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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This note elaborates the notion of duplicate detection through sequencing and the need for resynchronizing the sequence numbers in use on a full duplex connection under certain conditions.

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TCP RESYNCHRONIZATION

by

Vinton G. Cerf
January 11, 1976

Technical Note #79

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TCP RESYNCHRONIZATION

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Introduction

The basic sequence numbering strategy employed in the ARPA Internet Transmission Control Program (TCP) is to assign (implicitly) a sequence number to each octet (8 bit unit) of text transmitted in an internet packet. [1,2] As explained in Tomlinson and amplified by Dalal [3,4], the finiteness of the available sequence number space requires that after a time, sequence numbers must be re-used. Care must be taken that the available sequence number space not be used up so fast that some packets carrying old sequence numbers are still in the network when these numbers are re-used. To assure this, we assume that packets can only remain in the network for a certain maximum lifetime. The maximum rate at which sequence numbers are used is related to this lifetime and to the size of the sequence number space. If the lifetime is T seconds and the maximum bandwidth (rate of sequence number consumption) is B, octets/second and the size of the sequence space is S octets, then we must have (see [2])

$$S > 2 \cdot B \cdot T \tag{1}$$

Indeed, it may happen that T is really a random variable without a guaranteed maximum, in which case, reliability can be improved by writing

$$S = K \cdot B \cdot T \tag{2}$$

which, for sufficiently large K makes the probability nearly zero that two packets carrying different text are assigned the same or overlapping sequence numbers. We have chosen the following parameters for the initial internet experiments:

$S = 2^{32}$ octets = sequence number space

$B = 2^{18}$ octets/sec (≈ 2 mbits/second) = bandwidth

$T = 2^{5}$ seconds ($\approx 1/2$ minute) = lifetime

STEP = 1 second (= 2^{18} octets)

We can compute the minimum cycle time as

$$C = S/B = 2^{14} \text{ sec } (\approx 4.55 \text{ hours}) \tag{3}$$

Combining (3) and (2), we obtain

$$K = \frac{S \text{ octets}}{B \cdot T \text{ octets}} = \frac{2^{32}}{2^{18} \cdot 2^{5}} = 2^{9} = 512 \tag{4}$$

Even if T is not bounded by 2^5 seconds, we can survive

$T \leq 2^{8} \cdot 2^{5}$ seconds = 8192 seconds = 2.27 hours

Resynchronization

Tomlinson introduces the need to select an initial sequence number (ISN) [3] using some well-known, periodic value, such as the time of day. Figure 1 plots the ISN value against time, where time and ISN are measured in the same units (e.g. using B as a parameter).

The same sequence number cannot be used to start each a connection, since this might introduce unintentional duplicate sequence numbers. We cannot rely on remembering the last sequence number used on a given connection, since this information may have been lost (e.g. host failure). Even during

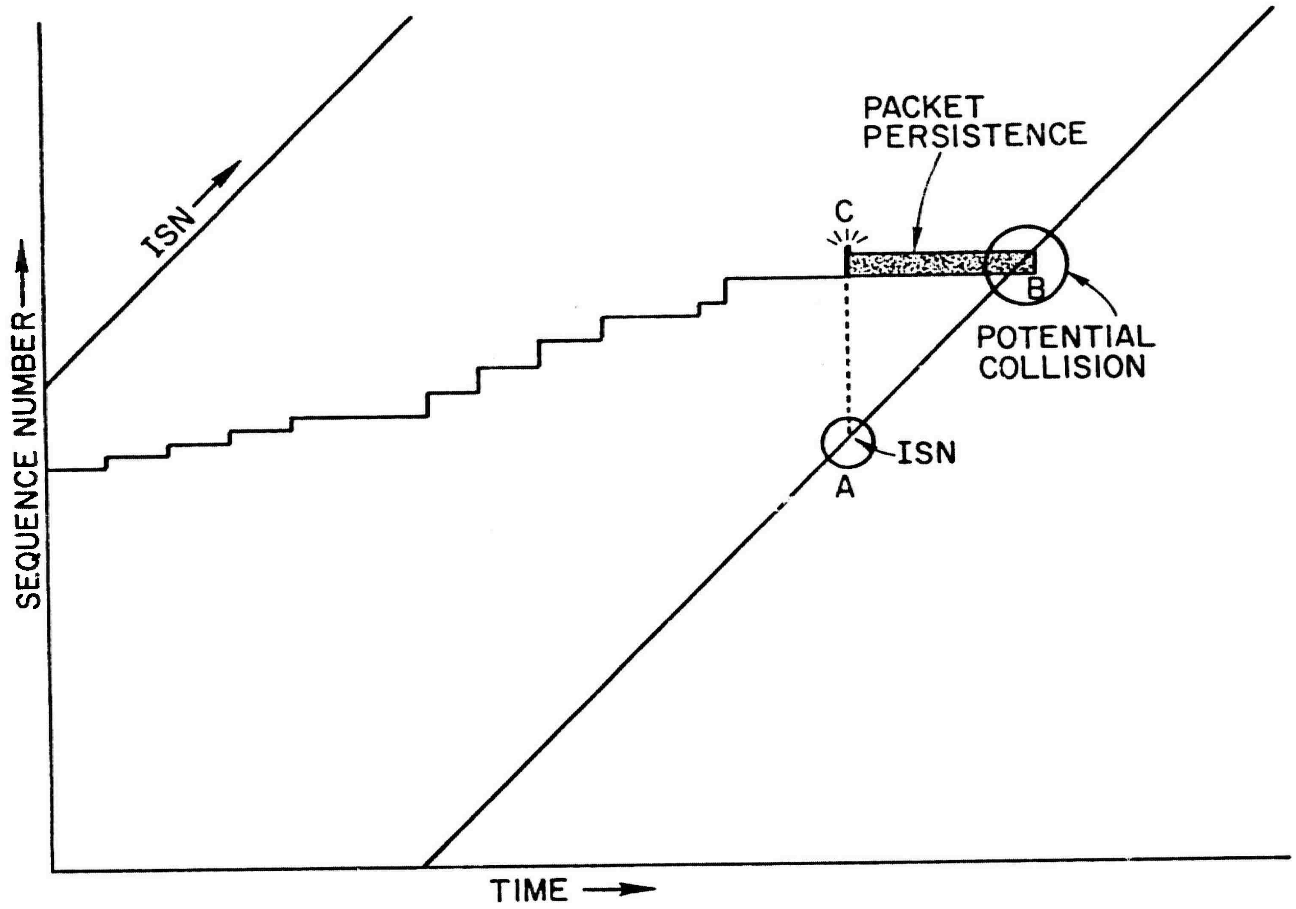

Figure 1

The Need for Resynchronization

the course of a particular connection, it may become necessary to resynchronize sequence numbers to avoid potential failures. In figure 1, we show the history of sequence numbers used by a particular connection. The lines labeled "ISN" represent the maximum permitted rate at which sequence numbers can be used. Suppose that the TCP supporting the connection fails at "C" and must be restarted. Assume, also, that the sequence number selected to restart is drawn from the value of ISN at the time event "C" occurred. The shaded area between "C" and "B" represents the maximum expected time that packets emitted at "C" can stay in the net. Clearly, the ISN line intersects this shaded area, indicating that, after the restart, it is possible that packets emitted at "C" may become undistinguishable from those potentially emitted along the ISN curve. To correct this flaw, the sequence number currently to be used on the connection must be resynchronized before running into the forbidden zone to the left of the ISN line.

Testing for the Need to Resynchronize

As packets are produced and sequence numbers assigned to them, the TCP must check for two possible conditions which indicate that resynchronization is needed. The first is that sequence numbers are being used up so fast that they advance faster than ISN. The other is that they advance so slowly that ISN "catches up with them."

The basic method of selecting an initial sequence number is to delay for an arbitrary period labelled a "clock tick" and then select the new ISN. In the TCP implementation, this amounts to one second of time during which up to 2^{18} octets may be transmitted. In figure 2, three sequence number histories are traced, ending in points "A", "B", and "C". In the

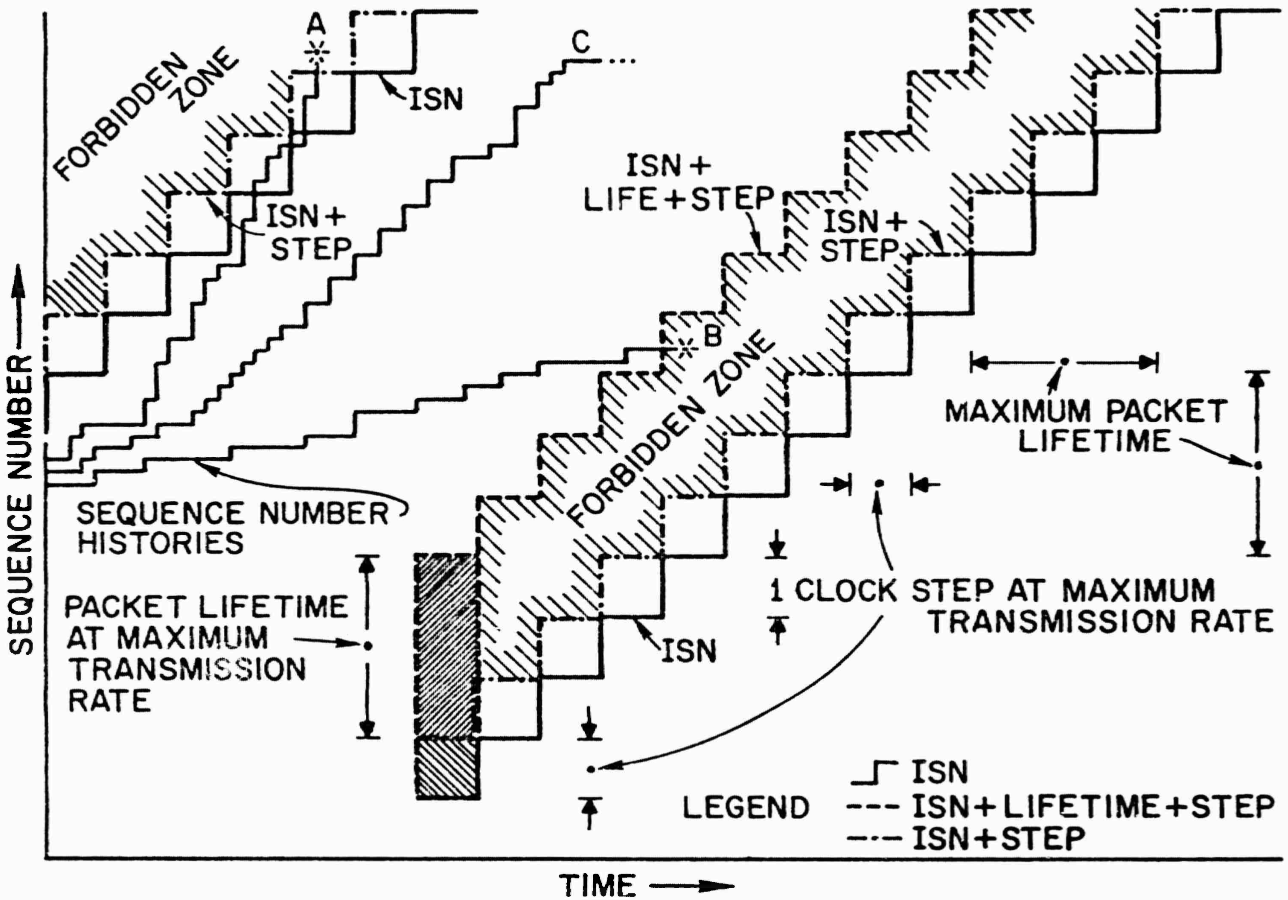

Figure 2

Detecting the Forbidden Zone

trace labelled "A," sequence numbers are used at such a rate that point "A" lies beyond ISN plus one step (clock tick). If the connection were to fail and be restarted at "A," the new ISN would be just below point "A" and would introduce potential unwanted duplicates.

This situation can be detected before transmission of the packet. Let SEQ represent the proposed sequence number of the packet, and SEQ+L-1 be the sequence number implicitly associated with the last octet of packet data. if ISN+STEP (at the moment that SEQ is to be assigned) lies in the range [SEQ, SEQ+L-1], then the type "A" ISN failure is about to occur. The solution is to send only as much text as is allowed (which does not result in the failure) and <u>wait</u> for the clock to tick again.

The situation in curve "B" is quite different. In this case, the connection is using sequence numbers so slowly that the forbidden zone preceding the ISN curve has advanced and run into the connection sequence number curve. There are two solutions. One is to wait for the packet lifetime plus one clock step to expire (in which case, the sequence history will pop out of the forbidden zone again. The other is to actively resynchronize the connection. The test for the type "B" situation is whether sequence number SEQ lies in the range [ISN, ISN+T+STEP] or [ISN, $ISN+33 \cdot 2^{18}$].

Note that all tests for inclusion must be modulo $S(2^{32})$ to account for the wraparound of sequence numbers.

Curve "C" in figure 2 shows a sequence number trace which tends, on the average, to lie within legal values at all times.

Conclusions

The value of clock step may be arbitrarily small, depending on the desired delay overhead to wait for the tick.

Checking for resynchronization is simple:

if SEQ ε [ISN, ISN+T+STEP] then resynchronize.

if ISN+STEP ε [SEQ, SEQ+L-1] (where L = packet length in octets)

then wait for clock to tick.

Appendix A - Window Size

There is a relationship between window size and the other quantities discussed in this paper. Let us call the average round-trip delay in the network D (measured so as to include the delay at the destination for accepting a packet and producing an acknowledgment). Maximum bandwidth cannot be achieved in this system unless the source is permitted to transmit continusously until receiving an acknowledgment. This leads to the relationship

$$W \geq B\ D = 2^{18} \text{ octets/second} \cdot D \text{ second} \qquad (5)$$

However, we have arbitrarily limited W to 2^{16} octets, which means that D must be bounded

$$D \leq \frac{2^{16}}{2^{18}} \text{ seconds} = .250 \text{ seconds} \qquad (6)$$

This is not unrealistic for a ground based network, but is inadequate for a satellite-based network where $D > .5$ sec (the result of a minimum 89,600 mile round-trip in space: 89,600/186,200 = .48 seconds).

In the Arpanet, the average line capacity is 50 kbit/sec, of which only about 48kbit/sec or 6k octets/sec are available to the host/host protocol. Since W measures permission to transmit data, we can further reduce effective bandwidth by a minimum overhead. The TCP header length is currently 40 octets (32 are defined in reference 1; 4 more are needed for the ARPANET leader, and 4 more are currently used for a timestamp). In the best case, an ARPANET message can be 8096 bits (1012 octets) including leader, so the overhead factor is 40/1012 = 4%.

Using 5.76 k octets/sec for B in equation 5 we obtain

$$W \geq 5.76 \text{ k octets/sec} \cdot D \qquad (5)$$

and, since $W = 2^{16}$ octets,

$$D \leq 2^{16}/5{,}760 \text{ sec} = 11.4 \text{ sec} \qquad (6)$$

This compares favorably with measured ARPANET delays which average less than 0.5 seconds [7].

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