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Reliable Data Transmission Sub-Channelisation and Full Duplex

by

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Abstract
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About the Author
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1. Introduction

A growing body of techniques exists concerning the reliable trans-
mission of data over unreliable facilities. Schwartz (5) first published a
reliable scheme in what turned out to be, unfortunately, an obscure article.
Lynch (3) republished the method and showed how the full duplex file trans-
mission could be accomplished over a half duplex facility. Saviers (4)
developed an alternate scheme which required less control information.
Independently, Bartlett, Scantlebury and Wilkinson (1) discovered and pub-
lished this same technique. They also suggested that some sort of theory
was required, perhaps based on automata theory, to verify or disprove the
reliability of various schemes being proposed. Recently Ladner (2) has
devised just such a theory.

Each of these theories requires the return of some control inform-
ation so as to verify or not verify a previous transmission. Each of
these methods when applied to a full duplex transmission facility results
in that facility being used in exactly the same way as a half duplex facility.
While the turnaround times on a full duplex facility are much less than those
on the typical half duplex facility, a method utilising the full potential of
the full duplex facility has not, to the best knowledge of this author, been
published. Likewise, little attention has been given in print to the diffi-
culties encountered when several files of information wish to be sent simul-
taneously over a single data transmission facility. Multiplexing of truly
independent files presents some severe operational difficulties.

2. Ready-resume logic

Let us begin by examining some of these difficulties. Any kind of
communication facility operates on what we shall call 'ready resume logic'.
The transmission facility, by definition, does not have a clock common to
both ends of the transmission line. As a result it must operate in an asyn-
cronous mode. This is typically accomplished on most computers by present-
ing the data to the transmission facility along with some signal that the data
is ready. It is assumed that it will take some non-trivial and undeterminable
amount of time for the data to traverse the transmission facility and be accep-
ted at the receiving end. Since the sending end can make no timing assump-
tions and has no clock information about the receiving end, a signal return
from the receiving end to the sending end is necessary to complete the synch-
ronization. Such a signal is usually called a resume signal. When the
receiving end has successfully received the data and is prepared to accept another piece of data it sends back to the sending end a resume signal. This resume signal indicates to the sending end that the receiving end has disposed of the previous piece of data and is in a position to accept more data. Since this resume signal also traverses the transmission line it will take again some non-trivial and unknown amount of time to reach the sending end. The receiving end knows that a resume signal has reached the sending end when it itself receives the ready signal back down the transmission line. This ready signal may or may not be accompanied with another piece of data.

We thus have a ping-ponging effect whereby each end of the line alternately transmits a signal to the other end of the line. Each end of the line is prohibited from sending additional data until it receives a signal from the opposite end of the line indicating that its previous transmission has been received. It is easily seen that at most one end of the line will be transmitting at any given time. Such a system operates in the half duplex mode without respect to the actual data transmission facility. If the data transmission facility is in fact full duplex it is being used in exactly the same fashion as a half duplex facility. It should also be observed that the ready resume logic requires strict alternation of the transmissions first one from one end of the line and then another from the other end of the line. This technique has been worked out in the papers cited earlier.

3. **An example of sub-channelisation**

Let us suppose that we wish to sub-divide the transmission facility in a given direction so as to provide for, say, two sub-channels each sharing the same data transmission facility. For a concrete example let us assume that a computer wishes to transmit to a remote terminal which is fitted with both a printer and a punch and which has the capability of running the printer and punch simultaneously. We may then want to transmit a print file to operate the printer or a punch file to operate the punch, or assuming the data transmission facility is fast enough, both, more or less simultaneously, so as to run the printer and punch both at their rated speeds. Assuming that both printing and punching is available a programming question which arises is how the transmitting end at the computer is to know whether to send next a print line or a punch line.
Suppose that the printer operates at 600 lines a minute and the punch at 300 cards per minute. If the computer strictly alternates between printing and punching it is obvious that both the printer and punch will each simultaneously operate at 300 lines per minute. The printer is thus being utilised at only half of its rated capacity. Under these circumstances a more reasonable scheme would be to alternate the printing and punching on a two for one basis. That is, transmit two print lines followed by one punch line, followed by two print lines, and so on. Such a scheme with a fast enough transmission line and an appropriate buffering at the receiving end is capable of operating both the printer and punch at their full rated speeds. If the printer and punch are only approximately 600 lines a minute and 300 cards a minute this discipline will definitely enforce an absolute two to one ratio. In such circumstances, it is clear that either the printer or punch or both will operate slightly less than their full speeds. If mechanical clutches are involved then they may operate at substantially less than their full speed.

Additional complications in such a program will arise from outage conditions. For example, what happens if the printer runs out of paper or the punch runs out of blank cards. In such a circumstance both the print lines and punch lines will continue to come towards the receiving terminal. Let us assume that the printer is out of paper. In this case, the receiving terminal will, after a short time when its buffers become completely filled, refuse to accept additional print images. Since printing and punching is strictly interleaved this means also that punch images will now be prevented from being transmitted from the computer to the terminal. Under such circumstances both the printer and punch will stop. Clearly this state of affairs is completely unsatisfactory.

4. Channel versus sub-channel resumes

Close examination of the situation will reveal that our simple ready resume model is not adequate to handle the sub-channelisation case. When a print image is sent over the transmission facility the terminal really should return two resume signals to the transmitting end. The first of these resume signals will indicate that the data transmission facility itself is clear and free for further usage. That is, the print line has properly been received at the terminal. It does not necessarily indicate that the print line has been cleared from its buffers to the printer and that
the terminal is in a position to receive further print lines. The second
kind of resume, which we will call a sub-channel resume, indicates that the
specified sub-channel is clear for receiving further information. This
would occur when a line has actually been printed and the buffer is free to
receive further information. In our previous simple-minded model both of
these functions, transmission facility clear and buffer clear, were indicated
by precisely the same resume signal. It is clear that the two resume signals
should be separated from each other. That is, there should be a separate
signal for transmission facility clear and another signal for sub-channel
clear. Thus, when a print line is sent from the computer to the terminal,
a channel resume signal is generated when the data transmission facility is
free and, at some appropriate later time, another resume signal is sent from
the terminal to the computer indicating that the terminal is now prepared to
receive data on that particular sub-channel. Thus, in our example, three
types of resume signals are present, a channel resume signal, a printer resume
signal and punch resume signal. The printer and punch resume signals are sub-
channel resumes. The data transmission resume signal is a channel resume.

If we examine the paper outage example we will notice that if the
printer runs out of paper the printer resume signals will be inhibited from
being returned to the computer. However, data transmission resume signals may
still be returned as may punch resume signals. The computer should be pro-
grammed in such a way that it will not send a printer image unless both the
data transmission channel resume and the printer resume have been received.
If the data transmission resume has been received but the printer resume has
not the computer is still free to send punch images so long as the punch resume
has been received. Thus, both the channel resume and a sub-channel resume are
required before further transmission of data on that sub-channel can occur.
Examination of the printing and punching where the printer is twice as fast as
the punch will indicate that the punch resume will take twice as long to come
back as the print resume. Thus, a punch line may be transmitted, a channel
resume will come back fairly quickly, a print line can be sent and the print
resume will come back, another print line can be sent and at that point both
the print resume and punch resume should come back. Thus, the system will
automatically accomplish a two for one interlace without the magic numbers
being explicitly coded into the transmission program.
5. Half duplex idle reversal

An extremely important point to notice about this process is that ready signals and resume signals are no longer in a one to one strictly alternating sequence. In general, twice as many resume signals will be sent as ready signals. In the simple ready resume scheme either a ready signal is appropriate and a resume signal is not, or vice versa, a resume signal is appropriate and a ready signal is not. In the more complicated case where sub-channel resumes are explicitly transmitted, the next appropriate signal may be either a ready signal or a resume signal. It is thus not possible at any given instant in time to say in which direction transmission is next appropriate.

It should be clear that this non-alternation of signals will present no difficulty at all if the data transmission facility is truly full duplex. If, on the other hand, the data transmission facility is half duplex severe problems arise. If it is not clear in which direction the next ready signal or resume signal should proceed, the channel must be reversed periodically in order to allow one side or the other to present the next logical transmission. We will call this phenomenon idle reversal since it is necessary when the channel is idle to periodically reverse the direction of transmission to accommodate the next appropriate signal.

A practical question of considerable significance is, at what rate should the idle reversal proceed. If the idle reversal proceeds at too high a rate an inordinate amount of computer time will be used managing the channel in a logically idle state. If too low an idle reversal rate is set the response time and, in some cases, the bandwidth of the system will be severely degraded since either the next ready signal or resume signal may have to wait up to half of an idle reversal cycle. We thus have a maximum practical rate which is determined by the computer overhead and a minimum practical rate determined by the response time and bandwidth requirements of the system. We have absolutely no assurance that the maximum acceptable rate in fact exceeds the minimum acceptable rate.

6. Utilising a full duplex channel - radial demultiplexing

We will now turn our attention to applications of this sub-channelisation technique to a number of interesting problems. We have already observed that the sub-channelisation technique vastly simplifies the synchronization in time division multiplexing problems involved in sending
independent files across a common data transmission facility. In the print-punch example the application of this sub-channelisation technique is not only less complicated to program but also gives considerably enhanced performance. Let us consider the problem of employing a full duplex data transmission facility to send a half duplex file over a full duplex channel, of course utilising the full duplex channel to the utmost.

We will need a special trick in order to do this. First off, we shall take our full duplex channel and sub-divide it in the transmission direction into two sub-channels. We shall then take our file to be transmitted and demultiplex it into two sub-files. We will accomplish this demultiplexing by dividing the records into even records and odd records so that they are demultiplexed on a one for one basis. The even records are then transmitted half duplex over one sub-channel while the odd records are transmitted half duplex over another sub-channel. The receiving end then sees two channels of information coming in. It disposes of the information that it is receiving by re-multiplexing it on a one for one basis. That is, it interleaves the odd records with the even records, thus reconstructing the original file. We will call this trick radial demultiplexing.

It should be noticed that the computer, in order to transmit the next record over the data transmission facility, need wait only for the channel resume. The sub-channel resume for the previous record is not required until after the transmission of the next record. Thus, the transmission of the next record can be overlapped with the sub-channel resume for the previous record. In many data transmission systems an adequate channel resume signal is merely the termination of the previous transmission. Thus, one can proceed to send the next record down the channel before the sub-channel resume signal for the previous record has been received. As long as the sub-channel resumes are received within one record transmission time this system can operate at the rated speed of the data transmission facility.

Let us assume that the data transmission facility in fact consists of serial links with a store and forward system connecting consecutive links. Thus, the transmission from sending end to receiving end will, in fact, take a considerable amount of time. Let us, for the sake of argument, assume that this time amounts to six record transmission times. That is, we will begin transmitting the seventh record at the same time that the receiving
end is receiving the first record. In such circumstances, the resume signal for the first record, if it retraces the path at the same rate that the record was transmitted, will be received at the sending end at about the time that it is ready to transmit the thirteenth record. In such circumstances, it would be appropriate to divide the transmission channel into, say, 16 sub-channels and demultiplex the file into 16 sub-files. If the number of sub-channels is greater than 12 the transmission facility will proceed at full rate. If the number of sub-channels is less than 12 the transmission facility will proceed at a reduced rate.

It can also be seen that radial demultiplexing is exactly equivalent to buffering the transmissions. As in most uses of buffering the buffering depth depends upon the exact system one is dealing with. This author knows of a number of schemes for using full duplex data transmission facilities to their full capacity. These schemes generally have been coded in an ad hoc way and have not been described in the literature. In each case the scheme selected could be described in terms of the radial demultiplexing technique.

7. Front end computers

Let us now apply this theory to front end machines. That is, small communications computers connected on to a larger computer so as to reduce the workload. Certainly the sub-channelisation theory which has been developed in this paper is applicable to the communications lines emanating from the front end machine. It should also be realised that the sub-channelisation technique equally well applies to the connection of the front end machine to the central computer. From the central computer's point of view the front end machine is to implement a number of logical channels within the central computer. The duty of the front end machine is to attend to many of the small details which would be burdensome on the central computer. Thus, the central computer will be involved in transmitting and receiving several independent files of information to and from the front end machine. It follows from this that the connection between the front end machine and the central computer should be sub-channelised. In order to avoid the idle reversal problem introduced earlier, the connection between the front end machine and the central computer should be a full duplex connection. Otherwise the sub-channelisation will require the passing back and forth of control from the front end machine to the central computer during periods of light activity. This will both raise the overhead on the central computer and degrade the response time of the system.
8. **Data Transmission Networks**

As a last application let us consider data transmission networks. Several such networks are currently in the process of being implemented. In many of these networks the routing of a message is determined dynamically, that is to say, the transmitting end does not know by which route the message will proceed to the receiving end. As a matter of fact a subsequent message in the same file may proceed from the sending end to the receiving end by an entirely different route. It is entirely possible for such a second message to arrive at the receiving end before the first one. As a matter of safety it is necessary to generate a resume signal for each message received and to prevent transmission of a subsequent message on that sub-channel until the resume message has been passed back all the way through the network to the original sender. Such a philosophy, while logically correct, does not allow for high transmission rates particularly if the network involves many serial links.

An obvious solution to this problem involves the division of the file to be transmitted into sub-files by means of the radial demultiplexing technique. Several messages from the same file may be in the transmission network at the same time, each being assigned to a separate sub-channel. The messages will be remultiplexed in their proper order at the receiving end. While the transmission time for an individual message may be quite long the total bandwidth for a given file may still be quite high.

9. **Conclusions**

This paper has described the technique of sub-channelisation and demonstrated its application to the utilisation of full duplex lines, to the solution of the problem of parallel transmission of logically independent files, to the connection problem for front end computers and to the problem of controlling the flow in a data transmission network.

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