear about the two famous model, OSI and TCP/IP. So, what different between the OCP and TCP/IP?

ALAIN DURAND:

So, this OSI model is what I started the presentation with, where it was different layers. And originally in OSI, there were seven layers. Okay? I showed you ten layers, from zero to nine. I expanded a little bit on each side.

This is a conceptual model. When you actually write code, you never do that. People tried to do that and write code for each of those different layers, and it became extraordinarily complicated and never worked.

So people said, “It doesn’t make sense, we need to collapse some more things when we actually write code.” So in the TCP model, most of those things have actually been collapse, and what you really have is things up to layer three, this is for switches, and things above layer three, this is TCP [inaudible] and the application on top of TCP.

So from an application perspective, the model has been collapsed into less layers. Those layers are very interesting to talk about the network, to conceptualize some ideas, but when you actually write code, you don’t want top do that. It is too difficult. Question? Going once, going twice.

Well, I think you still have another, what, 10, 15 minutes of your free time. We give it back to you. Don’t spend it all in one place. Thank you for coming.

UNIDENTIFIED MALE:

Thank you.

CATHY PETERSEN:

Thank you, everyone. Thank you, Alain. Our next How it Works tutorial is regarding root server operations, and I think we are starting at 3:15, so you have a few minutes to stretch your legs, get a cup of coffee or something. Same room.

Slide materials that Alain presented have already been uploaded to the public schedule. The recording and transcript for this session will also be added to the public schedule within a week or so. Thank you.

[END OF TRANSCRIPTION]