Network Security

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Week - 01

Lecture - 03

Review of Basic Concepts and Terminology in Communication Networks: Part 1

Hello, in this lecture and the next few lectures, we review the necessary background from communication networks. We will review some basic concepts and terminology from communication networks. This figure shows the components of a typical network, such as the internet. So, the different components are as follows. First we have the sources and sinks of data, which are shown here.

They consist of different user computers like these smartphones, like these, and servers like this one, and so on. So, these are known as end systems or hosts in communication network terminology. So, they generate data and/or they download data. For example, this server might send a file. A user connected to this desktop might download an email, and so on and so forth.

So, there are these sources and sinks of data called end systems or hosts. These end systems, or hosts, they run various network applications which are familiar to us, such as web, email, file transfer, and so on. And apart from these end systems, there are also routers, which are shown here by these blue icons. They transport the data exchanged by end systems between different end systems. For example, a file might be transferred from this server to this client through these routers.

So, this server might send its file to this router, which forwards it to this router, which forwards it to this router, which forwards it to this modem, which forwards it to this end system. So, there are these routers, which transport the data exchanged by end systems. Routers don't generate any data nor do they download any data. And finally, we have communication links, which are shown here connecting the different end systems and routers together. They are made up of various media, such as fiber, copper, wireless, and so on.

This picture shows the contrast between end systems and routers. The figure on the left shows end systems. The end systems are highlighted in red. So, in this picture in particular, there is a desktop computer downloading some data from a server. So, the server and the desktop computer are the end systems.

And the figure on the right shows routers highlighted in red. So, these routers are shown by the blue icons, and they transport data exchanged by different end systems. This example shows a fragment of the internet. So, we can see that the internet consists of a large number of networks connected together. It is a network of networks, hence the name internet or internetwork.

So, let's go through a few of the networks that constitute the internet. Here we have an enterprise network or a corporate network. There are different desktop computers and laptops of the employees. And there are different routers, which route the data among the end systems and the servers. Servers are shown here. They might store company emails, files, and so on.

And there are also smartphones and laptops which connect wirelessly to the company's network. So, this is an enterprise network. This is a mobile network. It might be 2G, 3G, 4G, or 5G based. So, it consists of a base station and several wireless devices, such as smartphones and laptops, in its range.

They exchange data wirelessly with the base station. This one and this one, they show typical home networks. In the case of a home network, there is internet connectivity to the rest of the internet via some technology such as digital subscriber line (DSL), or cable internet, or fiber to the home, and so on. And a typical home network consists of a router and a modem, which connects it to the rest of the internet via DSL, FTTH, or cable internet, and so on. And there is a wireless router, or a Wi-Fi router, which provides wireless connectivity to the smartphones and laptops within the home.

And the router also provides wired connectivity to the desktop computers in the home. So, this is a home network, and this is also a home network. And this network and this network, they are what are known as ISP networks or Internet Service Provider networks. An ISP is a company, such as Airtel, Vi, Tata Communications, Sprint, AT&T, and so on. It owns a network of a large number of routers and communication links.

And these ISPs, they connect together different access networks and the networks to which end users connect. So, we can see that this mobile network, these home networks, and this enterprise network, they are all connected together by these ISP networks. ISP networks operate at different scales. Some are local or regional. They might operate only within a city or a town and so on.

Some are national or global based. They might even span different continents. So, these ISPs, there are thousands of such ISP networks in the internet. They are all connected to each other. So, this shows a fragment of the internet. Now, one term that often arises in networking is distributed algorithm, also known as protocol.

So, most problems in networking require distributed solutions. Examples of such problems are routing, reliable data transfer, medium access control, congestion control, and so on. We'll discuss these different functions later on. In such a problem that requires a distributed solution, there are two or more entities at different locations. Examples of such entities are computers and routers.

These are at different geographical locations, and they need to jointly perform a task. This task might be finding routes or reliably transferring data or sharing a medium among themselves or controlling the congestion in a network and so on. So, these entities at different locations, they need to jointly perform a task. And to accomplish this task, they can take some actions locally, such as sending a message, starting a timer, stopping a timer, receiving a message, and so on, and they can exchange messages among themselves for coordination. So, this is a distributed algorithm, an algorithm which accomplishes such a task.

So, two or more entities at different locations, they exchange messages among themselves, and they perform some actions to accomplish a task jointly. Such an algorithm is known as a distributed algorithm or protocol. So, an algorithm to perform such a task is called a distributed algorithm or protocol. Examples of such protocols are TCP, which stands for transmission control protocol. It is a transport layer protocol.

We'll discuss layers later on. But this TCP performs different functions, such as congestion control, reliable data transfer, and so on. OSPF and RIP; they stand for open shortest path first and routing information protocol. They are routing protocols in the internet. They find routes among different routers and systems.

So, a distributed algorithm or protocol specifies the format and order of messages exchanged among network devices as well as the actions that are taken on message transmission, receipt timeouts, and other events. So, one of the functions of network engineers is to design efficient protocols or distributed algorithms to accomplish different tasks. As an example, this shows a simple protocol to transfer a file from this server to this desktop. The vertical axis is the time axis. First of all, this desktop sends a message requesting the connection to be set up between the server and the client.

Then this server responds with a response message which accepts the request. So, the reason for setting up this connection is so that the necessary variables can be initialized on both sides, and the required buffers can be set aside for storing parts of the file that will be subsequently transferred. So first, via these two messages, a connection is set up, and then the client requests for a particular file from the server, and then the transfer of the file starts from the server to the client that is shown by this arrow. So, this shows a simple protocol to transfer a file from a server to a client. We now discuss different networking architectures.

Broadly there are two kinds of architectures in a network. Circuit switching is extensively used in the telephone network, and packet switching is used in the internet. There are also hybrid architectures which use a combination of circuit switching and packet switching. So, let's understand what each of these architectures means. So, suppose data is to be exchanged between two different end systems, which are shown here by the red highlighting.

So, there are two architectures that can be used to accomplish this. One is circuit switching, which is used in telephony, and the other is packet switching, used in the internet. So, in the case of circuit switching, link bandwidth is reserved end-to-end. That is the necessary bandwidth that will be required for a particular call that is reserved end-to-end. So, the required bandwidth is reserved on every link between the two end systems. And in contrast, in the case of packet switching, which is used in the internet, there is no reservation of bandwidth in advance.

Instead, bandwidth and buffer space are allocated on demand. So, that means that if a server wants to send a file to a client, then it just breaks the file into chunks called packets and then sends the different packets independently over the network towards the client. So, it adds the destination IP address of this client to each packet, and then sends each packet independently over the network. And when a packet arrives at a particular router, it is allocated the available buffer space and the necessary bandwidth to be sent out on the outgoing link. So, packets may have to wait or may be dropped because there is no reservation of bandwidth that will be required for a data transfer.

Instead, when data is generated, it is just broken into packets, and sent without any reservation in advance. So, let's discuss circuit switching in more detail. Consider an end system A. So, let's suppose this is end system A, and this is end system B. They want to communicate over a network. Let's illustrate the network by a cloud. So, this is a network, and there are many routers in this network.

So first of all, before the call between A and B starts, a path is identified which consists of many routers from A to B. So, suppose this is the path identified for the call from A to B. Then the bandwidth of each link on this call path is divided into pieces either via FDM, that is, frequency division multiplexing, or time division multiplexing. So, it is broken into pieces called frequencies; these pieces might be frequency slots or time slots. And one or more pieces are reserved for each call. So, for example, on this link, there might be 100 pieces and one piece might be reserved for each call. So, call setup is required before a given call can start.

So in call setup, control messages are exchanged among the routers of the network, and they reserve the necessary bandwidth along the full path from A to B. So in this example, control messages are exchanged among different routers to reserve the required bandwidth for this call. Suppose this call requires 64 kbps of bandwidth. In that case, in this entire path from A to B, 64 kbps of bandwidth is resolved on each link from A to B. So, this is done via the exchange of control messages. So, hence, when you make a telephone call, there is an initial delay before the call starts. So, this delay is because this call setup process runs, and the necessary bandwidth is reserved on a path from you to the destination.

So, an advantage of circuit switching is that it provides guaranteed call performance. Once the call has been set up, all the bandwidth it requires will be available. There's a question of the callers running out of bandwidth because the required bandwidth is reserved from end to end. But circuit switching has some disadvantages. The reserved bandwidth is idle if it is not used by the owning call.

And this reserved bandwidth cannot be used by other calls. So, in the previous example, 64 kbps was reserved for the paths from A to B. If A and B are not using the call, they might be idle, or they might be thinking, or they might be away from their telephones. In that case, the bandwidth is idle. It cannot be used by other calls. So, there is some wastage of bandwidth. Another disadvantage is that once all the pieces of link bandwidth are reserved, new calls are blocked.

So, there might be a large number of users using a network. So, maybe some 50 users are currently using calls. If another user wants to make a call, then there might be no available bandwidth for making the call. All the pieces of link bandwidth might be resolved, so then new calls are blocked. So, in this case, a person making a call will receive a message: Network busy.

So, their call will not go through. So, to summarize, guaranteed performance is achieved at the expense of waste of resources under circuit switching. So, now let's discuss packet switching, which is used in the internet. So, to compare packet switching and circuit switching, circuit switching is suitable for traffic, such as voice calls and video calls, that is real-time traffic, whereas packet switching is suitable for data kind of traffic, such as web transfers, file transfers, and so on. All the packet switching can also support voice calls and video calls.

Fine, so we now discuss packet switching in detail. So, suppose this end system A wants to send some information to this end system C, and B wants to send some information to end system D. So, first of all, the file to be transferred is broken into small chunks of 1000 bytes each. The size of packets is variable, but it is typically about 1000 bytes or so. These chunks are called packets. There are different reasons for breaking a file into small chunks.

So, for example, it can be shown that the transfer is faster when the file is broken into chunks as opposed to sending the entire file in one go. So, there are multiple reasons for breaking the file into chunks, which we won't go into. So, yeah, the file is broken into chunks, so these packets are shown here. Then a destination IP address is added to every packet, and the packet is sent over the network. There is no bandwidth reserved in advance.

So, what A does is it breaks the file into packets and adds a destination IP address as well as its own source IP address and some other fields to the packet, and it sends the packet towards the destination, that is, C. There is no reservation of bandwidth in advance. When a packet arrives at the router on its path, so for example consider a packet arriving from A to this router. If the outgoing link is free, then the packet is transmitted immediately. So, in this case, this packet is to be sent from this router to the next router on the path to C. So, if this outgoing link is free, then the packet is transmitted immediately. Otherwise the packet waits in a queue for its turn to be transmitted on this outgoing link.

So, this queue of packets is shown here. So, queue means that in a buffer within the router, the packets wait in the form of a queue. That is, the first packet that arrives is sent first, and then the next packet is sent, and so on. So, these packets wait in a queue for that turn to be transmitted on the outgoing link. The link bandwidth is not divided into pieces unlike circuit switching.

Each packet uses the full link bandwidth. So, for example, this link is 1.5 Mbps. Each packet will be sent at this rate of 1.5 Mbps from this router to the next router. So, let's discuss the advantages and disadvantages of packet switching. An advantage of packet switching is that it supports more users than circuit switching can support.

We'll discuss a numerical example later, which illustrates this. There is no concept of call blocking. As more and more users get added to the network, they start seeing the longer delays until their data is transferred because packets wait in a queue for their turn to be transferred. So, the delays get longer but there is no concept of call blocking. So, unlike circuit switching, where there is a hard limit on the number of users who can be supported, in packet switching just the delays keep on increasing, and packets start getting dropped if the routers run out of buffer space, but there is no call blocking.

So, these are the advantages. The disadvantages of packet switching are as follows. The total resource demand can exceed the amount available. For example, we see that this link has speed 1.5 Mbps. If the total rate at which packets arrive from A and B towards this router exceeds 1.5 Mbps, then the queue will start growing at this router.

So, for example, if the total rate from A and B is, say, 2 Mbps, then the queue will start increasing. This is known as congestion, where it is similar to traffic jams in vehicular networks. So, when congestion happens, packets wait in a queue for their turn to be transmitted on the link. So, this results in a delay, which is known as queuing delay. This is a disadvantage for real-time services such as calls and video streaming.

For example, if there is a call between users A and B, then if the end-to-end delay from A to B is more than about 200 milliseconds or so, then the quality of the call is a bit poor. So, the end-to-end delay has to be small for real-time services, such as calls and video streaming. So, this is a disadvantage for real-time services. So, that's the reason that circuit switching was chosen for the telephone network. Yeah, but if there is enough bandwidth in a packet-switched network, then we can support real-time services well.

Packets are dropped if buffer space is unavailable, and they need to be retransmitted. So, in this example, consider packets arriving from A. So, the queue starts growing whenever the total rate at which A and B transmit data exceeds 1.5 Mbps. Eventually the entire memory available with the router will get full, and then what happens to new packets that arrive? They are dropped because there is no space to store them in the buffer.

So, they need to be retransmitted by A, so A has to somehow detect that a packet that it sent was dropped by an intermediate router, and it has to resend the same packet. So, this retransmission results in additional delays, and it results in a waste of bandwidth because the same information has to be transmitted again. So, these are some disadvantages of packet switching. So, to compare packet switching and circuit switching, packet switching can support more users than circuit switching since usually traffic is intermittent and bursty. By intermittent traffic, we mean that traffic starts and stops; it is not steadily sent.

And by bursty we mean, an example is web page browsing. So, when you might click on a link and read a web page contents, and then a burst of data, burst or a chunk of data is transferred. So, the web page is transferred, which might be, say, 1 Mb. Then, after some time, you click on another link, and start downloading another web page. So, that results in the download of another burst of data, so traffic is bursty.

It is in the form of chunks of data which are intermittently sent. So, for such traffic, packet switching can support more users than circuit switching. As we'll see an example which illustrates this. So, here's the example. There are N users, who share a 1 Mbps link.

The N users are S_1 to D_1 and up to S_N to D_N. So, the first user has source S_1 and destination D_1. And the N^{th} user has source S_N and destination D_N. They all share this 1 Mbps link. So, S_1 sends its data through this 1 Mbps link to D_1.

S_N sends its data through this 1 Mbps link to D_N and so on and so forth for the other sources, S_2 to S_{N-1}. So, assume that each user is active for 10% of the time sending data at 100 Kbps and is idle for the rest of the time. So, what is the maximum value of the number of users N that can be supported by circuit switching? So, recall that in circuit switching, the required bandwidth for a call is reserved in advance. Since each user requires a peak rate of 100 kbps, we need to reserve 100 kbps for every user on this link.

So, hence, the maximum value of N is obtained by noticing that this 1 Mbps bandwidth is divided into parts of 100 kbps each. So, hence, the number of users that can be supported is 10. So, hence, 10 users can be supported in circuit switching. Now, let's discuss what happens if we use packet switching and we use, if there are 11 or more users. So, $N \geq 11$.

When will there be congestion? Note that these users are intermittent. They don't always send data. A user sends data only for 10% of the time, and for the remaining 90% of the time, the user is inactive. Now, there is congestion when there happen to be 11 or more simultaneous users.

Otherwise, there is no congestion. So, if there are 10 or fewer active users, then the total rate at which data comes in at this router is less than or equal to 1 Mbps; in that case, there is no congestion. But if there are 11 or more simultaneous users, then the total rate at which data comes in at this router is more than 1 Mbps, and then there is congestion. There is a queue start growing at this router, and eventually it starts dropping packets. So, there is congestion when there are 11 or more simultaneous users; otherwise, there is no congestion.

So, let's find out the probability of 11 or more simultaneous users. So, we assume that at a random instant, a given user is active with probability 0.1, and inactive with probability 0.9. So, we assume that because of this, that a user is active for only 10% of the time, that is, for 0.1 fraction of the time. So, each user is active for a fraction 0.1 of the time. So, what is the probability of 11 or more simultaneous users?

First, let's find the probability that there are exactly k simultaneous users. So, the probability that there are exactly k simultaneous users is this, $\binom{N}{k}(0.1)^k(1-0.1)^{N-k}$.

That's because the k users who are active can be chosen from the N users, in $\binom{N}{k}$ ways.

And the probability that they are all active is, $(0.1)^k$ because each user is independently active with probability 0.1. And the probability that the other N-1, k users are inactive is, $(1-0.1)^{N-k}$, so, hence, this is the probability that there are exactly k users who are active.

Now, if we sum up this probability from k equal to 11 to N, then we get the probability that there are 11 or more simultaneous users. So, hence, this is the probability that there are 11 or more simultaneous users. If we substitute, N equals 35 in this expression, then we get a probability of 4×10^{-4}. So, notice that this is an extremely small probability. So, even if there are as many as 35 users, which is three and a half times the number of users of circuit switching, the network will be congested only for a fraction of time, 4×10^{-4}, which is extremely small.

So, the rest of the time, the network will have plenty of bandwidth to support these 35 users. So, in this example, packet switching supports three and a half times the number of users that circuit switching supports very comfortably. Notice that this happens because the traffic sent by users is intermittent. The traffic is not continuously sent but it is intermittent. It is sent for some time, and then the traffic sending stops, and then it resumes after some time.

So, for such traffic, packet switching can support many more users than circuit switching. So, this concludes our discussion of circuit switching and packet switching. Thank you.