A PRICING MODEL OF GPRS NETWORKS WITH WI-FI INTEGRATION FOR “HEAVY” DATA USERS

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Abstract: As wireless services have become increasingly integrated and their demand is mounting, Wi-Fi provides an appealing opportunity for the GSM/GPRS operators to enhance their data capability. By integrating both networks, operators are able to provide 3G-like services. However, both networks have different data rates and capacity, which makes pricing a challenging issue. In this paper we propose a pricing model for GPRS networks integrated with Wi-Fi, which applies to data users with high service demand (“heavy”). Through optimization technique, our proposed model identifies how the integration can play a significant role in increasing operators’ overall revenue and potentially improving the performance of GPRS networks.

1 INTRODUCTION

As wireless technologies have been emerging and improving, the boundary of their applications becomes blur. The wireless technologies, which once positioned for their own specific applications, now can provide comparable services. For certain wireless services, technologies being used for different applications can now be seen as alternative solutions. The obvious examples are the improvement in mobility and coverage of Wi-Fi and the increasing capacity of data services in cellular networks. Wi-Fi has been both a competing and a complementary technology to cellular networks (Salkintzis, 2002; Ahmavaara, 2003). It offers fast connectivity and relatively much cheaper services compared to 2.5G cellular networks, such as General Packet Radio Service (GPRS). However, coverage of cellular networks is much larger than that of Wi-Fi networks. Several GPRS operators consider providing Wi-Fi services along with their networks in order to improve their networks’ capacity and alleviate congestion in GPRS networks. As a result, the main challenge that they would encounter is the pricing issues of services in both networks. Traditionally, GPRS networks offer simple usage-based pricing (Courcoubetis, 2000) for each megabyte that users transmit over the network. On the other hand, Wi-Fi service providers find it more difficult to come up with a pricing plan for their service. There are several payment options, such as a subscription fee on monthly basis, a one-time charge per connection, or usage-based pricing. The pricing schemes vary among different service providers. However, most Wi-Fi charges are based on flat pricing (Anania, 1997; boingo) such as a connection fee, which the network charges a user per connection in one location. To alleviate this pricing confusion in both networks, cellular operators have an option to integrate their networks with the hotspots and provide a common bill to their customers. In addition, data access over Wi-Fi is cost effective compared to cellular networks. A cellular base station costs over 30 times more than a Wi-Fi hotspot (Salkintzis, 2002). Network operators would enjoy significant cost saving while offering broadband wireless services that are comparable to 3G, namely, *3G-like services* (Ahmavaara, 2003; Doufexi, 2003). With the integration of both networks, network users, especially the ones with high service demand (or heavy users), will be able to choose to transmit data over either GPRS networks, (which offer wide coverage but costly and limited transmission rate), or Wi-Fi networks (which offer cost-effective services and high transmission rate but limited coverage).

Network users are inherently price sensitive (Mason, 1995). Using prices, the network can signal to users, providing incentives, which influence their be-

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havior to choose the networks that meet their pricing criteria (Falkner, 2000). The fact that users choose to access networks based on prices is similar to the concept of Paris Metro Pricing (PMP) (Odlyzko, 1999). That is, the GPRS operators could promote self-differentiation by charging different prices on those two networks. Pricing incentive would likely to move the network users from the congested high-priced GPRS networks to the less congested inexpensive Wi-Fi networks. However, PMP networks are identical networks with different prices charged to users. GPRS and Wi-Fi networks are different in terms of capacity and coverage. Clearly, integration between the two networks will make the pricing problem challenging.

In this paper, we propose a simple but effective demand-based pricing model for the integration between GPRS and Wi-Fi networks. In Section 2, we describe the architectural overview of Wi-Fi integrated with GPRS. In the third section we propose our optimized pricing model, followed by Section 4 where we present the results of our numerical analysis. We draw our conclusions in Section 5.

2 ARCHITECTURAL OVERVIEW OF INTEGRATION: Wi-Fi WITH GPRS NETWORKS

Integrating GPRS and Wi-Fi gives both ubiquitous coverage and support high data rate in strategic locations (schools, office, airports, hotels, coffee shops etc.). If both Wi-Fi and GPRS networks are integrated then cellular operators are able to meet some requirements for 3G services. This would allow them to provide high quality data services which can be perceived as 3G-like services. The following are two types of integration, tight coupling architecture and loose coupling architecture (Salkintzis, 2002; Oliver, 2002).

2.1 Tight Coupling architecture

In this type of architecture the Wi-Fi is connected to the GPRS network as an alternative Radio Access Network (Salkintzis, 2002). It is connected to the operator's core network. The hotspot can reuse the GPRS infrastructure like core network resources, subscriber databases and billing systems. The mobile users can select their network preferences or choose to get connected at the best available network speed. This is all done in software and will automatically connect them to the network of their choice. Fig. 1 illustrates the tight coupling architecture for the integrated network.

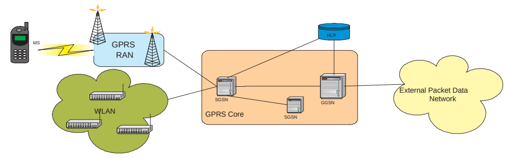

Figure 1: Tight coupling architecture for GPRS integrated with Wi-Fi networks.

2.2 Loose Coupling Architecture

The hotspots are coupled with the GPRS network in the operator's IP network. So the Wi-Fi data traffic goes directly to the operator's IP network, instead of going via the GPRS core network (Oliver, 2002). Though the Wi-Fi and cellular networks remain separate, there is a common platform for authentication, accounting and authorization. The hot spot may be owned by any third party carriers with roaming enabled via a dedicated connection between the cellular operators and Wi-Fi providers or over an existing Internet. Fig. 2 illustrates the loose coupling architecture for the integrated network.

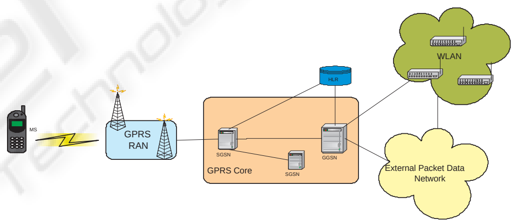

Figure 2: Loose coupling architecture for GPRS integrated with Wi-Fi networks.

3 PROPOSED PRICING MODEL

In our proposed model, we assume that a user is initially in the GPRS coverage and he is ready to perform a large file transfer. Users subscribes to both GPRS and Wi-Fi services. There will be one common Accounting, Authentication, and Authorization (AAA) server and billing system maintained by the cellular operators for all integrated hotspots. Now the user has two options: he can either perform file transfer right away over GPRS network paying a higher price, or he can search for Wi-Fi hot spots, assuming he regularly crosses Wi-Fi networks. Once users are in hotspot coverage, different types of hot spots would determine if users need to pay a roaming fee (third party hotspot case) or not (operator-owned hotspot case). We disregard the roaming fee at this point since that fee is not significant enough to contribute to the Wi-Fi charges when compared to charges from GPRS services. Fig. 3 illustrates a blocking diagram for the scenario we just described.

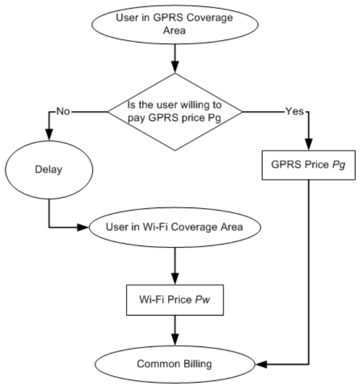

Figure 3: Pricing Block for GPRS networks with Wi-Fi integration.

As mentioned earlier, the cost of transmitting data over a GPRS network is quite high when compared to Wi-Fi network. This significant price difference between the two networks can influence the way users use these networks. Some users may be willing to search for a Wi-Fi network, if they need to perform a large file transfer. Hence, price incentive can influence users to use either GPRS services with higher price tag (more convenience since the network has larger coverage) or Wi-Fi services with lower price. We argue that the percentage of mobile users D who accept to be charged by GPRS networks, depends heavily on the price ratio between the two networks (Hou, 2001). D can be mostly influenced by the demand function which is a function that characterizes the reaction of users to changes in price. In this paper we use the demand function that appears in (Oldyzko, 2000) since it is used for different classes of users, that fit our model. The demand function is as follows:

$$D = e^{-(\frac{p_g}{p_w}-1)^2} \quad ,0 \leq D \leq 1,\ p_h \geq p_o \qquad (1)$$

where p_g is the GPRS charge and p_w is the Wi-Fi charge for each user (p_w could be either operator owned or third party owned hot spot charge). We are interested in the case when price incentive can influence decision of users. Therefore, the session volume charged by GPRS networks must be large enough to allow p_g to be greater than p_w. As we know GPRS pricing is usage-based charges, which do not depend on holding time but the session volume, therefore, p_g is a linear function of the number of megabytes transmitted over the network. For Wi-fi charge, it is based on flat pricing, which is basically a connection fee. Therefore, p_g and p_w can be described as follows:

$$P_g = r_g \cdot v$$
$$P_w = r_w \qquad (2)$$

where r_g is the charging rate per megabyte for the GPRS network, r_w is the connection fee of the Wi-Fi network, and v is the session volume of data that users transmit over the GPRS network.

Lower curve in Fig. 4 illustrates the demand function in (1). The horizontal axis represents the price ratio between GPRS and Wi-Fi charges ($\frac{p_g}{p_w} - 1$). This function works quite well in our model because, first, the demand function begins high for small price ratio representing the situation when users have small volume of data to transmit. The price charged by GPRS networks would not be much different from the Wi-Fi charge. The users have little incentive to seek for Wi-Fi hotspots resulting in the high user demand for GPRS usage. Then, the demand decreases rapidly as the curve gets into a mid-range and has very narrow tail. This part of the curve represents the increase in GPRS charges due to the increasing session volume from users. There is enough incentive for some users to start migrating to Wi-Fi resulting in the reduction of GPRS usage. For example, when the price difference at the horizontal axis equals to one, the GPRS charge is double the Wi-Fi charge, resulting in the GPRS demand dropping to 36.79 percents.

The revenue due to integration can be determined by the weighted sum of the revenue created by the GPRS networks and Wi-Fi networks based on their corresponding demand. Therefore, from equation (2), the average revenue of the integrated network can be determined as follows:

$$R_{int} = D \cdot (r_g \cdot v) + (1 - D) \cdot r_w \qquad (3)$$

Regarding the revenue gained from GPRS network without Wi-Fi integration, the GPRS users do not have an alternative to migrate their traffic. Therefore, the demand of users using non-integrated GPRS networks would be higher than equation (1). Since the distribution of session volume in GPRS networks is not available to us, we have to come up with a meaningful demand function. This function needs to be well above the demand function in equation (1), to represent the higher demand of GPRS networks in the absence of Wi-Fi. The demand function can be shown as follows (Oldyzko, 2000):

$$D_{w.o.int} = \frac{1}{1 + (\frac{P_g}{K} - 1)^4} \qquad (4)$$

where K is a constant. In our case, we set K equal to p_w for the purpose of fitting our demand curve according to our assumptions. That, does not mean that $D_{w.o.int}$ depends on the Wi-Fi charge. By comparing the revenue generated in both cases, we can gain some ideas about the effect of integration on the revenue stream. Fig. 4 illustrates both demand functions.

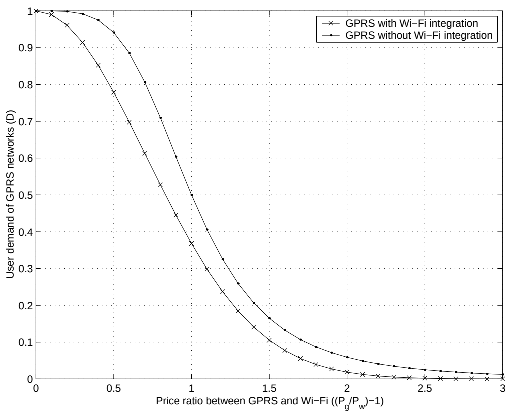

Figure 4: Demand functions.

Based on the user demand for GPRS network without integration, the revenue gained from GPRS network without integration is as follows:

$$R_{w.o.int} = D_{w.o.int} \cdot (r_g \cdot v) \tag{5}$$

In terms of performance improvement of GPRS networks with Wi-Fi integration, we focus on the portion of users' demand that we can offload to the Wi-fi network. Each GPRS user generates a certain amount of session volume based on their perference. We would need to find prices for both GPRS and Wi-fi networks that attracts users and reduces the their demand down to some target demand D. To be specific, we will set up an optimization model to find the optimal r_g and r_w based on target demand D

In our optimization model, we first set up our objective function. The most suitable objective function would be equation (3) due to the fact that the optimal r_g and r_w at any target demand should be able to yield the maximum revenue for the integrated networks. The objective function is subjected to certain constriants which are r_g, r_w and D. r_g and r_w must be constrainted based on the competitive market prices which the network operators should be able to provide based on their cost analysis of their networks. For the target demand D, it specifies the portion of data users who choose GPRS networks for their data transmission, which represent the network operation point of GPRS networks. Therefore,we can use D as the constraint for traffic offload to Wi-fi networks. Hence, we can set up our objective function and its constraints as follows:

$$Maximize\ R_{int} \tag{6}$$

subject to the following constraints

$$a \le r_g \le b$$
$$c \le r_w \le d$$
$$D = e^{-(\frac{p_g}{p_w}-1)^2} = D_t$$

where $[a, b]$ and $[c, d]$ are the constraints for r_g and r_w respectively, D_t is the target demand of GPRS users. Regarding average session volume (v), the distribution of v in GPRS networks with Wi-Fi integration is required for optimal charges in both networks. We do not have such distribution at this point. However, in (Kilpi, 2003), Kilpi illustrates cumulative session volume of a large number of GPRS sessions, giving an overview of typical GPRS sessions. The result shows that the session volume for very "big" sessions of GPRS services is hardly more than 5 MB due to slow user speeds and structural delay of GPRS networks. Therefore, we would be interested in some typical larger sessions (not more than 5 MB) that we could use pricing mechanism to offload them to Wi-Fi networks. By offloading the traffic to Wi-Fi, we expect that the performance of GPRS networks will be improved significantly (it is beyond the scope of the paper to prove that in a rigorous manner).

4 NUMERICAL ANALYSIS

In this section, we present our preliminary results based on the numerical analysis. We illustrate the revenue gained from network integration and the effect of Wi-Fi connection fee on the average revenue of the integrated networks. Furthermore, we present the results from our optimization model which allows us to setup the optimal prices which yield maximum revenue at a certain target user demand. The price setting attract GPRS users to migrate and reduce traffic load in GPRS networks.

4.1 Assumptions and parameters

We consider the case where users want to transmit relatively big data session, e.g., 1 MB or more. The large amount of users' traffic creates pricing incentive to seek and transmit their traffic onto less expensive Wi-Fi networks. Smaller session volume ($<$ 1 MB) will not create enough incentive for users to look for hot spots. We assume that pricing in GPRS networks is usage-based at a rate of 6 dollars per megabyte. Charging at Wi-Fi hot spots is flat, where users are charged per connection; users can transmit or receive as much traffic as they want during a connection. In addition, we assume that users have access to Wi-Fi hot spots, when they seek for them. The only incentive that drives them to hotspots is pricing. We do not include the coverage or location of hot spots into our pricing model.

4.2 Numerical Results

Fig. 5 shows the revenue gained from the integration of networks determined by equation (3), versus the average session volume. The Wi-Fi connection fee is 7 dollars per connection, regardless of the amount of traffic transmission. We can see that when data volume per connection increases, users would be influenced by price incentive to transmit their traffic over Wi-Fi hot spots, resulting in additional revenue. However, the revenue starts to drop at the average usage of 2 MB, since large amount of users would migrate to inexpensive Wi-Fi hotspots causing reduction in revenue.

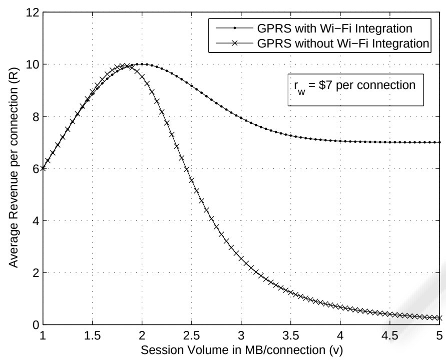

Figure 5: Revenue from GPRS networks with Wi-Fi integration with respect to average session volume.

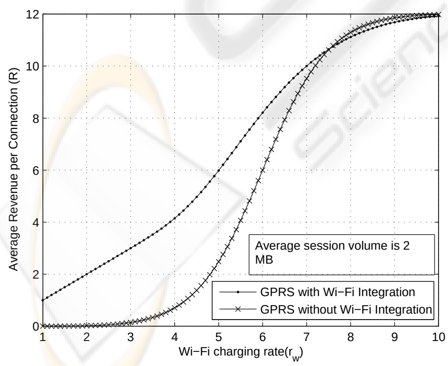

Figure 6: Revenue gained from GPRS and Wi-Fi integration with respect to the Wi-Fi connection fee.

Fig. 6 shows the average revenue gained from GPRS integrated with and without Wi-Fi versus r_w. We assume that each user transmits an average of 1 MB per connection. The result shows that when r_w increases, the revenue for GPRS with integration is no longer higher than non-integrated GPRS; users would continue using the GPRS network due to high r_w; there is no significant price incentive for them to switch to Wi-Fi. We could think of r_w that yields the largest difference between those two revenue curves, which represents the best tradeoff between revenue and traffic migration. Fig. 7 illustrates the revenue difference between equation (3) and (5) ($R_{int} - R_{w.o.int}$) versus r_w and v in a three-dimensional plane. The contour of the plane illustrates the line (dash line), where every point on that line yields the largest difference in revenue and their corresponding r_w and v. For example, at v equals to 2.2 MB, r_w equals to 5 dollars representing the largest difference in the revenue curve.

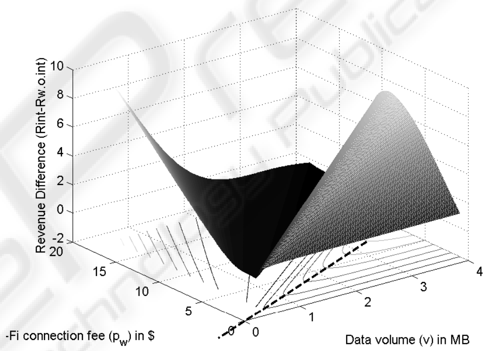

Figure 7: Difference in Revenue between GPRS integrated with Wi-Fi and non-integrated GPRS networks.

To offload the traffic from GPRS networks to Wi-Fi, r_g and r_w must be set appropriately so that the system yields maximum revenue and attracts GPRS users to migrate to Wi-Fi networks. Based on our assumption of the demand function and the proposed optimization model, Fig.8 illustrates charging rate of GPRS and Wi-Fi networks as well as the revenue generated from those charges. r_g and r_w are subject to constraints [1,4] and [3,10] according to the pricing information from commercial GPRS operators and Wi-Fi aggregators. We can see that, when average session volume equals 2 MB, the optimal r_g is at 4 dollars per MB for any target user demand D. The maximum revenue and user demand of the integrated network are, however, driven by r_w as they increase along with r_w. For the larger session volume,i.e., 5 MB, at D equals 0.5, r_w would reach the maximum market price (10 dollars per connection). The optimization model suggests that the GPRS operator should reduce the GPRS charge r_g in order to meet certain user demand and maximum revenue. Hence, based on our assumption and the optimization model,

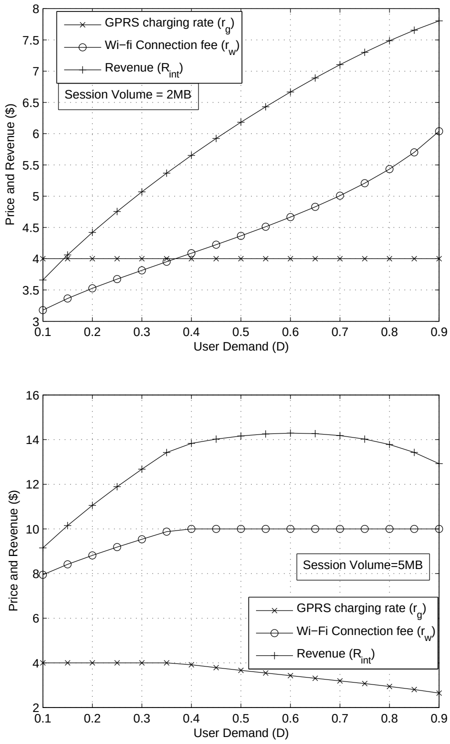

Figure 8: Price sets generated from optimization model and their corresponding revenue.

we can create price sets for both GPRS and Wi-Fi networks which allow us to migrate traffic demand between these two networks and yield maximum revenue.

5 CONCLUSION

In this paper we propose a simple but effective pricing model of GPRS networks integrated with Wi-Fi. We propose the use of demand functions to describe the response of users based on the prices charged in each networks. By integrating two technologies together, operators can attract new customers with value added services provided by Wi-Fi networks, thereby, reducing the churn. Furthermore, the GSM/GPRS cellular operators can delay their 3G deployments as the integration could offer 3G-like services. The integration is not only beneficial to the cellular operator but also to third party hotspots, because it increases revenue by increasing traffic load at their hotspot networks. Users who are not willing to pay high GPRS prices, will eventually start utilizing the Wi-Fi network, taking advantage of the price difference. Thus, integration provides profitable business strategy for both the cellular operators and the new Wi-Fi startup companies.

To extend our study, we are investigating the distribution of GPRS session volume and the estimation of traffic load migrated from GPRS to Wi-Fi.

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