Generalized Radio Resource Management for Overlapping MBS Zones

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Abstract. *Multicast and broadcast service (MBS) is a point-to-multipoint service where data packets are transmitted simultaneously from a single source to multiple destinations. In MBS, some base stations (BSs) may form an MBS zone and transmit identical MBS contents simultaneously using the same modulation and coding scheme. Hence, the network has to coordinate the transmission of BSs such that BSs belonging to multiple MBS zones may utilize non-conflict resources to transmit different MBS contents. This paper extends the work in [1] for accommodating MBS zones with different service presence probabilities and various bandwidth requirements. A continuous allocation algorithm and a non-continuous allocation algorithm are presented to allocate resource units for overlapping MBS zones. Simulations were conducted to verify the effectiveness of the proposed algorithms.*

Keywords

Multicast and broadcast services, multiple MBS zones, resource allocation.

1. Introduction

Multimedia broadcast/multicast service (MBMS), which is also known as multicast and broadcast service (MBS) in IEEE 802.16m, is one of the important services defined by 3GPP Long Term Evolution (LTE) for the 4th generation cellular systems. MBMS is a point-to-multipoint service where data packets are transmitted simultaneously from a single source to multiple destinations [2]. In MBMS, the same data is transmitted via a common broadcast or multicast channel to multiple MBMS subscribers. Two service architectures are supported by 3GPP for delivering MBMS services: single cell-point to multi-points (SC-PTM) and multicast broadcast single frequency network (MBSFN). In SC-PTM, each base station (BS) transmits MBS content using its own modulation coding scheme (MCS).

In MBSFN, the MBS content is transmitted over a geographical area identified as a zone. A cluster of base stations (BSs) that transmit the same content in a zone is referred as an MBS zone. In general, each BS may belong to one or more MBS zones. Two MBS zones are overlapped if there is at least one BS belonging to both zones [3]. The network should allocate separate radio resource units for overlapping MBS zones such that BSs belonging to different MBS zones may transmit individual MBS content without confliction [4]. Normally, the service interval of an MBS service is much longer than that of a voice call. Hence, the coverage area of an MBS zone may be changed during the MBS service interval due to the movement of mobile stations (MSs). A BS may decide to join a nearby MBS zone if an MS requests for a new MBS service that is not existed in this cell but is available at this MBS zone. A BS may also leave an MBS zone if there is no MS demanding the MBS service. In response to the topology change of the MBS zones, the network should reallocate the radio resource units during the service interval. Hence, the network should minimize the signalling exchanged in the air interface and the core network.

The radio resource allocation for overlapping MBS zones is similar to the channel assignment problem discussed in traditional cellular networks. However, they are different in nature. In the channel assignment problem, the network normally allocates a number of static channels to a cluster of BSs at the cell planning phase to prevent from co-channel interference among neighboring BSs [5], [6]. The network may further reserve some dynamic channels to support extra traffic demanding at a specific BS during a particular time interval [5], [6]. The radio resource allocation for overlapping MBS zones is similar to the static channel assignment problem. Both of them can be solved based on graph theory [7]. However, each BS has the same number of neighboring cells in channel assignment but an MBS zone may be overlapped with different number of MBS zones. The radio resource re-allocation for overlapping MBS zones is different to the dynamic channel assignment problem. It is because that the traffic demanding of two BSs are uncorrelated but the topologies between two overlapping MBS zones are highly correlated. Moreover, the number of channels is a constant in dynamic channel assignment problem but the number of radio resource units used by MBS zones is a variable. Hence, existing channel assignment techniques cannot be directly applied here.

The coverage area of an MBS zone can be in regular shape or irregular shape [8]. The MBS zone with regular shape consists of a center cell and one or more surrounding rings of cells. The total number of cell in an MBS zone can be determined based the number of surrounding rings. The MBS zone with irregular shape is a group of neighboring cells with arbitrary shape. For example, the number of cells in an MBS zone was modeled by a binomial distribution with a given service presence probability [9]. An MBS zone with a higher service presence probability contains more cells.

The radio resource management for overlapping MBS zones has been studied in [1]. The paper assumed that each non-isomorphic graph of overlapped MBS zones occur with equal probabilities and each MBS service consumes only one radio resource unit [1]. Based on the two assumptions, a radio resource allocation algorithm is proposed to assign radio resources to each MBS zone based on graph theory; a radio resource re-allocation algorithm is then proposed to minimize the number of re-allocated radio resource units by utilizing the correlation between successive MBS zone topologies; and a simple resource estimation model is presented for estimating the number of radio resource units required by a given number of MBS zones.

This paper considers a generalized radio resource management problem for overlapping MBS zones. We extend the work in [1] by relaxing the assumption of identical bandwidth requirement in each MBS zone. The rest of the paper is organized as follows. In Section 2, a system model is presented. A continuous allocation algorithm and a non-continuous allocation algorithm are elaborated. Numerical results are shown in Section 3. Section 4 summarizes the conclusions.

2. System Model

This paper considers a hexagonal cellular network with M cells supporting N MBS services ($M > N$) as shown in Fig. 1. Let $\vec{B} = [B_1 \dots B_N]$ be the bandwidth requirement of the MBS services, where B_i is the number of radio resource units required by the ith MBS zone and $B_1 \geq B_2 \geq \dots \geq B_N$. The ith MBS zone contains a center cell and R_i surrounding-ring of cells. For example, $R_1 = R_2 = 1$ and $R_3 = 2$ in Fig. 1.

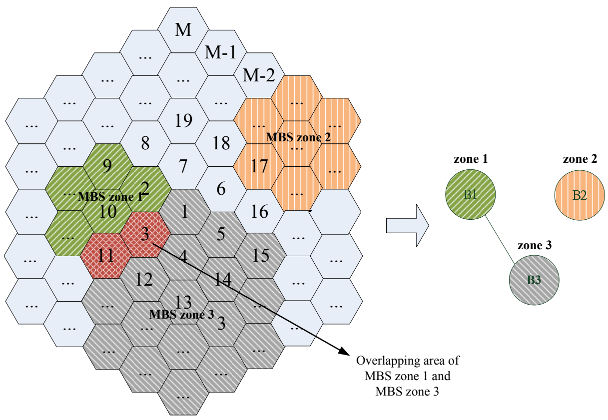

Fig. 1: System model.

We use an undirected labeled graph to represent the topology of the MBS zones. In this graph, each vertex represents an MBS zone; the number shown on the vertex represents the number of radio resource units required by the MBS service; and the edge connecting two vertexes indicates the overlapping of two MBS zones. Similar to [1], non-conflict radio resource units should be allocated to two vertexes connected by an edge. An M-by-N matrix $\mathbf{Q}$ ($\mathbf{Q}_{M\times N}$) is used herein to indicate the relationship among cells and their MBS zones. The ith row and the jth column element of $\mathbf{Q}$, $q_{i,j}$, is set as:

$$q_{i,j} = \begin{cases} 1 & \text{if cell } j \text{ belongs to MBS zone } i, \\ 0 & \text{otherwise.} \end{cases} \quad (1)$$

An N-by-N adjacent matrix $\mathbf{X}$ ($\mathbf{X}_{N\times N}$) presented in [1] is used to represent the interconnectivity of the network containing N MBS zones. Let $x_{i,j}$ be the ith row and the jth column element of $\mathbf{X}$, where

$$x_{i,j} = \begin{cases} 1 & \text{if MBS Zones } i \text{ and } j \text{ are overlaped,} \\ 0 & \text{otherwise.} \end{cases} \quad (2)$$

$\mathbf{X}$ can be obtained from $\mathbf{Q}$. That is,

$$x_{i,j} = \begin{cases} \text{sign}\left(\sum_{m=1}^{M} (q_{i,m} \times q_{j,m})\right), & i \neq j \\ 0, & i = j, \end{cases} \tag{3}$$

where sign(.) is the sign function.

For MBS zones with various bandwidth requirements, the network may allocate radio resource units for the MBS services in either continuous or non-continuous manner. In continuous resource allocation, a block of adjacent radio resource units are assigned to each MBS service. In non-continuous resource allocation, non-adjacent radio resource units are assigned to the MBS services [3].

2.1. Continuous Allocation (CA)

In continuous allocation, a block of radio resource units is first assign to MBS zone which has the maximum bandwidth requirement.

CA Algorithm

- Step 1: For a given $N \times N$ adjacent matrix $\mathbf{X}$, set $x_{i,j} = 0$.
- Step 2: Find a degree vector $\vec{d_x} = [d_1\ d_2\ d_3 \ldots d_N]$ of matrix $\mathbf{X}$, which is defined as:

$$d_i = \sum_{j=1}^{N} x_{i,j}. \tag{4}$$

- Step 3: Assign a block of resource unit to each MBS zone.
  - Step 3.1: Set all vertexes as uncolored. Let $C_0 = -\mathbf{X}$.
  - Step 3.2: Assign resource unit 1 to MBS zone n, (i.e., set $c_{n,n} = 1$) if MBS zone n has the maximum resource unit requirement (i.e., $B_n = \arg\max_i B_i, 1 \leq i \leq N, B_i \in \vec{B}$). Note, assign resource unit 1 to MBS zone n if $B_n = B_m$ and $d_n > d_m$. Construct C_1 by replacing the following elements in C_0,

$$\begin{cases} c_{i,n} = c_{n,n}, & \text{if } c_{i,n} = -1, i \in \{1, N\}, \\ c_{n,j} = c_{n,n}, & \text{if } c_{n,j} = -1, j \in \{1, N\}. \end{cases} \tag{5}$$

  - Step 3.3: Assign a used resource unit to MBS zone m (set $c_{m,m} = 1$ if resource unit 1 is assigned) if the unassigned MBS zone m has the maximum bandwidth requirement and its neighbor does not use this used color. Construct C_2 by replacing the following elements in C_1

$$\begin{cases} c_{i,m} = c_{m,m}, & \text{if } c_{i,m} = -1, i \in \{1, N\}, \\ c_{m,j} = c_{m,m}, & \text{if } c_{m,j} = -1, j \in \{1, N\}. \end{cases} \tag{6}$$

  - Step 3.4: Repeat Step 3.3 using an extra resource unit until each vertex is assigned a resource unit. The allocating resource block is conflict if $c_{q,i} \leq c_{q,q} \leq c_{q,i} + B_i - 1$ or $c_{q,i} \leq B_q \leq c_{q,i} + B_i - 1$. In this case, let $c_{q,q} = c_{q,q} + 1$. Repeat this process until no conflict is found. Construct C_k by replacing the following elements in C_{k-1},

$$\begin{cases} c_{i,q} = c_{q,q}, & \text{if } c_{i,q} = -1, i \in \{1, N\}, \\ c_{q,j} = c_{q,q}, & \text{if } c_{q,j} = -1, j \in \{1, N\}. \end{cases} \tag{7}$$

- Step 4: The resource unit vector set is $\vec{c}_X = diag(C_N)$.

2.2. Non-Continuous Allocation (NCA)

The concept proposed in [10] is used to transform a multi-coloring problem to a single-coloring problem by splitting each node i into B_i nodes.

Let $\overline{I_n}$ be the complement of the identity matrix of size n (i.e., an n-by-n square matrix with zeros on the diagonal and ones elsewhere). That is,

$$\overline{\mathbf{I_n}} = \begin{pmatrix} 0 & 1 & \cdots & 1 \\ 1 & 0 & \cdots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 1 & 1 & \cdots & 0 \end{pmatrix}. \tag{8}$$

Let $\mathbf{A}_{m\times n}$ be an m-by-n matrix with all elements equal to one. That is,

$$\mathbf{A_{m\times n}} = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ 1 & 1 & \cdots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 1 & 1 & \cdots & 1 \end{bmatrix}. \tag{9}$$

The adjacent matrix $\mathbf{X}$ can be transformed to the extended adjacent matrix $\mathbf{E}$ (i.e., a square matrix of size W, $W = \sum_{i=1}^{N}(B_i)$ by Eq. (10), where $x_{i,j}$ is the ith row and the jth column element of $\mathbf{X}$, B_i is the required radio resource units of the ith MBS zone. For example, $\mathbf{X} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$ and $\vec{B} = [\ 3 \quad 2 \quad 1\ ]$. We can have Eq. (11).

After splitting the adjacent matrix $\mathbf{X}$ to the extended adjacent matrix $\mathbf{E}$, the algorithm proposed in [1] can directly apply as below.

NCA Algorithm

- Step 1: For a given $N \times N$ adjacent matrix $\mathbf{X}$, find the extended adjacent matrix $\mathbf{E}$.

$$\mathbf{E} = \begin{bmatrix} \overline{I_{B_1}} & x_{1,2}A_{B_1\times B_2} & \cdots & x_{1,N}A_{B_1\times B_N} \\ x_{2,1}A_{B_2\times B_1} & \overline{I_{B_2}} & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ x_{N,1}A_{B_N\times B_1} & x_{N,2}A_{B_N\times B_2} & \cdots & \overline{I_{B_N}} \end{bmatrix}. \tag{10}$$

$$\mathbf{E} = \begin{bmatrix} \overline{I_3} & 1\times\begin{bmatrix}1&1\\1&1\\1&1\end{bmatrix} & 0\times\begin{bmatrix}1\\1\\1\end{bmatrix} \\ 1\times\begin{bmatrix}1&1&1\\1&1&1\end{bmatrix} & \overline{I_2} & 0\times\begin{bmatrix}1\\1\end{bmatrix} \\ 0\times\begin{bmatrix}1&1&1\end{bmatrix} & 0\times\begin{bmatrix}1&1\end{bmatrix} & \overline{I_1} \end{bmatrix} = \begin{bmatrix} 0&1&1&1&1&0\\ 1&0&1&1&1&0\\ 1&1&0&1&1&0\\ 1&1&1&0&1&0\\ 1&1&1&1&0&0\\ 0&0&0&0&0&0 \end{bmatrix}. \tag{11}$$

- Step 2: Find a degree vector $\vec{d_x} = [\ d_1\ \ d_2\ \ \ldots\ \ d_W\ ]$ of $\mathbf{E}$, which is defined as:

$$d_i = \sum_{j=1}^{W} e_{i,j}. \tag{12}$$

- Step 3: Assign one resource unit to each vertex.
  - Step 3.1: Set all vertexes as uncolored. Let $C_0 = -\mathbf{E}$.
  - Step 3.2: Assign the first resource unit to vertex n, (i.e., set $c_{n,n} = 1$) if vertex n has the maximum degree (i.e. $d_n = \arg\max_i d_i$, $1 \le i \le W$, $d_i \in \vec{d_E}$). Construct C_1 by replacing the following elements in C_0,

$$\begin{cases} c_{i,n} = c_{n,n}, & \text{if } c_{i,n} = -1, i \in \{1, W\}, \\ c_{n,j} = c_{n,n}, & \text{if } c_{n,j} = -1, j \in \{1, W\}. \end{cases} \tag{13}$$

  - Step 3.3: Assign a used resource unit to an unassigned vertex m (set $c_{m,m} = 1$) if the vertex m has the maximum degree and does not have a neighbor with the used resource unit. Construct C_2 by replacing the following elements in C_1,

$$\begin{cases} c_{i,m} = c_{m,m}, & \text{if } c_{i,m} = -1, i \in \{1, W\}, \\ c_{m,j} = c_{m,m}, & \text{if } c_{m,j} = -1, j \in \{1, W\}. \end{cases} \tag{14}$$

  - Step 3.4: Repeat Step 3.3 using extra resource unit until each vertex is assigned by a non-conflict resource unit. Note that color p can be assigned to vertex q if and only if:

$$\begin{cases} c_{q,q} \neq c_{i,q}, & \text{if } c_{i,q} \neq 0 \text{ or } -1, i \in \{1, W\}, \\ c_{q,q} \neq c_{q,j}, & \text{if } c_{q,j} \neq 0 \text{ or } -1, j \in \{1, W\}. \end{cases} \tag{15}$$

    Contruct C_k by replacing the following elements in C_{k-1},

$$\begin{cases} c_{i,q} = c_{q,q}, & \text{if } c_{i,q} = -1, i \in \{1, W\}, \\ c_{q,j} = c_{q,q}, & \text{if } c_{q,j} = -1, j \in \{1, W\}. \end{cases} \tag{16}$$

- Step 4: The resource unit vector set is $\vec{c}_E = diag(C_W)$.

Note that the NCA algorithm is expected to achieve a better performance than CA algorithm does but at the cost of a higher computational complexity. The computational complexity of the resource allocation algorithm depends on the dimension of the adjacent matrix or extended adjacent matrix. Hence, the complexity of the continuous resource allocation algorithm $O(N^2)$ and the complexity of the non-continuous resource allocation algorithm is $O(W^2)$, where $W = \sum_{i=1}^{N} B_i$. For all MBS zones have identical bandwidth requirements (i.e., B_i is a constant), the complexity of the non-continuous resource allocation algorithm is $O((B_i N)^2)$.

3. Simulation Results

Simulations were conducted on top of a C-based simulation platform to verify the effectiveness of the proposed algorithms. In the simulation, each sample was obtained by averaging 10000 outcomes. The results of a random allocation algorithm, CA algorithm, and NCA algorithm were evaluated. The random allocation algorithm randomly assigns a block of continuous radio resource units to each MBS zone. In the simulation, the number of radio resource units required by the ith MBS zone, Bi, was generated from a Gaussian distribution with parameter (μ,σ^2).

Figure 2 and Fig. 3 showed the mean number of allocated resource units required in three algorithms for different number of MBS zones with identical R_i and different R_i, respectively. In Figure 2 and Fig. 3, the number of cell M was 169 and N varied from 3 to 10. As defined in Sec. 2, R_i is the number of surrounding-ring of cells in the ith MBS zone. A larger R_i implies a larger MBS zone size. It can be found in Fig. 2 that the mean number of allocated resource units increases as the number of MBS zones increases; both CA and NCA algorithms require less resource units than the random allocation algorithm does; and the improvement of NCA over CA becomes noticeable when N reaches 7. Compare Fig. 2 and Fig. 3, it was found that the effect of R_i on the mean number of allocated resource units required in three algorithms is not significant. It is because that the size of the MBS zone and its bandwidth requirement (i.e, R_i and B_i) were independently generated.

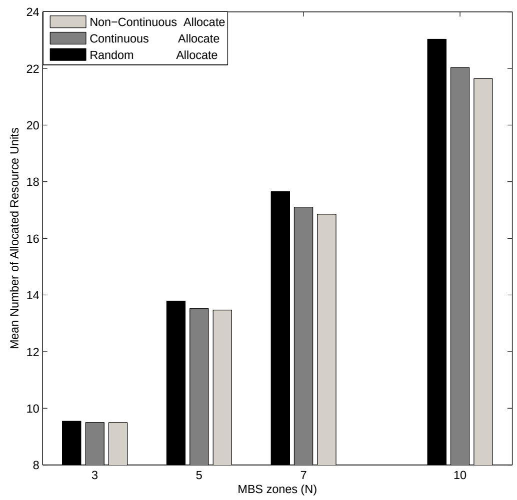

Fig. 2: Performance of radio resource allocation algorithm with identical R_i.

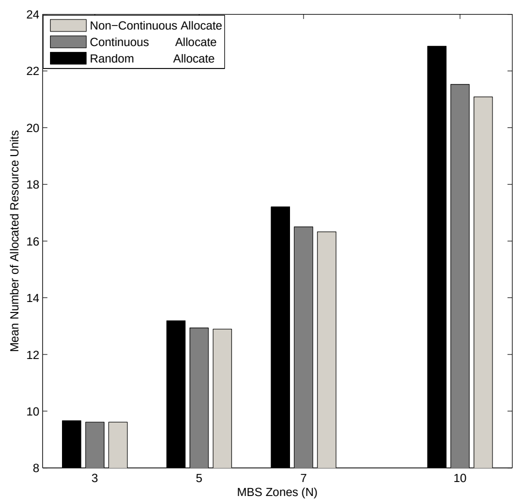

Fig. 3: Performance of radio resource allocation algorithms with different R_i.

Figure 4 showed the running time of the CA and NCA algorithms for MBS zones with different R_i and $M = 169$. A constant of $B_i = 5$ was chosen in order to verify the time complexity analysis. It can be found from Fig. 4 that NCA requires less resource units than CA does but at the cost of extra computational complexity. From the simulation results, it was found that the average running time of NCA algorithm is about B_i^2 times than that of CA algorithm. Note that the running time of the cases shown in Fig. 2 and Fig. 3 had similar results as that in Fig. 4. Therefore, the results are not demonstrated herein.

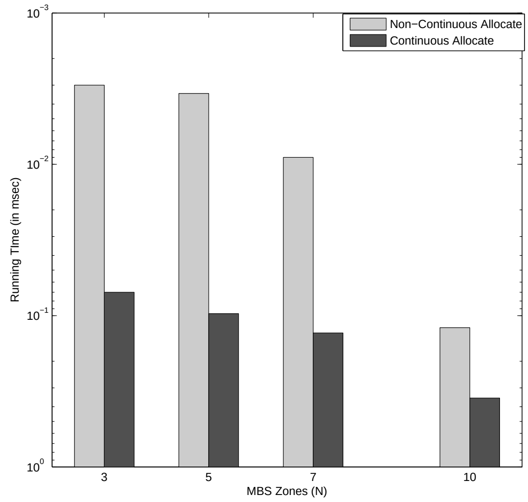

Fig. 4: Running time of CA and NCA algorithms.

Figure 5 and Fig. 6 showed the required resource units of the three resource allocation algorithms for $M = 169$ and 91, respectively. In Fig. 5 and Fig. 6, $B_i = 5$ and $R_i = 2$ were considered and the effect of the bandwidth requirement variation on the required number of resource units was investigated. The case of standard deviation equal to 0 is equivalent to the single resource allocation algorithm considered in [1]. In this case, CA and NCA are identical. Figure 5 and Fig. 6 showed that the mean number of required resource units increases as the bandwidth requirement variation increases. It can be found in Fig. 5 that the benefit of NCA was ignorable when the bandwidth requirement variation increases. Figure 6 demonstrated the effect of reducing M on the mean number of required resource units. Reducing M is equivalent to increasing R_i since both cases increase the overlapping probabilities of MBS zones. Figure 6 showed that the performance of CA and NCA was similar if the MBS zones were highly overlapped. Figure 7 showed the required resource units of the three resource allocation algorithms for $M = 37$ and $R_i = 1$. It can be found from Figure 6 and Fig. 7 that the performance of the three algorithms was similar in the two cases since the effect of reducing M was compensated by the effect of decreasing R_i.

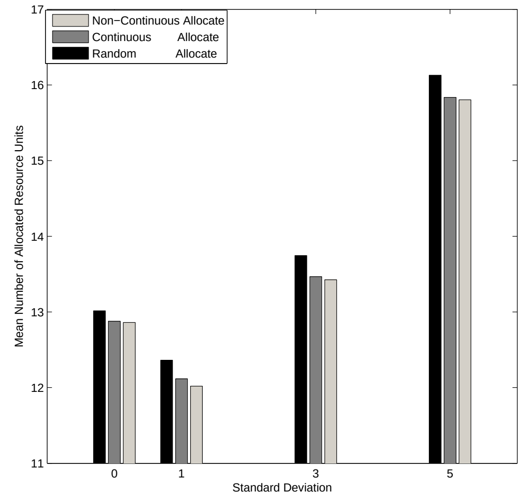

Fig. 5: Performance of radio resource allocation algorithm with different standard deviation $M = 169$.

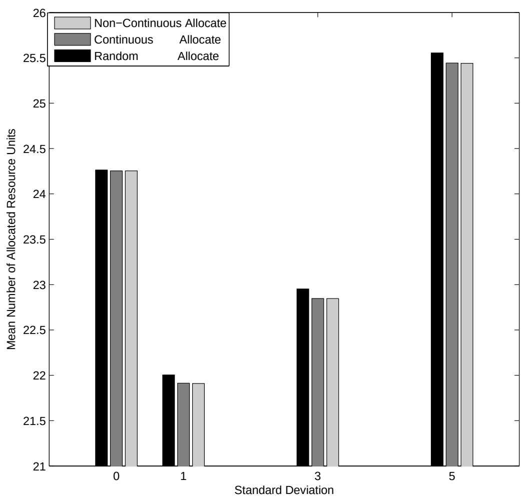

Fig. 6: Performance of radio resource allocation algorithm with different standard deviation $M = 91$.

4. Conclusion

This paper presents two algorithms to allocate radio resource units for overlapping MBS zones requiring different radio resource units. A continuous allocation algorithm and a non-continuous allocation algorithm were presented to allocate radio resource units to M overlapping MBS zones. Simulations were conducted to evaluate the effectiveness of the proposed

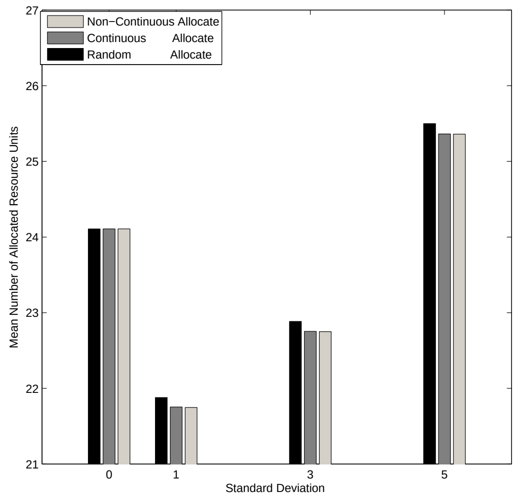

Fig. 7: Performance of radio resource allocation algorithm with different standard deviation $M = 37$.

algorithms. It was found that the proposed allocation algorithms may reduce the required number of resource units.

Currently, a radio resource re-allocation is under development. The radio resource re-allocation aims to re-allocate resource in response to the changing of MBS zone topology. It may utilize the correlation between the old and the new topologies to minimize the number of re-allocated zones. In addition, we are developing a resource estimation model which can accurately estimate the number of radio resources required by the MBS services.

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