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RESEARCH ARTICLE

Comparison of pre-paid rating methods

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Abstract

Despite the attractive post-paid tariff packages a lot of subscribers choos pre-paid mobile subscriptionsworldwide to gain more control on their spending. Usually services requested by pre-paid subscribers are rated by intelligent node platforms in a real-time manner, but the implementation of these systems varies from vendor to vendor and there are several key characteristics which shall be taken into consideration when comparing these systems. This article summarizes some of these major characteristics and gives analytic methods to calculate the number of unit reservation messages and ratings which are important indicators to size (dimension) these systems when a new service is introduced to the mass market. Our analytic calculations are confirmed by simulation results.

Keywords

pre-paid · charging · rating · unit reservation

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1 Introduction

When the early mobile telephony and GSM were introduced, pre-paid billing was managed by the serving network elements. As novel services were introduced and the rating (pricing) logic of these services got more and more complex, the need for a centralized pre-paid billing platform emerged. Currently in most operators' system an intelligent node (often referred as IN) is responsible to manage and charge the pre-paid subscribers [17][15][6].

Even though the pre-paid – post-paid convergence is still a hot topic, in most cases pre-paid and post-paid users are still rated and charged by two different systems[16]. This is mainly due to two reasons:

- The pre-paid systems are tied heavily to the network elements since they are playing a major role during call admission control. Most of these systems have out-of-the-box interfaces to the serving network elements (MSCs, SGSNs, etc) to allow the system to enable, deny or tier-down the user initiated services.
- To assure that the subscribers are unable to consume more services that they have already paid for, there is a very strong real-time requirement against these systems. On the other hand, the post-paid billing mechanism and approach allow the operators to process the call detail records with a significant delay. This condition implies that the pre-paid pricing logic is simpler and the pre-paid billing system is faster than their post-paid counterparts.

Due to these facts and requirements pre- and post-paid billing systems are using different approaches to rate and charge the services [1–3]. The price of the post-paid services is calculated from their *call detail record*, which is sent to the billing system after the call was made. These records (also known as *charging detail record*s or *event detail record*s and often abbreviated as CDRs, EDRs, or more generally xDRs) are generated and grouped together by the Mobile Switching Centers (MSCs) or other service enabler modules of the network and sent to the billing system through an offline, file based protocol [4, 5]. Once the records arrive to the system, the appropriate module determines the price of the calls using the information stored in the records, the rating logic of the purchased tariff packages and discounts of the customers and the accumulated usage information of the subscribers in the given billing period. Online charging is done while the call is made through socket based online interfaces and the price of the service is deducted from the subscribers' balance at the same time, when the service is requested by the subscribers [6–8]. Even though standards define the interfaces and protocols between the pre-paid billing platform and serving network elements, the implementation of these systems are significantly different and varies from product to product (see the list of offered functionalities of Alcatel-Lucent's, Huawei's or Ericsson's pre-paid platform)[15]- [17]. In Section 2 we will list the key characteristics of these systems, which will be explained through examples in Section 3. In Section 4 we will calculate the key indicators which can be used to size/dimension these systems. Section 5 summarizes the article.

2 Pre-paid rating methods

In this section we will summarize the technical restrictions and the main differentiators a pre-paid rating system may have. We have gathered five key characteristics; all of them are depending on the implementation and possibilities of the given system and on the consumed service. It is important to note, that a specific system may offer one solution for a specific service and another solution for a second one as it will be detailed later in the subsections below.

2.1 Nature of service

The rating approach is radically different for session and for event based services [1][3]. Event based services (such as SMS, MMS, Mobile payment or e-Gambling) allow easier rating mechanism. Once the user would like to consume the service, the pre-paid platform rates the service in advance and if the subscriber's balance is above this value then the call is authorized and the value of the service is deducted from the balance. If the subscriber does not have enough money on his/her account, then the call is rejected during the call admission control process [6–8].

The main problem with the session based services (such as voice call, GPRS/data session, video telephony, and so on) is that the price is not known until the service has ended, since the price is highly dependent on the length of the call (the length of the call is not necessary restricted or refers to the length of session in minutes, but to the length of session in the measured unit – e.g.: the amount of kilobytes transferred). The legacy approach was to deduct the balance only after the particular call has ended, but this method clearly carries the risk, that the account of the given subscriber does not cover fully the price of the service [11, 13]. Nowadays the reservation and rating is done in smaller chunks, allowing the operator to gain control over the long services and eliminating or lowering the before mentioned risk [1, 9].

Since the rating of the event based services is fairly simple, the following subsections will detail the technical restrictions and differentiators of the rating of session based services.

2.2 Inverse rating

Due to the real-time requirements against the pre-paid billing systems, the rating mechanisms and logic is generally simpler than the sophisticated rating logic allowed by post-paid/offline billing systems. With the evolution of hardware elements the pre-paid rating logic can be further enhanced and the significance of this limitation or difference will be reduced.

However, the key differentiator and technical restriction will be the so-called *inverse rating*. During post-paid services, the price of the service is defined once the service is consumed, and all the parameters of the requested service (including the length) are known. On the other hand, some pre-paid rating approaches require the calculation of the possible length of the service if the available balance is known. Calculating the price of the service from the parameters is called rating, and calculating the parameters (especially the length) of the service from the price is called *inverse* or *reverse* rating [14].

For a fairly simple rating logic (for example, the price of the service is $0.2\ credit/unit$) the implementation of inverse rating is fairly simple. However, as the rating logic gets more and more complex, the calculation of call length from the available balance gets harder and harder.

Most of the pre-paid systems are offering a framework or model, where the rating logic can be implemented. In some cases, this framework assures the existence of inverse rating by sacrificing some of the flexibility of the rating logic. Generally speaking, to assure a highly flexible pricing logic (such as different allowances, tiered discounts and subscriber specific discounted periods), we have to disclaim the existence of inverse rating.

2.3 Reserved amounts

During session based services the serving network elements are asking for predefined measurable units from the billing system. Once the billing system ensures that the subscriber's balance covers the requested amount, it allows the network element to serve the requested amount of service to the end-user. If the customer does not end the service before the requested amount is exhausted, the network element asks for additional units from the pre-paid billing system. When the service ends, the serving element reports the total consumed unit which will be re-rated by the billing system and the final price of the service is deducted from the subscribers balance while the possible additionally reserved units are released [1].

The consumed service, the used protocol, the rating logic and the serving network (or IT) element determine whether the amount of unit reserved in each transaction is static or dynamic [10][11][13]. A fairly simple implementation and rating logic allows the solution to reserve static amount of measured units (for example, if the price of the voice call is minute based, then we are allowed to reserve only minutes from the network elements). In such cases the more the reserved units are, the more money will remain on the subscribers' account, since this amount of money will not cover the requested amount of service. On the other hand, small amount of reservations results in high signaling (reservation) traffic and frequent ratings, which puts a high load on the billing system.

If inverse rating exists (see 2.2) the system and protocol shall be capable to derive and return the available units from the customer's available credits, thus eliminating the remaining balance issues even with high reservation amounts.

Another solution would be to define different tiers for reservation (8, 4, 2 and 1 units for example). The billing system would try to reserve the highest defined amount of units, and in case of failure (due to low-balance) it will try to reserve the next amount until it succeeds. Such approach would put additional rating load on the system, however assuming that this case would only occur during low-balance period (until the subscriber refills his balance) and efficient caching mechanism can be introduced, this load can be kept relatively low. This approach will be detailed in Section 4.

2.4 Preemptive reservations

The consumed service, the used protocol and the serving network (or IT) element determine whether the unit reservation is preemptive or not. Preemptive unit reservation means that even though a predefined amount of unit was reserved for a particular service, the billing system shall ask the serving network (or IT) system to report back the consumed units so far, and ask for another chunk of units to be reserved. This behavior is required if the user shall have more than one active service at a time, and priorities exist among the services. Please note, that the priorities does not have to be hard coded among the services. For example the service started earlier shall have priority over the services started later [12] to assure customer satisfaction.

Imagine that a HSDPA session is initiated during a voice call and the user's balance is relatively low. The HSDPA session can reserve the whole account once the PDP context is activated. In such case, the already active voice call will be terminated when the next reservation occurs, unless some of the reserved account is *taken back* from the HSDPA service.

Without preemptive reservation, the system shall be capable to somehow divide the available units among the active services preventing the HSDPA service (to stick to the previous example) to reserve the whole account. Several techniques are available on the market for such division [12].

2.5 Reservation control

In some special cases there is no need to exchange frequent reservation messages. This particular case can happen when the billing system can measure the consumed service without interacting with the serving network element. Basically this happens, if the measured length of the service can be derived from the length (minute) of the session. This is trivial in case of voice calls, but also possible if the data service assures some QoS and thus rated according to the length (minute) of the session. In some pre-paid billing embodiments, the system calculates the end of the service in advance, when the session is started, and only a tear-down message is sent to the serving network element if the user does not end the service till that moment [17].

3 Examples

Let us give some examples to light the previously detailed characteristics. GPRS sessions are initiated by the users and the SGSN (Serving GPRS Support Node) measures the service. Each time, the SGSN reserves 10KB in the billing system. This scenario is a session based service with static reservation amounts. If the billing system is capable to translate the last few credits to kilobytes, then inverse rating is implemented, and practically there will be no unused credit on the subscribers' account. If reverse rating does not exist then a few credits will remain unused.

If a voice session is initiated, and the pre-paid billing system calculates the end of the service and sends a tear-down message to the MSC, then this scenario is a session based service with reservation control and inverse rating. The reservation amount is not relevant in such cases.

We have created a few scenarios to demonstrate the differences between the approaches. In each scenario we have assumed, that the user has 850 credits on his account and starts service 1 at $t = 0$ and service 2 at $t = 7$. The prices of the services are 10 and 40 for each time interval respectively. $Ri(t)$ means, that the corresponding serving network element is reserving t amount of unit from the subscribers balance for service i, while $ENDi$ means, that the serving network element is aborting service i because the subscriber's balance does not cover further reservations. We assumed that there is no inverse rating despite of the fairly simple rating logic. The tables representing the scenarios are showing the time, the balance change and the event that occurs at that given time.

With these notations and assumptions we have modeled the static reservations in Table 1. In the A variant, the unit reservation was 8 units for both services, while we have applied a static, 2 unit reservation in variant B. It can be seen, that the A variant used only a few reservation message, but left a fairly huge amount of unused credit on the subscribers account.

In Table 2 we have calculated the required messages if dynamic unit reservation applies without (C) and with preemptive allocation (D). In both cases the amounts of reservable units were 8, 4, 2 and 1 for both services. Each time the reservation with a higher amount does not succeed, the system tries to reserve a smaller amount and tears down the service if not even the reservation of the smallest amount succeeds. During the preemptive reservation we have assumed, that service 1 has higher

Tab. 1. Static reservations

time	balance (A)	event (A)	balance (B)	event (B)
0	850 → 770	R1(8)	850 → 830	R1(2)
1				
2			830 → 810	R1(2)
3				
4			810 → 790	R1(2)
5				
6			790 → 770	R1(2)
7	770 → 450	R2(8)	770 → 690	R2(2)
8	450 → 370	R1(8)	690 → 670	R1(2)
9			670 → 590	R2(2)
10			590 → 570	R1(2)
11			570 → 490	R2(2)
12			490 → 470	R1(2)
13			470 → 390	R2(2)
14			390 → 370	R1(2)
15	370 → 50	R2(8)	370 → 290	R2(2)
16		END1	290 → 270	R1(2)
17			270 → 190	R2(2)
18			190 → 170	R1(2)
19			170 → 90	R2(2)
20			90 → 70	R1(2)
21				END2
22			70 → 50	R1(2)
23		END2		
24			50 → 30	R1(2)
25				
26			30 → 10	R1(2)
27				
28				END1
29				

priority (since it was started earlier), and when neither unit reservation succeeds at $t = 21$ it requests the second service to release the unused amount. Since there were two unused credits at that moment for the second service, its price (80) was released, and allowed service 1 to continue. Sadly, the first service consumed the whole amount, thus service 2 was aborted.

We have summarized the amount of reservation messages, the total served units for both services as well as the unused credits in each scenario in Table 3.

Tab. 2. Dynamic reservations

time	balance (C)	event (C)	balance (D)	event (D)
0	850 → 770	R1(8)	850 → 770	R1(8)
1				
2				
3				
4				
5				
6				
7	770 → 450	R2(8)	770 → 450	R2(8)
8	450 → 370	R1(8)	450 → 370	R1(8)
9				
10				
11				
12				
13				
14				
15	370 → 50	R2(8)	370 → 50	R2(8)
16	50 → 10	R1(4)	50 → 10	R1(4)
17				
18				
19				
20	10 → 0	R1(1)	10 → 0	R1(1)
21		END1	0 → 80	REALLOCATE
			80 → 0	R1(8), END2
22				
23		END2		
24				
25				
26				
27				
28				
29				END1
30				

Tab. 3. Summary

	A	B	C	D
final remaining balance	50	10	0	0
reservation messages	4	21	6	7+
service 1 length	16	28	21	29
service 2 length	16	14	16	14

4 Number of unit reservation messages

Proper dimensioning (sizing) of the pre-paid billing systems require a lot of information such as (but not limited to) the number of subscribers, the number and distribution of the calls and call lengths, the reservation messages in case of session based services and the required number of ratings. In this section we will estimate the average number of reservation messages for a call if the call length distribution is known. In addition we will show how the number of required ratings is depending on the number of unit reservation messages.

In Section 4.1 we will calculate the number of reservation messages in case of session based services, where no inverse rating is implemented, the amount of reserved units are fix, there is no preemptive reservation and reservation control. In Sections 4.2 and 4.3 we will show the impact of dynamic and preemptive reservation on the number of messages respectively. In Section 4.4 we will estimate the required number of ratings, while in Section 4.5 we will demonstrate our simulation and compare it with the analytic results.

4.1 Number of unit reservation messages

In order to calculate the average number of unit reservation messages for a given call length distribution, we have to observe and understand the protocol of the session based services. When a call is initiated, the serving network element is reserving the predefined amount of service and once this amount is consumed, it reserves another amount. At the end of the session it reports back the total consumed service (we will include this final reporting as an additional message in our calculations). With this algorithm, if K denotes the reserved units and P_{iK} represents the possibility that the session is longer than iK, then the amount of reservation messages (N) can be calculated as follows:

$$N = \sum_{i=0}^{\infty}(i+2)P_{iK} = \sum_{i=0}^{\infty} 2P_{iK} + \sum_{i=0}^{\infty} iP_{iK} = 2 + \sum_{i=0}^{\infty} iP_{iK}. \quad (1)$$

If $g(t)$ represents the probability density, while $G(T)$ the cumulative density functions of the call length distribution, then P_{iK} can be calculated as follows:

$$P_{iK} = \int_{iK}^{(i+1)K} g(t)dt = G((i+1)K) - G(iK). \quad (2)$$

We will prove that the number of unit reservation messages (including the final reporting message) is less than the expected value of $g(t)$ divided by K plus 2. Moreover, if the expected value of the call length is denoted with $E_g(t)$ and all the calls are completed (not even the last message is aborted), then

$$\frac{E_g(t)}{K} + 1 \leq N \leq \frac{E_g(t)}{K} + 2. \quad (3)$$

In order to do this, let us calculate the difference between $E_g(t)/K$ and the expected number of partial CDRs:

$$\frac{E_g(t)}{K} - N = \quad (4)$$

$$\frac{\int_0^{\infty} tg(t)dt}{K} - \sum_{i=0}^{\infty} iP_{iK} - 2 = \quad (5)$$

$$\sum_{i=0}^{\infty} \int_{iK}^{(i+1)K} \frac{t}{K} g(t)dt - \sum_{i=0}^{\infty} i \int_{iK}^{(i+1)K} g(t)dt - 2 = \quad (6)$$

$$\sum_{i=0}^{\infty} \int_{iK}^{(i+1)K} (\frac{t}{K} - i)g(t)dt - 2. \quad (7)$$

From (5) to (6) we have used the definition of P_{iK} from (2) and the fact, that

$$\int_0^{\infty} f(t)dt = \sum_{i=0}^{\infty} \int_{iX}^{(i+1)X} f(t)dt \quad (8)$$

for every $X > 0$. Since within the boundaries of the integral $iK \leq t \leq (i+1)K$, it can be easily understood, that

$$0 \leq \sum_{i=0}^{\infty} \int_{iK}^{(i+1)K} (\frac{t}{K} - i)g(t)dt \leq 1, \quad (9)$$

thus the difference between $\frac{E_g(t)}{K}$ and N is

$$-2 \leq \frac{E_g(t)}{K} - N \leq -1 \quad (10)$$

$$\frac{E_g(t)}{K} + 1 \leq N \leq \frac{E_g(t)}{K} + 2, \quad (11)$$

which was our theorem in (3).

Please note, that the lower boundaries in (3) is not valid, if the last call is aborted due to low balance. In this case, the lower boundary shall be downscaled to $(1 - \frac{1}{C})$ where C denotes the average number of calls. The average number of calls can be easily calculated with $\frac{U}{E_g(t)}$ where U denotes the total consumable service, thus (3) shall be modified as follows:

$$\Big(1 - \frac{E_g(t)}{U}\Big)\Big(\frac{E_g(t)}{K} + 1\Big) \leq N \leq \frac{E_g(t)}{K} + 2. \quad (12)$$

Sadly, the operators are only aware of the available balance, and to define the total consumable service from the balance requires the inverse rating functionality.

4.2 Additional messages in case of dynamic reservation

From Table 3 and (3) it can be seen, that longer reservation units result in fewer reservation messages but leaves more unused credits on the subscriber's account. Smaller credits are eliminating this problem but require more signaling traffic. Dynamic unit reservation is capable to solve both issues but requires a more complex mechanism and protocol. In light of reservation messages the upper boundary of (3) shall be extended, since the last few calls are issuing more signaling traffic.

If the units of the dynamic reservations are wisely chosen, the number of additional messages per call shall not exceed the number of available reservation steps. Moreover, if additional caching mechanism is introduced, then the total amount of additional messages shall not exceed this limit. In order to achieve this, we have to:

- Choose the steps in a way, that each step shall be the half of its preceding step. To give an example for voice calls, the available reservation steps shall be: 8, 4, 2 and 1 minutes. The last step shall be the minimum consumable service.
- Introduce a caching mechanism, so the system will remember the lowest step used. This cache shall be reset, when the subscriber topups his balance.

It can be easily understood, that with these innovations, the upper boundary of the number of reservation messages is

$$N \leq \frac{E_g(t)}{K} + 2 + \frac{L}{C}, \quad (13)$$

where L denotes the number of reservation steps and C represents the average number of calls in a topup-period.

4.3 Additional messages in case of preemptive reservation

During preemptive reservation (a service with higher priority requests the redistribution of the available balance) an additional unit reservation message is expected from the interrupted serving network element. If we also use dynamic reservation units and we denote the expected number of preemptive reservations with D, then the total reservation messages can be overestimated with

$$N \leq \frac{E_g(t)}{K} + 2 + \frac{DL + L}{C}. \quad (14)$$

4.4 Number of ratings

Due to the implementation and behavior of the protocol, it can be understood, that the maximum number of ratings does not exceed the maximum number of messages. Please note that this does not mean that in an actual scenario the number of ratings cannot exceed the number of messages. The dynamic reservation is a perfect example, since interim steps (4 and 2 in our example) have to be rated to check whether they can be applied or not, but should only be reported back to the serving network element if the subscriber's balance covers that step. Thus the maximum number of ratings can be calculated with (3), (13) or (14) for normal, dynamic and preemptive reservations respectively.

4.5 Simulations

We have created a simulation to demonstrate our calculations. We have implemented a stripped down version of the unit reservation protocol mentioned in the previous sections and calculated the average number of unit reservation messages and number of ratings for 10000 subscribers. The calls were following the log-normal distribution, while the price of the call was set to 20 $credit/unit$. During the simulations we have varied the available balance, the parameters (μ, σ) of the distribution and the unit reservation amount as displayed in Table 4. The dynamic reservation was used with 8, 4, 2, 1 and 0.5 units.

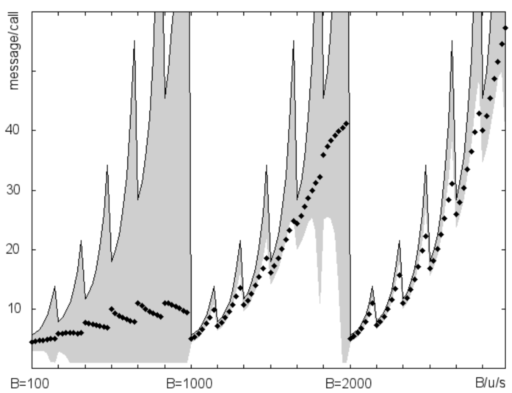

Fig. 1. Unit reservation messages for small unit reservation amounts

Tab. 4. Simulation parameters

parameter	values
balance	100, 1000, 2000, 4000
μ	0.5, 1, 1.5, 2, 2.5, 3
σ	0.4, 0.6, 0.8, 1, 1.2, 1.4, 1.6
reserved unit	0.5, 2, dynamic

On Fig. 1 we have showed the average number of unit reservation messages when the reserved unit was 0.5 and the balance, median (μ) and variation (σ) have changed during the simulation runs. The results of the simulations are represented with small black squares, the maximum value (from Eq. (3)) is represented with a solid line, while the minimum value (as calculated in Eq. (12)) is displayed as the lower boundary of the grey area.

Tab. 5. Selected simulations

parameter	S1	S2	S3	S4	S5	S6
balance	1000	1000	1000	4000	4000	4000
median (μ)	1	1	1	2.5	2.5	2.5
reserved unit	0.5	2	dynamic	0.5	2	dynamic

On the x axis the different parameters of the simulation were represented. The balance is explicitly stated, the minor tics representing the median change ($\mu = 0.5, 1, 1.5, 2, 2.5, 3$), while the variance change ($\sigma = 0.4, 0.6, 0.8, 1, 1.2, 1.4, 1.6$) is displayed between the ticmarks. We can observe that the simulation results were always below the estimated maximum; however, in some cases (when σ and the expected length of the calls were high) the results were below the expected minimum. This is due to the fact, that in these cases the total number of calls was less than the calculated value because of the long calls and the high variance.

On Fig. 2 we have plotted six simulation results as displayed in Table 5 to let us compare the effect of the used unit reservation amount. The x axis represents the variance (σ) change, while the y axis shows us the average number of reservation messages. The simulation results confirm our speculation in Section 4.2.

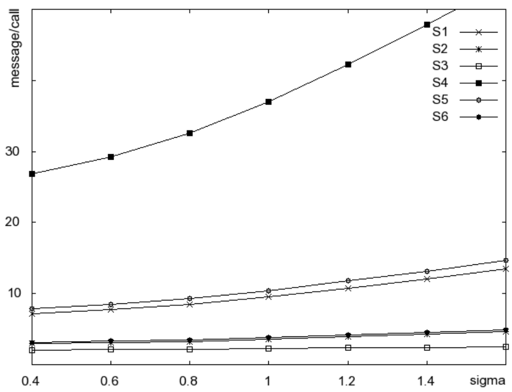

Fig. 2. Unit reservation messages

5 Conclusion

In this paper we have summarized the key characteristics and differentiators of the pre-paid billing systems such as the existence of inverse rating, dynamic and preemptive reservations or controlled service admission.

We have calculated a few scenarios and we gave a few analytic calculations to estimate the number of unit reservation messages and ratings per call and to show the effect of the different approaches. Our calculations were confirmed by our simulations in the last section. The calculated values can be beneficially used to dimension the pre-paid billing systems when a new service is deployed or when a new operator penetrates the market.

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