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NTP Lucky Packets: Accuracy and Precision

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The accuracy of Network Time Protocol (NTP) over the internet is almost entirely determined by the symmetry of the outgoing and incoming paths, and seen using the basic NTP equations in Figure 1:

t_1 is the client's timestamp of the request packet transmission,
t_2 is the server's timestamp of the request packet reception,
t_3 is the server's timestamp of the response packet transmission, and
t_4 is the client's timestamp of the response packet reception.

The clock offset (θ) between client's clock (t_c) and server's clock (t_s) is

$$\theta = t_c - t_s \tag{7.3.1}$$

Taking into account the network delays, one may write

$$t_2 - t_1 = t_c - t_s + d_{12} = \theta + d_{12} \tag{7.3.2}$$

and

$$t_4 - t_3 = t_s - t_c + d_{34} = -\theta + d_{34} \tag{7.3.3}$$

where d_{nm} is the time it takes the packet to move from where it is timestamped t_n to where it is timestamped t_m.

Combining (7.3.2) and (7.3.3) one gets clock offset θ as

$$\theta = \frac{(t_2 - t_1) - (t_4 - t_3)}{2} + \frac{d_{12} - d_{34}}{2} \tag{7.3.4}$$

and two-way path delay D as

$$D = d_{12} + d_{34} = (t_2 - t_1) + (t_4 - t_3) \tag{7.3.5}$$

In an ideal situation, there is symmetry between the paths, so the second term in the RHS of (7.3.4) is zero and

$$d_{12} = d_{34} = \frac{D}{2} \tag{7.3.6}$$

Figure 1. Basic NTP equations, from [1]

As indicated in equation (7.3.4) of Figure 1, inequality of the outgoing and returning time delays (d_{12} and d_{34}) invalidates the result given in equation (7.3.6). Instead, an error term equal to half the asymmetry contaminates the result. Given the structure of the internet, this contamination is non-Gaussian, of order milliseconds, and in general not predictable, although at times repeating structure has been observed. Because of this, it is highly plausible that packets (technically packet pairs) with the lowest round-trip time (D in equation 7.3.5) will tend to have the lowest asymmetry and yield the most accurate results. These packets that speed through the internet are termed lucky packets. It has been claimed that improved NTP time transfer can be achieved by ignoring all but the "luckiest" ones – the retained packets could even be a small percentage of the total.

While it is plausible that lucky packets can improve time-transfer accuracy, it need not be so. For example, consider an NTP exchange from Masterclock, Inc.'s headquarters in St. Louis, Mo. to NIST's facility in Boulder, Co. If both paths go through the same particular internet node in Chicago, there can be considerable cancellation. If however, the outgoing path from Masterclock, Inc. goes via Chicago while the return path from NIST goes over a more direct path, the round-trip time will be less but the asymmetry will be more.

It is possible to test this if both client and server are stratum one and independently timed to GNSS or a UTC(k), or are common clock. as has often been done [2 and references therein]. In that case, the most accurate method is that which yields an average value closest to zero. This paper will analyze the result of months of observations, so as to quantify any accuracy and precision improvements from use of lucky packets.

1. P. Banerjee and D. Matsakis, "Introduction to Modern Timekeeping and Time Transfer", Springer Press, 2023
2. A. Novick, M. Lombardi, K. Franzen, and J. Clark, "Improving Packet Synchronization in an NTP server", ION-PTTI, 2018