ISSN 2383-6318(Print) / ISSN 2383-6326(Online)
KIISE Transactions on Computing Practices, Vol. 24, No. 11, pp. 575-581, 2018. 11
https://doi.org/10.5626/KTCP.2018.24.11.575

QoE를 고려한 Unlicensed 스펙트럼에서의 LTE 배치 연구
(Coexistence of LTE-U and Wi-Fi System Considering the User's QoE)

아누팜 쿠마르 바이라기 † (Anupam Kumar Bairagi)
아시스 탈룩더 † (Ashis Talukder)
김 도 현 † (Do Hyeon Kim)
홍 충 선 †† (Choong Seon Hong)

요 약 무선 네트워크 트래픽의 기하급수적인 증가는 한편으로는 기회이지만, 또 다른 한편으로는 무선 네트워크의 병목 현상을 나타낸다. Unlicensed 스펙트럼의 LTE (Long-Term Evolution)은 제한된 license 스펙트럼으로 무선 네트워크의 병목 현상을 해결하려하는 네트워크 운영자에게 좋은 대안이 될 수 있다. 하지만 본 기술을 적용할 때, Wi-Fi와 같은 Unlicensed 스펙트럼 및 기존 LTE 시스템과의 공존 문제와 더불어 자원할당 문제를 고려해야 한다. 또한 대부분의 관련연구는 자원할당을 위해 사용자의 QoS 요구사항을 고려하지만 한계점을 보여주고 있다. 이에 본 논문에서는 사용자의 QoE (Quality of Experience)를 고려한 LTE-U와 Wi-Fi 시스템 간의 공존 메커니즘을 제안한다. 아울러 본 논문에서 해결하고자하는 최적화 문제를 공식화하고, 두 가지 문제를 해결하기 위해 Nash Bargaining 게임과 Bankruptcy 게임을 사용한다. 시뮬레이션 결과는 LTE 사용자와 Wi-Fi 사용자의 관점에서 제안된 방법의 효율성을 보여준다.
키워드: 비면허대역 LTE, 체감품질, 공존, 내쉬 협상 게임, 파산 게임

Abstract The exponential growth of wireless traffic is an opportunity on one side and bottleneck on the other for the wireless industries. Long-Term Evolution (LTE) in unlicensed spectrum can be a good alternative for the cellular network operators to clutch this opportunity owing to limited licensed spectra. Limitation in licensed spectra causes co-existence issue with other technologies in unlicensed spectra like Wi-Fi and resources allocation issue to the existing LTE system. Moreover, most of the works consider QoS requirements of the users for allocating resources, which could not meet user's requirement. Thus, we propose a co-existence technique between LTE-U and Wi-Fi system considering the quality of experience (QoE) of the users. We have formulated an optimization problem for the existing problem. To solve co-existence and resource allocation issues, we have employed the Nash bargaining game and Bankruptcy game, respectively. Simulation results revealed the effectiveness of the proposed method over other methods in case of LTE users and also for Wi-Fi users.
Keywords: LTE-U, Quality of experience (QoE), Co-existence, Nash bargaining game, Bankruptcy game

· This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT). (NRF-2017R1A2A2A05000995)
· 이 논문은 제44회 한국소프트웨어종합학술대회에서 'Deploying LTE in Unlicensed Spectrum Considering Quality of Experience (QoE)'의 제목으로 발표된 논문을 확장한 것임

† 학생회원 : 경희대학교 컴퓨터공학과
anupam@khu.ac.kr
ashis@khu.ac.kr
doma@khu.ac.kr
†† 종신회원 : 경희대학교 컴퓨터공학과 교수(Kyung Hee Univ.)
cshong@khu.ac.kr
(Corresponding author임)

논문접수 : 2018년 3월 9일
(Received 9 March 2018)
논문수정 : 2018년 7월 26일
(Revised 26 July 2018)
심사완료 : 2018년 8월 21일
(Accepted 21 August 2018)

정보과학회 컴퓨팅의 실제 논문지 제24권 제11호(2018. 11)

1. Introduction

With the booming explosion of cellular traffic, many researchers are recommending to employ free unlicensed spectrum with existing LTE networks to serve and meet the growing requirements of the users. 3GPP has already announced Licensed-Assisted Access (LAA) of unlicensed spectrum in LTE network for the downlink in part of their release 13 [1] with the help of carrier aggregation (CA).

Though this strategy can probably resolve the spectrum deficiency issue of cellular networks, it will create a great concern for the existence of already deployed technologies in the unlicensed spectrum like Wi-Fi. Thus, LTE in unlicensed (LTE-U) will create two issues namely co-existence and resource allocation for the LTE network.

For solving the co-existence issue of LTE-U deployment, different authors mainly focused on either listen-before-talk (LBT) based approach or resource sharing approach. The authors of paper [2] and [3] propose LBT based approach of co-existence between LTE-U and Wi-Fi systems. In [2], the authors use adaptive back-off window size depending on the rate requirements of LAA-UEs, but the performance of LBT based approach is not comparable with LTE system specially in dense deployment case. A proportional fair dynamic channel switch technique is proposed for LBT based LTE-U in order to coexist with Wi-Fi network in [3]. They introduce a frozen period by modifying binary exponential LBT to ensure correct channel switching decision. This approach is effective for low traffic only. Thus, when considering the performance issue of deploying unlicensed spectra with LTE network, authors mostly use resource sharing approaches ([4-8]) for solving the coexistence issue. The authors in both [4] and [5], proposed effective coexistence approaches based on cooperative Nash bargaining game (NBG). They considered inter-operators' interference in their model and found optimal sharing time. In [4], they used Bankruptcy game to allocate unlicensed resource among the users, whereas a heuristic algorithm is used in [5]. In both the cases, their approaches proved effective over other methods and can protect Wi-Fi system better way than basic LBT does. The authors formulated a resource allocation problem of an LTE-U system by decoupling the uplink-downlink and also a licensed-unlicensed band by engaging echo state network in [6]. They protect the Wi-Fi system by splitting the time between the two systems. But they didn't find optimal time and also did not consider interference from other LTE-U BSs. A ruin theory based coexistence model is proposed in the work [7]. It has no clear direction on how time resource will be shared between the two systems. In [8], the authors use game theoretic approach for solving the coexistence issue between LTE-U and WiFi systems.

Most of the research works consider quality-of-service (QoS) requirements of the users for allocating unlicensed resources to the users. But, QoS takes care of network operator's perspective, not the users' perceived quality of experience (QoE) and a system which is QoS fair, can be QoE unfair [9]. As per our knowledge, there is no work except [10] that deals with deploying LTE-U considering QoE of users. But authors of [10] did not consider the coexistence issue while trying to solve the spectrum sharing issue in 5G. Thus, in this paper, we propose a QoE-enabled co-existence mechanism for deploying LTE network in unlicensed spectra.

The rest of the paper is organized as follows: Section 2 presents the system model and problem formulation whereas Section 3 provides the solution approach for the concerned problem. Simulation and performance analysis are included in Section 4. Finally, we provide the concluding remarks in Section 5.

2. System Model and Problem Formulation

We have one small cell base station (SBS) and a set of non-overlapping Wi-Fi access points (WAP) working in downlink scenario as shown in Figure 1. SBS has a set of users N under its coverage area and each WAP has a set of connected users Ww. SBS has a set of licensed resource block L={1, 2, ..., L} for supporting its user. Both SBS and WAPs use same unlicensed spectrum in 5GHz band. The SBS can support a set of services S={1, 2, ..., S} by using a set of modulation and coding scheme (MCS) M={1, 2, ..., M}.

A. Application Model

QoE is application specific and we use mean

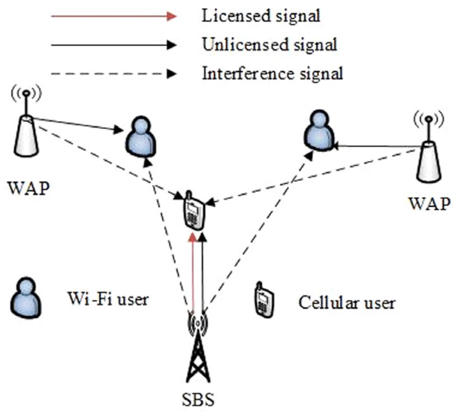

Fig. 1 System Model

opinion score (MOS) as the QoE metric to measure user's satisfaction. In the following section, we are going to represent the mapping between the transmission characteristics and MOS of different applications.

(i) **Web browsing:** Users are concerned about page loading time in case of web browsing. Authors of [11] present an MOS function for web browsing as follows:

$$\mu_b = 5 - \frac{578}{1+\left(11.77+\frac{22.61}{d}\right)^2} \quad (1)$$

where d is the service response time.

(ii) **File downloading:** File downloading is an elastic service. We user the following MOS-throughput [12] relationship:

$$\mu_d = a\log_{10}\left[br(1-p_e)\right] \quad (2)$$

where r is the current rate offered to a user, p_e is the packet error probability, and a,b are coefficients.

(iii) **Video Streaming:** We use the MOS value as introduced in [13] and shown as follows:

$$\mu_s = \frac{a_1 + a_2 f_r + a_3\log_2 r}{1 + a_4 p_e + a_5 p_e^2} \quad (3)$$

where f_r denotes frame rate, r indicates sender bit rate, $a_{1\sim}a_5$ are the coefficients and p_e is the packet error probability.

B. Network Model

LTE uses orthogonal frequency division multiple access (OFDMA) technique to allocate physical resources to its users. It also employs same MCS over multiple resource units in a time for a user. Thus, SBS will provide at least one resource block (RB) to all of its current users. It will provide unlicensed resources to those users who are unsatisfied with current QoE. For managing unlicensed resource, let us assume that SBS divides it a set of sub-carriers K={1, 2, ..., K}. Then, SBS can offer the following rate for a user $j \in N$.

$$r_j = \sum_{l\in L}\alpha_j^l \sum_{m\in M}\delta_j^m r_m + \sum_{k\in K}\beta_j^k \sum_{m\in M}\delta_j^m r_m^u \quad (4)$$

where $r_m = \frac{n_{sc} r_c^m \log_2 C_m}{t_s}$ and $r_m^u = \frac{r_m}{n_{sc}}$ with n_{sc}, r_c^m, C_m, and t_s representing number of sum-carriers in a RB, code rate of MCS m, constellation size of MCS m, and OFDM symbol duration respectively. Moreover, $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ represent the allocation vector for licensed and unlicensed spectrum, whereas δ indicates the choice of MCS for the user.

C. Problem Formulation

We assume that one user can use one application at a time and every user owns one licensed sub-channel. For co-existing with WAP, SBS needs to share $\psi \in [0,1]$ time in unlicensed spectrum. Rest of the time SBS can utilize for its unsatisfied users. Now, our goal is to maximize the sum of MOS and the problem statement is shown as follows:

$$\max \sum_{j\in U}\sum_{s\in S}\phi_j^s \mu_s^j \quad (5)$$

Subject to

$$C1:\ \alpha_j^l, \beta_j^k, \delta_j^m, \phi_j^s \in \{0,1\},\ \forall j,l,k,m,s$$

$$C2:\ \sum_{j\in U}\alpha_j^l \le 1, \sum_{j\in U}\beta_j^k \le 1,\ \forall l,k$$

$$C3:\ \sum_{l\in L}\alpha_j^l = 1, \sum_{k\in K}\beta_j^k \ge 1,\ \forall j$$

$$C4:\ \sum_{j\in U}\sum_{k\in K}\beta_j^k \le K$$

$$C5:\ \sum_{m\in M}\delta_j^m = 1, \sum_{s\in S}\phi_j^s = 1,\ \forall j$$

$$C6:\ \psi_0 \le \psi \le 1$$

Here, constraints $C1 \sim C6$ is for LTE-U system and C6 is for the co-existence with Wi-Fi system and ψ_0 is the minimum amount of time that is necessary for ensuring minimum rate to Wi-Fi users when SBS acts just like another WAP which affects the performance of all the Wi-Fi users. C1 indicates that each element of $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, $\boldsymbol{\delta}$, and$\boldsymbol{\phi}$ is binary, whereas C2 specifies that each licensed and unlicensed RB

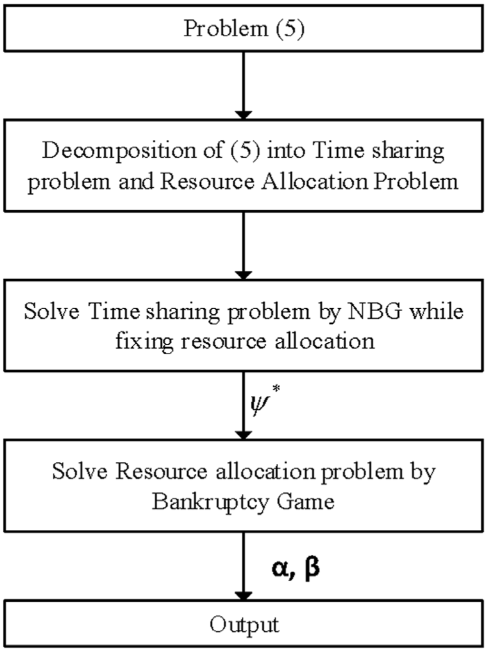

Fig. 2 Solution approach to the problem (5)

can be allocated to only one user. C3 shows that each user can have only one licensed RB while the user can pose more than one unlicensed RB. C4 presents unlicensed RB constraint; whereas C5 designates that each user can use only one MCS and one service at a time. This is a mixed integer non-linear programming (MINLP) problem and NP-hard to solve.

3. Solution of the Problem

To fulfill the objective of (5), SBS wants the major portion of ψ that will subdue the performance of Wi-Fi system. For a fair coexistence technique between these two systems, we need a win-win situation for both the parties. As ψ is limited, it is unlikely to maximize both parties objective simultaneously. That is why, we need an effective mechanism for sharing time between the two systems. The solution approach of the problem is shown in the Figure 2. For solving the co-existence issue between the SBS and Wi-Fi, we can use Nash Bargaining Game (NBG) [14] that gives one unique and fair solution between contending parties. Using the solution concept of NBG, we can find the optimal sharing (ψ*) time between the two systems and the result of our paper [4] is used here as follows:

$$\psi^* = \frac{1}{2} + \frac{\sigma}{2} \tag{6}$$

where σ is the ratio of average achieved rate of a Wi-Fi user without and with the presence of SBS in the unlicensed spectrum (like WAP).

Thus, SBS can utilize $1-\psi^*$ time for LTE-U users in the same unlicensed spectrum without affecting Wi-Fi users. For solving the resource allocation issue of the SBS, we use bankruptcy game (BG) [15] framework. In this framework, a bankrupt company wants to distribute the remaining money (P) among the creditors (A). The demand/claim ($\boldsymbol{c}$) of the creditors is larger than the money of the bankrupt company. For ensuring the fair allocation of money among the creditors, an N-person game is applied to get the equilibrium point to distribute the money. If $\boldsymbol{x}^*$ is a solution of the BG then the solution must have to satisfy the following conditions:

$$c_j \geq x_j \geq 0 \tag{7}$$

$$\sum_{j \in A} c_j \geq P \tag{8}$$

$$\sum_{j \in A} x_j = P \tag{9}$$

In our scenario, we have a set of unsatisfied users, amount of unlicensed sub-carriers with time $1-\psi^*$ and requirements of unlicensed sub-carrier for achieving highest MOS which act as A, P and $\boldsymbol{c}$ respectively. A BG based resource allocation process is shown in Algorithm 1. The algorithm consists of four basic steps. Licensed resources are allocated to the users in the first step. In the second step, MOS value of the users are calculated depending on either (1), (2) or (3) for the allocated resources of first step. The user satisfaction status is calculated in the third step. If the MOS value of a particular user is 5, then the user is fully satisfied. In other case, the user needs support from unlicensed spectrum for achieving better QoE. Step four is responsible for allocating unlicensed resources to the unsatisfied users. In this step, unlicensed resources are allocated to the users based upon proportional fairness manner.

Algorithm 1 Bankruptcy Game-Based Resource Allocation for the SBS

Inputs:
  Set of user U
  Set of licensed sub-channels L
  Set of unlicensed sub-channels K
  Users' requested services S
Output: α, β
Step 1: Allocation of licensed resource
for each j in U
  Set $\alpha_j = j$
end for
Step 2: Calculation of MOS for α
for each j in U
  Calculate $\mu_j^{S_j}$ *using* α_j *and (1)/(2)/(3)*
end for
Step 3: Status of satisfaction of the users
for each j in U
  Initialize $SS_j = 1$
  If $\mu_j^{S_j} \neq 5$ *then*
    Set $SS_j = 0$
  end if
end for
Step 4: Allocation of unlicensed resource
Set $Tot = 0$
for each j in U
  If $SS_j = 0$ *then*
    Set $Tot = Tot + 5 - (\mu_j^{S_j})$
  end if
end for
Set $idx = 1$
for each j in U
  Set $N_{RB} = \frac{5 - \mu_j^{S_j}}{Tot} K$
  for each k in $\{1, 2, ..., N_{RB}\}$
    Set $\beta_{idx} = j$
    Set $idx = idx + 1$
  end for
end for

4. Performance Evaluation

We evaluate the performance of the proposed method by comparing with LTE-A, LTE-U with equally distributed unlicensed resource (LTE-U(Equal)), LTE-U with randomly selected users (LTE-U (Random)) by using simulation. SBS has 50 users with 50-licensed RB for browsing, file downloading and video streaming and distributed randomly in the conflicting area of radius 150m. Both networks use 20MHz unlicensed band in 5GHz band. We use $15.3 + 37.5\log_{10}(d)$ as the path loss model for both licensed and unlicensed spectrum. For the Figures 3 and 4, we presented the results of 1000 runs of the program.

In Figure 3, we show the empirical cumulative distribution function (ECDF) comparison of the average MOS of LTE-U(Proposed) with the comparing schemes LTE-A, LTE-U(Equal), and LTE-U(Random). The figure shows that the ECDF of average MOS value resulting from the proposed method is better than all other baseline methods in this case. The same figure also reveal that the proposed method achieves average MOS of more than 4.6 with a probability 0.85, whereas LTE-U (Equal) and LTE-U(Random) archive the same with probability 0.60 and 0.10 respectively. However, LTE-A gains less than 4.3 MOS score with probability 0.75. More specifically, the average MOS values are 4.275, 4.608, 4.533, 4.659 for LTE-A, LTE-U(Equal), LTE-U(Random), respectively. That means, the proposed method achieves 8.24%, 1.08%, and 2.69% more MOS on average than

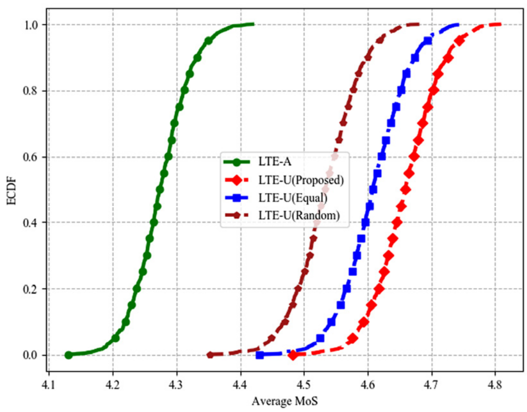

Fig. 3 Comparison of average MOS

LTE-A, LTE-U(Equal), LTE-U(Random) respectively.

Figure 4 shows the distribution of Jain's fairness index [16] among the users in different methods. We find from the figure that the proposed method offers a fairer allocation of resources than LTE-A, LTE-U(Equal), and LTE-U(Random) in most of the cases. Specifically, these scores of LTE-A reside between 99.3%～99.6% whereas the same indices for LTE-U(Equal) and LTE-U(Random) happen inside 99.65%～99.80%, and 99.60%～99.80% respectively. But this values of the proposed method are between 99.75% and 99.90%. Particularly, the average fairness scores are 0.9945, 0.9971, 0.9969, 0.9980 for LTE-A, LTE-U(Equal), LTE-U(Random), respectively. Therefore, the mean value of these fairness scores for the proposed method is 0.35%, 0.09%, and 0.11% better than LTE-A, LTE-U(Equal), and LTE-U(Random) respectively.

A comparison of normalized throughput of Wi-Fi user between the proposed method and LBT is presented in Figure 5. It shows that the proposed method protects Wi-Fi user better than basic LBT does in all cases, and the throughputs of the proposed method and basic LBT are decreasing with the increasing number of SBSs. This reduction in throughput is due to the escalating competition with increased SBSs. Specifically, the proposed approach achieves 29.50%, 69.40%, 83.86% more throughput for Wi-Fi users than the basic LBT. Moreover, this results shows a 64.28% better throughput for Wi-Fi user than basic LBT on average. Additionally, this protection reflects more on the denser deployment scenario than sparse environment.

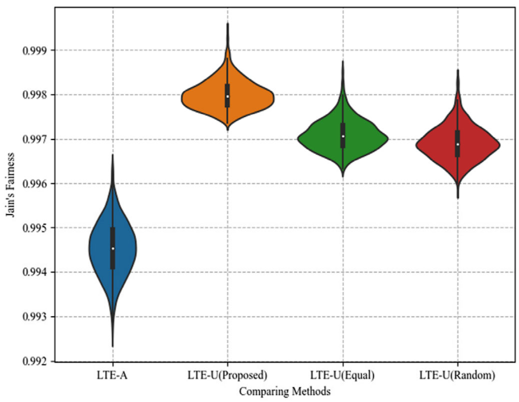

Fig. 4 Comparison of Wi-Fi user's normalized throughput considering variable SBSs

5. Conclusion

In this paper, we proposed a QoE oriented LTE-U technique that can co-exist with Wi-Fi system fairly. We formulated a MOS maximization optimization problem. For solving the problem, we used Nash bargaining game and Bankruptcy game. The proposed approach gave good average MOS and fairness among users than LTE-A, LTE-U(Equal), and LTE-U(Random) methods. Moreover, the proposed approach protected the Wi-Fi user fur better way than basic LBT.

References

[1] 3GPP TR 36.889 V13.0.0, "Study on licensed-assisted access to Unlicensed spectrum (Release 13)," Jun. 2015.

[2] R. Yin, G. Yu, A. Maaref, and G. Y. Li, "LBT based adaptive channel access for LTE-U system," *IEEE Transactions on Wireless Communications*, Vol. 15, No. 10, pp. 6585-6597, Oct. 2016.

[3] H. Li, Y. Chang, F. Hao, A. Men, J. Zhang, and W. Quan, "Study on dynamic channel switch in License-Assisted-Access based on Listen-Before-Talk," *2016 International Symposium on Wireless Communication Systems (ISWCS)*, pp. 506-510, Sep. 2016. (in Poland)

[4] A. K. Bairagi, N. H. Tran, and C. S. Hong, "A Multi-Game Approach for Effective Co-existence in Unlicensed Spectrum between LTE-U System and Wi-Fi Access Point," *2018 International Conference on Information Networking (ICOIN)*, pp. 380-385, Jan. 2018. (in Thailand)

[5] A. K. Bairagi, N. H. Tran, W. Saad, and C. S. Hong, "Bargaining Game for Effective Coexistence between LTE-U and Wi-Fi Systems," *2018 IEEE/IFIP Network Operations and Management Symposium (NOMS 2018)*, pp. 1-8, Apr. 2018. (in Taiwan)

[6] M. Chen, W. Saad, and C. Yin, "Echo state networks for self-organizing resource allocation in LTE-U with uplink-downlink decoupling," *IEEE Trans. Wireless Communication*, Vol. 16, No. 1, pp. 3-16, Jan. 2017.

[7] A. Manzoor, N. H. Tran and C. S. Hong, "Ruin Theory Based Modeling of Fair Spectrum Management in LTE-U," *2017 19th Asia-Pacific Network Operations and Management Symposium (APNOMS)*, Seoul, 2017. (in Korea)

[8] A. K. Bairagi, S. F. Abedin, N. H. Tran, D. Niyato, and C. S. Hong, "QoE-Enabled Unlicensed Spectrum

Sharing in 5G: A Game-Theoretic Approach," *IEEE Access*, Vol. 6, Sep. 2018.
[9] A. Mansy, M. Fayed, and M. Ammar, "Network-layer fairness for adaptive video streams," *Proc. IFIP Network Conference*, pp. 1-9, May 2015. (in France)
[10] N. Zhang, S. Zhang, J. Zheng, X. Fang, J. W. Mark, and X. Shen, "QoE Driven Decentralized Spectrum Sharing in 5G Networks: Potential Game Approach," *IEEE Transactions on Vehicular Technology*, Vol. 66, No. 9, pp. 7797-7808, Sep. 2017.
[11] P. Ameigeiras, and et al., "QoE oriented cross-layer design of a resource allocation algorithm in beyond 3G systems," *Computer Communications*, Vol. 33, No. 5, pp. 571-582, 2010.
[12] F. P. Kelly, "Charging and rate control for elastic traffic," *European Transactions on Telecommunications*, Vol. 8, No. 1, pp. 33-37, 1997.
[13] A. Khan, L. Sun, E. Jammeh, and E. Ifeachor, "Quality of experiencedriven adaptation scheme for video applications over wireless networks," *IET Communications*, Vol. 4, No. 11, pp. 1337-1347, Jul. 2010.
[14] M. Maschler, E. Solan and S. Zamir, Game Theory, Cambridge University Press, New York, 2013.
[15] B. ONeill, "A problem of rights arbitration from the Talmud," *Mathematical Social Sciences 2*, pp. 345-371, 1982.
[16] R. Jain, D.M. Chiu, and W.R. Hawe, "A quantitative measure of fairness and discrimination for resource allocation in shared computer system," *Eastern Research Laboratory, Digital Equipment Corporation*, Vol. 38, Sep. 1984.

Anupam Kumar Bairagi received his B.Sc. and M.Sc. degree in Computer Science and Engineering from Khulna University (KU), Bangladesh. Currently, he is pursuing his PhD degree from Kyung Hee University (KHU), South Korea, for which he was awarded a scholarship in 2014. He is a faculty member in the discipline of Computer Science and Engineering, Khulna University, Bangladesh. His research interests includes wireless resource management, cooperative communication and game theory.

Ashis Talukder received the BS and MS degrees in Computer Science and Engineering from University of Dhaka (DU), Bangladesh. He is an Assistant Professor, Department of Management Information Systems (MIS), University of Dhaka, Bangladesh. Currently, he is pursuing Ph.D. in the Department of Computer Science and Engineering at Kyung Hee University, South Korea. His research interests include social networks, influence maximization, network optimization, and data mining. He is a member of KIISE, and IEEE communication society.

Do Hyeon Kim received his B.S. degree in Communication Engineering from Jeju National University, in 2014 and received M.S. degree from Kyung Hee University in 2017. He is currently working toward his PhD degree at the Department of Computer Science and Engineering, Kyung Hee University. His research interests include SDN/NFV.

홍 충 선
정보과학회 컴퓨팅의 실제 논문지
제 24 권 제 6 호 참조