Mobility-adaptive QoE Provisioning Solution in Heterogeneous Wireless Access Networks

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ABSTRACT

This paper introduces the mobility-adaptive QoE provisioning solution. The key is placed on the intelligent selection of access network depending on the QoE criteria classified by the user mobility and the bandwidth demand for service. We further focus on the network-based smart handover scheme using the mobility-adaptive handover decision and the enhanced MIH-FMIP framework. The concept is the network-based calm service and the balance in order to facilitate vertical and seamless handover. In result, it is figured out that our solution improves QoE performance by selecting appropriate access network, repressing handover occurrence, and reducing handover delay as well.

Key Words : QoE, QoS, Network Selection, Handover, Heterogeneous Network

Ⅰ. Introduction

The evolution and the deployment of various wireless access technologies have brought the improvement of user circumstances that are bandwidth, communication range, mobility support, accessibility, and so on. Moreover the user demands for higher service quality including higher data rate, higher mobility, Quality of Service (QoS), and Quality of Experience (QoE) have continuously grown in these days. Especially, with the increased competition, improving the quality of the offered services as perceived by the users, commonly referred to as the QoE, becomes very important to providers in order to reduce customer churn and maintain and increase their competitive edge. However, such user demands, including QoS and QoE, have not been fulfilled by each wireless access technology alone.

In this motivation, lots of efforts are devoted to the mobility management techniques between heterogeneous wireless access networks[1-3]. But they have not met the condition of seamless handover due to the lack of the regard for both wireless signaling overhead and processing overhead of user terminal[4,5]. In addition, there are several standards documents, e.g. provided by IETF, ITU-T, 3GPP, referring to the QoS issues[6]. And plenty of researches evaluating QoS taking into account different aspects as architectures including traffic control mechanisms, QoS in core IP networks or in access networks are dedicated[7-9]. However, there are no competent solutions yet even though the frequent service disruption is one of the most critical reasons inducing the QoS degradation[10]. In particular, QoE has been defined as the totality of the QoS mechanisms, provided to ensure smooth provision of multimedia service over IP networks[11,12]. So the previous researches have been mainly done in terms of the original quality of the multimedia service and the quality of its delivery. The first term is about the encoding/decoding and the compression of multimedia data, while the second term is about the routing protocols[13,14]. However, it is disregarded that the QoE must be measured at the end-user. The terms considered by

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논문번호 : KICS2010-04-146, 접수일자 : 2010년 4월 1일, 최종논문접수일자 : 2010년 8월 3일

previous works only give the way how the service can be reached effectively to the end-user, regardless of how the end-user exactly experiences the service. In other words, the QoE is greatly affected by the end-user conditions, such as mobility.

In this paper, we hence design the mobility-adaptive QoE-driven solution focusing on:

1. Classification of users by the mobility, i.e. velocity, and the bandwidth demand for service.
2. Intelligent selection of access network depending on the QoE criteria classified.
3. Network-based smart handover using the mobility-adaptive handover decision engine and the Media Independent Handover (MIH) service.

Furthermore we employ the enhanced MIH framework, presented by our previous work[15]. This novel framework concentrates the network-based calm service and the balance in order to facilitate vertical and seamless handover. We additionally evaluate the performance of the proposed QoE provisioning solution by using both the numerical analysis and the NS-2 network simulations.

The rest of this paper is organized as follows. In the next section, we explain the correlation between mobility and QoE. In section 3, we describe the mobility-adaptive QoE provisioning solution. Section 4 evaluates and analysis the performance of the proposed solution, and then we conclude this paper in Section 5.

Ⅱ. Correlation between Mobility and QoE

Mobility, in general terms, is the state of being in motion of users or devices. It affects the whole network protocol stack from the physical layer up to the application layer. For instance, moving users create network topology changes via link breakages and link additions. These link changes require network protocol responses to ensure reliable services continue. Routing protocols may need to change routes in response to link changes. Route changes in turn alter the traffic distribution in the network which also varies the congestion each relay device experiences. All these complex interactions result in certain network dynamics which are experienced differently by all users in the network. In this manner, mobility practically means that moving (or mobile) users experience their services seamlessly through different access technologies either simultaneously or one at a time.

Besides the basic aspects of the mobility that cause network dynamics, there are many other characteristics that should be carefully considered when trying to understand the impact of mobility on communication potential in networks. Especially, as the QoE is the quality as perceived by the end-user, the mobility of the end-user has great impact on QoE. So, we firstly figure out how the mobility effects the variation of QoE at the end-user side.

Link duration: The link duration here means the time interval in which user stays online within the transmission range of the Point of Attachment (PoA), e.g. access point, radio access station, and base station, to network. It continues until user gets offline, i.e. link break, or moves away from the communication area (or the cell), i.e. link change. The link duration is measured by the user's speed, direction, and the distance from the PoA. For example, a user on a train, that moves 100m/sec, establishes a link with a base station of which communication radius is 1000m. If the train traverses straight the center of the communication area, the link duration of the user will be approximately 20 seconds. From this example, we find out that the link duration decreases due to either the limited range of PoA or the increase of user speed as well as both of them.

The link duration consists of the configuration term and the service term. When end-users connect to network, they initially associate with network in link configuration such as authentication and authorization, and the time it takes is the configuration term. Until the configuration successfully completes, users cannot start the service term, and so will perceive service delay. In addition, short link duration, as mentioned above, induces frequent network dynamics, e.g. link breaks, route changes, and handovers, which bring inconvenience to end-users[16]. Especially, frequent handovers cause critical problems, including handover delay, signaling overhead, and data packet loss, and thus make end-users to experience longer service delay and poor service quality simultaneously. Moreover, those problems get much worse in heterogeneous networks because of the complication of vertical handovers which need to detect and initiate handover from one media to another. Therefore shorter link duration allows users to experience the significant degradation of QoE, particularly, when they travel by heterogeneous access networks.

Call blocking/dropping probability: The call blocking probability is the possibility that the incoming/outgoing call or service is not reached the destination, while the call dropping probability is the possibility that the ongoing call or service is terminated unpredictably before it completes. Both probabilities are increased if either the mean or the variability of user speed is increased[17]. Because, while traveling fast, end-users may perceive sudden changes in signal quality caused by their movements, multipath propagation, and unintentional jamming, such as man-made noise, adjacent channel interference, and co-channel interference inherent to the mobile environments. So, higher probabilities of the call blocking and the call dropping cause the QoE degradation such as unexpected fservice disruption.

Data packet delivery ratio: It corresponds to the percentage of successful deliveries for the data packets. As explained above, inherent aspects of mobility bring the delivery fails of packets to fast-moving users. Additionally, the fast movement of user induces numerous handovers so that the percentage of the delivery fail, which occur frequently during handover, will be increased. Therefore, the higher percentage of delivery fails, i.e. the lower data packet delivery ratio, according to faster user velocity make end-users to experience non-QoE services.

Control packet overhead: It referred to as the ratio from the total transmitted control packets to the total received data packets. The control packets are sent when network dynamics are monitored by either user device or network devices. Regard that the probability of network dynamics is much higher if end-user moves fast. So faster velocity of end-user induces more control packets that allow the user or the network to lose the chance of data packet delivery, and hence QoE degradation happens.

The user mobility gives great impact on QoE at the end-user side. Especially, the fast velocity of end-user and the short communication range of network make users to experience critical QoE degradation in terms of the link duration, the call blocking/dropping probability, the data packet delivery ratio, and the control packet overhead. However, the movement and the velocity of users are absolutely up to their intention so that the management of those mobility aspects is not a compatible solution to improve QoE. On the other hand, the communication range gives both end-users and network administrators some options, i.e. the selection and the change of the network which provides proper communication range. Regard that the recent development of wireless communications has offered various range of technologies such as Wide Area Network (WAN), Regional Area Network (RAN), Metropolitan Area Network (MAN), Local Area Network (LAN), Personal Area network (PAN), and so on. Moreover, in the side of end-user devices, the multi radio device, capable of various wireless access technologies simultaneously, has been evolved out of the single radio device rapidly. Consequently, the intelligent network selection based on the user mobility will be the compatible solution weakening the impact of user mobility on QoE and providing the QoE-guaranteed service to end-users.

Ⅲ. Mobility-adaptive QoE Provisioning Solution

3.1 Mobility-adaptive network selection scheme

To guarantee QoE-driven service, we initially classify the QoE criteria by the mobility of end-user and the bandwidth demand for service as shown at Figure 1. The mobility is arranged in terms of the end-user velocity, while the bandwidth demand is

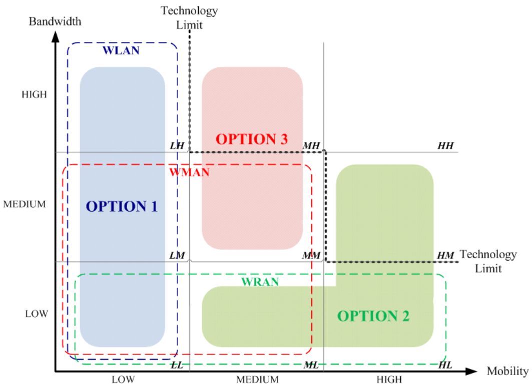

Fig. 1. Distribution of the wireless access technologies and the QoE criteria according to mobility and bandwidth
그림 1. 사용자 이동성과 서비스 대역폭에 따른 무선 접속 기술들과 QoE 보장 영역의 분류

arranged in terms of the data rate which is the service requirement for end-user demand. For instance, the criteria of right-upper side, referred as 'HH', represents the QoE requirements of the user moving at high velocity and requesting high data rate service such an Video on Demand (VoD). Note that the baselines of 'LOW', 'MEDIUM', and 'HIGH' are defined in section 4. is Figure 1 additionally shows the distribution of serving criteria by wireless access technologies that are WRAN, WMAN, and WLAN. According to their complementary characteristics, they cover most of QoE criteria except for which the currently challenging technologies, such as FGNs and IMT-advanced, will cover in near future.

Basically, the key of our solution is the intelligent selection of access technologies depending on the QoE criteria classified by the mobility condition of user and the bandwidth demand for requested service. Although there have already been many researches about the network selection, most of those have only considered the quality of wireless signal, e.g. Received Signal Strength (RSS), as the measure of network selection. And thus some researches have considered various factors, e.q. user profile, preference, data rate, and velocity, as the measure of network selection[18,19]. However, they have only assumed that MS manages whole network selection processes, even it causes serious problems such an process delay. In these motivation, we

Table 1. Priority of intelligent network selection
표 1. 각 옵션별 네트워크 선택의 우선순위

Priority	Option 1	Option 2	Option 3
High	WLAN	WRAN	WMAN
↕	WMAN	WMAN	WRAN
Low	WRAN	WLAN	WLAN

propose a network-based QoE provisioning network selection scheme. First of all, we provide three options of the intelligent network selection as detailed below.

Option 1: When users are stationary or move at low velocity, e.g. in state of *LH*, *LM*, and *LL*, the bandwidth-adaptive access technology, WLAN, is selected to use regardless of the bandwidth demand of service. If being already connected to WLAN, users just stay there, otherwise they handover to WLAN at the next time the handover is needed. The reason is that the possibility the stationary user suddenly moves fast is much smaller than which the user experiencing low bandwidth service changes it to high bandwidth one. In this manner, the link duration will increase and hence the handover probability will be dropped. Accordingly, the impact of mobility on QoE such as the call blocking/dropping probability will be improved. Therefore the bandwidth-adaptive WLAN is the optimum QoE solution for the low mobility users. Note that if there is no WLAN service but others, WMAN and WRAN are recommended to access in the order named since the delayed service gives better QoE than the unavailable service.

Option 2: When highly mobile users experience the low bandwidth service such a messenger, the mobility-adaptive and the long-ranged access technology, WRAN, is selected to use except who in *LL* state. If being already connected to WRAN, users just stay there, otherwise they handover to WRAN at the next time the handover is needed. Because, the highly mobile, i.e. medium or high mobility state, users are absolutely on the vehicles, and so tend to continue traveling at higher velocity. As explained above, higher velocity causes various problems such as shorter link duration and higher control packet overhead, especially, in access networks with shorter range, frequent handover will be perceived by users. Therefore the selection of WRAN will reduce the handover rate significantly so that the user experience will be improved. Additionally, the users in *HM* state that is the challenging QoE criteria are also recommended to connect to WRAN. The challenging areas, i.e. *MH*, *HH*, and *HM* state, will be covered by newly developing technologies in near future, but there need instant alternatives to enable users to be served. So we offer that the user in *HM* state handovers to WRAN in order to get service even though the quality is a little degraded. This is because the experience of service delayed or damaged, provided by WRAN, is much better than which of unavailable service, provided by WMAN, in terms of the end-user QoE.

Option 3: Users in *MM* state which is the serving criteria of WMAN are advised to access or handover to WMAN since it is only technology able to cover those requirements without QoE degradation. In addition, users in *MH* state which is the challenging criteria are advised to connect to WMAN since the delayed or damaged service served by WMAN is much better than the unavailable service served by WLAN in terms of the end-user QoE.

Those three options of the intelligent network selection are used by the Mobility-adaptive Handover Decision Engine (MHODE) implemented in the PoA or Access Router (AR). The operation of the optimized solution employing the mobility-adaptive handover decision engine is shown at Figure 2 and detailed below.

1. When Mobile Station (MS) requests service through current network, i.e. Serving Access Router (SAR), the bandwidth demand for service and the velocity of MS are delivered to MIHF through the novel MIH primitive. Note that the velocity can be detected by Global Positioning System (GPS)[21].
2. When handover needs, MS sends MIH_MN_HO_Grant request message containing the service bandwidth and the user velocity to SAR.
3. SAR performs the QoE-aware handover decision according to the one of three QoE options that is intelligently selected by using MHODE. Note that the information of candidate neighboring networks, which MS can handover to, are obtained by the Information Server (IS) when MS firstly connects to SAR. The IS supports the fundamental information about heterogeneous neighboring access networks in order to facilitate the handover[2].
4. SAR orders handover for MS and Target AR (TAR), i.e. the selected network, by using MIH functions.
5. MS handovers to TAR in order to experience the QoE-driven service.
6. TAR delivers the service which MS requested.

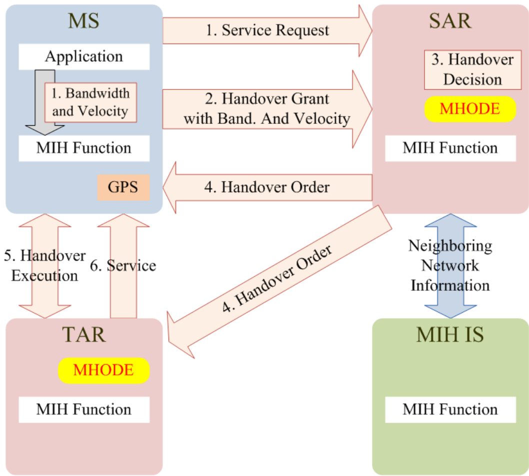

Fig. 2. Operation of the mobility-adaptive handover in order to provide the QoE-driven service
그림 2. QoE 보장된 서비스의 제공을 위한 이동성 적응적 핸드오버 기법의 동작 과정

3.2 Mobility-adaptive handover framework

The legacy handover framework simply combines MIH and FMIPv6 scheme regardless of efficiency, and so still has critical problems including handover latency. Particularly, a number of wireless signaling messages are still used in those works that induce handover latency, packet loss, and power loss of MS as well. These remaining problems are some of the most critical reasons for the degradation of QoS and QoE in heterogeneous wireless access networks. In this motivation, we concentrate the intelligent selection of access network depending on QoE criteria. We further employ the enhanced mobility management framework, i.e. proposed in our previous work [15], focusing on the coordination of FMIPv6 and MIH in order to minimize wireless signaling overhead. Consequently, we propose a QoE provisioning mobility-adaptive handover framework employing the MHODE and the enhanced MIH-FMIP scheme as shown at Figure 3 and addressed below.

1. When connected with MS, SAR queries information about candidate networks to IS by using MIH_Net_Get_Information request / response messages.
2. If MS requests service through SAR, the bandwidth demand for service and the velocity of MS are delivered to MIHF through MIH_App_QoE_Report indication primitive. And the service is delivered to MS through SAR.
3. When handover needs, MS sends MIH_MN_HO_Grant request message Note that the information of novel MIH message and primitive are explained at Table 2.
4. SAR queries the availability of resources at the neighboring candidate networks by employing MIH_N2N_HO_Query_Resources request / response messages.
5. Then SAR performs the QoE-aware handover decision according to the one of three QoE options that is intelligently selected by using MHODE.
6. Once requests the resource preparation at the target network, i.e. decision of the MHODE, by using MIH_N2N_HO_Commit request / response messages, SAR sends MIH_MN_HO_Grant response message to MS.
7. The MIHF of SAR then sends the MIH_BindingUpdate primitive including the identifiers and information about TAR required to formulate the prospective new CoA toward IP layer.
8. Using the proposed MIH-FMIPv6 framework, the link connection establishment without network discovery phase and the IP connection establishment without FBU phase are executed among MS, SAR, and TAR. In result, the service is provided to MS through TAR.

In addition, the concept of the enhanced

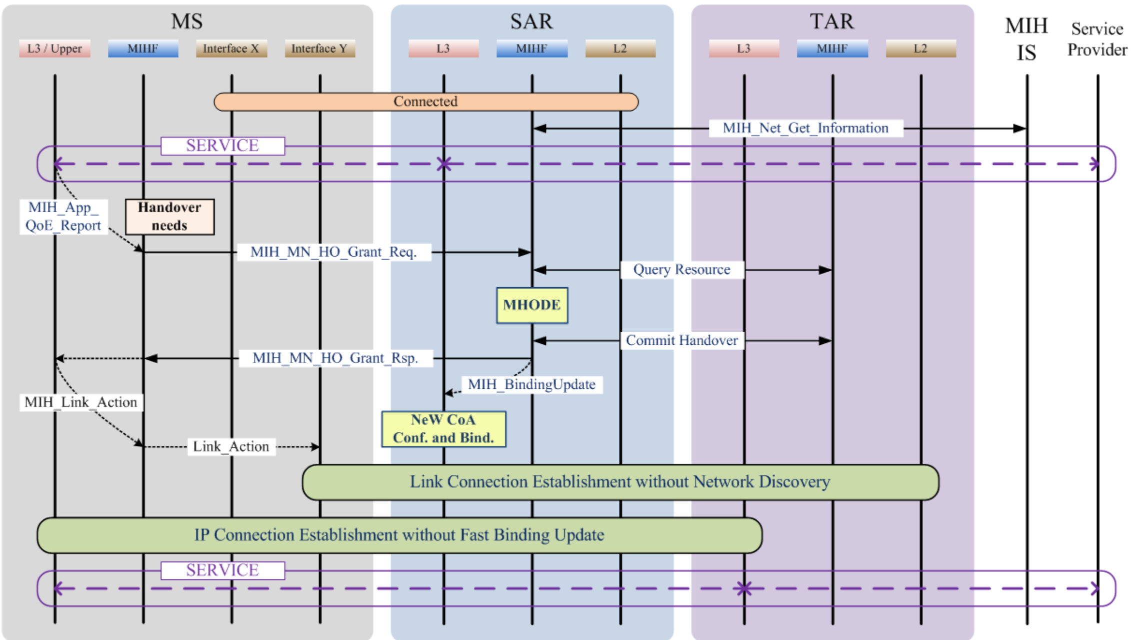

Fig. 3. Operation of QoE provisioning mobility management scheme
그림 3. QoE를 보장하는 이동성 관리 기법의 동작 과정

Table 2. Information of novel message and primitive specified (or modified) for the proposed solution
표 2. 제안된 기법에서 정의하는 새로운 메시지와 프리미티브

Name	Service	Field	Description
MIH_MN_HO_Grant Request	MICS	Source MIHF ID	The identifier of entity where the request is initiated.
		Destination MIHF ID	The destination identifier of request or response.
		Source Link ID	This identifies the current access net work over which the command needs to be sent.
		QoS Resource Requriements	Minimal QoS resources required at the candidate network.
		Service Information	The bandwidth demand for the service user requested (Kb/s).
		Mobility Information	The current velocity of user detected by GPS (m/s).
MIH_App_QoE_Report	MICS	Destination MIHF ID	Destination MIH Function Identifier.
		Service Information	The bandwidth demand for the service user requested (Kb/s).
		Mobility Information	The current velocity of user detected by GPS (m/s).

MIH-FMIP scheme is the calm service. The calm service denotes that user may not notice when, where, and how the handover occurs. So the enhanced scheme entrusts most of handover processes to network entities by employing novel MIH message and primitives. Furthermore, we focus on the balance of the MIH message flows. The balance is assumed to mean that ordering the wired networks to process more signaling messages is sufficient than the wireless networks to process. In this motivation, we design the balanced MIH-FMIP scheme to reduce signaling overhead in wireless networks[15].

Ⅳ. Performance Evaluation

We evaluate the performance of our QoE provisioning solution through network simulations using NS-2 release 2.29. In simulations, we design the simulation topology composed of WRAN, WMAN, and WLAN as illustrated in Figure 4. In addition, the configuration for simulations depending on the mobility and bandwidth options are addressed at Table 3. The simulations further employ the mobility package developed by NIST[22] to support WRAN, WMAN, and MIH services.

In Figure 5~7, we compare the number of inter-network handovers, occurred between heterogeneous networks, in accordance with the network selection schemes[19]. From those figures, it is verified that our network selection scheme

Table 3. Simulation configuration.
표 3. 시뮬레이션 설정.

Parameters	Value		
Options	**Low**	**Medium**	**High**
Agent	**CBR-TCP**		
Packet Size	**100byte**	**400byte**	**2000byte**
Packet Rate	**120Kbps**	**960Kbps**	**4800Kbps**
MS Velocity	**1m/sec.**	**10m/sec.**	**20m/sec.**
Mobility	**Random Model**		

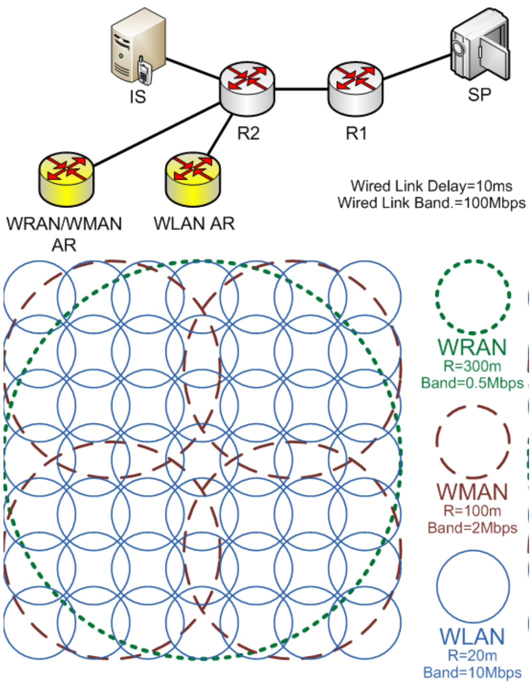

Fig. 4. Simulation topology
그림 4. 시뮬레이션 구성

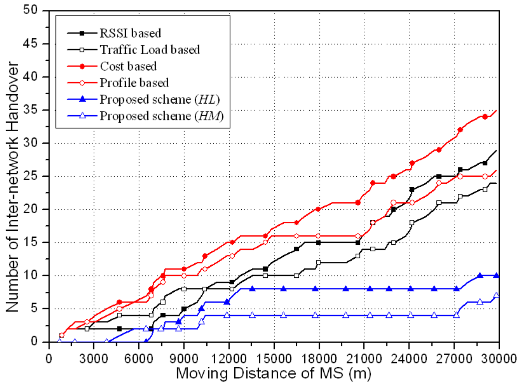

Fig. 5. Handover count of MS moving at 20m/sec
그림 5. 20m/s로 이동하는 MS의 핸드오버 발생 횟수

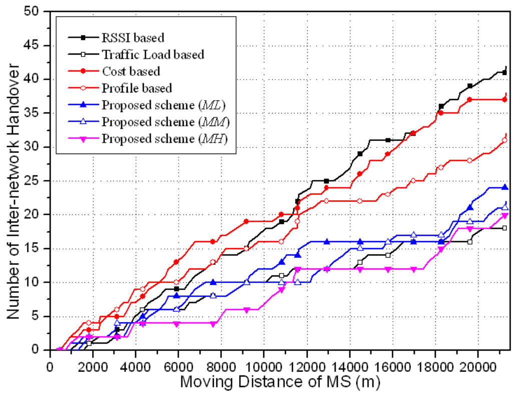

Fig. 6. Handover count of MS moving at 10m/sec
그림 6. 10m/s로 이동하는 MS의 핸드오버 발생 횟수

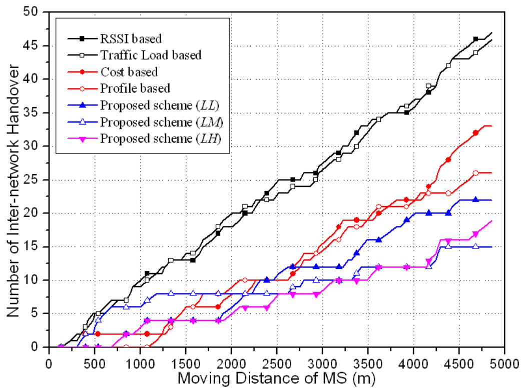

Fig. 7. Handover count of MS moving at 1m/sec
그림 7. 1m/s로 이동하는 MS의 핸드오버 발생 횟수

dramatically reduces the number of handovers by providing the mobility- and bandwidth- based handover decision engine that offers the limitation of needless handovers to guarantee longer link duration and stable QoE of end users.

Figure 8~10 describe the goodput performance which represents the quantity of actual service data received by MS. We can derive the goodput (D_{good}) as shown at Equation (1).

$$D_{good} = D_{TX} - E_{TX} - E_{HO} \qquad (1)$$

Note that D_{TX} is the total data transmitted by a base station, E_{TX} is the data loss caused by transmission error, and E_{HO} is the data loss caused by handover delay. Consequently, it is confirmed that our solution allows end users much more goodput datas than any other schemes regardless of the mobility of MS and the bandwidth for service. Regard that, in simulations, we adopt only the enhanced mobility management solution since the performance comparison of mobility management schemes is detailed in [15].

In addition, as depicted in Figure 11, we compared the average signaling overhead. Consequently, the simulation results show that the proposed scheme, in average, decreased 43~67 % of signaling overhead caused by legacy schemes. Because, the main concept of our handover framework is the network-based calm and balanced service which minimizes the use of wireless signaling messages. Also, the proposed network selection scheme restrains the occurrence of the vertical handover inducing many signaling messages.

In Figure 12~14, the QoE performance is evaluated by using the probability distribution of novel QoE factor. The QoE factor (Q) is designed in simple manner as depicted in Equation (2).

$$Q = \frac{D_{TX} - E_{TX} - E_{HO}}{D_{TX}} = \frac{D_{good}}{D_{TX}} \qquad (2)$$

So the more the value of Q is the same as 1, the better the QoE performance perceived by end-users is. In those Figures, it is shown that our solution guarantees at least 70% of requested service to be

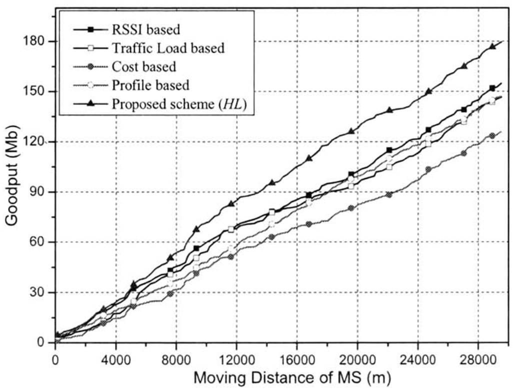

Fig. 8. Goodput performance (v=20m/s, b=120Kbps)
그림 8. Goodput 성능 비교 (속도=20m/s, 대역폭=120Kbps)

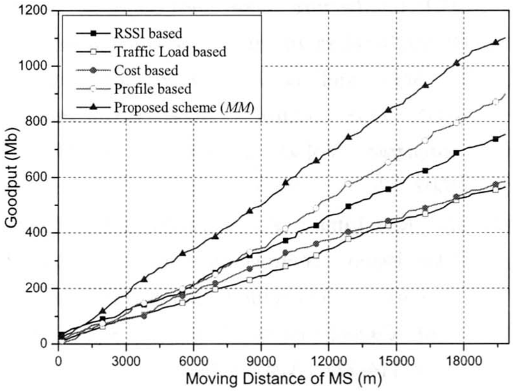

Fig. 9. Goodput performance (v=10m/s, b=0.98Mbps)
그림 9. Goodput 성능 비교 (속도=10m/s, 대역폭=0.98Mbps)

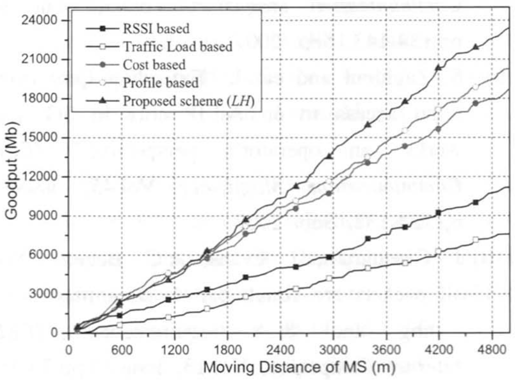

Fig. 10. Goodput performance (v=1m/s, b=4.8Mbps)
그림 10. Goodput 성능 비교 (속도=1m/s, 대역폭=4.8Mbps)

delivered to end users with more than 0.98 of QoE factor, even the others guarantee only at most 66% of those. In result, it is verified that our solution

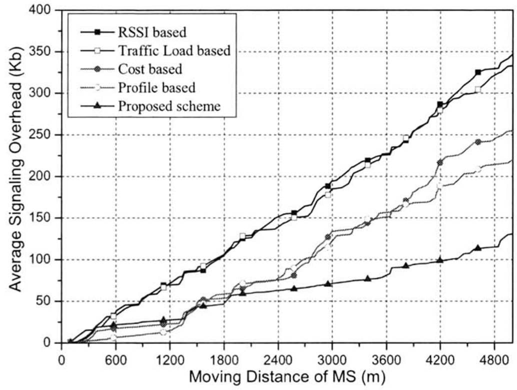

Fig. 11. Comparison of average signaling overhead
그림 11. 평균 signaling overhead 비교

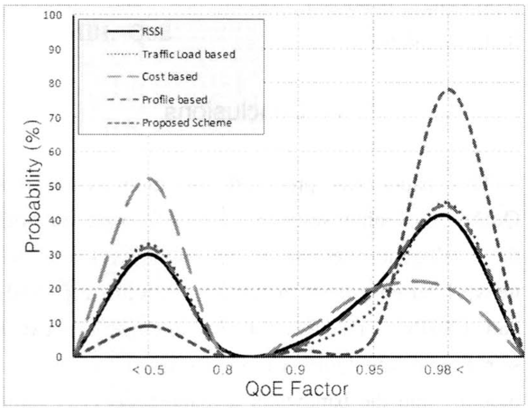

Fig. 12. QoE performance (v=20m/s, b=120Kbps).
그림 12. QoE 성능 비교 (속도=20m/s, 대역폭=120Kbps).

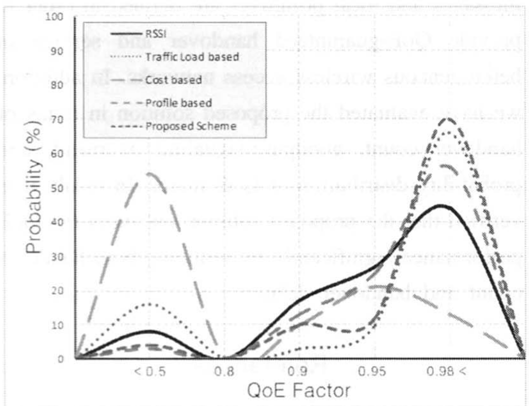

Fig. 13. QoE performance (v=10m/s, b=0.96Mbps).
그림 13. QoE 성능 비교 (속도=10m/s, 대역폭=0.96Mbps).

significantly improves the QoE performance by

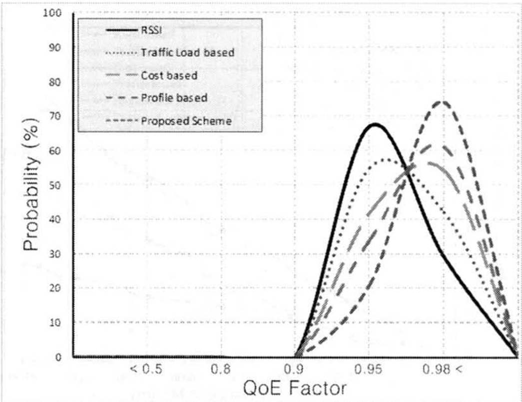

Fig. 14. QoE performance (v=1m/s, b=4.8Mbps).
그림 14. QoE 성능 비교 (속도=1m/s, 대역폭=4.8Mbps).

repressing handover occurrence and reducing handover delay.

V. Conclusions

This paper has proposed the mobility-adaptive QoE provisioning solution. It has focused on both the intelligent selection of access network and the network-based smart handover coordinating MIH and FMIPv6. The key of the intelligent network selection is the QoE criteria classified by the user mobility and the bandwidth demand for service. And the concepts of the smart handover are the calm service and the balance in order to facilitate the seamless handover. Therefore, the novel signaling messages and local primitives are defined in order to provide QoE-guaranteed handover and service in heterogeneous wireless access networks. In addition, we have evaluated the proposed solution in terms of handover count, goodput, signaling overhead, and probability distribution of QoE factor. In result, it is verified that the proposed solution enhances the QoE performance significantly by reducing both handover count and handover delay.

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