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Computer Networks—The ALOHA System*

Franklin F. Kuo

University of Hawaii, Honolulu, HI 96822

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The ALOHA System, an experimental UHF radio computer communication network, was developed at the University of Hawaii, 1970-76. In this survey paper, we give a general overview of packet communication techniques applied to computer networks. Then we discuss the concept of packet broadcasting and give a short description of the ALOHANET. Next, a discussion of the application of ALOHA techniques to satellite communications is presented. Finally, a short survey of present-day research and development efforts in packet broadcasting is presented.

Key words: ALOHA System; ALOHANET; compter network; packet broadcasting; radio computer communication network; satellite communication.

1. Introduction

Developments in remote access computing in the 1970's have resulted in greater and greater importance attached to computer-communication networks. In discussing computer-communications it is useful to distinguish between communications among computers, and communications using computers. For example, the ARPANET [1][1] is a computer-communications network that interconnects a collection of large or specialized research computers and uses both kinds of communications. Communications among the ARPANET computers is made possible through the use of message switching computers called IMP's (Interface Message Processor) and TIP's (Terminal Interface Processors).

In discussing the ALOHA broadcast packet communication network, we concentrate on communications using computers. The term *"broadcast"* implies radio. ALHOHA is one of the world's first time-sharing networks that uses packet radio as the communications medium. By the word *"packet"* we mean an allocated unit of transmitted information in terms of a specific number of bits. For example, in the mail system, a packet is a letter with a variable number of bits; in the ARPANET, a packet is a string of data of 1024 bits. Before we discuss the specifics of the ALOHANET, it is useful to examine what we mean by packet communications.

2. Packet Communications

In the early days of time-sharing, remote access to the central computer depended almost exclusively on the use of leased or dial-up facilities provided by the telephone company. Generally the terminal-to-computer access was by means of dial-up facilities which made use of telephone circuits on a *circuit-switched* basis. In circuit switching the telephone system's exchanges are switching nodes which piece together a continuous path or circuit from caller to receiver. The connection is maintained until either party hangs up. Usually the call is charged on an elapsed time and/or distance basis. Circuit switching is a technique that was developed at the turn of the century for voice communications. When applied to computer-communications, circuit switching is applicable but not totally satisfactory for one reason: cost effectiveness. Computer data is usually transmitted as bursts interspered between varying quiescent periods. When two people are conversing over a voice circuit, the circuit is used quite efficiently. However, for interactive computing on a time-sharing system, the circuit is utilized only a small percent of the total connect time for actual transmission of data [2].

Packet switching is a technique which has evolved in the late 1960's and early 1970's and is ideally suited for computer data communications. In a packet switching network, the topology takes the form of a highly connected (but not fully connected) set of nodes. At each node is a computer that acts as a message switch. In the case of the ARPANET this computer is the IMP or TIP.

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[1] Figures in brackets indicate literature references at the end of this paper.

Messages from Computer A to Computer B in the network are transmitted in the form of packets of a given number of bits. Each packet has a *"header"* which contains information giving a complete specification of the communication desired (e.g. destination, source size sequence number, priority, etc.). Each packet also has a given number of checksum bits for error detection purposes. A packet sent from A to B does not have a fixed route. It is sent to intermediate nodes in a store-and-forward manner. Each node examines the packet for its ultimate destination and makes a parity check to determine any error. If the packet is received with no errors, an acknowledgement is sent to the previous node traversed and the packet is successively forwarded to the next node down the line until it is received, error free at its ultimate destination. Route selection is dynamic in that each packet is directed along a path for which the total estimated transit time is minimum. This path is not predetermined but calculated at each intermediate node.

Since packet switching uses computers so heavily in the communications process, it has only become feasible in the past few years because of the increasing speed and lowered costs of digital computers. Roberts [3] makes clear this point in the introduction of his paper:

> "Packet switching (is) strongly dependent upon the cost of computing since it uses computers to correct transmission errors, to provide high reliability through alternate routing, and to allocate communication bandwidth on a demand basis rather than as a preassigned bandwidth."

Metcalfe [4] gives a good summary of the reasons why packet switching is too efficacious for computer communications.

> "In pure packet-switching, on the other hand, the communication system does not dedicate circuits to set up connections; rather, the messages which form a conversation are injected individually at the exact moment of their readiness. Because there is no connection setup to amortize over a conversation, short conversations are not seriously disadvantaged relative to long ones; because a packet-switching system allocates its resources to messages rather than conversations, the inactive periods in one conversation can be used to support other conversations. Packet-switching makes good use of communications facilities when the conversations being carried are either short or very bursty."

3. Packet Broadcasting

Packet broadcasting is a technique whereby data is sent from one node in a net to another by attaching address information to the data to form a packet typically from 30 to 100 bits in length. The packet is then *broadcast* over a communication channel which is shared by a large number of nodes in the net; as the packet is received by these nodes the address is scanned and the packet is accepted by the proper addressee (or addressees) and ignored by the others. The physical communication channel employed by a packet broadcasting net can be a ground based radio channel, a satellite transponder or a cable.

Packet broadcasting networks can achieve the same efficiencies as packet switched networks [1] but in addition they have special advantages for local distribution data networks, and for data networks using satellite channels [5]. In this paper we concentrate on those characteristics which are of interest for a local distribution data network. In particular, we discuss the design and implementation of the ALOHANET, a packet broadcasting radio network in operation at the University of Hawaii during 1970–76.

The ALOHANET was the first system which successfully utilized the packet broadcasting concept for on-line access of a central computer via radio. Although it has not been in operation since 1976, its design principles have been applied to a number of successfully operating present-day networks including ETHERNET [6], the Packet Radio Network (PRNET) [7], and the Packet Satellite Net (SATNET) [8]. In the next section we will briefly examine the operations of the ALOHANET [5].

4. Alohanet operations

In the ALOHANET, two 100 KHz channels were used in the UHF band—a *random access* channel for user-to-computer communication at 407.350 MHz and a *broadcast channel* at 413.375 MHz for computer-to-user messages. The original system was configured as a star network, allowing only a central node to receive transmissions in the random channel; all users received each transmission made by the central node in the broadcast channel. However, the subsequent addition of ALOHA repeaters generalized the network structure.

A block diagram of the ALOHANET is shown in figure 1. The central communications processor of the net is an HP 2100 minicomputer (32K of core, 16 bit words) called the MENEHUNE [5] (Hawaiian for IMP) which functioned as a multiplexor/concentrator in much the same way as an ARPANET IMP [1]. The MENEHUNE accepts messages from the UH central computer, and IBM System 370/158 running TSO or from ALOHA's own time-sharing computer, the BCC 500, or from any ARPANET computer linked to the MENEHUNE via the ALOHA TIP. Outgoing messages in the MENEHUNE are converted into packets, the packets are queued on a first-in, first-out basis, and are

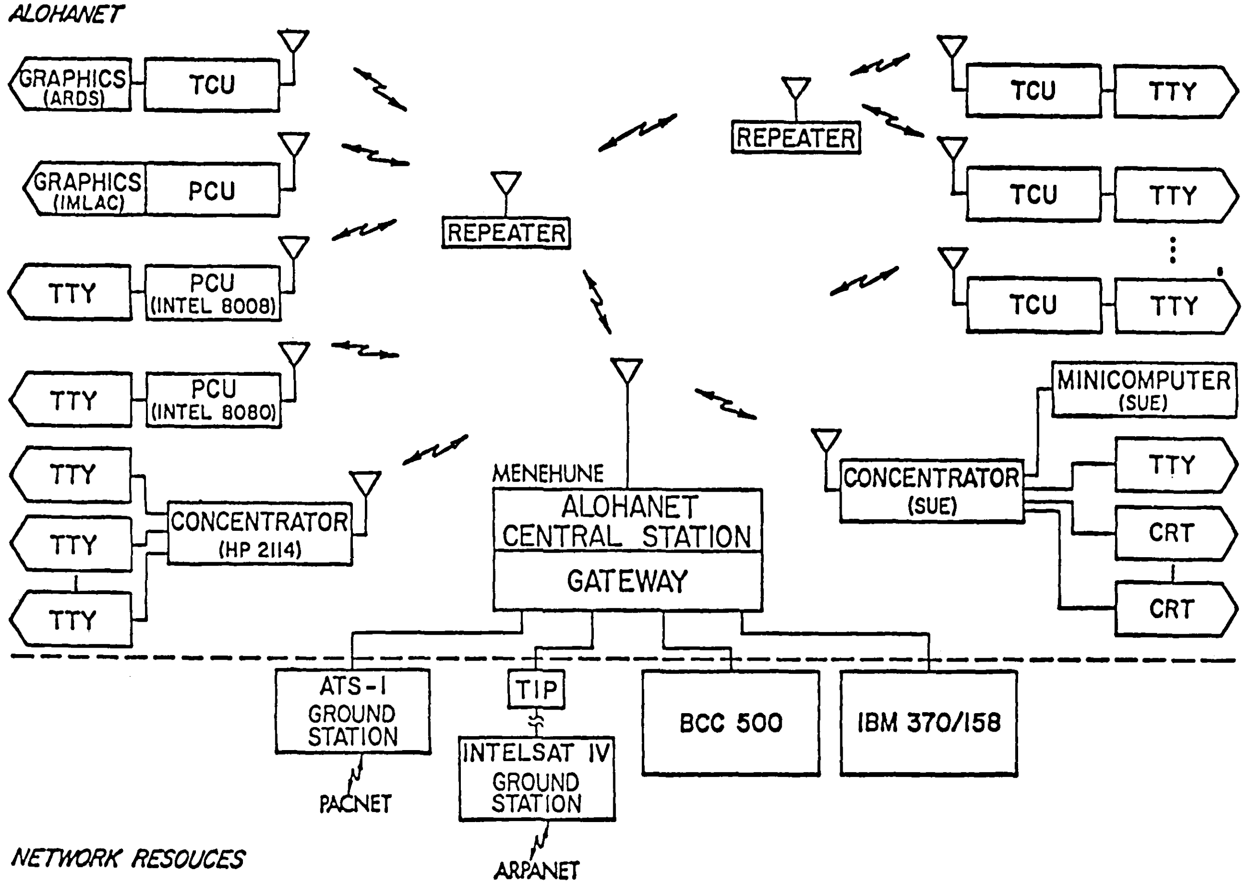

FIGURE 1.

then broadcast to remote users at a data rate of 9600 baud.

The packet consists of a header (32 bits) and a header parity check word (16 bits), followed by up to 80 bytes of data and a 16-bit data parity check word. The header contains information identifying the particular user so that when the MENEHUNE broadcasts a packet, only the intended user's node will accept it.

The random access channel (at 407.35 MHz) for communication between users and the MENEHUNE was designed specifically for the traffic characteristics of interactive computing. In a conventional communication system a user might be assigned a portion of the channel on either an FDMA or TDMA basis. Since it is well known that in time sharing systems, computer and user data streams are bursty [2] such fixed assignments are generally wasteful of bandwidth because of the high peak-to-average data rates that characterize the traffic. The multiplexing technique that was utilized by the ALOHANET was a purely random access packet switching method that has come to be known as the *pure ALOHA* technique [9]. Under a pure ALOHA mode of operation, packets were sent by the user nodes to the MENEHUNE in a completely unsynchronized manner—when a node was idle it used none of the channel. Each full packet of 704 bits required only 73 ms at a rate of 9600 baud to transmit (neglecting propagation time).

The random or multi-access channel can be regarded as a resource which is shared among a large number of users in much the same way as a multiprocessor's memory is "shared." Each active user node is in contention with all other active users for the use of the MENEHUNE receiver. If two nodes transmit packets at the same time, a collision occurs and both packets are rejected. In the ALOHANET, a positive acknowledgement protocol was used for packets sent on the random-access channel. Whenever a node sent a packet it had to receive an acknowledgement message (ACK) from the MENEHUNE within a certain time-out period. If the ACK was not received within this interval the node automatically retransmitted the packet after a randomized delay to avoid further collisions. These collisions, however, limited the number of users and the amount of data which could be transmitted over the channel as loading was increased.

An analysis [9] of the random access method of transmitting packets in a pure ALOHA channel showed that the normalized theoretical capacity of such a channel was $1/2e = 0.184$. Thus, the average data rate which can be supported is about one sixth the data rate which could be supported if we were able to synchronize the packets from each user in order to fill up the channel completely. Put another way, this result shows the ALOHA 9600 bit/second random access channel could have supported between 100 and 500 active teletype users—depending upon the rate at which they generated packets and upon the packet lengths.

4.1. ALOHANET Remote Units

The original user interface developed for the system was an all-hardware unit called an ALOHANET Terminal Control Unit (TCU), and was the sole piece of equipment necessary to connect any terminal or minicomputer into the ALOHA channel. As such it took the place of two dedicated modems for each user, a dial-up connection and a multiplexor port usually used for computer networks. The TCU was composed of a UHF antenna, transceiver, modem, buffer and control unit.

The buffer and control unit functions of the TCU were also handled by minicomputers or microcomputers. In the ALOHA system several minicomputers were connected in this manner in order to act as multiplexors for terminal clusters or as computing stations with network access for resource sharing. A later version of the TCU, using an Intel 8080 microcomputer for buffer and control, was built. Since these programmable units allowed a high degree of flexibility for packet formats and system protocols, they were referred to as PCU's (Programmable Control Units).

Since the transmission scheme of the ALOHANET was by line-of-sight, the radio range of the transceivers was severely limited by the diversity of terrain (mountains, high rise buildings, heavy foliage) that exists in Hawaii. A late development allowed the system to expand its geographical coverage beyond the range of its central transmitting station. Because of the burst nature of the transmissions in the ALOHA channel it was possible to build a simple store-and-forward repeater which accepted a packet within a certain range of ID's and then repeated the packet on the same frequency. Each repeater performed identically and independently for packets directed either to or from the MENEHUNE. Two of the repeaters were built which extended coverage of the ALOHANET from the island of Oahu to other islands in the Hawaiian chain.

5. Satellite communications

Because of the geographic isolation, one of the original objectives of the ALOHA system was to study the feasibility of the computer-communications by means of satellite. With the development of digital communication systems by COMSAT in which data at the rate of 50K baud can be transmitted through a single voice channel data transmission by satellite has become both technologically and economically feasible [10].

There is a basic and important difference between the use of a satellite channel and a wire channel for data communications. The satellite channel is a broadcast channel as opposed to a point-to-point wire channel, so that a single voice channel, say between ground stations A and B can be used in broadcast mode among any set of ground stations, providing a full broadcast capability of two 50K baud channels. Thus a single commercial satellite voice channel could be employed with the following characteristics:

1. The single voice channel could provide two up-link and two down-link 50K baud data channels.
2. Each of these four channels could be simultaneously available to any COMSAT ground station in sight of the satellite.

In December 1972, the ALOHA system became the first operational satellite node on the ARPA network. The satellite used was the Pacific Ocean INTELSAT IV, and the mode of operation is the single-channel-per-carrier PCM voice link that is employed on the SPADE demand assignment system [11]. The PCM voice channel converts analog voice into 56 kilobit PCM. With 50 kilobit data transmission the conversion is unnecessary. The tariff for this service is charged on the basis of a single voice channel, which is a remarkable savings over land-line rates.

In addition to the operational satellite link on INTELSAT, we also worked on the NASA satellite ATA-1 doing experiments on packet broadcasting. In contrast to the standard 97 foot earth station of INTELSAT that costs several million dollars, the ATS–1 ground stations operating on a VHF channel used an antenna as small as ten feet and total ground station electronics costs were less than $5,000. In conjunction with NASA-Ames Research Center (ARC) and the University of Alaska we set up an experimental packet broadcasting network in which the ATS–1 VHF transponder was utilized as a broadcast repeater and was operated in the ALOHA random access burst mode.

6. Present-Day Packet Broadcasting Networks

When funding ran out from the various U.S. Government sponsors, the ALOHANET stopped operations in the FALL of 1976. However, the spirit of ALOHA lives on in the following networks which are in operation today.

6.1 ETHERNET [6]

This network was one of the first cable-based local area networks ever developed. The basic concept of operation of ETHERNET is to use the cable transmission medium (The "ETHER") in an ALOHA mode with some embellishments such as reducing the probability of packet collisions by listening before and while transmitting. ETHERNET, developed by Metcalfe and Boggs at the Xerox Palo Alto Research Center in 1973-75, has spawned a number of imitators in the burgeoning field of local area networks. Thus, it appears that three generations of techology have evolved from the original ALOHA technology, developed only 10 years ago.

6.2 Packet Radio Network [7]

The PRNET is a direct descendent of the ALOHANET and was developed by a constortium, including the University of Hawaii, under the sponsorship of the Defense Advanced Research Projects Agency (DARPA). Although the original ALOHANET did use repeaters, it nevertheless represented a centralized system in that there existed only a centered computing facility to which the remote TCU's served as subscribers. The PRNET is a basic extension of ALOHANET and extends the domain of packet communications to permit mobile applications over a wide geographic area by the extensive use of repeaters and sophisticated protocols for addressing and routing. The PRNET is in prototype operation in the San Francisco Bay area, with its central station located at SRI International in Menlo Park, California.

6.3. Packet Satellite Network [8]

The Atlantic Packet Satellite System or SATNET, is another DARPA-sponsored effort that has led to a quasi-operational packet broadcasting system operating on a INTESAT IV satellite over the Atlantic. One of the most significant achievements of the SATNET experiment was the development of a very sophisticated demand-assignment protocol called PODA (Priority-Oriented Demand Assignment). Its design represents an integration of both circuit and packet-switched demand assignment and control techniques. For large populations of low duty-cycle stations, random access techniques (known as slotted ALOHA) are used in the system known as CPODA (Contention-PODA). Thus, it appears that the contention techniques, pioneered in the original ALOHANET, are being used in some of the most advanced packet communications systems of the 1980's.

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