Adaptive Configuration of Forward Channels for Terminal Collaborative Reception

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Abstract Collaborative reception has been proposed to improve frequency utilization efficiency in wireless networks. This paper proposes adaptive configuration of forward channels that selects not only terminals to forward received signals to the destination terminal but also higher frequency bands for the forward links. We propose adaptive terminal selection algorithms to implement the proposed adaptive configuration of forward channels. The proposed adaptive configuration based on the algorithms achieves higher frequency utilization efficiency than fixed configurations. While the proposed two algorithms attain similar frequency utilization efficiency, one of the algorithms, so called, a complexity-reduced selection algorithm reduces the computational complexity to almost \( \frac{1}{200} \) of the other of the optimum selection algorithm.

Key words: Collaborative reception, Wireless relaying, distributed antennas, complexity reduction, utilization of multiple higher frequency bands.

1. Introduction

Traffic in wireless networks has been increasing exponentially since the launch of smart-phones. Because frequency band allocated to wireless systems is limited, lots of techniques to accommodate such a high traffic in wireless communication systems have been investigated. Since user data rate gets higher in the next generation wireless communication systems, frequency utilization efficiency will become more important. Many techniques have been proposed to raise frequency utilization efficiency, e.g., adaptive modulation and coding (AMC)\(^1\), and multiple input and multiple output (MIMO)\(^2\). Distributed antenna concept, which is regarded as a type of MIMO, has also been proposed for the next generation mobile communication\(^3\). A lot of antennas are scattered in a cell in distributed antenna systems, in contrast with a centralized antenna systems where antennas are concentrated on a base station. The distributed antenna concept improves distribution of received signal power in a cell, which results in improvement of frequency utilization efficiency in wireless communication systems.

When signals are transmitted from those antennas simultaneously in distributed antenna systems, they interfere each other. To mitigate such harmful interference, coordinated multipoint (CoMP) concept has been considered\(^5\). CoMP applies precoding to distributed antenna systems even though those antennas are geographically apart from each other. However, precoding needs channel state information to be fed back from terminals to the central signal processing server through uplinks of the wireless network, which reduces the user data rate in the uplink.

On the other hand, terminal collaborative reception has been proposed for the same purpose\(^6\). Even if only one antenna is installed in a user terminal, many spatially multiplexed signals can be detected at the destination terminal with assistance of terminals surrounding the destination terminal. (These terminals are hereafter called collaboration terminals.) In the collaborative reception, the signals received at the collaboration terminals are forwarded to the destination terminal through a higher frequency band than that of the link between the distributed antennas and the collaboration terminals. This forwarding step is regarded as overhead in the terminal collaborative reception. As the number of the collaboration terminals increases, the signal detection performance is more improved in principle, whereas the overhead increases. Therefore, the terminals have to be selected carefully. In addition, the detection performance is dependent on not only the channel from the distributed antennas to the collaboration terminals, but also those in the higher frequency bands.
This paper proposes an adaptive configuration of forward channels for the terminal collaborative reception. The terminal collaborative reception with the proposed adaptive configuration applies multiple higher frequency bands for the signal forwarding. The higher frequency bands for the signal forwarding are adaptively selected in the proposed scheme. Because communication quality greatly depends on a frequency band of a channel in wireless communications, the terminals should be reselected whenever the frequency band is altered. Therefore, the proposed adaptive configuration selects terminals to join the collaborative reception in conjunction with the selection of higher frequency bands. This paper evaluates the performance of the proposed adaptive configuration in terms of frequency utilization efficiency.

Next section describes a system model. The proposed adaptive configuration of forward channels is explained in Sec.3, and the performance of the proposed adaptive configuration is evaluated in Sec.4. Finally, Sec.5 presents concluding remarks.

2. System Model

We assume that $N_T$ distributed antennas emit their radio signals and $N_U$ terminals receive those signals. Let $x(i) \in \mathbb{C}$ denote the radio signal that is sent from the $i$th antenna, the signal received at the $k$th collaboration terminal can be written in an equivalent low-pass system.

$$y(k) = \sum_{i=0}^{N_T-1} h(k,i)x(i) + n(k) \quad k = 0, \ldots, N_U - 1 \quad (1)$$

where $y(k) \in \mathbb{C}$, $h(k,i) \in \mathbb{C}$, and $n(k) \in \mathbb{C}$ denote the signal received at the $k$th collaboration terminal, an impulse response in lower microwave frequency band between the $i$th antenna to the $k$th collaboration terminal, and the additive white Gaussian noise (AWGN).

In this paper, we assume that the $(N_U - 1)$th terminal is the destination terminal. The received analog signals are up-converted to higher frequency bands after amplification, and are transmitted for the destination terminal. However, only $N_S$ signals out of all the received signals are forwarded to the destination terminal via the channels in the higher frequency bands.

$$y_m(k) = h_m(k)y(k) + n_m(k)$$

$$= \sum_{i=1}^{N_T} h_{m(k)}(i)x(i) + \bar{n}_m(k),$$

$$k = k_0, \ldots, k_{N_S-1}$$

In (2), $y_m(k) \in \mathbb{C}$, $h_m(k) \in \mathbb{C}$, and, $n_m(k) \in \mathbb{C}$, $k_l \in \mathbb{Z}$ represent a received signal sent from the $k_l$th collaboration terminal, a channel impulse response in an $m(k)$th higher frequency band $f_{m(k)}$ between the $k$th collaboration terminal to the destination terminal, the AWGN added at the destination terminal, and, an index of the terminal forwarding their received signals in the $l$th slot in the forwarding time slots. In addition, $h_{m(k)}(i) \in \mathbb{C}$, and $\bar{n}_m(k) \in \mathbb{C}$ denote an equivalent channel impulse response between the $i$th antenna to the destination via the $k$th collaboration terminal, and an equivalent AWGN, which are defined as $h_{m(k)}(i) = h_{m(k)}h(k,i)$ and $\bar{n}_m(k) = h_{m(k)}n(k) + n_m(k)$. Obviously, the signal processing in (2) is similar as amplify-and-forward relaying which is applied in non-regenerative relaying systems.

The collaborative reception scheme is shown in Fig.1. In the figure, the several distributed antennas simultaneously send their signals to the three terminals, the middle of which is the destination terminal. The two terminals sandwiching the destination terminal forward their received signals to the destination terminal. The destination terminal gets the signals received at the other terminals. Though the destination terminal has only one antenna, the destination terminal looks as if the destination terminal has three antennas. This is the principle of the collaborative reception that the destination terminal can detects multiple signals even though only one antenna is installed.

The signals received at the $N_S$ collaboration terminals are sent to the destination terminal in a way of
time division duplex, which is illustrated in Fig.2. In the figure, the signals are transmitted from the antennas in “Down link-1” and the signals received at the 1st collaboration terminal are forwarded to the destination terminal in a channel of the \( m(1) \)th frequency band, which is followed by the signal forwarding from the 2nd collaboration terminal. Whereas the transmission performance is more improved as the number of the collaboration terminals, \( N_S \), increases, it takes longer time to forward the signals. The slots for the forwarding are regarded as overhead in the collaborative reception. In other words, increasing the number of the collaboration terminals raises the frequency utilization efficiency through improvement of the transmission performance, and increases the overhead which reduces the frequency utilization efficiency. The determining the number of the collaboration terminals is a crucial issue in the collaborative reception. On the other hand, although the AWGN is added at not only the collaboration terminals but also the destination terminal, the AWGN generated at the destination terminal can be negligible if the channel impulse response in the \( m(k) \)th higher frequency band is large enough. Since transmission signals are more attenuated in higher frequency bands, it might be better to select lower frequency bands in terms of transmission performance. However, since bandwidth tends to be wider in higher frequency bands, overhead to forward the signals is reduced in higher frequency bands. There might be trade-off in selection of frequency bands for the forwarding. Therefore, the frequency band selection has to be performed in conjunction with the terminal selection, taking account of the available bandwidth for the frequency bands.

The next section proposes a novel technique to select the terminals and the frequency bands in order to maximize frequency utilization efficiency of the lower frequency band.

### 3. Adaptive Configuration Of Forward Channels

#### 3.1 Frequency Utilization Efficiency

While the transmission signals are received at \( N_U \) terminals, \( N_S \) terminals selected out of the \( N_U \) terminals forward their received signals to the destination via the higher frequency bands. In a word, the destination terminal obtains those signals received at the other \( N_S \) terminals via the higher frequency bands in addition to the own received signal \( y(N_U - 1) \). All the signals obtained by the destination terminal are expressed in a vector format \( \mathbf{Y}(\phi) \in \mathbb{C}^{(N_S + 1) \times 1} \), which is defined as

\[
\mathbf{Y}(\phi) = \begin{pmatrix} y(m(k_0)) \cdots y(m(k_{N_S - 1})) \ y(N_U - 1) \end{pmatrix}^T
\]

where superscript \( T \) and \( \phi \in \mathbb{R}^{S \times 3} \) denote transpose of a matrix or a vector and an index vector of a combination of the terminals and the frequency bands. For instance, when \( N_F \) frequency bands are available, \( \phi \) can be defined as

\[
\phi = \left( N_S, \sum_{i=0}^{N_S-1} k_i N_U, \sum_{i=0}^{N_S-1} m(k_i) N_F \right)
\]

The first entry of \( \phi \) denotes the number of the collaboration terminals, the second entry expresses the set of the collaboration terminals, and the third one represents the set of the frequency bands in which the collaboration terminals forward their received signal to the destination.

Let \( \mathbf{X} \in \mathbb{C}^{N_T} \) denote a transmission signal vector from the antennas, the vector is defined as \( \mathbf{X} = (x(0) \cdots x(N_T - 1))^T \). The signal vector \( \mathbf{Y}(\phi) \) is written as follows.

\[
\mathbf{Y}(\phi) = \mathbf{H_D}(\phi) \mathbf{Y} + \mathbf{N_D} = \mathbf{H}(\phi) \mathbf{X} + \mathbf{N}(\phi) \quad (3)
\]

In (3), \( \mathbf{Y}, \mathbf{N_D} \in \mathbb{C}^{(N_S + 1) \times 1} \), \( \mathbf{N}(\phi) \in \mathbb{C}^{(N_S + 1) \times 1} \) and, \( \mathbf{H_D}(\phi) \in \mathbb{C}^{(N_S + 1) \times (N_S - 1)} \) denote the forwarded signal vector, the noise vector generated at the destination terminal, an equivalent noise vector, and a channel matrix between the collaboration terminals and the destination terminal, respectively. They are defined as

\[
\mathbf{Y} = \begin{pmatrix} y(m(k_0)) \cdots y(m(k_{N_S - 1})) \end{pmatrix}^T, \quad \mathbf{N_D} = \begin{pmatrix} n(m(0)) \cdots n(m(N_S - 1)) \end{pmatrix}^T, \quad \mathbf{N}(\phi) = \mathbf{H_D}(\phi) \mathbf{N} + \mathbf{N_D}, \quad \mathbf{H_D}(\phi) = \begin{pmatrix} h_m(k_0) & O & 0 \\ O & \ddots & O \\ \vdots & O & h_m(k_{N_S - 1}) \\ 0 & \cdots & 0 & 1 \end{pmatrix}
\]

respectively. In addition, the equivalent channel matrix \( \mathbf{H}(\phi) \in \mathbb{C}^{(N_S + 1) \times N_T} \) is defined as \( \mathbf{H}(\phi) = \mathbf{H_D}(\phi) \mathbf{H_C}(\phi) \) where \( \mathbf{H_C}(\phi) \in \mathbb{C}^{(N_S + 1) \times N_T} \) represents a channel matrix between the terminals and the distributed antennas defined as,

\[
\mathbf{H_C}(\phi) = \left( \mathbf{H}_{k_0}^T \cdots \mathbf{H}_{k_{N_S - 1}}^T \mathbf{H}_{N_U - 1}^T \right)^T, \quad \mathbf{H}_i = (h(l,0) \cdots h(l,N_T - 1))
\]

For evaluating the frequency utilization efficiency, because the equivalent noise power \( E\left[|\mathbf{N}(\phi)|^2\right] \) is affected
by the channel impulse response \( h_{m(k)} \), the channel matrix has to be normalized by a gain matrix \( H_G(\phi) \in \mathbb{C}^{(N_T+1)\times(N_T+1)} \). The gain matrix can be defined as,

\[
H_G(\phi) = \begin{pmatrix}
g_0(\phi) & O & \cdots & 0 \\
O & \ddots & \ddots & \vdots \\
\vdots & O & g_{N_T}(\phi) & 0 \\
\cdots & \cdots & \cdots & 1
\end{pmatrix},
\]

(6)

where \( g_i(\phi) \in \mathbb{R} \) denotes a scalar defined as,

\[
g_i(\phi) = \sqrt{\frac{\sigma^2}{\|h_{m(k)}\|^2 \sigma^2(k_i) + \sigma^2_m(k_i)}}.
\]

(7)

In (7), \( \sigma^2(k) \in \mathbb{R}, \sigma^2_m(k) \in \mathbb{R} \), and \( \sigma^2 \in \mathbb{R} \) represent the power of the AWGN \( n(k) \) at the lower microwave band, that of the AWGN \( n_m(k) \) at the \( m(k) \)th frequency band, and equivalent noise power. The normalized channel matrix \( H_N(\phi) \in \mathbb{C}^{N_T\times N_T} \) is defined as \( H_N(\phi) = H_G(\phi) H(\phi) \). This means that (3) can be rewritten as follows.

\[
Y(\phi) = H_G(H(\phi) X + N(\phi)) = H_N(\phi) X + \hat{N}(\phi)
\]

(8)

where \( \hat{N}(\phi) \in \mathbb{C}^{(N_T+1)\times 1} \) represents a normalized noise vector defined as \( \hat{N}(\phi) = H_G N(\phi) \). Obviously, the normalized noise vector has a property \( E[\hat{N}(\phi)^H \hat{N}(\phi)] = \sigma^2 I \) where \( E[\alpha] \in \mathbb{C}^{N_T\times N_T} \) and superscript \( H \) denote ensemble average of a variable \( \alpha \), the identity matrix, and Hermitian transpose of a matrix or a vector.

The frequency utilization efficiency of the terminal collaborative reception can be obtained as follows. First of all, the eigen values of the normalized channel matrix \( H_N \) is calculated by the singular value decomposition (SVD),

\[
H_N(\phi)^H H_N(\phi) = U(\phi) \Gamma(\phi) U(\phi)^H
\]

\[
\Gamma(\phi) = \begin{pmatrix}
\gamma_0(\phi) & O & \cdots & 0 \\
O & \ddots & \ddots & \vdots \\
\vdots & O & \gamma_{N_T}(\phi) & 0 \\
\cdots & \cdots & \cdots & 1
\end{pmatrix}
\]

(9)

\( U(\phi) \in \mathbb{C}^{N_T\times N_T}, \Gamma(\phi) \in \mathbb{C}^{N_T\times N_T}, \) and \( \gamma_i(\phi) \in \mathbb{C} \) denote a unitary matrix, a diagonal matrix with eigenvalues in diagonal positions, and the \( i \)th eigenvalue. When the signals are forwarded without any overhead, as is known, the Ergodic capacity in the channel between the distributed antennas and the destination terminal can be obtained with the eigen values\(^9\). As is shown in Fig.2, however, the collaborative reception needs the overhead to forward the received signals to the destination terminal. Therefore, the overhead has to be taken into account, which is described as follows.

We introduce time period \( T_{DL} \in \mathbb{R} \) and \( T_{m(k)} \in \mathbb{R} \) in this paper. The period \( T_{DL} \) is defined as a time length needed for the distributed antenna to send a packet to the collaboration terminals. On the other hand, the time period \( T_{m(k)} \) is defined as a time length for the \( k \)th terminal to forward the received signals to the destination terminal via the \( m(k) \)th frequency band. Let \( T(\phi) \in \mathbb{R} \) represent a time period needed to send a packet from the distributed antennas to the destination terminal in the collaborative reception, the time period \( T(\phi) \) can be defined as,

\[
T(\phi) = T_{DL} + \sum_{i=0}^{N_T-1} T_{m(k_i)} + (N_S + 1) \Delta_{FS}.
\]

(10)

In (10), \( \Delta_{FS} \in \mathbb{R} \) denotes an time interval between the slots, which is called “inter frame space” in this paper. The frequency utilization efficiency of the collaborative reception with the use of higher frequency bands for signal forwarding can be defined as follows.

\[
c(\phi) = \frac{T_{DL} \sum_{i=0}^{N_T-1} \log_2 \left( 1 + \frac{\gamma_i(\phi)}{\sigma^2} \right)}{T(\phi)}
\]

(11)

Since the frequency utilization efficiency is dependent on the combination \( \phi \) as shown in the (11), we propose an algorithm to select the terminals and the frequency band for the forwarding.

### 3.2 Optimum Selection

Because our goal is to maximize the frequency utilization efficiency, we propose to find the best combination of a set of the terminals and higher frequencies for the forwarding. When the best combination is referred by the optimum index vector \( \phi_{max} \), the proposed algorithm finds the optimum index vector \( \phi_{max} \) that maximizes the following frequency utilization efficiency.

\[
\phi_{max} = \arg \max_\phi \frac{T_{DL} \sum_{i=0}^{N_T-1} \log_2 \left( 1 + \frac{\gamma_i(\phi)}{\sigma^2} \right)}{T(\phi)}
\]

(12)

Not only the number of the collaboration terminals \( N_S \) but also the set of the terminals to forward their signals, and the frequency bands for the forwarding are selected jointly in the above maximization process. Although the highest frequency utilization efficiency is achieved by the maximization process, in principle, the maximization is carried out by the exhaustive search, because (12) is quite non-linear. When
After the frequency band selection, the combination of the terminals that maximizes a metric of the following frequency utilization efficiency is selected in the proposed selection algorithm.

\[
\phi_{\text{subopt}} = \arg\max_{\phi_{m}} \frac{T_{\text{DL}}}{T(\phi)} \sum_{l=0}^{N_{F}-1} \log_{2} \left( 1 + \frac{\gamma_l(\phi)}{\sigma^2} \right) \tag{14}
\]

In (14), \(\phi_{\text{subopt}}\) and \(\phi_{m}\) represent an index vector searched by the proposed algorithm and an candidate of the index vector defined as \(\phi_{m} = (N_{S}, \sum_{i=0}^{N_{F}-1} k_{i}, N_{U}, \sum_{i=0}^{N_{F}-1} m_{\text{max}}(k_{i}), N_{F})\) where \(m_{\text{max}}(k)\) determined in (13) is applied, and \(N_{S}\) and \(k_{i}\) are variables. In a word, only a set of the terminals is found because the frequencies for the signal forwarding have been determined in (13). Hence, the optimization process is divided into two steps, i.e., (13) and (14), and \(m_{\text{max}}(k)\) is chosen regardless of the other channel gains.

This makes the complexity of the selection algorithm proposed in this section greatly less than that of the optimum selection algorithm. This is the reason why the selection algorithm proposed in this section is called “complexity-reduced selection”.

Because the channel state information between the collaboration terminals and the destination terminal in the frequency selection is only taken into account, the proposed algorithm only achieves suboptimum performance. Therefore, the index \(\phi_{\text{subopt}}\) has subscript “sub-opt” that means suboptimum performance. Finally, the transmission signals are detected at the destination terminal.

The proposed algorithm can be implemented with small additional overhead as follows.

a) Collaboration terminals send sounding packets in which all the available frequency band pilot signals are multiplexed in the time domain.

b) The destination terminal selects the best frequency band for every channel, using (13.)

c) All the collaboration terminals and the destination terminal receive the signals sent from the distributed antennas simultaneously.

d) Just after the reception, the destination terminal send a request packet in the inter frame space, which informs the collaboration terminals the result of the best frequency band selection.

e) The collaboration terminals send the received signals to the destination terminal through the frequency band informed by the destination in a manner of time division duplex.

The proposed algorithm is illustrated in Fig.3 where \(S_{k}\)
and $R_D$ represent the sounding packet send by the $k$th terminal and the request packet. $S_{k,n}$ represents a short sounding sequence for the $k$th terminal to send in the $n$th frequency band in the figure. Because some of the sounding packets are inserted in the inter frame space, the overhead is only the sounding packet at the begging of the sequence. Because no channel state information is sent to the destination terminal, the additional overhead is reduced to be negligible small.

Consequently, the proposed complexity-reduced selection algorithm not only reduces the computational load of the designation terminal but also enables the collaborative reception to be implemented with negligible small additional overhead.

### 4. Simulation

We assume that 5 distributed antennas transmit their signals simultaneously to 5 terminals including one destination terminal, i.e. $N_T = N_U = 5$. The frequency band of the transmission is 2GHz. On the other hand, 5GHz, 12GHz, and 20GHz are available as higher frequency bands for the signal forwarding. When bandwidth of the frequency band $f_m(k)$ is denoted by $B_m(k) \in \mathbb{R}$, the bandwidth is assumed to be proportional to the frequency band, because wider bandwidth tends to be allocated as the frequency band gets higher, which is drawn in Fig.4.

$$B_{m(k)} = \frac{f_{m(k)}}{f_{m(0)}} B_{m(0)}$$

(15)

In the simulation, $f_{m(0)}$ is set to 2GHz. While we apply the Rayleigh fading to all the channels *, the path loss model for the free-space is taken into account in the channels between the destination terminal and the collaboration terminals. The performance is evaluated in a wireless network shown in Fig.5. In the figure, $T_i$ represents the $i$th distributed antenna. The system parameters are listed in Table 1.

While the distances $d_4$ and $d_1$ are kept constant in the performance evaluation, $d_2$ that denotes the distance between the destination terminal and the collaboration terminal $R_2$ is changed for analyzing the performance. We analyze the performance of the collaborative reception when a group of terminals go away from the destination terminal.

#### 4.1 Probability of Collaborations

As is described previously, the proposed selection algorithm finds the combination of the terminals to maximizes the frequency utilization efficiency. Obviously, the number of collaboration terminals, $N_S$, depends on wireless communication environment, e.g., wireless network topology. Therefore, we confirm how the number of the collaboration terminals, $N_S$, is changed as the distance $d_2$ gets long in the simulation model drawn in Fig.5. The number of the collaboration terminals $N_S$ with respect to $d_2$ is drawn in Fig.6. The optimum selection algorithm is applied in the figure. Because the destination terminal seems to be able to always collaborate with the terminal $R_1$, the probability of no collaboration is very small in spite of the distance $d_2$. Also, the probability of the 5-collaboration is also small. On the other hand, when the terminals $R_2 \sim R_4$ are close by the destination terminal, e.g., $d_2 = 30, 3$ or 4 terminals are collaborating with the destination terminal. As the distance $d_2$ gets long, 2-collaboration becomes dominant. In other words, the destination terminal becomes collaborating with only the $R_1$ terminal.

The probability of the collaboration is shown in Fig.7 where the complexity-reduced selection algorithm is applied. Although probability of every collaboration except for no-collaboration is smaller than that shown in

*While the amplitude of the impulse response is distributed with Rayleigh distribution, the impulse response is kept constant during a slot for the signal forwarding and the signal transmission

![System parameters](image)

![Simulation model](image)
Fig. 6, the performance of the complexity-reduced selection algorithm is almost same as that of the optimum selection algorithm.

### 4.2 Frequency Utilization Efficiency

Whereas it is shown in the previous section that the complexity-reduced selection algorithm looks achieving similar performance as the optimum selection algorithm in terms of the collaboration performance, the performance of the complexity-reduced selection algorithm is compared with that of the optimum selection algorithm in terms of the frequency utilization efficiency in this section. The frequency utilization efficiency of the proposed selections is shown in Fig. 8 where the distance $d_2$ is 30m. In the figure, the performance of the 5-collaborative reception where the 5 terminals are always collaborating with only one higher frequency band, is added for comparison. In the figure, “20GHz/fixed” and “5GHz/fixed” show the performances of the 5-collaborative reception with 20GHz and 5GHz, respectively. Obviously, the proposed two selection algorithms attain much better frequency utilization efficiency than the 5-collaborations. The optimum selection algorithm achieves about 1bit/Hz better performance than the complexity-reduced selection algorithm at the CDF of 50%.

On the other hand, Fig. 9 shows the frequency utilization efficiency of the proposed two algorithms. However, the distance $d_2$ is set to 270m. The performance of the proposed two selection algorithms is much superior to that of the 5-collaborations. The complexity-reduced selection algorithm attains the maximum gain when some terminals are far from the destination terminal. In a word, because the terminals far from the destination terminals are not useful for the collaborative reception, it can be judged by only the gain of the channel impulse response between the terminals and the destination whether they are useful or not for the collaborative reception. In a word, the complexity-reduced selection algorithm attains superior performance, especially when some terminals are apart from the destination terminal.

### 4.3 Complexity

Fig. 10 shows computational complexity of the proposed complexity-reduced selection algorithm with respect to the number of the higher frequency bands $N_F$. Computation complexity is evaluated in terms of the number of the combinations $\phi^*$. In the figure, the computational complexity of the optimum selection is also drawn. Obviously, the proposed complexity-reduced selection algorithm can keep complexity almost same in spite of the number of the frequency bands and is much less than that of the optimum selection as far as the number of the frequency bands is more than 1. When $N_S = 5$ and $N_F = 3$, the complexity of the proposed complexity-reduced selection algorithm is 1/200 as much as that of the optimum selection algorithm.

### 5. Conclusion

This paper has proposed an adaptive configuration...
of forward channels for the terminal collaborative reception. Not only terminals to forward their received signals to the destination terminal but also the frequency bands for the forwarding are adaptively selected in the proposed adaptive configuration, in order to maximize the frequency utilization efficiency. Furthermore, this paper proposes two algorithms to implement the proposed adaptive configuration. One of them is called “optimum selection algorithm”, and the other is named “complexity-reduced selection algorithm”. While the optimum selection algorithm achieves the best frequency utilization efficiency, the algorithm imposes huge computational load on the destination terminal. On the other hand, although the complexity-reduced selection algorithm only achieves suboptimum frequency utilization efficiency, the computational complexity is much less than that of the optimum selection algorithm. The performance is confirmed by computer simulation. The proposed adaptive configuration based on the proposed algorithms improves about 2 times higher frequency utilization efficiency than the fixed configuration. The proposed complexity-reduced selection algorithm not only achieves similar frequency utilization efficiency as the optimum selection algorithm, but also reduces the complexity to 1/200 of the optimum selection algorithm. In addition, the adaptive configuration based on the complexity-reduced selection algorithm can be implemented with negligible small overhead.

Acknowledgment

This research and development work was supported by the MIC/SCOPE ♯165007006 and JSPS KAKENHI Grant Number 15K06066.

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