2010

Integration of WiMAX and WiFi Services: Bandwidth Sharing and Channel Collaboration

Yung-Ming Li
National Chiao Tung University, yml@mail.nctu.edu.tw

Jhih-Hua Jhang-Li
National Chiao Tung University, jhangli@gmail.com

INTEGRATION OF WIMAX AND WIFI SERVICES: BANDWIDTH SHARING AND CHANNEL COLLABORATION

Yung-Ming Li, Institute of Information Management, National Chiao Tung University, Hsinchu, Taiwan, yml@mail.nctu.edu.tw

Jhih-Hua Jhang-Li, Institute of Information Management, National Chiao Tung University, Hsinchu, Taiwan, jhangli@gmail.com

Abstract

Several emerging study has focused on the pricing issue of bandwidth sharing between WiFi and WiMAX networks; however, most of them either concentrate on the design of collaborated protocols or figure out the issue without the overall consideration of customer preference and contract design. In the present study, we consider a wireless service market in which there are two wireless service providers operating WiFi and WiMAX, respectively. One of the research dimensions given in the study is whether wireless operators implement bandwidth sharing, while the other is whether wireless operators make decisions independently or jointly. By involving customer preference and wholesale price contract in the present model, we find that bandwidth sharing would benefit a WiMAX service provider, yet a WiFi service provider has no significant saving under a wholesale price contract. In addition, the profit of a WiMAX service may increase with WiFi coverage when bandwidth sharing is implemented but decease with WiFi coverage when both wireless services operate without bandwidth sharing. Besides, the WiMAX service provider would allocate more capacity when average usage rate increases, but decrease the amount of capacity when average usage rate is too large.

Keywords: WiFi, WiMAX, Bandwidth Sharing, Service Strategy, Wholesale Price Contract

1   Introduction

While wireless service providers are competitors for their market shares, they also collaboratively provide Internet connectivity. WiFi and WiMAX are the two most influential technologies that have been implemented by wireless service providers. WiFi technology is mostly used in laptops today and is commonly available in coffee shops and other public places around the world. The WiFi operators aggregate the wireless networks provided by micro carriers, such as Starbucks coffee-shops and Borders bookstores in the United States, and provide a single access to the end user (Yaiparoj et al., 2008). The main disadvantages of using WiFi network would be the lower coverage as it operates in public bands so that the wireless signals broadcasted by WiFi hotspots are so weak to avoid interference. On the other hand, WiMAX, an emerging technology, promises to offer data speeds faster than current 3G wireless networks and over much longer distances than comparably fast WiFi technology; hence, WiMAX can be considered a solution to fill holes in WiFi hotspots coverage and enable wireless connectivity on trains or buses (Ballon 2007). Currently, Sprint, a wireless company utilizing WiMAX to offer 4G service, has admitted that true download speeds are between 2M bps (bits per second) and 4M bps, comparable with many DSL (Digital Subscriber Line) and cable modem services. Besides, the company has committed itself to spending $5 billion on the WiMAX network. Consequently, its WiMAX coverage will be available to over 22 million potential customers by 2010. As time passes by, the rates and terms for WiMAX services are fairly attractive and could put pressure on competitors (Reardon 2007, Lawson 2008, Myslewski 2009).

Pricing and the features of transmission media affect the allocation of the wireless network resources between WiFi and WiMAX. Some of the wireless ISPs with financial power and high level of technology are big companies and are concentrated in urban metropolitan regions. Because of the limitation of coverage provided by a WiFi hotspot, a WiFi service provider has to allocate thousands of hotspots to reduce customer's inconvenience cost of finding the nearest hotspot. Since each WiFi hotspot needs a wired backhaul to offer Internet connectivity, the capacity cost of WiFi services spent on wired backhauls can be saved if Internet connectivity is offered by a wireless backhaul, such as a WiMAX base station. The focus in recent years has been towards real-time data services in the wireless environment. Wireless service providers can charge users a service fee to influence their consumption decisions towards more efficient network usage. In general, wireless users are inherently time-sensitive and the aspects to coverage are highly subjective and depend heavily on user experiences. Thus, wireless service providers can rely on user network preferences and the characteristics of their own media to implement traffic management and versioning strategy by pricing their services accordingly.

1.1   Research Problem

It is practicable that WiMAX base stations can serve as wireless backhauls where the bandwidth of WiMAX networks is shared by WiFi access points to provide Internet connectivity to mobile WiFi customers (Fantacci and Tarchi 2006; Lin et al. 2009; Huang et al. 2010). From the aspect of practicability, the integration of WiFi and WiMAX can benefit WiFi service providers because costly wired infrastructure can be avoided. However, it is not clear that the impact of bandwidth sharing on wireless network providers' service strategies. The market share of wireless Internet service is easily affected by price, transmission rate, and coverage; thus, this study emphasizes the service strategies universally adopted by a wireless service provider, such as how to allocate service capacity and how to determine service coverage. We find that bandwidth sharing would benefit a WiMAX service provider, yet a WiFi service provider has no significant saving under a wholesale price contract. In addition, the profit of a WiMAX service may increase with WiFi coverage when bandwidth sharing is implemented but decease with WiFi coverage when both wireless services operate without bandwidth sharing. The WiMAX service provider would allocate more capacity when average usage rate increases, but decrease the amount of capacity when average usage rate is too large. Finally, we also identify the difference in service strategies between channel competition and channel collaboration.

1.2   Research Architecture

The present study can be split into four different scenarios which are shown in Table 1. The first dimension is whether WiFi and WiMAX services operate with bandwidth sharing or not. The WiMAX service provider can choose to offer the contract of bandwidth sharing or not. If the WiMAX operator does offer the contract, the WiFi service provider makes a take-it-or-leave-it decision. The other dimension is channel collaboration in which both wireless service providers can make their decisions independently or jointly.

Table 1. Research Architecture

		Bandwidth Sharing	
		No	Yes
Channel Collaboration	No	(I)	(II)
	Yes	(III)	(IV)

2   Literature Review

It is widely accepted that the Internet industry in the United States is a vertical structure which is composed of Internet Backbone Providers (IBPs) and Internet Service Providers (ISPs) (Shin et al, 2007). The relationship between IBPs and ISPs can be considered that of wholesalers and retailers and ISPs can independently pay IBPs a transit fee the for the Internet access. Recently, there are several emerging study focusing on the revenue and benefit in the integration of WiFi and WiMAX. Gunasekaran and Harmantzis (2006) propose a service model that uses WiFi and WiMAX to deliver cost-effective broadband services in which WiFi access points use WiMAX backhaul systems to lower infrastructure costs. Niyato et al. (2007) consider a single WiMAX base station with multiple connections from WiMAX customers and WiFi access points. In their setting, the WiMAX networks serve real-time traffic, while the WiFi networks serve best effort traffic. The authors show that the WiMAX service provider needs to increase the price charged to WiFi routers when the traffic arrival rate increases, in order to compensate for the loss in revenue due to the degraded QoS performance for customers using WiMAX services. Niyato et al. (2008) utilize two oligopolistic models for price competition among service providers in a heterogeneous wireless environment composed of WiMAX and WiFi access networks. Their research outcomes show that the WiMAX service provider can increase its offered price to gain a higher profit when the transmission quality becomes better. Maillé and Tuffin (2008) study a pricing game between two wireless access providers, one operating WiFi access and the other operating WiMAX access. Surprisingly, the authors find that the overall utility of the system is maximized at equilibrium. Ibrahim et al. (2009) provide tractable formulae of the end-user mean capacity and coverage probability in order to properly dimension the integration of WiFi and WiMAX. Ognenoski et al. (2008) consider that a single service provider runs two wireless networks, including WiFi and WiMAX, and show how the mean utility, total system utility, and revenue change for a backup network offering voice and file download services.

Our present study is different from extant researches by concentrating on the following dimensions. First, we rely on the aspect of customer perceptions to model user preference regarding transmission rate and coverage. Second, the WiFi and WiMAX service providers can make their pricing and service decisions independently or jointly. Third, we propose a wholesale price contract to solve the issue of bandwidth sharing between WiFi and WiMAX.

3   The Model

In this study, we are interested in a more general case when there are demand for both WiFi and WiMAX. We consider a wireless service zone in which there are two wireless service providers operating different wireless technology, WiFi and WiMAX. The number of customers in the market who want to purchase wireless services is denoted as h_0. To offer access services, a WiFi service provider has to deploy a number of access points to cover most of the areas in which customers usually hang out. An access point is also known as a wireless router or hotspot. Similarly, WiMAX signals are broadcasted by a WiMAX base station, which works exactly like GSM network phones towers standing high up in the air to broadcast radio signals. We use Figure 1 to demonstrate the difference between WiFi and WiMAX. Both service providers charge customers a service fee for offering access services and customers choose preferred access services based on their utilities. The price of WiFi service is denoted as p_F while the price of WiMAX service is denoted as p_M. All notations used in the present model can be found in Table 2.
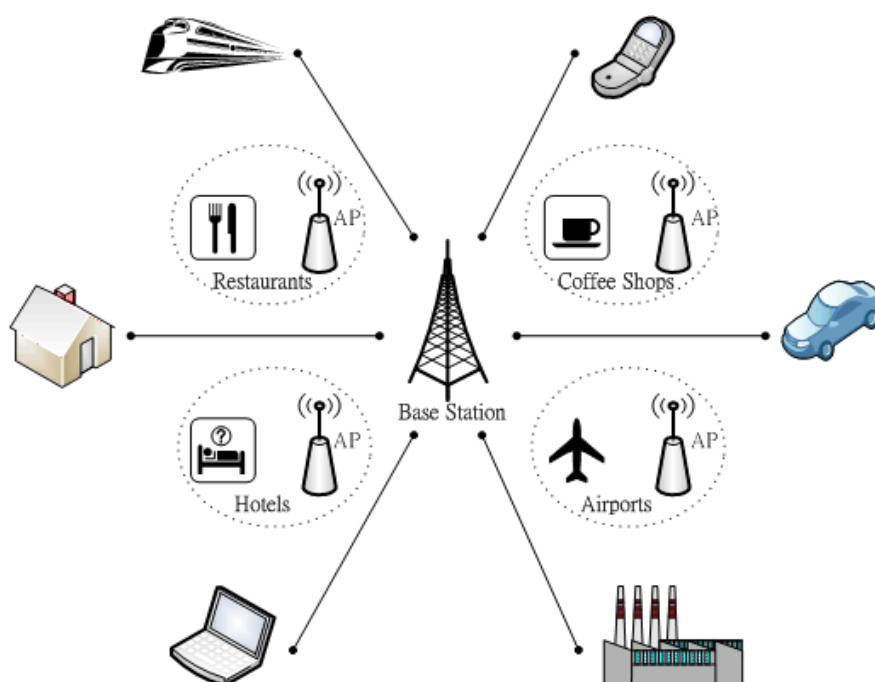

Figure 1. The comparison between WiFi network and WiMAX network

3.1   Channel Competition

A well-known characteristic of Internet industry is that the Internet access service is almost homogeneous (Shin et al., 2007). On the other hand, the main factors that influence user preferences of wireless network are transmission rate, coverage, and price (Yaiparoj et al., 2008). Thus, we assume that customers have homogeneous valuation of V for both access services and their preferences are decreasingly differentiated according to transmission rate and coverage. One of the most important differences between WiFi and WiMAX is that the maximal transmission distances a WiMAX base station and a WiFi wireless router can support are 9.6 KM and 90 meters long, respectively. Accordingly, in a certain geographical zone served by a WiMAX base station, if the number of access points deployed by a WiFi service provider is insufficient, customers would bear transportation cost for finding the nearest access points. The expected transportation cost resulted from finding the nearest access points is denoted as $c_a(n)$, where n is the number of access points, and $\partial c_a(n) / \partial n < 0$ and $\partial c_a(n) / \partial n^2 > 0$.

Table 2.   Definition of Notation

Notation	Description
p_F (p_M)	The price of WiFi servie (WiMAX service)
c_d (c_{ld})	The delay cost resulted from the transmission speed rate of WiFi service (WiMAX service)
n	The number of access points
$c_a(n)$	The transporation cost resulted from finding the nearest access points
V	The value of access services
θ	Customer's sensitivity to the inconveince cost resulted from coverage and transmssion rate
η_0	The number of customers who want to buy the wireless services
η_F (η_M)	The demand of WiFi service (WiMAX service)
U_F (U_M)	Customers' utilities when using WiFi service (WiMAX service)
c_F (c_M)	The service related cost of WiFi service (WiMAX service)
γ_F (γ_M)	The network realted cost of WiFi serivce (WiMAX service)
μ	The service rate of a WiMAX base station
K_M	The maringal capacity cost of a WiMAX base station
$\lambda(b)$	Customer's arrival rate (usage rate)
d	The threshold of average delay in WiMAX netowrks
W	The wholesale price per WiFi customer

As for transmission rate, although WiFi technology typically provides local network access for around a few hundred feet with speeds of up to 54 Mbps, the real transmission rate is limited to fixed backhaul. Because the cost of fixed backhaul is expensive, most of the WiFi access points, in practice, are connected to T1 lines (or other media with lower transmission rates) which have a transmission speed rate of 1.5 Mbps. On the other hand, WiFi and WiMAX adopt different channel access methods for shared medium networks. Because WiMAX technology operates in TDMA (Time Division Multiple Access), it can provide better QoS than WiFi technology operating in CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). With TDMA, WiMAX can serve real-time traffic for customers and guarantee its service level (i.e., the delay time), while most of the WiFi access points around the world, in general, only serve best effort traffic. The reason of serving best effort traffic is that customers may randomly enter and exit access points. Due to the characteristics of best effort traffic, the delay time customers suffered from WiFi technology is affected by many external factors, such as whether the access point is located at a prosperous and bustling area.

As compared to WiFi, because the WiMAX provider can deploy a singe WiMAX base station to serve customers at a wider range than WiFi, the cost of fixed backhaul can be reduced down; consequently, the WiMAX service provider can offer real-time traffic by connecting its base stations to high speed fixed backhaul, such as a T3 line which has a transmission speed rate of 44.736 Mbps. Therefore, in the present model, we consider that the WiFi service networks serve best effort traffic and the WiMAX service networks serve real-time traffic. As customer may expect to experience low-speed WiFi services and prior study have supported the aspect that a mobile Internet service will be mainly used for low bandwidth applications (Ooteghem 2009), we use c_d to estimate the delay cost of WiFi. The assumption is reasonable because nearly all WiFi service providers, such as T-Mobile and Boingo, have never mentioned the transmission rate in their web pages. The delay cost of WiMAX is denoted as c_{ld} for real-time traffic, where $c_{ld} < c_d$.

Because customers have heterogeneous sensitivity to the inconvenience cost resulted from short coverage and low transmission rate, we follow prior study (Chuna and Kim 2005; Fan et al. 2007−2008; Fan et al. 2009) to denote the inconvenience cost sensitivity as q , which is randomly

drawn from a uniform distribution with support on $[0,1]$. Customers choose the two access services based on price, coverage, transmission rate, and their own sensitivity to the inconvenience cost. A customer's utilities are $U_M(q) = V - p_M - qc_{ld}$ and $U_F(q) = V - p_F - q(c_a(n) + c_d)$ for using WiMAX service and WiFi service, respectively. Since the difference in transmission rate between WiMAX networks serving real-time traffic and WiFi networks serving best effort traffic is rather large, we may consider WiMAX technology a benchmark for mobile Internet services and normalize it as zero for simplicity. In fact, many businesses have regarded WiMAX technology as a standard-based technology that enables the delivery of "last mile" wireless broadband access (Gunasekaran and Harmantzis 2008). While the setting $c_{ld} = 0$ is mainly for analytical convenience, it can be applied to the case in which the difference in transmission rate between two access services is very significant.

A customer is indifferent between the two access services if $U_M = U_F$ holds. Solving the equation leads to $q^* = (p_M - p_F)/(c_a(n) + c_d)$, which is the indifferent point for customers. Therefore, the demands for the WiFi service and WiMAX service are $h_F = q^* h_0$ and $h_M = (1 - q^*)h_0$, respectively. According to the comprehensive study conducted by Ooteghem et al. (2009), operational expenditures for a wireless access network can be split between network related and service related costs. The service related cost is composed of service provisioning and customer relationship management (CRM), consisting of pricing & billing, helpdesk, and marketing. We denote c_F as the service related cost of WiFi service and c_M as the service related cost of WiMAX service. On the other hand, both access services have much difference in the network related cost, including operations, administration, and maintenance.

First, the network related cost of the WiFi service increases with the number of access points, while the one of the WiMAX service increases with the number of users as WiMAX networks serve real-time traffic. Second, because the WiMAX service uses licensed spectrum to deliver a point-to-point connection to the Internet, the WiMAX service provider has to pay a license fee to broadcast WiMAX signals. Third, according to the chosen media, such as T1 and T3, the costs of fixed backhaul are also different. Each access point, i.e., a wireless router, has to been connected with respective fixed backhaul to offer Internet connection. In addition, both service providers bear the cost for site rental which is the multiplication of the number of sites with the cost per site to rent (Ooteghem et al. 2009). Because WiFi networks serve best effort traffic, the total capacity cost is given by $n \cdot K_F$, where K_F is the capacity cost per access point. Therefore, the WiFi service provider's profit function π_F can be written as:

$$\pi_F = (p_F - c_F)\eta_F - n \cdot \gamma_F \tag{3.1}$$

where $\gamma_F = T1 + Rent_F + K_F$.

On the contrary, the WiMAX service provider needs to consider the queuing delay and the processing rate for access services. Here, following prior study, we use M/M/1 queue to formulate the average delay for a customer, which can be represented as $w = 1/(m - l)$ where m is the service rate and l is customer's arrival rate (Tan and Mookerjee 2005). Therefore, the total capacity cost of WiMAX can be represented by $K_M \cdot \mu$. In order to serve real-time traffic in WiMAX networks, the maximal average delay cannot be higher than a specific threshold d. Therefore, the WiMAX service provider's profit function π_M can be written as:

$$\pi_M = (p_M - c_M)\eta_M - (\gamma_M + K_M\mu)$$
$$s.t. \frac{1}{\mu - \lambda} \leq d \tag{3.2}$$

where $\gamma_M = T3 + Rent_M + Licence$.

Although the total number of customers subscribing the WiMAX service is η_M, at any time, only a portion of all the customers use the access service. Letting b be the average usage rate of all the customers, we have $\lambda = \beta\eta_M$. Furthermore, given arbitrary p_M, the WiMAX service provider can optimize its profit by choosing μ as follows.

$$\mu = \beta\eta_M + \frac{1}{d} \tag{3.3}$$

Proposition 1. **(Scenario I)** The capacity investment made by the WiMAX provider may increase in the usage rate; however, when the portion of all the customers using the WiMAX service at any time is too large, the WiMAX provider would reduce the capacity investment if capacity cost is expensive. Formally, $\partial\mu/\partial\beta > 0$ when $\beta < \beta^*$ and $\partial\mu/\partial\beta < 0$ when $\beta > \beta^*$, where β^* is given by

$$\beta^* = \left(2\left(c_a(n) + c_d\right) - c_M + c_F\right)\big/\left(2K_M\right). \tag{3.4}$$

When the usage rate becomes higher, it is intuitive that the WiMAX provider would provide more capacity to attain the delay guarantee. Nevertheless, when the average usage rate is too high, the capacity cost to guarantee service delay is so expensive that the WiMAX provider has incentive to reduce capacity and charge customers a higher service fee to decrease the demand of WiMAX service. In practice, WiMAX equipment is rather expensive and the total investment is even larger for a single WiMAX base station than for the high number of WiFi access points (Ooteghem et al. 2009). Thus, the government should take account of the possible outcome and compensate the WiMAX service provider to optimize the social welfare of wireless access services when the average usage rate becomes higher. The relationship between the average usage rate and processing capacity (WiMAX's price and demand) is shown in Figure 2. For convenience, all results are scaled but the qualitative results are unchanged.

3.2 Optimal WiFi Coverage

Subsequently, we consider the question of how a WiFi service provider decides the number of access points in a long-term competition. The game has two stages: (i) the WiFi service provider decides the number of access points; and (ii) both service providers simultaneously decide their prices. Because we have known the equilibrium prices, we can only solve the first stage of the game. Thus, the WiFi service provider's problem is

$$\underset{n}{Max}\ \pi_F = \left(p_F - c_F\right)\eta_F - n \cdot \gamma_F$$

$s.t.$

$$p_M(n) = Min\left\{\frac{2c_a(n) + 2c_d + 2c_M + 2\beta K_M + c_F}{3}, V\right\} \tag{3.5}$$

$$p_F(n) = Min\left\{\frac{c_a(n) + c_d + c_M + \beta K_M + 2c_F}{3}, \frac{V + c_F}{2}\right\}$$

Proposition 2. When the capacity cost of WiMAX is not too high and the difference between the two service related costs is not too large, the coverage investment made by the WiFi provider may decrease with customer's valuation of access services, but may increase with the service related costs, the delay cost of WiFi service, average usage rate, and the marginal capacity cost of WiMAX service. Formally, when $K_M < c_d$ and $c_M \approx c_F$, the optimal n is given by

$$c_a\left(n^*\right) = \frac{3V - 2\left(c_d + c_M + \beta K_M\right) - c_F}{2}, \text{ and}$$

(3.6)

we have $\partial n^*/\partial V < 0$, $\partial n^*/\partial c_M > 0$, $\partial n^*/\partial c_F > 0$, $\partial n^*/\partial c_d > 0$, $\partial n^*/\partial \beta > 0$, and $\partial n^*/\partial K_M > 0$.

Before the WiMAX provider enters the market, the WiFi service provider would provide rather high number of access points to satisfy customer requirements. Once the WiMAX service becomes mature, the best strategy for the WiFi service provider is to reduce the number of access points. When the transportation cost resulted from finding the nearest access point becomes higher, the WiMAX service provider can raise the price of its service so that the WiFi service provider can also does to enhance the profit. The strategy of reducing WiFi coverage works until the WiMAX service provider raises its service price up to customer's valuation of access services. Thus, the optimal number of access points would decrease with customer's valuation of access services, but increase with the other system parameters mentioned in Proposition 2.
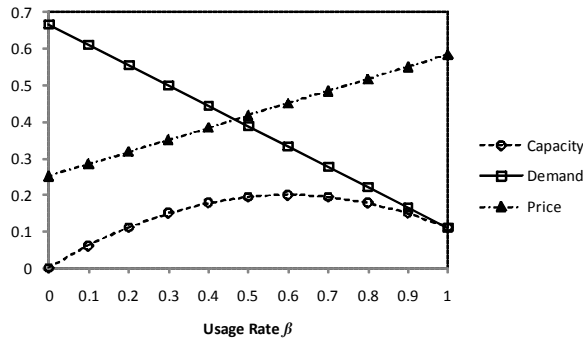

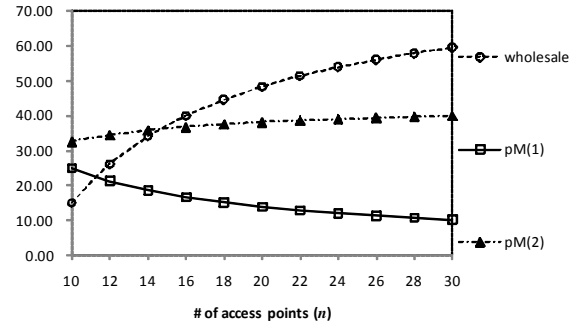**Figure 2.** The relationship between usage rate and processing capacity (WiMAX's price and demand)

Figure 3. The relationship between # of access points and wholesale price (WiMAX's profit)

4   Bandwidth Sharing

Currently, there is much technology study focusing on the development of integration of WiFi and WiMAX. In the section, we consider the business model in which the WiMAX service provider sells extra bandwidth to the WiFi service provider by providing wireless backhaul support and then the WiFi service provider can save the cost of wired infrastructure. The WiMAX service provider may charge the WiFi service provider a wholesale price w per WiFi demand. Thus, the WiFi service provider's problem can be rewritten as

$$\underset{p_F}{Max}\ \pi_{FI} = \left(p_F - c_F - \omega\right)\eta_F - n \cdot \gamma_{FI}$$

(4.1)

where $\gamma_{FI} = Rent_F + K_F$

On the other hand, the WiMAX service provider can receive the revenue of bandwidth sharing from the WiFi service provider. In the case, in addition to all customers who subscribe the WiMAX service, the WiMAX base station also serves real-time traffic for each WiFi access points to provide wireless backhaul support instead of wired backhaul support like T1. The WiMAX service provider's problem can be rewritten as

$$\underset{p_M}{Max}\ \pi_{MI} = \left(p_M - c_M\right)\eta_M - \left(\gamma_M + K_M\mu\right) + \omega \cdot \eta_F$$

$$s.t.\ \frac{1}{\mu - \lambda} \le d$$

(4.2)

In addition to the usage rate derived from the customers who subscribe the WiMAX service, the customer' arrive rate of a WiMAX base station has to involve the expected number of access points requesting Internet connection, which is given by

$$H\left(n,\beta\eta_F\right)=n\left\{1-\left(1-\frac{1}{n}\right)^{\beta\cdot\eta_F}\right\} \tag{4.3}$$

When the number of customers in the market is sufficiently large, we can directly approximate $H\left(n,\beta\eta_F\right)$ as the number of access points. Thus, given arbitrary p_M, the WiMAX service provider would maximize its profit by choosing capacity as

$$\mu=\beta\eta_M+n+\frac{1}{d} \tag{4.4}$$

By the same approach mentioned in Proposition 1, we can have $p_M^*\left(\omega\right)$ and $p_F^*\left(\omega\right)$. As a result, the problem of choosing an optimal wholesale price is given by

$$\underset{\omega}{Max}\ \pi_{MI}$$

$$s.t.$$

$$\pi_{FI}\geq\pi_F \tag{4.5}$$

$$p_M^*\left(\omega\right)=Min\left\{\frac{2\left(c_a\left(n\right)+c_d+c_M+\beta K_M\right)+3\omega+c_F}{3},V\right\}$$

$$p_F^*\left(\omega\right)=Min\left\{\frac{\left(c_a\left(n\right)+c_d+c_M+\beta K_M\right)+3\omega+2c_F}{3},\frac{V+c_F+\omega}{2}\right\}$$

Proposition 3. (Scenario II)

The optimal wholesale price charged by the WiMAX service provider may decrease with the usage rate. Formally, 順$\omega^*/$ $b<0$.

When one service provider raises its price, the other would also adopt the same pricing strategy until customers cannot afford to to pay such a high price. As a result, when the wholesale price is not too large, the WiFi service provider can always raise its price to offset the loss resulted from the wholesale price charged by the WiMAX service provider. Accordingly, the situation of bandwidth sharing would hurt consumers and lead to higher prices. Examining the profit of the WiFi service provider, we find the business model of integration cannot benefit the WiFi service provider in most of cases. The case of $\pi_{FI}>\pi_F$ only arises when the usage rate is between a specific range of two close values and the cost of T1 is very expensive; thus, in the following, we examine the relation between WiFi coverage and the wholesale price when $\pi_{FI}=\pi_F$ holds.

Corollary 1. In general case, the WiMAX service provider would raise the wholesale price when the number of access points increases. Formally, $\partial\omega^*/\partial n>0$ when $\pi_{FI}=\pi_F$.

A scaled numeral example is shown in Figure 3 where the WiMAX profit without bandwidth sharing and with bandwidth sharing are denoted as $\pi_M\left(1\right)$ and $\pi_M\left(2\right)$, respectively. Without bandwidth sharing, we find that the WiMAX service provider's profit may decrease with WiFi coverage; however, its profit may increase with WiFi coverage when the WiMAX base station serves as the wireless backhaul for the access points in WiFi networks.

5   Channel Collaboration

Subsequently, we consider the scenario in which both service providers can reach an agreement to collaborate in the wireless service market and split the collaborating profit. The channel collaboration problem without bandwidth sharing can be formulated as follows.

$$\pi_{M+F} = \left(p_M - c_M \right)\eta_M + \left(p_F - c_F \right)\eta_F - \left(\gamma_M + K_M \mu \right) - n \cdot \gamma_F$$

$$s.t. \frac{1}{\mu - \lambda} \leq d \tag{5.1}$$

, where μ is given by (3.3). The channel collaboration problem with bandwidth sharing can be derived from (4.6) by replacing γ_F with γ_{FI} and considering μ from (4.4).

Proposition 4. (Scenario III and IV)

1. Without bandwidth sharing, the WiMAX capacity in channel collaboration is more than that in channel competition.

2. If channel collaboration with bandwidth sharing is more (less) profitable than that without bandwidth sharing, the optimal coverage of the WiFi service in the former setup is higher (lower) than that in the latter setup.

Because the demand of the WiMAX service in channel collaboration is higher than that in channel competition, the WiMAX service provider has to raise the amount of capacity to fit the requirement of real-time traffic. In addition, in channel collaboration, whether the WiMAX base station should share bandwidth for the access points in WiFi networks would depend on the saved cost of T1 and the marginal cost of the WiMAX capacity. When the saved cost of T1 is higher than the marginal cost of the WiMAX capacity, bandwidth sharing benefits channel collaboration; thus, the WiFi service provider can increase the number of access points to raise the collaborating profit in the case.

6   Conclusion

In the present research, we consider a wireless service zone in which there are two wireless service providers operating different technology, WiFi and WiMAX. The aim of the study is to examine the impact of the integration of WiFi and WiMAX on wireless operators' service strategies. Several emerging study has focused on the pricing issue of bandwidth sharing between WiFi and WiMAX networks; however, most of them either concentrate on the design of collaborated protocols or figure out the issue without the consideration of customer preference. Comparing with prior study, the present study applies a wholesale price contract to solve the issue of bandwidth sharing; thus, our analytical results based on the aspect of enterprise operations can serve as an important reference for the current wireless operators.

In the future research, we would relax the normalized assumption of the delay cost of WiMAX networks and consider it the function of the average gauranteed delay. Consquently, the WiMAX servie provider can change the tranmssion rate of real-time traffic to optimize its profit. In addtion, we would consider the impact of bargaining power on the wireless operators' service straetgies. In the present study, since the WiMAX service provider holds the bargaing power so that the WiFi service provider cannot gain substatinanl benefit from bandwidth sharing. We plan to examine how the bagaining power held by the wirelss operators affects their service strtegies.

References

Ballon, P. (2007). Changing business models for Europe's mobile telecommunications industry: The impact of alternative wireless technologies. Telematics and Informatics, 24 (3), 192−205.

Chun, S.-H., Kim J.-C. (2005). Pricing strategies in B2C electronic commerce: analytical and empirical approaches. Decision Support Systems, 40 (2), 375–388.

Fan, M., Kumar, S, Whinston A.B. (2007−2008). Selling or Advertising: Strategies for Providing Digital Media Online. Journal of Management Information Systems, 24 (3), 143–166.

Fan, M., Kumar, S, Whinston A.B. (2009). Short-term and long-term competition between providers of shrink-wrap software and software as a service. European Journal of Operational Research, 196 (2), 661–671.

Fantacci, R., Tarchi D. (2006). Bridging Solutions for a Heterogeneous WiMAX-WiFi Scenario. Journal of Communications and Networks, 8 (4), 1−9.

Gunasekaran, V., Harmantzis, F. (2006). Financial Assessment of Citywide Wi-Fi/WiMAX Deployment. Communications & Strategies, 63, 1-23.

Gunasekaran, V., Harmantzis, F.C. (2008). Towards a Wi-Fi ecosystem: Technology integration and emerging service models. Telecommunications Policy, 32 (3–4), 163–181.

Huang, C.-J., Hu, K.W., Chen, I.F., Chen, Y.J., and Chen, H.X. (2010). An Intelligent Resource Management Scheme for Heterogeneous WiFi and WiMAX Multi-Hop Relay Networks. Expert Systems with Applications 37 (2) 1134−1142.

Ibrahim, M. Khawam, K., Samhat, A.E., Tohme, S. (2009). Analytical framework for dimensioning hierarchical WiMax-WiFi networks. Computer Networks, 53 (3), 299−309.

Lawson, S. (2008). Sprint's WiMax shines on price, not on coverage. ITworld, http://www.itworld.com/mobile-amp-wireless/55497/sprints-wimax-shines-price-not-coverage

Lin, H.-T., Lin, Y.-Y., Chang, W.-R., Cheng, R.-S. (2009). An Integrated WiMAX/WiFi Architecture with QoS Consistency over Broadband Wireless Networks, IEEE Consumer Communications & Networking Conference (CCNC'09), 10−13.

Maillé, P., Tuffin, B. (2008). Price war in heterogeneous wireless networks (submitted), http://www.irisa.fr/dionysos/pages_perso/tuffin/Publis/PM-BT-heterogeneous.pdf

Myslewski, R. (2009). Sprint preps 15-city WiMAX roll-out. The Register. http://www.theregister.co.uk/2009/03/26/sprint_wimax/

Niyato, D., Hossain, E. (2007). Integration of WiMAX and WiFi: Optimal Pricing for Bandwidth Sharing. IEEE Communications Magazine, 45 (5), 140−146.

Niyato, D., Hossain, E. (2008). Integration of WiMAX and WiFi: Competitive Pricing in Heterogeneous Wireless Access Networks: Issues and Approaches. IEEE Network, 22 (6), 4−11.

Ognenoski, O., Rakovic, V., Bogatinovski, M., Atanasovski, V., Gavrilovska, L. (2009). User Perception of QoS and Economics for a WiMAX Network in a Backup Scenario. Wireless VITAE'09.

Ooteghem, J.V., Lannoo, B., Casier, K., Verbrugge, S., Tanghe, E., Joseph, W., Martens, L., Colle, D., Pickavet, M., Moerman, Ingrid., Demeester, Piet. (2009). Municipalities as a Driver for Wireless Broadband Access. Wireless Personal Communications, 49 (3), 391−414.

Reardon, M. (2007). Sprint's WiMax dilemma. CNET News. http://news.cnet.com/Sprints-WiMax-dilemma/2100-1039_3-6212618.html

Shin, S.-J., Weiss, M.B., Tucci, J. (2007). Rural Internet access: over-subscription strategies, regulation and equilibrium. Managerial and Decision Economics, 28 (1), 1−12.

Tan, Y., Mookerjee, V.S. (2005). Allocating spending between advertising and information technology in electronic retailing. Management Science 51 (8), 1236−1249.

Yaiparoj, S., Harmantzis, F., Gunasekaran, V. (2008). On the economics of GPRS networks with Wi-Fi integration. European Journal of Operational Research, 187 (3), 1