Asymmetric Path Delay Optimization in Mobile Multi-homed SCTP Multimedia Transport

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ABSTRACT

Multimedia applications are very demanding of quality parameters from network provision, especially in a mobile wireless scenario. End-to-end delay is a primary concern for real-time applications. Much work have been done recently in order to fully exploit the multi-homing character of emerging wireless mobile systems addressing both communication performance as well as seamless handover. We propose an algorithm for path selection based on smallest delay that takes into account the dynamic asymmetry over the available routes. An example is provided showing how a multimedia application could benefit from this approach.

Categories and Subject Descriptors

C.2.2 [**Computer-Communication Networks**]: Network Architecture and Design – *Wireless communication.*; C.2.0 [**Computer-Communication Networks**]: General – *Data communications.*

General Terms

Algorithms, Measurement, Performance, Design, Theory.

Keywords

Asymmetric path, Multi-homing, SCTP, Delay, Mobile network, Multimedia.

1. INTRODUCTION

The increasing availability of options for network connections has been raising the question of how to choose the best network interface. There is a mix of parameters to be taken into account such as cost, bandwidth, delay, security, etc. Multimedia applications, in particular real-time conversations with voice or video are very demanding of network quality parameters. End-to-end delay and jitter are of particular importance. Networks can not always provide the needed service quality because of many factors such as congestion, failure or simple because the mobile user has moved out of the area of coverage. Many strategies are sought to maintain communication and allow seamless handover for wandering users. Only recently have some studies focused on the problem of maintaining the communication session while trying to optimize the best route in terms of network access, as it becomes increasingly common for a wireless device to be connected to more than one access networks employing either a homogeneous technology or heterogeneous forms of access such as Wi-Fi, Bluetooth, Wi-Max, UMTS, just to cite a few.

The Stream Control Transmission Protocol (SCTP) [17] provides a good framework to support multi-homing. Its original perspective was resilience as it was designed to address the link failure scenario by allowing alternate paths (defined by pairs of source and destination IP addresses) to be associated with a connection during its establishment. A recent extension for dynamic address reconfiguration (DAR) [16], also referred as the mobile extension of SCTP (mSCTP) [14], enables a more flexible way to reconfigure connection paths by allowing new source/destination IP addresses to be added to an ongoing SCTP association on the fly and invoked for reasons other than link failure, thus providing an elegant method to support terminal mobility across different networks. With multiple paths potentially available to an SCTP connection during various times, how to select among several available paths remains an open problem.

We propose an algorithm to select the one-way path with the lowest delay taking into account the possible asymmetry on delay values over the forward and reverse paths. As it minimizes end-to-end latency, the proposed scheme is well suited for real-time multimedia applications. It also facilitates the initiation of seamless handover for mobile users using SCTP DAR, by always selecting the lowest delay path in each direction. Current research on delay-centric handover has focused on round-trip measurements over symmetric forward-reverse paths. When path asymmetry is allowed, all the possible cross-combinations of forward and reverse paths should be considered to find the combination with the lower round-trip delays. Our approach provides a simple mechanism for the lowest delay path in each forward direction to be identified and selected independently at the source, thus ensuring that the overall round-trip delay over all possible combinations of forward and reverse paths is minimized.

This work is organized as follows: The next section provides some background on SCTP. Section 3 presents a brief review of

MSWiM'05, October 10–13, 2005, Montreal, Quebec, Canada.

related works. Section 4 delineates the proposed method, which is evaluated in section 5 by simulation involving a hypothetical scenario for delay sensitive multimedia transmissions. Section 6 concludes the paper.

2. SCTP

SCTP has been extensively evaluated for its ability to provide multi-homing at the transport level. While other transport protocols such as TCP and UDP define an end point as a pair (address, port), in SCTP an end point is allowed to have more than one IP addresses. When a session is established for communications between two hosts an association between the two endpoints is setup [15]. For example if one host has Internet access through 3 different access networks it should have 3 different IP addresses (IP1, IP2, IP3). When it establishes a session with another host with two IP addresses (IP4, IP5) then the association will be:

association={[IP1,IP2,IP3: PortA] ; [IP4,IP5: PortB]}.

Data exchange occurs between the end points over the primary addresses selected when the association is established. Other addresses are used for backup in the case of failure of one or both of the primary addresses. In this work the port number will not be considered to focus only on the address selection issue.

In the original SCTP RFC [17] the IP addresses present in an association, and the primary address selected at each end, could only be defined at session initialization. Recently proposed extensions [14,16] allow the addition/deletion of IP addresses and the reassignment of the primary address during a communication session. This has permitted the use of SCTP in a constantly changing mobile scenario [9].

There are some issues related to multi-homing [2] that have been addressed with different solutions. On most implementations, the transport layer (layer 4) cannot dictate which output interface to send a packet. This is usually done by the network layer (layer 3) after consulting its routing table, as IP normally uses only the destination address for datagram forwarding. Some proposals have overcome this problem by using the DAR extensions [14,16] and signaling the other end point to change the primary IP address of the mobile node in its table so that thereafter the communications flow to and from the newly selected primary IP addresses [9,10]. Another possibility is to assume that the SCTP implementation could tell layer 3 which source IP address to use and hence which interface to send the datagram.

There are several papers that explore the simultaneous availability of multiple paths to enable transmissions on them at the same time and achieve some level of load balance [3,4,21].

Another important extension, particularly useful for real-time multimedia applications, introduces partial reliability (PR) to SCTP [18]. Applications can decide on a per packet basis what is the lifetime of the packet or the duration of time that the sender should try to retransmit the packet. This characteristic of mixed reliability has been exploited for MPEG-4 multimedia streaming [11]. A technique coordinating PR-SCTP with session invitation protocol (SIP) for efficient error recovery in multimedia signaling has been developed [19].

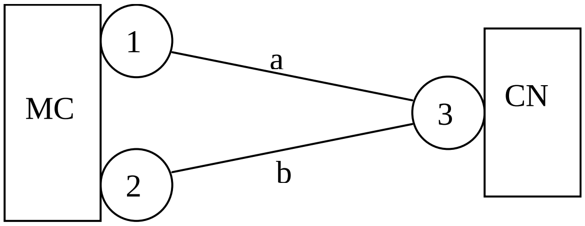

Figure 1. Multi-homed Mobile Client and Single-homed Correspondent Node.

3. RELATED WORK

Many researchers have advocated the use of mSCTP as a substitute for or extension of IP mobility [5,8,9,13]. The handover process can be decided by the client based on lower layer information such as signal intensity, power level, or upper layer application requirements.

The use of end-to-end delay for path selection in the multi-homing scenario is not new [1,20] but only recently has this idea gained momentum due its synergy with the SCTP framework. A delay-centric handover scheme have been proposed [7] and simulated for multimedia traffic [12].

Most of previous work considers a simplified scenario where one of the end points is multi-homed, usually the client. Figure 1 shows an example where the Mobile Client (MC) is multi-homed to two access networks while the Correspondent Node (CN) is single-homed.

A usual assumption is that transmission path and receiving path are the same. In fact, the round trip time (RTT) as the name implies intrinsically presumes the measurement of total time for a packet to transverse the forward path and come back over the reverse path. RTT measurement is accurate and easy to implement as it does not require tight synchronization of clocks at both end-points as would be the case for one-way trip delay measurements. However, it is not being taken into account that the reverse path could be different from the forward path. It is usually further assumed that the one-way time would be half of RTT which may not be true.

Even if all the links on both forward and reverse paths have the same capacity their end-to-end delays can vary substantially due to different traffic loads on each direction. It is not uncommon for the traffic of an application to exhibit an asymmetric behavior for the duration of a session, e.g., a video on demand transfer, or the asymmetry may change sides during the session as in a real-time audio conversation. One must keep separate track of RTTs for different paths, e.g., path ‘a’ and path ‘b’, as is already specified in the SCTP standard [17]. However, what to do if a packet goes from interface 1 to the destination and the SACK (selective acknowledgment) comes back to interface 2? What would be the meaning of round-trip in this case?

4. PROPOSED METHOD

To deal with the possible asymmetry in path traversal we introduce the following notation, where each forward path is designated by a lowercase letter (a,b,c,d) and the corresponding reverse path is designated by an uppercase letter (A,B,C,D). The

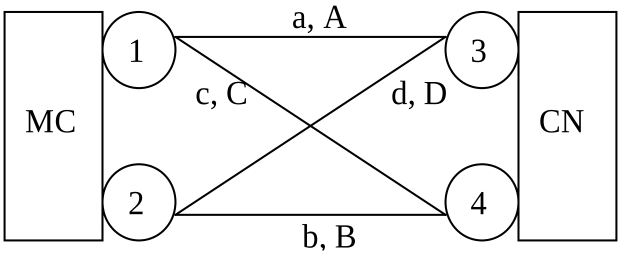

Figure 2. Both end points multi-homed; lowercase/uppercase letters designate forward/reverse paths.

letter also designates the one-way end-to-end delay over the corresponding path. Without loss of generality, we consider the simplified scenario depicted in Figure 2.

Both Mobile Client (MC) and Correspondent Node (CN) are multi-homed. The SCTP association is {[1,2] ; [3,4]}. It is assumed that datagrams can be transmitted freely between any interfaces (nodes) of the end points. The transmitter should maintain a separate table of delay statistics on RTT, SRTT (smoothed round-trip time), and RTTVAR (round-trip time variation); they are used to estimate the path round-trip timeout (RTO) value for each of the four possible round-trip path combinations, instead of a RTO value for each the two possible destination addresses as required in the SCTP standard.

In this example the generalized round-trip path combinations are displayed in Table 1.

Table 1. All possible round-trip path combinations

		Reverse path			
		A	B	C	D
Forward path	a	aA	aB	aC	aD
	b	bA	bB	bC	bD
	c	cA	cB	cC	cD
	d	dA	dB	dC	dD

The RTT from node 1 to node 3 and back to node 1 would be designated ‘aA’ (which has a numerical value of a+A). The main diagonal contains the four symmetric paths for this example. The RTTs could be collected either by Heartbeat (HB) measurements or by normal operation of the protocol which uses the SACKs to update the estimates. One extension that is desired to give this approach more flexibility is to include a field in the HB chunk that specifies the reverse path over which the receiver should respond to the HB. This way the transmitter has means of testing all possible path combinations regardless of which path (or more than one concurrently) may be carrying the HB chunk.

From this collection of RTT measurements it is not an easy task to estimate the absolute values of individual one-way delays. But fortunately it is extremely easy to compare a one-way path delay with another, which is what is desired to select the path with the lowest delay. In fact, to do so for the forward path, only one column of the table would be required. Using the first column as an example, the difference between the first cell in the first row and the corresponding cell on the second row gives:

$$aA - bA = a + A - (b + A) = a - b \tag{1}$$

A positive result indicates the excess delay path ‘a’ has in comparison to path ‘b’. A negative result indicates the opposite, i.e., path ‘a’ has less delay than path ‘b’.

To assess which forward path would have the lowest delay, the same evaluation has to be carried out with the third and fourth rows yielding:

$$aA - cA = a + A - (c + A) = a - c \tag{2}$$

$$aA - dA = a + A - (d + A) = a - d \tag{3}$$

In other words, it is possible to know the pairwise differences between single paths delays. It is straightforward then to determine the path with the lowest delay.

The same reasoning can be applied to the rows of the table in order to determine the reverse path with the lowest delay, e.g.,:

$$aA - aB = a + A - (a + B) = A - B \tag{4}$$

It should be noted that equations (1-4) will work under the strong assumption that the path delays do not change while the table is being assembled. In an actual environment this is usually not true but a fairly good approximation should be possible if the measurements are gathered within a very short interval or alternatively by working with the smoothed round-trip times. SCTP standard [1] prescribes that SRTT should be obtained by time averaging every new RTT measurement according to:

$$SRTT = (1-\alpha)\, SRTT_{old} + \alpha\, RTT \tag{5}$$

where the recommended value for α is 1/8. The best way to calculate SRTT for a fast changing asymmetric scenario is certainly a topic for further research.

But there is also the question: who should choose the optimal paths: client, server or both? One approach is to let the client or the session initiator select all the paths (both forward and reverse) and let the server (or CN) knows which path to use by using a protocol extension to send this information on an additional chunk. If the CN does not support this extension it will use regular SCTP behavior and either try to send data to the MC’s primary address or reply SACKs to the reverse path of the incoming datagram. In this manner, the CN at the other end could still run a standard SCTP implementation and the MC should be able to manage the optimization process.

Another approach is to let the client optimize the forward path and the other end to optimize the reverse path; in other words, always let the transmitter select its forward path. This is a good way of dividing the task given that ultimately the RTT measurements are obtained when the transmitter receives SACKs (or HB replies). So the CN should also maintain its own table (of reverse path with respect to the MC) and choose its forward path when sending data to the MC. As with standard SCTP, SACKs can piggyback on application data to increase efficiency.

Also, as some other studies have considered, more than one paths may be in use concurrently for load sharing, without disrupting the ability of both ends to monitor RTTs and compare all one-way paths delay estimates.

As in other delay-centric strategies, the proposed method can also be applied to the estimated path SRTT or any other time weighted RTT to prevent unnecessary path oscillations. A hysteresis threshold could also be established for the same purpose.

5. RESULTS

The configuration presented in Figure 2, where both ends are multi-homed to two access networks, was evaluated in two scenarios. The first scenario considers a static condition where the path delays do not change over time. The values considered for each one-way path and the two way corresponding sum are displayed in Table 2.

Table 2. Static scenario – one-way delays and all RTT combinations in ms

		Reverse path			
		A: 50	B: 100	C: 400	D: 800
Forward path	a : 600	650	700	1000	1400
	b : 300	350	400	700	1100
	c : 40	90	140	440	840
	d : 20	70	120	420	820

Depending on the combination of forward and reverse paths the RTT can be as low as 70ms or as high as 1400ms. Forward path ‘a’ has a delay of 600ms and forward path ‘b’ has a delay of 300ms which are both considered high for real time multimedia applications. Both forward path ‘c’ and forward path ‘d’ have small delays of 40ms and 20ms, respectively. The dark shaded cells corresponds to RTT of symmetric paths ‘aA’ and ‘bB’ and have round-trip delays of 650 and 400 ms, respectively. Most standard SCTP applications would recognize only the two distinct destination addresses (nodes 3 and 4) and choose the outgoing interface appropriately (in this case node 1 for destination 3 and node 2 for destination 4). Therefore, they restrict their option to only those two cells, and if they are running a delay-centric path selection scheme, would probably end up choosing path ‘bB’, which has a lower delay compared to ‘aA’, but still has a high forward delay of 300ms. Other proposed methods consider that outgoing interfaces can be freely chosen allowing for any symmetrical path combination. This will include the lightly shaded cells containing paths ‘cC’ and ‘dD’. But their RTT delays (440 and 820ms) are higher than 400ms and the path selected would still be ‘bB’. Our proposed algorithm will always select forward path ‘d’ which has the lowest delay value (20ms) regardless of which return path is used for measurement of the RTT. Should both ends be using this algorithm the reverse path selected would be ‘A’. The communications for both ends would have an RTT of 70ms. The MC would transmit from node 1 to node 4 with a delay of 20ms and CN should transmit from node 3 to node 1 with a delay of 50ms. The SACKs would also flow piggybacked on data chunks on the respective reverse paths.

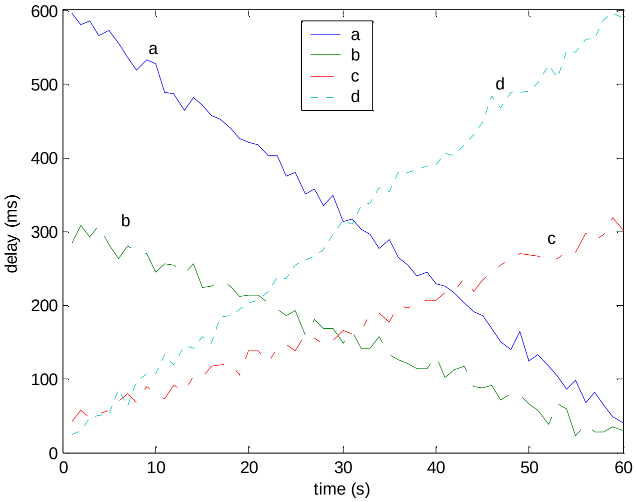

Figure 3. Forward path delay evolution over time.

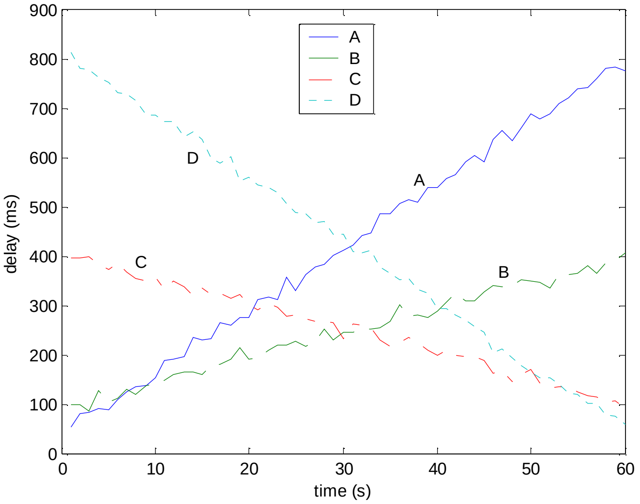

Figure 4. Reverse path delay evolution over time.

The second scenario considers a dynamical condition where the delays constantly change over time. The forward path delay profiles are depicted in Figure 3 and reverse path delay profiles in Figure 4. They are simply linearly changing values with added Gaussian random noise over a 60s time interval sampled every second.

Each side tries to use its lowest delay forward path. It is supposed that the MC sends HB chunks over all its forward paths to the CN every other second, while the CN send HB chunks to the MC over all its forward paths every 4 seconds starting at 2s. No measurements based on SACKs nor any packet losses were considered. The measurements of RTT were essentially gathered using the HB chunks, just to illustrate the concept of the proposed algorithm. Simulation was carried out using Matlab. A more detailed investigation using a network simulation is in progress. Figure 5 shows the selected forward paths (circles) which are computed every 2 seconds by comparing the smallest delay path every second. Transmission starts with

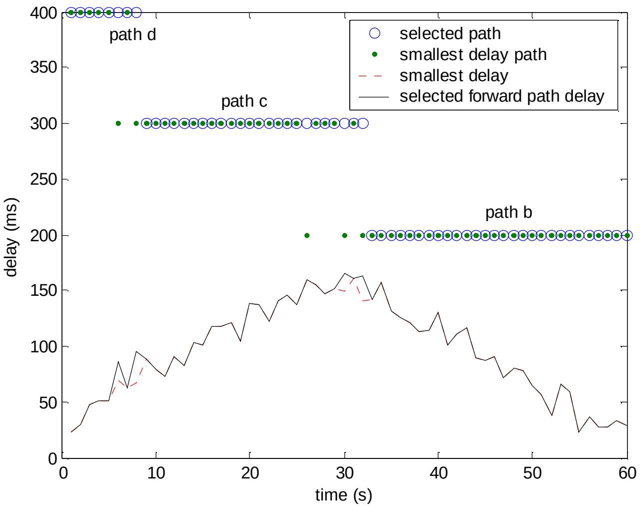

Figure 5. Selected forward path and resulting path delays

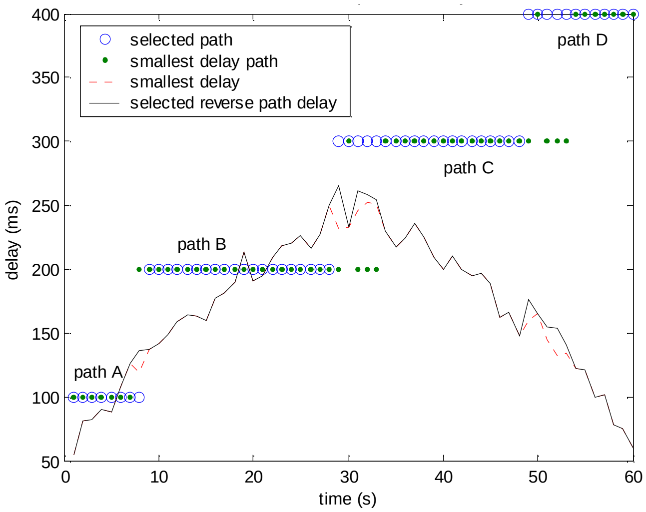

Figure 6. Selected reverse path and resulting path delays

path ‘d’, then at 9s changes to path ‘c’, and finally t 32s changes to path ‘b’. Notice that the smallest delay path (dot) is not selected all the times because the MC does not sample the path every second. On the same figure the experienced delay and the minimum available delay are displayed.

Figure 6 shows the same type of plot for the reverse path, or the forward path with respect to the CN. Again the smallest delay path is not always chosen because the path delays are only measured in 4s intervals. One can notice that the delay sampling period also works like a filter to prevent too frequent path changes. Delay averaging should also act in the same fashion.

Figure 7 shows the round-trip delays for the symmetrical paths compared to the selected path delay and the smallest possible delay. When there are asymmetries on forward and reverse path delay values the optimization obtained is readily apparent (before 20s and after 40s). Around time 30s, forward paths ‘c’ and ‘b’ have delays around 150ms and reverse path ‘C’ and ‘D’ have delays of 250ms so round-trip times are about 400ms and there is no cross combination that gives a smaller delay than the symmetrical round-trip paths ‘cC’ ‘dD’.

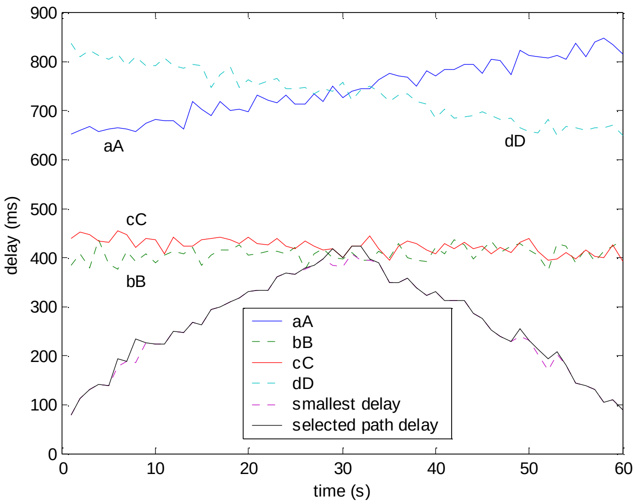

Figure 7. Round-trip delays of different path combinations

The ability to select the lowest delay cross-combination of forward and reverse paths should not be overlooked as it can imply a perceptive delay improvement that could greatly benefit multimedia real-time communications. The SCTP multi-homing framework with the already proposed DAR extensions can easily tackle this problem requiring none or minor extra protocol extensions.

6. CONCLUSIONS

A simple path selection algorithm based on asymmetric routes has been devised for the transport of delay sensitive multimedia traffic within the framework of multi-homed mobile SCTP. This approach is end to end and does not depend on network support. It should be capable of providing seamless handover across homogeneous and heterogeneous wireless networks. It requires minor extensions to SCTP. The proposed scheme allows each side to select the lowest delay one-way path yielding a general optimization of the round-trip time for both sides. It enables delay sensitive communications to take advantage of the multi-homed environment when either one end or both ends are multi-homed.

Two scenarios were simulated to illustrate the concept, where a simple real time multimedia application is able to follow the lowest delay path as close as the accuracy of delay estimation allows. More detailed simulations should be carried out especially in the presence of heavy traffic to assess the stability and performance gain of the proposed approach.

7. ACKNOWLEDGMENTS

This work was partially supported by a grant from Telus Mobility, and by the Natural Sciences and Engineering Research Council of Canada under grant CRD247855-01.

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