FUNDAMENTALS OF TELECOMMUNICATIONS

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Contents

Summary

Telecommunications is one of the most dynamic industries that builds upon advances on networking, computing, electronics, and manufacturing. In this article, we provide an overview of the basics of telecommunications and concentrate the discussion on fundamental concepts and technologies in telecommunications. The coverage includes telephony networks and the Internet. Future outlook and a discussion of the on-going convergence between these two separate networks are included.

1. Introduction

Webster defines telecommunication as communication at a distance. The IEEE Standard Dictionary [1] defines telecommunication as the transmission of signals over long distance, such as by telegraph, radio, or television. The telecommunication industry is one of the largest industries in existence today. INSIGHT Research [2] predicts that worldwide telecommunication carrier revenues to grow from under $1.2 trillion in 2005 to just over $1.5 trillion in 2010 with an overall compound annual growth rate (CAGR) of 5.9 percent.

Since its inception, telecommunication has driven human progress. There is a direct relationship between the well-being of a society and the state of the telecommunications infrastructure. One of the most important indicators in which countries are assessed in the UNDP Human Report is the tele-density (defined as number of fixed or mobile phones per 1000 inhabitants). The average tele-density in high human development regions is 495, while for low human development regions, it is just 8 [3]. Not only it is a great industry by itself, but it has driven advances in electronics, computing, software, manufacturing, management practices, etc.

Many think of telecommunication systems as those dealing with telephony systems. We adopt the notion that telecommunication is the electrical communication at a distance of information whatever its media is. The media can be voice, data, image, or video. Ubiquitous telecommunication cannot be realized economically without networks that connect multiple communicating entities. We concentrate our coverage on the basics of networks covering topics such as types of networks, switching and multiplexing, example network technologies focusing on public-switched telephone network (PSTN), the Internet, and the Open System Interconnect (OSI) Model.

2. Types of Telecommunication Networks Procedure

Generally, telecommunication networks can be classified into two main categories: broadcast networks and switched networks. This is depicted in Figure 1. In broadcast networks, a sender sends a unit of information over a shared medium. The shared medium is typically a bus in the wired medium or a specific frequency band in the wireless medium case. Any receiver connected to the medium can listen and receive the sent information. Examples of broadcast networks include Ethernet/IEEE 802.3 [4] and WiFi/IEEE 802.11x based networks [5]. Usually broadcast networks suffer from limited coverage. This is attributed to the shared medium characteristics. In essence, a shared medium can only be used by one sender at a time. If two or more nodes send in the same time, a collision is said to occur and information is lost. Therefore, there must be a mechanism to coordinate access to the shared medium. Such a mechanism is called media access control and it involves either limiting access to one sender at a time, or detecting of collisions and taking corrective actions to prevent loss of data occurring from collision. Usually media access control involves communication between nodes sharing the bus. In order to limit the time needed to coordinate the media access, the maximum distance over the shared media should be limited. Therefore, most broadcast networks are limited in distance. For example, the maximum distance for IEEE 802.3 is 200 meters and 2500 meters for the case of unshielded-twisted pair media and coaxial cable media with 4 repeaters respectively [4].

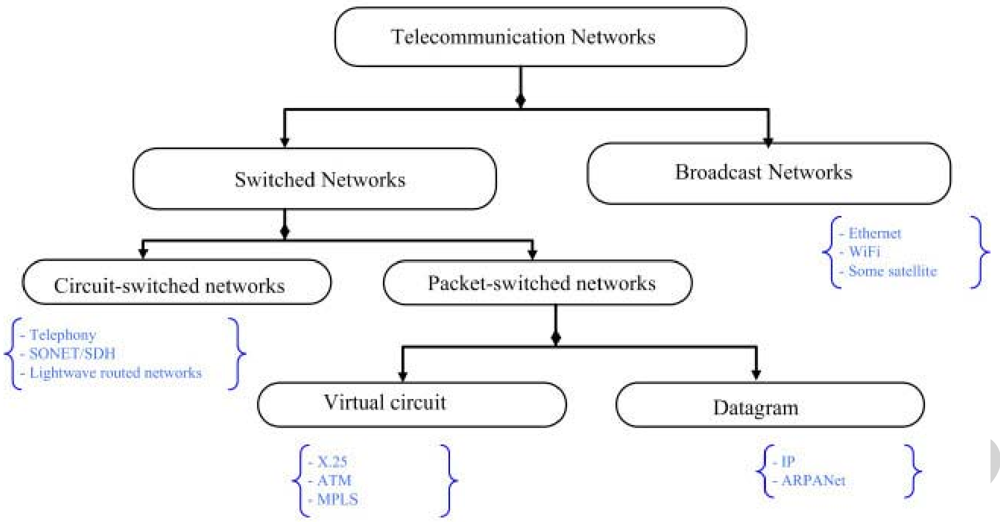

Figure 1: Classification of Telecommunication Networks

Switching is defined as the operation of forwarding a unit of information from one place to another. Switching is the main mechanism through which the construction of a network serving a large number of users becomes feasible. Switching importance can be illustrated from the following example. Consider the situation in Figure 2. Let us consider two users “Ahmad” and “Thomas” with two telephone sets. In order for them to communicate we can extend a direct link between the two telephone sets. Now consider a third user “Sarah” wants to join the network, then we will extend a link from Sarah to both Ahmed and Thomas. Now, with an additional user “Li” we have to extend additional links to all previous users. Things start to get ugly as additional users are added. Now think of connecting the thousands of telephone sets in even a single large high-rise building (needless to say the billions of phone sets on the planet) and we have an infeasible problem. In general for the case of N users, we need $N(N-1)/2$ links to connect all users by direct links. Such mechanism is doomed to fail for two main reasons: 1) Economies of scale: an operator cannot build a profitable network if there is no reuse of the resources 2) Engineering infeasibility: as the number of links grows quadratically with the number of users, we will run out of space and wires (as well as the stamina needed) to wire a large network.

This is where switching comes into the rescue. Instead of providing one to one connection for each potential pair of communicating nodes, a special purpose node will be provided to connect the nodes together on an on-demand basis. This node is called a switch. Each node is connected to the switch via dedicated link. When a particular node X wants to establish a connection to node Y, it “signals” the switch of its desire to connect to the destination node Y, the switch will determine if it has a “path” to the given node and if so establishes a connection between the two nodes. Once there is no need for the connection, either one of the end nodes will again “signal” the switch of its desire to terminate the connection. The path would minimally consist of two links: the first from the source node to the switch and the second from the switch to the destination.

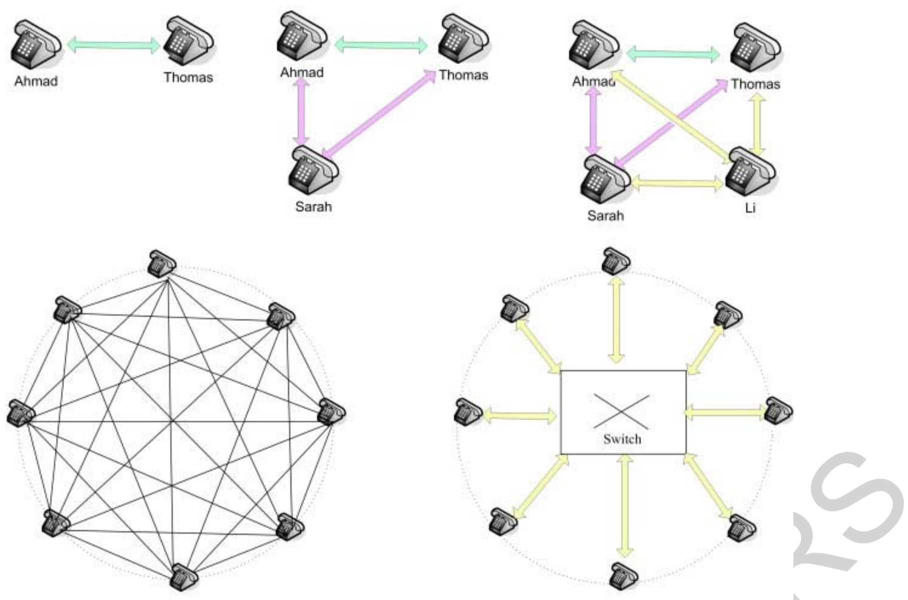

Figure 2: Switching versus dedicated connections

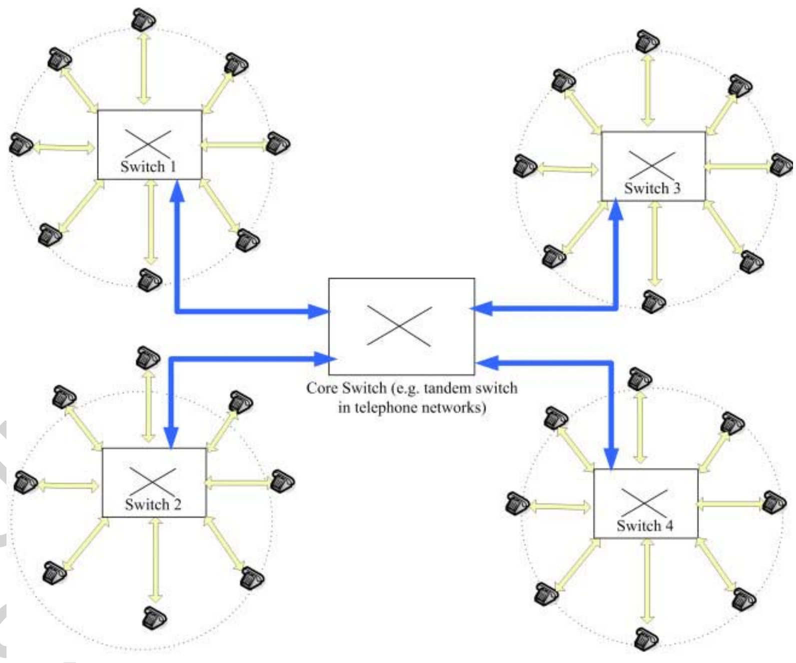

Figure 3: Construction of large switched networks

The above scenario can be adequate for a small number of nodes, now when the number of nodes grows to thousands or millions, a single switch will not be able to scale to the large size. The solution will be to introduce levels of switching. The end nodes are usually connected to an "access" switch. A set of access switches will be further connected by "core" switches that can be interconnected among themselves to form a complex hierarchical network topology as shown in Figure 3.

Definition: Switching is defined as the operation of forwarding a unit of information from one node to another via two or more links and using at least one intermediate node.

Switched networks can be classified into circuit-switched and packet-switched networks as illustrated in Figure 1. The most well-known examples of the two types are the PSTN and the Internet respectively. Furthermore, packet-switched networks can be categorized into datagram packet switching and virtual circuit packet switching. In the following subsections, we provide more information about each of these types of networks.

2.1. Circuit-Switched Networks

In circuit switching the unit of switching is a "circuit". To transfer information between two nodes a circuit is setup from the source node to the destination node by signaling the switches in the chosen path between the two nodes. All information between the source and destination are transmitted over the established circuit. This circuit is kept open as long as there is a need to transmit information between the source and destination nodes. An important characteristic of circuit switching is that all resources needed by the circuit are allocated exclusively for this circuit. These resources are typically some capacity on the communication links and a form of a "state machine" in the switches that keeps information about the circuit (e.g., the source and destination nodes, the duration of the connection, the capacity used for the connection and so on).

As said previously the source node establishes the connection by signaling its access switch. The access switch usually has some intelligence to determine how the destination could be reached. If it does not it usually consults other switches in the network. If no path is known to the destination or if the network cannot accommodate the new connection request, a signal is provided back to the user.

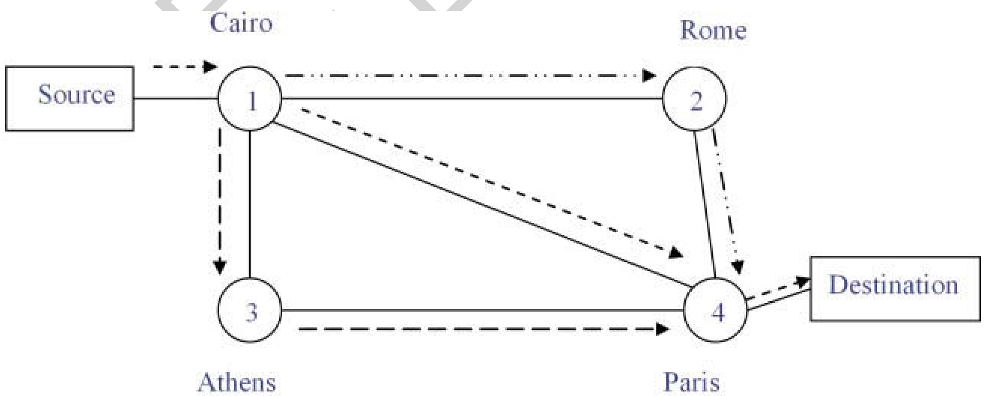

Figure 4: Circuit establishment in circuit-switched networks

Consider the example in Figure 4; assume a node in Cairo wishes to communicate with a node in Paris. The Cairo node will signal its switch node 1, which will then decide that to reach the node in Paris; it should connect via switch 4. If all capacity between 1 and 4 is used up, it should try other paths such as going through the path Cairo -> Rome -> Paris, or the path Cairo -> Athens -> Paris.

The best known network that is based on circuit-switching is the successful pubic switched telephone network (PSTN). We will inspect PSTN more closely at Section 5.1.

2.2. Packet-Switched Networks

For decades, circuit switched networks were the only dominant type of networks available. In the early 1960's researchers in various parts of the world were busy exploring alternative forms of network building [6]. Possibly the most well-documented effort was that of the Advanced Research Projects Agency (ARPA) of the United States. At that time the cold war between the US and the ex-Soviet Union was at its peak. ARPA put out some request for proposals for building networks that offer utmost reliability for connecting critical operations and military control centers. In essence ARPA envisioned networks that can survive and operate even under massive nuclear attacks. And thus packet switching was born. We will see in a while why packet networks offer such reliability.

In packet-switched networks the unit of switching is called a packet. A packet is a typically "small/medium" sized unit of data logically consisting of a header (control information) and payload (actual data to be transmitted) as shown in Figure 5. A message containing some information to be transmitted from the source to the destination node is divided into a number of such packets. The actual data is placed in the payload part of the packet. Since the packet size typically has some maximum size and is desired to be kept small, it is expected that the original message will be divided into a number of packets. The header would contain control information needed for processing the packet inside the network. For example, the header would contain information about the destination and source nodes network addresses, the length of the payload/packet, and some rules for processing the packet in certain fashion inside the network (e.g. priority, sequence, time stamps, header/payload error check bits, etc).

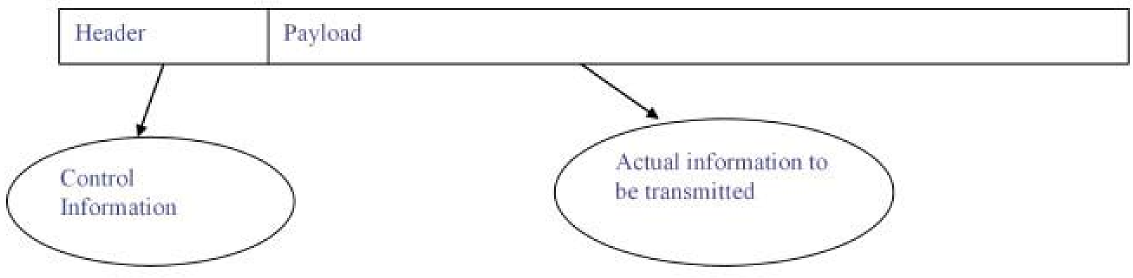

Figure 5: The format of a packet

The key concept in packet-switched networks is based on each packet being switched independently of other packets whereas switching is done by inspecting the packet's header information at each intermediate switch. This form of packet switching is known as datagram packet switching (DGPS) in analogy to telegrams that typically contain short messages.

In circuit switched networks, dedicated resources are allocated to a connection during its life-time. This provides isolation between connections and thus the quality of service for a particular connection can be provisioned as desired. However, this usually leads to inefficient use of the network resources (see Chapter 3 of Bertsekas and Gallager [7]) since for many traffic types, the connections are not always in the transmission mode and thus a large portion of the network capacity goes unused and the efficiency of utilizing the available resources is low. In contrast, in packet switching more efficient use of resources is possible since there is essentially no allocation of the resources to the connections. Allocations are done on a packet-by-packet basis where packets share the network resources. Some form of resource sharing scheme is used to arbitrate the access to the shared resources.

Since each packet is switched independently, this provides a more resilient form of connecting the end nodes. In circuit switching, if a particular link fails, all connections passing through the link are terminated. In packet switching, since packets are switched independently, it is possible to route around the failed links by using an alternate path given that the network topology and link loading state allow such routing.

The best known example of DGPS is the Internet based on the Internet Protocol (IP) [8].

2.2.1. Virtual-Circuit Packet Switching

Datagram packet-switched networks offer good properties with respect to resilience and adaptability. However, the main problem here is the lack of quality of service (QoS) control, with no strong control on packet delays or loss. Usually, datagram packet switching offers what is called a best-effort service. The packets are injected into the network, if the network loading is low, the perceived service will be good. If the network load is high, the performance will degrade.

Virtual-circuit packet switching (VCPS) offers a midway between circuit switching (with its strong resource reservation and QoS control) and datagram packet switching. In VCPS the unit of switching is still a packet; the main characteristic of VCPS is the establishment of an association along the network between the two end points of the communication before data is actually transmitted. This association records information about the connection characteristics, such as the end-points, the requested bit rate and other QoS parameters, the connection’s path, and information needed for the forwarding of packets. This association is called a “virtual circuit” and is kept along each node in the path between the two end points.

VCPS borrows the concept of signaling from circuit-switched networks. A connection establishment phase precedes the actual transfer of data. During this establishment phase, each switching node will calculate a locally unique number that should refer to this connection afterwards. This number is known as the virtual circuit identifier (VCID) and is used to switch packets along their way. Each packet will contain a VCID that distinguishes it from other connections’ packets rather than a full source and destination network address. When a packet arrives into a certain switch port, it inspect the packet’s input VCID (as told by previous node) and then finds its local VCID and exchanges the input VCID with the its local VCID (the output VCID) and determines the output port over which the packet is to be forwarded, and finally forwards the packet to the output port. The association between the input VCID, input port, output VCID, output port, and the connection's QoS parameters is created during the connection establishment phase, and released after the data transfer is complete. The association is kept in what is typically known as a "virtual circuit routing table".

In essence VCPS offers the efficiency of DGPS but offers the flexibility of better control on network QoS and resources. The best known example of VCPS is Asynchronous Transfer Mode (ATM) networks [9]. A comparison between DGPS and VCPS is provided in Table 1.

	Datagram	**Virtual circuit**
Circuit setup	Not needed.	Required.
Addressing	Each packet contains full address and destination address.	Each packet contains a "short" VC number.
Routing	Each packet is routed independently.	Route is established at connection setup.
Robustness to failure	Exhibits better robustness to failures.	When a failure occurs all VC's need to be reestablished.
Congestion occurrence probability	More likelihood of congestion occurrence.	Exhibits better control that should avoid congestion occurrence.
Reaction to congestion	Better ability to handle congestion on a per-packet basis.	Rerouting needs to be done for affected VC's.
Example network technologies	IP networks, Ethernet.	ATM, frame relay, X.25

Table 1: Comparison between datagram and packet switching

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Biographical Sketch

Khaled M. F. Elsayed received his Ph.D. in Computer Science and Computer Engineering from North

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He is now an associate professor of networking and communications in Cairo University and a technical director with SysdSoft where he is leading the implementation of mobile broadband systems. Previously, he has been with Nortel Wireless Systems Engineering at Richardson/TX and ITWorx. His work in Nortel was influential in the realization of the MTX-CDMA wireless product. His work with ITWorx as chief architect resulted in the realization of the NetCelera network appliance that was acquired by SwanLabs and eventually by F5 Networks. He had adjunct positions with the American University in Cairo and the Egyptian National Telecom Institute.

Dr. Elsayed area of research is quality-of-service support in multi-service packet networks and resource management in wireless networks. He has more than forty publications in refereed international journals and conferences. He was an editor for the IEEE Communications Magazine from Nov. 1998 till Dec. 2002. He has also been a member of the technical program committees and session chair for several IEEE, IFIP, and ITC conferences. He was the technical program co-chair for the IFIP MWCN’2003 conference in Singapore. He has also worked as an expert evaluator and panelist for the European Commission in Brussels for evaluating the research proposals submitted to the EU FP6/FP5 IST and TEMPUS programs.