다중 셀 하향링크 시스템에서 간섭 영역을 고려한 동적 채널 할당

정회원 이 능 형*, 박 세 웅**

Dynamic Channel Allocation Considering the Interference Range in Multi-cell Downlink Systems

Neung-Hyung Lee* and Saewoong Bahk** *Regular Members*

요 약

무선 네트워크가 OFDMA 시스템으로 발전되어감에 따라 무선 자원 관리에서 셀 간 간섭 제어가 중요한 이슈가 되고 있다. 인접 셀에서 같은 채널을 할당하는 것은 셀 간 간섭을 야기하므로, 채널 할당은 셀 간 간섭을 낮추도록 이루어져야 한다. 분산 방식의 채널 할당에서는 독립적으로 채널을 할당하면서, 각 셀이 낮은 간섭 수준을 겪도록 해야 한다. 이 논문에서는 간섭 영역의 개념을 소개하고 이를 이용한 두 가지 알고리즘을 제안한다. 두 가지 알고리즘은 이동성이 낮은 사용자를 가정한다. 기본 알고리즘은 할당하고자하는 채널에서 간섭 영역 탐지를 하여 할당을 결정하지만, 조합 알고리즘은 이에 더해 채널 상태도 확인하여 할당을 결정한다. 이들은 낮은 복잡도에 비해 좋은 수율과 공평성 성능을 보인다.

Key Words : Channel Allocation, Ofdma, Interference Range

ABSTRACT

As wireless networks evolve to orthogonal frequency division multiple access(OFDMA) systems, inter-cell interference control becomes a critical issue in radio resource management. The allocation of the same channels in neighbor cells cause inter-cell interference, so the channel allocation needs to be taken carefully to lower the inter-cell interference. In distributed channel allocation, each cell independently tries to allocate channels that suffer low interference level. In this paper, under the assumption of static users, we introduce the concept of interference range and use it in designing our two algorithms; basic and combined. The basic algorithm performs interference range detection and determines whether to use the considered channel, while the combined algorithm checks the channel quality in addition to detecting the interference range. The two algorithms dynamically perform channel allocation with low complexity and show good throughput and fairness performance.

Ⅰ. Introduction

As wireless networks evolve, some standards to support packet data services of high bandwidth have been developed. IEEE 802.16e[1], 802.20, and 3GPP long term evolution(LTE) are the recently developed standards regarded as the preliminary versions for next generation wireless

* 서울대학교 전기컴퓨터공학부 박사과정 (nhlee@netlab.snu.ac.kr)
** 서울대학교 전기컴퓨터공학부 교수 (sbahk@snu.ac.k)
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communications. The common feature of these standards is in use of orthogonal frequency division multiple access (OFDMA) instead of code division multiple access (CDMA) for multiple access. In OFDMA systems, data is transmitted over many mutually orthogonal sub-carriers, so multiple data streams can be transmitted over different sub-carriers. In real systems, resource allocation in frequency axis is performed in the unit of sub-channel that possibly uses multiple sub-carriers. OFDMA systems allocate different sub-channels for different mobile terminals (MTs) to achieve good performance by taking advantage of highly selective frequency environments.

In downlink OFDMA systems, allocation of multiple channels is a main part of radio resource management. The allocation messages are broadcasted at the beginning of each frame. The first step in resource allocation is searching for available sub-channels that are not allocated yet. If the inter-cell interference control forbids the use of some sub-channels, those will be excluded from allocation. In channel allocation, the base station (BS) considers each MT's quality of service (QoS), fairness, and the channel feedback information from each MT. The transmit power can be also adjusted if the power control is possible.

There are two types of approaches to handle the inter-cell interference problem: centralized and distributed. In centralized approach, a central controller collects all channel information from all cells and allocates channels. In this approach, static schemes determine an available channel set for each cell without using any dynamic information while adaptive schemes dynamically allocate channels considering each MT's requirements and current channel information. The static schemes design the frequency reuse factor (FRF) at the cell planning stage[2]. FRF N divides the given frequency band equally for N neighboring cells, while FRF 1 allows each cell to use the whole bandwidth. So the cell throughput in FRF 1 is larger compared to that in FRF 3 or 7 scheme. However FRF 1 scheme can not support cell boundary MTs properly because of strong inter-cell interference[3]. In[4], the concept of fractional frequency reuse was introduced and fractional frequency reuse set management algorithm was proposed. The algorithm defines non-integer frequency reuse factor and updates the reuse set dynamically. In distributed approach, the BS allocates a channel for each MT whenever requested and also considers power allocation. In[5], a distributed non-cooperative game approach was used to allocate channels with minimum power consumption.

In this paper, we investigate the channel allocation problem in a multi-cell environment, and consider centralized and distributed allocation algorithms under the assumption of static users. Our algorithms measure the interference range and use it. By restricting the allocation of some channels in neighbor cells that possibly create the inter-cell interference, the considered MT can receive the signal with acceptable quality. Our distributed algorithms use the interference range for channel allocation and achieves high total throughput, low outage ratio and good fairness.

In Section II, we explain the interference range and consider it in distributed channel allocation algorithms. Numerical analysis and simulation results are given in Section III. We conclude our paper in Section IV.

Ⅱ. Channel Allocation Schemes

The use of the same channels at neighboring cells causes the inter-cell interference that lowers the system throughput. We deal with distributed channel allocation schemes where each BS allocates channels independently. Each BS and MTs can exchange some information but message overhead should be minimized. We propose two schemes and evaluate their performances.

2.1. Interference range

Our schemes use the interference range in channel allocation which was originally used to deal with spatial reuse in ad hoc and sensor networks[6]. We adopt its basic concept and generalize its definition for our

networks. We define the interference range as the area surrounding the receiver that can be interfered by other transmitters in it. If any transmitter is working within the area, the receiver obtains lower SINR than a given SINR threshold. Fig. 1 shows an example of the interference range of an MT and the transmission range of a BS. If two or more communicating stations interfere with each other, collision occurs. To avoid the collision, each transmitter should check whether there is any active receiver in its transmission range. Similarly, each receiver should check whether any active transmitter is in its interference range before starting communication.

The transmission range (or cell coverage) depends on the transmission power of a BS. However, the interference range depends on not only the transmission power of the BS but also the distance between the BS and the MT. Fig. 2 shows an example that depicts the interference ranges of MT 1 and MT 2 in a multi-cell environment. MT 1 is closer to BS 1 than MT 2, so it receives a stronger signal from BS 1 than MT 2 does. This means that MT 1's interference range is smaller than that of MT 2. If a receiver has high SINR threshold, its interference range is smaller than those of other receivers with lower SINR thresholds. In this example, MT 1 has only BS 1 in its interference range, accordingly it receives negligibly small interference from neighbor cells. On the other hand, there are three neighbor BSes in the interference range of MT 2, so MT 2 experiences much stronger interference from other BSes.

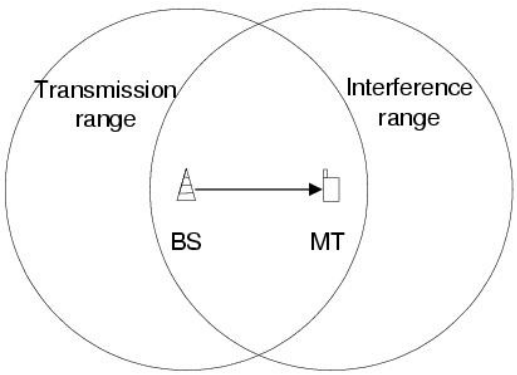

Fig. 1. Interference range in single cell.

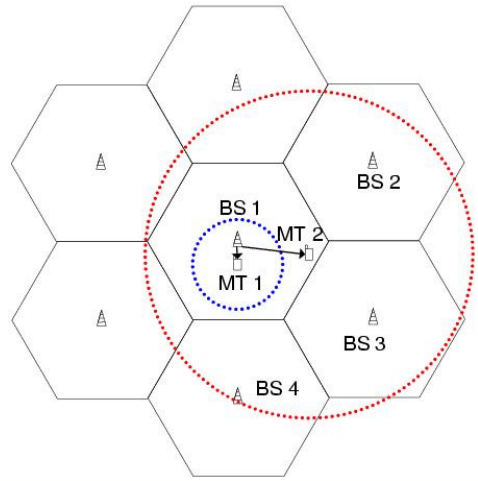

Fig. 2. Interference range in multi-cells.

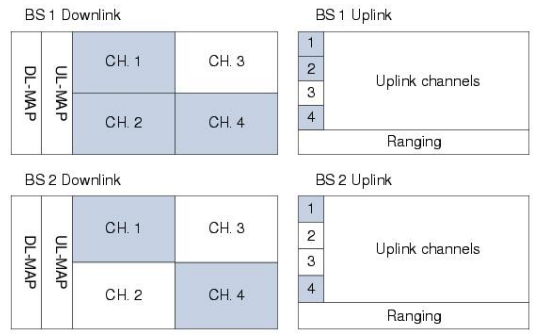

Fig. 3. OFDMA/TDD frame and DCA-MAP.

In our simple channel model, the interference range radius R_I is defined as the following

$$R_I \leqq (\eta SINR_{th})^{-1/\alpha} R \tag{1}$$

where R is the distance between the BS and the MT, $SINR_{th}$ is the SINR threshold, and α and η are the path loss exponent and the number of neighbor cells, respectively.

To determine whether the BS lies in the interference ranges of MTs in neighbor cells, some assistant system is necessary. For instance, if each MT is with a global positioning system (GPS), it can calculate the interference range according to its geometric location information and eq. (1). An alternative way is to use a downlink channel allo-

cation map (DCA-MAP) that requires synchronization among BSes. The role of DCA-MAP is similar to that of downlink map (DL-MAP) in an OFDMA system. While the DL-MAP broadcasted by a BS contains the information about downlink channel allocation, the DCA-MAP is broadcasted by each MT that transmits the pilot signal at the mapped position. Fig. 3 shows an example of frame structure in an OFDMA/TDD (time division duplexing) system. Each frame consists of downlink period and uplink period. At the beginning of downlink period, DL-MAP and uplink map (UL-MAP) are broadcasted. UL-MAP contains the information about uplink channel allocation.[1] The DCA-MAP needs to use the minimum resource unit. For example, one subcarrier and one symbol per downlink channel can be used for DCA-MAP. Fig. 3 shows a case of 2 cells and 4 downlink channels. The DCA-MAP is transmitted at the beginning of uplink period. In cell 1, the downlink channels of 1, 2, and 4 are used, so the MTs that are allocated for these channels transmit the pilot signal in the DCA-MAP. In cell 2, the downlink channels of 1 and 4 are used. Assume that a new flow arrives at BS 2. Before BS 2 starts channel allocation, it determines whether it lies in the interference ranges of neighbor cell MTs from their respective DAC-MAPs. In this example, channel 3 is available because BS 1 does not use it either. Regarding the possibility of using channel 2, more considerations are necessary. If BS 2 lies in the interference range of the MT using channel 2 in cell 1, its received pilot signal power for channel 2 is strong enough for detection, so it avoids assigning channel 2 for the new flow.

2.2 Interference range detection

To use the interference range in channel allocation, we need an interference range detection method that is performed by each BS. Fig. 4

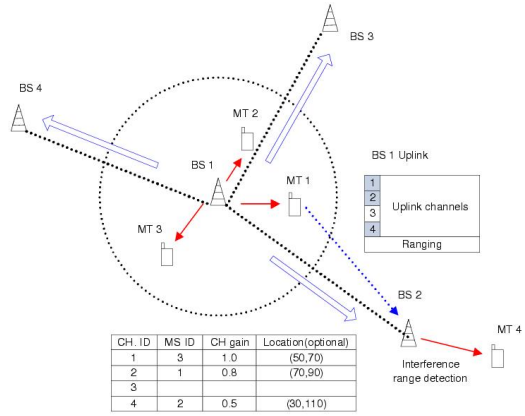

Fig. 4. Channel information signalling.

shows an example of message broadcasting and DCA-MAP for interference range detection. In cell 1, three channels are allocated for MTs 1, 2, and 3. The channel allocation information is delivered to neighbor BSes 2, 3, and 4 by broadcasting through the wire-line. As the broadcasting has been already used during fast handover procedures, it does not incur overhead in the current system. The channel allocation information contains channel ID, MT ID, and channel gain. If we assume the use of GPS, the broadcasting message will include the location information of each MT. Independently from the wire-line signalling, MTs transmit the pilot signal according to DCA-MAP. From the wire-line broadcasting message and DCA-MAP, each neighbor BS can decide whether it belongs to the interference ranges of neighbor cells' MTs.

Let's consider the case that there is a transmission in channel c at cell i and the BS in cell j wants to allocate a channel to an MT. If the BS j allocates the considered channel, the SINR of MT in cell i is given by

$$SINR_i = \frac{P_0 gii}{P_0 g_{ij} + N_i}. \quad (2)$$

The interference range detection at BS j depends on $SINR_i$. If $SINR_i$ is smaller than the threshold value S_0, BS j is considered to be in

1) In uplink period, data channels, control message channels, and ranging channels are positioned. The ranging channels are used for initial random access and uplink synchronization.

the interference range of the MT in cell i. Thus the BS should know the channel gains g_{ii} and g_{ij} to decide whether BS j belongs to the interference range of the MT in cell i. The channel gain g_{ii} between the MT in cell i and BS i is obtained through the broadcasting from BS i. During the broadcasting, g_{ii} may contain an error. Assuming that the broadcasting is done frequently, we can ignore this error. The channel gain g_{ij} between the MT in cell i and BS j can be obtained from DCA-MAP received by BS j. In DCA-MAP, the MT transmits the pilot signal with fixed power, so BS j can estimate g_{ij}. Since there is a distance between the pilot channel in DCA-MAP and the allocated channel in frequency axis, g_{ij} contains some error according to the frequency selection. In this paper, we ignore this type of error.

Under the assumption that the noise is sufficiently small compared to the interference, $SINR_i$ can be expressed as

$$SINR_i = \frac{P_0 g_{ii}}{P_0 g_{ij} + N_i} \simeq \frac{g_{ij}}{g_{ij}} = \frac{P_0 g_{ii}}{q_j}, \quad (3)$$

where g_{ij} is given as q_j / P_0 and q_j is the received pilot power at BS j. Then the interference range detection result is false if $P_0 g_{ii} / q_j > S_0$, and true otherwise. If BS j is located in the interference range of the MT in cell i, the detection result is true, so BS j should not allocate the channel. Otherwise BS j can allocate it.

The weakness of channel allocation following the interference range detection is in the possibility of low channel utilization. For the channel of interest, let's define P_{use} and $P_{\det}$ as the probabilities of the channel use and the detection result with 'true', respectively. If the number of neighbor cells are n_b and the traffic loads of all the cells are uniformly distributed, P_{use} can be approximately calculated by P_{use}'s and $P_{\det}$'s of neighbor cells as follows.

$$\begin{aligned} P_{use} &\simeq P_{use}(1 - P_{\det}) + (1 - P_{use})^{n_b} \\ &= (1 - P_{use} P_{\det})^{n_b} \end{aligned} \quad (4)$$

Therefore we can obtain P_{use} by a recursive method. If BS j receives the channel allocation information from BS i according to the broadcasted messages and DCA-MAP, we obtain $P_{\det}$ as follows.

$$P_{\det} = Pr\left[\frac{P_0 G_{ii}}{Q_j} < S_0\right], \quad (5)$$

where $G_{ii} = g_{ii}(\boldsymbol{x_i})$ and $Q_j = P_0 g_{ij}(\boldsymbol{x_i})$, and $\boldsymbol{x_i}$ is the random variable vector of MTs' locations in BS i. Assuming g_{ii} and q_j are time invariant, we have

$$\begin{aligned} P_{\det} &= Pr\left[\frac{P_0 g_{ii}(\boldsymbol{x_i})}{Q_j(\boldsymbol{x_i})} < S_0\right] \\ &= Pr\left[\frac{g_{ii}(x_i)}{g_{ij}(x_i)} < S_0 | \boldsymbol{x_i} = x_i\right] \Pr[\boldsymbol{x_i} = x_i]. \end{aligned}$$

If MTs are uniformly distributed within the cell radius R and the channel gain is determined by path loss only, we obtain

$$\begin{aligned} P_{\det} &= \frac{1}{Area} \int_A I\left[\frac{g_{ii}(x_i)}{g_{ij}(x_i)} < S_0\right] \\ &= \frac{1}{Area} \iint_A I\left\{\frac{\sqrt{x^2+y^2}}{\sqrt{(2R-x)^2+y^2}}\right\}^{-\alpha} < S_0 dx dy. \end{aligned}$$

where A and $Area$ are the domain of x_i and its area, respectively, and the indicator function $I(B)$ has 1 if the event B is true, and 0 otherwise. If the interference range detection is used, the average SINR of

MTs is obtained by

$$\begin{aligned} &E[SINR_i] \\ &= \frac{1}{Area} \int_A \frac{g_{ii}(x_i) P_0 P_{use}}{P_0 \sum_{j=1, j \neq i}^{N} g_{ij}(x_i) U_{ij}(x_i) P_{use} + N_0} \end{aligned}$$

where $U_{ij}(x_i) = I\left[\frac{g_{ii}(x_i)}{g_{ij}(x_i)} < S_0\right]$.

2.3. Proposed channel allocation algorithm

Firstly, we review a conventional channel allocation algorithm that uses the channel feedback information[8]. It selects a channel from unused channels and checks whether the SINR of the selected channel is greater than $SINR_0$. If the channel passes the test, it will be allocated. Several algorithms belonging to this category use power control to reduce the inter-cell interference. When fixed P_0 is assumed, this type of algorithm does not have any means to count the impact of the considered channel allocation on neighbor cells. It only considers whether its own SINR is sufficiently high, so it is a selfish algorithm.

Compared to the existing algorithm, our proposed algorithm is conservative because it does not allocate the considered channel if the allocation creates severe interference to neighbor cells. Fig. 5 shows our proposed algorithm that checks the availability of the selected channel according to the interference range detection. If the selected channel is usable, the corresponding BS allocates the channel and performs the interference range signaling.

Another approach is combining the existing algorithm with our algorithm. As the selfishness of the conventional algorithm and the interference consideration of our algorithm show some complementary features, they can be combined as shown

Table I. MCS Level

Level	Modulation	Coding rate	Required SIR	Data rate (kbps)
1	QPSK	1/12	-1.8	9.78
2	QPSK	1/6	-0.3	19.55
3	QPSK	1/3	2.6	39.11
4	QPSK	2/5	4.2	46.93
5	16QAM	1/4	5.2	58.67
6	16QAM	1/3	6.8	78.21
7	16QAM	2/5	8.3	93.87
8	16QAM	1/2	11.3	117.33

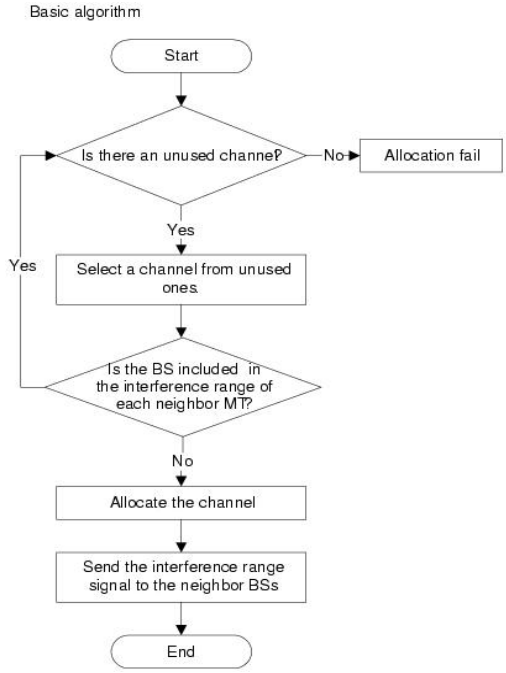

Fig. 5. Flow chart of basic algorithm.

in Fig. 6. The first step checks the availability of the selected channel by considering the interference range. Then the second step tests whether the condition of the selected channel is acceptable. If the channel passes the two tests, it is allocated for the MT and the interference range information is sent to neighbor BSes. It is expected that the successful allocation ratio in our combined algorithm is smaller than those in the conventional algorithm and our basic algorithm because of the hard checking conditions. However, owing to the strict checking procedures, our combined algorithm suffers lower interference, resulting in higher SINR compared to the other schemes. Proposed algorithms need one or two comparison process, but they do not have much calculational complexity.

Ⅲ. Numerical Results

To examine our proposed distributed algorithms, we performed simulations. In each simulation, we use a simple channel model with the path loss exponent of -4. Assume that Gaussian noise is

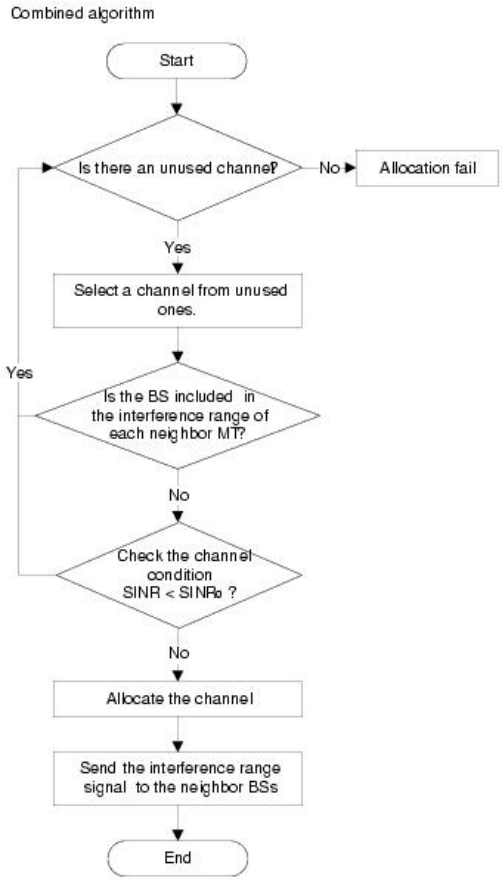

Fig. 6. Flow chart of combined algorithm.

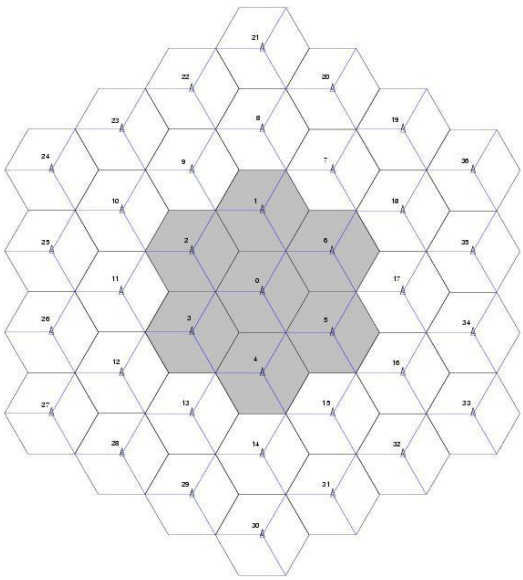

Fig. 7. Example of a cell topology: 37 cells and 3 sectors per cell.

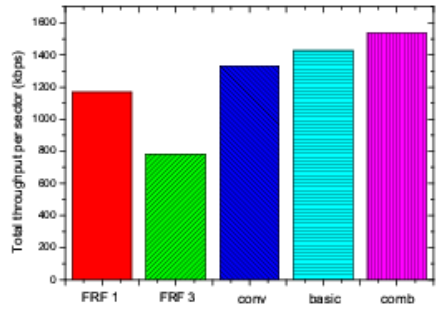

Fig. 8. Total throughput per sector.

negligible compared to the interference level in calculating SINR. For data rate according to the modulation and coding selection (MCS) level, we use the values in the WiBro system as given in Table I. We set $SINR_{th}$ and $SINR_0$ at 5dB.

Fig. 7 shows the considered topology of 37 cells with the cell radius 1000m. Each cell has 3 sectors each of which has 21 downlink channels. Users are randomly distributed within the sector and the channels are allocated for cells 0 through 36. Performances including the cell throughput are measured for cells 0 through 6.[2] Simulations are executed 10,000 times and the results are averaged. Our proposed algorithms, denoted as 'basic' and 'comb', are compared with three algorithms: FRF 1, FRF 3, and the conventional algorithm ('conv').

Fig. 8 shows the total throughput per sector. FRF 1 and FRF 3 schemes show the throughputs of 1.17Mbps and 780kbps, respectively. FRF 1 uses the whole channels so it shows good throughput performance. However, MTs that are located near the cell boundary experience the heavy interference, so they fail to have channel allocation. In FRF 3, adjacent cells use different channels, so boundary MTs have good channel conditions but the total cell throughput is much lower than that in FRF 1. The conventional scheme does not allocate a channel for an MT

2) We have not measured the performances at the outer cells because they experience lesser and lesser interference due to the edge effect.

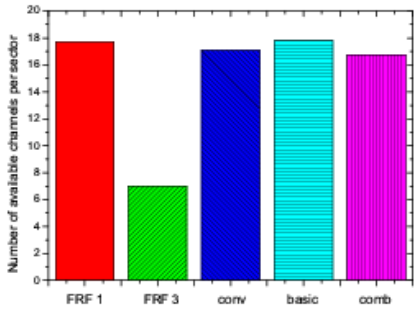

Fig. 9. Number of available channels per sector.

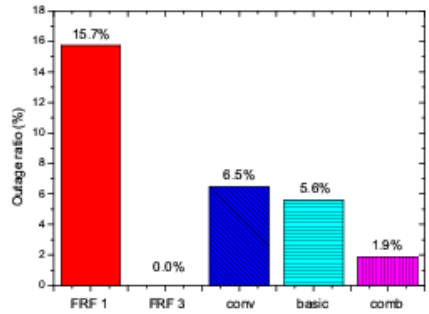

Fig. 10. Outage ratio of channels.

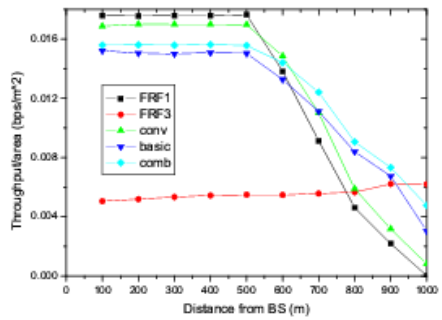

Fig. 11. Per unit area throughput according to the distance between the BS and an MT.

if the considered channel condition is not good. It reduces the inter-cell interference and achieves throughput increase by 14% compared to FRF 1 scheme. Our proposed scheme performs better than the conventional scheme, and achieves 22.3% more throughput compared to FRF 1. This is because channel allocations for cell boundary MTs in our algorithm restrict neighbor cells' allocations of the same channels through the interference range signalling. Our combined proposal shows the best performance and achieves more throughput by 31.6% compared to FRF 1.

In Fig. 9, we count the number of available channels per sector as a measure of fairness. 'Available' means that the channel of interest does not experience outage (i.e., zero data rate). FRF 1 has 17.7 available channels among the allocated 21 channels. The conventional scheme and our scheme are not able to use the whole channels because some channels fail to pass the channel test. They show the results comparable to FRF 1. FRF 3 has seven available channels that equal one third of 21 channels as expected. The number of available channels is highly related to the outage ratio. Fig. 10 shows the outage ratio of allocated channels. FRF 1 shows the highest outage ratio and FRF 3 shows no outage. Our combined scheme shows lower outage compared to the conventional scheme and our basic scheme. FRF 1 suffers from high outage ratio because a channel experiences heavy interference after being allocated. This phenomenon mainly occurs to cell boundary MTs. Our basic algorithm shows the outage ratio similar to the conventional algorithm and our combined algorithm shows an acceptable low outage ratio of 1.9% at the cost of slight decrease in the number of available channels.

In Fig. 11, we observe per unit area throughput which also can be interpreted as a measure for fairness. We vary the distance between the BS and the MT. FRF 3 shows the best performance indicated by its flat curve. The performance in FRF 1 drops rapidly when the MT moves towards the cell boundary. This means that FRF 1 gains more total throughput by sacrificing cell boundary users. Thus FRF 1 shows the worst fairness performance. The conventional scheme and FRF 1 scheme show the similar tendency in terms of throughput decrease, while our two schemes achieve good fairness performance. In conclusion, these simulation results demonstrate that our combined algorithm performs best considering total throughput, outage ratio, and fairness all together.

Our schemes require some signaling overheads

compared to the conventional scheme. Each BS transmits its channel allocation state to neighbor BSes whenever channel is allocated(or withdrawn). The signaling messages are exchanged through the wired line between BSes, so it is not overhead for the wireless network. However, the pilot transmission of an MT for DCA-MAP needs wireless transmission. This overhead can be minimized through the efficient DCA-MAP design and sub-carrier selection in frequency axis.

Ⅳ. Conclusion

In this paper, we investigated channel allocation algorithms in downlink multi-cell wireless systems. Channel allocation has been a difficult problem because of the complexity in handling the inter-cell interference. We proposed two dynamic channel allocation algorithms of 'basic' and 'combined' that use the interference range detection with low complexity. To support the interference range estimation, we considered the approach of using either GPS or uplink map. Through simulations, our proposed algorithms are compared with FRF 1, FRF 3 and the conventional algorithm. From the results, we confirmed that the combined algorithm shows high total throughput, low outage ratio, and fair channel usage. The advantage of our proposed algorithm is in supporting cell boundary MTs with good total throughput and acceptable fairness.

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이 능 형 (Neung-Hyung Lee) 정회원

2000년 2월 서울대학교 전기 공학부 졸업

2002년 8월 서울대학교 전기 컴퓨터공학부 석사

2002년 9월~현재 서울대학교 전기컴퓨터공학부 박사과정

<관심분야> 차세대 무선 네트워크

박 세 웅 (Saewoong Bahk) 정회원

1984년 2월 서울대학교 전기 공학과 졸업

1988년 2월 서울대학교 전기 공학과 석사

1991년 University of Pennsylvania 박사

<관심분야> 차세대 무선 네트워크, 네트워크 보안