Network Controlled Handover for Improving TCP Performance in LEO Satellite Networks

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Abstract— **In this paper, we propose the method for reducing out-of-order packets at handover event in LEO satellite networks. In LEO satellite networks, every communicating terminal handovers independently. Therefore, delay between terminals varies drastically within a short period. This drastic delay variation causes out-of-order packets and unnecessary fast retransmission of TCP. To avoid such delay variation, the proposed method makes a satellite to predict and control handover timing of connected user terminals. In the proposed method, two communicating terminals handover in a synchronized manner. By doing this, out-of-order packets at a handover can be reduced and this contributes to avoid occurrence of TCP's false retransmissions.**

I. INTRODUCTION

The Internet has expanded rapidly in recent years with proliferation of new applications and expansion in number of hosts. It has become the backbone of the present Information Age by providing us with the freedom to exchange information with ease. The information exchanged over the Internet in recent times have shifted from just textual information to audio and video information, resulting in the need for infrastructure and technologies capable of providing high speed and high quality services for these multimedia applications with strict QoS (quality of service) requirements. In addition, to provide ubiquitous Internet access, appropriate mobility support is required. Satellite networks with global coverage, broadcast capability, bandwidth on demand flexibility and the ability to support mobility is an excellent candidate for the globally scattered Internet users. Therefore, the integration of LEO satellite networks into today's IP-based terrestrial networks is also needed [1].

In LEO satellite networks, routing tables of satellites should be updated when a handover occurs. However, when a handover occurs in process of communication, until the updating of the routing tables is completed, the sender may send packets to the previous satellite which the receiver terminal is connected to before the handover. These packets have to be forwarded to current satellite by the previous satellite. Once the routing tables are updated, a sender can send packet directly toward the receiver's current satellite. This results that the later packets bypass the former packets and arrive at the receiver earlier than the former packets. This results in packet reordering at the receiver [2] as shown in Fig. 1.

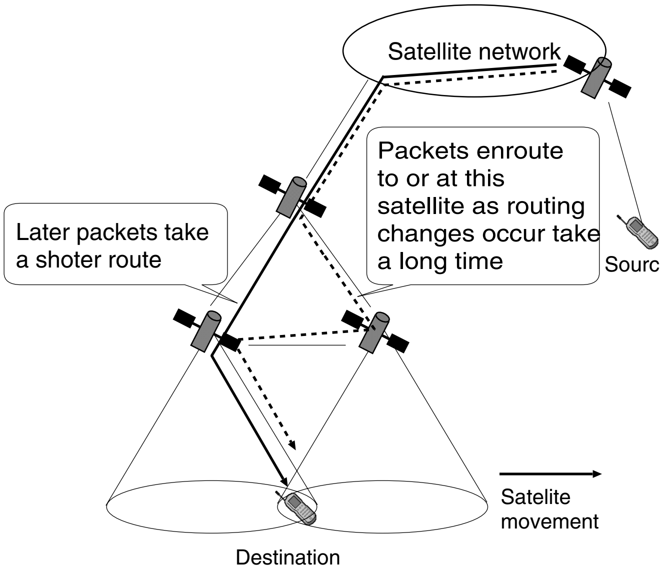

Fig. 1. The Typical Situation of Packet Reordering Occurrence

The degree of packet reordering depends on communication bit rate and the difference of propagation delay before or after handover. The number of reordered packet can increase when the propagation delay between sender's and receiver's current satellites T_{new} is shorter than sender's and receiver's previous satellites T_{old}. In addition, as the communication bit rate increases, the number of reordered packets also increases.

Packet reordering adversely effects upper layer protocols. TCP [3] can interpret reordered packets as packet loss due to congestion. In this case, transmission rate is unnecessary reduced [4], [5]. UDP [6] is commonly used for multi media applications. In such applications, packet reordering might be interpreted as packet loss, thus resulting in degradation of communication quality. As a consequence, application throughput is adversely effected.

In this paper, we point out another cause of packet reordering, which is delay variation within a short period. In the conventional handover strategy, each communicating terminal handovers independently. Therefore, the communicating path can be extended for a short period and then the path length becomes short again.

To reduce delay variation resulting in handover of communicating terminals within a short period, we propose the

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network controlled synchronized handover scheme. Proposed methods are effective in reducing jitter caused by handover and resulting packet reordering.

The rest of the paper is organized as follows. Section II explains the TCP performance degradation problem in LEO satellite networks. In section III, we present the proposed scheme to make communicating terminals handover at the same timing. Section IV evaluates applicability of the proposed method. Concluding remarks are in section V.

II. DELAY VARIATION WITHIN A SHORT PERIOD AND TCP PERFORMANCE DEGRADATION

In the conventional handover procedure, handover of each terminal occurs independently. As a consequence, there are instances of handover of each communicating terminal occurring in a very short period. This results in variation of propagation delay in a short period and has an adverse effect communication. This type of handovers occurs more frequently in communication between some terrestrial locations than others.

We show the example of this scenario through a simulation using NS-2 [7]. In this simulation, the Next generation LEO System (NeLS) [8], [9], which is a kind of Walker Delta Constellation [10] developed in Japan, is used. NeLS consists of 120 satellites on 10 orbits. Altitude of satellite is 1,200 kilometers and the orbit inclination is 55 degrees. NeLS covers the region from latitude 60 degrees north to latitude 60 degrees south. The orbit parameters are listed in Table I. The minimum elevation angle is the lowest angle of elevation from a terminal to a satellite, and a terminal can connect only the satellite whose elevation angle is larger than the minimum elevation angle. For all simulations, the minimum elevation angle is set to 13° for providing double mesh coverage to terminals, unless otherwise specifies. Double mesh coverage is having more than one satellite visible to a terminal from each of the ascending and descending mesh all at time [11]. This significantly increases flexibility of satellite selection by a terminal.

TABLE I

ORBIT PARAMETERS OF NELS CONSTELLATION

Orbit parameters	Value
Altitude	1,200km
Eccentricity	0(circular)
Inclination	55°
# of planes	10
# of satellites	120
# of satellites per plane	12
# of Intra-Plane ISLs per satellite	2
# of Inter-Plane ISLs per satellite	2
Minimum elevation angle	20° or 13°

Figure 2 represents delay variation between two terminals locating in Tokyo ($35.41E$, $139.45N$) and Sendai ($38.16E$, $140.52N$). We can find short bursts of high delay in this figure.

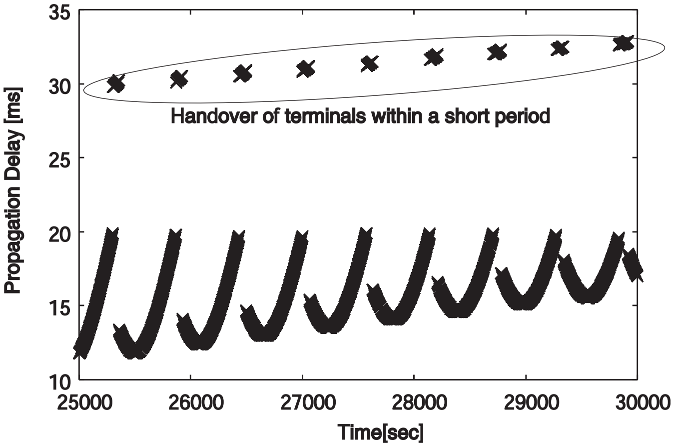

Fig. 2. Example of Delay Variation within Short Period

The error and congestion control mechanisms of TCP are based on the assumption that packet losses indicate network congestion. Hence, when the a packet loss detection is made the TCP backs off its transmission rate by reducing its congestion window (cwnd). Two strategies are used to detect packet loss. One is based on sender's retransmission time out (RTO) expiring. When a sender times out, congestion control causes sender to enter slow-start, drastically reducing its cwnd to one segment. The second mechanism to detect loss originates at the receiver and uses TCP's sequence number. The receiver observes the sequence numbers of packets it receives; a break in the order of sequence is considered to indicate packet loss. Since TCP uses cumulative acknowledgment, "duplicate acknowledgment" (or DUPACK) for every "out-of-order" segment it receives is generated by the receiver. The DUPACKs are generated until the "out-of-order" segment is received. The retransmit algorithm in modern TCP implementations infers a packet has been lost after few (usually 3) DUPACKs are received. The sender then retransmits the lost packet without waiting for a timeout and reduces its congestion window in half. This algorithm is referred to as fast retransmission.

If the receiver gets 3 out of order packets during handover, it causes a fast retransmission despite no packets being lost. Since the path is always there is a drastic increase and decrease in path length therefore the delay between the terminal. The packet reordering occur when a reduction in path length occurs due to a handover.

Figure 3 depicts the cwnd reduction due to fast retransmission at a handover. A TCP sender and a receiver is connected to a path with 20ms delay at t=0. At time 100s the connection is switched to a 30ms path. At time 130s it is switched back to the 20ms path again. The path bandwidth is 11Mbps for all the cases. Reduction of window size is observed at 130s. This is a result of packet reordering occurrence due to reduction of path delay.

III. NETWORK CONTROLLED SYNCHRONIZED HANDOVER

For avoiding the drastic increasing and decreasing of delay in a short period, we propose a handover scheme in which both communicating terminals are simultaneously handed over.

In the proposed method, a service satellite (a satellite which

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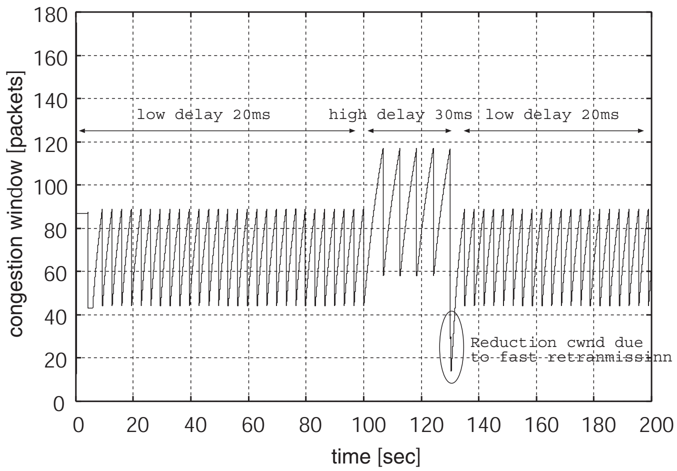

Fig. 3. Fast retrasmission occurence at handover

a terminal connected to) controlls a handover procedure. Both service satellites of a sender and a receiver calculate remaining times to next handover occurrence t_H. Then if the difference between t_H of the terminals are small, handover of both terminals to the next satellite take place at the smallest t_H. Fig. 4 depict the comparison between the proposed handover method with the conventional method.

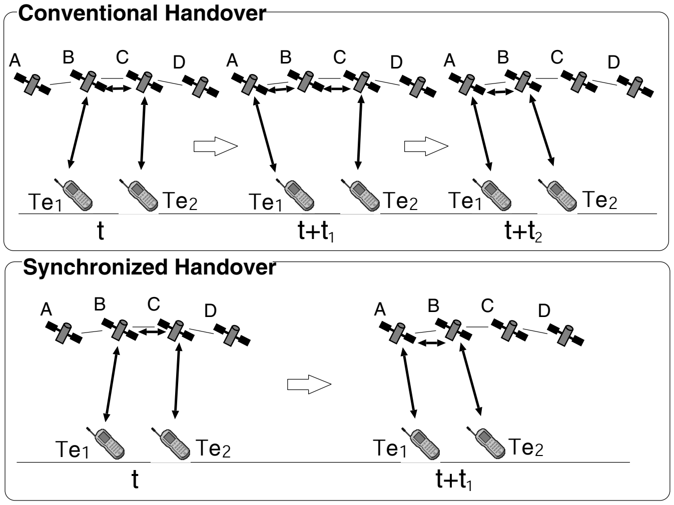

Fig. 4. Illustration of Conventional Handover and Synchronized Handover

In this scheme, t_H of each terminal is calculated by its connected satellite and exchanged between the connected satellites of a sender and a receiver. In addition, handovers of terminals are initiated by the satellites. Thus, we call the proposed method as network controlled synchronized handover scheme. For this purpose, we assume that a satellite has onboard processing capability and can calculate t_H based on the scheme proposed in [12]. at the start of a communication session and every handover event.

Figure 5 depicts lowest bandwidth at which fast retransmission is observed for a given delay difference at handover $(T_{old} - T_{new})$. To calculate this bandwidth, the TCP sender and receiver is connected with 30ms delay path at first and switched to a path with $30ms-(T_{old}-T_{new})$ delay. For NeLS constellation, conventional handover method results in a delay difference of between 10ms to 20ms in minimum. Once the proposed method is implemented the delay difference is less than 7ms. Therefore the bandwidth at fast retransmission occur is significantly increased. Hence, communication can take place at higer bit rates without packet reordering occurrence when syncronized handover is implemented.

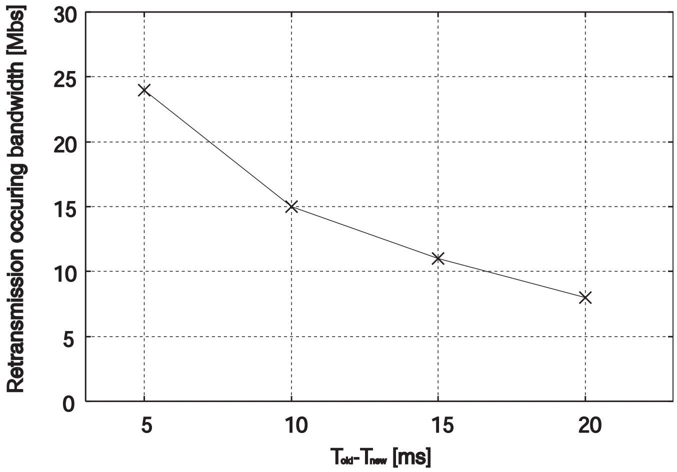

Fig. 5. Fast retrasmission occurence and $T_{old} - T_{new}$

IV. EVALUATION OF THE APPLICABILITY OF THE PROPOSED METHOD

A. Location of Terminals and Applicability of Synchronized Handover

We conduct simulations to investigate the relationship of terminal location and applicability of synchronized handover.

It is conducted over NeLS constellation using network simulator NS-2. For realizing syncronized handover, both of the communicating terminals must be able to catch the next satellites when one of the terminals tries to handover. Hence, it is clear that the possibility of syncronized handovers depends on the location of each terminal. Therefore, simulation is carried out for various latitudes of source and destination pairs. Source latitude and destination latitude is varied from northern latitude 50° to 0° with an interval of 10°. Longitude difference between source and destination is varied from 0° to 180° with 10° interval for each source and destination latitude. We calculated percentage of possible synchronized handover events out of all the handover events for 24 hours between two source and destination pairs. When both sender and receiver terminals handover within a short period (60 seconds in this simulation), we consider such handover event as possible syncrhonized handover. A handover event consist of handover of both sender and receiver terminals. Results are shown in Fig. 6.

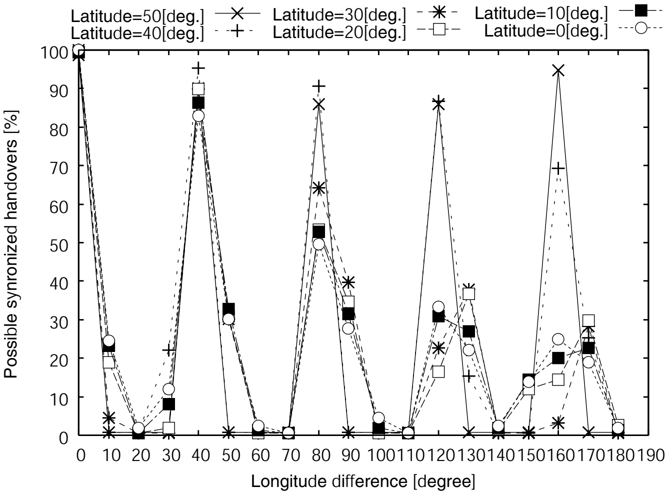

Fig. 6. Location of terminals and possibility of synchronized handover

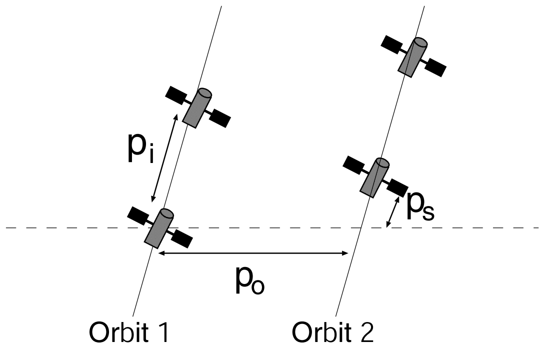

Fig. 7. Reason for shifting of the peaks (p_i: Intra orbital satellite separation)

Five peaks can be observered. These peaks correspond to the values in which multiple of orbital spacing is equal to a longitude difference of the terminals. When the longitude difference between terminals are equal to orbital spacing there is a higher possibility of satellites coming into view of each terminals from the same direction resulting in higher possibility of synchronized handover. However in Fig. 6 peaks are not exactly equal to the multiples of orbital spacing p_o. This is due to inclination of NeLS orbits and the inter orbital phasing p_s of satellites as given in Fig. 7.

B. Synchronized Handover Occurrence in Communication

In this section we evaluate the possibility of synchronized handover occurrence in a constellation. It is considered that terminals are uniformly distributed on the earth and the possibility of communication occurring between any two terminals are the same. For the sake of simplicity, we assume that he earth surface is divide into square cells with ΔL length sides as shown in Fig. 8. In this case, the number of cells N is given as:

$$N = \frac{4\pi R_E^2}{(\Delta L)^2} \tag{1}$$

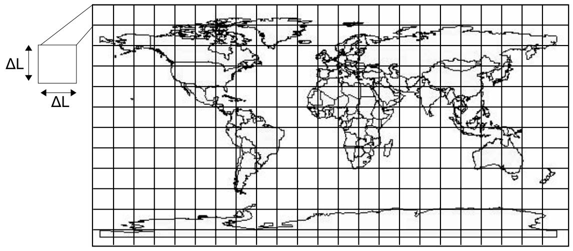

Fig. 8. Division of the earth surface into cells

where R_E denotes the radius of the earth.

If each cell has one terminal, possible number of communication combinations is $N\times N$. Then, if a cell is covered by one satellite and number of satellites in a constellation is N_{sat}, possible communication combination in which synchronized handover is possible can be given as $N\times N_{sat}$.

The probability of a communication being a combination in which synchronized handover is possible is

$$P = \frac{N\times N_{sat}}{N\times N} = \frac{N_{sat}}{N} = \frac{N_{sat}}{\frac{4\pi R_E^2}{(\Delta L)^2}} \tag{2}$$

Figure. 9 depicts the variation of P for different number of satellites against cell length ΔL. To calculate the value of P for a certain constellation, ΔL needs to be calculated.

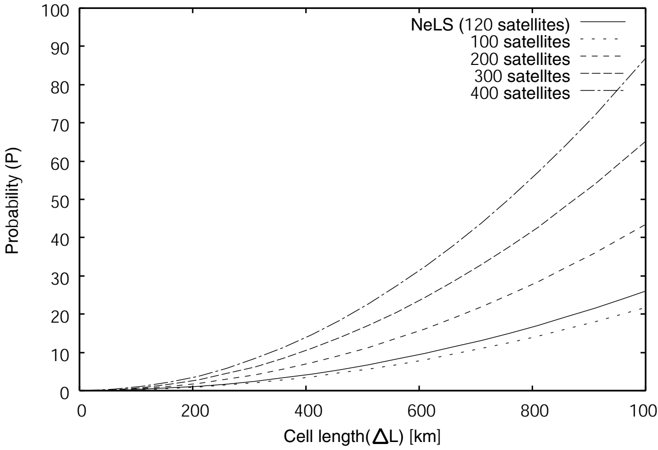

Fig. 9. Cell length, Probability, Number of Satellites

To calculate P for NeLS constellation we considered communication between 2 terminals in which almost all handover events are synchronized handover [terminal 1 (0°,0°) terminal2 (2°30', 37°30')]. One of the terminals (terminal 1) is shifted horizontally (longitude wise) by 5° up to 20° and vertically (latitude wise) by 5° up to 20°. Percentage of possible synchronized handover events are calculated for communication between terminals for each location. Results are given in Fig. 10. Synchronized handover is possible 20 percent of the time when the terminal is shifted 15° from

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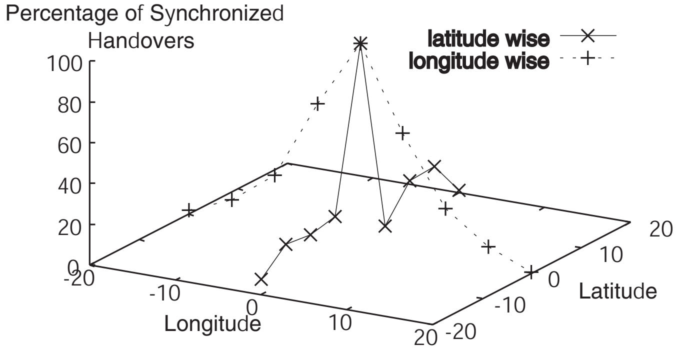

Fig. 10. Evaluation of ΔL

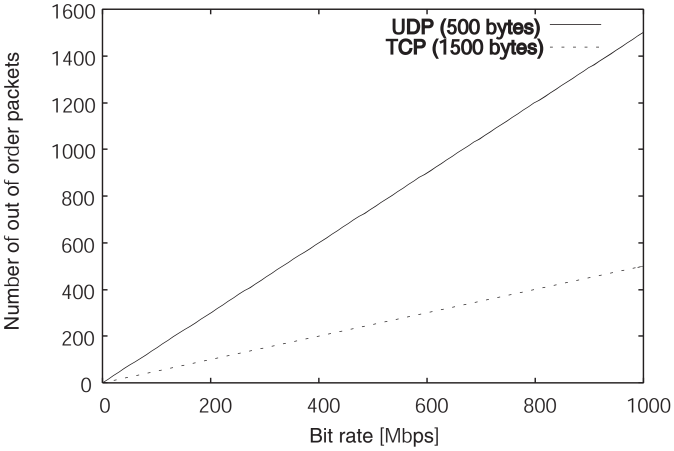

Fig. 11. Effectiveness in avoiding packet re-ordering

the initial position. In that case ΔL is around 1670km. Considering the fact that NeLS cover only 90% of the earth and, its coverage area is calculated as $0.9 \times 4\pi \times R_E^2$, P becomes around 0.72.

C. Effectiveness in Avoiding Packet Reordering

We calculated the average delay reduction achieved by synchronized handover between 2 location in which a synchronized handover is possible for almost all handovers. On average 6.5ms is reduced per handover which counts to as much as 40% of the path propagation delay in some instances. Variation of the reduced delay is between 3ms to 15ms. Fig. 11 shows the number of packets that would be prevented from reordering when the delay reduction by the proposed synchronized handover scheme is 6ms. In this simulation, we assume that the size of UDP packet is 500 bytes and the size of TCP packet is 1500 bytes. As shown in the figure, the proposed method contributes to prevent hundreds of packets from reordering and works more effectivelly as bit rate increases. For TCP communication, this results in avoiding the occurrence of false retransmission. Since the false retranmission is one of the cause of throughput degradation, the proposed method can improve throughput of TCP communication. Additionally, the proposed method is useful not only for improving TCP throughput but also for avoiding degradation of communication quality of UDP application.

V. CONCLUSIONS

LEO satellite networks are capable of providing global coverage, while supplementing the terrestrial network. In this paper, we proposed network-controlled synchronized terminal handover scheme for LEO satellite networks. The proposed method is for avoiding variation of delay during a short period due to asynchronous handover occurrence of communicating terminals in a short period. In the proposed method, a synchronized handover is controlled by the each service satellite which is connected to a sender or a receiver. Assuming that each satellite can calculate remaining time to next handover occurrence for every connected terminal, the service satellites exchange the information about next handover time each other. If the next handover time is close, the service satellites let the terminals handover to a next service satellite. The applicability of the proposed method was evaluated for NeLS constellation. Synchronized handover reduce delay variation due to handover and is effective for preventing packet reordering. Further, it reduces the occurrence of fast retransmission due to packet reordering in TCP. Consequently the proposed method contributes to enhance TCP performance over LEO satellite networks.

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