Real-Time Charging in Third-Generation Mobile Networks

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Abstract— **Due to the advent of UMTS, large number of new, packet based services and functions will be available. The open interfaces of the IP Multimedia Subsystem give the possibility for 3rd party providers to offer services and content for the mobile subscribers. Because these providers are financially isolated from the infrastructure provider, an accurate and fair accounting mechanism is needed; however such a method in a distributed packet based and real-time system is not so simple, and hasn't been developed yet. In our paper we will present these new functions and possibilities, we summarize the legal and technical difficulties of the 3rd party providers, and we give a functional model which is compliant with the related standards and solves the problems of real-time accounting and QoS measurement.**

I. Introduction

At the beginning of the 21st century a new, packet based mobile telecommunication network was (or being) introduced in many countries in Europe. The Universal Mobile Telecommunications System (UMTS), this new generation mobile network, contains major changes to the well known GSM (Global System for Mobile Communications) system. The evolution includes the increase of bandwidth and the fulfillment of the All-IP concept, thus different multimedia services like on-line streaming, video conferencing, Internet browsing and several packet based, on-demand services could be available with a next generation mobile phone. These changes were mostly called forth by the divided subscriber sector, which is almost saturated, and split between the current mobile network providers. Providing and offering more services and more convenient services can re-divide the marketplace. The IP Multimedia Subsystem (IMS) of UMTS supports telecommunication based services with the flexibility of Session Initiation Protocol (SIP), moreover, with its standardized, open interface 3rd party application providers can be easily connected to the system [4].

International telecommunication companies have made huge investments in UMTS, although a fully operating 3rd generation mobile network does not exist yet. The reason is that the changes are so significant, that the existing management systems are unable to handle these new demands. Not only the services should be developed but also the managing part should be revised, extended, and new features must be added, to realize the functions defined in the standards.

One of the main parts of the management system is charging. The return of the invested funds can only be hoped by new „killer-applications" and their proper accounting. The charging system of GSM networks was not designed to handle the bandwidth and the data/media types of UMTS services. A new charging concept should be developed, capable to handle the existence of 3rd party providers, support all kind of charging methods, like pre-paid, paynow, or post-paid mode.

The new architecture must be compatible with the existing GSM network charging architecture, and must operate real-time. Because the subscribers want to pay to only one provider (one-stop-shop concept), this accentuated provider has to maintain a financial relationship with the other providers and has to settle the bills. The business model must be flexible, in order to support all combination of content and provider relationships, hence the charging system must be accurate, convenient, transparent, and must be able to cooperate with other autonomous systems [5]. This paper is organized as follows: We give a short survey of business models in Section II. Section III and IV summarizes the state of the art technical challenges and the current state of the UMTS charging. We introduce our new concept in Section V. Finally Section VI concludes the work and presents future directions. In this paper the terms "subscriber" and "user" are used as synonyms.

II. Business Models

Taking the business scope of 3rd generation networks, several business roles exist. The network operator provides access and transport services. The role of the content provider is to provide services, contents or applications that add value to transport services. These applications or contents can be produced by the content provider itself or purchased from other providers. The key function of the content aggregator is to package and

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offer services from one or several content providers. In third generation networks the key solution is flexibility [5]. A subscriber can belong to the content or the network provider, and both of them can charge the user. In an extreme situation the customer knows only the content provider, who supports the end equipment, and the subscriber doesn't have any relationship with the infrastructure provider [6], as the content provider settles the transport charges.

The content provider and the network operator have to agree on the parameters of the provided services (e.g.: required transport quality, parameters to be measured). Both providers must authenticate the user, and must know his or her financial status to decide, whether to accept or reject the service request. Moreover, if some information exchange exists between the providers, they have to identify and authenticate each other.

Although several combinations of the roles and relationships are possible, the UMTS Forum outlined the three most presumable business models [6]. A charging system must be prepared to deal with the different combination of business roles, and the charging systems of the providers must be compatible with each other.

A. Network Operator Centric Business Model

In this model the network operator provides the content indirectly, charges the user and does the payoff to the 3rd parties. The subscriber can use the money on his/her infrastructure-account to pay for the content. In this way content providing seems to the user like a value added network resource usage. The provider does not store the data and isn't responsible for it's content, therefore the Internet connection strongly determines the quality of the service (QoS). This model is the most convenient for the subscriber, although the operator has full control over the content providing.

B. Content Aggregation Centric Business Model

In the content aggregation centric business model, the content is accessed through a portal (which is not part of the mobile network). The service cost is split into two parts: the cost of the access to the aggregator (network resource usage) which is paid to the infrastructure provider, and the cost of the content accessed, which is paid to the aggregator. The fee of the content is defined by the content aggregator, who may be in connection with other content providers. In this way a chain of providers is involved in the transaction. To avoid the subscriber's chagrin, caused by the multiple payoffs, the content aggregator and the network operator should be in financial relationship and settle the bills among the 3rd party providers.

C. Content Provider Centric Business Model

The content provider centric business model is quite similar to the content aggregation centric business model, but the content provider plays the role of the content aggregator as well. Because of the huge number of 3rd party providers, the realization of the business relationship is much harder, than it was in the content aggregation centric business model. The main disadvantages of this solution are that the content/application providers must solve the accounting of services on their own, which can be more expensive than the service itself [8] and that the subscribers have to maintain an account with every content provider separately. This solution could lead to problems in case there are many providers. This model brings huge freedom to the services offered, but it means enormous administrative overhead as well.

III. Technical Challenges

After finding the adequate business model, we face several technical difficulties. Charging in a circuit switched environment was much easier; all services were chargeable by measuring the time of the connection. In GPRS and UMTS systems the packet switched method brought along difficulties in charging. In the new system wider range of media are accessible [1], such as:

- speech,
- voice (real-time / streaming),
- video (real-time / streaming),
- data (download / upload / interactive content),
- messages (SMS / E-mail),
- data-flow (unspecified content),
- accessed web-pages, portals,
- etc.

The charging system should support charging different media to different accounts of the same user. The cost of the charged service should depend on the served amount of data or content and the quality of the transport. The amount of data can be measured with the exact counting of bits, which consumes huge amount of network resources, or with some tradeoffs, the system can use bigger units (hundreds of bytes for instance). The quality factors must also be determined (delay, jitter, bit error ratio, etc.) and considered, in order to assure proper charging. With IPv6 the problems of handovers can be set aside because of the micro/macro mobility protocols, but these functions also boost the quantity of the network overhead. If the IP address of the end-equipment changes at cell change, the system must be capable to summarize the charging information, as they belong to different IP addresses, but for the same user.

Since standards [2] give the possibility for post-paid users to limit their credit for a service, these users must be handled like pre-paid users. The charging mechanism for these subscribers must operate real-time, to assure that the requested service terminates when the user's account reaches zero and/or the specified limit.

The accurate value of the account must be well known to all of the charging functions and network entities, as the user can request more than one service at a time. To support this, the available money for a user must be stored in a centralized way, and the charging functions have to refresh the account respectively, to avoid over or under charging. The more often the system refreshes the accounts, the more accurate the charging, and the larger the network overhead will be. The optimal solution must be found to maximize the system's performance.

IV. Charging in UMTS Networks

Besides the service and quality measurement the charging process also includes the settlement of invoices among the serving parties (network and content provider). The price of network usage must also be settled between the network providers in case of roaming. This procedure is standardized, and uses the transfer account procedure (TAP) and a specific TAP format [1]. The construction of the bill presented to the user is also important; it must be simple and easily understandable [5]. The real money transaction between the parties (including the user) is usually obliged by contracts. These problems, solutions and mechanisms are beyond the scope of this article.

A. Service Charging

The charging model must be constructed according to the related standards. 3GPP specifies guidelines for UMTS charging systems (including the architecture and the main role/functionality of the network elements). In data measurement the gateway (GGSN – Gateway GPRS Support Node) and the inner-nodes (SGSN – Serving GPRS Support Node) are sending charging information to the Billing System (BS). This charging information must be in standardized format, called Charging Data Record (CDR). These records are sent to the Charging Gateway Function (CGF), which acts like a storage buffer, cleans, and preprocesses the CDRs, and then sends the processed CDRs to the Billing System (Fig. 1). Standards also define the trigger events to send these Charging Detail Records [1]. The events include:

- determinate data amount,
- determinate time-interval,
- the change of charging conditions,
- the change of QoS,
- the change of tariff,
- the change of position or cell,
- and the closure of voice, data or multimedia sessions.

Because these charging records carry information about the services required, the functionality of the CDRs extends beyond charging. With the CDRs it's possible to analyze service-utilization, and gain statistical information about the services and content [1]. By archiving the CDRs, the user-complaints can also be easily settled.

B. Release 6

The development of standards for UMTS is currently in progress, and has not been finished yet. The development process is divided into several phases called "Releases". Release 5 was frozen in September 2004, and the early versions of Release 6 are now available. In this phase, several innovations are appearing. The transport, service and content layer are separated in management and in charging to assure flexibility for the various business models. A new function called Online Charging Function (OCF) is also introduced (Fig. 2). The main task of this function is to realize real-time charging by continuously delegating certain amount of credit to the serving network elements. These credits are deducted from the user's account. This method is called: unit reservation. If the service terminates before all credits are consumed, the network elements are retransfering the remaining credits to the OCF. To assure continuous service delivery, if the users do not terminate the service, a new amount of granted credit should be sent to the serving network element before the previous one runs out [3] [4].

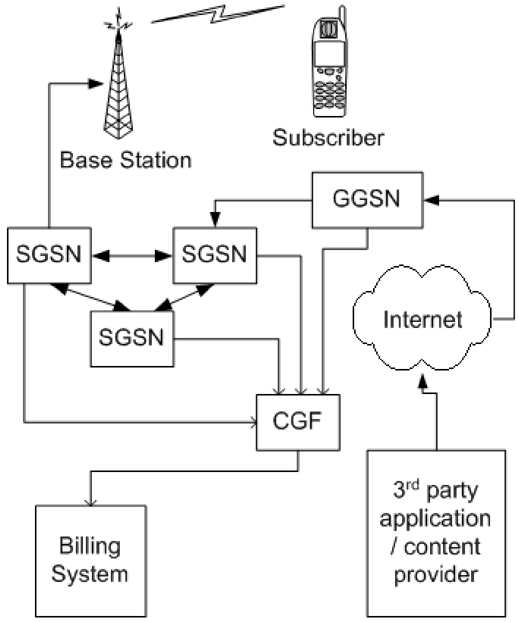

Figure 1. Packet-switched charging architecture

As it was mentioned the transport, service and content layers are separated and so, Release 6 provide functions that implement offline and/or online charging mechanisms on the bearer, subsystem and service level. The bearer level stands for the transport services (like GPRS), the subsystem layer represents the subsystem of the UMTS networks (packet switched, circuit switched, IMS), and the service levels means the available and requestable services (Video-streaming, MMS – Multimedia Messaging Service, etc.).

The offline charging mode (non-real-time charging mode) is also revised and functionally separated. The Charging Trigger Function (CTF) generates charging events based on the observation of network resource usage. The Charging Data Function (CDF) receives charging events from the Charging Trigger Function, and then uses the information contained in the charging events to construct CDRs. These functions were not separated in the previous releases however, the presence and implementation of the functions of these logical entities was necessary. The role of the CGF is not changed, and it operated as it was described in the previous section.

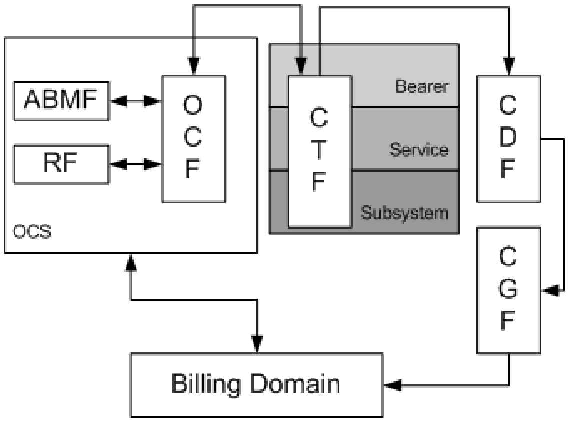

Figure 2. Functional architecture of the offline and online charging

In online mode (real-time charging mode) the Online Charging System (OCS) is responsible for proper charging. The CTF generates charging events for the OCF, but this communication is bidirectional, as the OCF has to grant credits for the service. The OCS also includes the Account Balance Management Function (ABMF) and the Rating Function (RF). The Account Balance Management Function is the location of the subscriber's account balance within the OCS. The Rating Function is used to determinate the value of the network resource usage and responsible for the

- rating of data volume (e.g. based on charging initiated by an access network entity),
- rating of session / connection time (e.g. based on charging initiated by a SIP application),
- and for rating of service events (e.g. based on charging of web content or MMS).

C. Charging Modes

Standards define two different charging methods: the offline and the online charging. In offline mode the required information is gathered into charging data records (CDRs), and sent to the billing system trough the charging gateway function (CGF). Since this information is collected after the event/service, and sent trough a widespread network, real-time charging is not possible. According to the standards, post-paid users can limit their account for a specific service; a real-time charging method should be used for pre-paid users and for post-paid users with credit limit. To ensure this, online charging should be applied.

V. MODE-SWITCHING MODEL

For correct modeling it is obligatory to suit the related standards. The optimal model can be developed using the proper determination of the free parameters. Such variable parameters are the amount of data and/or time that triggers the CDR generation and the amount of granted credit during unit reservation. Other variable parameters are the physical realization of the charging functions, inasmuch as these functions are not attached to hardware entities. The third variable parameter or method is the measurement of the services. The standards are not dealing with the measuring methods, therefore for data transfer the estimation of bandwidth or the exact bit count are possible solutions.

Our idea was not to glue the charging mode to the type of the payment (pre-paid, post-paid), but to dynamically switch between offline and online charging (if online charging is required) considering the user's account as well. Moreover, the overhead of the continuous unit reservation can also be reduced, by granting units only once. The quality of service should also be supervised, in order to charge services properly.

In our model, we assign a service specific limit to every service offered. If the user's account is above this limit, then charging is done in offline mode. If the subscriber's account drops below this limit, the online charging mechanism is applied (if required), and we grant all the consumable credit to the serving network element. In multi-task systems, it is possible to access more than one service. In such cases, when the account drops below the limit, we shall delegate the credits to multiple network elements. A good solution is to distribute the account among the services with statistical methods, considering the money-consumption and properties of the services, and the behavior of the user.

The UMTS services are based on a packet switched network, so we have to count with the packet-loss. The majority of these failures occure on the wireless part of the network but, of course (like on the regular Internet), some packet-loss or fault happens on the backbone as well. Statistical methods can be used to deal with these failures. Considering the quality of the operator's network, we can send more packets to the user, than it would be necessary with a perfect, flawless network, so the user presumably gets the proper amount of packets.

In order to measure the packet-loss and packet based QoS, the presence of trusted equipment is needed at the end of the connection. This could be the base station, or we can implement the protocol in the low level layer of the mobile phone. The main idea of this solution is that the element has to send some kind of information to the billing system, in order to inform it about the quality. The quality measurement of the data sequence is done with a sliding-window algorithm. After the arrival of a proper amount of packets, the delay (average, maximum, minimum and jitter), packet-loss, bandwidth and other QoS parameters can be calculated. The retransmission of the lost packets and signaling is done by higher protocols.

The measurement of quality can be eliminated with the usage of pre-calculated statistical information about the network, but in this case the results won't mach the exact situation.

A. Estimation of Network Overhead

Let us denote d_{data} for the amount of useful data transmitted. If the size of a CDR is d_{cdr} and the amount of data that triggers the CDR generation is referred as t_{cdr}, then the quotient of the charging messages and the useful data ($O_{offline}$) is

$$O_{offline} = [\ (\ d_{data} / t_{cdr}\ ) \cdot d_{cdr}\ ] / d_{data} = d_{cdr} / t_{cdr} \qquad (1)$$

in offline mode (if we use the same unit for d_{data}, d_{cdr} and t_{cdr}). Similar to this, the quotient of the charging messages and the useful data in online mode (O_{online}) is

$$O_{online} = [\ (d_{data} / t_{ur}) \cdot d_{ur}\ ] / d_{data} = d_{ur} / t_{ur}, \qquad (2)$$

where d_{ur} is the size of the unit reservation message and t_{ur} is the amount of granted data. Since the unit reservation message should contain more or less the same information as the CDRs, we assume that d_{ur} is equal to d_{cdr}. In online charging, if the service reserves a large amount of credit from the user's account, access to additional, parallel resources could be denied, because there is no credit left on the account for another resource usage request; even if some service terminates afterwards, and the unused credits are returned to the users. In light of this, a more frequent unit reservation, with a smaller amount of credit should be applied. Because CDRs indicate the used services/data, this problem doesn't occur during offline charging. As follows, t_{ur} is smaller than t_{cdr}, and thus online charging causes bigger network overhead, than offline charging:

$$O_{\text{offline}} = d_{cdr} / t_{cdr} < d_{ur} / t_{ur} = O_{online}. \qquad (3)$$

Our idea is to apply offline charging for pre-paid users if their account is far above zero and for post-paid users with credit threshold, if their account is far from the specified limit. If the user's account is close to zero (or to the specified credit limit) online charging should be applied. A crucial question is to determine the threshold limit to switch between offline and online charging.

B. Mode-Switching Limit

Let us define a function called unit consumption speed

$$C(T), \qquad (4)$$

having the measure of [*unit/sec*], which represents the consumed units in one second. The consumption rate depends on time to give the possibility to the operators to assign different prices to different time of the day and week for traffic shaping reasons. The consumed unit and money can be calculated from the consumption rate by means of the following equations

$$unit = C(T) \cdot t \qquad (5)$$
$$money = unit \cdot R(T), \qquad (6)$$

where $R(T)$ represents the relation [2] between unit and money. The time-dependence of this function can be used to change the price of the units in case of inflation or discounts, or to apply different prices for different groups of users. Although the time dependence of the price can be divided into consumption speed and rating, it is not necessary, and it depends on the needs of the network operator.

Let T_c represent the time needed to query the user's proper account. The network elements are sending the CDRs usually in bigger time-intervals and the billing system debit the user's account periodically. T_c represents these intervals. With these notations and definitions the limit for mode-switch can be calculated. In ideal case it is

$$L = C(T) \cdot T_c. \qquad (7)$$

If we own more units on our account than L, the charging is done offline with small network overhead; otherwise accounting is done online, with unit reservation. If we require more than one service at a time, the limit can be calculated by the sum of the limits of the services:

$$L = \sum L_i. \qquad (8)$$

To reduce the network overhead, all credits below this threshold can be reserved. In case of multiple service demands, the units can be distributed to the serving network elements with the rate of the service's consumption speed. A re-sharing should be done every time a service ends, a new service started, or when an event based service occurs (SMS – Short Messaging Service - for example). In order to ensure this, new functionality is required. The online charging function (OCF) should be able to force the network elements to retransfer the currently unused credits. After the transfer, the online charging function could re-share the credits among the services considering the new circumstances.

When a fix consumption speed can not be assigned to the service (browsing, or interactive content), the average consumption speed should be determined using various statistical models.

C. Propagation Delay

The events occurring in a distributed, wide network (signaling, queries) have propagation delay, which is not constant in general. If we want to determine the mode-switching threshold properly, we have to consider the time needed the query the account (T_c) and to switch between modes (T_d), together with the variation of these values (T_{cj} and T_{dj}):

$$L = C(T) \cdot (T_c + T_{cj} + T_d + T_{dj}). \qquad (9)$$

To ensure accurate charging, we should count with the maximum values of the jitters (T_{ci} and T_{di}). If we want to reduce the values of the mode-switching limits (in order to reduce the network overhead), we shall count with smaller values (with the expected value for example). In this case the possibility of users gaining more service than they paid for can be calculated from the distributions of the jitters.

In case of re-sharing the control messages should be labeled with proper time-stamps to be able to charge the services gained during the retransfer and mode switching process.

The mode-switching thresholds can be calculated offline for every service offered, and the system can use these pre-calculated values to switch between the charging modes. However, the actual limit can be dependant on the time of the day and on the user profile (discounts for group of users, statistical behavior for interactive content).

D. Measurement of QoS

Performance can be defined using a sliding-window algorithm; always using the last *N* packets arrived to the user. With this method, the measured and experienced performance should be close to each other. Let t_j be the transmission starting time and a_j the arrival time of packet *j*. If the size of the sliding-window is *N*, the delay (average, minimum, maximum) can be calculated:

$$D_{average} = \sum(a_i - t_i) / N, \quad (10)$$
$$D_{min} = \min(a_i - t_i), \quad (11)$$
$$D_{max} = \max(a_i - t_i). \quad (12)$$

The jitter of the delay is the difference of the maximal and minimal delay:

$$D_{jitter} = D_{max} - D_{min.} \quad (13)$$

The packet-loss in case of *N* arrived, and *M* sent packets is:

$$Loss = N/M. \quad (14)$$

E. Calculations for streaming-video

To demonstrate the profits of our model let's assume, that a user requires a streaming video service with 4 € on his/her account. The used parameters[1] of the network and the streaming-service are listed in Table I. With these parameters, the network overhead in offline and in online mode can be calculated, such as the mode-switching limit using (1), (2) and (9):

$$O_{offline} = 102400 / 7372800 = 0.01388, \quad (15)$$
$$O_{online} = 81920 / 1474560 = 0.05555, \quad (16)$$
$$L = 0.2 \cdot 7.5 = 1.5. \quad (17)$$

With 4 € the user can stream twenty minutes of video. During that period four CDRs or twenty Unit Reservation messages are produced. In offline mode, the user's account drops below 1.5 € after 900 seconds (as the system receives the third CDR). With mode-switching three CDRs and one Unit Reservation message are sent, and so the network overhead is:

[1] The parameters in Table 1 are hypothetical, but thay may approximate the real values.

TABLE I.
PARAMETERS FOR VIDEO-STREAMING

Parameter name	Parameter value
Data rate of the streaming-video	24576 bit/sec
Price of the service ($C(t)$)	0.2 €/min
Size of a CDR (d_{cdr})	102400 bit
Size of an Unit Reservation message (d_{ur})	81920 bit
Amount of data that triggers the CDR generation (t_{cdr})	7372800 bit
Amount of granted data in one Unit Reservation message (t_{ur})	1474560 bit
Time needed to query the user's account and switch between charging modes (T_c+T_{cj}+T_d+T_{dj})	7.5 sec

$$O_{mode\text{-}swith} = 0.01319 \quad (18)$$

Fig. 3 and Fig. 4 demonstrate the graphical representation of the network overhead during the streaming-service, using a 60 second quantum for time. The overhead of the mode-switching model is equal to the overhead of the offline mode till the account drops below 1.5 €. At the end of the service (1200 second) the overhead of the mode-switching model is smaller than as it is with the other two methods.

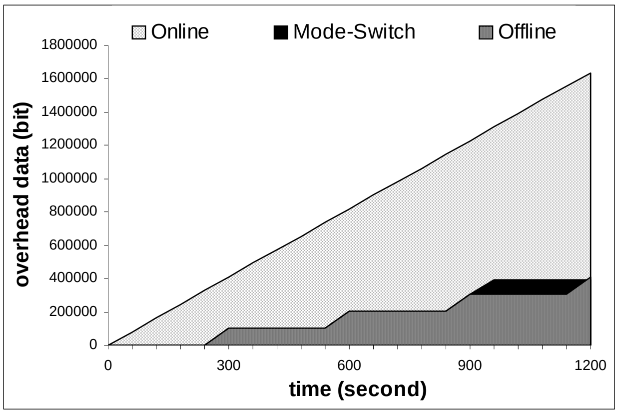

Figure 3. Size of the charging overhead during the service

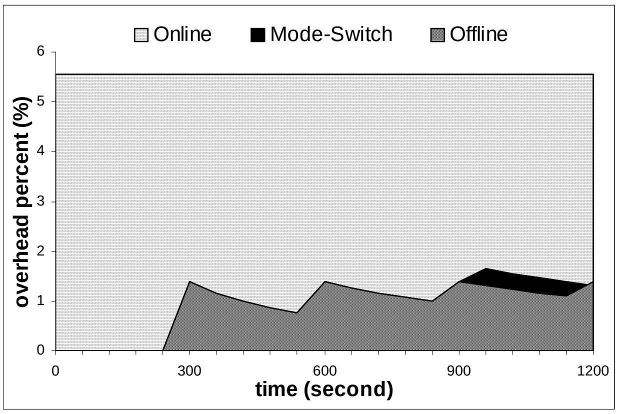

Figure 4. Percentage of the charging overhead during the service

VI. Conclusions and Future Plans

In our study, we enumerated the motivations for the appearance of 3rd party providers. We have showed the legal and technical issues of this new concept. Most of the technical problems come from the real-time nature and mobility in the packet based network. We gave a small summary about the current state of the 3GPP standards, and we listed the newly introduced functions. Finally, we gave a model to solve these problems. The model operates in such a way, that charging is made in the network offline, without a need for a real-time approach, to a large volume of users (who have more money on their account than the critical amount). Thismethod invokes low CDR transfer, and low network overhead. Billing to critical users is more complicated, but supported by 3GPP standards. With this idea the necessary network overhead can be decreased. Moreover, with a small function extension and statistical estimation, the overhead can be further reduced. As mentioned in Section I, charging is crucial in the telecommunication world, but its realization is (more or less) differs in every network operator domain. Our concept is a high level model, thus can be adopted in every mobile telecommunication network and it's suitable with every business model mentioned in Section II.

In the future, in order to develop the complete charging method, it is required to work out the exact method of measuring the data flow and the method to derive the quality of service from the IP based quality. For this, it is crucial to determine the statistic parameters of the services and users. The model is not complete unless the protocols and algorithms are fully developed.

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