Dynamic Pricing for 3G Networks Using Admission Control and Traffic Differentiation

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***Abstract*— In the pricing of network resources, network operators and service providers aim at facilitating the use of the limited network resources in a manner that would encourage responsibility among the end-users and lead to the maximisation of profits. The optimum tariff rates used for charging the mobile services are affected by factors like the market forces affecting the industry. However, the tariff rates generally increase with the achieved QoS level. Next generation networks will offer higher QoS, hence users need incentives to utilise the enhanced capacity. In this paper, we propose a pricing approach that introduces service profiles into a DiffServ-enabled network, whose prices and QoS levels depend on the degree of congestion in the network. The use of the UMTS connection admission control to support the proposed pricing scheme is explored. An emulation testbed is used to evaluate the scheme.**

***Index Terms*—Pricing, Quality of Service (QoS)[1], Class of Service (CoS), Differentiated Services (DiffServ), PDP context, 3rd generation (3G).**

I. Introduction

The provision of mobile communication services requires installation of expensive network equipment that need constant maintenance to guarantee the availability of services to end-users at all times. The demand for network services has increased rapidly, thus leading to the need for proper management of the limited resources. Pricing is used for controlling the use of network resources, and it facilitates charging that enables the network operators/service providers to generate revenue for offsetting their capital and operating expenses (CAPEX and OPEX). The prices for the services are reflected in the applicable tariff rates, and they determine the market advantage gained over other operators in the region. This calls for market surveys [2], [3] that are targeted at the interests of the end-user.

3G networks offer new services (e.g., real-time multimedia) and they are designed to offer guaranteed (QoS) together with increased levels of resource availability [4]. Multimedia services require guaranteed network conditions e.g., low delay and jitter [5]. Some Internet services (e.g., e-mail access, web browsing etc.,) can tolerate unstable network performance conditions. In the General Packet Radio Service (GPRS) and the Universal Mobile Telecommunication System (UMTS), network resources are defined using QoS parameters, whose values are specified during the initialisation or modification of a packet data protocol (PDP) context [6]. Although the tariff rate used for charging a given PDP session depends on factors that are service specific, the applicable QoS parameter values would have a substantial influence [7].

The individual services offered on mobile networks differ in the amount of resources that are required for successful delivery. Congestion is always directly proportional to the demand of network resources at a given time, hence when the number of PDP sessions that are being served increases, congestion is bound to occur. Considering the amount of bandwidth and other resources that are specified in the design of 3G and future generation networks, a PDP session can request and be allocated QoS resources that could be a multiple number of times greater than the levels achievable on 2G networks. End-users will not get incentives to use some mobile services (e.g., multimedia applications) if the current tariff structures are used, due the possibility of incurring high charges. There are periods when 3G networks are bound to have a surplus resources. This paper proposes a criterion that could be used to authorise the extra resources, at a discounted tariff rate, to user applications that request them. Since this will lead to dynamic prices and QoS levels, users need to indicate, in real-time, their willingness to continue using the services at new tariff rates and QoS levels.

The introduction of service profiles will allow users to specify, prior to using the network, their service usage profile and in turn influence the QoS vs. cost relationship of the services delivered to them. In this paper, a platinum profile that guarantees high QoS, a constant-tariff rate gold profile, and a flat-rate priced silver profile that offers best effort service are explored. This architecture is designed for IP services in 3G networks, in which the DiffServ architecture [8] is used for QoS provisioning.

The rest of this paper is organised as follows; Section II gives a review of pricing and QoS in mobile communication networks, Section III presents the architectural design of our proposal, the design and implementation of the testbed are given is section IV and V respectively, section VI presents the evaluation results, and section VII concludes the paper.

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[1]Refer to [1] for the definition of terms related to QoS

II. PRICING AND QOS IN MOBILE NETWORKS

The evolution of pricing and charging schemes for telecommunication and Internet services is a continuous process. Many pricing proposals have been made, yet a few have been implemented in commercial systems. In the selection of pricing schemes, network operators consider factors like simplicity, scalability, the signalling and processing overhead, and the feasibility of implementation [9]. On the other hand, the users' requirements for a pricing/charging[2] scheme include: predictability of charges, accuracy and convenience [11]. In terms of simplicity, the flat-rate pricing [12] scheme is at the top of the list, and it is popularly associated with the Internet. In flat-rate pricing, the charges do not reflect the level of network resource usage, which leads to unfairness between heavy and light utility users and also loss of revenue for operators when service usage is above the estimated average levels. The usage-based and special pricing schemes that have been proposed include, Paris Metro Pricing (PMP) [13], which creates differentially priced channels with better service expected in the higher priced channels due to less usage, and the responsive pricing, which exploits the adaptive nature of users to improve economic and network efficiency by increasing network prices during periods of congestion [3]. Other interesting pricing proposals are priority pricing, edge pricing, and effective bandwidth pricing.

Charging enables network operators to generate revenue from the services offered. The charging approach used is operator specific; however, it depends on the pricing scheme. A common trend in telecommunication charging relies on the time-of-day (ToD) pricing [14], which is a version of the responsive pricing scheme. In ToD, network congestion is assumed to be higher during daytime than nighttime, hence the former is priced higher than the latter. It is clear that pricing and congestion control are closely linked. All applications have minimum network performance requirements, hence most networks are designed to meet these requirements. QoS provisioning in IP networks can be achieved using two architectures; the integrated services (IntServ) [15] and the differentiated services (DiffServ) [8]. The DiffServ architecture creates classes of service (CoS), to which different applications are grouped. Packets belonging to different CoS would receive a characteristic network performance treatment called per-hop-behaviour (PHB). The 3GPP has proposed standards for an all-IP mobile network. This makes it possible to use DiffServ for QoS provisioning in mobile networks [16].

Since DiffServ does not guarantee QoS for individual flows in a CoS, the use of connection admission control facilitates the reservation of QoS resources the active flows. In the UMTS, the amount of resources needed to support a PDP context are specified in terms of QoS parameters. For packet data communication, control of the use of network resources, in the core network (CN) and the radio access network (RAN), is done by the gateway GPRS support node (GGSN), the policy

[2]Refer to [10] for a definition of terms related to billing

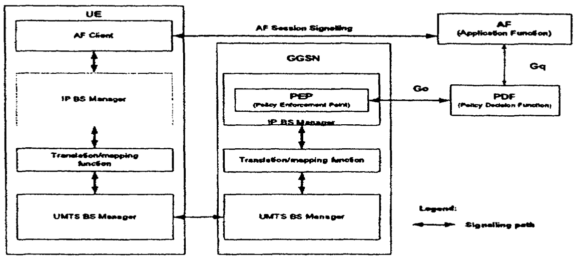


Fig. 1. UMTS QoS signalling flows.

decision function (PDF) and the application function (AF) [6]. A PDP session is identified by the combination of the source and destination IP addresses and port numbers. Within the UMTS CN, the MSISDN (Mobile Station ISDN) and the IMSI (International Mobile Subscriber Identity) are also used for session identification [4].

When the user equipment (UE) activates a PDP context, authorisation of UMTS resources for the up-link and down-link directions would be done if the network has the resources needed to support the request. Downgrading of the requested UMTS QoS parameters may be done when the available network resources are less than the required amount. Fig.1 illustrates the flow of information during the PDP context activation[3]. The information needed for charging the session, e.g. the applicable tariff rate is exchanged during this procedure. Individual operators decide on the exact monetary values to use for the tariffs. However they rely on factors like market forces affecting the mobile industry, and their aim is to offset the CAPEX and OPEX and to generate profits. From a technical view point, the QoS authorised for the bearer affects the applicable tariff rate [18].

Accounting of network resource usage is required in usage-based charging. Charging detail records (CDR) are formated files that contain information on the service and the user to whom it was delivered. They are generated by the SGSN and the GGSN [18], and they are used in billing for the use of the network. Whereas flat-rate charging only attracts a periodical subscription charge, usage-based charging comprises a subscription charge and a per-connection charge. The per-connection (access) charge can be expressed in an *abc* format;

$$aV + bT + c \tag{1}$$

where T and V are the measured duration and volume of the connection respectively, and a, b, c are tariff parameters applying to the connection.

The data rates available in mobile networks increase with each generation. 2.5G networks offered up to 144kbps, while 3G networks are designed to provide up to 2Mbps. Future generation networks will have higher data rates, since inter-working between 3G and wireless local area networks (WLAN) creates access networks with more than 10Mbps [19]. The enhanced data rates will facilitate the authorisation of high QoS

[3]Full details for information flow in Fig. 1 are available in [17]

for network services and applications. Using current mobile tariff structures, authorisation of higher QoS would lead to incurring charges that could be hundreds of times the values charged currently.

It is worth noting that very high charges will fail to provide incentives for the utilisation of the full capacity of the network, which is necessary for improving the efficiency of the network and user satisfaction. These are the key features that would enable network operators to generate more revenue. Section III presents an architecture for pricing network resources during periods when congestion is high and when the network has an abundance of resources. The use of service profiles that would enable users to influence the QoS vs. cost relationship of the services is investigated.

III. Architectural Design of the Pricing Scheme

The Dynamic QoS-based Charging Model (DQBCM), as proposed in this paper, utilises the four UMTS QoS classes that have been standardised by the 3GPP [5], [20]. Considering the limited resources in the access networks, we model a network with a total amount of resources R_t. These resources are shared by traffic in the different CoS of the system. The distribution of network resources to the individual CoS would be operator specific. In this architecture, the conversational and streaming multimedia CoS are combined to form one multimedia CoS, hence the system uses three CoS, i.e. multimedia, interactive and background. Flows in the multimedia CoS require expedited forwarding and minimum jitter, while data integrity (i.e assured packet forwarding) is the main requirement of the interactive and background CoS. Applying the formula in eq. 2, the multimedia CoS will receive a bigger proportion of Q_t, which corresponds to higher queue priority, while the interactive and the background CoS will receive a larger proportion of b_t. Here b_t represents the buffer capacity at each node along the end-to-end path. Network bandwidth (B_t) is required by traffic in each CoS.

$$R_t = \sum_{n=1}^{n=n}(B_t + b_t + Q_t) \qquad (2)$$

Flexibility is introduced into the system through network service profile that enable the users to specify, before hand, their QoS requirements. With the introduction of admission control, each CoS can guarantee QoS from a minimum to a maximum level, depending on the number of active flows. The introduction of profiles into each CoS partitions the QoS range into portions that can be used to enable the users to optimise QoS for specific services. The fragmentation of each CoS creates profiles that are priced differently, with the profiles offering higher QoS levels being priced higher as compared to the others. When users select a given profile, they enter into a service level agreement (SLA) with the network operator, and at the same time they give indication to the network management system on their willingness to pay for services at conditions specific to the profile.

A. Network service profiles

Three profiles are used in this architecture; however more profiles could be used. R_{tp} represents the amount of resources allocated to a given profile. If the number of active flows/sessions in a the profile is I_p, the amount of resources allocated to each flow would be;

$$r_{ip} = \frac{R_{tp}}{I_p} \qquad (3)$$

This formula assumes that each flow in the profile is allocated an equal amount of network resources. When CAC is used to limit the maximum number of sessions in a profile to N_p, each flow would be guaranteed a minimum amount of resources that is equivalent to;

$$r_{mp} = \frac{R_{tp}}{N_p} \qquad (4)$$

The value of r_{ip} will be equal to r_{mp} when $I_p = N_p$, i.e when the full capacity of the profile is used.

Platinum profile : This profile offers services at the highest QoS level in any CoS. When congestion occurs in the network, the QoS received by flows in this profile is guaranteed. In this architecture, the number of active sessions is used to quantify the demand for network resources, which also relates to the degree of network congestion. The tariff rate for charging users of this profile is dynamic, and it varies with the number of active sessions, i.e. $t \propto \frac{I_p}{N_p}$. The tariff rate reaches its maximum when $I_p = N_p$. We define a value of I_p, where $I_p = S$, below which the tariff rate would remain constant, thus the incremental tariff rate for the platinum profile is $t_i = \kappa_p(\frac{I_p - S}{N_p})$, where κ_p is a tariff constant for the platinum profile. By setting a minimum tariff threshold, the operators are guaranteed of revenue during periods of light network utilisation. Lowering tariffs encourages users to use to utilise the network during periods of less congestion, hence the overall network efficiency is improved. Raising of tariffs during congestion periods helps in the control of congestion. Since users are not able to predict tariff changes, this profile targets users who are less sensitive to network price changes, and whose main aim is to get services at guaranteed high QoS level.

Gold profile: The gold profile is designed for users who are very sensitive to changes in network prices, and also want to receive services with some level of QoS guarantee. The tariff rates are not affected by the demand of network resources, hence they remain constant. The cost of transmitting, say a multimedia message (MMS) of a certain size remains the same over periods of different congestion levels. There is a trade-off between predictable tariff rates and the achievable QoS, i.e. the QoS offered by this profile is affected by the demand for network resources. The QoS will be at the minimum when $I_p = N_p$, as illustrated by eq. 4. Using the thresholds defined for the platinum profile, when $I_p = S$, the QoS received by each flow in this profile will be at the maximum, and the decremental change in QoS as the number of active sessions increase is given by $q_i = \kappa_g(\frac{S - I_p}{N_p})$. Since the maximum QoS resource value for each flow in the gold profile ($\frac{R_{tp}}{S}$) is equal to the resource allocations for each flow in the platinum profile, the tariff rates used for the gold profile will be equal to the minimum tariff rates of the platinum profile.

Silver profile: The silver profile suits users whose main aim is to remain connected to the network for long durations. This profile is characterised by the lack of QoS guarantee and flat-rate pricing. Some applications in the interactive and background CoS, which are adaptive to substantial changes in QoS, would be appropriate for this profile. The best effort transport is appropriate for this profile; hence it is considered unsuitable for the multimedia CoS, since the minimum QoS requirement would not be met [5]. The CAC function limits the maximum number of flows that can be admitted to this profile, thus ensuring that the active sessions do not suffer breakdown as a result of excess congestion.

B. Bandwidth sharing between profiles

The architectural design of the DQBCM scheme allows resource sharing between service profiles. Resource sharing is done when the demand of resources in a given profile is less than its capacity, and it is achieved by allocating the excess bandwidth to a profile where the demand for resources is high. The sharing of resources can be done between profiles of different CoS. When , for instance, the gold profile gets excess bandwidth, the QoS received by its flows can be increased, or an extra session can be admitted, which makes $I_p > N_p$. This condition allows the operators to maximise revenue by shifting excess resources to profiles where demand is high. The platinum profile would benefit from resource sharing, since the extra sessions will be charged at the peak tariff rate. The following condition must be met for resources to be shifted from the gold profile to the platinum profile; the excess resources in the gold profile should be at least equal to the amount of resources required to support one session in the platinum profile. Referring to eq. 3 and 4, eq. 5 illustrates this requirement;

$$\frac{(r_{ipg} - r_{mpg}) * N_{pg}}{f} \geq r_{mpp} \tag{5}$$

f is a constant representing the ratio of resource allocations in the platinum profile to the minimum resource allocations in the gold profile, i.e. $f = \frac{r_{mpp}}{r_{ipg}}$, r_{ipg} and r_{mpg} are the respective current and minimum resource allocations for the gold profile, while r_{mpp} represents the resource requirements for each platinum flow. N_{pg} is the maximum number of admissible sessions for the gold profile.

C. Admission control strategy

Admission control is done so as to limit the number of sessions that are served in a given profile. With reference to the UMTS network, policy-based admission control is done by the GGSN in conjunction with the PDF and the AF (refer to fig. 1). In the DQBCM architecture, the admission control function

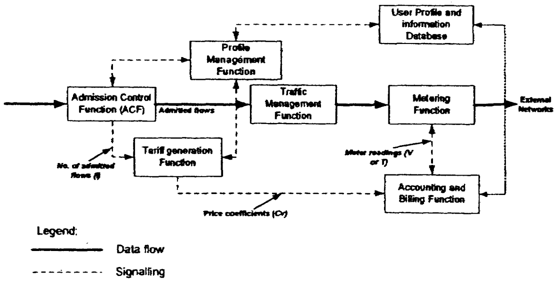


Fig. 2. DQBCM network management architecture

(ACF) keeps track of the number of active sessions (I_p) in each profile and the resource allocations for each session. In the UMTS, the total amount of resources allocated in a profile will be given by the sum of the values of the authorised PDP context parameters of all the sessions. The ACF will authorise new session establishment attempts when $I_p < N_p$ in the profile. Fig. 2 illustrates the network management architecture of the DQBCM scheme.

IV. Design of the Emulation Testbed

Various functions of the DQBCM architecture can be evaluated on a testbed. This section presents the design of the testbed used in performing the evaluations. Classes of service (CoS) are defined based on the network performance requirements of the traffic they would handle. Packets belonging to a given CoS can be identified using the type of service (ToS) byte in each packet. Peer-to-server (p2s) and server-to-server (s2s) communications generally use standard port numbers that are issued by the Internet Assigned Numbers Authority (IANA), hence classifying their traffic is simpler, and can be done in a static fashion; however, peer-to-peer (p2p) sessions use ports that are randomly assigned by the end nodes. For this reason, the classification of traffic from p2p applications must be done dynamically. The user profiles are stored in a database on the network management system (refer to fig.2), and will be matched against the user's static network ID. The network access identifier (NAI) for each user equipment (UE) is dynamically assigned. Mapping of the NAI to the network ID makes it possible to identify the service profile that is applicable to the user.

The UEs will be mobile and their access to the network can be achieved by configuring a media access gateway (AG). The AGs would be remotely located, and a network can have many AGs that are managed centrally by a network access controller (AC). The service profiles selected by the users, plus other user information should be stored in a database close to the AC. The AC would handle the connection admission control functions, traffic management and tariff generation, as illustrated in fig. 2. The DQBCM system manages the radio access network resources (e.g., the total bandwidth B_t). B_t is a limited resource that would be allocated to the active flows that are admitted to each profile. Since the traffic control is partly based on the DiffServ architecture [8], the assumption made is

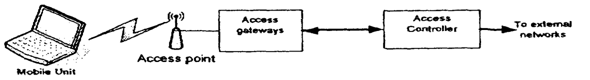


Fig. 3. Testbed layout

that traffic is handled according to the appropriate PHBs on the external networks. The main entities of the network system are as follows:

User Equipment: The user equipment (UE) enables the user to connect to the network, and also provides the profile modification interface. The interface can be menu-driven or web-based.

Media Access Gateway: The media access gateway (AG) assigns a NAI to the UE, and enforces the network access control decisions that are made by the AC.

Network Access Controller: The network access controller (AC) handles the network management functions, i.e. authentication, authorisation, user profile management etc. These are either enforced within the AC, as shown in fig. 2, or the AC authorises another network entity e.g. the AG to perform the function. The AC performs user authentication and authorisation (AA) upon receiving a request from the AG to which the UE is connected. AA is done by querying the user database for user identities. The AC performs a two-step authorisation procedure before granting services to the user. In the first step, the UE gets authorisation to access the network, and initiates requests for services. The second authorisation step is performed upon receiving service requests from the user. This step would only succeed if the user profile in which the requested service falls has sufficient network resources; this is done done by the admission control function. Tariff generation for the platinum profile is done as described in section III-A.

V. Implementation of the Testbed

A testbed for evaluating the DQBCM scheme was setup on a WLAN. The AG and the AC were implemented on Linux PCs. Three Classes of service (CoS) were created based on standard port numbers of network applications (e.g., port 25 for SMTP and port 80 for HTTP traffic). Details on implementing DiffServ on Linux may be found in [21], [22]. The profile selected by each user was identified by mapping the NAI (i.e. UE's IP address) to the corresponding profile entry that matched the user's unique network ID (i.e. UE's MAC address) in the profiles database. The UEs were emulated using laptops with wireless connection to an access point, as shown in fig 3.

The various entities of the testbed worked as follows: each UE was issued with a NAI by a dynamic host configuration protocol (DHCP) process on the AG. The AG transmitted the NAI and UE's MAC address to the AC for processing. On successful authentication, the AG was instructed to perform the first authorisation step. This was done by adding the NAI and the MAC address to an IP-TABLES firewall list on the AG. The second authorisation step was evaluated using TCP traffic. The TCP connection setup process uses SYN packets, which were only permitted through the AC's traffic control system when $I_p < N_p$ for the profile affected by the request. Admission control for TCP traffic was achieved using the connection tracking module that is available in Linux [22], and which was used to count the number of active connections (I_p) in each profile. Connections were uniquely identified using their source/destination IP address and port combinations.

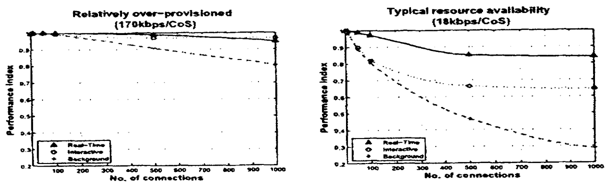
In conducting a performance evaluation of the QoS mechanism, UDP traffic generators [23] were introduced. The AG was replaced by three traffic generators, which sent traffic to a host node located on the external networks side (refer to fig. 3).

VI. Evaluation and Results

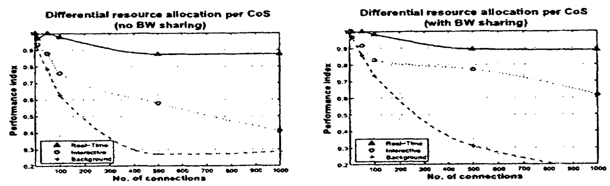
Timing data for the authentication and authorisation (AA) of the UE were as follows; the average time between detecting the UE and authorising it to use the network was 0.214s, which included the average time between initiating an AA request by the AG and receiving a response from the AC, which was 0.044s. These delay times are small and would not have diverse effects on the performance of other network related procedures e.g. handoffs between networks. The connection admission control function achieved 100% efficiency under TCP traffic; however, it could not be tested with UDP traffic. In mobile networks, admission control algorithms are quite advanced (e.g., as illustrated in section II). The performance of the DQBCM scheme when tested with traffic generators is given by fig.4 and 5. Fig.4 compares an over-provisioned and a typical network, where the former gives better performance than the latter. In the second set of graphs in fig.4, the real-time CoS is allocated higher bandwidth (BW) and a higher queue priority than the interactive and background CoS, with the background CoS getting minimum BW and lowest queue priority. The real-time CoS depicts a better performance index as congestion sets in. With bandwidth sharing, the performance index of the interactive and background CoS improves, before congestion sets in. This is because some of the unused BW from the real-time CoS is allocated to them hence boosting their throughput. In fig.5, the platinum, gold and silver profiles have same queue priority, but the BW allocation is greater for the platinum CoS and least for the background CoS. The BW sharing effect also applies to this case.

A. Comparative evaluation of the DQBCM

Using the evaluation criteria given in [3], the DQBCM scheme compares as follows: it is compliant with IP networks, hence it targets 3G and next generation networks (NGN). Network resources are needed for resource usage accounting in the gold and platinum profiles. Connection admission control enables congestion control in the network, which facilitates the achievement of individual QoS guarantee in the platinum and gold profiles. Achievement of high network efficiency is possible due to the incentives that come with the lowering of tariffs for services in the platinum profile during periods when the network has abundant resources. The characteristics

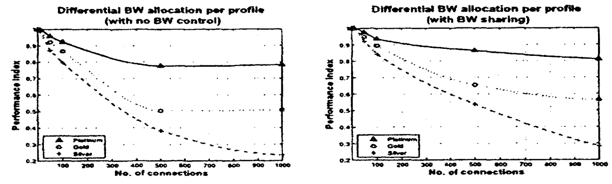


(a) Overprovisioned network (b) Typical resource availability



(c) No resource sharing (d) With resource sharing

Fig. 4. Network performance characteristics for the classes of service



(a) No bandwidth sharing (b) With bandwidth sharing

Fig. 5. Network performance characteristics of the profiles in one CoS

of different profiles enhance flexibility in the system, since users can select the profile that suits their needs, and encourage social fairness. Flat-rate pricing for the silver profile introduces economic fairness to users who cannot afford the higher charges of the gold and platinum profiles. The traffic control strategy works on short time frames, which reflects the characteristic nature of congestion in communication networks.

VII. Conclusions and Recommendations

The DQBCM scheme introduces of service usage profiles, and formulates an architecture for using policy-based admission control and DiffServ to achieve the QoS and charging requirements of communication networks, i.e. improving of network efficiency, controlling congestion, providing social and economic fairness among users and maximising profits for the network operators and service providers.

The network operators can configure the systems so that the actual change in tariffs for the platinum profile occurs at certain interval of $I - S$, as opposed to a linear tariff change format. This will reduce the rate at which new CDR sessions need to be created.

The application scenarios for the DQBCM scheme include: 3G networks, NGN, Internet service providers and telecom operators who enforce SLAs with their users. In practical deployment, the media access gateway, described in section IV, can be built in a small gadget like a conventional residential gateway device.

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