

Decision Support Tool for IoT Service Providers for Utilization of Multi Clouds

Mohammad Mahdi Kashef, Hyenyoung Yoon, Mehdi Keshavarz, Junseok Hwang

Technology Management, Economics and Policy Program Department of Industrial and Management Engineering College of Engineering, Seoul National University

mmkashef@snu.ac.kr, hyyoon00@snu.ac.kr, keshavarzm@snu.ac.kr, junhwang@snu.ac.kr

Abstract— The Internet of Things (IoT) refers to uniquely identifiable objects (things) and their virtual representations in an Internet-like structure. IoT service Providers (IoTSP), i.e. the companies who intend to offer IoT-based services, may utilize cloud computing which offers a cheap, ubiquitous, unlimited and elastic solution for the supporting infrastructure. In this way the IoTSP will deploy its Virtual Machines (VM) on various cloud service providers (multi clouds) to have satisfactory coverage and performance for its globally distributed users.

In this context, one of the major problems is to minimize the overall cost of cloud infrastructure while keeping satisfactory level of performance. To achieve this the IoTSP has to cost-optimally place its VMs on the available cloud service providers.

This paper proposes a decision support tool for IoTSP to find their cost-optimum VM placement on multi clouds. The tool comprises a cost estimation model as well as an optimization algorithm. Our decision support tool is examined by several simulation scenarios and the results demonstrate the working of the tool.

Keywords— Internet of Things, IoT Service Providers, cloud computing, multi Clouds, Decision Support Tool, cost estimation, cost optimization, VM placement

I. INTRODUCTION

The Internet-of-Things (IoT) has burst onto the stage, interconnecting every types of objects over the Internet, which acts as endless sources of data and information. The phenomenon has required a combination of three developments. First, miniaturization, with technology being available in hands of users through smart devices any-where, any-time. Secondly, an overcoming of the limitations of the mobile telephony infrastructure which brings ubiquity. And thirdly, the intelligence embedded in the applications and services that make use of the vast amount of data created via the IoT Sensor networks [1].

On the other hand, IoT devices are location dependent, and the supporting infrastructure i.e. computing power, storage and networks are resource constrained and expensive to develop and deploy. On the contrary, cloud computing infrastructures are location independent, elastic and provide access to a multitude of computing resources [2]. That's why many works has suggested that cloud can be the most promising and cost-effective solution to connect, manage and track the IoT [3-6].

Figure 1 depicts the schematic view of IoT and Cloud integration.

Nevertheless, integrations of IoT and clouds will raise new issues and problems to be addressed; one of which is the cost-effectiveness. Finding the cheapest cloud service provider (CSP) can't be always solution of the problem. There are multiple reasons e.g. geographically distributed demand causes the Internet-of-Things Service Providers (IoTSP) to distribute its services over various CSPs, which in this paper is called as multi clouds [7].

Hence IoTSPs have to establish suitable infrastructure offering their services for their users any-where any-time. The IoTSPs require to place its services in form of Virtual Machines (VMs) on different Cloud Service Providers (CSPs). Therefore they face variety of VM placement options and need to decide how to place their VMs in multi clouds environment. To maximize their profit, the IoTSP need to maintain the cost of the infrastructure at optimum level; which means the IoTSP should place its VMs cost-optimally over different CSPs. Finding the optimum placement for IoTSP is challenging because the more the number of services and their features, CSPs, their available types of VMs and price differences, the more calculation complexity to find the optimum placement [7].

The aim of this work is to support Internet-of-Things Service Providers (IoTSP) to find out optimum VM placement on different CSPs. During the infrastructure utilization of different cloud service providers, there are bunches of possible VM-placements. Among the various possible placements, the IoTSP needs to find the optimum one; so that there is need for a tool to facilitate the VM-placement optimization task.

In particular, we intend to construct a *decision support tool* that can be used by IoTSPs to find out their optimum placement. The tool considers *total infrastructure costs* incurred by deployment of the VMs of the IoTSP. Total infrastructure cost includes cost of running VMs on different clouds as well as the traffic costs of users. An *optimization algorithm* enables the tool to help placement decision making of the IoTSP i.e. how to place their VMs such that it minimizes their infrastructure cost. By estimating total cost of each placement, execution of the optimization algorithm results in the *optimum placement*.

Seeking the mentioned objectives, this work is to answer two questions: 1) How to estimate cost of running a set of VMs of

IoTSP on different cloud providers? 2) How to find out the cost-optimum VM placement of IoTSP on different cloud providers?

To answer the research questions, we conduct the following steps: First, we perform a systematic literature review on cost estimation and cost optimization of IoT using clouds. Second, we study and collect all types of infrastructure costs incurred by IoTSP. Based on the results of second step, we propose infrastructure cost estimation as long as optimization algorithm for VM placement of IoTSP on multi clouds. Based on these results, we construct a decision support tool to help the IoTSP find their cost-optimum placement. Finally, we conduct some simulation experiments to demonstrate working of the proposed decision making support tool for IoTSP.

This paper proposes a *decision support tool* to be used by the IoTSPs to determine their VM placement on the clouds. The tool comprises estimation of total infrastructure cost as well as an optimization algorithm. The estimator considers total infrastructure costs incurred by of the IoTSP. It should address cost of running VMs as well as the traffic costs. The optimizer examines total cost of every possible VM placement, and suggests the cost-effective one for the IoTSP. A novel architecture is designed to contain the proposed modules as a working system.

The remainder of this paper is organized as follows: Second

II. RELATED WORKS

In recent years, the Internet-of-Things (IoT) has taken significant research attention. IoT is based on intelligent objects (things) [8] which are dynamically interconnected [9] empowering ubiquitous scenario with the real objects of the world [8, 10]. But the *things* have limited storage and processing capacity and they need certain infrastructure for their connectivity [8]. Therefore reliability, performance and connectivity are among the concerns mentioned about the utilizing IoT by the researchers [11].

On the other hand, cloud computing supports virtually unlimited storage capacity and processing power also supports pervasive infrastructure [12-14]. This implies that most of the IoT issues can be solved (at least to some extent) getting benefitted from Cloud computing [3, 11, 15]. As a result it is believed that cloud computing can be one of the best fitting choices to connect the *things* around us so that we can access them in a ubiquitous environment; i.e. anything at any time and any place [11].

Although these two phenomena are independently developed, but because of certain reasons they seem to be complementing one another [4, 8]. Among the drivers for integration of IoT and clouds, we may highlight communication (Data and application sharing) [2], storage and need for big data [16], and computation [11]. The result of merging IoT and cloud is said to be a very powerful disruptive technology which is going to shape the major part of future Internet [10]. The term CloudIoT is suggested for the paradigm by [11] emphasizing on the novel application of this convergence.

Nevertheless, on the way of this integration there are still problems and issues to be studied and addressed. Many researchers has put their efforts to tackle them in various methods. We categorize them into three general types: 1) technical approaches, 2) security and privacy-driven approaches, 3) economic and business approaches.

The major focus of the literature is on the technical issue. As the objective of this work is non-technical issues, we only mention an instance of the technical approach. The authors of [2] proposes the building blocks of a middleware framework for the convergence of IoT and clouds. Their framework utilizes Linked Sensor Data and W3C Semantic Sensor Networks standard to the proposed framework enables the IoT service providers to deploy their IoT services onto cloud infrastructure.

About the security-driven approaches we may mention [17] which focuses on the privacy concerns of individual users and data in the integrated system. They present UPECSI, which is their proposed solution for User-driven Privacy Enforcement for Cloud-based Services in the IoT. UPECSI takes a comprehensive approach to privacy for the cloud-based IoT by providing an integrated solution for privacy enforcements that focuses on individual end-users and developers of cloud services at the same time. Another example is the works on SensorCloud project [18-20] aim at protecting the sensor data inside the sensor network, and before being uploaded to the cloud. Similarly [21, 22] also realize the protection of sensor

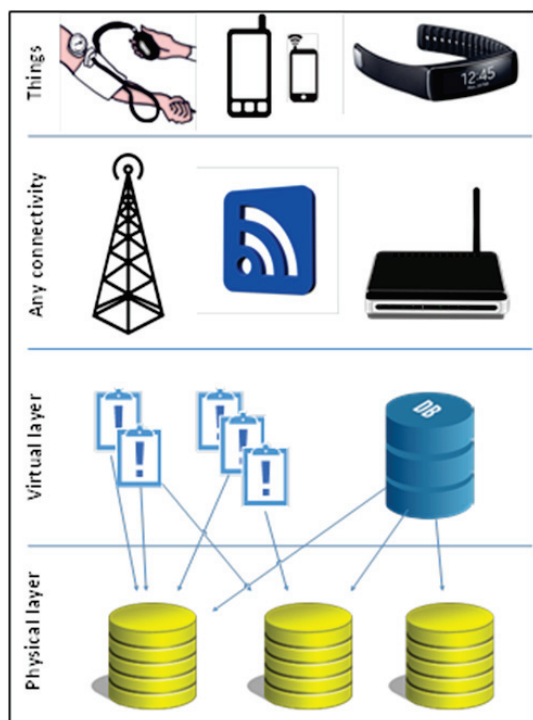


Figure 1 A diagram which shows the model for IoTSP utilizing clouds

section gives an overview about the related work. In third section we explain our cost estimation and the novel decision support model is presented. In forth section we examine the workings of the model with few simulation experiments. Fifth section concludes the paper with a brief discussion.

data already within the sensor network. On the other hand some works propose securing data when it is outsourced to the clouds. As few examples we may mention [23-25].

Unfortunately the research community has not paid much attention to the last category i.e. economic and business issues of IoT and cloud integration. We could mention [26] has put the first steps of clarification of IoT business models. The research community is seemed to be in its infancy about economic issues of the integration and much progress is expected to happen in near future. Nevertheless when it comes to the cost-effectiveness and other economic aspects, the academia has not contributed anything. Hence, proper research should study and address the economic challenges of IoT and cloud integration.

It worth to mention that both proprietary and open source platforms have stepped forward and implemented the CloudIoT applications. Just to mention an example of each, SAP HANA is a novel system based on clouds which offers IoT services [27], while OpenIoT from GitHub is an open source project developing a middleware for integrating IoT solutions [28].

III. SYSTEM MODELLING

In this chapter first we explain the problem scenario and we discuss the input factors. Then we depict the proposed decision support tool architecture and explain its components. Then our placement cost estimation and cost optimization algorithm is discussed in details.



Figure 2 Schematic view of a placement

A. Problem Scenario

As explained in the introduction section the IoTSP intends to offer particular services utilizing the multi cloud environment. Because its users are from various locations of the globe, the IoTSP needs to have satisfactory coverage for its servers (VMs). The IoTSP servers could be placed on any possible CSP. This implies several possible placements among which the IoTSP should decide and select one. On the other hand different VM placements incur various placement costs (due to price differences of different CSPs). This complicates the decision making of the IoTSP. A general snapshot of the VM placement is depicted in **Figure 2**.

To remove unnecessary complications, following assumptions are considered in this work. It's notable that these assumptions won't make this work to lose its generality. We assume total number of VMs to be v , and available types of VM spec which are supported by CSPs is given identifying the VM

processor, memory, storage size and bandwidth. Obviously each spec might have its own price. Besides we assume the globe is divided into n regions with their own given number of users, Internet connectivity rates and available CSPs. It is assumed that the traffic generated by each VM is Θ portion its bandwidth. The average required bandwidth for each user is assumed to be β . Also the traffic cost from any region to all other regions is one of the input factors. If the IoTSP does not place any VM in a particular region, the users of that region will be connected to the cheapest CSP for them. The capacity of all of the CSPs are assumed to be unlimited.

B. The Decision Support Tool Architecture

For the sake of cost optimizing the placement of one IoTSP, we propose the system architecture as shown in **Figure 3**. The proposed architecture for the decision support tool for IoTSP includes a coordinator, Optimization Module (OM), placement cost estimation module (PCEM), monitoring module and a Database. The user of the proposed decision support tool is IoTSP. The Database is being fed by the monitoring module which keeps capturing the situation of different regions and cloud service providers, their offered VMs and their prices. The sequence of utilizing the tool by IoTSP is follows: The coordinator communicates with the IoTSP to receive the requests as well as the required data and to send back the reports. OM is triggered by the request from the coordinator. Then it sets the given data from IoTSP as well as the Database. Based on the collected data, OM runs the optimization algorithm to find out the optimum placement for IoTSP. To achieve the optimum placement, OM triggers the PCEM which calculates three parts of the cost explained in 3.3. Therewith PCEM returns the total cost of the given placement to OM to be used in the optimization algorithm. Finally OM results the optimum placement for the IoTSP and sends it to coordinator so that it is delivered to the user.

C. Cost Estimation Function

Selection of a placement amongst all possible ones, can be done based on different criteria. In this paper, the cost optimality of the placement is the criterion. In other words, we intend to help the IoTSP to find the cost optimum placement so that it maximizes the profit of its business.

We base our cost estimation on [7] in which the authors have collected all types of infrastructure costs on multi clouds. The costs includes cost of running VMs on multiple clouds as well as the traffic cost among VMs of different clouds. For the case of this research i.e. IoTSP, we add another cost factor which is the traffic costs from users to the VMs. As the company has to provide internet access for the devices which are given to the users, the connectivity of the devices is the responsibility of the IoTSP. Hence Internet costs should be considered in this study.

For further calculations, we use following definitions for our mathematical model:

1. *Traffic Cost Rate Matrix (TCR)*: this is proposed by [7] which is a $P \times P$ -dimensional matrix, in which the rate per unit traffic (i, j) from Cloud provider i to Cloud provider j is shown. That means, it is the sum of the cost for one unit of outgoing traffic from provider i to provider j and the cost for one unit of

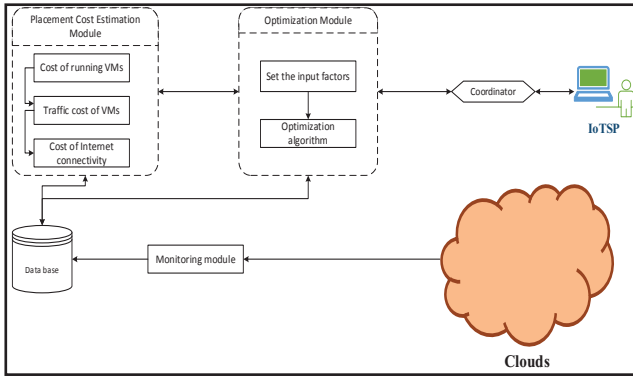


Figure 3 Proposed architecture for the decision support tool

incoming traffic to provider j from provider i . As Cloud providers usually charge only for in-bound and out-bound traffic of a service (i.e., for traffic that is related to outside their Cloud), all main diagonal elements of TCR are zero. However, if a provider also charges users for their internal data traffic, the corresponding main diagonal element will be unequal zero.

2. *SpecList (SL)*: a $4 \times S$ matrix which keeps the details of possible specs. The total number of possible specs is s . The matrix rows represent the 1) VM processor, 2) memory, 3) storage size and 4) bandwidth.

3. *VM Spec Vector (Spec)*: a $1 \times V$ vector which records the spec number (referring to SL matrix) of each VM. Note that some of the specs is common among the CSPs.

4. *CostPSpec (Spec, CSP)*: a $S \times P$ matrix which gives the cost of a given spec on a given CSP. This matrix would be extracted from CSP price list. We use this as a function with two input factors: Spec and CSP.

5. *Placement Matrix (Plc_{D×M})*: a $D \times M$ matrix in which D represents all of possible placements. The matrix holds details of all of placements giving each of them a code for further references. While using the matrix $Plc(m,*)$ gives a vector which represents placement # m .

6. *Internet Connectivity price (IC)*: a $1 \times n$ vector holding the Internet cost per month for each of the n assumed region.

7. *User*: a $1 \times n$ vector for the number are users of each of the n regions.

To capture total infrastructure cost we should consider three cost factors: 1) cost of running VMs 2) traffic cost among VMs (for synchronization and replication purposes) 3) Internet connectivity costs for users. We formulate them in equation 1:

$$\text{Total Cost of Placement: } TCP_m(j) = CVM_m + TrC_VM_m + CIC_m \quad (1)$$

Which returns the total cost of a given placement of IoTSP as a function of time (m). Which normally (but not necessarily always) the time unit is considered to be month. Basically total cost of placement is sum of three factors: cost of running VMs, traffic cost among VMs and cost of internet connectivity. The details of the equation is explained in equations 2~4:

$$\text{Cost of running VMs: } CVM_m(j) = m \sum_{i=1}^M (\text{CostPSpec}(\text{Spec}(i), \text{Plc}(j, i))) \quad (2)$$

Which calculates the computing costs of IoTSP incurred by a given placement j . *CostPSpec* gives the price of running VM # i on its CSP. The corresponding CSP could be known from $Plc(j, i)$ in which j refers to the given placement. The sigma

considers all of VMs of the placement. Hence the parameter i refers to all of the VMs starting from 1 to M which is number of VMs.

$$\text{Traffic Cost of VM: } TrC_VM_m(j) = m \sum_{k=1}^M \sum_{i=1}^M (TCR(Plc(j, i), Plc(j, k)) * (\theta * SL(4, Spec(i)))) \quad (3)$$

Which calculates traffic cost among VMs of the IoTSP in a given placement j over time. In the equation $Plc(j, i)$ and $Plc(j, k)$ return the CSP corresponding to VM # i and k accordingly. Then *TCR* gives the traffic cost between those two CSPs. Multiplying the cost rate to $\theta * SL(4, Spec(i))$ i.e. the amount of traffic generated by the VM # i calculates the traffic cost of the VM. The sigma accumulates traffic cost of all of the VMs in the given placement and returns the total traffic cost at end.

$$\text{Cost of Internet Connectivity: } CIC_m = m * \sum_{i=1}^n IC(i) * User(i) \quad (4)$$

Which calculates the accumulative Internet cost that is incurred by the usage of the n given regions. *IC(i)* gives the Internet price per each region per month while *User(i)* shows the assumed number of the users of the region.

D. Optimization Function

1) *Objective Function*: The objective function is to minimize the overall cost of VM placement while offering satisfactory coverage and performance for the users of the IoTSP.

2) *Optimization Algorithm*: We propose an optimization algorithm for the raised problem scenario. The algorithm returns the cost optimum VM placement among all of the possible VM placements **Figure 4** illustrates the steps of the algorithm. In details, the algorithm works as follows: First, it generates list of all possible VM placements. Step 3 picks one of the placements and step 4 calculates the total cost of this placement (TCP) using equation 1. The next step compares the TCP with the latest optimum placement. If the current placement incurs less cost, the algorithm picks it (step 6) and substitute the TCP to be the optimum cost (step 7). Then the algorithm checks if there more placements to be calculated and evaluated or not. If still there are remaining placements, it goes to step 3 to pick one of them and continue the loop until all of the possible placements are traced. Finally the algorithm returns the optimum placement and its total cost.

IV. SIMULATION: INTERNET-OF-HEALTH (IOH): PATIENT MANAGEMENT AND MONITORING

E. An Illustrative Scenario:

One company intends to offer an IoT-based health service to its clients. The purpose of the system is to collect all of the essential health data of patients. The *things* in this simulation are health measurement tools for different purposes (e.g. blood pressure, heart beat rate, blood sugar, blood fats, etc. [29]). All of the health info of the clients are to be stored in proper infrastructure.

The company needs to utilize proper infrastructure to connect all of the users and *things*; collect the required data and store them in proper database for on-time access as well as

further uses. The company should maintain the infrastructure cost-effectively so that the business makes reasonable profit.

The demand for infrastructure for the company varies over time and place. Hence it is not reasonable for the company to invest on establishment of its datacenter, rather the company intends to utilize multi cloud for its pay-as-you-use feature. The elasticity of clouds will help the company to increase the number of its servers and connectivity on high demand or shrink them on low demand. Besides, the coverage of the servers can easily be adjusted to the location-based demand. (Which is too difficult to manage if company wants to establish its Datacenter).

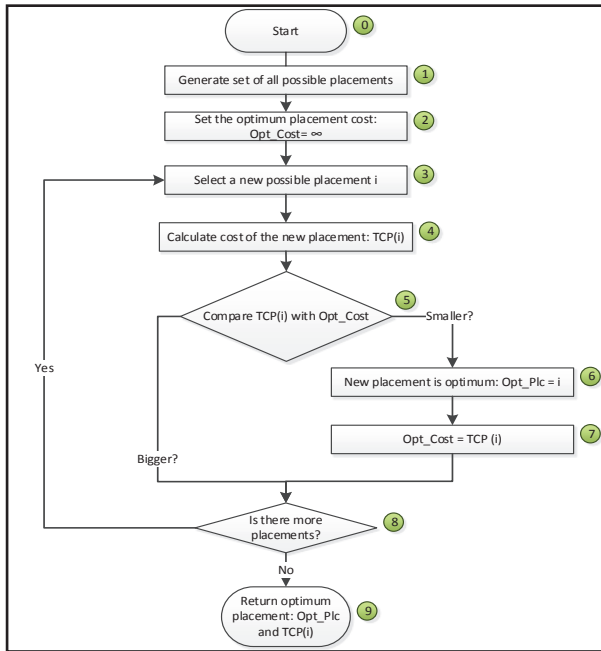


Figure 5 The proposed optimization algorithm

F. Input Factors:

For simplicity of the simulation (without losing generality) we assume to have 6 regions. The number of simultaneous connected users are assumed to be high at the working hours. Furthermore, each user's device (*thing*) makes a new request every 2 minutes while connected. Table 1 depicts the input parameters.

Table 1. Regions, no. of users during peak and off-peak and their prices

Region	users during peak hrs	users during off-peak hrs	VM price	Traffic cost
N. America	500,000	50,000	0.6	0.6
S. America	450,000	45,000	0.7	0.7
Europe	300,000	30,000	0.6	0.6
Asia	1,000,000	100,000	0.9	0.9
Africa	50,000	5,000	NA	NA
Oceania	70,000	7,000	0.8	0.8

G. Simulation experiment:

Several experiments are considered in our research to evaluate the working of the proposed model: **Figure 5** demonstrates the situation while the IoTSP does not utilize multi clouds and while utilizing it. Several experiments are conducted based on each scenario in which the *overall response time* (RT) and the *overall cost* is compared.

V. CONCLUSION

The integration of IoT and cloud computing is becoming a norm of future technology trends, hence studying the issues of the integration is a must for both industry and academia. In this work we have addressed cost-optimization for the IoT service providers which intends to offer services on clouds. It can be concluded from this research that the IoT decision makers need to consider monetary aspects of the cloud placement as well as the performance achieved by it. Our future study will focus more on other economic aspect of IoT in a dynamic environment aiming the business to be more profitable for the IoT companies.

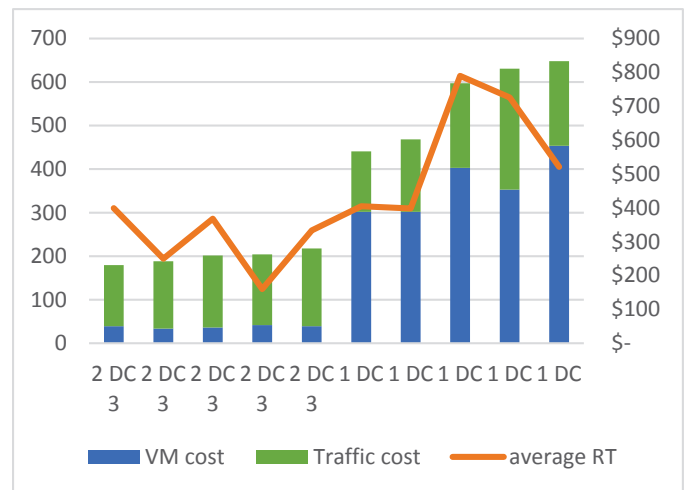


Figure 4 Comparison of the results of simulation experiments

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Mohammad Mahdi Kashef (mmkashef@snu.ac.kr) is a Ph.D. student at the Technology Management, Economics, and Policy Program (TEMPEP) of the College of Engineering, Seoul National University. His research interest is economics of Internet-of-Things, economics of cloud computing, service placement in clouds, cost-optimization.



Dr. Hyenyoung Yoon (hyeyoon00@snu.ac.kr) is a visiting professor for Technology Management, Economics and Policy Program at Seoul National University in Korea. Prior to this, she worked as a senior researcher in a Korea Communications Agency and LG Electronics. She received her Ph.D. in Technology Management Economics and Policy Program from Seoul National University, a Master's degree in Information and telecommunication engineering from Ewha Woman's University. Her current research interests are internet of things, personal information protection, resource management for cloud computing and spectrum management policy.



Mehdi Keshavarz (keshavarzm@snu.ac.kr) is a Ph.D. student at the Technology Management, Economics, and Policy Program of the College of Engineering, Seoul National University. His research interest is cloud computing, cloud federation, and simulation.



Prof. Junseok Hwang (junhwang@snu.ac.kr) is professor of Information Science and Technology at Technology Management, Economics and Policy program (TEMPEP), Seoul National University and Director of International Technology Policy Program (ITPP). Prior to this, he was an Assistant Professor in the School of Information Studies at Syracuse University. He received his Ph.D. in Information Science and Telecommunications from the University of Pittsburgh, a Master's degree in Telecommunications from the University of Colorado. His current research focuses on economics of information and network s, management and policy of convergence technologies, social impact study and forecasting of emerging technologies, knowledge management, patent research and policy analysis. On this topic of research, he is actively working for Digitalogy, and Technology and Humanities Convergence study.