行政院國家科學委員會專題研究計畫成果報告

計劃名稱: 以高速網路提供視訊點播服務系統之研究:以非同步傳輸模式網路提供視訊點播之允入控制研究(三)

The Study of Video-On-Demand Services over High-Speed Networks: Admission Control of VOD Services over ATM Networks (III)

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計劃主持人: 林永松副教授 yslin@im.ntu.edu.tw
執行機構：國立台灣大學資訊管理系

英文摘要

In this project, the ATM network design problem with reliability constraints in support for the Video-On-Demand service is considered. The problem is formulated as a combinatorial optimization problem where the objective function is to minimize the ATM network construction cost subject principally the reliability constraints. The basic approach to the algorithm development is Lagrangean relaxation. An efficient and effective algorithm is then proposed.

計畫緣由與目的

國家資訊通信基本建設(National Information Infrastructure, NII)**之推廣將使使用者得以享受各種多媒體服務。在諸多服務中，尤以視訊點播**(Video-On-Demand, VOD)**因具有極高的市場潛力而備受矚目。各先進國家均將其列為先導性推廣服務項目，並全力投入相關科技及關鍵性零組件(例如視訊伺服器**(video server)**之研發)。**

NII **之基本傳輸硬體架構包括骨幹網路** (backbone networks) **及社區網路** (community networks)**兩部份。由於非同步傳輸模式**(Asynchronous Transfer Mode, ATM)**具寬頻及整合性服務等諸多優點，各國(包括我國)均選定其為骨幹網路之傳輸技術。由於**ATM**具有資料延遲及漏失之特性，而視訊點播亦有其獨特而嚴格之服務品質**(Quality-Of-Service, QOS)**要求，因此若欲由**ATM**網路提供視訊點播服務，**ATM **對於服務品質所造成之效應必須謹慎加以研究及評量。**

本三年期子計劃之前兩年乃就資訊服務提供者之觀點分別探討下列諸議題：

（一）在資訊服務提供者及網路服務提供者互異之狀況下，資訊服務提供者如何有效地決定視訊伺服器之允入控制並與網路提供者商議最廉價的網路服務品質要求，以期提高系統之流通量(throughput)、**降低營運成本並確保客戶服務品質之要求。本議題亦可由另一觀點加以敘述：在給定之**ATM**網路服務品質下，決定視訊點播服務之允入控制。**

（二）在資訊及網路服務提供者為一共同經營體之狀況下，更可進一步藉由路由(routing)**控制以期更加提高系統之流通量及利潤。本子計劃乃研究一最佳化**(optimal)**整合性單點**(single-destination)**及多點**(multi-destination)**路由策略，同時亦將考慮一最佳化永久型虛擬線路**(Permanent Virtual Connection, PVC)**路由策略。**

而本第三年子計畫之目的乃在與（二）相同前提下，考慮ATM網路規劃與設計相關問題。我們將提出一個新的數學規劃問題與解題程序，在ATM網路規劃中加入網路可靠度的需求限制，以確保使用者對一個網路系統的O-D pairs間傳輸可靠度需求(reliability requirement)被滿足，這個最佳化數學模式不但可幫助規劃高可靠度的ATM網路，更進一步能優化視訊點播服務系統的效能及利潤。

結果與討論

本問題的目的在於規劃一個 ATM 網路，其能確保使用者所選擇傳輸的每對 O-D pair 之間的網路可靠度 (reliability) 能達到事先給定之水準，亦即設計一個保證使用者對網路可靠度之需求能被滿足的 ATM 網路，作為適合提供隨選視迅服務的平台。

針對傳輸網路可靠度的問題，本研究所採行的解決方略是透過 O-D pair 間傳輸路徑的路由決策與數目的共同配合，來確保此O-D pair間的網路連通率(connectivity)可滿足使用者對可靠度的要求。換言之，我們提供一個端對端之間連通 (connected) 的網路環境，使得系統在某些路徑中發生問題時仍能藉著其他仍保持連通狀態的路徑繼續傳輸。

1.問題數學模式化

對於每個 O-D pair 之間的傳輸網路而言，存在著可靠度與建置成本之間的一種 trade-off；倘若我們在 O-D pair 間建立越多條的傳輸路徑，網路連通性便越高，而相對的此 O-D pair 間的網路建置成本也越高。為求得最佳化的系統建置成本與網路可靠度的組合，我們將此網路以圖形 $G(V,L)$ 表示，其中 V 是交換節點的集合，L 是所有可行之 link 的集合。假設網路中每個 link 的出錯率 (failure probability) 與 O-D pair 間所有可行路徑 (candidate path) 的集合皆為已知，且此系統必須事先輸入可靠度需求 (reliability requirements)，則我們可將問題以下一節中之數學模式表示。

2.數學符號（Notation）

2.1 已知參數 (given parameters):

- ª W: 此網路中 OD pair w 的集合, $w\in W$
- ª L: 此網路中 link l 的集合, $l\in L$
- ª a_l: 建置 link l 所需成本
- ª δ_{pl}: 選擇 path p 上的 link l 與否的指標函數, 1 if path p uses link $l\in L$, 0 otherwise
- ª F_w: reliability requirement of O-D pair w
- ª f_l: failure probability of link l

2.2 決策變數 (decision variables) :

- ª y_l: 選擇 link l 與否的決策變數, 1 if choose link $l\in L$, 0 otherwise
- ª k_w: number of disjoint paths planned for O-D pair $w\in W$

3.問題數學式

$$\min \sum_{l\in L} a_l y_l \qquad \text{(IP)}$$

s.t.:

$$(1)\quad \sum_{p\in P_w} ¢_{pl} x_p \le y_l \qquad \forall w\in W, l\in L$$

$$(2)\quad y_l = 0 \ or 1 \qquad \forall l\in L$$

$$(3)\quad \sum_{p\in P_w} x_p = k_w \qquad \forall w\in W$$

$$(4)\quad x_p = 0 \ or \ 1 \qquad \forall p\in P_w, w\in W$$

$$(5)\quad \sum_{l\in L}\sum_{p\in P_w} ¢_{pl} x_p f_l \le k_w \sqrt[k_w]{F_w} \qquad \forall w\in W$$

$$(6)\quad \sum_{p\in P_w} ¢_{pl} x_p \le 1 \qquad \forall w\in W, l\in L$$

$$(7)\quad k_w \in \text{int} \qquad \forall w\in W.$$

本問題之目標函數目的在於決定 O-D pair

間的網路傳輸路徑，使建置成本最小化。Constraint (1)是就 O-D pair $w\in W$中的每一條 path 其上的每個 link *l*Č*L* 而言，其被選擇使用的次數必須不超過一次，配合 Constraint (2)的 link 整數限制來看，每個 link 只能被 O-D pair 中的 path $p\in P_w$使用零或一次, 此二式之物理意義代表 O-D pair w 中的傳輸路徑$p\in P_w$是獨立的(disjoint)，即不會有兩條路徑使用同一 link 的情況。Constraint (3)將每對 O-D pair w之間的路徑加總成為k條 disjoint paths, Constraint (4)表示了 O-D pair 間每條可行路徑的整數限制，同時每對 O-D pair 間所選擇傳輸的 k_w 條 disjoint paths 整數限制表示於 Constraint (7)。Constraint (5)的左式代表系統每個 link 皆出錯的機率，根據算數平均數≧幾何平均數的定理使得 Constraint (5)之左式≧右式[1]，將 Constraints (3), (4), (5), (6) and (7)合在一起，可確保系統可靠度達到使用者需要之水準 F_w。Constraint (6)則是為解題方便而存在之 redundant variable。由數學式的結構我們可知本問題除卻整數條件限制則具有 simple and convex 之數學特性。

4. Solution Procedure:

基本上我們採用一種稱為拉格蘭式鬆弛法 (Lagrangean relaxation)的演算法發展方式。首先我們 dualize Constraints (1) and (5) 再經過移項可得下列兩個 Lagrangean relaxation problems :

$$Z_{LR1}(u)=\min(\sum_{l\in L}a_l-\sum_{w\in W}u_{wl})\,y_l$$

s.t.: (2).

$$Z_{LR2}(u,v)=\min\sum_{w\in W}\sum_{p\in P_w}\sum_{l\in L}(u_{wl}+v_w f_l)\,\text{¢}_{pl}\,x_p$$

s.t.: (3), (4) ,(6) and (7).

根據 Lagrangean duality theorem，Lagrangean Relaxation 的目標函數最佳值是原問題(IP)的下限(lower bound)，我們想找到下限中的最大值，因此可將問題化為下式：

$$\max_{u,v\ge 0}(Z_{LR1}(u)+Z_{LR2}(u,v)-\sum_{w\in W}v_w k_w\sqrt[k_w]{F_w})$$

於是我們可以採用一種常用的逼近法—subgradient method 來解此 dual problem。在第 k 次的 subgradient 最佳化推演過程中，multiplier 向量 $m^k=(u^k_{wl},v^k_w)$ 將以下列形式被修改

$$m^{k+1}=m^k+\sim^k\quad{}^k$$

上式中 ^{k}為 a subgradient and step size $\sim^k$ 以下列算式求得

$$\sim^k=\text{¢}\frac{Z^h_{IP}-Z_{LR}(m^k)}{\left\|\quad{}^k\right\|^2}$$

其中 Z^h_{IP} 是以 heuristic 解法求得之(IP)目標函數值，$Z_{LR}=Z_{LR1}+Z_{LR2}$，且¢為介於 0 與 2 之間的常數。

基本上我們採用 Lagrangean relaxation problem 中求得的解來找 primal feasible solutions，如果這組 routing assignment 與 path 數目能滿足原始問題中的可靠度需求限制，則求得我們需要的 primal feasible solution，若這組解不 feasible，我們必須應用其他 heuristic 來修正，一種方法是將這些不 feasible 的 path 照 failure probability 排

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[1] According to Constraint (3), there will exist at least k_w paths for O-D pair w, where $1\le i\le k_w$. The proof is complete by Properties 1, 2 below and Constraint (5).

Property 1: Exact failure probability of O-D pair w is no greater than $\prod_{i=1}^{k_w}\sum_{m\in l_{iw}}f_m$.

Property 2: $\sqrt[k_w]{\prod_{i=1}^{k_w}\sum_{m\in l_{iw}}f_m}\le(\sum_{i=1}^{k_w}\sum_{m\in l_{iw}}f_m)/k_w$.

序，依序由最大者加入一些 link 使該 path 的可靠度增加，倘若這種作法仍不能求得 primal feasible solution，最後可以在 O-D pair w 之間直接採用 min. cost flow 的演算法, 以各個 link 的 failure probability f_l 為 cost 來求出問題的最佳解。

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