Analysis of SCTP Handover by Movement Patterns+

Dong Phil Kim, Seok Joo Koh, and Sang Wook Kim

Department of Computer Science, Kyungpook National University, Korea
{dpkim, sjkoh, swkim}@cs.knu.ac.kr

Abstract. Stream Control Transmission Protocol (SCTP) is a new end-to-end transport protocol, which can be used to support the mobility of mobile terminals. This paper describes a framework of SCTP handover and analyzes the handover latency for the single-homing mobile terminals. We then show the experimental results of the SCTP handover in terms of the handover latency and throughput for the two different movement patterns: linear and crossover patterns. For the linear movement pattern, it is shown that the SCTP handover latency may severely depend on the handover delay at the underlying link layer. In the case of the crossover movement pattern, we see that the throughput of the data transmission could be degraded, as the crossover movements occur more frequently.

1 Introduction

As the wireless access technology gets rapidly improved, the demand of mobility support has been more increased. With this trend, some protocols to support the mobility have so far been focused, which include Mobile IP (MIP) [1] and Session Initiation Protocol (SIP) [2] and Stream Control Transmission Protocol (SCTP) [3]. In particular, it is noted that the SCTP can be used to support the soft handover for mobile terminals with the help of the SCTP multi-homing feature [4].

In this paper, we analyze the SCTP handover algorithm in terms of handover latency. We perform the experimental analysis of the SCTP handover over Linux platforms for the single-homing mobile terminals (with a single network interface). In particular, we compare the performance of the SCTP handover for the two different movement patterns of the mobile terminals: linear and crossover patterns.

This paper is organized as follows. Section 2 describes an overview of SCTP handover and briefly compares the existing mobility protocols. In Section 3, we analyze the latency of SCTP handover theoretically. Section 4 describes some experimental results of SCTP handover that have been performed on the Linux platforms. Section 5 concludes this paper.

2 SCTP Handover

This section describes SCTP handover and compares the existing mobility protocols.

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2.1 SCTP Handover Mechanism

Stream Control Transmission Protocol (SCTP) as defined in IETF RFC 2960 [3] is an end-to-end, connection-oriented transport layer protocol, next to TCP and UDP. The SCTP is featured by 'multi-streaming' and 'multi-homing'. In particular, the multi-homing feature of SCTP can be used to provide the handover capability for the mobile terminals (MT) by adding a new IP address and deleting the old IP address during the active session [5].

Figure 1 sketches the SCTP handover for a mobile terminal (MT) between two different IP networks, where the MT is moving from Base Station (BS) A to B.

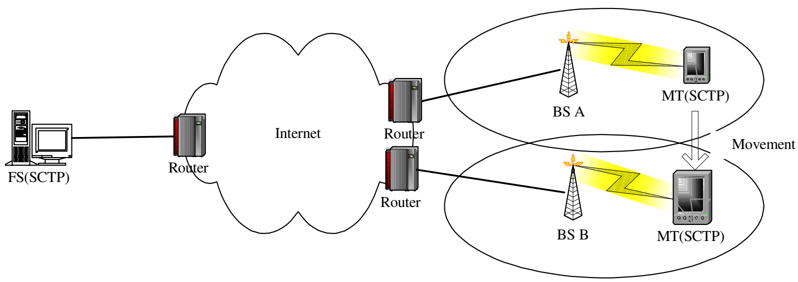

Fig. 1. SCTP Handover

In the figure, we assume that an MT initiates an SCTP association with a Fixed Server (FS). For the SCTP association, FS has 'IP address 1', whereas MT uses 'IP address 2'. Then, the overall SCTP handover procedures could be performed as follows:

(1) When the MT moves from BS A toward BS B, now it is in the overlapping region. In this phase, the MT obtains a new address 'IP address 3' from the BS B by using an address configuration scheme such as Dynamic Host Configuration Protocol (DHCP).

(2) The newly obtained IP address 3 will be informed by MT to FS in the tranport layer. This is done by sending an SCTP Address Configuration (ASCONF) chunk to FS. The MT receives the responding ASCONF-ACK chunk from the FS. This is called the 'Add-IP' operation.

(3) The MT is now in a dual homing state. The old IP address is still used as the primary address, until the new IP address 3 is set to be the "Primary Address" by the MT. Before the new primary address is set, IP address 3 is used as a backup path.

(4) As the MT further continues to move towards BS B, it needs to change the new IP address into its primary IP address according to an appropriate rule. Once the primary address is changed, the FS sends the outgoing data packets over the new primary IP address of MT (IP address 3). This is called the 'Primary-Change' operation.

(5) As the MT progresses to move toward B, it will delete the old IP address from the association. This is called the 'Delete-IP' operation.

The procedural steps described above will be repeated each time the MT moves to a new BS.

2.2 Comparison of the Existing Mobility Protocols

In this chapter, we review the existing IP-based mobility protocols that have so far been developed. More especially, we analyze and compare SCTP with the two existing protocols for supporting mobility: Mobile IP and SIP.

A. Mobile IP

Mobile IP (MIP) is a well-known protocol used to support IP mobility, which was standardized in the IETF. As per the associated IP version, MIP could be divided into MIPv4 [6] and MIPv6 [7]. MIP has been developed to support seamless Internet service against any change of the IP address, when the MT progresses toward the new IP region.

In this paper, we focus on the MIPv4 scheme. The specification of MIPv4 describes the protocol operations between the following entities: Mobile Terminal (MT), Home Agent (HA), Foreign Agent (FA), and Correspondent Node (CN). The basic protocol operations of MIPv4 are done as follows:

Step 1. When a MT moves into a new subnet, it can be assigned the CoA (Care of Address) from FA such as a router. The CoA could be the CoA of FA (IP address of FA) or the Co-located CoA (e.g., obtainted by Dynamic Host Configuration Protocol).

Step 2. After that, the MT registers its CoA with the HA.

Step 3. If the HA receives data packets destined for the MT from the CN, the HA will intercept these packets and forward them to the MT by using the Mobile IP tunneling.

Step 4. The FA (in case of using CoA of FA) will de-capsulate the packets received from HA and then deliver the original packets to the MT.

The basic specification of MIP cannot support fast handover for time-critical and loss-sensitive applications. To address this problem, some extensions of MIP are being developed in the IETF, such as Fast handover for MIP [8, 9] and Hierarchical MIP [10].

B. Session Initiation Protocol

The Session Initiation Protocol (SIP) has been made in the IETF for supporting the control of IP-based multimedia sessions as a signaling protocol [11]. The SIP is an application-layer protocol that can establish, modify, and terminate multimedia sessions for supporting user mobility.

It is noted that the SIP can support user mobility to provide the location management [12]. The following describes the SIP operations for mobility.

Step 1. When an MT moves into a new network, it will register its current location by sending an SIP REGISTER message to the SIP Registrar.

Step 2. The Registrar may deny or accept the request. In the acceptance case, the SIP server will update the location database with the new location information.

When the MT moves into a new network or system, the SIP registration procedures are repeated to update the location.
On the other hand, the SIP may be used to support handover using the SIP RE-INVITE message.

Step 3. When an MT moves to a new network region during a session, it will send a new RE-INVITE message to CN.
Step 4. The RE-INIVITE message must include a new IP address of the MT. When CN receives the RE-INVITE message, it replies with the SIP OK message. Now, the MT can directly communicate with CN.

It is noted that the SIP-based handover cannot provide seamless mobility, since the on-going TCP/UDP session will be terminated when the MT changes its IP address.

C. Comparison of the Existing Mobility Protocols

Table 1 summarizes the comparison of the existing mobility protocols: MIP, SCTP, and SIP.

Fist of all, the MIP operates at the IP network layer to support the mobility. The MIP needs the route optimization extension to avoid the so-called triangular routing problem. Furthermore, the MIP provides the location management but supports the limited handover with the help of the mobility agents such as Home Agent (HA) and Foreign Agent (FA). In order to support the fast and seamless handover, the MIP needs to be extended as the Fast Handover to MIP (FMIP).
Secondly, the SCTP can be used to provide the seamless handover in the transport layer. The SCTP does not support the location management, but it can be used along with the MIP or SIP for location management. On the other hand, the SCTP does not require any additional mobility agents. It intrinsically provides the route optimization for data transport

Finally, the SIP is an application layer signaling protocol. The SIP could provide the location management. It is noted that most of the next-generation network systems consider the SIP as a signaling protocol for IP-based multimedia services. However, the SIP could not support seamless handover.

Table 1. Comparison of the existing mobility protocols

	MIP	**SCTP**	**SIP**
Operation Layer	Network Layer	Transport Layer	Application Layer
Location Management	Provided	Not Provided (May be used with MIP)	Provided
Mobility Agents	HA, FA (MIPv4)	No need of mobility agents	SIP Servers (e.g. Registrar)
Route Optimization	Need an extension for route opt.	Intrinsically provided	Intrinsically provided
Handover Support	Limited handover by MIP, (FMIP as extension)	Provided	Limit handover in the application layer

3 Analysis of SCTP Handover of Handover Latency

In this section, we analyze the latency of SCTP handover for a mobile terminal (MT). The handover latency is defined as the gap between 'the time that the MT has received the last DATA chunk over the old IP address', and 'the time that the MT has received the first DATA chunk over the new IP address' [13, 14].
For handover analysis, we consider the single-homing MT that can only use a single network interface at a time. This scenario could be applied to the horizontal handover of an MT that is moving within homogenous networks. In this case, the "link-up" of a new link and "link-down" of the old link will occur at the same time in the underlying link and network layers. That is, the SCTP handover will occur together with the link-layer handover at the same time.

For the single-homing MT, the handover latency $T_{handover\text{-}latency}$ can be calculated by summing up the time T_{DHCP} (for the configuration of a new IP address from a DHCP server), the time T_{ASCONF} (for the Add-IP and Primary-Change and Delete-IP operations in the SCTP handover), and the time $T_{link\text{-}handover}$ (for the handover at the underlying link layer). Accordingly, the total handover latency of SCTP will be

$$T_{handover\_latency} = T_{ASCONF} + T_{link\_handover} + T_{DHCP} \tag{1}$$

In the equation, T_{ASCONF} corresponds to the Round Trip Time (RTT) for exchange of ASCONF and ASCONF-ACK chunks between MT and FS. It is noted that the RTT is proportional to the distance between two endpoints and also inversely proportional to the bandwidth of the link. We also note that the SCTP handover requires three times of exchanges of ASCONF and ASCONF-ACK chunks for ADD-IP, Primary-Change, Delete-IP, respectively. That is, we can rewrite T_{ASCONF} as

$$T_{ASCONF} = 3\times\left(\frac{L\times D_{AR\_FS}}{BW_{wired}} + \frac{L\times D_{MT\_AR}}{BW_{wireless}}\right) \tag{2}$$

where L is the packet length of chunks, and $D_{AR\text{-}FS}$ is the distance AR (Access Router) and FS , and $D_{MT\text{-}AR}$ is the distance between MT and AR, and BW_{wired} is the bandwidth of the wired link, and $BW_{wireless}$ is the bandwidth of the wireless link.

From the equation (1) and (2), and by considering that the address configuration time T_{DHCP} can relatively be viewed to be a constant value, we may conclude that the SCTP handover latency $T_{handover\text{-}latency}$ depends on the handover delay of the underlying link layer $T_{link\text{-}handover}$ and the RTT for exchange of ASCONF chunks T_{ASCONF}.

4 Experimentation of SCTP Handover on Linux Platform

In this section, we describe some experimental results of the SCTP handover that have been performed over Linux platform.

4.1 Test Scenarios

To experiment the SCTP handover, we construct a small test network, which consists of one router and two hosts (FS and MT). Each host supports Linux Kernel 2.6.8 together with LK-SCTP [15] tools.

We consider the handover of MT that is moving between two IP networks and have experiment the following two test scenarios, as shown in Fig. 2.

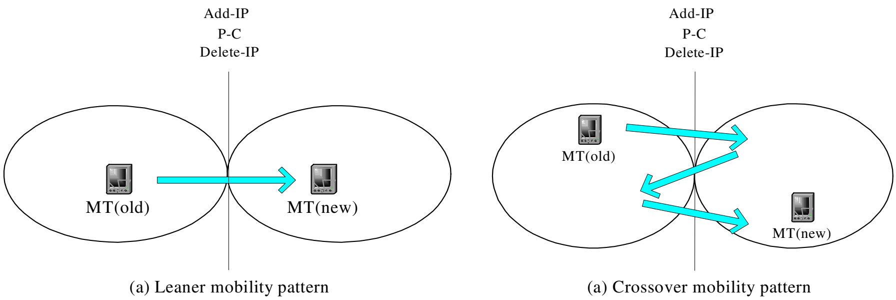

Fig. 2. Mobility pattern for SCTP Handover

<u>Scenario A: linear mobility pattern (Fig. 2(a))</u>
In the linear mobility pattern, an MT moves straightforward from an old IP region toward a new IP region linearly, without coming back to the old region. That is, an MT will not be affected by the so-called ping-pong effect. In this case, the handover of MT could occur only once.

<u>Scenario B: crossover mobility pattern (Fig. 2(b))</u>
In the crossover mobility pattern, an MT is moving forward and backward between the old IP region and the new IP region. That is, an MT is affected by the ping-pong effect. In this case, the handover of MT would occur several times.

For those two scenarios, we commonly applied the following handover procedures:

1) MT initiates an SCTP association with the FS. Initially, the MT uses the IP address 192.168.0.101, and the FS binds to the IP address 192.168.0.100. After initiation, two endpoints start to exchange the data packets.
2) MT adds a new IP address "192.168.0.102" to the association using *sctp_bindx()*.
3) MT requests the Primary-Change to the FS using *setsockopt()*.
4) MT deletes the old IP address from the association using *sctp_bindx()*.
5) When the data transport is completed, the MT shutdown the SCTP association.

For the analysis of the linear mobility pattern, we measured the 'handover latency' as a performance metric of SCTP. In addition, in the case of the crossover mobility pattern, we measured the 'throughput for data transmission" as the total number of bytes transmitted during the association period". The purpose of the throughput measurement is to identify whether the SCTP handover performance will be affected by the ping-pong effect in the crossover mobility pattern of MT.

4.2 Results and Discussion

From the table, we see that the FS and MT (old) establish an SCTP association through the 1^{st} ~ 4^{th} packets. At packets 10 and 11, the SCTP Add-IP operation is performed between MT and FS.

For the Primary-Change operation, the MT sends an ASCONF chunk to the FS at Packet 15, and the FS replies with ASCONF-ACK to the MT at Packet 19. It is noted that after the primary IP address is changed, the FS transmits all DATA packets to the new IP address of MT.

When the existing old link gets down, the MT sends the ASCONF chunk to FS for the Delete-IP operation, as shown at Packet 27. The FS then replies with ASCONF-ACK to MT at Packet 28.

From the table, we note that after the Add-IP operation is completed, the MT uses only the new IP address for all the SCTP packets. This is because the old link and IP address are not available any more since the "link-down" of the old link occurs at the same time together with the Add-IP operation for the single-homing MT.

Table 2 shows the result of SCTP handover for the single-homing MT.

Table 2. Results of SCTP Handover for the linear mobility pattern

NUM	TIME	PACKET	FROM	TO	NUM	TIME	PACKET INFO	FROM	TO
1	0.0000	INIT	MT (old)	FS	19	2.779674	ASCONF_ACK	FS	MT(new)
2	0.000221	INIT_ACK	FS	MT(old)	20	2.780051	DATA	MT(new)	FS
3	0.000430	COOKIE_ECHO	MT(old)	FS	21	2.780357	DATA	FS	MT(new)
4	0.000678	COOKIE_ACK	FS	MT(old)	22	2.780567	DATA	FS	MT(new)
5	0.002023	DATA	FS	MT(old)	23	2.780699	SACK	MT(new)	FS
6	0.002196	SACK	MT(old)	FS	24	2.780729	DATA	FS	MT(new)
7	0.002277	DATA	FS	MT(old)	25	2.805702	DATA	MT(new)	FS
8	0.021647	SCAK_DATA	MT (old)	FS	26	2.805919	SCAK	FS	MT(new)
9	0.021926	SACK	FS	MT(old)	27	2.806360	ASCONF	MT(new)	FS
10	0.023800	ASCONF	MT(old)	FS	28	2.806505	ASCONF_ACK	FS	MT(new)
11	0.223489	ASCONF_ACK	FS	MT(old)	29	2.806784	DATA	FS	MT(new)
12	2.463763	DATA	FS	MT(old)	30	2.806900	DATA	MT(new)	FS
13	2.463948	DATA	MT(old)	FS	31	2.807058	SACK	MT(new)	FS
14	2.778830	DATA	FS	MT(old)	32	2.807483	DATA	MT(new)	FS
15	2.779132	ASCONF	MT(old)	FS	33	2.807483	SACK	FS	MT(new)
16	2.779296	DATA	FS	MT(old)	34	2.807808	SHOUTDOWN	FS	MT(new)
17	2.779431	SACK	MT(old)	FS	35	2.807970	SHUTDOWN_ACK	MT(new)	FS
18	2.779466	SACK	FS	MT(old)	36	2.808103	SHUTDOWN_COMPLETE	FS	MT(old)

From the table, the SCTP handover latency is measured as the time gap between Packet 9 and 12, "2.463 - 0.022 = 2.441 (sec). In fact, this handover latency approximately corresponds to the time taken for processing link-down (old-link) and link-up

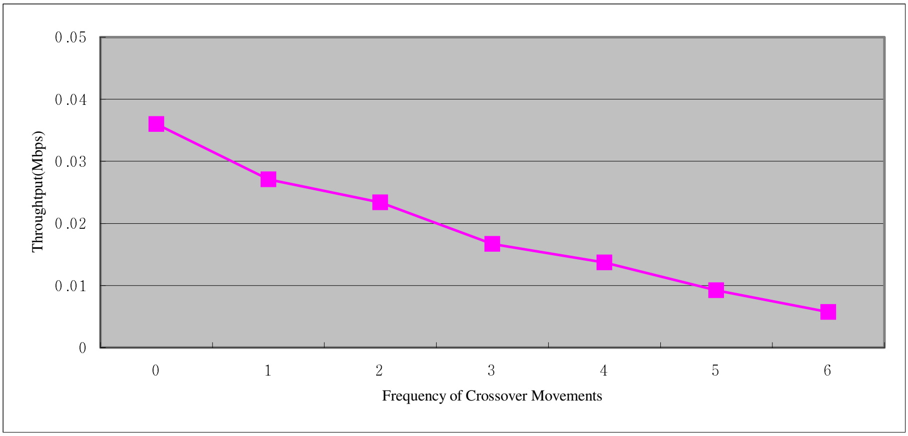

Fig. 3. Throughput for the crossover movements of MT

(new link) at MT (note that these events occur at Packet 11 and 12 in this experiment). Accordingly, we see that the handover latency for the single-homing MT is severely affected by the processing time of the link-down and link-up at the underlying layer.

This result can be interpreted from the formula (1) in Section 3. More specifically, the SCTP handover latency $T_{handover\text{-}latency}$ is linearly proportional to both $T_{link\text{-}handover}$ (the processing time of the link-down and link-up in the underlying layer) and T_{ASCONF} (RTT between MT and FS). However, we can see that the SCTP handover latency is more affected by $T_{link\text{-}handover}$ rather than the T_{ASCONF} for the single-homing MT.

On the other hand, Figure 3 shows the result of the throughput for the crossover mobility patterns of MT. In the figure, the measured throughputs are depicted for the different numbers of the crossover occurrences.

From the figure, it is shown that the throughput performance gets degraded, as the number of the crossover movements of an MT gets larger. This is because the total handover latency will cumulatively increase, as the MT moves across (handover) the different IP network regions more frequently. That is, the larger (cumulatively) handover latency will result in the lower throughput during the SCTP association period.

5 Conclusions

In this paper, we analyze the latency of SCTP handover for the single-homing mobile terminal theoretically and by experimentations over Linux platform. From the results, it is shown that the SCTP handover latency may severely depend on the handover delay at the underlying link layer. Instead, the RTT between two SCTP endpoints is negligible in the terms of the overall handover latency. On the other hand, in the case of the crossover movement pattern, the throughput of the data transmission could be degraded, as the MT performs the crossover movements more frequently.

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