# Vertical Handover Control Considering End-to-End Communication Quality in IP Mobility

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*Abstract*—**In this paper, we propose a vertical handover decision system for IP mobility communication and describe its implementation with existing IP mobility architecture. Our proposed handover decision tries to reflect that a specified communication quality such as VoIP takes a priority. In other words, the purpose of our proposal is to prefer the specified communication quality in handover across heterogeneous networks. To realize this, the proposed decision method decides handover by a given user policy that a specified communication has priority and by end-to-end network performance. These handover criteria are measured between a mobile node and its correspondent node in IP mobility communication. In evaluations by experiments with the prototype system, we show that the proposal improves end-to-end communication quality in the viewpoint of QoS class classified by ITU-T Y.1541 compared the existing decision methods. Also, we mention the difficulty of deployment of this system.**

***Vertical handover; IP mobility; QoS; End-to-End network performance; User Policy***

## I. Introduction

Broadband wireless links such as WiMAX and 4G make accelerate to use of mobile wireless communication of high-speed data for mobile phones and data terminals on the Internet. For seamless communications over different IP networks, IP mobility is used such as MIP6[1] and MAT[2]. IP mobility makes a mobile node (MN) can continue communication with its correspondent node (CN) without interruption if the MN moves to the different IP networks, that is an address of the MN changes. In this kind of communication using IP mobility, a vertical handover across heterogeneous networks is often required. In this vertical handover, the MN can select one of multiple links devices differing from a horizontal handover in only one link.

Most of horizontal handover uses handover criteria of a link layer such as RSSI (Received Signal Strength Indication). To handle the criteria in the link layer in vertical handover, IEEE802.21 proposed that each status of each different link is abstracted and the abstracted data is used for handover control[3]. However, the link layer status is just information between the MN and the nearest base station such as an access point of a wireless LAN. These criteria cannot reflect end-to-end network status such as IP packet losses and delay between the MN and its CN. However, handover criteria should be used to improve QoS of communications[4]. Also, a user policy should be considered such as a communication cost and bandwidth[5][6]. Then, any handover decision method is needed to compare multiple criteria and decide one solution to select one wireless link among some alternatives. One approach for this decision is Analytic Hierarchy Process (AHP) [7][8].

In this paper, we propose a vertical handover control system used in IP mobility communications over heterogeneous networks. In our system, we focus on end-to-end communication criteria in a network layer between a MN and its CN. By this way, the purpose of this system is to improve QoS of mobile communication over heterogeneous networks.

The remainder of this paper is organized as follows. Sec. II describes the existing research on IP mobility and vertical handover. Sec. III presents our proposal. Sec. IV shows implementation of the prototype system. In Sec. V, we qualitatively evaluate our system. Finally, we conclude and mention the future works in Sec. VII.

## II. Vertical Handover

Here, we define a vertical handover as a handover between two links that use different link layer technologies. For example, it is from Wi-Fi to 3G. As we described in the previous section, handover control should coordinate with IP mobility function. There are three processes as follows for handover control, in general.

(1) Gathering handover criteria
(2) Decision of handover using the criteria
(3) Execution of handover

There is a lot of information as handover decision. For example, communication covering area, available bandwidth, delay, RSSI and user's profile and likes. For example, NAV (Network Allocation Vector) and RSSI in link layer information are used for vertical handover between WLAN and WMAN[9]. As an example of media independent, a vertical handover system using link layer information and MIP6 is proposed using the protocol stack of IEEE802.21[3]. Moreover, handover information in the

978-0-7695-4737-4/12 $26.00 © 2012 IEEE
DOI 10.1109/SAINT.2012.60

upper layer such as available bandwidth and communication fee is used[5].

## III. PROPOSAL OF HANDOVER CONTROL SYSTEM (HOCS)

### *A. Purpose to develop HOCS*

Our proposed system called as HOCS (Handover Control System) uses end-to-end network performance between a MN and its preferred CN and decides handover timing using these multiple criteria. It is the purpose of the system to reflect end-to-end network performance and to satisfy QoS class of the communication between the MN and CN. This is different from the existing proposals using media-dependent and last-one-hope information.

Also, handover of HOCS tries to satisfy QoS class of a specified communication policy between the MN and CN.

### *B. Handover Process of HOCS*

Three processes of HOCS handover are shown in Fig.1. First, handover criteria is gathered from both inside and outside applications through API. Inside application can be embedded in HOCS itself. Examples of the outside applications are a performance meter of Skype and a RTT measurement tool using RTCP. Using gathered criteria, HOCS decides which link is the best among two or more links of a MN. Finally, HOCS informs the selected interface to an IP mobility daemon in MAT or MIP6. The actual handover is executed by the mobility daemon.

### *C. Handover Decision of HOCS*

There are two phases in handover decision of HOCS.

*1) First decision phase*

The first phase is to calculate cost of each wireless link of MN. Assume that we are given $W_{rtt}$, $W_{jitter}$, and $W_{loss}$ as the weight of RTT, jitter, and IP packet loss ratio (loss ration, in later), respectively. $N(RTT_i)$, $N(Jitter_i)$, and $N(Loss_i)$ are the normalized values between 0 and 1 of the latest value of RTT[ms], jitter[ms] and loss ratio[%], respectively. Normalization is calculated by the (1). Each value is measured between a MN and its preferential CN that is selected as a preferred host defined in Sec. IV, A. The $cost_i$ as the cost of a link (interface) i is defined as (2).

$$N(value) = \frac{value - Min(value)}{Max(value) - Min(value)} \quad (1)$$

$$cost_i = W_{rtt} * N(RTT_i) + W_{jitter} * N(Jitter_i) + W_{loss} * N(Loss_i) \quad (2)$$

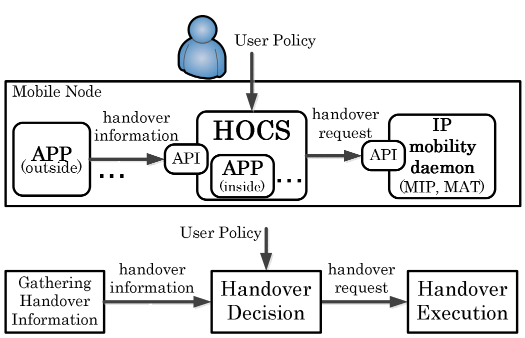



Figure 1. Three proceesses of HOCS

Here, each weight is calculated similarly to [7] by AHP. AHP is one of multi-attribute decision and structured techniques to handle with complex decisions. This method provides quantification of each criterion and cost estimation of each alternative decision. Here, the goal is to decide suitable link among multiple wireless links such as WiMAX, Wi-Fi, and 3G. The criteria are network characteristics such as delay and packet losses and alternatives are three wireless links. Then, paired comparisons of criteria and alternatives are calculated for the priority value by AHP. Assume that we are given n as the number of criteria or alternatives, and $w_1$, $w_2$, …, $w_n$ as the weight of each criteria or alternative, and paired comparison of each element is expressed as $a_{ij} = w_i/w_j$. From these, the paired comparison matrix is A as the following.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix} \quad (3)$$

Here, $a_{ij} = w_i/w_j$ (4)

By (4), each element of normalized $A_{norm}$ is obtained.

$$b_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \quad (5)$$

Also, each priority $p_i$ for criteria is defined as (6). This $p_i$ is substituted into W of (2).

$$p_i = \frac{\sum_{l=1}^{n} b_{il}}{n} \quad (6)$$

Here, $w_i$ is decided as the value from 1 to 9 depending on the goal such as that video stream is preferred (later, Video priority) and these values are used in the calculation in $a_{ij}$ and $p_i$. In our handover decision, we assumed to use the following weights in the comparison pair matrix A.

In Video priority, since the order of the priority is "jitter > loss > delay", weight is decided as following.

weight(delay) : weight(jitter) = $w_1 : w_2 = 1:9$ (7)
weight(delay) : weight(loss) = $w_1 : w_3 = 1:5$ (8)
weight(jitter) : weight(loss) = $w_2 : w_3 = 2:1$ (9)

Then, the criteria for the goal such of Video priority are shown as Table 1. Similar to this way, the criteria for other goals such as VoIP priority and Text priority are calculated. Finally, the weights of the goal of video priority are $W_{rtt} = 0.07$, $W_{jitter} = 0.62$, and $W_{loss} = 0.32$.

TABLE I. EXAMPLE OF PAIRED COMPARISON MATRIX ON CRITERIA

| Goal: Video Priority | Delay | Jitter | packet loss rate |
|---|---|---|---|
| Delay | 1 | 1/9 | 1/5 |
| Jitter | 9 | 1 | 2 |
| packet loss rate | 5 | 1/2 | 1 |

*2) Second decision phase*

The second phase is to decide the suitable interface. In this phase, new concept called as STATE is introduced. STATE is the value to express a level of network performance of each link. The purpose of STATE is having hysteresis to prevent frequent changing of used link decided only by dynamically changed cost of each link.

A cost of each link is classified into four STATEs (levels) depending on two thresholds. The first threshold (T1) and the second threshold (T2) are defined referring class 0 and class 1 of ITU-T Recommendation Y.1541 (approved in Feb. 2006). Two thresholds in each link are obtained as costs in the assumption of RTT, jitter, and loss ratio of these classes by calculating in the same way using AHP. Each $STATE_i$ of $cost_i$ of each link is decided as the following;

*if* $cost_i < T1$
    *then* $STATE_i$ *is 4,*
*else if* $T1 <= cost_i < T2$
    *then* $STATE_i$ *is 3,*
*else if* $T2 <= cost_i <$ *the maximum cost of link i*
    *then* $STATE_i$ *is 2,*
*else if* $cost_i =$ *the maximum cost of link i*
    *then* $STATE_i$ *is 1.*

Here, the maximum value of $cost_i$ is from 0 to the number of handover criteria since each criterion value is normalized from 0 to 1. In the prototype system described in the next section, RTT, jitter and packet loss rate are observed as handover criteria.

Final decision algorithm is as the following;

*if* $STATE_i$ *of the current = 4*
  *then no handover*
*else then*
  *if* $STATE_j$ *(j is different link from link i) > STATEi*
    *then handover to link j with the best STATEj.*

## D. System Configuration of HOCS

Fig. 2 shows the system configuration of HOCS. Outside Measurer and Inside Measurer gather various criteria in link layer and upper layers. If a measurement module runs in HOCS, it is installed in Inside Measurer. If any external application such as a RTP measurement tool is used for network performance measurement, it coordinates with HOCS as Outside Measurer. The measurement results goes to Status Updater. Status Updater provides API for the Inside Measure and Outside Measurer and updates the interface status (IF Status) and informs them to Mobility Manager. Mobility Manager manages handover information such as delay and packet loss from the Status Manager and the mobile node information such as node identification and the locater identification. If Handover Decider requests IF Status, Status Manager replies the requested information. Handover Decider decides the best interface using this information and a user policy from Policy Manager. Policy Manager also gives a user policy to Inside Measurer when the policy is used in measurement of handover criteria.

# IV. Implementation of Prototype System

We implemented the HOCS prototype system using MAT as IP mobility architecture.

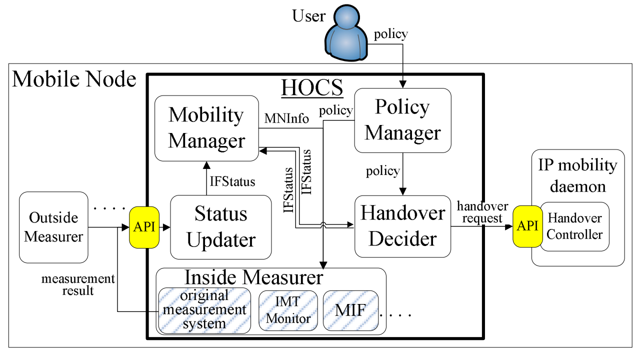



Figure 2. System Configuration of HOCS

## A. Policy Manager

There are two priorities as user policies in the prototype system as the following;

- Factors Weight: Network performance such as RTT, jitter and packet losses are given by each weight
- Preferred Host: Which CN is preferred for MN

These policies are managed in the Policy Manager. These polices are given to the HOCS by an initial file. An example of the configuration file is shown in Fig.3.

## B. Mobilty Manager

Mobility Manager manages IF Status that has interface index, link name, and so on. An initial configuration file of HOCS gives the information of IF Status. Also, the information about mobile addresses of a MN is managed in this manager. The results measured in inside or Outside Measurer are stored in this manager. The cost and STATE of each link are calculated from the given measurement results.

## C. Inside Measurer

In Inside Measurer, we implemented some modules. Here, we describe our original measurement system. This provides RTT, jitter and loss ratio from a MN and the specified CN given by the Policy Manager. This system sends a measurement packet to the CN or its related node and receives its response. There are three kinds of measurement packets. One is a pair of ICMP packets (echo request/reply) between the MN and its CN. The second one is a pair of TCP packets (SYN and SYN ACK) by hping[1].

```
policy = FactorsWeight
weight[rtt] = 0.07
weight[jitter] = 0.62
weight[loss] = 0.32

policy = Preferred Host
ipaddress = Home Address of CN
```

Figure 3. Example of a initial file for a user policy

[1] A command-line oriented TCP/IP packet analyzer http://www.hping.org/

The third one is a pair of DNS packets. In this way, the developed measurement system searches a DNS server providing CN's domain information. If the DNS server is located at the same or near network of CN in network routing, a pair of a DNS query packet from MN to the DNS server and its answer is used as the measurement packets. These measurement request packets are sent every one second in the current implementation.

If the MN receives the reply packet by one of these ways as the above, RTT is calculated as the difference between the request time and arrival time of its reply packet. Loss ratio is obtained as the ratio of the number of reply packets to the latest 100 reply packets. Jitter is defined as the difference of arriving time of every reply message. Here, a moving average of these criteria is used. The moving average of the latest 10 values is used for RTT and jitter. That of the latest 100 values is used for loss ratio.

### D. Handover Decider

Handover Decider decides which link is selected by the information from Policy Manager and Mobility Manager. Weights and cost of each interface and decision of STATE of each interface are calculated as described in the Sec. III. In the implementation, two thresholds, T1 and T2 are calculated by the assumption that RTT=100, jitter=50, and loss ratio= 0.01 (class 0 of Y.1541) and RTT=400, jitter=50, and loss ratio=0.01 (class 1 of Y.1541), respectively. Handover Decider sorts the list of IF Status. If the top item is changed from the previous decision, the message for handover is sent to IP mobility daemon of MAT.

### E. IP mobility daemon

We use MAT [2] as IP mobility daemon. This architecture provides an optimal path between a MN and its CN. MNs supporting MAT also have two addresses. One is a HoA that is an identifier of each node. The other is a Mobile Address (MoA) that is an identifier of location like CoA. Since HoA is used upper transport layer and MoA is used under network layer, MAT achieves transparent communications in the network layer for applications. In MAT, IP address Mapping Server (IMS) manages many mappings of the addresses of MAT nodes. When a MN starts communications, it makes a request of a mapping of the correspondent node. MAT architecture has an assumption that MNs have multiple interfaces. MAT supports a seamless handover without packet losses because it prepares another interface to connect other network.

### F. Development Environment

HOCS is implemented in the environment as Table II. We use Java for OS independency.

### G. Verification of the Prototype System in the Actual Field

In this experiment, we verified that HOCS works as expected in actual wireless networks such as WiMAX, Wi-Fi and 3G. A mobile node, MN with three links moves on the moving route in the speed of about 5km/h and the distance of the route is about 600m. 3G area covers all moving route of MN. WiMAX area covers about half of the route of MN. Wi-Fi area covers only a spot of the route of MN. Fig.4 shows a network environment of the experiment field. However, it is assumed that there is no congestion on the up link of WiMAX base station though the congestion icon is drawn in Fig.4. A mobile address of MN is changes when it moves to each area. In the whole route of the MN, it receives UDP stream of 1Mbps sent by Iperf from the CN located on the Internet. MAT is installed in both MN and CN for IP mobility. During MN's movement, our developed measurement system in Inside Measure of HOCS periodically gathers end-to-end criteria from MN to CN in each route using WiMAX, Wi-Fi and 3G. By these measurement results, HOCS decides which route is the best.

In this verification, we assume that "Video Priority" is used as a user policy and the weights used in calculation of cost of each interface are shown in Table I. Through some times of the measurements of RTT and throughput, we confirmed that handover occurred as we expected.

## V. EVALUATIONS

To evaluate of effectiveness of the proposed system, we had the comparison experiment.

### A. Purpose and Outline of Comparison Experiment

The experiment is to compare three handover decision methods. The first one is HOCS using end-to-end information as handover criteria. This is called as "end-to-end". The second one is HOCS using last one hop information that was measured as RTT by ping command from a MN to the nearest host such as a default gateway on the same link. This is called as "last-one- hop." The third one is a decision using media-dependent information such as RSSI in the link layer.

Here, we assume that congestions occur on the route from the MN to CN only when any link is selected as a route. Congestions are emulated as 400ms delay, 50ms jitter, and 0.1% loss ratio. These values are referred as the upper bound of delay, jitter and loss ratio to satisfy Class 1 of QoS class in Y.1541. Since a real-time video transmission is assumed to be sent from the CN to MN in the comparison experiment, we assume Class 1 that targets an IP service that is sensitive to jitter and loss ratio. The purpose of this experiment is to investigate how each handover decision method prevents the congestion.

### B. Experiment Environment

The network environment is the same with the previous experiment as Fig.4. Here, congestions are assumed to occur on the uplink of a WiMAX as Fig.4. Congestions are emulated by "tc" command to configure traffic control in the Linux kernel as the following.

TABLE II. DEVELOPMENT ENVIRONMENT

| | |
|---|---|
| **Language** | Java |
| **Development** | Java Development Kit 1.6.0.20 |
| **Runtime** | Java Runtime Environment 1.6.0.20 |
| **OS** | Ubuntu 10.04 |
| **Kernel** | Linux ubuntu-vm 2.6.32-37-generic |

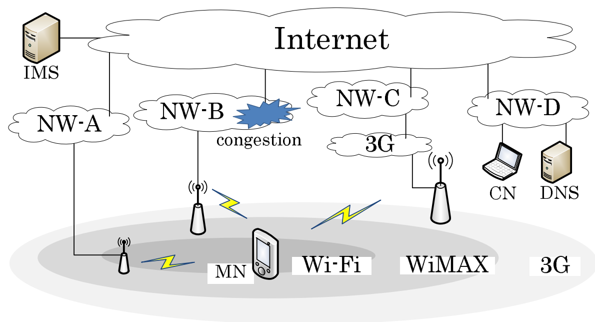



Figure 4. Experiment environment

"tc qdisc add dev ethX root netem delay 400ms 50ms distribution normal loss 0.1%"

Conditions such as the movement of MN, the location of CN and priority are the same with the experiment described in Sec. IV, G.

The measurement of RSSI is depending on each device. We use "iwconfig" command of Linux for Wi-Fi, a dedicated commercial tool for WiMAX and "AT" command for 3G. In a handover decision method by RSSI, the classification using STATE and the decision algorithm is similar to HOCS described in Sec. III, C,2) to have hysteresis. Here, RSSI values are assumed to be classified to three levels between the maximum and minimum value in all measurement results in each link.

## C. Experiment Results

The RSSI transition of each link during the measurement period is shown in Fig. 5. The STATE of using handover is obtained from these RSSI values. The RTT transition and handover points of HOCS(end-to-end), HOCS(last-one-hop) and RSSI are shown as Fig.6 (a), (b) and (c), respectively. A down arrow in Fig.6 means handover timing and a sequence of link names such as "Wi-Fi" and "3G" means the used links during the period. The link name sequence of (c) is omitted since there are many handover timings. The results of the number of times of handover in (a), (b) and (c) are 3, 3, and 23, respectively. In the assumed conditions, Wi-Fi is the best for the requested quality to satisfy Class 1 (Video priority). The next is 3G and the third is WiMAX since congestion occurs on the uplink of WiMAX.

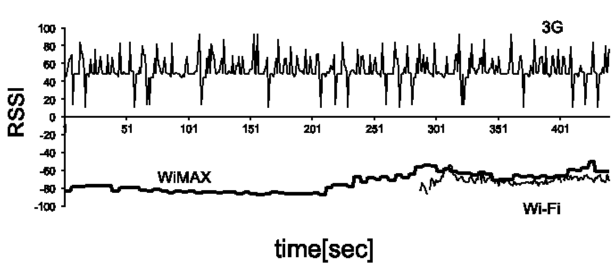



Figure 5. RSSI transition each link

TABLE III. COMPARISON OF QOS BY HANDOVER DECISION METHODS

| Handover decision | | RTT <=400ms | Jitter <=50 ms | Loss ratio > 0.1% |
|---|---|---|---|---|
| HOCS | end-to-end | 98.1% | 92.0% | 0% |
| | last-one-hop | 41.6% | 79.5% | 44.8% |
| RSSI | | 81.4% | 85.7% | 49.1% |

## D. Consideration

Here, we consider the experiment results from two viewpoints. These are the number of times of handover and QoS of end-to-end communication.

From the viewpoint of the number of times of handover, Fig.6 shows that (a) and (b) are similar since the number of times of handover is 3, where that of (c) is 23. Handover is one factor to reduce communication quality because of communication interruption and network performance gap such as delay difference among links. This result shows that only criteria in the link layer are not enough for communication quality.

To investigate from the view point of QoS, we count the number of measurement results to satisfy Class 1 of Y.1541 during the experiment period. Table III shows the ratio of satisfaction of each condition. Through this table, HOCS (end-to-end) obtains the best result among three methods. Here, we used the bound value of Class 1 of Y.1541 for reference. Note that definition of criteria in Y.1540 referred in Y.1541 is not same as our definition. In our definition, RTT is round trip time, not one way. Jitter and loss ratio are calculated by measurement packets every one second, where per packet is in Y.1540.

Through the experiment, we obtained that the proposed system improves mobile communication quality including handover by considering a user policy and end-to-end network performance.

# VI. DISCUSSIONS

One of the purposes of this paper is to show the effectiveness of end-to-end network performance for vertical handover. A measurement method is important since it affects on handover decision. Here, we discuss our measurement method.

One is the accuracy of the measurement. Our method sends measurement packets all links attached with MN. On the other hand, communication data packets are sent and received on only one link selected by handover decision. As a result, measurements packets only on the selected link may be affected by the communication data. Traffic of each measurement way is 0.67kbps in the case of ICMP and DNS query. That of the case of DNS answer is 2.18kbps. That of the case of TCP SYN is 0.32kbps. Measurement traffic itself is small but large or burst traffic of communication data may affect on the measurement packets. When each link has enough bandwidth including measurement and communication data, the proposed method is useful to improve QoS of the specified communication by a user policy.

The other is the measurement implementation using a DNS query. Our proposed measurement has three ways described in Sec. VI, B. DNS way is used when other ways are rejected by any security policy in a CN side. Though the measurement way tries to find the CN's DNS server, network location of the DNS server is not always the same or near at the location of CN. If the DNS server is far from the CN, the measurement result is not valid for network criteria between MN and CN. The current measurement system implementation informs to Policy Manager that the measurement way is not suitable.

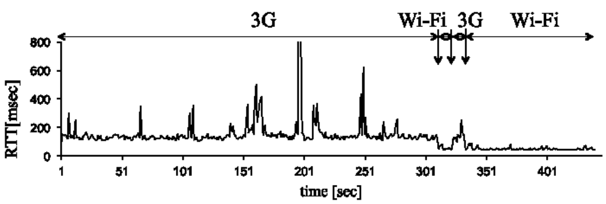
HOCS itself can coordinate any measurement method as Outside Measure or Inside Measure. We are considering more accurate and practical implementation of the measurement method as future works.

## VII. CONCLUSION

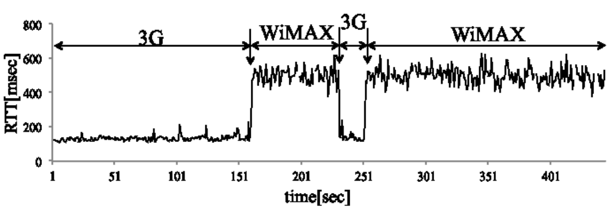
In this paper, we propose a vertical handover decision system in IP mobility communication and implement it with the existing IP mobility architecture. Through the field experiments, we show the effectiveness of our proposal to improve end-to-end communication quality that is required by a user policy, especially in handover.

To show the effectiveness of our proposal, we use a satisfaction of network performance parameters of QoS classes. As most of criteria on seamless of IP mobility, communication interruption time is discussed. However, total QoS of mobile communication with IP mobility should be discussed. This paper appears different criteria to show QoS of IP mobility.

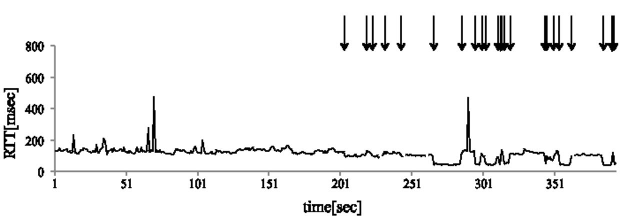
As future works, the handover decision algorithm should be discussed and the difficulty mentioned in Sec. VI should be considered.




(a) Handover by HOCS(end-to-end)




(b) handover by HOCS(last-one-hop)




(c) Handover by RSSI

Figure 6. RTT transition and handover points

## ACKNOWLEDGMENT

We thank all members of MAT project for their help of implementation and evaluation of HOCS. For field evaluation, we thank dit Company Limited and the staff of Information Processing Center in Hiroshima City University.

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