行政院國家科學委員會專題研究計畫 期中進度報告

下一代多層級多媒體應用服務匯流網路--子計畫三:兼顧服務品質與可重新組態的下一代服務匯流網路架構(2/3)

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行政院國家科學委員會專題研究計劃成果報告

下一代多層級多媒體應用服務匯流網路-子計畫三：兼顧服務品質與可重新組態的下一代服務匯流網路架構(2/3)

Next Generation Service Convergence Network Architecture with QoS and Re-configuration Capability

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一、摘要

為滿足多種跨專屬頻譜及免執照頻譜的行動網路及固定無線網路服務的匯流服務，以及對服務品質敏感的網路電話及視訊需求，我們提出了兩種架構，分別允許不同電信業者服務之間可以共享部分頻譜或頻寬。以使該網路架構達到足以支援服務品質敏感之服務，以及快速之頻譜/頻寬共享之功能。

在此計畫第二年中，我們已先完成多細胞頻譜共享架構之演算法設計，同時另提出一利用動態規劃演算法之頻寬共享機制。後者並以模擬分析驗證其效能。我們完成之網路模擬工具，已可用於整合實驗未來的服務匯流實驗平台。

關鍵詞：服務匯流，服務品質，無線網路

To cope with the fast emerging service convergence environment among many different cellular services, and fixed wireless services across licensed and unlicensed bands, and the rapid growth of QoS sensitive applications such as network video/TV and VoIP, we propose a service-convergence network architecture in which different operators' services can share the wireless access spectrum and its backbone bandwidth, so that the whole network architecture can support QoS sensitive services and fast spectrum /bandwidth sharing.

In the second year of this project, we have completed the algorithm design of a multi-cell spectrum sharing architecture. In addition, a bandwidth sharing mechanism using dynamic programming algorithm is proposed and evaluated with simulation results. We have implemented a network simulation tool for integration experiment of future service convergence platform.

Keyword: Service convergence, Qos, Wireless Network

二、計畫背景與目的

In traditional cellular wireless networks, spectrums are allocated in advance and are always fixed. Such usage of the wireless spectrum can be inflexible and wasteful. Therefore, we propose an architecture to take advantage of the idea of spectrum sharing. In this architecture, two or more network operators provide a portion of their frequency bands as the shared band. The frequency blocks in the shared band are then dynamically allocated to the operators according to their demands. If the traffic patterns of different networks are complementary, it should be beneficial to share the spectrum.

The concept of mobile virtual network operator (MVNO) arose during the planning and roll-out phase of 3G networks for the purpose of cost saving[1]. Sharing the wireless network has been analyzed to be a long-term beneficial strategy for the network operators[2]. There is a trend that network sharing will play an important role not only in the cellular but also in the broadband wireless access networks[3]. Therefore, we propose an architecture in which multiple MVNOs share the wireless bandwidth of a facility based operator called the Wireless Bandwidth Provider (WBP). By estimating the expected income from each MVNO, the WBP runs a dynamic programming algorithm to compute the optimal bandwidth allocations and achieve higher total revenue.

三、多細胞頻譜共享系統架構與演算法

In this section, an architecture for sharing spectrum between two wireless network operators and the algorithms for each component are presented.

3.1 System Architecture

We assume that there are two cellular

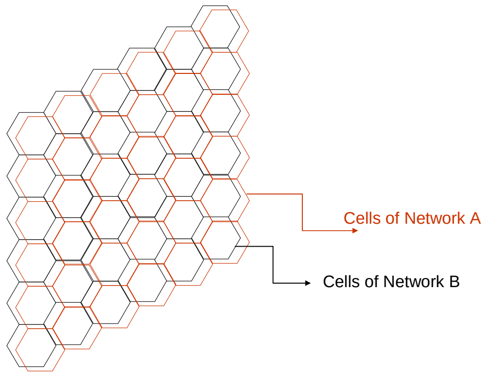

Fig. 1. Overlapping cell layouts of two wireless network operators.

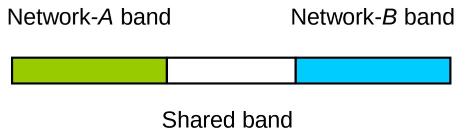

Fig. 2. Shared spectrum diagram.

network operators *A* and *B* located in the same region and the cell layouts of them are the same (Fig. 1). The spectrum is separated into three parts. Network-*A* band and Network-*B* band are dedicated to these two operators respectively, and the shared band can be allocated dynamically to one of them (Fig. 2).

Under the assumptions, we propose an architecture (Fig. 3) for the two wireless network operators to share the spectrum dynamically. There are three main components in the system: the Base Station Radio Resource Manager (*BS_RRM*), the *Broker*, and the *Arbiter*. In each cell, there is one *BS_RRM* for each operator. The function of the *BS_RRM*s is to predict the expected traffic pattern of the next period using historical data and report the least amount of frequency blocks required for maintaining the call blocking probability under certain predefined threshold. Each

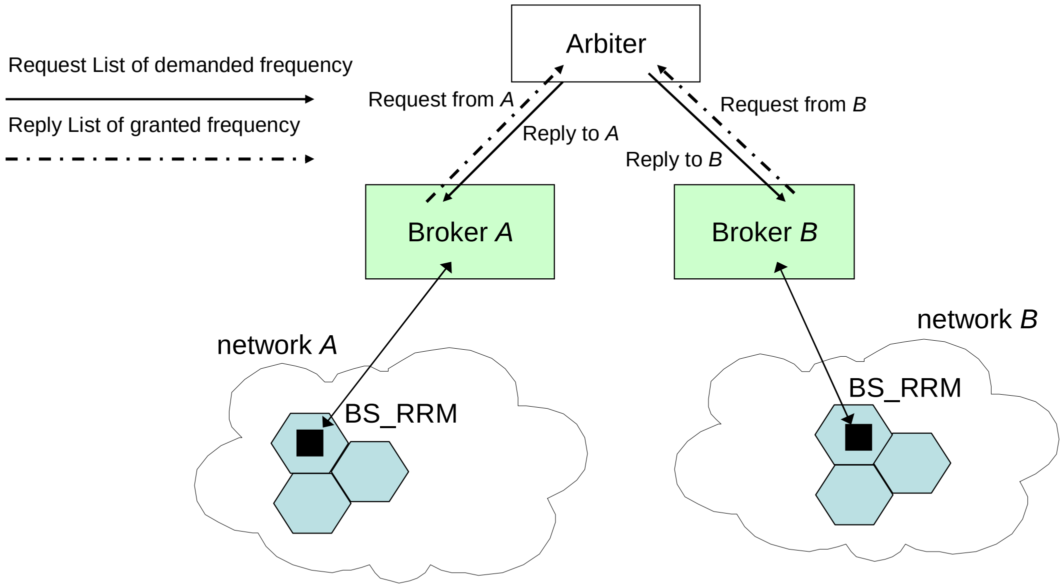

Fig. 3. System architecture for spectrum sharing between two networks.

network operator has its own *Broker* which allocates frequency blocks in its own band to the cells according to the demands reported by the *BS_RRM*s. If the demands can not be satisfied by its dedicated band, the *Broker* is also responsible for acquiring frequency blocks in the shared band by sending requests to the *Arbiter*. The *Arbiter* dynamically allocates frequency blocks in the shared band according to these requests.

In the following subsection, we describe the algorithms for each component.

3.2 *BS_RRM*

BS_RRM needs to record the traffic pattern continuously and predict the spectrum amount needed in the next period. More precisely, *BS_RRM* estimates the expected spectrum amount $\underline{N_i^m}(t)$, upon the expected traffic loads $\underline{\lambda_i^m}(t)$. In each BS, we assume there is enough computational and storage resource. In each cell, we adopt the assumption that the arrival is Poisson process. Given a threshold of call blocking probability, we can compute the minimum number of channels the network need.

Given the threshold of call blocking probability *Th(t)*, *BS_RRM* need to provide *Broker* a suitable expected amount of required frequency blocks, $N_i(t)$. Again, the traffic arrival is a Poisson process and the service duration is exponentially distributed. After estimating the traffic rate $\overline{\lambda_i^m}(t)$, *BS_RRM* figures out the minimum number of frequency blocks satisfying the call blocking probability constraints. We assume that if *h* frequency blocks are enough, *BS_RRM* will not ask for more than *h* frequency blocks. That is, $N_i(t) = \min\{n \mid P_B^{M/M/C/C}(n \cdot M, \lambda_i(t)) < Th(t)\}$ where $P_B^{M/M/C/C}(K, \lambda)$ is the call blocking probability of an M/M/C/C queue, where λ is the arrival rate and *K* is the number of channels.

3.3 The *Broker*

For a single wireless network *m*, at the beginning of each period *t*, the *Broker* of knows all $N_i^m(t)$, the expected spectrum amount in cell *i*, from each BS_RRM. Given all $N_i^m(t)$, *Broker* applies spectrum allocation algorithm to efficiently use the spectrum resource. At first, we assume all shared frequencies are available, and apply spectrum allocation algorithm to assign the frequency blocks in both $\mathcal{F}$*_m* and $\mathcal{F}$*_shared*, where $\mathcal{F}$*_m* is the set of frequency blocks dedicated to network *m*, and $\mathcal{F}$*_shared* is the set of shared frequency blocks. The objective of the *Broker* is to meet the demands and use as few frequencies in $\mathcal{F}$*_shared* as possible.

Broker could make plans of the allocation of the shared spectrum and send the plan to the *Arbiter* to request for the shared spectrum. If a demand element in cell *i* have been denied, *Broker* knows that there have been no available shared frequencies in the cell *i*, thus, in the next round, *Broker* will not ask for shared frequencies in the cell *i*.

The spectrum allocation algorithm can be written as an integer programming problem. It has been shown to be an N-P complete problem [4]. Therefore, instead of finding the optimal solution, we propose a greedy algorithm to get an approximate solution which is good enough and time-efficient. The greedy degree of each cell is a function of the number of available frequencies and the number of unsatisfied demands in this cell. More precisely, the degree is the difference between the number of available frequencies and unsatisfied demand plus a random number.

Assume in a cell there are *p* available frequencies and need *q* frequencies. The number of possible allocations is C(*p*,*q*), that is, the number of possible combination of n elements chosen from m elements. It is good to choose the cell with fewest possible allocations. But to calculate C(*p*,*q*) cost much time as m, n are big, thus, we use (*p*-*q*) instead because it is much more easily to compute (*p*-*q*) than to compute C(*p*,*q*).

The cells are sorted according to the degrees of cells in a non-decreasing order. If the degrees of several cells are the same, the order of them is random. The randomness make the solution more diversified. The order is dynamically changed because every time a vertex is colored, the degree of some vertices may changes.

Every time the cell has been selected, we choose the smallest available frequency. Here, we introduce the concept of compact allocation pattern [5]. A compact pattern is the set of cells which can use the same frequency. Here, the cluster size is three, thus, we have three different compact patterns. Every time a cell is assigned a frequency, for each cell belongs to the same compact pattern, if the cell has unsatisfied demand, we will assign the color to it, too. In other words, instead of assigning a frequency to a cell at one time, we assign a frequency to a set of cells.

Additionally, while a cell has no available frequency to use, we perform the

m : network index, $m=A,B$

$Weight(m)$: weight of network m

D^m: list_of_demanded_frequency of network m.

S_m: the number of shared frequencies which have been assigned to network m.

R_m: the number of remaining demanded frequencies of network m.

x: the current cell in which a demand will be determined

Y_{ik}^S : indicator of the k-th shared frequency assignment in cell i.

```
Centralized_Spectrum_Allocation_Algorithm (D^A, D^B) {
    while (Not both D^A and D^B are empty) {
        Weight(A) ← α · S_B+(1-α) · R_A
        Weight(B) ← α · S_A+(1-α) · R_B
        Find the network m with maximum weight Weight(m);
        if (D^m != NULL)
            Remove the first element from D^m;
        x← the value of this element;
        if (there is no available shared frequency in cell x)
            Insert an element with value (–x) into G^m;
        else
            Find available frequency k, where k= min{ k'| Y^S_ik' ==0 };
        Insert an element with value x into G^m;
        Y^S_ik ←m ;
    }
}
```

Fig. 4. The centralized shared band allocation algorithm of the *Arbiter*.

backtracking and return to nearest cell in which a frequency is just assigned and assign the cell with an alternative available frequency[6]. We apply backtracking in order to reduce the probability of finding no feasible solutions because the selection rule (according to the degrees) and assignment rule (smallest frequency to the compact pattern) are fixed, if the rules are not so suitable, we will not be able to find any feasible solution. However, in order to reduce the running time of the algorithm, we set constraints on the number of backtrackings the algorithm performed. For example, for each assignment, backtracking can be performed at most k times.

3.4 The *Arbiter*

At the time to reallocate the spectrum, (we set the time points in advanced, for example, trigger the dynamic spectrum allocation mechanism periodically, and we call the period between spectrum allocation as spectrum allocation period), *Arbiter* receive the list of demanded frequencies $D^m(t,j)$ from the *Broker*s if they have any requests.

After receiving $D^m(t,j)$'s from all the *Broker*s, the *Arbiter* applies the centralized spectrum allocation algorithm (Fig. 4), and

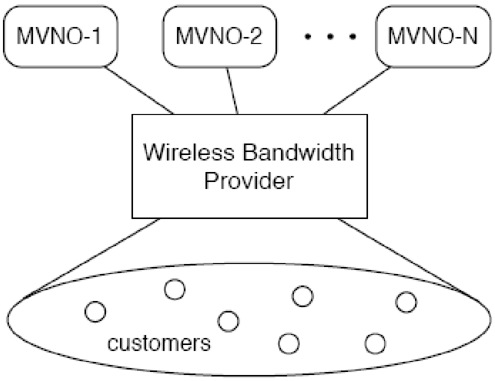

Fig. 5. A shared wireless data network model.

return a list of granted frequencies $G^m(t,,r)$ to the *Broker*s respectively.

四、頻寬共享系統之架構與分析

In this section, we propose a generic model for multiple MVNOs to share the bandwidth of a single provider. In addition, we also derive the formulas of the dynamic programming algorithm for the bandwidth provider to maximize its total revenue.

4.1 System Model

In our model (Fig. 5), there are N MVNOs and one wireless bandwidth provider (WBP). The WBP owns the core network and wireless access facilities such as 3G/3.5G base stations, WiMAX base stations, or Wi-Fi access points. It acts as a bridge between the customers and the MVNOs. The N MVNOs provide different sorts of services to the customers via the connection service of the WBP. The MVNOs are in charge of the service provisioning and customer management without operating a physical network.

The WBP charges for the connection service in a usage-based fashion. In order to maximize its total revenue, the WBP can

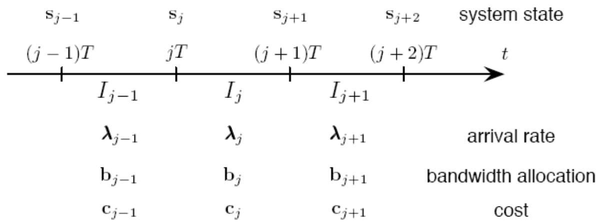

Fig. 6. Timing diagram for bandwidth allocation.

adjust the bandwidth allocations to each MVNO every interval T. Changes of the allocations can only happen on time epochs jT, j = 1, 2,…, and the setting should keep unchanged in the following interval, which is denoted by I_j (see Fig. 6). The allocation decisions are based on the traffic patterns and the service contracts of the MVNOs. The traffic patterns of the customers can be supplied by the MVNOs or estimated by WBP according to previous measurements.

We assume that the customer arrival processes of the MVNOs are all Poisson but the arrival rates could change across different intervals. The arrival rates during I_j are denoted by $\boldsymbol{\lambda}_j = [\lambda_{j1}, \lambda_{j2}, \ldots, \lambda_{jN}]$. The service time distributions are assumed general but do not change with time. $B_i(t)$ denotes the CDF of the service time of MVNO-i and $1/\mu_i$ is its average service time. $\mathbf{s}_j = [s_{j1}, s_{j2}, \ldots, s_{jN}]$ denotes the system state at the beginning of interval I_j and s_{ji} is the number of customers in MVNO-i at jT. The cost vector which WBP charges the MVNOs per customer per second can also vary across time intervals and is denoted by $\mathbf{c}_j = [c_{j1}, c_{j1}, \ldots, c_{jN}]$.

The bandwidth allocation during I_j is $\mathbf{b}_j = [b_{j1}, b_{j1}, \ldots, b_{jN}]$ and the total bandwidth W of the WBP should not be exceeded, i.e. $\sum_{i=1}^{N} b_{ji} \le W, \forall j$. Once the WBP determines

$\mathbf{b}_j$ at jT, it enforces new upper bounds to the number of customers of the MVNOs. This mechanism might incur some dropping of the customers. In compensation, the WBP should pay d_i to MVNO-i for each customer dropping event.

4.2 Estimate of the Income

According to the system model, we could model the behavior of each MVNO with an *M/G/c/c* queue with variable arrival rate. However, it is difficult to derive the transcient distribution of the number of customers in an *M/G/c/c* queue as the arrival rate changes. Therefore, in order to estimate the income of MVNO-i during interval I_j, we first derive the transcient behavior of an *M/G/∞* system. Afterwards, we truncate the probability mass function (PMF) of the *M/G/∞* queue so that its maximum system size equals the capacity limit of the MVNO, and use the result as an approximate transcient distribution of the *M/G/c/c* queue.

We assume that $X_{ji}(t)$ is the number of MVNO-i's customers who entered the system during $(jT, jT+t]$ and are still in the system at $jT+t$, and $Y_{ji}(t)$ is the number of MVNO-i's customers who were in the system at jT and remain in the system at $jT+t$. Consequently, we have $X_{ji}(0) = 0$ and $Y_{ji}(0) = s_{ji}$. For $t > 0$, $X_{ji}(t)$ and $Y_{ji}(t)$ are random variables. According to [7], it can be shown that the conditional probability of $X_{ji}(t) = n$ given arrival rate λ_{ji}, denoted as $f_{ji}(n,t; \lambda_{ji})$, would be

$$f_{ji}(n,t;\lambda_{ji}) = \Pr\left\{X_{ji}(t) = n \middle| arrival = \lambda_{ji}\right\} = \frac{\left(\lambda_{ji} q_i(t)\right)^n \exp\left\{-\lambda_{ji} q_i(t)\right\}}{n!}$$

and the conditional probability of $Y_{ji}(t) = n$ given $Y_{ji}(0) = s_{ji}$, denoted as $g_{ji}(n, t; s_{ji})$, is

$$g_{ji}(n,t;s_{ji}) = \Pr\left\{Y_{ji}(t) = n \middle| Y_{ji}(0) = s_{ji}\right\} = \binom{s_{ji}}{n}\left(1 - r_i(t)\right)^n r_i(t)^{s_{ji}-n}$$

, where $q_i(t) = \int_0^t \left[1 - B_i(x)\right] dx$ and $r_i(t) = \mu_i q_i(t)$. In fact, $r_i(t)$ is the *residual time distribution* for the MVNO-i's customers.

Let $Z_{ji}(t) = X_{ji}(t) + Y_{ji}(t)$ be the total number of customers of MVNO-i in system at time $jT+t$, and $h_{ji}(n, t; s_{ji}, \lambda_{ji})$ denote the conditional probability that $Z_{ji}(t) = n$ given s_{ji} and λ_{ji}. Hence,

$$h_{ji}(n,t;s_{ji},\lambda_{ji}) = \Pr\left\{Z_{ji}(t) = n \middle| s_{ji},\lambda_{ji}\right\} = \sum_{m=0}^{n} f_{ji}(m,t;\lambda_{ji}) g_{ji}(n-m,t;s_{ji})$$

Note that the equation above is derived under the assumption that the system size can grow without bound. Assume that the bandwidth allocated to MVNO-i is only b_{ji} during the j-th interval and the corresponding maximum number of customers is $v_i(b_{ji})$. We must truncate the PMF to approximate the distribution of the system size in the *M/G/c/c* queue. As a result, the probability that $Z_{ji}(t) = n$ given s_{ji}, λ_{ji}, and b_{ji}, denoted as $y_{ji}(n, t; s_{ji}, \lambda_{ji}, b_{ji})$, can be approximated as

$$y_{ji}(n,t;s_{ji},\lambda_{ji},b_{ji}) = \Pr\left\{ Z_{ji}(t) = n \middle| s_{ji},\lambda_{ji},b_{ji} \right\}$$
$$\approx \frac{h_{ji}(n,t;s_{ji},\lambda_{ji})}{\sum_{l=0}^{v_i(b_{ji})} h_{ji}(l,t;s_{ji},\lambda_{ji})}$$
$$n = 0,1,\ldots,v_i(b_{ji})$$

The expected total usage of MVNO-i's customers during I_j, denoted as U_{ji}, given the initial system size s_{ji}, the arrival rate λ_{ji} and the bandwidth limit b_{ji} should be

$$U_{ji}(s_{ji},\lambda_{ji},b_{ji}) = \int_0^T E\left[Z_{ji}(t) \middle| s_{ji},\lambda_{ji},b_{ji} \right] dt$$

However, there is no closed form formula to carry out this integration. We compute the income estimation numerically with the following equation instead.

$$G_{ji}(s_{ji}\lambda_{ji},b_{ji}) = c_{ji}\tau \sum_{k=1}^{K} E\left[Z_{ji}(t) \middle| s_{ji},\lambda_{ji},b_{ji} \right]$$
$$= c_{ji}\tau \sum_{k=1}^{K} \sum_{n=1}^{v_i(b_{ji})} n \cdot y_{ji}(n,k\tau;s_{ji}\lambda_{ji},b_{ji})$$

, where $\tau = T/K$, and K is an integer. The value of τ affects both the estimation accuracy and the amount of computation required. There is a trade-off in choosing the value. If τ is too small, it will lead to higher computation complexity. On the opposite, if τ is too large, there will be accuracy issues.

4.3 The Optimality Equation

Maximizing the total returns in the previously described model is a positive dynamic programming problem[8]. According to the derivation in the previous subsection, the expected total return from all MVNOs during interval I_j given the state $\mathbf{s}_j$, the arrival rate $\boldsymbol{\lambda}_j$, and the bandwidth allocation $\mathbf{b}_j$ (i.e. the *action* taken) can be expressed as

$$R_j(\mathbf{s}_j,\boldsymbol{\lambda}_j,\mathbf{b}_j) = G_j(\mathbf{s}_j,\boldsymbol{\lambda}_j,\mathbf{b}_j) - L_j(\mathbf{s}_j,\mathbf{b}_j)$$
$$G_j(\mathbf{s}_j,\boldsymbol{\lambda}_j,\mathbf{b}_j) = \sum_{i=1}^{N} G_{ji}(s_{ji}\lambda_{ji},b_{ji})$$
$$L_j(\mathbf{s}_j,\mathbf{b}_j) = \sum_{i=1}^{N} d_i \left[s_{ji} - v_i(b_{ji}) \right]^+$$

The operation $[x]^+$ equals x if $x>0$ and 0 otherwise. We can also obtain the transition probability from state $\mathbf{s}_j$ to $\mathbf{s}_{j+1}$ as

$$P(\mathbf{s}_j,\mathbf{s}_{j+1}) = \Pr\left\{ \mathbf{Z}_j(T) = \mathbf{s}_{j+1} \middle| \mathbf{s}_j,\boldsymbol{\lambda}_j,\mathbf{b}_j \right\}$$
$$= \prod_{i=1}^{N} y_{ji}(s_{j+1,i},T;s_{ji},\lambda_{ji},b_{ji}).$$

Thus, the optimality equation is

$$V_j(\mathbf{s}_j,\boldsymbol{\lambda}_j) = \max_{\mathbf{b}_j}\left\{ R_j(\mathbf{s}_j,\boldsymbol{\lambda}_j,\mathbf{b}_j) + \sum_{\mathbf{s}_{j+1}} P(\mathbf{s}_j,\mathbf{s}_{j+1}) V_{j+1}(\mathbf{s}_{j+1},\boldsymbol{\lambda}_{j+1}) \right\}$$

and the optimal policy $\mathbf{b}_j^*$ is the bandwidth allocation which makes $V_j(\mathbf{s}_j, \boldsymbol{\lambda}_j)$ maximal.

Let M_i denote the maximum number of customers of MVNO-i when the highest level of bandwidth is allocated to it. The size of the state space is approximately $O(\prod_{i=1}^{N} M_i)$. If the number of MVNOs (N) is small, the computational complexity of the optimality equation will be mainly on computing the expected revenue R_j. Therefore, the overall complexity is $O\left(C_b K (\prod_{i=1}^{N} M_i)(\sum_{i=1}^{N} M_i^3)\right)$ where C_b is the number of possible bandwidth allocations.

Note that one can incorporate as many stages of recursion as possible when computing the optimal allocation. However, the solution would converge after extending to certain number of stages. Since the computing process of the DPA is actually backward, it is important to decide the

	MVNO-1(VoIP)		MVNO-2(IPTV)	
	regular	discount	regular	discount
Time period	8:00 ~ 23:00	23:00 ~ 8:00	18:00 ~ 24:00	24:00 ~ 18:00
Usage cost	0.005	0.0015	0.07	0.035
Drop penalty	25.0		40.0	

Table I. Usage-based prices per customer per second.

number of stages in advance to avoid the waste of computing power. There are more discussions on this issue in next subsection.

4.4 Performance Evaluation

We evaluate the effectiveness of the proposed DPA with C++ coded simulations. There are two MVNOs in the simulated scenario. MVNO-1 is a VoIP operator and MVNO-2 is an IPTV operator. We also assume the WBP operates a WiMAX based wireless access network.

4.4.1 Parameter Settings

The total MAC layer bandwidths provided by one single BS are set to be 9Mbps and 6Mbps for downlink and uplink respectively. According to [9], these amounts of bandwidth can be achieved via either a 5 or 10 MHz channel if efficient modulation and coding schemes are adopted.

We assume that the VoIP system adopts the G.711 codec and thus each direction of a voice call requires 80Kbps of bandwidth at MAC layer. The distribution of the call duration is exponential with mean = 100 seconds. The bandwidth requirement for a downlink IPTV stream is assumed to be 768Kbps and the service

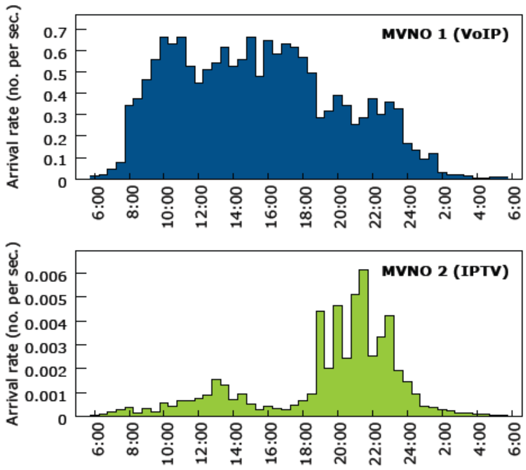

Fig. 7. Arrival patterns adopted in the simulation.

time distribution is exponential with mean = 2500 seconds.

Fig. 7 shows the arrival rate patterns for a 24-hour period and Table I gives the costs and the dropping penalties of each MVNO. The pricing policy together with the traffic pattern affects the expected revenue from each MVNO and thus the allocation strategy of the WBP. Therefore, it is possible that an MVNO can demand more bandwidth by accepting higher costs. However, we adopt only fixed pricing policy in this paper in order to put more emphasis on the performance of DPA. The usage costs and drop penalties should be negotiated by the WBP and the MVNOs in the beginning. Further research of the dynamic pricing mechanisms will be our future work.

The bandwidth allocation takes 1Mbps as the basic unit and the minimum allocated bandwidth for both MVNOs is also set to be 1Mbps. However, because of the bandwidth asymmetry, the upper bound of the number of VoIP customers is determined by the uplink bandwidth. Thus, the maximum bandwidth for MVNO-1 is 6Mbps. The

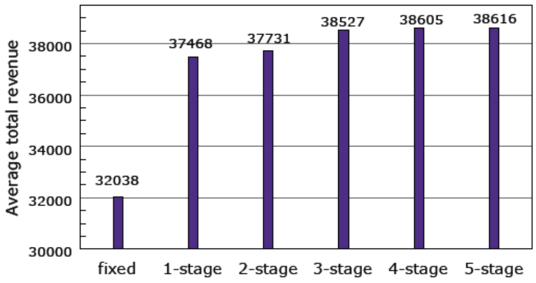

Fig. 8. Comparison of the average total revenues obtained under different stages of dynamic programming, using default parameters.

computation of the DPA for each possible system state should be completed before the start of each interval. Then the WBP decides which bandwidth allocation (action) to take according to the actual system state at the start of the interval and the computed results.

Based on these parameter settings, maximum number of customers of the two MVNOs are 75 and 10 respectively, and the size of the state space is 508. The number of possible bandwidth allocations (C_b) is 6.

During simulation, the length of each interval T is set to be 30 minutes, i.e. the WBP runs DPA and decides the optimal action every 30 minutes. The value of τ is set to be 10 seconds, i.e. K = 180. The number of dynamic programming stages affects both the effectiveness and the amount of computations of the proposed algorithm. We ran simulations for 1 to 5 stages and compare the results with the fixed bandwidth allocation scenario (in which 4.5Mbps allocated for both MVNO-1 and MVNO-2).

We ran 20 repetitions of the simulations, each lasting for a 24-hour period, and took the average of the results.

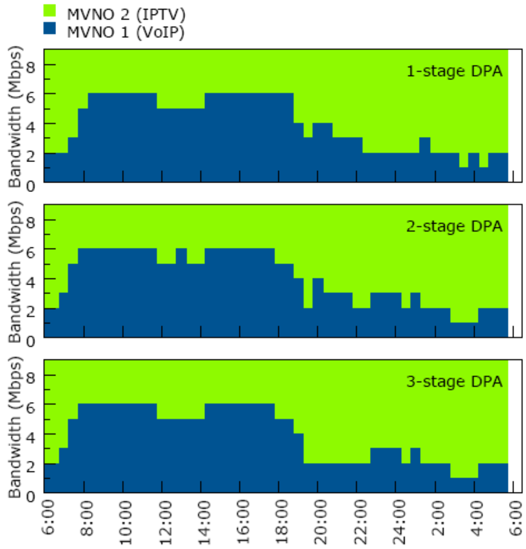

Fig. 9. Bandwidth allocation decisions generated by 1, 2 and 3-stage DPA.

4.4.2 Simulation Results

Fig. 8 compares the total revenues achieved by adopting the fixed allocation scheme or DPA with different number of stages. The improvements of the DPA are around 14.5% to 20.5%. As the number of stages increases, the gain of the total revenue gradually saturates just as expected.

Fig. 9 gives an example of the resulting bandwidth allocations via computing different number of stages in DPA. We find that the results of 4 and 5-stage DPA are very close to the 3-stage DPA in most simulation repetitions under the default parameter settings. Hence, only the plots of 1 to 3-stage DPA bandwidth allocations are shown in Fig. 9. This example shows that one can get “smoother'” bandwidth allocations, i.e. there are less bandwidth fluctuations, if more stages are incorporated in the DPA. In addition, since the average service time of IPTV customers is longer than the length of a single stage, DPA with 3 or more stages can predict the

	fixed	1-stage	2-stage	3-stage	4-stage	5-stage
MVNO-1	0.086	0.037	0.057	0.069	0.071	0.071
MVNO-2	0.343	0.230	0.198	0.170	0.169	0.168

Table II. Blocking probabilities with default parameters.

behavior of them well and allocate more resources to MVNO-2. On the other hand, the results in the first two plots do not allocate as sufficient bandwidth to MVNO-2 during the peak of its arrival pattern.

The blocking probabilities under different stages of DPA are shown in Table II. Obviously, all DPA results outperform the fixed allocation scheme. As the number of stages increases, the blocking probabilities of IPTV customers decrease while those of the VoIP customers increase. This is because the optimalty equation considers only the total revenue. It is possible to add some QoS constraints, such as the minimum blocking probability, in the service level agreements between WBP and MVNOs, and thus the optimality equations should be revised to reflect the change in the model.

In order to examine the relationship between the number of stages and the average service time, we ran another set of simulations with the average connection duration of the IPTV customer doubled (i.e. mean = 5000 sec.). Accordingly, the arrival rates are halved to maintain the same traffic loads. Fig. 10 is the resulting average total revenues. Notice that the total revenues are higher while the traffic loads are kept the same. This is because that the blocking rate of IPTV customers decreases as the arrival

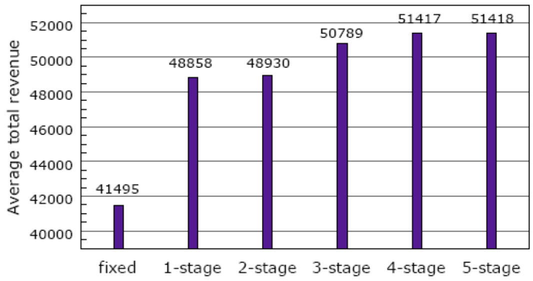

Fig. 10. Comparison of the average total revenue results with doubled IPTV customer service time and halved arrival rates.

rate gets smaller. Therefore, the increase in revenue mainly comes from MVNO-2.

The revenue improvements vary from 17.7% to 23.9% in the second set of simulations. Furthermore, unlike the previous case, the improvement of total revenue saturates after incorporating 4 stages instead of 3 stages. It shows that more stages are required if the probability that a connection duration might span several stages increases. However, the number of stages required to attain saturation not only depends on the average service time but also the service time distribution. It is yet to be shown either via mathematical derivation or more extensive simulations.

Last but not least, using a Xeon 2.8GHz CPU with 1GB RAM, the execution time of the DPA is found to require only about 42 seconds per stage, which implies that such approach can be employed in real operations.

五、結論與展望

We have presented two models for sharing the wireless spectrum or bandwidth. In the spectrum sharing case, we proposed the algorithms for computing the multi-cell frequency allocations that satisfy the blocking probability requirements of both network operators.

In the bandwidth sharing case, we proposed a dynamic programming algorithm together with the estimation formulas of the system behavior to determine the optimized bandwidth allocations for the wireless bandwidth provider. According to the simulation results, we have found that by computing the optimal allocation considering both the possible income and loss across several stages, DPA can achieve quite significant improvements in the average total revenue.

In future work, spectrum trading mechanisms will be incorporated in the multi-cell spectrum sharing model and the algorithms will be evaluated by simulations. For the bandwidth sharing model, auction based dynamic pricing of the bandwidth and therefore the strategies of the MVNOs can be further incorporated. In addition, it is also possible that more than one WBPs coexist in the same area, and the competition among different WBPs can introduce high complexity in deciding the strategies in this market. It should be easy to develope other models and various resource allocaiton algorithms based on the works presented in this report.

六、參考文獻

[1] G. Beckman and G. Smith, “Shared networks: making wireless communication affordable,” *IEEE Wireless Communications*, vol. 12, no. 2, pp. 78-85, April 2005.

[2] A. Bartlett and N. N. Jackson, “Network planning considerations for network sharing in UMTS,” in *Proc. IEEE Third International Conference on 3G Mobile Communication Technologies*, May 2002, pp. 17-21.

[3] B. T. Olsen, D. Katsianis, D. Varoutas, K. Stordahl, J. Harno, N. K. Elnegaard, I. Welling, f. Loizillon, T. Monath, and P. Cadro, “Technoeconomic evaluation of the major telecommunication investment options for European players,” *IEEE Network*, vol. 20, no. 4, pp. 6-15, July/August 2006.

[4] W. K. Hale, “Frequency assignment: theory and applications,” *Proceeding of the IEEE*, vol.68, no.12, December 1980.

[5] M. Zhang and T. P. Yum, “The nonuniform compact pattern allocation algorithm for cellular mobile systems,” *IEEE Transaction on Vehicular Technology*, vol.40, no.2, May 1991.

[6] W. Klotz, “Graph coloring algorithms,” *Technical Report Mathematik-Bericht 2002/5*, TU Clausthal, 2002.

[7] D. Gross and C. M. Harris, *Fundamentals of Queueing Theory*, 3rd ed. John Wiley & Sons, Inc., 1998.

[8] S. Ross, *Introduction to Stochastic Dynamic Programming.* Academic Press, Inc., 1983.

[9] WiMAX Forum, “Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation,” August 2006.