Providing QoS and Rate Limiting for WiMAX Mobile Hotspots based on Policy and Charging Control Architecture

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Abstract

A hotspot offers Internet access over Wi-Fi through the use of a router connected to a link to an internet service provider. If the link is wireless, e.g., WiMAX, the hotspot becomes mobile. Under such a heterogeneous network, it is challenging to provide QoS and/or to control data rate. In this paper, we design and implement a policy server for commercial WiMAX mobile hotspots based on Policy and Charging Control (PCC) architecture defined in WiMAX Forum. The paper investigates a suitable QoS configuration including scheduling type. The experimental results show the feasibility of VoIP service over the mobile hotspots. The paper also shows how the rate limiting feature of our policy server can be utilized for different levels of customer service.

Keywords: *QoS, Rate Limiting, Mobile Hotspot, WiMAX, Policy Server*

1. Introduction

Recently, with the growth of user devices markets, various high-performance and high-attractive user devices have been developing and releasing. These include tethering devices as well as end user's mobile devices such as smart phones and tablets. A tethering device converts communication protocol signals, for an example, from a WiMAX signal to Wi-Fi, to enhance the accessibility to the mobile internet.

Although the technologies of wireless networks have highly evolved, it has been an issue to handle the rapidly increasing data traffics so-called data traffic explosions. Furthermore, because wireless radio environments undergo Additive White Gaussian Noise (AWGN) and large- and small-scale fadings [3], the transmission errors occur frequently. Thus, it is challenging to support a QoS sensitive traffic such as VoIP traffic despite of its narrow bandwidth. Furthermore, some heavy users may monopolize radio resources. For example, a File Transfer Protocol (FTP) traffic may occupy excessive radio resources depriving other QoS sensitive traffics. This problem becomes more serious in tethering environments because a tethering device often accommodates multiple end user devices through mobile to mobile heterogeneous networks. Previous studies [1, 2] focused on QoS and cell capacity improvement of communication networks without considering a tethering environment.

To overcome this situation, we can use the PCC architecture, which is a QoS support framework and standardized in the 3rd Generation Partnership Project (3GPP) and WiMAX Forum. In this architecture, the Policy and Charging Rule Function (PCRF) plays a central role. It determines policy rules for different users and servers in real-time in order to provide different level of QoS and charging for both IP Multimedia Subsystem (IMS) and non-IMS services. With PCC architecture, it is also possible to control traffic rates of heavy users or malicious users. Providing the rate limiting feature is as important as guaranteeing QoS.

In this paper, we design and implement a PCRF system for commercial WiMAX mobile hotspots based on PCC architecture. The paper investigates a suitable QoS configuration including scheduling type, bandwidth, and resource allocation interval, for VoIP service as an target service. The experimental results show the feasibility of VoIP service over the WiBro mobile hotspots (called WiBro Egg) which are controlled by our PCRF. The paper also shows how the rate limiting feature can be utilized for different levels of customer service. WiBro (Wireless Broadband) is a wireless broadband Internet technology developed by the South Korean telecoms industry and is standardized by TTAS.KO-06.0082 [5]. WiBro is the South Korean service name for IEEE 802.16e (mobile WiMAX) international standard [6].

The rest of this paper is organized as follows: In Section 2, we explain the PCC architecture and the QoS mechanisms of standard IEEE 802.16e. In Section 3, we introduce our implemented PCRF system and the WiBro-tethering. In Section 4, we show the experimental results using the PCRF. Finally, we present conclusion in Section 5.

2. WiMAX PCC Architecture

The concept of PCC was first introduced in 3GPP release 7. The PCRF was initially defined by integrating the Policy Decision Function (PDF) and Charging Rule Function (CRF) [7]. The PCRF determines PCC rules for each service flow, and commands the Policy and Charging Enforcement Function (PCEF) to enforce the rules. In release 8, according to the System Architecture Evolution (SAE), the PCRF became to control the PCC rules for various wireless networks not only UTRAN but also GERAN, WiMAX and Wi-Fi [8].

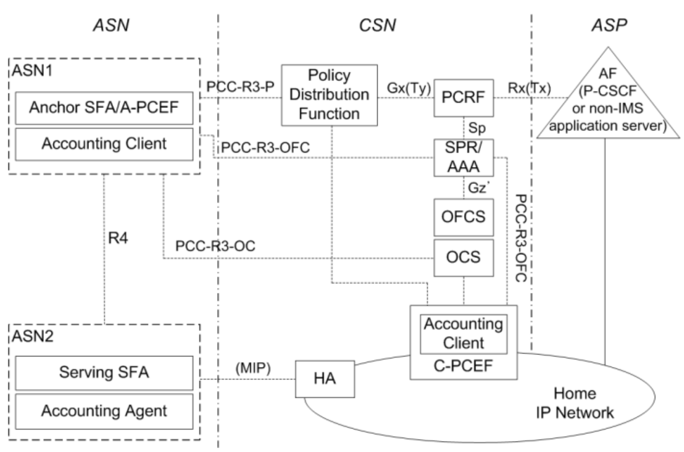


Figure 1. WiMAX PCC architecture

Meanwhile, WiMAX PCC architecture was also defined in WiMAX Network Working Group (NWG) release 1.5 [9] and it is based on that of 3GPP. Figure 1 shows WiMAX PCC architecture comprising the Access Service Network (ASN), the Connectivity Service Network (CSN), and the Application Service Provider (ASP). The IEEE 802.16 air interface is implemented by the mobile station on the subscriber's end and the base station (BS) in the ASN on the network side. The ASN is divided into BS and ASN Gateway (ASN-GW is not shown in the figure). The BS handles wireless resource management, QoS support, and handover control. The ASN-GW plays a key role in IP-based data services, including IP packet routing, security, QoS, and handover control. The IP allocation function (DHCP) can be employed within ASN-GW. The ASN-GW also interacts with the PCRF server in CSN to have PCC rules and also with the AAA (Authentication, Authorization, and Accounting) server for user authentication and billing. In Application Service Provider (ASP), Application Function (AF) servers interwork with the CSN to deliver service specific requirements.

Figure 2 illustrates a dynamic PCC setup procedure. The AF requests a policy control to the PCRF. Then, the PCRF decides PCC rules based on the service information provided by the AF, and commands the PCEF in ASN-GW to provision the decided PCC rules via the Policy Distribution Function (PDF). The PCEF requests for the BS to establish a dynamic services flow for a target MS. In this way, the MS can establish a service flow of which QoS characteristics have been determined by the PCRF.

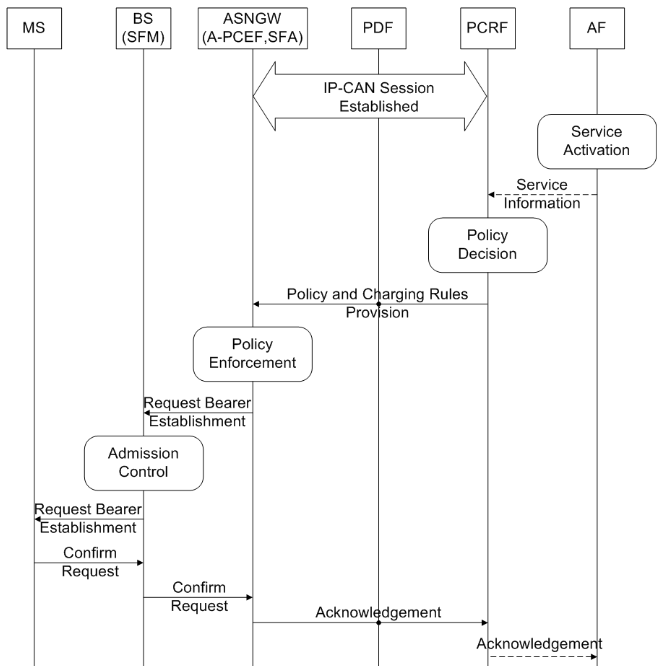


Figure 2. Dynamic QoS Setup based on PCC

3. Design and Implementation of PCRF

In this section, we introduce our implemented PCRF system which manages the PCC rules for WiBro networks, and explain how to control QoS in WiBro-tethered networks.

3.1. Architecture of Implemented PCRF

As depicted in Figure 3, our implemented PCRF has two functional entities, QoS Manager (QM) and Resource Control Subsystem (RCS). The QM mediates the QoS provision between AFs and network devices (PCEFs). The IMS systems access to the QM through Rx interface which is defined as a DIAMETER protocol [9], while Non-IMS systems use WebService (XML over SOAP) protocol. Upon receiving a QoS request message, the coordinator decides a PCC rule for a service flow based on its own database, and transfers them to the target RCS. Here, the service flow is identified by 5-tuples (source IP/port, destination IP/port and protocol). The QM maintains network topologies and thus it can figure out which RCS is responsible for the network the target MS is currently connected to. The RCS controls and/or monitors access networks and backbone networks. The RCS-F controls the edge routers and switches in 'F'ixed access networks through Simple Network Management Protocol (SNMP). The RCS-B monitors the routers in 'B'ackbone networks through SNMP. The RCS-W controls the Access Control Routers (ACR), which is ASN-GW, in 'W'iBro networks through Gx DIAMETER protocol [9].

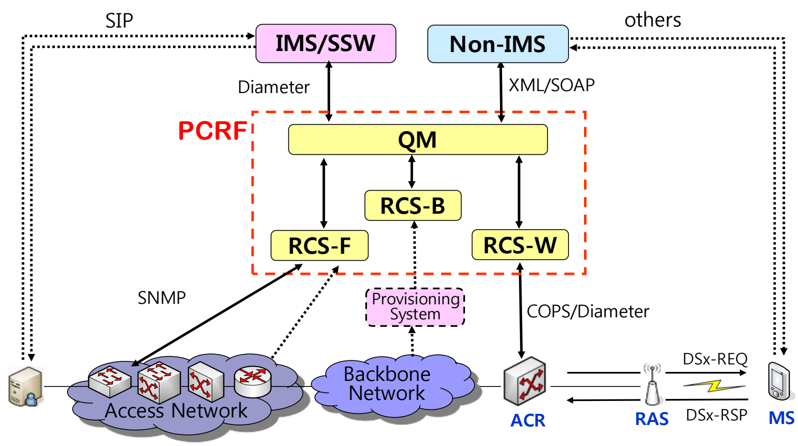


Figure 3. Implemented PCRF architecture

3.2. QoS Control in WiBro System

The WiBro systems have been constructed according to the ASN Profile A defined in WiMAX NWG. Thus, ACR have the functionality of PCC rule enforcement. When an ACR receives a PCC rule provisioning command from RCS-W, it enforces the rules by initiating the establishment of service flow for the MS. The service flow is characterized by QoS related MAC parameters listed in Table 1.

Table 1. WiMAX QoS Parameters

Scheduling Type	Applications	Common parameters	Specific QoS parameters
Unsolicited Grant Service (UGS)	VoIP without silence suppression	Maximum sustained traffic rate Request/Transmission policy -broadcast BR request -piggyback request -fragment data -suppress payload header -pack multiple SDU -CRC in MAC PDU	Minimum reserved traffic rate (=Maximum sustained traffic rate) Maximum latency Tolerated jitter Traffic priority Unsolicited grant interval SDU size if fixed length SDU
Extended real-time Polling Service (ertPS)	VoIP with silence suppression		Minimum reserved traffic rate Maximum latency Tolerated jitter Traffic priority Unsolicited grant interval
Real-time Polling Service (rtPS)	Streaming audio or video		Minimum reserved traffic rate Maximum latency Traffic priority Unsolicited polling interval
Non-real-time Polling Service (nrtPS)	File Transfer Protocol (FTP)		Minimum reserved traffic rate Traffic priority
Best Effort Service (BE)	Data transfer, Web browsing		Traffic priority

There are five scheduling types. The common parameters used in all types are maximum sustained traffic rate (MSTR) and request/transmission policy (RTP). So, in any case, rate limiting is feasible with MSTR setting. Specific QoS parameters per scheduling type are explained as follows:

- In UGS, a BS allocates fixed amount of radio resources with a fixed grant interval to a specific service flow based on the minimum reserve traffic rate (MRTR) and the unsolicited grant interval (UGI). In this case, the MS is guaranteed a fixed bandwidth without any bandwidth request procedure.
- In ertPS, a BS operates similarly to the case of UGS. But the amount of allocated radio resources can be varied according to Bandwidth Request Header (BRH) and Grant Management Subheader (GMS) transmitted from a MS. Thus both the UGS and the ertPS are suitable for VoIP services. The ertPS enables the BS to efficiently use the air resource for the VoIP service with Voice Activity Detection (VAD) where the voice traffic is suppressed in a silence period.
- In rtPS, the amount of allocated radio resources can be varied according to Bandwidth Request Header (BRH) every unsolicited polling interval (UPI) with a high priority. Because the rtPS guarantees the MRTR instantaneously, it is effective in the services with variable rate such as streaming audio and video service.
- In nrtPS, the BS gives a high priority to a specific service flow in contention-based environments, and guarantees the MRTR in relatively long polling interval. It can be used in FTP services which require a certain average data rate for fairly long time period.
- In a BE, all service flows should contend one another to be allocated radio resources from a BS and are not guaranteed a specific traffic rate.

The concepts of radio resource allocation for the five scheduling types are described in Figure 4.

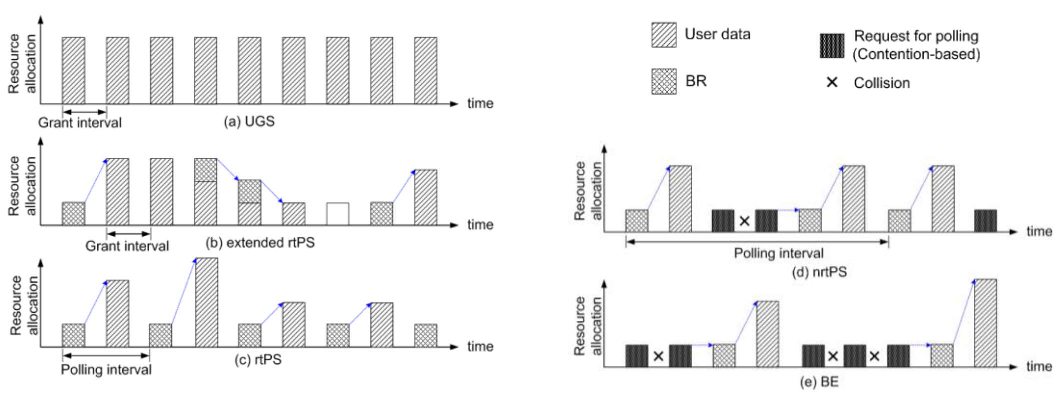


Figure 4. Scheduling Types of WiMAX system

3.3. QoS Control for WiBro-tethering device

The WiBro-tethering device, WiBro Egg, converts the WiBro (IEEE 802.16e) signal to Wi-Fi (IEEE 802.11b/g) signal, and has a Network Address Translation (NAT) functionality accommodating multiple Wi-Fi end user devices. The Wi-Fi-enabled end user devices can communicate through WiBro networks via the WiBro-tethering equipments. In this case, the end user devices will have private IP addresses while the tethering equipment has a public IP address. Here, the PCRF recognizes the tethering equipment as an end user device. In order to handles each data traffic from the accommodated end user devices, we distinguishes the service flow with different port numbers and protocol. As previously explained, the PCRF identify a service flow by 5-tuples. In this way, the PCRF can provide QoS and/or limit the traffic rate of a WiBro-tethering device, and prevents radio resources from being monopolized by greedy user(s) of the device.

4. Experiments in WiMAX-tethered Networks

In this section, we verify our implementation of PCRF by measuring the QoS of VoIP services and investigate how to support QoS for VoIP service in WiMAX-tethered network environments. We also verify the rate limiting feature of our system. The QoS of VoIP service is best expressed as the Mean Opinion Score (MOS) which is an objective quality index defined in ITU-T G.107 E-model [10].

4.1. Experiment 1: VoIP MOS in WiMAX-only network

First, we introduce the results measured in a WiBro-only network (without tethering). The purpose of this experiment is to verify basic QoS support and to see whether there is side effect for the normal data users. The test environment is shown in Figure 5. We set the WiBro channel quality as a regular level with the Carrier-to-Interference-and-Noise-Ratio (CINR)=6 [dB] and the Received Signal Strength Indication (RSSI)=-80 [dBm]. And then, we made a congestion with 5 uplink and 5 downlink background FTP traffics to/from the remote FTP servers. Since FTP is based on TCP flow control, they use radio resources as much as possible (up to the maximum throughputs). The codec of VoIP streams is G.711. We also measure one FTP traffic as a representative data user as shown in right-hand side of the figure.

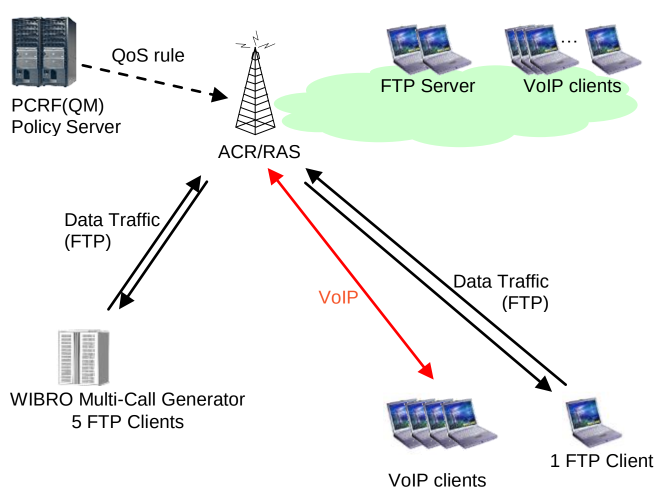
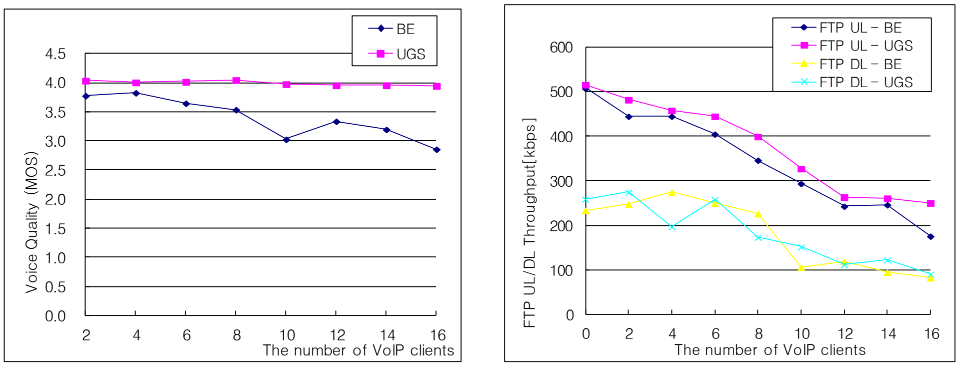


Figure 5. WiMAX-only environment with congestion



(a) VoIP MOS (b) FTP throughput

Figure 6. Performances in WiMAX-only network

In this environment, we measured MOS value(s) of VoIP traffic(s) and the throughput of a FTP connection as we increase the number of VoIP clients. We compare them for two typical scheduling types, BE and UGS (UGI=20 [ms], MRTR=84 [kbps]), which are provisioned by our PCRF. The measured results are illustrated in Figure 6. In Figure 6(a), we can see that the scheduling type UGS guarantees the MOS of VoIP services to about 4.0 which is much higher than the voice quality criterion defined as above 3.6 for the wired Internet telephony service [11]. However, with BE, the MOS gradually decreases as the number of VoIP clients increases. This is because, as mentioned earlier, with UGS, a fixed bandwidth is allocated to MS without any overhead for bandwidth requests. However, with BE, MS should compete with one another making many overheads. Note that an average value of MOS for BE VoIP traffics go below 3.5 when the number of VoIP clients become 8 or more.

According to our previous research [4], the UGS is superior to the BE not only quality but also cell capacity of VoIP service. The UGS improves the cell capacity by about 10 [%] for G.711, and about 30 [%] for G.729. This can be seen in this experiment as depicted in Figure 6(b). The figure basically shows that although the number of VoIP clients increases, it does not affect other normal data users. Namely, the throughput of the FTP client gradually decreases as much as the amount of total VoIP traffics. Note that, in the case of uplink (UL), if VoIP uses UGS scheduling, the throughput of the FTP client is even improved about 15 [%] compared to the BE case. It is also because the UGS does not induce any overhead for bandwidth requests which are uplink messages. This result is meaningful in that QoS is not the case of tradeoff. You can keep the traffic quality and increase the cell capacity.

4.2. Experiment 2: VoIP MOS in WiMAX-tethered network

Next, we explain the VoIP MOS values measured in a WiBro-tethered network. As shown in Figure 7, the VoIP clients and a FTP client communicate through Wi-Fi interfaces via the WiMAX-tethering device. In this experiment, we made more background traffic such that 6 uplink and 13 downlink FTP traffics. The WiBro channel quality was measured as a regular level with CINR=20 [dB] and RSSI=-70 [dBm].

Because the tethering device operates as a NAT, the VoIP and FTP clients are hidden to the PCRF. In other words, the PCRF considers the tethering equipment as an end user device in the WiMAX network. Thus, when an accommodated client uses a service provided by an AF, the AF requests a PCC rule to the PCRF for the tethering equipment, not for the client behind the tethering device.

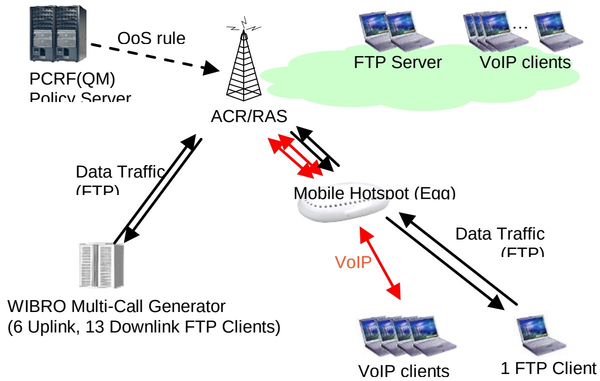
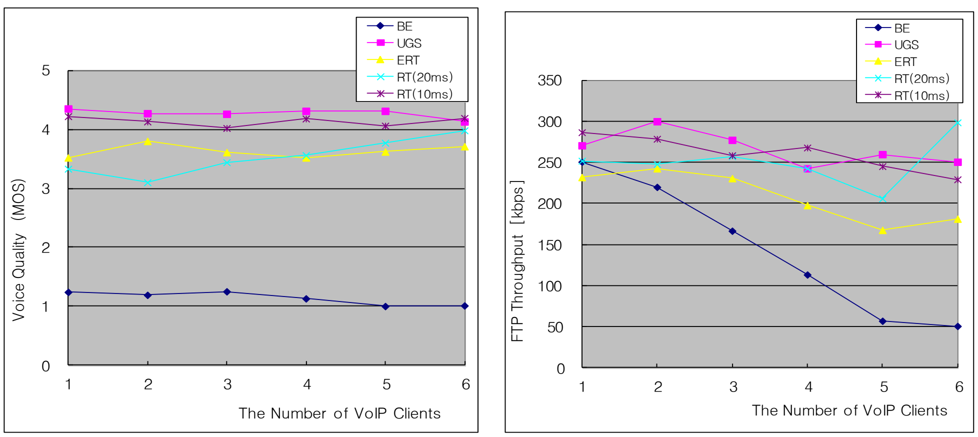


Figure 7. WiMAX-only environment (in congestion)



(a) VoIP MOS (b) FTP throughput

Figure 8. Performances in WiMAX-tethered network

One of the purposes in this experiment is to find suitable QoS parameters for VoIP over WiBro mobile hotspot. We measured the performances for four different scheduling types, UGS (UGI=20 [ms], MRTR=84 [kbps]), ertPS (UGI=20 [ms], MRTR=84 [kbps]), rtPS ((UPI=20 [ms], MRTR=84 [kbps]) and BE. Note that the selected grant interval (20ms) and traffic rate (84 [kbps]) are found best fit to this service but we do not introduce the details.

Figure 8 shows the performance results. Due to the heavy congestion, the tethering device lacks bandwidth. Thus, with BE, the VoIP MOS became about 1.1 which is too bad quality for voice communication, as illustrated in Figure 8(a). On the contrary, if we establish a UGS service flow for the tethering device, average VoIP MOS values are constant about 4.2. It is notable that although the number of VoIP clients increases and there is a large amount of background traffic, the voice quality is maintained. This is because the UGS scheduling type uses a fixed amount of bandwidth irrespective of other environments. The other scheduling types, ertPS and rtPS, also support the VoIP MOS to about 3.5 which is fairly good for VoIP services but lower than that of UGS. Because the ertPS and rtPS need some procedures for bandwidth requests, the VoIP traffic get some delay or jitter. Figure 8(b) shows that if VoIP traffics are served with BE, the throughput of the FTP client gets affected much more than the

VoIP traffic actually required. It is because the BE uses a contention-based resource allocation. Therefore, it is the most effective to use a UGS scheduling with 20 [ms] grant interval for a WiBro-tethering device for both voice quality and resource utilization.

4.3. Experiment 3: Rate Limiting in WiBro-tethered Networks

We verify the rate limiting feature for a tethering device. Figure 9 shows the test environment and screen shots of real-time policy control where an administrator can limit traffic rate of a certain device both manually and automatically with precondition. Because the purpose of this experiment is only to verify whether or not the traffic rate of the tethering device is limited to the MSTR set in our PCRF, we do not make any background traffic.

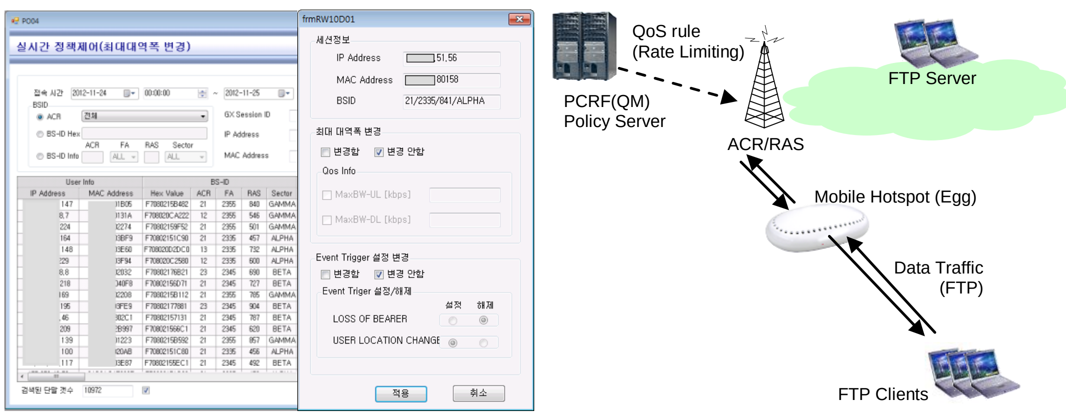


Figure 9. Rate Limiting for Mobile Hotspot device

We tested two cases as the followings. In the Case 1, we set uplink MSTR=600 [kbps] and downlink MSTR=800 [kbps]. In the Case 2, we set uplink MSTR=1,200 [kbps] and downlink MSTR=1,600 [kbps]. The measurements are repeated five times for each case, and averaged. The results are summarized in Table 2. From the results, we can see that the total throughput of three clients does not exceed the MSTR within a tolerable error range (1%). Thus, the PCRF prevents WiBro hotspots, particularly publicly deployed ones, from monopolizing whole resources of the cell by heavy users or free-riders attached to the hotspots.

Table 2. Measured average throughput (unit: [kbps])

	MSTR_UL=600 MSTR_DL=800		MSTR_UL=1,200 MSTR_DL=1,600	
	UL	UL	UL	DL
Client 1	197	264	387	533
Client 2	192	272	387	528
Client 3	192	272	387	531
Sum	581	808	1,160	1,592

5. Conclusions

In this paper, we designed a policy server for multi services and heterogeneous networks and implemented it based on standard WiMAX PCC architecture. We conducted series of experiments in a real testbed to provide suitable QoS parameters for VoIP over WiBro hotspots. It is shown that QoS-guaranteed VoIP service is feasible while improving total network utilization in both WiMAX-only and WiMAX-tethered networks. We also verified that our PCRF's rate limiting feature for WiBro hotspots. It is meaningful in that the PCRF prevents a (public) WiBro hotspot from monopolizing radio resources. Therefore, we conclude that the PCRF should be considered in managing radio resources in the future wireless networks such as the 3GPP LTE-advanced networks as well as WiMAX networks, where various complex network topologies, like a tethering, can be used.

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