A Concise History of the Internet–I*

V. Rajaraman

In this two-part article, I trace the history of the Internet. The Internet started in 1969 as an experiment by the Advanced Research Projects Agency (ARPA) of the US Department of Defense to use packet switching on leased telephone lines to connect four mainframe computers. Email was invented in 1971 and it became a "killer application" as it promoted easy interaction among its users. By 1972, fifty computers were connected using leased telephone lines to form what was known as the ARPANET which was successfully demonstrated at an international conference – ICCC 72. ARPANET was followed by Packet Radio Network (PRNET), which connected mobile computers, and Satellite Network (SATNET), which connected computers in Europe with those in the US. A protocol named Transmission Control Protocol/ Internet Protocol (TCP/IP) was invented in 1973 to interconnect ARPANET, PRNET, and SATNET. The success of the TCP/IP protocol in connecting disparate networks paved the way for the development of the Internet.

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Introduction

The Internet today is an essential infrastructure utility like electricity and water supply. Waking up in the morning we read news feeds or tweets on our mobile phones or tablet computer connected wirelessly to the Internet. The Internet enabled working from home. During the pandemic schools and colleges conducted online classes using the Internet. We shop from home using e-commerce sites on the Internet. We watch movies streamed by Netflix or similar video-on-demand sites connected to the Inter-

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net. Internet banking has allowed us to send money to anyone sitting at home. Social networks such as Facebook have proliferated on the Internet. Writing and mailing postcards or inland letters have become a rarity with the emergence of email and WhatsApp messages transported over the Internet. I wrote this article by reading journal articles from my Institute's library connected to the World Wide Web (WWW), that stores enormous information and is accessed using the Internet. The Internet has become so essential in our daily life that cutting it off by a government is now considered as a denial of civil rights.

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Amazingly an experiment started in 1968 to connect four computers located in the southwest of the US has resulted in a worldwide infrastructure that has changed the way we live. How did this revolution occur? Who were the actors responsible for this? What technologies enabled this? Who governs the Internet? I will answer these questions in this article.

The Genesis of the ARPANET

4 October 1957, was a historic day on which the erstwhile USSR launched Sputnik, the first artificial satellite. The US administration was shocked as they had always thought that they were technologically superior to the USSR. Launching a satellite requires a very powerful rocket that could also be used to launch a nuclear-armed ballistic missile threatening security of the USA. There was an immediate reaction in the USA to fund research not only to launch a satellite but also to defend the USA from any nuclear attack. The Department of Defence (DoD) of the US established in 1958, the Advanced Research Projects Agency (ARPA) to conduct research in advanced technologies by primarily outsourcing research projects of relevance to DoD to universities and research-oriented companies.

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J.C.R. Licklider who was working in Bolt Beranek and Newman Inc. (BBN), in Cambridge, Massachusetts was invited in October 1962 to join ARPA as the head of the Information Processing Techniques Office (IPTO). Licklider was a psychologist who was

Figure 1. J.C.R. Licklider (Photo courtesy fergusson.edu).

adept in using computers. In the 1960s computers were mostly batch processing machines that did not allow any interaction between users and computers. He was convinced that the potential of computers can be fully realised only through close interaction between computers and humans and wrote a classic paper in March 1960 entitled "Man-Computer Symbiosis" [1]. In this paper, he argued that humans can postulate hypotheses and develop models, whereas computers can calculate and remember. The results obtained from computers need to be evaluated by humans, who can then modify the model appropriately and compute it again. Interaction between humans and computers is essential to expedite this iterative process that would lead to discoveries. The first interactive time-sharing computer was built at MIT in 1961 and other commercial time-shared systems followed. IPTO funded several universities across the US to build or buy time-shared computer systems. In October 1963, Licklider wrote a memo titled "Intergalactic Computer Network" that proposed inter-connecting computers spread worldwide that would enable scientists to cooperate by sharing their ideas and computing resources. Licklider left IPTO in 1964 and Ivan Sutherland succeeded him for a year, and followed by Robert Taylor in 1966.

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Robert Taylor read Licklider's report on Intergalactic Networks and was convinced of the need to interconnect time-shared computers funded by IPTO not only for him to access them from a single terminal in his office but also to permit the centres to exchange software and access each others computers to improve research productivity. He requested the ARPA director to sanction a million dollars for this project and it was immediately approved. Taylor invited Lawrence G. Roberts who was working at the Lincoln Laboratory of MIT in January 1967 to interconnect the widely separated computers funded by ARPA using the existing telephone system. Roberts tried convincing the directors of these computer centres to interconnect their computers and explained to them the advantages of resource sharing. They were reluctant as they felt that their computers would be slowed down as substantial computer resources would be needed to manage the network. Wesley Clark, a member of Roberts' group, suggested that a separate minicomputer named Interface Message Processor (IMP) be used at each computing node to manage the communication chores, relieving the mainframe computers from this task. This idea was acceptable to the directors of the computer centres. In the ACM Symposium on Operating Systems Principles held in Gatlinburg, Tennessee, in October 1967, Roberts presented a paper [2] explaining the advantages of networking time-shared computers and the functions of the IMPs that were to be used to connect computers using leased telephone lines. IMPs were to be used to buffer messages, check transmission errors, request data re-transmission if there are any errors, and take routing decisions. Roberts was concerned about the inefficient use of leased telephone lines in transmitting digital data. At the same Symposium, Roger Scantlebury, a member of a group headed by Donald Davies of the National Physical Laboratory, Teddington, UK, presented a paper [3] on connecting computers using packet switching that used telephone lines efficiently to transmit "bursty" digital data. After listening to his talk Roberts was convinced that packet switching should be used in the ARPANET. He soon found out that Paul Baran of the RAND corporation had described the packet switching idea in a set of reports. He read Baran's reports and discussed with him how packet switching could be used in the ARPANET. It was decided to network computer centres at the University of California, Los Angeles (UCLA) headed by Leonard Kleinrock, Stanford Research Institute (SRI) at Menlo Park (near San Francisco) headed by Douglas Engelbart, Uni-

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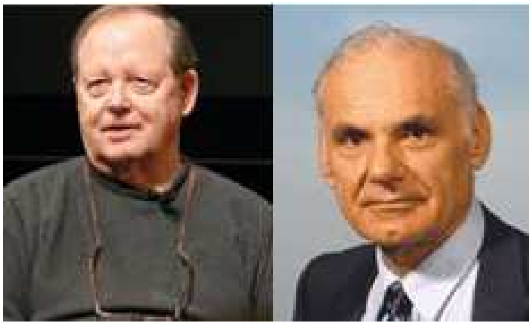

Figure 2. **(Left)** Robert Taylor **(Right)** Larry Roberts (Photo courtesy Wikipedia) .

versity of California at Santa Barbara (UCSB) headed by Glenn Culler, and the University of Utah headed by David Evans using packet switching over leased telephone lines. An IMP was to be installed at each of these centres to connect the computers. Both Leonard Kleinrock and Larry Roberts were PhD students at MIT and had shared an office. Kleinrock had developed a queuing theory model of message switching networks as a part of his PhD thesis. Roberts was aware of this and requested Kleinrock to analyse the packet switched network being planned and its feasibility. UCLA had an SDS Sigma 7 computer. SRI had an SDS 940 computer and Engelbart had pioneered work on interactive computing. UCSB had an IBM 360/75 running OS/MVT time-shared OS. Culler and Fried, two professors there had extensively worked on the graphical display of mathematical functions. The University of Utah had a DEC PDP-10 with TENEX time-sharing OS and had an excellent research group on computer graphics led by Ivan Sutherland. Note that these computers were diverse with different Operating Systems and it would have been very difficult to interconnect them without IMPs.

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Four Node ARPANET

As soon as IPTO decided to interconnect computers using IMPs and packet switching, a tender was floated on 29 July 1968, giving rough specifications of the requirements of an IMP. Major companies such as IBM and CDC were not interested in building IMPs. The two final contestants were Raytheon and BBN. The proposal of BBN was detailed and impressed IPTO. BBN was

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awarded the tender for a million dollars on 7 April 1969 to build and install four IMPs. BBN was to deliver and install an IMP at each of the four centres in monthly intervals starting in September 1969 at UCLA. BBN selected a ruggedised Honeywell DDP-516 minicomputer to build the IMPs. An interface was built in each IMP with adequate buffering for it to connect to any computer. IMP management software was written in the assembly language of the Honeywell computer.

Box 1. What is packet switching?

From the early days of telecommunications until the mid-1960s Public Switched Telephone Networks (PSTN) were primarily used for voice calls between subscribers. PSTN used a technology called circuit switching in which a dedicated circuit is established between a calling subscriber and a called subscriber for the entire duration of a telephone call. Circuit switching does not use the communication lines efficiently as the line is reserved for the exclusive use of two communicating subscribers even when one of the subscribers is silent during a call. This method was necessary for voice communication as a small delay during the transmission of voice disturbs the flow of conversation.

The situation changes when a computer is accessed remotely from a terminal using a telephone line. The traffic from the terminal is in bursts. For example, in interactive computing the typing speed of a user is slow and the communication line is idle for most of the time. If circuit switching is used the communication line does not carry any traffic for almost 90% of the time. In computer to computer communication also data is sent in bursts. Digital data can tolerate delay, unlike audio. Circuit switching is thus inefficient for data traffic between computers and an alternate more efficient method is required. Packet switching is the method. In packet switching, when a file is sent from one computer to another in a network of computers, it is broken into packets of around 1000 bytes. Each packet is labelled with a serial number, addresses of the source and the destination computers, a chunk of data, error detecting bits, and despatched. When a packet arrives at an intermediate computer in the network, this computer examines the packet and sends it along the best available path towards the destination computer. Packets belonging to a file may not arrive at the destination computer in the correct serial order. The destination computer collects all the packets and rearranges them in the right order using the serial number of the packet. The advantage of this method is that once a packet reaches a computer the path it traversed is freed. Many independent files may be broken into packets and share the communication paths thereby utilising the full capacity of the communication system.

The first IMP was delivered to UCLA on 30 August 1969, the second one to SRI on 1 October 1969, the third one to UCSB on

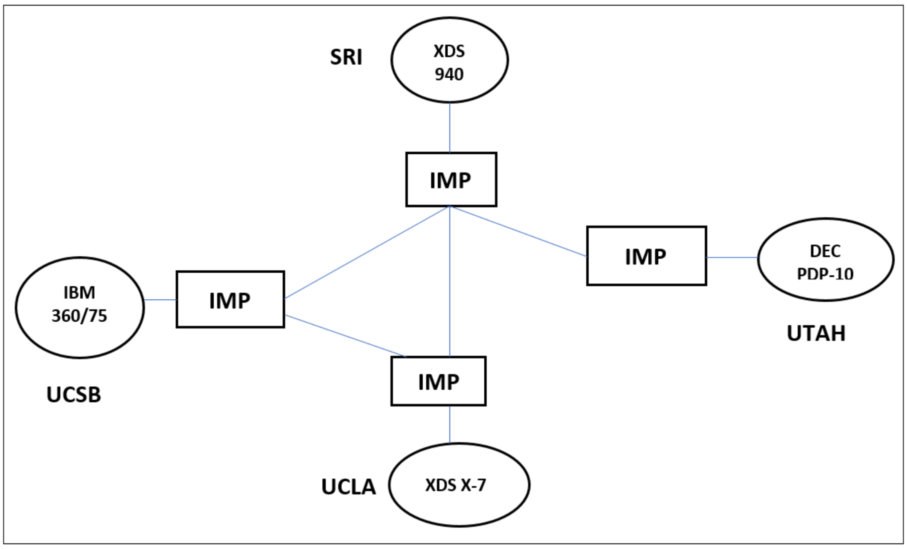

Figure 3. The first 4 nodes of ARPANET.

1 November 1969, and the last one to Utah in December 1969. As soon as an IMP was delivered to UCLA, Charlie Klein, a student of Kleinrock, wrote a program to log into the computer at SRI via IMP. The letters L and O were successfully transmitted from UCLA to SRI. As soon as he typed the third letter G, the system crashed! Thus LO was the first message transmitted on the ARPANET. The bug was fixed and the first login to the SRI machine was successful on 29 October 1969. By 21 November 1969, the first link via two IMPs at UCLA and SRI started working. This software made it simple to connect the other IMPs as soon as they were installed and tested. By 5 December 1969, the first four nodes of the ARPANET started exchanging packets at a speed of 56 Kbps using leased telephone lines.

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Expansion of ARPANET

Once the four computers were connected, a Network Control Program was implemented in 1970 that allowed the systematic exchange of data among the computers. Subsequently, programs were written for remote login, file transfer between computers, and email. Interestingly the most popular use of the network was

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email! Soon the network expanded in March 1970 to the east coast of the USA with an IMP at BBN. In 1971 a satellite link connected ARPANET to the University College, London.

Box 2. Email on ARPANET

Even though resource sharing was claimed as the main reason for interconnecting computers it turned out that email exchange between members of organizations connected to the ARPANET became its most popular use.

Tom Van Vleck and Noel Morris wrote the first email program in 1965 for the Compatible Time-Sharing System (CTSS) at MIT. Each user of CTSS had a mailbox file in which other users could write but not overwrite or read. Ray Tomlinson, a programmer at BBN, wrote an email program for the ARPANET during the autumn of 1971. Tomlinson was working on the TENEX Operating System for PDP-10 and improving an inter-user mail program named SNDMSG for it. He had earlier developed a simple file transfer program called CPYNET to exchange files between computers connected to a local network. In a flash of intuition, he decided to add the code from CPYNET to SNDMSG to allow mail to be sent to remote computers connected to PDP-10. To address a recipient of a remote computer he placed @, a rarely used symbol on the teletype, between the receiver's login id and his/her host computer name (for instance RAJA@ SDI). To test his code he typed a message on a teletype connected to the ARPANET and addressed it to another computer on it. It worked! This emailing program was released for general use and became very popular. It was gradually improved. Bells and whistles were added to this email program by Roberts and others to include features such as cc, list of sent and received emails, reply, forwarding, and address books. Email became a "killer application" of ARPANET and later the Internet.

A controversy arose when Shiva Ayyadurai copyrighted a program named EMAIL and claimed he invented email. As a 14-year-old high school student and a summer intern in 1978 at the University of Medicine and Dentistry, New Jersey (UMDNJ) he wrote an elaborate email program (comprising 50,000 lines of FORTRAN IV code) for inter-office correspondence among computers connected to the university's network. It had all the features of a modern email program such as: from, subject, body, cc, bcc, forwarding, reply etc. UMDNJ was not connected to the ARPANET. Probably Ayyadurai was not even aware of ARPANET.

A landmark event was the public demonstration of ARPANET at the International Conference on Computer Communications (ICCC) held in Washington D.C. in October 1972.

Many computer centres joined rapidly and by August 1972 there were 29 computers in ARPANET. BBN built a Terminal Interface Processor (TIP) using a Honeywell H-316 computer to which numerous terminals could be connected. TIP was connected to the ARPANET allowing the terminals to access a host of their choice. A landmark event was the public demonstration of ARPANET at the International Conference on Computer Communications

(ICCC) held in Washington D.C. in October 1972 where 50 terminals were installed and delegates could log on to any computer in the ARPANET, write programs, send mail, and transfer files.

Box 3. Request for Comments (RFC)

During the early stages of the development of the ARPANET specifications of the software being developed and the code were written by graduate students and technical staff at the four centres. Students used to exchange notes on the design by post (there was no email) and met at one of the four ARPA locations to discuss their designs. Soon they felt that the final decisions that were taken and the specifications of the software should be documented. Steve Crocker of the University of California at Los Angeles volunteered to document his design and circulate it to all the centres. Fearful of sounding presumptuous he labelled his first memo "Request for Comments" or RFC 1 on 6 April 1969. Writing in the New York Times on 6 April 2009, the 40th anniversary of RFC 1, Crocker states: *"The early R.F.C.'s ranged from grand visions to mundane details, although the latter quickly became the most common. Less important than the content of those first documents was that they were available free of charge and anyone could write one. Instead of authority-based decision-making, we relied on a process we called "rough consensus and running code." Everyone was welcome to propose ideas, and if enough people liked it and used it, the design became a standard."*

Soon RFCs became more formal and subjected to peer review. RFCs are now open and widely available on the Internet. As of May 2022, there are 9250 RFCs. The easy availability and open character of RFCs have been instrumental in the rapid development of the Internet. Concluding his article in the New York Times, Crocker writes: *"I was reminded of the power and vitality of the R.F.C.'s when I made my first trip to Bangalore, India, 15 years ago. I was invited to give a talk at the Indian Institute of Science, and as part of the visit, I was introduced to a student who had built a fairly complex software system. Impressed, I asked where he had learned to do so much. He simply said, "I downloaded the R.F.C.'s and read them. "."*

Inter-networking Project

The ARPANET project demonstrated the reliability of packet switched networks. By 1972, 50 computers spread throughout the US, and computers at the University College, London were connected using IMPs. Bureaucrats of the US Department of Defence (DoD) were uneasy that the ARPANET project financed by the DoD was not directly related to defence needs.

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Box 4. Was ARPANET built to survive a nuclear attack?

It is often stated that the motivation for building the ARPANET was to survive a nuclear war. In the literature opinions are contradictory. Robert Taylor's motivation was primarily to access ARPA-funded large time-shared mainframe computers from a single terminal in his office and to enable these centres to interact and share resources. Charles Herzfeld, ARPA Director, who sanctioned several million dollars for the project opined that *"ARPANET came out of our frustration that there were only a limited number of large, powerful research computers in the country, and that many research investigators, who should have access to them, were geographically separated from them".*

Stephen Lukasik who was Herzfeld's deputy and signed the cheques for the project stated that *" The goal was to exploit new computer technologies to meet the needs of military command and control against nuclear threats, achieve survivable control of US nuclear forces, and improve military tactical and managerial decision making ".*

The Internet Society agrees with Herzfeld and opines that the rumour that the ARPANET was built primarily to resist a nuclear attack is false. The rumour probably arose from Paul Baran's design of a packet switching network, while he was a researcher at the RAND Corporation, which was intended to protect the US telephone system from a nuclear attack. Lukasik was probably justifying sanctioning defence funds for a purpose not directly related to defence.

To alleviate this feeling two projects were undertaken that could be justified as having direct relevance to the DoD. One was called the Packet Radio System (PRS) whose aim was to demonstrate how wireless packet data communication can take place among mobile computers placed in trucks, tanks, etc., on a battlefield. ARPA started a project called PRNET (Packet Radio Network) in 1973. The other was packet data communication between ground stations via a satellite. This was of relevance to DoD as underground nuclear tests being carried out by the erstwhile Soviet Union were monitored by a seismic data collection centre called NORSAR (Norwegian Seismic Array) in Kjeller near Oslo. These data were being sent by satellite to a ground station in the US which was connected to a terrestrial data collection network. This satellite communication system was also used for communication among computers. This project was called SATNET. The next logical project was to connect PRNET, SATNET, and ARPANET. A successful connection of three disparate networks with their only commonality being packet switching would be a

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spectacular demonstration of inter-networking. This project had unflinching support from the DoD. Robert Kahn who had earlier worked at BBN on designing the IMPs of the ARPANET joined the Information Processing Techniques Office (IPTO) of ARPA in 1972 and led the internetworking project.

Packet Radio Network (PRNET)

Norman Abramson and his group used packet switching for the first time with wireless signals in the ALOHA net in Hawaii in 1971. ALOHA net allowed terminals located on the Hawaiian Islands to access the mainframe computer located on the main campus of the University of Hawaii. Packet switching had not been used to communicate between *mobile* computers. PRNET project's objective was to investigate the feasibility of using packet switched radio to communicate among computers placed in mobile vans. Mobile vans may go through tunnels that would blackout wireless signals and the system should be able to recover from such events. Arrays of ground-based repeaters were used to enhance signal strength and route the signals among the mobile computers. Stanford Research Institute (SRI) coordinated this project with BBN and Collins Radio as partners. SRI provided the vans and computers with appropriate software, BBN the networking technology, and Collins Radio the packet radio equipment. The system used spread spectrum wireless technology for reliable transmission of data in an electromagnetically noisy environment. The system could transmit data at a speed of 100 to 400 kbps. An experimental system was ready in 1973 that successfully transmitted data among mobile computers and with SRI. The packet switched system was fully operational in September 1976 when a computer mounted in a van driven on a highway in the San Francisco Bay Area (that had long bridges and tunnels) could communicate reliably with other vans and also with a computer in SRI.

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Figure 4. SRI packet radio van with a computer used in PRNET (Photo courtesy Wikipedia - SRI).

SATNET

Roberts of IPTO initiated this project in 1971 to connect ARPANET to the packet network at NPL designed by Donald Davies. Due to political reasons explained by Peter Kirstein [4], this did not fructify. Roberts decided to connect the University College London's (UCL) computer centre headed by Peter Kirstein to ARPANET using a communication satellite link that ARPA had with NORSAR and a cable connection from there to London.

In 1973 a commercial satellite provided by COMSAT became operational and provided a 64 Kbps link to earth stations. Multiple earth stations spread all over Europe covering England, Germany, Norway, and Italy received the satellite signal.

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Roberts proposed that all these earth stations could share this link using packet switching. Kahn who succeeded Roberts in IPTO carried through this project with BBN, COMSAT, Linkabit Corporation, UCLA, UCL, Norwegian Defence Research Establishment, and the Royal Signals and Radar Establishment of the UK. Each earth station had a simple message processor. At the end of this project, the participants of SATNET could communicate reliably among them.

Interconnecting ARPANET, PRNET, and SATNET

ARPANET, PRNET, and SATNET were disparate in their interfaces, packet sizes, speed of data transmission, and packet labelling. In June 1973 Robert Kahn wanted to interconnect these

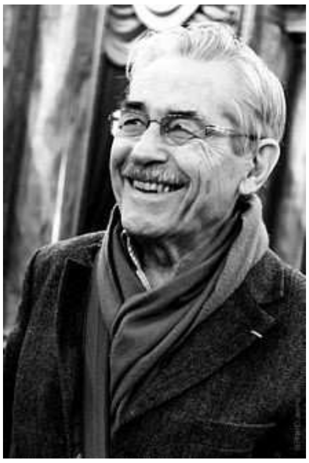

Figure 5. Louis Pouzin (Photo courtesy Wikipedia).

three systems which was quite a challenge.

The first step was to design a gateway for each network to connect with the other. The next step was to be able to design a net-to-net connection protocol. In the summer of 1973, Kahn requested Vinton Cerf, who was on the faculty of Stanford University, to lead the project. Cerf started a series of meetings attended by his graduate students, Kahn, and computer scientists from SRI and Xerox PARC to find a solution to the internetworking problem. Among the people who attended these meetings was Gerard LeLann from France who was on sabbatical at Stanford University. He had worked on the French computer networking project known as the Cyclades led by Louis Pouzin.

Cyclades network unlike ARPANET did not have separate IMPs to manage networking functions. The computers in the network exchanged what Pouzin called datagrams, which contained besides data, addresses of the sending computer and the receiving computer, and error detection bits. The datagrams sent from a host computer would travel independently to the receiving computer which would assemble them. The computers at the two ends were responsible for the error-free transmission of datagrams. This idea was attractive for interconnecting disparate networks.

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Cerf and Kahn designed a protocol for inter-networking based on inputs provided by Pouzin. The protocol satisfied the following four key requirements to ensure error-free communication:

Figure 6. Left Vinton Cerf **Right** Robert Kahn (Photos courtesy Wikipedia) .

- Each network was treated as an independent entity.
- Gateways (nowadays called routers) were interposed between the networks to control the transmission of packets between them.
- The transmission of packets was "best effort". If a packet was lost in transit, the receiver detected it and requested the sender to re-transmit it. In other words, the sending and the receiving computers, called hosts, assumed the responsibility for error-free communication.
- The communication of packets among the networks was not globally controlled.

Cerf and Kahn [5] published the first version of the protocol, called Transmission Control Program (TCP v1), in May 1974. Meanwhile, the International Working Group (INWG), which was formed in 1972, chaired by Cerf to design protocols for internetworking was also working in parallel and met many times [6]. The formulation of the first version of TCP gained numerous ideas during discussions in INWG meetings.

The formulation of the first version of the Transmission Control Protocol gained numerous ideas during discussions in the International Working Group meetings.

TCP v1 was followed by the improved version TCP v2. In August 1977, Jon Postel suggested that the routing function and the error-free transmission function should be separated in the protocol. Based on his suggestion TCP was divided into two parts TCP (Transmission Control Protocol) and Internet Protocol (IP) – TCP/IP v3. In this protocol, each computer or device connected to the network is given a unique address called the IP address. Four bytes were used as IP addresses which allowed 4 billion devices in the network. In 1977, this number of connected devices was considered huge. TCP breaks up a message into packets of around 1000 characters, attaches the IP addresses of the sender and the receiver, the serial number of the packet, and error detecting bits. IP routes the packets via the gateways (now called routers) to the intended receiver using an optimal path through the network. TCP reassembles the received packets into the original message ensuring they are in the correct order, there are no missing packets, and no errors in the received message. Minor improvements were made to this protocol and a final stable version TCP/IP v4 was standardized in 1980. It became the standard Internet protocol in 1983.

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Testing TCP/IP

In 1976, Cerf left Stanford University and joined ARPA to devote full time to the internetworking project. An important experiment was conducted by his group on 22 November 1977, to examine whether the TCP/IP protocol was able to connect PRNET, ARPANET, and SATNET. From a computer in a van moving on a highway in the San Francisco Bay Area a message was sent via PRNET to the ARPANET. It reached the east coast of the US and was sent by SATNET to the University College, London from where it was retransmitted to ARPANET and received back by the computer in the moving van connected to the PRNET. After a round trip journey of 150,000 Km, the message was received without a single bit error! This proved the reliability of the networks and the TCP/IP protocol.

In 1975, Robert Metcalfe and David Boggs successfully networked Alto computers at Xerox PARC using the Ethernet protocol. With the advent of Personal Computers and workstations in the late 1970s, Local Area Networks (LAN) began proliferating. TCP/IP became the standard to interconnect these LANs. ARPANET was soon transformed into a network that connected several networks and became the Internet. I will describe this evolution in the next part of this article.

Acknowledgment

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