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Corresponding Author: Dr. Jae-Hoon Kim,

Corresponding Author's Institution:

First Author: Jae-Hoon Kim

Order of Authors: Jae-Hoon Kim; Jung-Gyo Sohn; Mira Yun; Ga-Young Oh; Hyeong-In Choi; Hyeong-Ah Choi

Design of a Web-based Decision Support System for Service Portfolios in Heterogeneous Radio Access Network Environment

Jae-Hoon Kim[a], Jung-Gyo Sohn[b], Mira Yun[c], Ga-Young Oh[d], Hyeong-In Choi[1)b], Hyeong-Ah Choi[c]

[a] Department of Industrial & Information Systems Engineering, Ajou University
San5,Woncheon-dong, Yeongtong-gu, Suwon 443-749, KOREA
Phone:+82-10-3129-7996, Fax:+82-31-219-1610
Email: jayhoon.kim@gmail.com

[b] Department of Mathematics, Seoul National University

[c] Department of Computer Science, George Washington University

[d] Department of Access Network Operations, SK Telecom

Abstract

By the newly emerging radio access technologies, we face the new heterogeneous network environment. Focusing on the co-existence of multiple access networks and the complex service combinations, the wireless service operators should build the best service portfolio strategy for each user, while maximizing whole network utilization. The web-based Decision Support System (web-based DSS) is the one of the best ways of making the service portfolios for every user in multiple access network environment. Any of service designers, customer relationship managers, even if network engineers could build the best matching relation between services and networks which gives most valuable user utilization. Also, the easily accessible web-based DSS under the optimal heterogeneous network operation framework gives the open opportunities for designing new services. By the promptly testing function of the DSS, the network load and financial effect of the newly designed services could be easily analyzed and re-shaped to the given network environment. The various mathematical tools, such as multi-stage linear programming or marginal cost estimation, are integrated in the developed DSS to evaluate the effect of introducing new services. To prove the applicability of the developed system, we test the various service scenarios in heterogeneous network environment by the versatile functions of the web-based DSS.

Keywords: Heterogeneous Network, Service Portfolio, Decision Support System, Operations Research

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[1)] "He is also the director of Research Institute of Mathematics, Seoul National University

1. Introduction

Leading to fundamental changes in the communications paradigm, wireless communication networks have been experienced drastic growth in the last decade. While the technological advances are developed to provide various services to various users, with different traffic characteristics and hardware capabilities, it is expected that new radio access technologies (RATs) will be deployed. However, the existing RATs could not be completely replaced by the new RATs [1]. The existing wireless networks, such as CDMA (Code Divisional Multiple Access), WCDMA (Wideband Code Divisional Multiple Access), and GSM (Global System for Mobile Communication), would co-exist with the newly emerging communication networks. The convergence of heterogeneous networks is hard to be implemented in a practical field. The entire convergence concept includes various sub-projects for realization. The practical implementation of network convergence is still remained in a starting phase. However, the leadership on the network convergence would be a critical success factor in the future telecommunication world.

The trends of research and development for future network convergence are classified into three major approaches: the integrated operation management for multiple networks [2][3], the efficient unified management of network resources, such as bandwidth or radio spectrum [4][5], and the development of an intelligent service platform by the network/context awareness [6][7]. The Always Best Connected (ABC) [8][9][10][11] is one of the prototypes as network convergence. The impacts of ABC are focused on both of the business optimization by the minimum cost network selection and the user satisfaction by the seamless connectivity. The ambient network [2][3] is an open-project for network reconfiguration. It includes the new standards for network convergence and operation schemes of multi-mode mobile stations. Focusing on the maximizing benefit of network convergence, the wireless service operators should build the best service portfolio strategy for each user while maximizing whole network utilization. The Decision Support System (DSS) is the one of the best ways of making the service portfolios for every user in multiple access network environment. Any of service designers, customer relationship managers, even if network engineers could build the best matching relation between services and networks, which gives most valuable user utilization, by the easily accessible web-based Decision Support System for building service portfolio.

In this article, we develop a new web-based DSS for building service portfolio strategy under the network convergence environment. A new operation framework designed for multiple access networks, which combines the services and networks, is applied to the newly developed web-based DSS as the fundamental methodologies. The web-based DSS using the optimal heterogeneous network operation framework gives the open opportunities for designing new services. By the promptly testing function of the DSS, the network load and financial effect of the newly designed services could be easily analyzed and adapted to the given network environment. The decision making processes of service deployment include the Common Radio Resource Management (CRRM) [12] functions whose essential part is the estimation of network effect of the deploying services. We suggest the various mathematical tools in the CRRM functions, such as multi-stage linear programming or marginal cost estimation, to evaluate the effect of newly designed services. To prove the applicability of the developed system, we test the various service scenarios in heterogeneous network environment using the versatile functions of the web-based DSS. By the intuitive web user interface, service scenarios (including various characteristics of each service) and service policies of mobile operators are easily built to be evaluated in given heterogeneous network environment. Also, the developed whole DSS platform has fully separated layered structure consisted of the web presentation server, application server, and network database. The well-designed separated structure guarantees simple maintenance capability to apply new features of services or networks.

>>insert Figure 1<<

After the introduction, we address the related works for network convergence and management in section 2. Then, we present the DSS software architecture and flow controls in section 3. In section 4, the models and algorithms in DSS are described. Finally, section 5 presents the practical application and the user interfaces of DSS followed by the concluding remarks in section 6.

2. Related Works

As the deficiencies of the communication architecture are widely acknowledged in network convergence, considerable effort is currently being made to devise future network architecture. The work in [13] propagates a kind of meta-control plane for future intelligent management of the communication network. The work [14] proposes to separate the network into domains or contexts. For these separate contexts, the concept of mappings is used to provide interworking between heterogeneous networks deploying different technologies. However, it is left as an open issue how these mapping between networks can be created. The dynamic creation for reconfigurable network topologies is the main reason of changing mapping relations. In [15], an abstraction, called region, is presented as a key design element of architecture for extremely large scale and heterogeneous networks. The focus of this work is put on the dynamic interworking and creation of common control of networks.

The standardization fora 3GPP, 3GPP2, and IEEE are investigating the integration of 3G and 2G cellular systems [16][17] as well as the integration of WLAN (Wireless Local Access Network) and 3G systems [18][19][20][21]. Some further research works investigated joint resource management for different access technologies [22][23][24][25][26][27][28]. Moreover, some works considering sharing of resources between different operators can be found in [29][30].

The related works listed above have limitations in several ways. One part of the prior works focuses only on two specific radio access technologies which are tightly integrated and may even allow joint radio resource management. These approaches cannot be easily extended to other radio access technologies. Another part of prior works concentrates on loosely integrated radio access technologies, which can comprise a number of radio access technologies. But these approaches allow only for a limited amount of joint resource management – usually limited to availability based access selection and not considering fast variations of system load or radio link quality variations. They do not fully address the emerging needs of future wireless and ubiquitous networks. But most of all, the previous researches have the focus on the technologies adaptation of heterogeneous network environment. We need to consider the approach coordinating service portfolio strategy under the technically optimized network utilization. The control functions, such as Quality of Service and mobility management, in highly dynamic networks should be built under the consideration on the best service portfolio for each user.

The approaches taken in the proposed DSS, including all existing/incoming radio access technologies and service combinations, is broad and general. The coordination between various radio access technologies and user services can be supported by the various mathematical methodologies. The multi-stage linear programming, marginal cost function estimation, and packet level simulation give the strict evaluation on the coordination between networks and services, focusing on the business efficiency and operational superior.

The development of a new web-based DSS for building service portfolio strategy in heterogeneous network convergence environment is a totally novel approach. The usefulness of web-based DSS using the optimal heterogeneous network operation framework, which gives the best portfolio strategy between the services and networks, is proved in commercially deployed heterogeneous networks in South Korea. The development and evaluation of the DSS in a commercial network environment is the world first case study. This gives the open opportunities for designing new services by the promptly testing and applying in the novel web-based DSS.

3. DSS Software Architecture and Flows

>>insert Figure 2<<

Figure 2 shows the DSS software architecture and flows. According to the user's activities in web interface pages, Web Server sends a SOCKET request which could be a mathematical programming optimization request to the Flow Controller (the Flow Controller creates a separated thread to handle the request, such that concurrency is supported). After the Flow Controller gets the request from the Web Server, it downloads network and service scenario data set from the Data Management.

The mathematical programming module builds the appropriate mathematical optimization model, such as Linear Programming, and then makes the mathematically optimized outputs. The Flow Controller uploads all of the mathematical outputs to the Data Management. These mathematically optimized outputs are displayed via the Web Server using an interactive dialog. If the user is not satisfied with the outputs, the steps above can be multiply iterated until the user is satisfied for outputs. The mathematical programming module can generate a very fast solution as a service portfolio strategy. However, the mathematical outputs only reflect the static snapshot of service and network status. Therefore we have the second optimization module, the session-level simulation to reflect dynamic network environment. Adopting the user feedback for mathematical output, the Flow Controller generates the initiation for a session-level simulation to the session-level simulation module. The session-level simulation module contains functions of base stations, mobile stations, and a CRRM element. Each element supports the data processing procedure in MAC (Media Access Control) layer and higher layer signaling interfaces. The higher layer signaling includes the entire required upper layers of MAC layer. To simulate multiple access networks, the simulator contains RRC (Radio Resource Control, including RRM), RLC (Radio Link Control) and transport layer (TCP/IP). These protocol layers and interfaces are implemented for each network, respectively. Note that, the CRRM interworking interface is implemented onto the RRC interface of each network.

>>insert Figure 3<<

Figure 3 shows the session-level simulator functional blocks and interactions. The simulator functional blocks includes mobile station block, network configuration block, protocol blocks, CRRM block, and session management block. The interactions between the functional blocks are performed by the traffic/signaling interfaces of functional blocks. To achieve the highest effect of CRRM, the updating interval should be the same as the minimum length of radio frame, such as 10ms for WiMAX, 5ms for EV-DO, and 10ms for WCDMA. However, the volume of signaling information is increased by the updating frequency. We set 5 seconds as the primary updating interval. We verify the usefulness of the 5 seconds interval by the experiments. With the finalized outputs of session-level simulation, we can apply the packet-level simulation. The packet-level simulation has precise operations on packet transmission over the networks. Based on the precise traffic & mobility models, the packet-level simulator tracks entire packet-level behaviors of mobile stations. More than 20 different traffic models based on data from real wireless subscribers (From the networks with more than 1700 contents and 6 years of operation) are included in the packet-level simulator. Thus, the packet-level simulator can precisely estimate the network utilization, resource efficiency, quality of service on the level of cell, mobile station, and network system. Figure 4 shows the illustration for the packet-level simulation.

>> insert Figure 4<<

The packet-level simulator can track the entire behavior of networks and mobile stations. However, the simulation time is extremely long (maybe 2 or 3 days for small network size). The DSS gives an option as a user preference whether to select packet-level simulation or not.

4. Models and Algorithms

4.1. Service & Network Modeling

The developed DSS contains the service and network models. In the service model, we define service categories first. Based on the practical service applications of service operators, we define total 13 categories which encompass all of current services: Entertainment, Community, Game, Finance, Information, Communication, Music, Mobile Web, Location Based Service, Telemetics, Movie, Commerce, and Ect.. Figure 5 shows the 13 categories and input checkbox in the DSS. We can easily define an individual service by the setup of its service category (the service category contains representative service parameters). When we define a new service, we first select its service category and then, manipulate its detailed parameter values.

>> insert Figure 5<<

The service parameters using in the DSS are shown in table 1. Each service session related data, *session duration* and *session inter-arrival time* can be defined using diverse distribution models. It also includes aggregated traffic volume of service (*traffic load*) and service user count (*subscriber*). *Benefit* indicates the total profit earned for each service and it can be set as dollar amount per kilobit. To calculate the total profit, DSS uses Net Present Value (NPV) method. *Mobile Station* indicates the types of mobile devices and their distribution that supports the service. *High-end* is defined as all devices that became available after year 2007 and priced above $500, all other devices are considered *Low-end*.

The service parameters using in the DSS are shown in table 1.

>>insert Table 1<<

Figure 6 shows the input box for the service parameters.

>> insert Figure 6<<

To setup the network environment, total five types of base stations are included: CDMA1x, EV-DO, WCDMA-only, WCDMA/HSDPA, and WiMAX. Each base station in the network environment has defining parameters such as, network type, maximum capacity, peak-to-average capacity ratio, service coverage, access cost function, and CRRM availability. The maximum capacity denotes the peak data rate of a base station on given network type and the peak-to-average capacity ratio is used to measure the practical cell throughput. Given that the PF scheduling algorithm provides peak-data-rate of 21.1Mbps to 20 active users in HSDPA, the median-user-throughput is observed to be about 350kbps [31]. To reproduce this phenomenon, DSS provides a parameter, peak-to-median capacity ratio, to set the ratio between peak and median data rate. The access cost function of a cell represents the marginal cost function to access the cell (see the section 4.2). The On/Off of CRRM availability can be selected for each base station. Note that, the CDMA1x and WCDMA-only support only realtime traffic and the EV-DO and WiMAX support non-realtime traffic. The WCDMA/HSDPA supports both of realtime and non-realtime traffic, such that realtime traffic is supported by the non-HSDPA part and non-realtime traffic is supported by the HSDPA part. The capacity of HSDPA is dynamically adjusted based on the amount of realtime traffic that needs to be accommodated. The service coverage should determine the shape of each cell. In practice, the cell shape cannot be hexagonal, rather it depends on many environmental factors, such as the topology of the area where the base station is located, buildings, moving objects, and even weather situation. The DSS allows users to generate random cell shape. The cell shape also can be adjusted manually. Figure 7 shows the network setup interface in DSS.

>>insert Figure7<<

4.2. Network Management Algorithms

Two essential network management algorithms are included in the DSS to build optimal service portfolio strategy. The mathematical programming estimates the generated load of each service and then, allocates to an appropriate network under the load balancing constraints. The policy-based market driven network selection and traffic re-distribution algorithms are used to the dynamic distribution of service traffics in session-level and packet-level simulation module.

A. Mathematical Programming

The mathematical programming is used to build an initial service portfolio strategy. The multi-stage linear programming model (MLP) is applied to make mathematically optimized output which reflects static snapshot of service and network status. The main objective of the MLP is the load balancing among networks. The loads can be estimated per day, week, and month. These aggregated loads show the snapshot of given network status. The MLP makes an optimized service portfolio strategy for the snapshot under the aggregated load balancing. The session-level simulator and packet-level simulator use the output from the MLP as an initial solution to build the finalized service portfolio strategy in dynamic environment. The input factors for MLP are as follows: 1) estimated aggregated load of each service, 2) network structure and network capacity, and 3) network availability for each service. Then, the generated output from MLP contains 1) the allocated load to each network for each service and 2) load balancing information among networks.

Now, we formulate MLP. The decision variables of MLP formulation are $x_{i,1}, x_{i,2}, \cdots, x_{i,n}$ which denote load of i th service when the number of networks is n. That is, $x_{i,j}$ means the load of i th service in j th network. When the total load of i th service is T_i, $\sum_j x_{i,j} = T_i$ should be satisfied (*constraint* 1). If i th service can be supported by multiple transmission channels which have different channel speed or QoS, $T_i = \sum_k d_{i,k} t_{i,k}$ should be included (*constraint* 2). $t_{i,k}$ denotes the maximum volume of admitted load of k th transmission channel and $d_{i,k}$ is a binary variable for the determination of using of k th transmission channel. Thus, $\sum_k d_{i,k} = 1$ should be satisfied to select only one transmission channel for i th service (*constraint* 3). The ratio of total load of j th network, L_j, is presented as $L_j = \frac{1}{C_j} \sum_i w_{i,j} x_{i,j}$ where C_j denotes total capacity of j th network and $w_{i,j}$ means the weighting factor for i th service allocated to j th network. When M and m are maximum ratio and minimum ratio of total load of each network respectively, $m \le L_j \le M$ should be added as the admitted load range of j th network (*constraint* 4). Under the aforementioned constraints, we formulate the *first stage objective function* as $obj_1 = c_1(M - m) + c_2 M$ for load balancing and minimization of total load. c_1 denotes the weighting factor for load balancing and c_2 for the minimization of total load.

Attached to aforementioned linear programming model, we can apply network usage policy: lower and upper bounds of network resource consumption for each service. When the strict lower and upper bounds for i th service in j th network is given as $\alpha_{i,j}$ and $\beta_{i,j}$, we simply add a new constraints named as policy constraint, $\alpha_{i,j} T_i \leq x_{i,j} \leq \beta_{i,j} T_i$ (*constraint* 5).

Based on the aforementioned MLP, we provide two sets of mathematical optimizations as follows:

Set 1 (*Multi-Network Solution)*

For existing services and new services, we keep the lower bounds and upper bounds as the constraints of MLP (lower and upper bound are kept unchanged) and generate the multi-access network solution. In this scenario, we can have a solution where a good load balancing is achieved in the multi-access network.

Set 2 (*Single Network Solutions*)

In order to check the load when the new services are supported by only one network in the multi-network environment, MLP is carried out *n* times, for each *n* networks. For each time, lower and upper bound for existing services are kept unchanged. For new services, however, lower and upper bound are set to be 1 for one network, and 0 for the other networks. For example, if there are three networks {EVDO, HSDPA, WiMAX} and a new service *i*, the lower and upper bounds are given as ($\alpha_{i,EVDO} = 1$, $\beta_{i,EVDO} = 1$), ($\alpha_{i,HSDPA} = 0$, $\beta_{i,HSDPA} = 0$), and ($\alpha_{i,WiMAX} = 0$, $\beta_{i,WiMAX} = 0$) for EVDO network solution.

In this scenario, we can have single network solutions where the new services are allocated to the single network and the load balancing is achieved within the multi-access network. Thus we can check the impacts on the different networks with different service allocations.

After the mathematical modeling module of DSS is executed, all possible solutions are displayed. For each solution, the summary of results shows increment of load for each network, increment of network usage ratio, financial benefit of services, and additional cost.

B. Policy-based Market Driven Network Selection & Traffic Re-distribution

The policy-based market driven network selection & traffic re-distribution are used to guarantee load balancing for cell level in the session-level and packet-level simulators. By the appropriate network evaluation, we build an effective operational policy for heterogeneous network environment.

The fundamental design objective of operational policy in heterogeneous networks is to minimize the additional "costs" as a result of deviating from various operational policies including load balancing in the heterogeneous networks. For this purpose, we assign a positive function of traffic load, called a marginal cost function, to each cell in the networks. The value of marginal cost function at a given load on the cell can be interpreted as the additional cost incurred from utilizing one more unit of remaining traffic resource in the cell. Taking into account of the fact that the capacity of each cell is limited and the market principle that resources get expensive due to scarcity, we assume that marginal cost function for each cell is increasing. One simple way of defining marginal cost function for the cell is to use an increasing linear function. See Figure. 8

>> insert Figure 8<<

The accumulated cost due to traffic load u taken by the cell can be calculated by integrating the corresponding marginal cost function from 0 to u. If we have N cells $B_1,...,B_N$ that are respectively provided with marginal cost functions $f_1,...,f_N$, the total accumulated cost T over all the cells at traffic distribution $(u_1,u_2,...,u_N)$ is given by

$$T(u_1,u_2,...,u_N)=\int_0^{u_1} f_1(u)du+\cdots+\int_0^{u_N} f_N(u)du \quad (1),$$

where f_i is the marginal cost function associated with the cell B_i and u_i the current load taken by the cell $B_i(i=1,...,N)$. It can be seen that the minimum of the total accumulated cost T is achieved at an equilibrium state $(u_1^*,...,u_N^*)$, which satisfies the following equation:

$$f_1(u_1^*)=f_2(u_1^*)=...=f_N(u_N^*) \quad (2)$$

when it is assumed that the total amount of traffic is constant over time. At equilibrium states any change in traffic distribution always produces an additional cost.

The above result gives us an insight into how to adjust traffic distribution dynamically in the heterogeneous networks. To set up a dynamical model for this, let $G=(B,C)$ be a connected graph of N cells in the heterogeneous networks, where $B=\{B_i\}_{i=1,...,N}$ represents the set of N cells and $C=(c_{ij})$ is the corresponding adjacency matrix with

$$c_{ij}=\begin{cases}1, \text{ if cell } B_i \text{ is a neighbor of cell } B_j\\ 0, \text{otherwise.}\end{cases} \quad (i,j=1,...,N)\ (3)$$

A neighborhood relationship between two cells implies that traffic can transit between them. Our traffic transition strategy is that if the marginal cost in the cell B_i is greater than the average of the marginal costs of all neighboring cells, then we make traffic transit dynamically from the cell B_i to the neighboring cells so that the differences of marginal costs among the cells are gradually diminished. The following nonlinear system of autonomous differential equations embodies the traffic transition strategy:

$$\frac{du_1}{dt} = -\lambda \sum_{j=1}^{N} c_{1j} (f_1(u_j) - f_j(u_j))$$
$$\frac{du_2}{dt} = -\lambda \sum_{j=1}^{N} c_{2j} (f_2(u_j) - f_j(u_j)) \qquad (4)$$
$$\vdots$$
$$\frac{du_N}{dt} = -\lambda \sum_{j=1}^{N} c_{Nj} (f_N(u_j) - f_j(u_j))$$

where λ is a fixed transition rate and traffic conservation in the system is assumed. The dynamical system has a unique equilibrium; indeed, $\dot{u}_1 = ... = \dot{u}_N = 0$ implies that $f_1(u_1) = f_2(u_2) = ... = f_N(u_N)$, which has a unique solution $(u_1^*,...,u_N^*)$, since each function $f_i(i = 1,\ldots.N)$ is strictly increasing and the total traffic $u_1 + \cdots + u_N$ is constant over time. To see whether the traffic distribution state $(u_1,...,u_N)$ actually converges to the equilibrium state $(u_1^*,...,u_N^*)$, we introduce a measure of variation of marginal costs among the cells as follows:

$$V(t) = \sum_{i,j} c_{ij} (f_i(u_i(t)) - f_j(u_j(t)))^2 \qquad (5)$$

The function $V(t)$ converges to zero as time goes to infinity, showing that $(u_1,...,u_N)$ converges to the equilibrium state $(u_1^*,...,u_N^*)$. (See appendix for a proof).

>>insert Figure 9<<

For neighboring cells B_1, B_2, B_3 and B_4 corresponding current marginal cost has been respectively calculated. The red solid arrows show the directions of traffic transition among the neighboring cells according to the traffic transition strategy (Figure 9).

Now, we build a practical operation framework which consists of an access network selection method and a traffic redistribution scheme, based on the mathematical analysis of marginal cost function. The marginal cost function includes the load balancing and additional policies of service operators, such as call priority handing (The load balancing is the main objective of access selection and traffic redistribution. But, the load balancing should be operated under the restriction of priority handling among cells).

To show the practical applicability of policy-based marginal cost function, we think two types of services in CDMA1x, EV-DO, WCDMA-only, WCDMA/HSDPA, and WiMAX cells. The realtime traffic has the higher priority than non-realtime traffic (new realtime traffic may be admitted to a non-HSDPA part of the WCDMA/HSDPA by dropping or redirecting the existing data traffic in HSDPA part). Then, we build a single operation framework for realtime and non-realtime traffic in heterogeneous network environment. We define a marginal cost function for each RAT whose purposed is to assign a marginal cost value to each of its cells. The whole set of following marginal cost functions acts as the core of operation framework: the CDMA 1x and WCDMA-only cells are more preferable for realtime traffic and the capacity of WCDMA/HSDPA cells is reserved for upcoming non-realtime traffic, while minimizing the total load.

(1) For CDMA 1x , $f_r(x_v) = \begin{cases} (x_r/c_r)^2 & \text{if } x_r/c_r < \alpha \\ (x_r/c_r)^2 + 1 & \text{otherwise} \end{cases}$

Where x_r and c_r denote the load and the total capacity of CDMA 1x cell r.

(2) For WCDMA-only, $f_r(x_v) = \begin{cases} (x_r/c_r)^2 & \text{if } x_r/c_r < \alpha \\ (x_r/c_r)^2 + 1 & \text{otherwise} \end{cases}$

Where x_r and c_r denote the load and the total capacity of WCDMA-only cell r.

(3) For EV-DO, $f_{nr}(x_{nr}) = (x_{nr}/c_{nr})^2 + 1$

Where x_{nr} and c_{nr} denote the load and the total capacity of EV-DO cell nr.

(4) For WCDMA/HSDPA, $$f_{nr}(x_r, x_{nr}) = (x_{nr}/c_{nr})^2 / (1 - x_r/c_r)^2 + 1$$ $$f_r(x_r) = (x_r/c_r)^2 + 1$$

Where x_r and c_r (x_{nr} and c_{nr} respectively) denote the load and the total capacity of non-HSDPA part r of WCDMA/HSDPA cell (HSDPA part nr of WCDMA/HSDPA cell).

(5) For WiMAX, $f_{nr}(x_{nr}) = (x_{nr}/c_{nr})^2 + 1$

Where x_{nr} and c_{nr} denote the load and the total capacity of WiMAX cell nr.

>>insert Figure 10<<

Figure 10 shows the functional behavior of above marginal cost functions. When (x_r/c_r) is less than the α, realtime traffic is allocated to WCDMA-only or CDMA 1x cells by the estimation of (x_r/c_r). The marginal cost of WCDMA-only or CDMA 1x is lower than that of non-HSDPA part of WCDMA/HSDPA. However, when (x_r/c_r) is higher than α, realtime traffic is allocated among the WCDMA-only, CDMA 1x, or non-HSDPA part of WCDMA/HSDPA by the estimation of (x_r/c_r). The marginal cost of non-HSDPA part of WCDMA/HSDPA has the same level of WCDMA-only or CDMA 1x. The non-realtime traffic allocation of HSDPA part of WCDMA/HSDPA is determined by (x_r/c_r) of non-HSDPA part of WCDMA/HSDPA. If the

(x_r / c_r) is in a lower level, the marginal cost of HSDPA part of WCDMA/HSDPA has a similar value of EV-DO or WiMAX. However, If the (x_r / c_r) is higher, the marginal cost of HSDPA part of WCDMA/HSDPA is rapidly increased than that of EV-DO or WiMAX. So, the using of HSDPA part of WCDMA/HSDPA is strictly managed for the incoming realtime traffic of WCDMA/HSDPA.

Based on the proposed marginal cost function, now we introduce an operation framework which consists of an access network selection method and a traffic redistribution scheme. Each cell reports the current load to the CRRM module periodically or in event-driven way (i.e., by the report requests of CRRM module). Then, the CRRM estimates the marginal cost of each cell. The access network selection process is initiated by the connection request from a mobile station. The CRRM selects a cell with the minimum marginal cost, and direct the mobile station to the selected cell. The traffic redistribution process is more complex. In every fixed time interval, the marginal cost of each cell is updated by the CRRM. Then, the CRRM guides mobile stations to perform handovers.

Note that, the main assumption of this modeling is the uniform measurement of load of each network. We set the cell load, referred as percents, as the measurable value for each cell. Then, we build marginal cost functions to maintain the balance of cell load. Also, we assume the free traffic redistribution among networks. By the estimation of marginal cost for each network, traffic can move from one cell to another cell without any limitation. Load and utilization have the same measurable values. Only difference between them is just point of view. Load is used in view of network resource consumption for network operators and Utilization is in view of profit generation for customers

5. Practical Applications

We illustrate a practical application of building service portfolio and network impact analysis. From running DSS, we have the capacity to observe the financial and network-wise impact a newly introduced service can have on a multi-access network environments.

5.1. Service Test Scenario

First, we initialize the simulator environment. Using the scenario manager we are able to define the physical properties of the network and the list of existing services present in the network as shown in Figure 11.

>>insert Figure 11<

The service test scenario consists of test simulation time, time band, test region, service combination set, and traffic models for service combination set. The table 2 shows the setup of service test scenario.

>>insert Table 2<<

5.2. Adding new service

Once all the preliminary settings have been completed, project is created to add the new services to the scenario and to run it through the simulation. Figure 12 shows adding of two new services (Service1 and Service2) to an existing scenario. This creates a new environment in which the impact of new services and the cost/profit analysis can be performed.

>>insert Figure 12<<

Next, as it is shown in Figure 13, the distribution of service over network is set. Along side the interface, the distribution of mobile devices and existing services are presented. These values are used to set the lower and upper bounds for each networks as the policy constraint described in section 4.2.A.

>> insert Figure 13<<

5.3. Results

Once the project has been configured completely, DSS provides initial results through the mathematical programming module described in chapter 3 and final result of session level simulation.

Initial results provide both multi-network scenario and single-network scenario results. They are based on the project configuration and two sets of mathematical optimizations from 4.2.A: new services in the multi and single network environment. The user has the choice of two different view of the impact of the new service to be used in the final simulation.

As the session level simulation is being performed, an interface is shown that provides the user with satisfaction level in Figure 14. Satisfaction level is defined as (Assigned Bandwidth / Bandwidth Requirement) * 100, and all the base stations that falls below 90% satisfaction level are displayed in the list on the left hand side.

>>Insert Figure 14<<

Once the simulation has been completed, we obtain the following results of test scenario. The summary of results shows increment of load for each network, increment of network usage ratio, financial benefit of services, and additional cost in Figure 15.

>>Insert Figure 15<<

The increment of load for each network and increment of network usage ratio could be shown for each service in the service combination set. In this service scenario, the service 1 and service 2 are newly introduced in the service combination set. The increment of load for each network and increment of network usage ratio can be estimated in the level of test region, national-wide area, and single base station area in the DSS.

Figure 16(a) describes the impact due to the new services being added for each network compared to the existing services. In this example, Service1 added 273,715Mbit increase to EVDO network which makes up 0.07% of the existing services. As for Service2, it caused increase of 323,482mbit in HSDPA network which is a 0.06% increase over the existing services. Figure 16(b) shows load increases for each of new and existing services. Here how much of the total load is caused by each services, more interestingly new services, is displayed. Our example shows 0.003% composition of Service1 and 0.0094% for Service2.

>>insert Figure 16<<

The financial benefit and additional cost of newly introduced services are also estimated in the DSS. Based on the defined financial benefit of each service in table 1 and the target number of service scribers, we can estimate expected revenue of newly introduced services (the target number of service scribers is defined by the marketing plan of service operator). Figure 17 shows the net present value of the newly introduced service 1 and service 2.

>>insert Figure 17<<

Finally, we can obtain the service portfolio strategy. The service portfolio strategy contains the recommended network and service quality level for each service. The table 3 shows the part of service portfolio of the tested service scenario.

>>insert Table 3<<

6. Concluding Remarks

Focusing on the maximizing benefit of network convergence, the wireless service operators should build the best service portfolio strategy for each user while maximizing whole network utilization. The Decision Support System (DSS) is the one of the best ways of making the service portfolios for every user in multiple access networks. Any of service designers, customer relationship managers, even if network engineers could build the best matching relation between services and networks, which gives most valuable user utilization, by the easily accessible web-based DSS for service portfolio. Our objective is developing a new web-based DSS for service portfolio strategy in heterogeneous network convergence environment. We adopt optimal heterogeneous network operation framework consists of multi-stage linear programming and policy-based market driven network access method. The market-based marginal cost function is used to evaluate the relative value of resources for each network. The usefulness of web-based DSS under the optimal heterogeneous network operation framework gives the open opportunities for designing new services. By the promptly testing function of the DSS, the network effect of the newly designed services could be easily tested and adapted to the given network environment. The practical application of DSS shows the proper decision making process for the new service adaptation in a service portfolio. Also, it shows the efficient resource assignment by the multistage linear programming and marginal cost function in heterogeneous network environment.

APPENDIX

We will prove that $V(t)$ converges to zero as time t goes to infinity.

Let $A_{ij} := c_{ij}(f_i(u_i) - f_j(u_j))$. The total traffic $u_1 + u_2 + \cdots + u_N$ is conserved over time since

$$\frac{d(u_1 + u_2 + \cdots + u_N)}{dt} = -\lambda \sum_{i,j} A_{ij} = 0 \quad (\because A_{ij} = -A_{ji})$$

Using the fact that $A_{ij} = -A_{ji}$ and the marginal costs functions are increasing, we have

$$\dot{V} = \frac{d}{dt} \sum_{i,j} c_{ij} (f_i(u_i) - f_j(u_j))^2$$

$$= 2\sum_{i,j} A_{ij} (f'_i(u_i)\dot{u}_i - f'_j(u_j)\dot{u}_j)$$

$$= -2\lambda \sum_{i,j} A_{ij} \left(f'_i(u_i) \sum_k A_{ik} - f'_j(u_j) \sum_k A_{jk} \right)$$

$$= -2\lambda \left(\sum_{i,j} \sum_k f'_i(u_i) A_{ij} A_{ik} - \sum_{i,j} \sum_k f'_j(u_j) A_{ij} A_{jk} \right)$$

$$= -4\lambda \left(\sum_i f'_i(u_i) \sum_{j,k} A_{ij} A_{ik} \right)$$

$$= -4\lambda \sum_i f'_i(u_i) \left(\sum_k A_{ik} \right)^2$$

$$= -\frac{4}{\lambda} \sum_i f'_i(u_i)(\dot{u}_i)^2 \leq 0,$$

which implies that $V(t)$ always decreases unless the traffic distribution $(u_1(t),...u_N(t))$ is not in the unique equilibrium state. Since $V(t)$ is bounded below, we should have $\dot{V} \to 0$ as $t \to \infty$. But $\dot{V} = 0$ if and only if $\dot{u}_i = 0$ for all $i = 1, \ldots, N$, which is also equivalent to the equation $f_1(u_1) = f_2(u_2) = \ldots = f_N(u_N)$, leading to $V = 0$. Therefore, as dynamics evolve with time, it follows that $\dot{u}_i \to 0$ $(i = 1, \ldots, N)$. This completes the proof.

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List of Tables

List of Figures

Table 1. Service Parameters

Name	Description	Option
Session Duration	Probabilistic Model for the period of continuous data transmission	⇒ Uniform(a, b) ⇒ Poisson (mean) ⇒ Normal (mean, sigma) ⇒ Lognormal (mean, sigma) ⇒ Exponential (mean) ⇒ Constant (c) ⇒ Binormal (mean, N) ⇒ Bernoulli (mean) ⇒ Weibull (scale, shape)
Session Interarrival	Probabilistic Model for the time between one session and the other session	⇒ Uniform(a, b) ⇒ Poisson (mean) ⇒ Normal (mean, sigma) ⇒ Lognormal (mean, sigma) ⇒ Exponential (mean) ⇒ Constant (c) ⇒ Binormal (mean, N) ⇒ Bernoulli (mean) ⇒ Weibull (scale, shape)
Traffic Load	Generated traffic volume counted by (Kbits/month)	
Benefit	Total financial benefit of the service counted by ($/Kbits)	
Subscriber	The number of subscribers who use the service	
Mobile Station	Probabilistic model for the mobile stations which supports the service.	Single mode Mobile Station EVDO High-end/ EVDO Low-end HSDPA High-end/ HSDPA Low-end WCDMA High-end/WCDMA Low-end WiBro Low-end Dual mode Mobile Station EVDO/WCDMA Low-end HSDPA/WiBro Low-end EVDO/HSDPA Low-end

Table 2. Service Test Scenario

Descriptor	Description
Simulation Time	Total simulation time for the service test scenario.
Time Band	Practical time band such as, Morning, Afternoon, and Evening. The volume of traffic varies according to the time band.
Test Region	Geographical region for test scenario. The google map is displayed to visualize test region. The demographic of base stations is supported.
Traffic Fraction of Test Region	The ratio of traffic volume generated in the test region compared with national wide traffic generation. For example, the generated traffic volume of test region is 3.5% of national wide traffic generation.
Service Combination Set	The list of services in the test scenario. Each service is defined by the service editing function.
Traffic Model	Probabilistic Models of Services in the test scenario. The list of models is announced in table 1.

Table 3. Exemplar of Service Portfolio

⊞ **Service Portfolio (Milyang)**

Service1 - new

- Service Type
    - Communication (WAP)
- Suggested Network
    - EVDO : 42,02 %
    - HSDPA : 57,98 %
- Suggested Paramters
    - Datarate : 9,60 kbps

Service2 - new

- Service Type
    - Finance (WAP)
- Suggested Network
    - EVDO : 100,00 %
    - HSDPA : 0,00 %
- Suggested Paramters
    - Datarate : 9,60 kbps

Caller Ring

- Service Type
    - Music (WAP)
- Suggested Network
    - EVDO : 55,46 %
    - HSDPA : 44,54 %
- Suggested Paramters
    - Datarate : 9,60 kbps

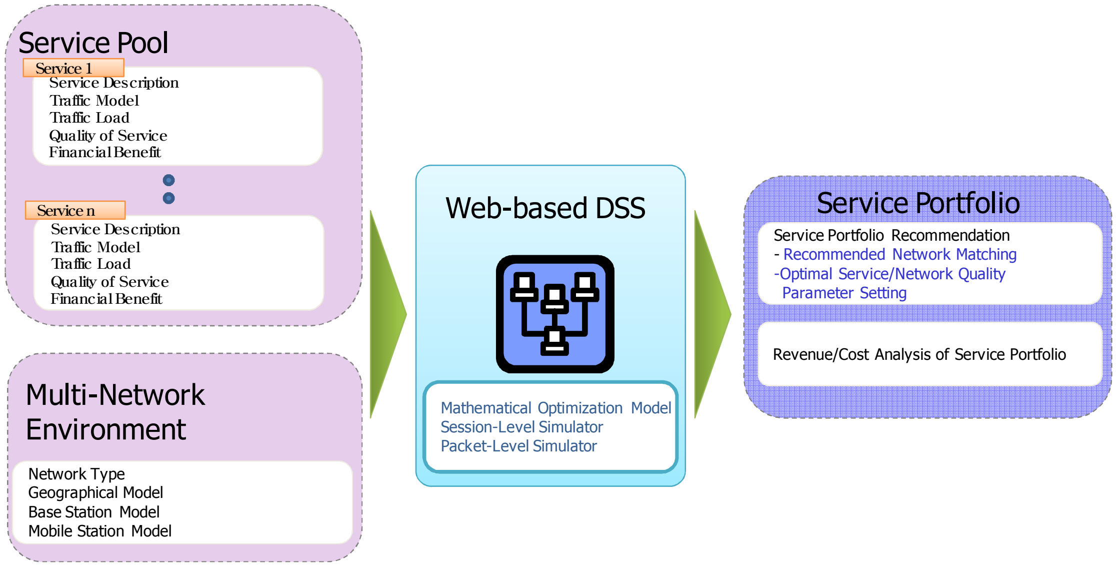


Figure 1. Service-Network Matching Relation

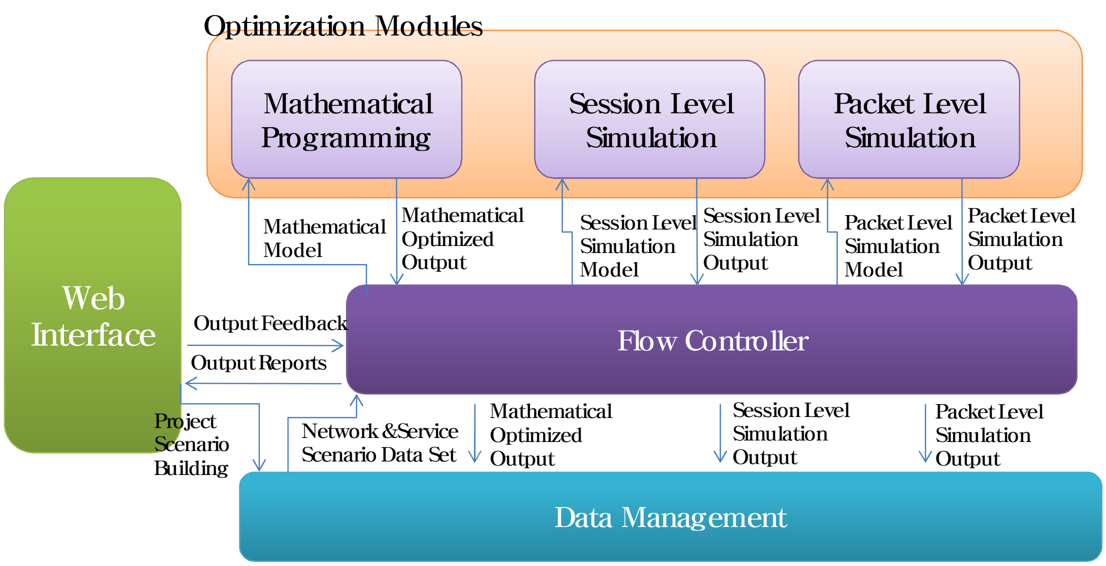


Figure 2. Software Architecture and Flows

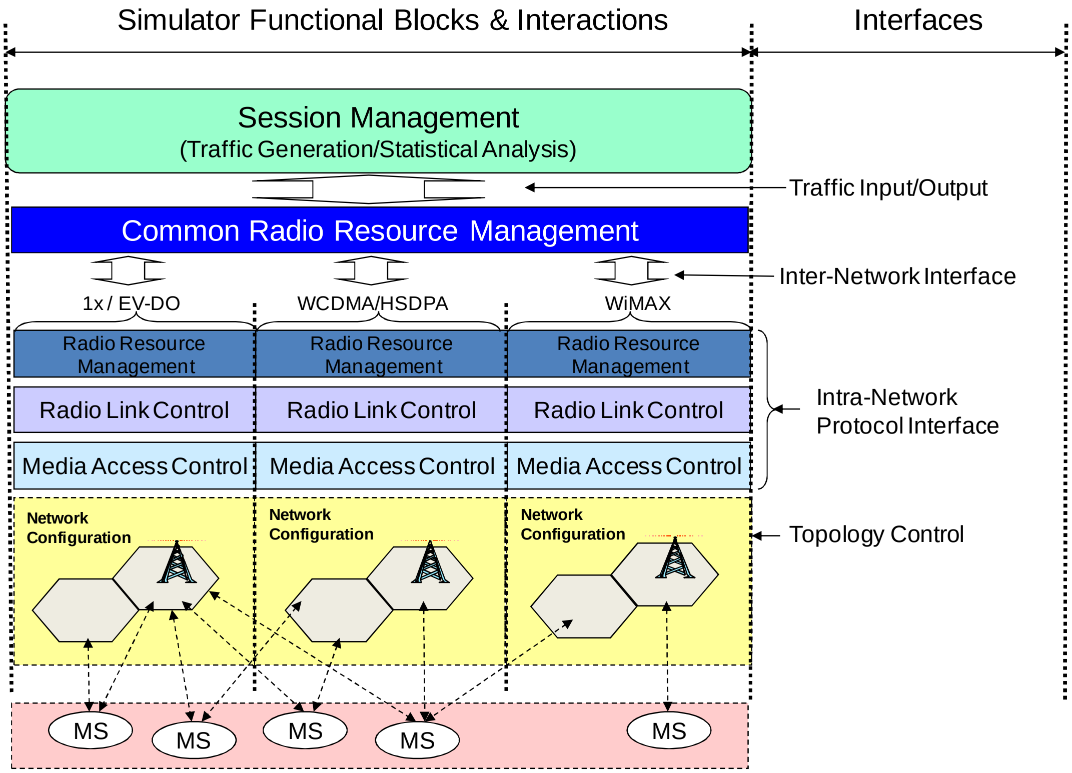
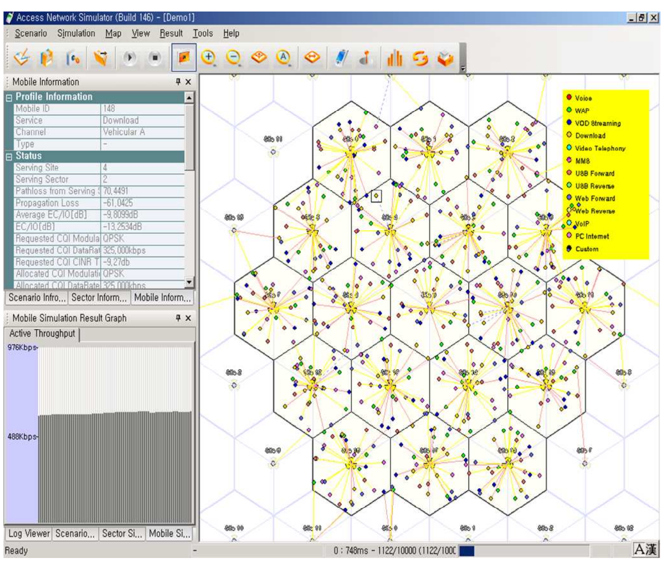
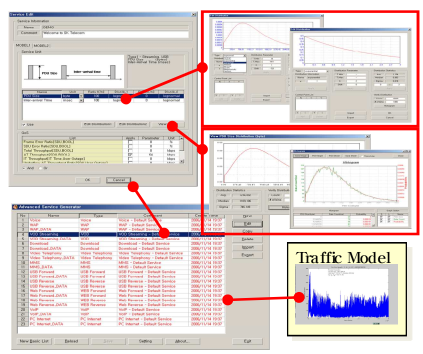


Figure 3. Architecture of Session-Level Simulator Module



(a) Network Simulation Interface



(b) Traffic & Mobility Model Interface

Figure 4. Screenshot of Packet-Level Simulation

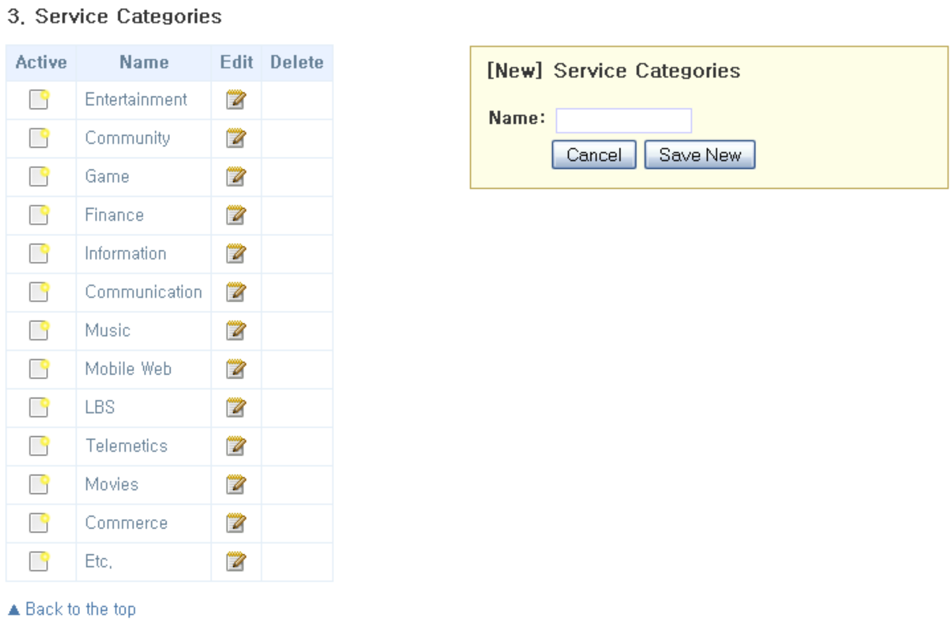


Figure 5. Service Category Setup

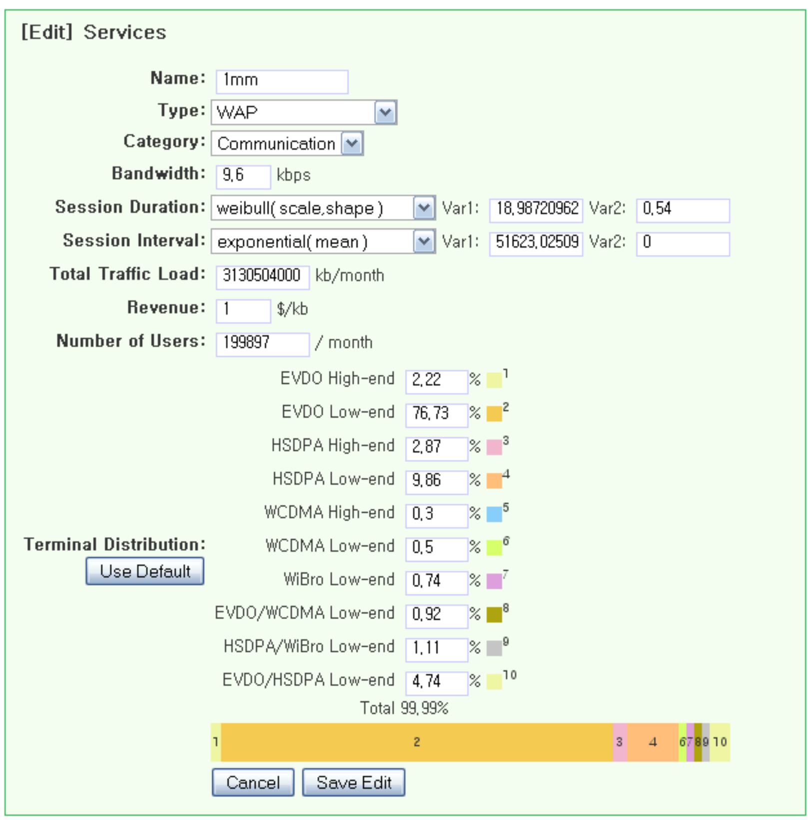


Figure 6. Service Parameter Setup

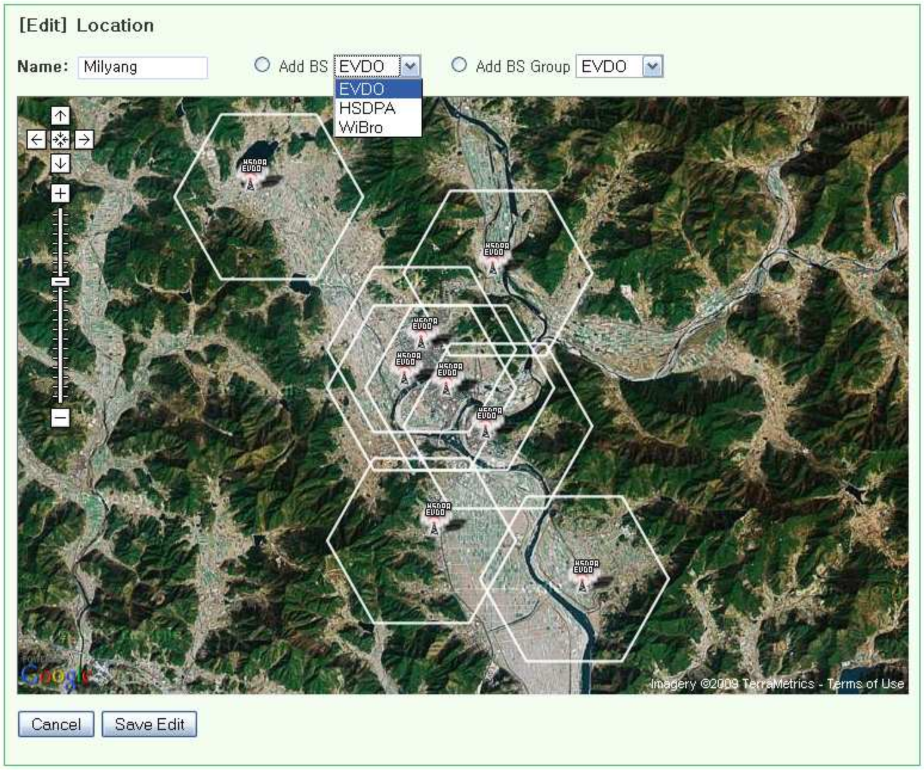


Figure 7. Network Setup Interface

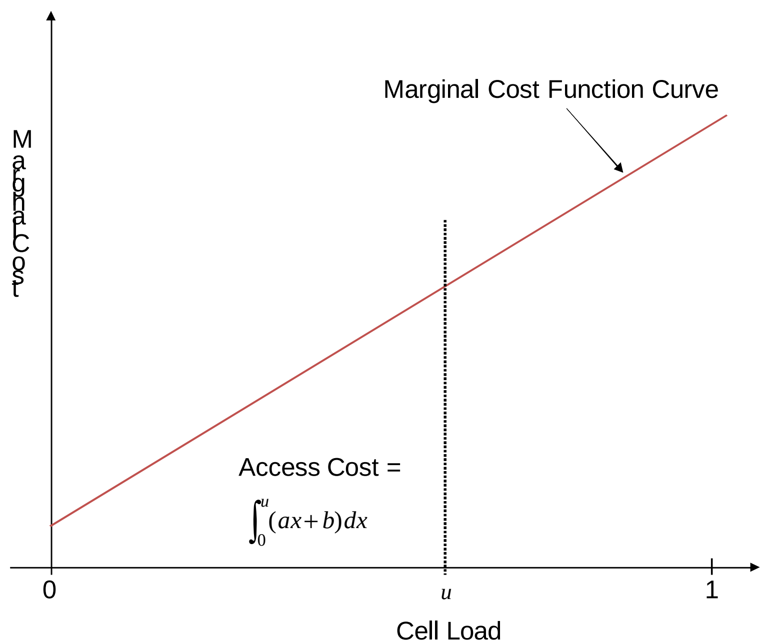


Figure 8. The figure illustrates an example of linear marginal cost function.

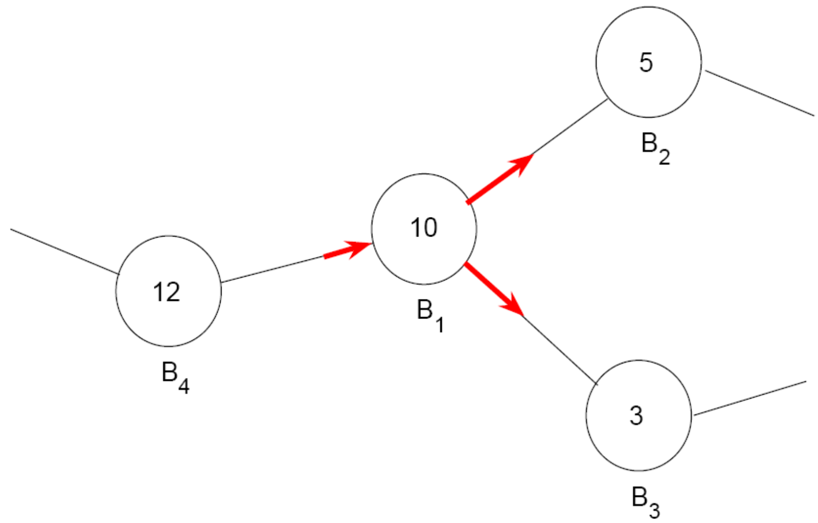


Figure 9. Traffic Transition

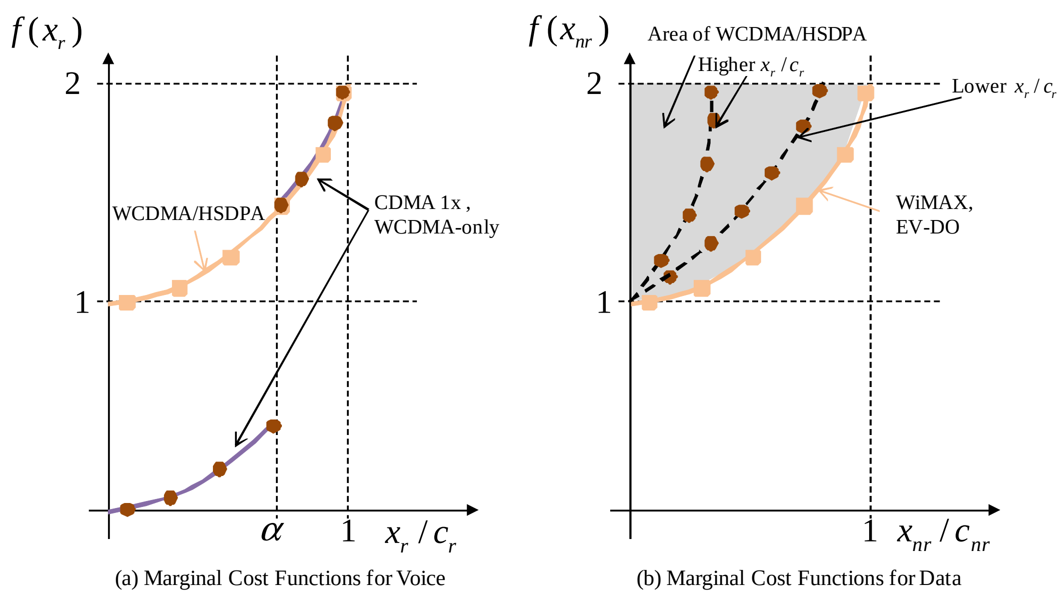


Figure 10. Functional Behavior of Marginal Cost Function

Fig. 11 The service test scenario

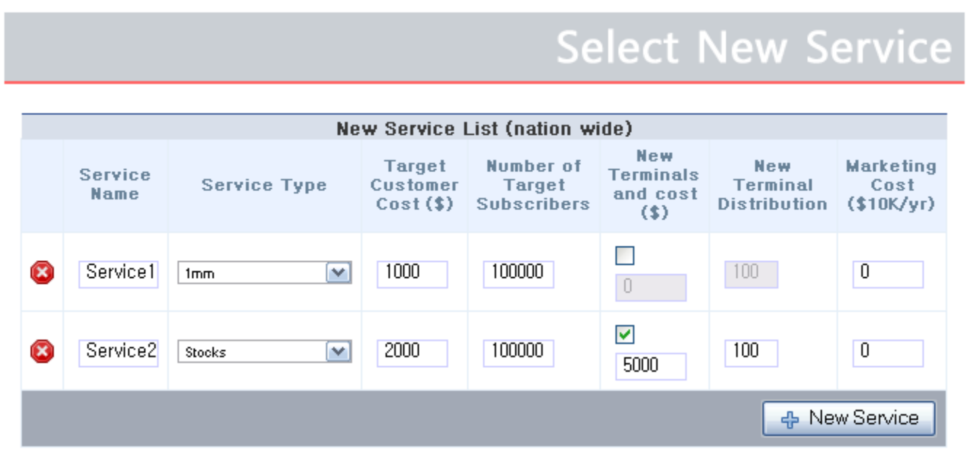


Figure 12. New Service Creation

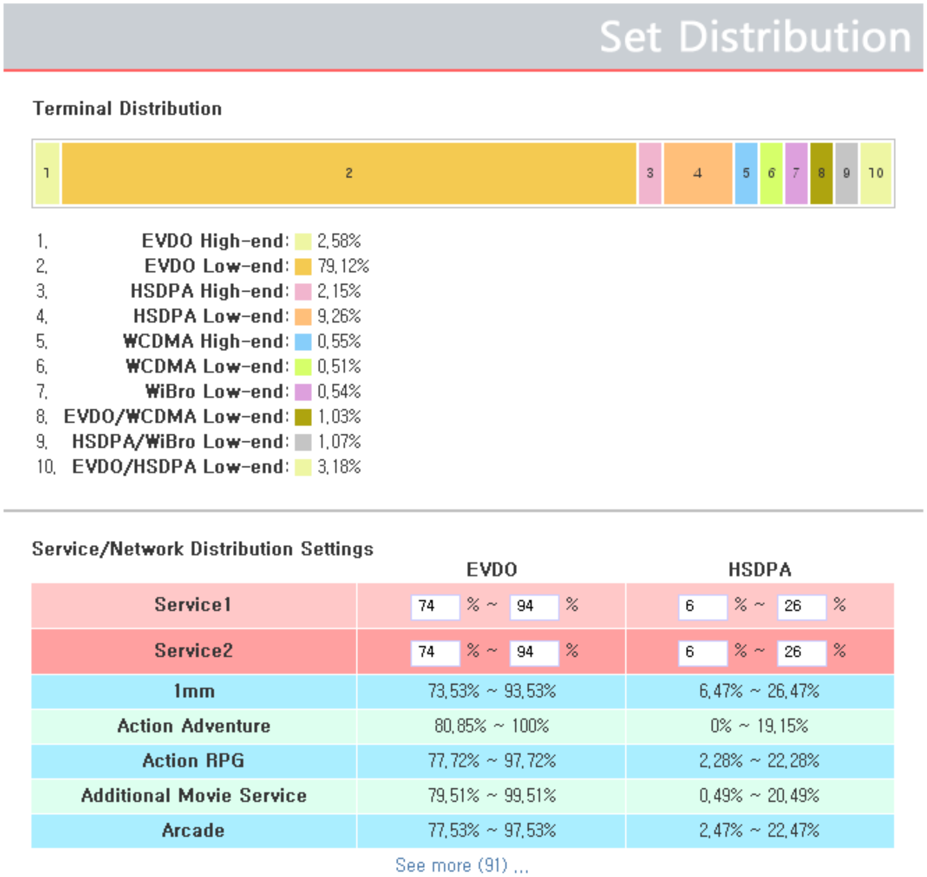


Figure 13.Distribution of Services over Networks

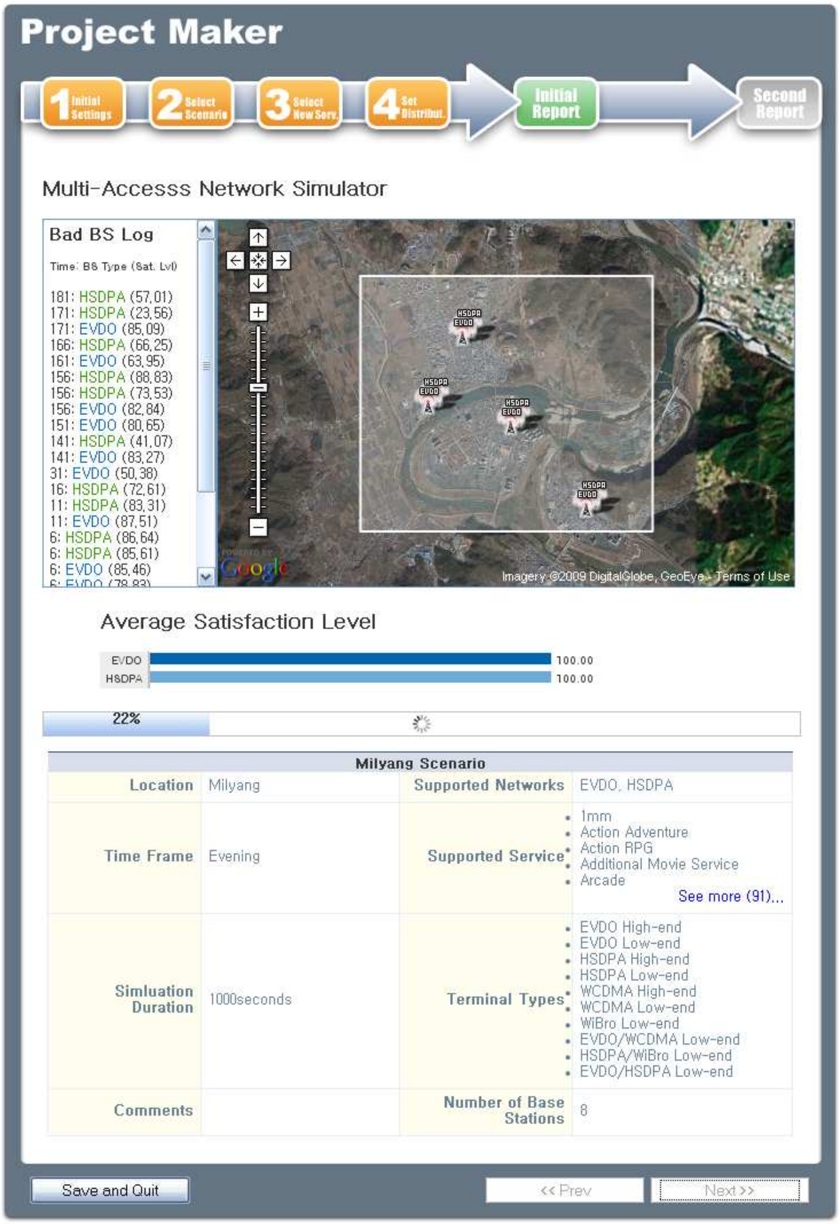


Figure 14. Snapshot of Simulation Running

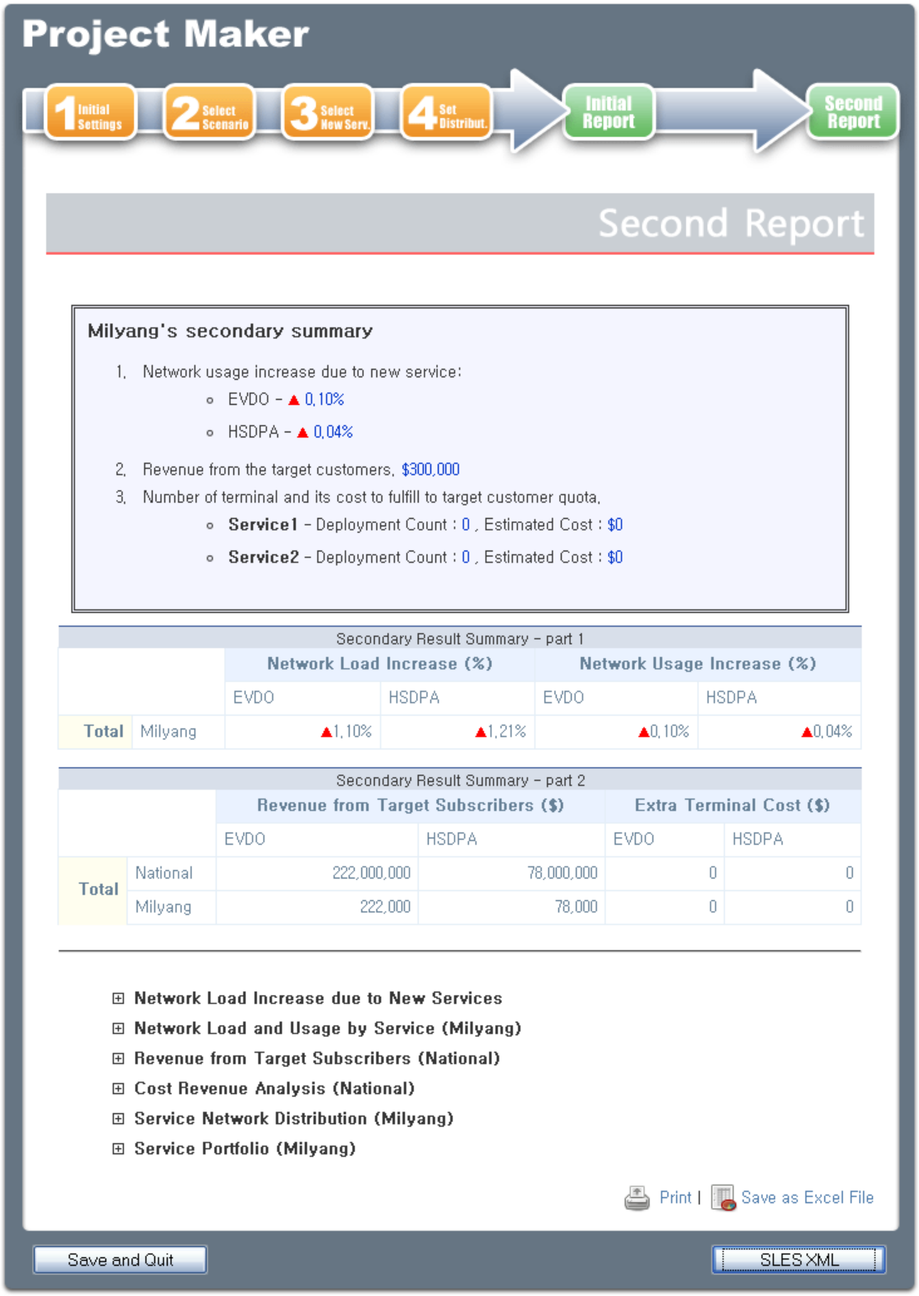


Figure 15. Summary of Results

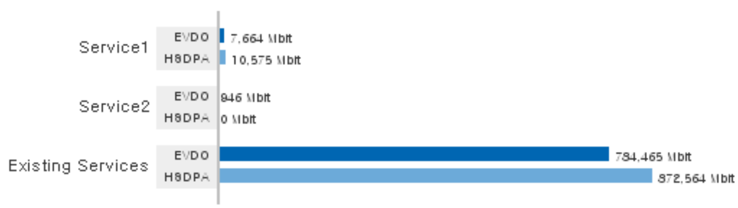
⊞ **Network Load Increase due to New Services**

Network Load Increase due to New Services							
		Existing Services (Mbit)		New Service (Mbit)		Increase (%)	
		EVDO	HSDPA	EVDO	HSDPA	EVDO	HSDPA
Service1	National	784,464,653	872,563,622	7,664,026	10,575,360	▲ 0,98%	▲ 1,21%
	Milyang	784,465	872,564	7,664	10,575	▲ 0,98%	▲ 1,21%
	Base Station	98,058	109,070	958	1,322	▲ 0,98%	▲ 1,21%
Service2	National	784,464,653	872,563,622	945,562	0	▲ 0,12%	▲ 0,00%
	Milyang	784,465	872,564	946	0	▲ 0,12%	▲ 0,00%
	Base Station	98,058	109,070	118	0	▲ 0,12%	▲ 0,00%
Total	National	784,464,653	872,563,622	8,609,587	10,575,360	▲ 1,10%	▲ 1,21%
	Milyang	784,465	872,564	8,610	10,575	▲ 1,10%	▲ 1,21%
	Base Station	98,058	109,070	1,076	1,322	▲ 1,10%	▲ 1,21%

(a) Increment of load for each network

⊞ **Network Load and Usage by Service (Milyang)**

Network Load and Usage by Service				
	Supported Network Load (Mbit)		Supported Network Usage	
	EVDO	HSDPA	EVDO	HSDPA
Service1	7,664	10,575	0,092400%	0,042500%
Service2	946	0	0,011400%	0,000000%
Caller Ring	4,678	3,757	0,056400%	0,015100%
M-Stock(CHIP)	6,818	6,171	0,082200%	0,024800%
Star Pictures	1,617	6,843	0,019500%	0,027500%
See more (93)...				
Total	793,074	883,139	9,561563%	3,549138%



(b) Increment of network usage ratio

Figure 16. Network Load and Usage Ratio

Cost Revenue Analysis (National)

Cost Analysis: Terminal cost		
Service1	Investments	$ 0
	0th year profit	$ 100,000,000
	1st year profit	$ 93,457,944
	2nd year profit	$ 87,343,873
	3rd year profit	$ 81,629,788
	Net Present Value	$ 362,431,604
Service2	Investments	$ 0
	0th year profit	$ 200,000,000
	1st year profit	$ 186,915,888
	2nd year profit	$ 174,687,746
	3rd year profit	$ 163,259,575
	Net Present Value	$ 724,863,209
Total	Investments	$ 0
	0th year profit	$ 300,000,000
	1st year profit	$ 280,373,832
	2nd year profit	$ 262,031,618
	3rd year profit	$ 244,889,363
	Net Present Value	$ 1,087,294,813

Figure 17. Financial Analysis