Minimum Delay Path Selection in Multi-Homed Systems with Path Asymmetry

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***Abstract*— As mobile and fixed hosts are increasingly equipped with multiple network interfaces that enable multi-homing, there is significant current interest to seek appropriate method for access network selection. To address the presence of asymmetric forward-return path combinations in practice, we propose a simple but novel scheme to determine the one-way path with the lowest delay independently for both directions. This method provides delay sensitive multimedia applications with the lowest possible round-trip time in a multi-homed environment, compared to existing methods which assume path symmetry.**

***Index Terms*— Multi-home, asymmetric path, low-delay.**

I. Introduction

IT IS increasingly common for fixed and mobile hosts to be able to access the Internet via more than one access networks. To take full advantage of multi-homing, it is of significant current interest to address the issue of how to select the best network interface to transmit data. Several studies have pointed out that not only resilience but also efficiency may be improved by using the most appropriate path [1]. There are several parameters such as bandwidth, delay, jitter, cost and security that could be optimized alone or jointly for each specific destination address [2]. The availability of multiple network interfaces at both ends opens the possibility of using different forward and reverse path combinations for asymmetric round-trips to a specific destination. So far only symmetric round-trip combinations have been considered [3][4] as the problem is very challenging *per se*. However, using a different return path may help to increase efficiency and reduce latency by overcoming the traffic asymmetries present over the Internet in practice, e.g., web traffic. Asymmetric bandwidth demands and network delays are magnified by highly variable link bandwidths and loss rates in heterogeneous internetworks, especially where wireless networks are involved.

Asymmetric delays over forward and return paths have been a concern for TCP congestion control [5]. Because TCP performs round-trip time (RTT) measurements over a two-way path, it cannot distinguish if an increase in delay is due to the forward or reverse path, possibly resulting in underutilization of the available bandwidth. This problem has been addressed by TCP extensions [6] that change the way congestion window is calculated. However, these solutions cannot take advantage of multi-homing since TCP does not support it.

Stream Control Transmission Protocol (SCTP) [7] is an Internet standard transport protocol that includes the functions of TCP and UDP, as well as additional functionalities. One of these is the support of multi-homing, which allows multiple source and destination IP addresses to be associated with an SCTP connection. Extension of SCTP to allow dynamic address reconfiguration effectively supports seamless handover in a mobile environment [8][9]. Furthermore, use of Network Address Translation (NAT) to support multi-homing at layer 3 has been proposed [10].

Current research on delay-centric handover has focused on RTT measurements over symmetric paths [3]. The scheme selects the path with the lowest smoothed RTT (SRTT) from periodic RTT measurements. A similar approach called delay-sensitive SCTP (DS-SCTP) [4] has been proposed and evaluated with voice traffic between multi-homed hosts, which demonstrates performance improvements by choosing the lowest delay path.

II. Proposed Scheme

We propose a novel and easy to implement approach to select the one-way path with the lowest delay by taking into account the possible asymmetry of delay values over the forward and reverse paths, under the condition that only one of the available paths is selected for data transmissions in each direction. By considering all cross-combinations of forward and reverse paths between two multi-homed hosts, our method allow each host to independently determine the lowest delay path and select it for transmitting data to the other host. This allows each one-way data stream to experience the minimum possible delay, and consequently also minimizes round-trip delay. This approach is targeted to certain real-time multimedia applications such as voice conversation that require low delay for its periodically transmitted small packages.

Refer to Figure 1, which shows the paths connecting two multi-homed hosts, H1 and H2. Nodes 1, 2 and 3 represent the network interfaces of H1, while nodes 4 and 5 represent the network interfaces of H2. Assume that packets can be transmitted freely between any pair of interfaces (nodes) of the two hosts. To deal with the possible asymmetry in path traversal we introduce the following notation. Each forward path (relative to H1 in Figure 1) is designated f_i and the corresponding reverse path is designated r_i, where $i = 1, \ldots, N$ ($N = 6$ in Figure 1) spans the one-way paths existing in each direction. The transmission delay over the corresponding one-way path is d_{f_i} (or d_{r_i}). Each host's sender should maintain

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a matrix of RTTs for all possible round-trip paths originating from the host. In this example, the possible round-trip path combinations originating at H1 are $f_i r_j$ where $i, j = 1, ..., 6$, and the corresponding RTTs are

$$\mathrm{RTT}(f_i r_j) = d_{f_i} + d_{r_j} \qquad i, j = 1, ..., 6 \tag{1}$$

The main diagonal of the RTT matrix contains the RTTs of the symmetrical round-trip paths (6 elements in this example). The RTTs could be estimated by sending special probing packets that are returned by the receiver via a specific return path (in SCTP this is done via heartbeat chunks, HBs, extended to specify the return paths for the replies). This enables the sender to test all possible asymmetrical path combinations.

We do not consider direct measurements of forward path delays as it requires tight synchronization of sender/receiver clocks and is difficult to implement. The collection of RTT measurements described above, however, does not allow us to determine the absolute values of individual one-way delays. Fortunately, the path with the lowest delay can be selected based on relative rather than absolute delay values. A simple method is presented below.

To determine relative delays for the forward paths, not all N^2 RTT combinations are required, but a set of N probes along different forward paths returned via the same reverse path are sufficient. The difference in RTTs between round-trip paths $f_i r_k$ and $f_j r_k$ yields the delay difference between forward paths f_i and f_j:

$$\begin{aligned} &\mathrm{RTT}(f_i r_k) - \mathrm{RTT}(f_j r_k) = d_{f_i} + d_{r_k} - (d_{f_j} + d_{r_k}) \\ &\quad = d_{f_i} - d_{f_j}, \qquad i \neq j; \quad i, j = 1, \ldots, 6 \end{aligned} \tag{2}$$

Comparing the RTTs among all forward paths, it is straightforward to determine the one-way path with the lowest delay. The same can be applied to determine the reverse path with the lowest delay, by comparing N RTTs with the same common forward path and different reverse paths.

It should be noted that the accuracy of the estimated relative path delays deteriorates if path delays change substantially over the measurement period. In practice, to avoid path delay fluctuations, the measurements should be completed within a very short time interval, or alternately smoothed round-trip times (SRTT) based on sliding windows should be used.

The above method allows the sender at each host to independently select among available access networks to minimize data transmission delays to any other host in a multi-homed system.

III. Example

The following numerical example, based on the same configuration in Figure 1, illustrates how asymmetrical one-way delays can influence the choice of the outgoing interface for each direction. It is assumed that the delay experienced on each path is due to cross-traffic buffering along the intermediate routers. The impact of self generated traffic on intermediate queues is not considered. This approximation should be fine for applications that are not bandwidth intensive. Table I lists the hypothetical delay values of the one-way paths and all two-way path combinations.

The forward path delays vary from 10ms (f_6) to 800ms (f_1), and the reverse path delays vary from 50ms (r_1) to

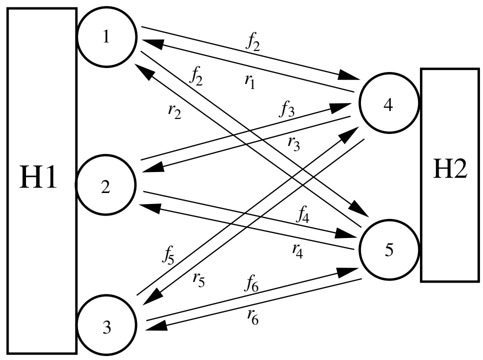

Fig. 1. Example where both hosts H1 and H2 are multi-homed. Forward paths are represented by f_i and reverse paths are represented by r_i.

1400ms (r_6). The RTTs of the combined forward-reverse paths range from as low as 60ms to as high as 2200ms. The shaded diagonal cells give the RTTs of the symmetric two-way paths. A simple delay-centric path selection method [3,4] that measures only symmetric RTTs will choose the lowest among these shaded values and pick path $f_2 r_2$ which has a RTT of 400ms. However, packets will experience a 300ms delay over the forward path, which may exceed the delay requirement of some multimedia traffic. Our proposed algorithm will select forward path f6 which has the lowest delay value (10ms) among the forward paths regardless of which common return path is used for measurement of the RTTs. If the proposed algorithm is used to select also the return path then r_1 which has the lowest delay (50ms) will be chosen. The communications for both ends would have a resulting RTT of 60ms. Host H1 will transmit from node 3 to node 5 with a delay of 10ms (over path f_6) and host H2 will transmit from node 5 to node 1 with a delay of 50ms (over path r_1). The ACKs in case they are used would also flow piggybacked on data packets on the same paths. This approach thus minimizes the overall RTT that was estimated at a given time. The frequency at which the estimation should be done may depend on the specific dynamic characteristics of each scenario and is a topic of further research. The use of time average estimate such as SRTT (smoothed RTT) has been one strategy used by several protocols to deal with this kind of fluctuation.

IV. Conclusion

We have proposed a novel and simple-to-implement route selection scheme for the transport of delay sensitive multimedia traffic between multi-homed hosts. It considers path delay asymmetries and is based on comparisons of round-trip time measurements among the different asymmetric cross-combinations of forward-reverse paths to determine the path that has the lowest delay. The proposed scheme allows each side to select the lowest-delay one-way path based on their probed estimation. It does not rely on clock synchronization between communicating hosts. It allows a general optimization of the round-trip time for both sides as long as the RTT estimates can capture the current delay conditions due to the effects of cross-traffic on intermediate queues. It enables delay sensitive communications to take full advantage of the multi-homed system. We have presented an example to illustrate

TABLE I

ONE-WAY DELAYS AND ALL RTT COMBINATIONS IN MS

			reverse path					
			r_1	r_2	r_3	r_4	r_5	r_6
		one-way delay	**50**	**100**	**400**	**800**	**1200**	**1400**
forward path	f_1	**800**	850	900	1200	1600	2000	2200
	f_2	**300**	350	400	700	1100	1500	1700
	f_3	**100**	150	200	500	900	1300	1500
	f_4	**40**	90	140	440	840	1240	1440
	f_5	**20**	70	120	420	820	1220	1420
	f_6	**10**	60	110	410	810	1210	1410

how the lowest two-way delay can be achieved by using the proper asymmetric bidirectional path instead of relying only on the symmetric path options. More detailed simulations using a network simulator should be carried out to verify under which circumstances the proposed approach can provide an effective performance gain. It is also of interest to extend our approach for delay minimization of transmissions over multiple concurrent paths in multi-homed systems.

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