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Packet Radio for Library Online Catalogs

The Problem of Wiring

The advent of online catalogs in libraries has resulted in a problem that could not have been foreseen when most library buildings were built—the need for wiring to transmit data between terminals and the online catalog. This problem is particularly serious in older libraries, where there are insufficient conduits, false ceilings are rare, and one faces the prospect of running cables through marble floors.

Installing such wiring can be costly. The experience of the University of California demonstrates that the cost of installing terminals in quantities of eight to ten may range from $8,000 to $12,000, not including staff costs. Even if the wiring for data communications makes up only half of this figure ($4000 to $6000), it is evident that the wiring can cost as much as or more than the terminal itself.

In addition, it can take months to arrange to install the wiring, and further, new wiring must be installed when the terminal is moved to a new location, making it costly and time-consuming to relocate online catalog terminals.

Packet Radio Technology

The University of California Division of Library Automation (DLA) is exploring packet radio technology—the marriage of radio and packet-switched telecommunications—as one solution to this costly problem. With packet radio, wireless terminals are possible—i.e., radio transceivers take the place of the usual data cables. A packet radio unit consists of a radio transceiver and a microprocessor that, when connected to a terminal or microcomputer, allows the device to send and receive data.

Using packet radio for transmitting data to and from an online catalog avoids the expense of installing a cable for each terminal, and it also makes the terminals far more portable. Unlike terminals that communicate across a cable, a packet radio terminal can be installed very quickly.

Packet switching is widely used to route data through complex, long-haul telecommunications networks. It involves breaking the data to be transmitted into chunks called packets. The address of the data's destination is added to each packet, and the packet is then routed through the network until it reaches its destination.[1]

In a packet radio network in which a group of terminals are all communicating with a central computer's base station, the data packets, each tagged with an address, are broadcast by the base station to all terminals in the area. A terminal will recognize and accept only packets that bear its address. Packetized data makes sense in a radio-based terminal system not only because it is necessary to address data to the proper terminal, but because a number of terminals must contend for the broadcast channel across which they communicate with the base station. Breaking the data into packets makes possible the use of communications protocols that will avoid most data collisions, and will recognize collisions when they occur and retransmit the data packet.

A packet radio system operates simultaneously on one or, at the most, two radio channels or frequencies. This distinguishes it from cellular radio (a technique that is beginning to be used for mobile telephones), in which a large pool of frequencies is maintained with each caller allocated a frequency for the duration of the call's existence within a cell.[2] Packet radio has more in common with some recently announced hybrid systems such as Motorola, Inc.'s portable computer system, which features a handheld computer that can communicate with a remote computer by radio over a single pair of frequencies.[3] However, there are substantial differences in the two systems—Motorola's system has a hierarchical design that relies on centralized control and does not allow communication between terminals or portable computers except by passing the message through a central site. It is also designed to cover larger geographical areas than those covered by typical packet radio networks.

A BRIEF HISTORY OF PACKET RADIO

Military Activities

The military has been interested in packet radio for over a decade, primarily as a battlefield communications network that can be deployed rapidly, can quickly adapt to rapidly moving nodes (such as a terminal mounted on a truck or an aircraft), can avoid single points of failure, and is robust in the face of jamming or other interference. The development of packet radio began in the early 1970s with the University of Hawaii's ALOHA packet radio network, a watershed in the development of modern telecommunications protocols. The ARPANET, a large-scale wire- and satellite-based packet communications network developed by Bolt Beranek and Newman for the Department of Defense's Advanced Research Projects Agency (DARPA), had already been in operation for several years by then (the ARPANET was established in 1969). The ALOHA network was initially a single-hop system using no repeaters in which various devices such as terminals, minicomputers and graphics processors communicated via radio with a central computer. The protocols developed for the ALOHA network were later redefined and adapted for many other systems (see reference 4 for a description of the ALOHA network).[4]

After the ALOHA project, DARPA sponsored the development of a multihop packet radio network called the PRNET in the San Francisco Bay Area. The U.S. Department of Defense (DOD) is now working with second- and third-generation systems, and operates a number of testbed systems, such as the Fort Bragg Packet Radio Network. These feature very sophisticated, high-throughput, highly robust designs and equipment intended to support major networks under the most adverse circumstances; consequently, they are quite expensive.[5]

Amateur Packet Radio Activities

At the other end of the packet radio spectrum are amateur radio operators who have been experimenting for some years with very low cost, low-throughput systems. The first amateur packet radio network in North America was established in 1978 in Vancouver, British Columbia, after the Canadian government, seeking to encourage the use of packet radio, allocated a set of frequencies (221 to 223 MHz and 433 to 434 MHz) for packet and digital transmissions. The Vancouver Amateur Digital Communication Group (VADCG) soon began to produce and sell a packet radio terminal node controller (TNC)—i.e., a microprocessor combined with memory that allows a terminal or microcomputer to communicate via radio with other similarly equipped devices.

In 1980, in the United States, the FCC legalized ASCII transmissions, and in 1982 it removed many of the remaining restrictions on radio data communications. Since then, the Tucson Amateur Packet Radio Group (TAPR) has established a network and is now marketing its own TNC. Both the VADCG and TAPR TNCs can transmit at a data rate of up to 1200 bits per second using on-board modems (they can operate at somewhat higher speeds using external modems). These boards perform modulation in an audio subcarrier and do not include error correction. The digital side of the TNC includes a 6809 microprocessor operating at 3.6 MHz, a Western Digital HDLC chip, and a single-chip 1200-baud modem from EXAR. The board also includes 32K of ROM and 8K of RAM. Since the TNC is designed for use by ham operators, there is no radio on-board; most ham radios can be adapted fairly easily for use with the board.

Today there is much interest within the amateur radio community in packet radio. Amateur packet radio networks now in operation range from these local networks in Vancouver and Tucson to a national network that uses a system of repeaters. Several conferences on Amateur Radio Computer Networking have been held, and the Amateur Radio Research and Development group has issued preliminary protocol standards for packet radio networks.[6]

SPECIAL CONSIDERATIONS IN APPLYING PACKET RADIO TO ONLINE CATALOGS

The application of packet radio to library automation involves several unique considerations not well addressed by the current state of the art. First, current systems and the communications protocols developed for them have been designed to handle symmetric data rates: equal amounts of information are received and transmitted between any one station and another. Many library automation systems such as online catalogs, however, are highly asymmetric—about two or three characters are received by the host computer for every thousand characters it sends out to the terminal.

A second consideration is cost and its relation to the performance and reliability of the system. It may be possible to take advantage of the asymmetric data rate to achieve a compromise between the sophisticated and expensive military system and the inexpensive but somewhat unreliable amateur system. For example, one could use less expensive transmitters in the terminals where data speed is not crucial, and achieve a high data rate in the other direction by placing a high-quality transmitter in the online catalog's base station and sensitive receivers in the terminals. This would provide high performance while keeping costs to a minimum.

Finally, there is a special consideration involving repeaters and routing. It is unclear whether the ultimate library packet radio system will have to incorporate repeaters—devices that receive and rebroadcast a signal, making it possible to communicate over long distances. In many applications, one is concerned with networks that are limited geographically—

i.e., a building or a campus. If repeaters are used it will be necessary to explore different approaches to routing. Some compromise should be possible between the military system (in which the routing must adapt very quickly to fast-moving vehicles, node failures, and other drastic changes in network topology) and the amateur systems (in which the topology is extremely stable and there is not much concern for automatic selection of alternate routes).

DESIGNING A PACKET RADIO SYSTEM FOR LIBRARY AUTOMATION

The task of designing a packet radio network for a library automation application involves two basic questions: (1) What is the best way to share and manage a broadcast channel? (2) How should data be routed in a packet radio network large enough to require repeaters? A number of technical issues must be addressed in answering these questions. These issues are discussed briefly below.

Physical Characteristics of a Packet Radio Network

The first major issue involves choosing the right blend of transmission frequencies, transmitter power, modulation techniques, and antenna configurations for a given situation.

Frequencies

Unless one is transmitting at less than one-tenth of a watt, the broadcast frequencies must be allocated and licensed by the FCC. Virtually all packet radio systems operate at high frequencies which require line-of-sight transmission. The propagation characteristics of the frequency used will determine the cost of the transceivers. The frequency allocations will determine system bandwidth (capacity).

Modulation Techniques

This area encompasses two issues. The first is the method used to encode digital data into an analog signal so that it can be transmitted over a radio channel. This function is generally performed by a modem of some sort. It is important here to choose an encoding scheme that minimizes interference and maximizes bandwidth use. Some possible methods are:

—frequency shift keying (FSK), in which a slight variation in frequency indicates whether a bit is a "0" or a "1";

—quadrature phase shift keying (QPSK), in which wavelengths at different phases represent different combinations of bits; and

—pulse code modulation (PCM), where binary digits are conveyed as the presence or absence of a pulse.

The second issue involves the method used to encode the analog signal into an analog carrier (the broadcast channel). Possible methods include frequency modulation (FM), amplitude modulation (AM), and frequency modulation using a single sideband (FM/SSB).

An alternative that involves both of these issues would be to use spread spectrum techniques, which are very resistant to interference. Because interference tends to occur sporadically—either in short bursts, or centered around a frequency—spread spectrum acts to spread the data as widely as possible in order to minimize the amount of data destroyed by these bursts. Spread spectrum techniques can be applied either just before the digital signal is converted to analog, or as an extra input when the signal is encoded into the radio channel.

At the digital-to-analog stage, spread spectrum can be applied by incorporating pseudo-noise into the digital signal. Pseudo-noise is a stream of bits generated by a random number generator. For every bit of data to be transmitted, the encoding device will intermix a certain number of random bits into the data stream. The device receiving the data would use the same random number algorithm and the same starting point, allowing it to separate the actual data from the random bits. Spreading the data out in this manner reduces the probability that short bursts of interference will destroy data.[7]

At the analog-to-radio-carrier stage, spread spectrum can be applied by switching very rapidly among a number of different broadcast frequencies (called frequency hopping), with each frequency selected at random. Spreading the data across a broad spectrum of frequencies reduces the chance that interference on a specific frequency will destroy data.

While spread spectrum is ideal for library packet radio because of its great resistance to interference, the cost may be too high, and there are complex problems of synchronization between the stations that must be resolved. FCC licensing may also be a problem with spread spectrum modulation, although the FCC has recently indicated that it may deregulate the use of spread spectrum techniques.[8]

Transmitter Power

Transmitter power will determine the geographic area that the system can cover reliably, and the relationship between transmitter power, antenna configuration, cost of the transmitter, and the sensitivity (and hence the cost) of the receivers. In addition to propagation in open atmosphere, one must consider the ability of the radio signal to penetrate into buildings.

Antenna Configurations

Selection and configuration of antennas will depend upon the application. For indoor applications, long-wire antennas could possibly be run along the ceilings and up elevator shafts for the base station, and simple polarized antennas could be used on the terminal radios. For very short distances, infrared light is an interesting possibility. For interbuilding communications, a vertical nondirectional antenna might be used for the base station, with a vertically polarized yagi antenna of short length for the terminal cluster node station.

PROTOCOLS FOR A SHARED BROADCAST CHANNEL

The usual protocols for managing a shared broadcast channel are either some variant of ALOHA (standard or slotted), or Carrier Sense Multiple Access/Collision Detection (CSMA/CD).[9]

In standard ALOHA, transmission is done at any time, and the receiver sends an acknowledgment to the sender for each packet it receives. The sender detects problems if, after a given time interval, it has not received an acknowledgment from the receiver. The sender then delays for a random interval and retransmits. In slotted ALOHA, transmissions may only begin at the beginning of a time interval or "slot"; errors are detected in the same manner as in standard ALOHA. (This has implications for packet length size distributions if it is to make effective use of the channel.)

In the CSMA/CD protocol, the transmitter first listens to the channel to see if it is in use, and also listens while it is transmitting to detect collisions. In a network with repeaters (i.e., where every terminal cannot hear every other terminal), attempts to listen for collisions can be dangerous. A source node may be unable to hear a collision occurring at a destination node, or may "hear" a collision locally that the destination node cannot hear. There is also a problem, but a less serious one, in sensing if the channel is busy. There are a variety of proposals to resolve this such as transmitting a busy tone at higher power than standard data transmission, but they are all fairly complex. Another variant is straight CSMA, where the transmitter tests the channel to see if it is clear, but does not listen while it is transmitting. With CSMA, collisions are detected only when the receiver does not acknowledge a packet.

Simple ALOHA may be sufficient for terminal-to-base-station transmissions, given the low data rates for this channel. There are well-known analyses of all of these protocols in cases where the data rate is symmetric, but the extent to which asymmetric data rates affect these analyses is not entirely clear.

Routing and Repeaters

A packet radio network with no repeaters, in which a node can directly communicate with every other node, is called a "full broadcast network." In a full broadcast network, the network level protocol is fairly simple since there is no issue of routing. The simple act of transmission causes the message to be routed to any node that wishes to receive it.

Routing is only an issue if the network is large enough to require repeaters. Networks that require repeaters for end-to-end communications are called "semibroadcast networks." In semibroadcast packet radio networks, routing algorithms will be necessary in order to control the repeating of packets. A basic issue in routing is the choice between the virtual circuit approach or the datagram approach.

In the virtual circuit approach, once a route between sender and receiver has been established (by one of several different methods), that route is used for the duration of the transmission. The packets are sent and received in order. The virtual circuit approach has the advantage of being efficient once a route has been located, but it can also be time-consuming to identify and find another route if the established route is interrupted by, for example, an equipment failure. Virtual-circuit-type routing methods that select a wide path rather than a single set of repeaters can alleviate this, but such methods are difficult to implement.

In the datagram approach, each packet is considered an individual entity, and packets may travel in the network independently of the other packets in its data stream. Datagram methods frequently involve broadcasting packets throughout much of the network, rather than along a specific route, so that some packets will arrive at their destination via roundabout routes, and the same packet will often be broadcast a number of times. The datagram approach allows packets to be received out of sequence, and offers more flexibility and adaptivity than the virtual circuit approach. However, datagram routing methods can be fairly inefficient—i.e., requiring a great deal of system bandwidth to cope with the increased amount of traffic.

Routing in very large semibroadcast networks seems to be an intrinsically difficult problem, and remains an active area for research.

INTEGRATING A PACKET RADIO NETWORK WITH THE BACKBONE NETWORK

Packet radio is primarily a local technology. At the University of California, for example, we are viewing it as a means of providing access to the online catalog in certain campus buildings, or perhaps on an entire campus. Therefore, it must be tied to a more traditional long-haul backbone network—at DLA, the network linking the campuses across the state to the DLA computer center in Berkeley. The nature of this interconnection is somewhat dependent on the architecture of the long-haul network in question, and this section is oriented toward DLA's long-haul TCP/IP-based packet switching network described in reference 1, although many of the same considerations arise in connecting packet radio networks to any long-haul network.

The simplest means of integrating a packet radio network with a long-haul network is to keep the existence of the packet radio network hidden from the long-haul network by simply plugging the packet radio network into the RS-232 interfaces on a terminal access controller (TAC), and having the packet radio network appear to the long-haul network as a group of terminals. While conceptually simple, this approach creates a mass of wiring and extra hardware at the TAC, since data from the terminals will have to be de-packetized and fed into the RS-232 interfaces, only to be re-packetized by the TAC. Also, it does not allow many of the sophisticated routing features that would be available if it were treated as a local-area network and became a formal part of the internet. Finally, it means that all users of the packet radio network must appear to the long-haul network as terminals, even when they are using computers, preventing computer-to-computer communication.

A second approach would still treat the packet radio network as an "invisible" network—i.e., not part of the internet. It involves building a specialized interface into the TAC in order to eliminate the extra cabling and RS-232 interfaces, and perhaps allowing the TAC to support terminals that appear to be passing data through an X.25 packet assembler/disassembler (PAD). This can in many ways be viewed as a more elegant version of the first method.

The final approach is to treat the packet radio network as an actual network in the internet. This is the most complex but also by far the most flexible approach. It involves two tasks. First, a gateway must be put in place between each packet radio network and the nearest interface message processor (IMP). Building such gateways is not trivial, as they implement a substantial amount of logic and protocol.[10]

The second consideration in treating a packet radio network as a true network arises in the end-to-end protocols that must be used. In order to gateway to the internet, the packet radio network must run standard Department of Defense Internet Protocol (IP) above whatever network-level protocol it uses. In addition, the higher-level protocols that are understood on an end-to-end basis throughout the network (normally TCP and TELNET) must be used on top of IP. The implication here is that either a packet radio TAC must be developed (providing TCP and

TELNET for packet radio clients) or each packet radio must effectively function as a "host" on the network, implementing TCP/IP itself. It might be possible to take both approaches: a TAC or terminal server for simple terminals, with the option that intelligent hosts, such as personal computers, on the packet radio network could run TCP/IP themselves and communicate directly with the gateway, allowing them to talk to hosts that are not on the local packet radio network. Some argument could be made for incorporating the packet radio TAC into the base station, possibly by modifying a standard TAC.

NOTE: This paper is a recapitulation of an article by Edwin Brownrigg, et al. *Information Technology and Libraries* 3(Sept. 1984):229-44.

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