A Network Selection Mechanism for Next Generation Networks

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***Abstract*–The predominant objective of next-generation networks (i.e. 4G) is to support high bandwidth with high mobility. 3G technologies provide low bandwidth at a cellular level, and Wireless Local Area Network (WLAN) supports much higher bandwidth at a local level. The two types of technologies will be seamlessly integrated in 4G networks. In this paper, we present an efficient network selection mechanism for next-generation networks to guarantee mobile users being always best connected (ABC). Two mathematical techniques are combined in the mechanism to decide the optimum network for mobile users through finding the tradeoff among user's preference, service application, and network condition.**

Keywords-4G networks; network selection; quality of service

I. INTRODUCTION

One primary characteristic of next-generation communication systems (i.e. 4G) will be a composite communication model, where various access systems such as cellular, satellite, Wireless Local Area Network (WLAN) and even wired networks will be combined to provide an optimum service at any time from any where. One of the popular heterogeneous systems discussed in recent literature is the integration of the WLAN and cellular 3G systems. Cellular networks such as General Packet Radio Service (GPRS), Universal Mobile Telecommunication System (UMTS), and cdma2000 support low bandwidth over a wide geographical area. While WLAN, based on IEEE 802.11 and HiperLAN/2 standards, can provide relatively high bandwidth (up to 54 Mbps) in a small coverage of a few thousand square meters around a single access point. As a result, the integration of the WLAN and cellular systems can efficiently achieve the required capacity and QoS level. In a heterogeneous system, a dynamical network selection mechanism has to be developed to decide an appropriate radio access technology for a specific service.

Three main types of network selection methods have been proposed for the heterogeneous systems. In the traditional methods such as [1], only the radio signal strength (RSS) threshold and hysteresis values are considered and processed in a fuzzy logic based algorithm. However, with a vision of multi-network environment and universal access, the traditional algorithm is not sufficient to make a handoff decision, as they do not take into account the current context or user's preference. When more handoff decision factors are considered, a number of two-dimension cost functions such as [2], are developed. In one dimension, the function reflects the types of services requested by the user, while in the second dimension, it represents the cost to the network according to specific parameters. [3] optimizes the cost function-based algorithm by separating cost function factors into three different categories: QoS factors, weighting factors, and network priority factors. QoS factors are defined based on the user- and network-specific requirements. The weight factors reflect the dominances of the particular requirements with respect to the user. The network priority factors present the abilities of the networks that fulfill the requirements. In this paper, we propose a network selection mechanism that belongs to the last type of method.

In order to assure required QoS for various applications and meanwhile avoid frequent handoffs in the heterogeneous systems, we integrates the analytic hierarchy process (AHP) and the grey relational analysis (GRA) into the network selection algorithm to decide the best network for mobile users. AHP [4] is a mathematical-based technology to analyze complex problems and assist in finding the best solution by synthesizing all deciding factors. AHP has already been applied to a number of areas, such as predicting economic outcomes [5] and resolving conflicts [6]. GRA was introduced in [7] to analyze the relational grade for several discrete sequences and select the best sequence. The technique is largely adopted in project selection [8] and factor effect evaluation [9].

In this paper, keeping mobile users always best connected (ABC) [10] is considered as design goal, and QoS characteristics in matter of user's preference, service application and network condition are adopted as decision factors. AHP is responsible to derive the weights of QoS parameters based on user's preference and service application. GRA takes charge of ranking the network alternatives through faster and simpler calculations. UMTS and WLAN are considered as network alternatives in this paper.

The rest of this paper is organized as follows. Section II and Section III introduce AHP and GRA, respectively. Section IV presents the proposed network selection algorithm. Section V contains some simulation results conducted in a simple topology. Section VI presents the conclusions and further research.

II. ANALITIC HIERARCHY PROCESS

AHP is a means of decomposing a complicated problem into a hierarchy of simpler and more manageable subproblems. These subproblems are usually called decision factors and weighted according to their relative dominances to the problem. The bottom decision factors are actually the solution

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alternatives. AHP selects the solution alternative with the largest synthesized weight. AHP performs following four main steps: decomposition, pairwise comparison, local weight calculation, and weight synthesis.

Structuring a problem as a hierarchy of multiple criteria is the first step of implementing AHP. The decision factors of the problem are identified and inserted into the hierarchy. The overall objective is placed at the topmost node of the hierarchy. The subsequent nodes present the decision factors. The solution alternatives are located at the bottom nodes. For instance, John is trying to make a selection among three new houses A, B, and C. His preferences are location, price and space. The hierarchy on "choosing a house" is established as shown in Fig. 1.

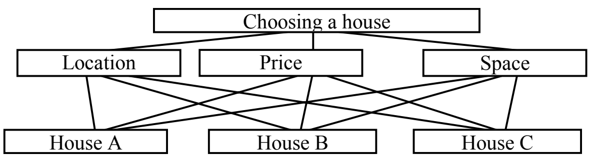

Fig. 1. An example of AHP hierarchy establishment.

The second step is the evaluation stage where each factor is compared to all other factors within the same parent. The comparison results within each parent are presented in a square matrix, as shown in Fig. 2. The pairwise comparisons are finished through answering the question "Which of the two is more important?" and, second, "By how much?" A fundamental 1 to 9 scale is used in AHP to allow the decision maker to express the strength of preference based on his intuition, experience, and knowledge. The numbers from 1 to 9 are used to respectively present equally, weakly moderately, moderately, moderately plus, strongly, strongly plus, very strongly, very very strongly, and extremely important to the objective. The smaller one in a pair is chosen as a unit and the larger one is estimated as a multiple of that unit and assigned a number based on the perceived intensity of importance. Similarly, the reciprocals of these numbers are used to show the inverted comparison results. We thus obtain a reciprocal matrix where the entries are symmetric with respect to the diagonal.

For a reciprocal $n \times n$ matrix $\mathbf{M}$, there exits an eigenvalue equation $\mathbf{MV} = x\mathbf{V}$, where $\mathbf{V}$ is non-zero vector called eigenvector, and x is a scalar called eigenvalue. $\mathbf{V}$ and x appear as a pair and cannot be taken apart. When $\mathbf{M}$ is consistent, it can be easily deduced that $m_{ij} = m_{ik} m_{kj}$ ($i, j, k = 1,2,\ldots n$). Since each element in the AHP matrix is the ratio of the weight of one decision factor to another with respect to their parents, we can denote $\mathbf{M}$ as

$$\mathbf{M} = \begin{bmatrix} m_{11} & m_{12} & \cdots & m_{1n} \\ m_{21} & m_{22} & \cdots & m_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ m_{n1} & m_{n2} & \cdots & m_{nn} \end{bmatrix} = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \tag{1}$$

where w_i is the weights of the decision factors and n is the number of decision factors. If all w_i is constructed into a weight matrix $(\mathbf{W})^T=[w_1\ w_2\ \ldots\ w_n]$, $\mathbf{MW}=n\mathbf{W}$ can be proved to be true. Thus, the weight vector equals $\mathbf{V}$ and the number of elements becomes the corresponding x. As a result, the weights of the decision factors can be achieved by calculating the eigenvector of AHP matrix and the eigenvalue that approximately equals the number of assessed elements [6].

However, people's assessments are not entirely consistent. The judgment errors can be detected by calculating a consistency index (CI).

$$CI = (x_{\max} - n)/(n-1) \tag{2}$$

where x_{max} is the eigenvalue. This CI is then divided by a random index (RI), which is the average CI of a randomly generated reciprocal matrix as described in Table I [6]. CI/RI is called the consistency ratio (CR). [6] suggests that judgment errors are tolerable if $CR \le 10\%$.

In the last step, the overall weights of the factors are achieved by computing the product of the local weights from each level.

III. Grey Relational Analysis

GRA is an effective method to analyze the relationship grade for discrete sequences. One of the sequences is defined as reference sequence presenting the idea situation. The grey relationship between the reference sequence and other sequences can be achieved by calculating grey relational coefficient (GRC) according to the level of similarity and variability. The sequence with the largest GRC is the most desirable one. GRA is usually implemented following three steps: normalizing data, defining the ideal sequence, and computing GRC [7].

	Location	Price	Space
Location	1	1/2	3
Price	2	1	6
Space	1/3	1/6	1

Fig. 2. An example of an AHP matrix.

TABLE I
Random Index

Dimension	1	2	3	4	5	6	7	8	9	10	11	…
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	…

Given n sequences (X_1, $X_2\ldots$, X_n) are compared, and each sequence has k elements, i.e., $X_i = (x_i(1), x_i(2), \ldots x_i(k))$ where i = 1, 2... n. The normalization of the sequence data is performed according to three situations (larger-the-better, smaller-the-better, and nominal-the-best) as follows:

$$x_i^*(j) = \frac{x_i(j) - l_j}{u_j - l_j} \tag{3}$$

$$x_i^*(j) = \frac{u_j - x_i(j)}{u_j - l_j} \tag{4}$$

$$x_i^*(j) = 1 - \frac{|x_i(j) - m_j|}{\max\{u_j - m_j, m_j - l_j\}} \tag{5}$$

where $u_j = \max\{x_1(j), x_2(j), \ldots x_n(j)\}$,

$l_j = \min\{x_1(j), x_2(j), \ldots x_n(j)\}$, m_j is the target value in the situation of nominal-the-best, and $j = 1, 2, \ldots k$. The ideal sequence (X_0) is defined to contain the upper bound, lower bound, or moderate bound respectively in larger-the-better, smaller-the-better or nominal-the-better situations. The GRC can be then calculated as following:

$$GRC_i = \frac{1}{m} \sum_{j=1}^{m} \frac{\Delta_{\min} + \Delta_{\max}}{\Delta_i + \Delta_{\max}} \tag{6}$$

where $\Delta_i = \left| x_0^*(j) - x_i^*(j) \right|$, $\Delta_{\max} = \max_{(i,\, j)}(\Delta_i)$ and $\Delta_{\min} = \min_{(i,\, j)}(\Delta_i)$, where $\max_{(i,\, j)}(\ )$ ($\min_{(i,\, j)}(\ )$)is the function of computing the maximum (minimum) value of a set of numbers varying with i and j, which are independent. The larger the GRC, the more preferable the sequence will be.

available network alternatives, which are located in the bottom level of the hierarchy.

The network selection mechanism is divided into three main logical function blocks: collecting data, processing data and making decision, as shown in Fig. 3. It is noted that the availability of WLAN has to be detected before collecting data because WLAN usually has relatively small coverage. If RSS from the WLAN is stale enough for communications service and the user would not leave WLAN soon, the network selection mechanism begins to collect other QoS parameters. If either of the requirements fails to be fulfilled, UMTS is directly selected through assigning the GRCs of the network alternatives.

Two types of data (user's preferences and network conditions) in the matter of QoS parameters are collected. User-based data are processed by AHP to derive the global weights (**GW**) of second-level factors and local weights (**LW1**,

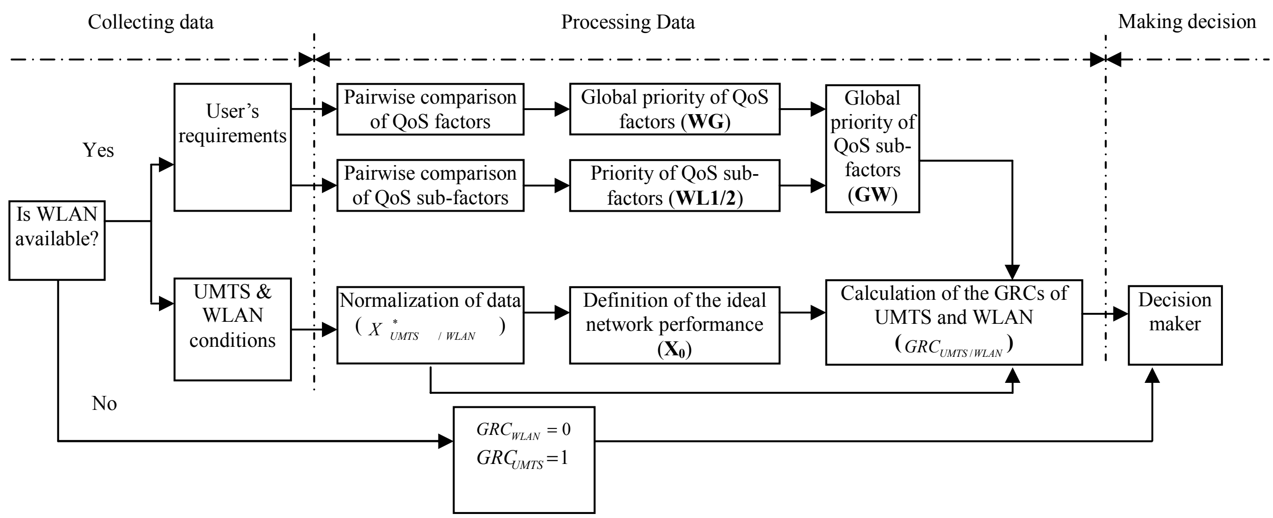

Fig. 3. AHP and GRA based network selection model.

IV. Network Selection Scheme Using AHP and GRA

In this section, we define the network selection decision factors and present how AHP and GRA cooperate to determine the best available network for the user.

For the purpose of supporting best possible QoS, we consider as many QoS factors as possible. The factors are constructed into an AHP hierarchy based on their relationships. QoS is placed in the topmost level of the hierarchy as the objective. The main QoS factors that describe network condition are defined as *availability*, *throughput (α), timeliness* (*β*), *reliability* (*γ*), *security* (*δ*), *cost* (*ε*), which are in the second level of the hierarchy. In order to make decision correctly and efficiently, we decompose the general element *timeliness* into *delay* (*ζ*), *response time* (*η*), and *jitter* (*θ*), and separate *reliability* into *BER* (*λ*), *burst error* (*μ*), *average number of retransmissions per packet* (*ν*), and *packet loss ratio* (*σ*). These sub-factors are arranged in the third level. Additionally, we adopt *received signal strength* (*RSS*) and *coverage area* as sub-factors determining *availability* to avoid frequent handoffs for high-speed users. Finally, we consider UMTS and WLAN as

LW2) of third-level factors. If $\mathbf{GW} = \{w_\alpha, w_\beta, w_\gamma, w_\delta, w_\varepsilon, w_\kappa\}$, $\mathbf{LW1} = \{w_\zeta, w_\eta, w_\theta\}$ and $\mathbf{LW2} = \{w_\lambda, w_\mu, w_\nu, w_\sigma\}$, the final weights of all factors are the synthesis of the local weights and corresponding global weights,

$$\mathbf{W} = \{w_1, w_2, \ldots, w_{10}\} = \begin{Bmatrix} w_\alpha, w_\beta w_\xi, w_\beta w_\eta, w_\beta w_\theta, w_\gamma w_\lambda, \\ w_\gamma w_\mu, w_\gamma w_\nu, w_\gamma w_\varepsilon, w_\delta, w_\varepsilon \end{Bmatrix}$$

The network-based data are normalized by GRA according to two situations: larger-the-better and smaller-the-better. It is derived that $\Delta_{\max} = 1$ and $\Delta_{\min} = 0$ when the nominal-the-best situation dose not exist. Additionally, the ideal network conditions are presented by a series of 1s after normalization. Then, the GRC is expressed as:

$$GRC_{UMTS/WLAN} = \frac{1}{\sum_{P=1}^{10} w_p \left| x^*_{UMTS/WLAN}(p) - 1 \right| + 1} \tag{7}$$

where $x^*_{UMTS/WLAN}(p)$ is the normalization of the UMTS data or the WLAN data. The network alternative with the larger GRC is more desirable.

V. Simulation Results

In the simulation, we consider an area in which there are three WLAN APs (referred to as AP-1, AP-2, AP-3) and a UMTS BS, as shown in Fig. 4. We assume that the coverage (diameters) of the APs and BS are 200m and 1000m respectively. Distance from AP-2 to AP-1 and AP-3 are respectively 400m and 100m. The conditions of the networks are shown in Table II. In the simulation scenario, a mobile user, who is transferring a file, moves anticlockwise at 1m/s from the BS to AP-1, AP-2, AP-3, and then backs to the starting point.

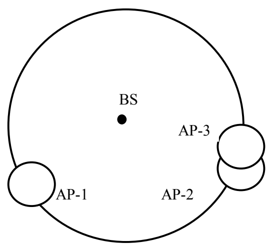

Fig. 4. Network selection simulation scenario.

The network-based data are normalized according to four possible network selection scenarios including UMTS vs. WLAN-1; UMTS vs. WLAN-2; UMTS vs. WLAN-2 vs. WLAN-3; and UMTS vs. WLAN-3, as shown in Table III. User's preference on QoS factors and subfactors are defined in Table IV and V. The network selection results are shown in Fig. 5.

During the normalizations, it is observed that 1s are directly assigned to the upper bounds in larger-the-better situations and the lower bounds in smaller-the-better situations when there are only two network alternatives. Other entries in the table are set to 0s. The time on achieving the exact QoS values and normalizing them presented in [3] are significantly reduced.

Additionally, it is noted that the mobile user selects high-throughput-and-high-reliability WLAN_3, when UMTS, WLAN_2 and WLAN_3 are simultaneously available. However, the selection result would change if the user changes his preference as shown in Fig. 6, where the vertical axis presents the weights of the factors and the horizontal axis presents the difference between the GRCs calculated for WLAN-2 and WLAN-3. WLAN-2 is selected if the horizontal value is positive. This example shows that when the weight of cost increases, lower-cost WLAN-2 is selected instead of WLAN-3. It illustrates that the network selection mechanism is actually a process of balancing user preference, service application and network condition.

VI. Conclusions

In this article, we developed a novel network selection algorithm for next generation networks. We integrated QoS factors, weighting factors, and network priority factors to select the best network for mobile user. AHP was adopted to achieve weighting factors and GRE was utilized to prioritize the networks. The simulation results revealed that the proposed mechanism can not only work efficiently for an UMTS/WLAN system but also reduce the complexity of implementation significantly.

TABLE II
UMTS and WLAN Network Parameters

QoS parameters		UMTS	WLAN-1	WLAN-2	WLAN-3
α (Mb/s)		1.7	25	20	25
β	ζ (ms)	19	30	45	50
	η (ms)	9	30	28	30
	θ (ms)	6	10	10	10
γ	λ (dB)	10^{-3}	10^{-5}	10^{-5}	10^{-6}
	μ	0.5	0.2	0.25	0.2
	ν	0.4	0.2	0.3	0.2
	σ	0.07	0.05	0.04	0.04
δ (level)		8	7	6.5	6
ε (per kbyte)		0.9	0.1	0.2	0.5

TABLE III
Normalizations of Network Parameters

Situations		α	β			γ				δ	ε
			ζ	η	θ	λ	μ	ν	σ		
1	UMTS	0	1	1	1	0	0	0	0	1	0
	WLAN-1	1	0	0	0	1	1	1	1	0	1
2	UMTS	0	1	1	1	0	0	0	0	1	0
	WLAN-2	1	0	0	0	1	1	1	1	0	1
3	UMTS	0	1	1	1	0	0	0	0	1	0
	WLAN-2	0.79	0.16	0.1	0	0.99	0.83	0.5	1	0.25	1
	WLAN-3	1	0	0	0	1	1	1	1	0	0.57
4	UMTS	0	1	1	1	0	0	0	0	1	0
	WLAN-3	1	0	0	0	1	1	1	1	0	1

TABLE IV
QoS Factor Comparisons

	α	β	γ	δ	ε	GW
α	1	7	2	5	7	0.46
β	0.14	1	0.14	0.33	1	0.05
γ	0.5	7	1	5	7	0.34
δ	0.2	3	0.2	1	3	0.11
ε	0.14	1	0.14	0.33	1	0.05

TABLE V
QoS Subfactor Comparisons

Timeliness (β)					Reliability (γ)				
	ζ	η	θ			Λ	μ	ν	σ
ζ	1	1	3		λ	1	3	6	2
η	1	1	3		μ	0.33	1	2	0.5
θ	0.33	0.33	1		ν	0.17	0.5	1	0.33
					σ	0.5	2	3	1
LW1	0.43	0.43	0.14		LW2	0.5	0.15	0.08	0.27
GW	0.02	0.02	0.01		GW	0.17	0.05	0.03	0.09

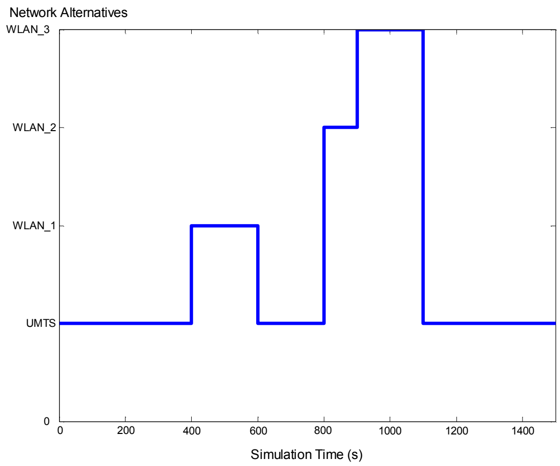

Fig. 5. Network selections versus simulation

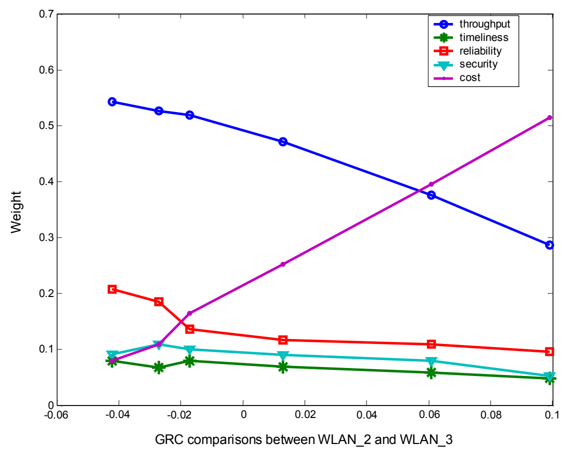

Fig. 6. Network selections with the changes of user preference.

REFERENCES

[1] N.D. Tripathi, J.H. Reed and H.F. Vanlandinghum, "Adaptive handoff algorithm for cellular overlay systems using fuzzy logic", IEEE 49th Vehicular Technology Conference, vol. 2, pp. 1413-1418, 16-20 May 1999.

[2] H. Park, S. Yoon, T. Kim, J. Park, M. Do, and J. Lee, "Vertical handoff procedure and algorithm between IEEE802.11 WLAN and CDMA cellular network", *Mobile Communications: 7th CDMA International Conference*, pp. 103-112, Seoul, Korea, 29 Oct. – 1 Nov., 2003.

[3] A. Roveri, C. Chiasserini, M. Femminella, T. Melodia, G. Morabito, M. Rossi, and I. Tinnirello, "The RAMON Module: Architecture Framework and Performance Results", M.A. Marsan, G. Corazza, M. Listanti and A. Roveri (Eds.): QoS-IP 2003, LNCS 2601, pp. 471-484, Springer-Verlag Berlin Heidelberg 2003.

[4] T. L. Saaty, *Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process*, RWS Publications, U.S.A., 2000.

[5] A. Blair, R. Nachtmann, and T.L. Saaty, "Incorporating expect judgment in economic forecasts: The case of the U.S. economy in 1992," *Fundamentals of the Analytic Hierarchy Process*, pp. 175-192, 1993.

[6] J. M. Alexander and T. L. Saaty, *Conflict Resolution – The Analytic Hierarchy Process*, Praeger, NY, 1989.

[7] J. L. Deng, "Introduction to grey system theory", *The Journal of Grey System*, vol.1, no. 1, pp. 1-24, 1989.

[8] C. T. Lin and S. Y. Yang, "Selection of home mortgage loans using grey relational analysis", *The Journal of Grey System*, Vol.11, No. 4, pp. 359-368, 1999.

[9] M. Sun, "Grey relational analyzing the influencing factor of economic benefit in hospital", *The Journal of Grey System*, vol. 11, no. 1, pp. 53-59, 1999.

[10] E. Gustafsson and A. Jonsson, "Always best connected," *IEEE Wireless Communications Magazine*, vol. 10, no. 1, pp. 49-55, Feb. 2003.