PACKET SWITCHED DATA NETWORK AND ITS EVOLUTION

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Summary

In computer networking and telecommunications, *packet switching* is a method of data transmission in which small blocks of data are transmitted rapidly over a channel dedicated to the connection only for the duration of the packet's transmission. This differs from circuit switching, which estabilishes a dedicated connection between the two nodes for their exclusive use for the duration of the communication. Packet switching enables a more efficient use of the communication medium, and all emerging broadband wireless access networks have also adapted packet switching for the same reason. Packet switching is used to optimize the use of the bandwidth available in a network, to minimize the transmission latency, and to increase robustness of communication.

While circuit switching was a natural choice for voice only networks, it cannot handle bursty traffic efficiently. With increasing amount of data usage happening on the access network, packetisation and packet switching has become absolutely essential to support such bursty traffic. Packet switching has always excelled at handling messages of different lengths, as well as different priorities, providing quality of service (QoS) attributes was included. However, packet switching was designed for data. Today, using

the IP protocol, packet networks are becoming faster, cheaper, and more ubiquitous. In the near future, packet networks are likely to replace circuit-switched networks nearly everywhere, since with proper QoS guarantees, voice, video and other low latency applications can travel as effortlessly as data applications over such packet networks.

1. History of packet switching

The concept of packet switching had two independent beginnings, with Paul Baran and Donald Davies [1],[2]. Leonard Kleinrock [3] conducted early research and authored a book in 1961 in the related field of digital message switching (without explicitly using the concept of packets), and also later played a leading role in building and management of the world's first packet switched network, namely the ARPANET.

Baran [4] developed the concept of packet switching during his research for the US Air Force into survivable communications networks, first published in 1962, and then including and expanding somewhat within a series of eleven papers titled “On distributed communications” in 1964 . Baran's earlier paper described a general architecture for a large-scale, distributed, survivable communications network. This paper focused on three key ideas: firstly, the use of a decentralized network with multiple paths between any two points; secondly, dividing complete user messages into what he called *message blocks* (later called *packets*); and thirdly, delivery of these messages by store and forward switching. Baran's study paved the way for Robert Taylor and J.C.R. Licklider, both wide-area network evangelists working at the Information Processing Technology Office, and it also helped influence Lawrence Roberts to adopt the technology when Taylor put him in charge of development of the ARPANET.

Baran's packet switching work was similar to the research performed independently by Donald Davies at the National Physical Laboratory, UK. In 1965, Davies developed the concept of packet switched networks and proposed development of a U.K. wide network. He gave a talk on the proposal in 1966, after which a person from the Ministry of Defense told him about Baran's work. Davies met Roberts at the 1967 ACM Symposium on Operating System Principles, bringing the two groups together.

Interestingly, Davies had chosen some of the same parameters for his original network design as Baran, such as a packet size of 1024 bits. Roberts and the ARPANET team took the name "*packet switching*" itself from Davies work [1]. In 1970, Davies helped build a packet switched network called the Mark I to serve the NPL in the UK. It was replaced with the Mark II in 1973, and remained in operation until 1986, influencing other packet communications research in the U.K. and Europe [2].

2. Packet switching

Packet switching implies a network technology that breaks up a message into small packets for transmission. Any message exceeding a network-defined maximum length is broken up into shorter units, known as *packets*, for transmission. Unlike circuit switching, which requires the establishment of a dedicated point-to-point connection, each packet in a packet-switched network contains a destination address. Thus, all packets in a single message do not have to travel the same path. As traffic conditions change, they can be dynamically routed via different paths in the network, and they can even arrive out of order. The destination computer reassembles the packets into their proper sequence.

Figure 1. Packet data format

Typically, a packet consists of header information, user data, and a trailer, as shown in Figure 1. The header specifies the beginning of a new packet and contains the source address, destination address, packet sequence number, and other routing and billing information. The user data contains information that is generally protected with error control coding. The trailer contains a cyclic redundancy checksum that is used for error detection at the receiver. Think of a packet as an envelope in which the destination address is written on the outside of the envelope and data goes inside. Figure 1 illustrates the sequential format of a packet transmission.

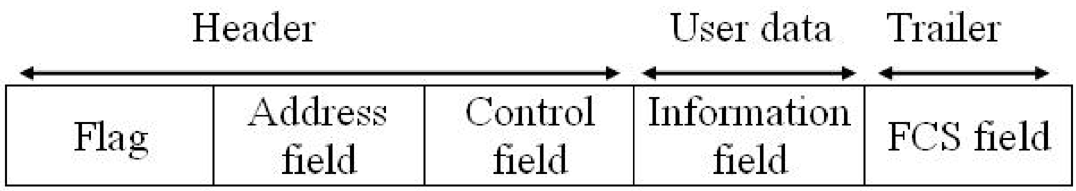

Figure 2. Fields in a typical packet of data

Figure 2 shows the structure of a transmitted packet, which typically consists of five fields: the flag bits, the address field, the control field, the information field and the Frame Check Sequence (FCS) field. The flag bits are specific (or reserved) bit sequences that indicate the beginning and end of each packet. The address field contains the source and the destination address for transmitting messages and for receiving acknowledgements. The control field defines functions such as transfer of acknowledgements, Automatic Repeat Request (ARQ) and packet sequencing. The information field contains the user data and may have variable length. The final field is the FCS field or the Cyclic Redundancy Check (CRC) that is used for error detection.

A single transmission may require hundreds or thousands of packets-for example, a large file is broken up into many small pieces that are inserted in the payload area of packets. This scheme helps overcome transmission problems. If a glitch occurs, only one packet may be affected. Then it is only necessary to retransmit that one packet rather than the entire file.

In relation to the OSI protocol model, packets are formed in the network layer and passed down to the data link layer, where they are encapsulated into the frames of the underlying network. Frames cross a single point-to-point link between network devices, while packets cross multiple router-connected links. In other words, frames are isolated to a single link, while packets are envelopes for delivering data across internetworks. Packets are broken up into frames for delivery across a network; but, when the frames reach the next router, the packet information is examined by the router and a decision is made about how to forward the packet across the next link.

Packet switching is also called *connectionless networking* because no connections are established. The advantage of the connectionless packet model is that packets are forwarded independent of other packets. Packets are forwarded on-the-fly by routers, based on the most current best path to a destination. If a link or router fails, packets are quickly diverted along another path.

There are three important benefits from packet switching:

(a) The first and most important benefit is that since packets are typically short, the communication links between the nodes are only allocated to transferring a single message for a short period of time while transmitting each packet. Longer messages require a series of packets to be sent, but do not require the link to be dedicated between the transmission of each packet. The implication is that packets belonging to other messages may be sent between the packets of the message being sent from one node to other node. This provides a much fairer sharing of the resources of each of the links.
(b) The ability to do statistical multiplexing which can exploit the inherent "burstiness" in many data applications (web browsing is a clear example), and thereby enable sharing of the network resources more efficiently amongst multiple data streams is a major advantage.
(c) Another benefit of packet switching is known as "pipelining". This simultaneous use of communications links represents a gain in efficiency; the total delay for transmission across a packet network may be considerably less than for message switching, despite the inclusion of a header in each packet rather than in each message.

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Biographical Sketch

K. Giridhar is a Professor at the Indian Institute of Technology Madras (www.iitm.ac.in), Chennai. He studied BSc (Applied Sciences) at PSG College of Technology, Coimbatore, ME (Electrical Communications) at Indian Institute of Science, Bangalore, and received a PhD (Electrical Engineering) from University of California, Santa Barbara. During 1989-90, he was a member of research staff at Bharat Electronics, Bangalore, and during 1993-94, was a research affiliate in Electrical Engineering at Stanford University, California. Since 1994, he has been with the Department of Electrical Engineering at IIT Madras.

His research interests are broadly in the areas of adaptive signal processing and wireless communications systems, with an emphasis on various transceiver algorithms and performance analysis of cellular and broadband wireless systems and networks. Much of this work has been communicated in over 140 research papers in various journals and conference proceedings, and also has over three dozen issued/filed patents pertaining to OFDMA-MIMO transceiver technologies. During a sabbatical with Beceem Communications, Bangalore, in 2004-05, he contributed several PHY layer proposals into the IEEE 802.16e WMAN standard.

Giridhar is a member of the Telecommunications and Computer Networks (TeNeT) Group which has successfully incubated several telecom and IT companies over the last decade (www.tenet.res.in). He is also actively associated with many research activities at the Center of Excellence in Wireless Technology (www.cewit.org), including several contributions to IEEE 802.16m and the LTE-A mobile broadband standards. He has been a consultant to many telecom companies in India, and has been a visiting faculty at Sri Sathya Sai University, Prasanthi Nilayam, Andhra Pradesh, and at Stanford University, California.