A Novel Co-operative Channel Assignment Scheme for Indoor Base Stations

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Abstract—**This paper presents a co-operation technique of channel assignment (CA) for indoor base stations (BSs). Indoor BSs are most of the time deployed by users in an ad-hoc manner which makes prior network planning by network operators impossible. If the same pool of radio resources (e.g channels) is used by close BSs, co-operation between these BSs is vital for resolving problems such as interference. In the proposed scheme, femtocell base station (FBS), which is a typical example of indoor BS, is considered. FBSs in close proximity exchange UE-assisted (User Equipment) measured reference power information, and based on individual position of each FBS, inter-BS interaction is used to form clusters. In each cluster, the cluster-head (CH) uses channel assignment tables to assign channel resources to cluster-members (CMs) in a distributed manner. This scheme helps to ensure that the interest of neighbor BSs is always considered whenever a BS makes use of the available network resources. Our simulation results show that co-operative CA using a cluster-based approach yields higher average user throughput than autonomous channel selection by individual BSs.**

Keywords-*: indoor BS; femtocell; cluster; channel assignment; LTE-advanced*

I. INTRODUCTION

As a result of the merits associated with the use of indoor base stations (BSs), new radio resource management techniques are continuously emerging such as [1]. A femtocell base station (FBS) is an example of indoor BS and it has been estimated that about 70 million FBSs will be deployed by 2012 [2]. In [3]**,** the authors point out that femto-to-femto interference is an important issue for indoor performance, especially when FBSs are densely deployed. Since the number and position of femtocell access points (FAPs) will be unknown, interference management cannot be further handled by the network operator using traditional network planning and optimization techniques [4]. Hence, it has become imperative to develop ingenious algorithms capable of mitigating interference in the next generation of wireless access networks.

Some viable approaches for limiting inter-cell interference problems include, power control, opportunistic spectrum access, intra and inter-BS interference cancellation, adaptive fractional frequency reuse, spatial antenna techniques such as MIMO and SDMA, and adaptive beam forming [5]. Inter-cell interference mitigation techniques are generally classified as three types: inter-cell interference randomization, inter-cell interference cancellation, and inter-cell interference coordination [6]. Inter-cell interference randomization is aimed at randomizing the interference and allowing interference mitigation through processing gain. Inter-cell interference cancellation techniques are proposed to cancel interference at receivers by using multiple antenna techniques or interleaved division multiple access (IDMA) schemes. Inter-cell interference coordination (ICIC) is achieved by restrictions imposed on resource usage in terms of resource partitioning and power allocation. In this paper, we will discuss ICIC in the context of base station co-operation.

In [7]**,** a controller-based coordination is proposed to mitigate interference. The controller receives measured signals from all BSs and then runs an algorithm so that the result is used in making decision whether to increase the pilot strength of some BSs and decrease the pilot strength of others. The authors in [8] introduce the concept of a controller based distributed cognitive pilot channel for radio resource management. This is an extension of cognitive pilot channel (CPC) technique, but in this case, instead of covering the various networks by a single CPC, the proposal describes the deployment of CPC transmission in a distributed manner within each of individual smart FBS controlled composite network. Ref. [9] discusses an autonomous component carrier selection technique for LTE-Advanced networks and explains how each cell selects the most attractive frequency configuration for use. This scheme follows an autonomous approach; however, there is no co-operation among BSs which could lead to an undesired interference situation.

This paper is an extension of [1] in which we discussed base station co-operation protocol. In this paper we will extend our previous work and discuss co-operative channel assignment (CA) for a cluster network. Unlike the above related works [7]-[9], our proposed scheme, co-operative CA scheme, rely strongly on the co-operation between BSs. Co-operation is achieved in a distributed manner, using a series of messages which are exchanged between BSs that are located in close proximity [1]. The distributed nature of the scheme makes the scheme particularly suitable for large networks.

The rest of this paper is organized as follows: In Section II we describe the system model while in Section III we introduce the cluster scheme. Section IV contains a numerical evaluation of the performance of our proposed co-operative channel assignment scheme. Finally, conclusions are summarized in Section **V**.

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II. SYSTEM MODEL

Throughout this paper, the downlink of the LTE-Advanced system is considered. The 100 MHz LTE-Advanced consists of five component carriers (CCs), each with a bandwidth of 20MHz. We assume that each FBS uses only one of the 20MHz bandwidth CCs for transmission. Each CC contains 100 resource blocks (RBs) and each RB has a bandwidth of 180KHz. Our BS deployment technique follows the approach discussed in [10] where a 5 X 5 grid model was used to simulate FBS deployment. This simulation assumption represents a realistic case in which an apartment may or may not have a FBS deployed in it. FBSs are randomly and uniformly dropped with a probability p in each of the 25 apartments being considered and the FBSs are placed at the centre of the apartments. Each apartment has a dimension of 10 X 10 m^2 and whichever one contains an FBS also contains exactly one associated user equipment (UE). The UE is dropped randomly and uniformly at a specified minimum separation distance of 0.2 m [10] and a maximum separation distance d m from its serving BS which operates in the closed access mode [4]. In this consideration, the closed access mode ensures that a UE connects to its serving FBS only, notwithstanding its closeness to other neighbor FBSs. In order to compute the useful/interfering signal, a simplified pathloss model recommended in [10] for the 5 X 5 grid deployment in LTE-advanced is used such that pathloss is calculated as

$$L(\mathrm{dB}) = 127 + 30\log_{10}\left(\frac{R}{1000}\right). \tag{1}$$

R is the distance between the UE and the FBS. This simplified LTE-Advanced model avoids the need to model wall penetration loss. A realistic link level model suggested by the 3rd Generation Partnership Project (3GPP) for LTE link level simulation [11] is used to model the link adaptation:

$$R_u = \begin{cases} 0 & \text{for } \gamma_u < \gamma_{\min}, \\ \alpha \cdot B \cdot A(\gamma_u) & \text{for } \gamma_{\min} < \gamma_u < \gamma_{\max}, \\ \beta \cdot B & \text{for } \gamma_u > \gamma_{\max}, \end{cases} \tag{2}$$

where $A(\gamma_u) = \log_2(1+\gamma_u)$ and R_u is the capacity achieved by user u in bps at SINR γ_u. B denotes the channel bandwidth in Hz, α is the attenuation factor representing implementation losses, while β is the maximum throughput of the ACM codeset in bps/Hz. $\gamma_{\min}$ denotes minimum SINR of the codeset while $\gamma_{\max}$ is the SINR at which maximum throughput is reached. These parameters are summarized in Table I.

Table I: Link to system mapping parameters

Parameter	Value	Note
α	0.6	Implementation losses
$\gamma_{\min}$[dB]	-10	QPSK
$\gamma_{\max}$[dB]	19.5	64QAM
β[bps/Hz]	4.4	Maximum spectral efficiency

III. CLUSTER SCHEME

In this section, we describe how cluster scheme can be beneficial in a network that comprises of many user-deployed FBSs. Before explaining schemes, we should clarify the problem. The problem we are considering is a channel assignment problem, but the word “channel” has several notations. In this paper, we use the word “channel” to represent “bandwidth”. If nearby BSs use different channels, the problem of interference does not arise. But, if the same channel is used by very close BSs, interference is introduced and this could result in a poor network performance.

Automatic coordination among closely located indoor BSs is therefore vital. This coordination helps to improve the network radio resource distribution pattern at high activation ratio. The activation ratio is the percentage of active FBSs in a network at any particular time [10]. One way of achieving this type of automatic coordination is through the formation of clusters which we will now explain.

A. *CLUSTER CONCEPT*

In conventional cellular networks, handover is often done when the signal strength received from the serving BS becomes significantly weaker than the strength received from a neighbor BS. Indoor BSs are, however, usually purchased and deployed by users and handover functionality may not be available, depending on the access mode of the BS such as, closed access mode. Since indoor BSs are deployed by users, network planning prior to deployment is impossible, owing to the fact that the position of each BS is usually not previously known. Moreover, the BS is not a fixed structure and a user can move it to a new location, thereby disrupting initially configured RF parameters. Fig. 1 illustrates a typical cluster structure. In the proposed cluster system, one BS assumes the duty of a cluster-head (CH), and this BS is responsible for making final decision regarding the radio resource usage (for example, channel

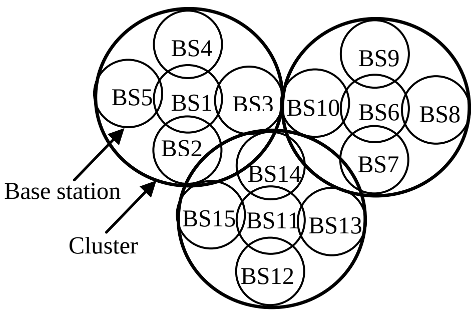

Figure 1. Typical base station clusters

utilization, optimum pilot strength, time-slot usage, joint scheduling coordination etc.) by members of its cluster. If a cluster-member (CM) is being restricted to use a channel on which it is experiencing high interference, the CH can re-organize spectrum usage in the cluster, thus achieving a better user experience at each BS.

The CH will normally communicate with its CMs over radio or DSL (or X2 interface in the case of LTE networks), so that it is not necessary for other members of the cluster to communicate directly with each other since resource sharing will be centrally coordinated by the CH. In order to realize an effective resource assignment procedure by the CH, we divide the whole process into three major steps, which are: (1) *cluster formation*, (2) *interference coordination*, and (3) *channel assignment*.

B. CLUSTER FORMATION

We propose two types of cluster formation techniques, which are, *choose first request* and *choose best request* schemes. These two schemes differ by the way in which the CM candidate selects its CH. In the *choose first request* scheme, the CM candidate waits for the first request to come from a CH candidate and it immediately sends a response when it receives the request. This scheme is particularly useful in a network in which there are no existing clusters or in a network in which few clusters have been formed. It ensures that the expected minimum allowed cluster size is guaranteed throughout the network, since a CH candidate that nominates itself will certainly get responses from all the CM candidates it sends requests to. However, in the *choose best request* scheme, the CM candidate does not send response after receiving the first request from a CH candidate. Instead, it waits for a pre-configured time delay before it chooses one of the several requests it receives from multiple CH candidates. This is particularly useful in a network in which several clusters have been formed. It gives the CM candidate the opportunity to send response to the CH to which it could possibly cause the highest interference.

(i) Choose first request

The *choose first request* scheme is illustrated in Fig. 2. When a *form cluster* instruction is initiated, all BSs in the network use UE-assisted measurements to determine the reference power received from their neighbor BSs. Due to the random position of BSs and user equipments, the measured values at individual cells follow a random pattern; hence, some stations receive stronger power from more neighbors than others. These BSs become CH candidates because they are in higher interference regions compared to others. The CH candidates send *Join Cluster* (JC) requests to a predetermined number of neighbor BSs from which strongest powers are measured. These neighbors immediately send acknowledgement messages in response to the request.

(ii) Choose best request

The *choose best request* scheme is illustrated in Fig. 3. Assuming in a network, a number of BSs have already formed clusters before a new BS is turned-on, it is possible for this newly switched-on BS to receive JC requests from more than one CH. Since the CHs are at different distances away from the newly switched-on BS, their path losses are also different. In this situation, the best CH for this newly switched-on BS is the CH to which it could possibly cause the highest interference. Hence, only the CH whose UE measures the strongest pilot strength from the CM candidate receives an acknowledgement message as illustrated in Fig. 3.

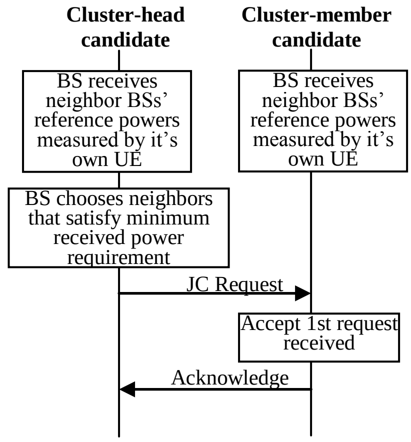

Figure 2. *Choose first request* cluster formation scheme

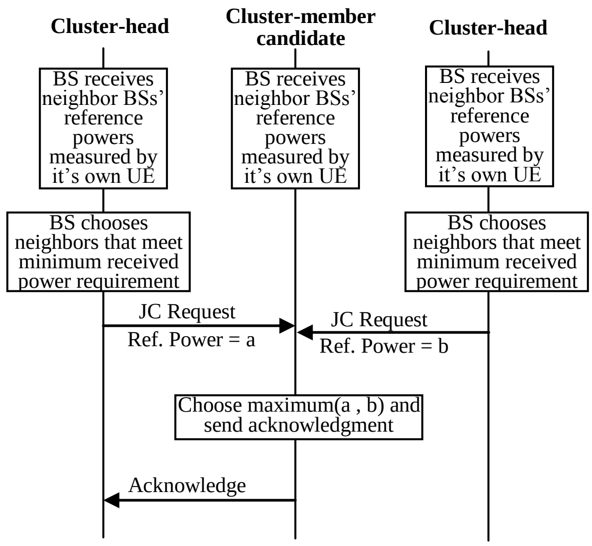

Figure 3. *Choose best request* cluster formation scheme

C. INTERFERENCE COORDINATION

The CH classifies its CMs according to the pilot strength that each CM receives from other same cluster CMs. If two or more CMs mutually measure low pilot strength from one another, they are grouped together for co-channel operation.

Also, each CM classifies all the channels according to the carrier to interference ratio (C/I). Channels with a value of C/I below a given threshold value are classified as *unusable channels* while channels with a C/I value greater than or equal to this threshold value are classified as *usable channels.* The

C/I classification information is sent by the CMs to their respective CHs which in return assign channels to the CMs after processing the received information.

D. CHANNEL ASSIGNMENT

The CH refers to the channel assignment table to determine how best the usable channels of cluster members can be permuted with each other in order to achieve the highest reuse at the shortest possible distance. The CA table contains a permutation of all the *usable* channels in such a way that avoids intra-cluster interference. Without loss of generality, we develop typical CA tables for a 5-channel system as the case of LTE-Advanced standard, and we illustrate them in Tables II and III. Assuming the available channels are ‘a’, ‘b’, ‘c’, ‘d’, and ‘e’, tables II and III illustrate some possible permutations with different reuse levels. In order to explain the usage of these tables, we describe a typical channel distribution in a cluster with Figs. 4 and 5. In Fig. 4, all the CMs classify the channels as either *usable* or *unusable* according to earlier discussion, and make this information available to the CH.

Also, according to earlier discussion, they inform the CH about the pilot strength measured from other BSs that are members of the same cluster. In Fig. 5, BS1 is the CH and it uses the channel state information and mutual pilot strength measurement information it receives from its CMs to search the resource allocation table for an interference-free pattern. In this particular case, the CH chooses pattern P_3 of table II which ensures that all the CMs are able to use the channels that they classified as *usable*. Both BS2 and BS3 use the same channel, ‘c,’ because they have been grouped together by the CH owing to the fact that they mutually receive low pilot strength from each other. It should be noted that we can have more CA tables

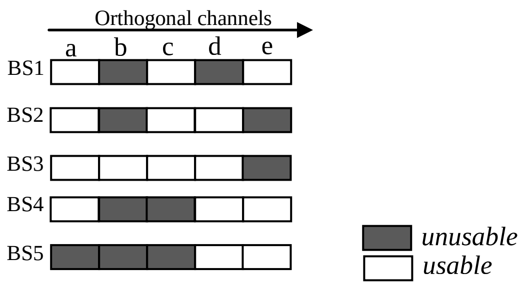

Figure 4. Cluster-members group channels into *usable* and *unusable* channels

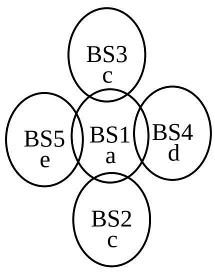

Figure 5. Cluster uses pattern P_3 of Table II

with different reuse factors such that each CH makes effort to choose patterns having highest re-use first.

Table II. Channel assignment table with reuse

Pattern	**BS$_1$**	**BS$_2$**	**BS$_3$**	**BS$_4$**	**BS$_5$**
P_1	a	b	b	d	e
P_2	a	b	b	e	d
P_3	a	c	c	d	e
P_4	a	c	c	e	d
⋮	⋮	⋮	⋮	⋮	⋮
P_{120}	e	d	d	b	a

Table III. Channel assignment table without reuse

Pattern	**BS$_1$**	**BS$_2$**	**BS$_3$**	**BS$_4$**	**BS$_5$**
P_1	a	b	c	d	e
P_2	a	b	c	e	d
P_3	a	b	d	c	e
P_4	a	b	d	e	c
⋮	⋮	⋮	⋮	⋮	⋮
P_{120}	e	d	c	b	a

IV. NUMERICAL EVALUATION

We will investigate 3 CA methods namely, *autonomous*, *greedy cluster*, and *fair cluster* CA methods.

- *autonomous* CA method is used by BSs that does not belong to any cluster, and the channel selection method is similar to the *primary component carrier selection* CA method discussed in [7]. In this channel selection method, BSs independently pick their best channels based on measurement reports received from their UEs.

- *greedy cluster* CA method is when a CH selects high-gain channels for the CMs without considering the interference that the selection may cause to neighbor clusters. The CH picks a CA pattern from the CA table that yields the highest cluster throughput. There is a tradeoff between increasing self-throughput and avoiding causing interference to neighbor BSs. This CA method disregards interference caused to neighbors.

- *fair cluster* CA method is when a CH selects channels for the CMs after first considering the interference that the selection may cause to neighbor clusters. The CH selects a pattern from the CA table that increases the current network throughput the most. This CA method balances the throughput-interference tradeoff.

A. System Level Simulation Setup

We evaluate the CA scheme with a 5 X 5 grid model. Our simulator is setup to feature the following:

(1) *autonomous:* In this setup, no cluster is formed by the FBSs. Each FBS autonomously assigns channel based on the measurement report it obtains from its UE. This setup is used as a comparative scheme.

(2) *fair cluster* (*size: 4 to 5*)*:* In this setup, the FBSs are allowed to cooperate to form clusters such that each cluster contains a minimum of 4 FBSs and a maximum of 5 FBSs. FBSs that cannot join any cluster are first allowed to select channels using *autonomous* method after which the CHs use the *fair cluster* CA method to allocate channels to their CMs.

(3) *fair cluster* (*size: 3 to 5*)*:* This is exactly the same as *fair cluster* (*size: 4 to 5*) except that in this case, each cluster is allowed to contain a minimum of 3 FBSs.

(4) *greedy cluster* (*size: 4 to 5*): In this setup, the FBSs are allowed to cooperate to form clusters such that each cluster contains a minimum of 4 FBSs and a maximum of 5 FBSs. FBSs that cannot join any cluster are allowed to pick channels using *autonomous* method after which the CHs use the *greedy cluster* CA method to allocate channels to their CMs.

(5) *greedy cluster* (*size: 3 to 5*): This is exactly the same as *greedy cluster* (*size: 4 to 5*) except that in this case, each cluster is permitted to have minimum of 3 FBSs.

B. Simulation Results

Fig. 6 compares the average UE throughput performance of the discussed CA methods when the FBS deployment probability is varied from 0.1 to 1.0 while the maximum separation distance between an FBS and its UE is fixed at 8 m. It can be seen from Fig. 6 that all *cluster* schemes outperform the *autonomous* scheme in terms of average user throughput. This is because in the *autonomous* scenario, each FBS is a candidate source of interference to the UE of any of the FBSs around it. In the *greedy cluster* scenario on the other hand, the cluster members reduce intra-cluster interference but do not consider inter-cluster interference. In the *fair cluster* scenario, however, all the CHs ensure that their CMs make effort to reduce the interference caused to the UEs of neighbor FBSs and at the same time selecting high-gain channels. This made the *fair cluster* scenario to result in a higher average user throughput in all levels of network congestion compared to other CA methods. Higher throughput is achieved in the *greedy cluster* (size: 4 to 5) compared to *greedy cluster* (size: 3 to 5) because in the case of *greedy cluster* (size: 4 to 5), more FBSs are able to reduce interference caused to neighbor BSs belonging to the same cluster due to larger cluster size.

Fig. 7 compares the average user throughput for the CA methods at a high deployment probability of 1.0. Again the *fair cluster* CA scheme performs best. The *greedy cluster* schemes do not significantly perform better than the *autonomous* scheme because the clusters are close to one another due to high deployment density such that, inter-cluster interference becomes worse. Considering Fig. 8, where deployment probability is set to 0.5, all *cluster* schemes

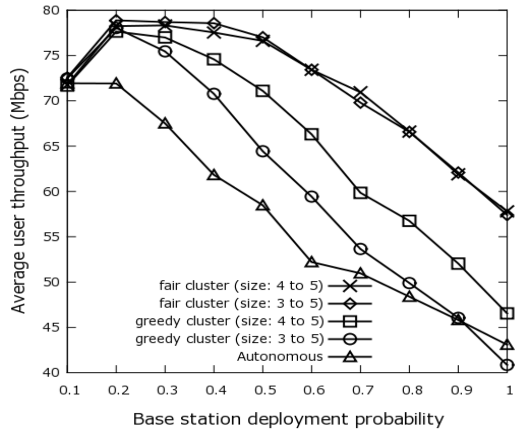

Figure 6. Average user throughput when user is placed at a maximum separation distance of 8 m from the serving BS

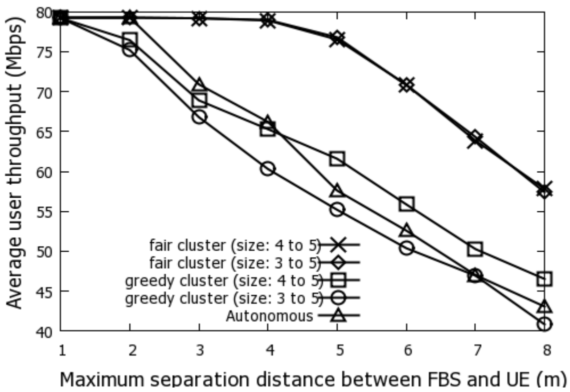

Figure 7. Average user throughput with BS deployment probability fixed at 1.0

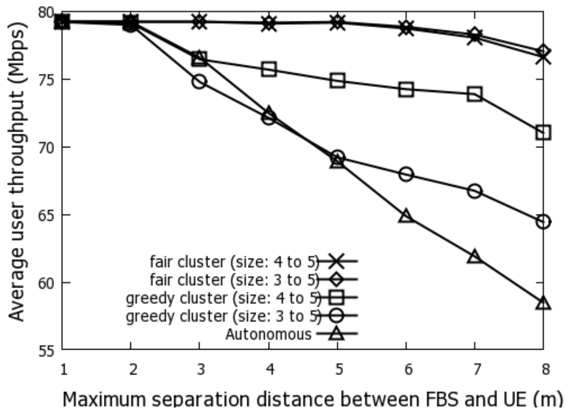

Figure 8. Average user throughput with BS deployment probability fixed at 0.5

perform better than the *autonomous* scheme as the UE moves farther away from its serving BS. This is because the impact of interference becomes significant when a receiver moves away from its serving BS but closer to the interfering BS. In our proposed schemes, the supposed interfering BS is usually a co-operating BS, hence, uses a channel that causes little interference to the UE. In summary, it is observed from our simulations that the *fair cluster* CA scheme yields the best average user throughput performance in all deployment density cases. Also, *greedy cluster* CA yields a higher average user throughput than *autonomous* CA in sparse deployment density conditions. Finally, high cluster size is better than low cluster size in the case of *greedy cluster* CA method.

V. CONCLUSIONS

A novel interference coordination scheme (co-operative channel assignment) which employs base station co-operation is presented in this work. The performance of the proposed scheme is compared with autonomous-based reference scheme available in the literature. It is observed from simulation results that the proposed co-operative channel assignment scheme yields higher throughput performance when a user is separated at a relatively far distance from the base station. The improvement in performance achieved by our proposed scheme is as a result of a combination of interference reduction and the use of high-gain channels which is realized through co-operation among neighboring base stations.

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BIOGRAPHIES

Akindele Segun Afolabi received his Bachelor and Master degrees in electrical engineering from the University of Ilorin, Nigeria, in 2004 and 2009 respectively. In 2009, he was awarded the Monbukagakusho (MEXT) Scholarship by the Japanese Government to pursue his Ph.D. degree in Japan. Afolabi, who is a lecturer in the Department of Electrical Engineering, University of Ilorin, Nigeria, is currently a Ph.D. candidate in the Graduate School of Engineering, Kobe University, Japan, where he is working on a research on the next generation wireless communication systems. His current research interests include multicarrier digital communications, adaptive resource allocation, cross-layer design, and cognitive radio. He is a student member of the IEICE.

Chikara Ohta was born in Osaka, Japan, on July 25, 1967. He received the B.E., M.E. and Ph.D. (Eng.) degrees in communication engineering from Osaka University, Osaka, Japan, in 1990, 1992 and 1995, respectively. From April 1995, he was with the Department of Computer Science, Faculty of Engineering, Gunma University, Gunma, Japan, as an Assistant Professor. In October 1996, he joined the Department of Information Science and Intelligent Systems, Faculty of Engineering, University of Tokushima, Tokushima, Japan, as a Lecturer, and there he had been an Associate Professor since March 2001. Since November 2002, he had been an Associate Professor of the Department of Computer and Systems Engineering, Faculty of Engineering, Kobe University, Japan. Since April 2010, he has been an Associate Professor of the Graduate School of System Informatics, Kobe University, Japan. From March 2003 to February 2004, he was a visiting scholar in the University of Massachusetts at Amherst, USA. His current research interests include performance evaluation of communication networks. He is a member of IPSJ, IEEE and SIGCOMM.

Hisashi Tamaki graduated from the Department of Electrical Engineering, Kyoto University, Japan, in 1985, and received Master of Engineering, and Doctor of Engineering from Kyoto University, Japan, in 1987 and 1993 respectively. He was a Research Associate (an Instructor) at the Department of Electrical Engineering in Kyoto University (1990 - 1995). Since 1995, he has been working with Kobe University, Japan, and currently he is a Professor at the Graduate School of System Informatics. His research interests include modeling and solution of combinotarial optimization and methodology of emergent approach for problem-solving.