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Source(s)	Heesoo Lee 161 Gajeong-dong Yuseong-gu, Daejeon, Korea Voice: +82-42-860-5375 Fax: +82-42-860-6732 Email: heelee@etri.re.kr
Re:	MBWA Call for Proposals
Abstract	This document provides basic aspects, frame structure, channelization, salient features of the proposal, etc.
Purpose	This document addresses high-level description of key elements of the proposal.
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Technology Overview Document

Heesoo Lee

heelee@etri.re.kr

ETRI

1 Introduction

The proposal is for an FDD technology.

The downlink and uplink transmission schemes are based on OFDM/FDMA (OFDMA) and SC-FDMA, respectively.

2 Downlink Transmission

2.1 Basic Aspects

The proposed downlink transmission scheme is based on OFDM/FDMA (OFDMA) and supports four different block assignment sizes of 5, 10, 15, and 20 MHz. The basic transmission parameter sets are specified in Table 2-1.

Table 2-1. Parameters for downlink transmission scheme

Transmission BW	5 MHz	10 MHz	15 MHz	20 MHz
Sub-frame duration	0.5 ms			
Sub-carrier spacing	15 kHz			
Sampling frequency	7.68 MHz (2 × 3.84 MHz)	15.36 MHz (4 × 3.84 MHz)	23.04 MHz (6 × 3.84 MHz)	30.72 MHz (8 × 3.84 MHz)
FFT size	512	1024	1536	2048
Number of occupied sub-carriers	301	601	901	1201
Number of OFDM symbols per sub frame	7			
CP length (μs/samples)	(4.69/36) × 3, (4.82/37) × 4	(4.75/73) × 6, (4.82/74) × 1	(4.73/109) × 2, (4.77/110) × 5	(4.75/146) × 5, (4.79/147) ×2

2.1.1 Modulation Scheme

The supported data-modulation schemes for downlink are QPSK, 16QAM, and 64QAM.

2.1.2 Channel Coding and Hybrid ARQ

LDPC codes and Convolutional Turbo codes are employed for FEC coding;

- LDPC codes
  - Structured LDPC codes with multi-rate compatibility

- Convolutional Turbo codes
  - 8-state tail-biting constituent encoder

The mandatory coding method is LDPC coding, and convolutional Turbo coding is optional.

The following hybrid-ARQ schemes are used;

- Chase combining and Type-II & Type-III H-ARQ

- Incremental redundancy based on retransmission request for a part of codeword

2.1.3 MIMO Schemes

The number of transmit antennas at the base station is 1, 2 or 4. The following MIMO schemes are supported;

- For high speed users
  - STTD
  - Spatial multiplexing

- For low speed/fixed users
  - Single user precoding
  - S-PUSRC (SIC-based Per User & Stream Rate Control), which is a multi-use r precoding MIMO scheme and explained in detail in section 4.2.

2.1.4 Multicast/Broadcast Support

Soft combining is basically considered for multi-cellular multicast/broadcast.

Additional macro diversity is supported through the following;

- Space-frequency (or space-time) transmit diversity among sectors/BSs to achieve more symbol level diversity

- Rotation of SFBC antenna combining pattern to achieve more coding block level diversity

Synchronization is required to use the above schemes;

- Inter-sector synchronization is natural.
- Inter-BS synchronization is preferred.

The proposed macro diversity scheme for multicast/broadcast services is explained in section 4. 4.

2.1.5 Inter-cell Interference Mitigation

The virtual MIMO technique based on coordinated symbol repetition is applied to control channels and interference-susceptible traffic channels. The characteristic features of the Virtual MIMO technique are as follows.

- Symbol repetition on identically allocated resources among cells/sectors
- Dynamic resource management considering interference-susceptible traffic
- Enhanced joint symbol detection by employing double-layered code sequences
    - Cell-specific scrambling codes as signature randomizers
    - Sector-specific orthogonal codes or random phasers

Further details are explained in section 4. 1.

2.2 Frame Structure

Figure 2-1 shows the frame structure and the resource partitioning of each sub-frame (downlink traffic packet; DTP).

A 10 ms frame consists of 20 equally divided sub-frames, whose duration in consequence is 0.5 ms.

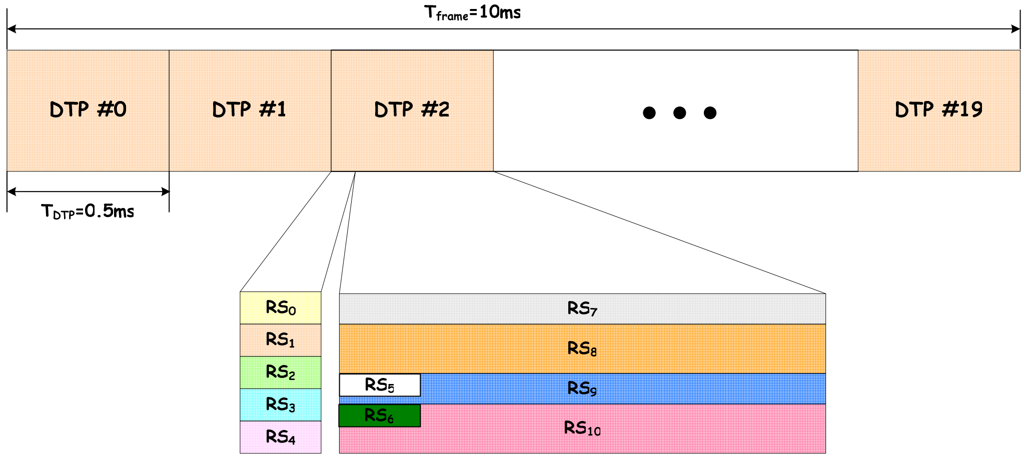

Figure 2-1. Frame structure and (logical) sub-frame resource partitioning

The sub-frame resources are partitioned into 11 resource spaces (RSs);

- RS_0, RS_1: resource space for pilot channels for Tx antenna 0 and 1
- RS_5, RS_6: resource space for pilot channels for Tx antenna 2 and 3
- RS_2, RS_3, RS_4: resource spaces for control channels
- $RS_7 \sim RS_{10}$: resource spaces for shared data channels
    - RS_7: for users with high mobility and located near the cell/sector edge
    - RS_8: for users with high mobility and located near the cell center
    - RS_9: for users with low mobility and located near the cell/sector edge
    - RS_{10}: for users with low mobility and located near the cell center

RS_7 and RS_8 are for the distributed control/data channels to achieve frequency diversity gain and RS_9 and RS_{10} are for the localized data channels to obtain multiuser diversity gain through frequency domain scheduling.

The sizes of $RS_7 \sim RS_{10}$ are adjustable by taking into account of the portion of users with high mobility and the geographical user distributions.

2.2.1 Pilot Structure

The proposed pilot structure is shown in Figure 2-2.

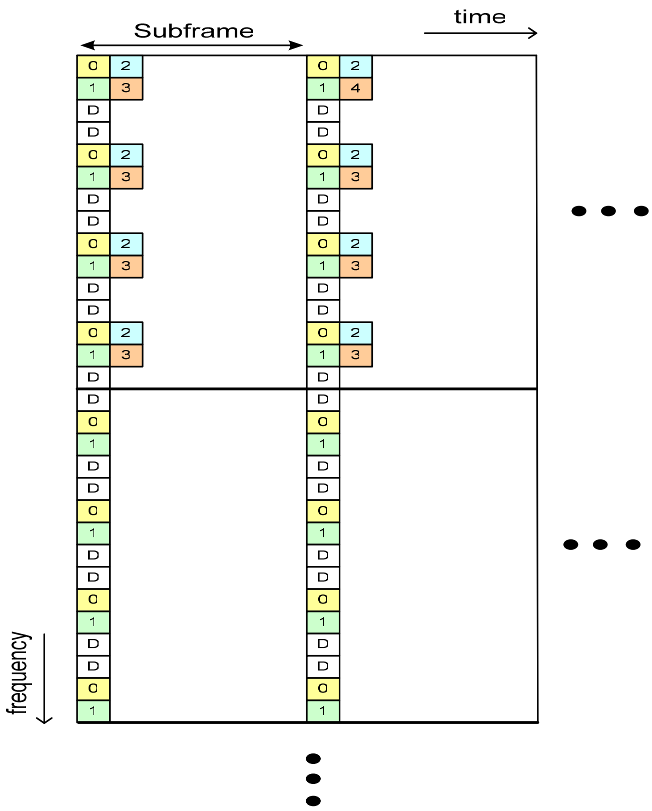

Figure 2-2. Pilot pattern

In the Figure 2-2, '0', '1', '2', and '3' denote the pilot symbols for antenna 0, 1, 2, and 3, respectively.

The pilot symbols for antenna 2 and 3 are transmitted by puncturing a part of data symbols in RS_9 and RS_{10}.

2.2.2 Scrambling Code

All sectors in the same cell use the same cell-specific scrambling code, which is applied for all the symbols including pilot symbols in a sub-frame. The cell-specific scrambling code is repeated in every sub-frame.

In addition to applying the cell-specific scrambling code, sector-specific orthogonal sequence for pilot channels is used to avoid inter-sector interference.

2.2.3 Synchronization Channel

The Synchronization Channel for cell search is formed using the pilot symbols, so that no preamble is required.

In section 4.5, the proposed Synchronization Channel structure and cell search scheme are explained.

2.3 Physical Channels and Multiplexing

There are two different kinds of physical channels, distributed and localized types. The entire channel band is segmented into a number of chunks which consist of contiguous frequency-time bins.

One or several chunks are assigned to a localized physical channel. By assigning chunks of good quality to each user (physical channel), frequency domain multiuser diversity gain can be achieved.

As Figure 2-3 shows, on the other hand, distributed physical channel uses scattered frequency-time bins, which provides frequency diversity over the whole channel bandwidth. In the figure, user 0~3 and user 4~6 use localized physical channels and distributed physical channels respectively.

Distributed physical channels are appropriate for control channels and high speed users, since frequency domain scheduling is impossible. Localized physical channels can be used by low mobility users or multiuser MIMO applications in combination with appropriate frequency domain scheduling.

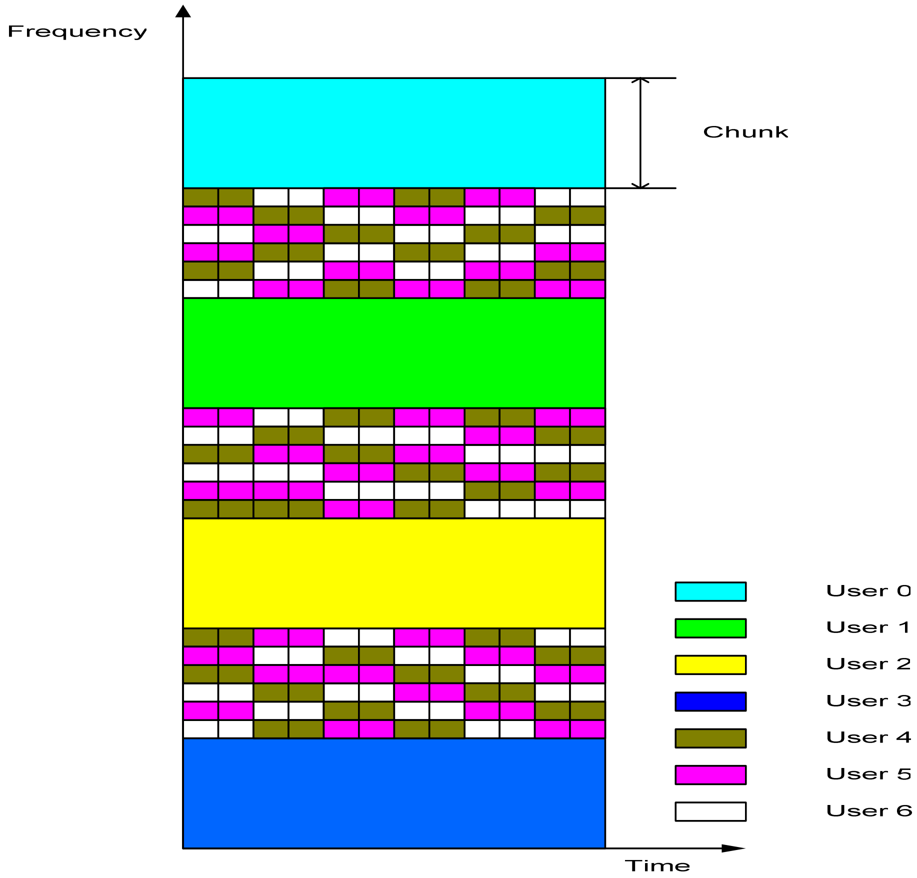

Figure 2-3. Multiplexing of distributed and localized channels

For downlink inter-cell interference mitigation, each of the localized and distributed channels is further categorized into two types of channel, repetition and non-repetition type channels. The repetition channel is used for cell/sector edge users to cancel the inter-cell/sector interference. The detailed explanation for the resource allocation and Tx & Rx schemes for downlink inter-cell interference mitigation is given in section 4.1.

2.4 Adaptive Transmission

Link adaptation in time, frequency, and space domain is supported;

- For efficient time domain link adaptation, the sub-frame size is chosen very shortly, that is, 0.5ms
- Frequency domain link adaptation: each user is assigned the chunks that are the best or good for the user
- Spatial domain link adaptation: the multiuser precoding MIMO scheme can obtain spatial domain multiuser diversity gain

3 Uplink Transmission

3.1 Basic Aspects

Uplink transmission scheme is based on SC-FDMA (Single Carrier Frequency Division Multiple Access). SC-FDMA transmitted signal has low PAPR characteristic. PAPR (Peak to Average Power Ratio) is one of the important issues in uplink in order to provide wide coverage and power efficiency. Furthermore, it can be processed in frequency domain with cyclic prefix guard interval, which simplifies receiver complexity. Some properties of the proposed specifications are as follows

- *support various block assignment*
- *provide link adaptive modulation and coding scheme in frequency/time/space domain*
- *provide fine granularity for supporting various types of services*
- *provide uplink MIMO transmission including multi-user MIMO*
- *no intra-cell interference*
- *inter-cell interference avoidance/mitigation with resource coordination*

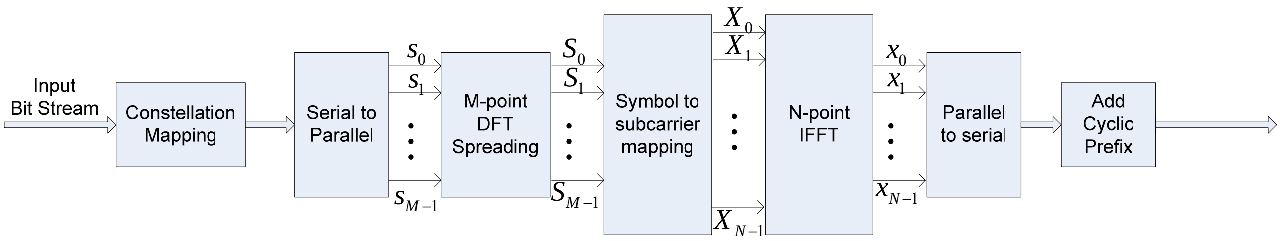

Figure 3-1. DFT spread OFDM

Table 3-1 shows fundamental parameter sets for transmission bandwidths.

Table 3-1. Fundamental parameter sets for uplink transmission

Transmission BW	5 MHz	10 MHz	15 MHz	20 MHz
Sub-frame duration	0.5 ms			
Sub-carrier spacing	15 kHz			
Sampling frequency	7.68 MHz (2 × 3.84 MHz)	15.36 MHz (4 × 3.84 MHz)	23.04 MHz (6 × 3.84 MHz)	30.72 MHz (8 × 3.84 MHz)
FFT size	512	1024	1536	2048
Number of occupied sub-carriers (incl. d.c.)	301	601	901	1201
Number of block symbols per sub frame	6 Long Blocks + 2 Short Blocks Short Blocks can be used for Pilot			
CP length (μs/samples)	(4.04/31) × 7, (5.08/39) × 1	(4.1/63) × 7, (4.62/71) × 1	(4.12/95) × 7, (4.47/103) × 1	(4.13/127) × 7, (4.39/135) ×1

3.2 Frame Structure

Radio frame length is 10 msec. The frame consists of 20 UTPs (Uplink Traffic Packet, UTP and sub-frame are the same in this context), each packet has length of 0.5 msec. UTPs are consist of 6 regular symbol blocks and 2 half-length symbol blocks, which is denoted by LB (long block) and SB (short block), respectively. The basic frame structures are illustrated in Figure 3-2.

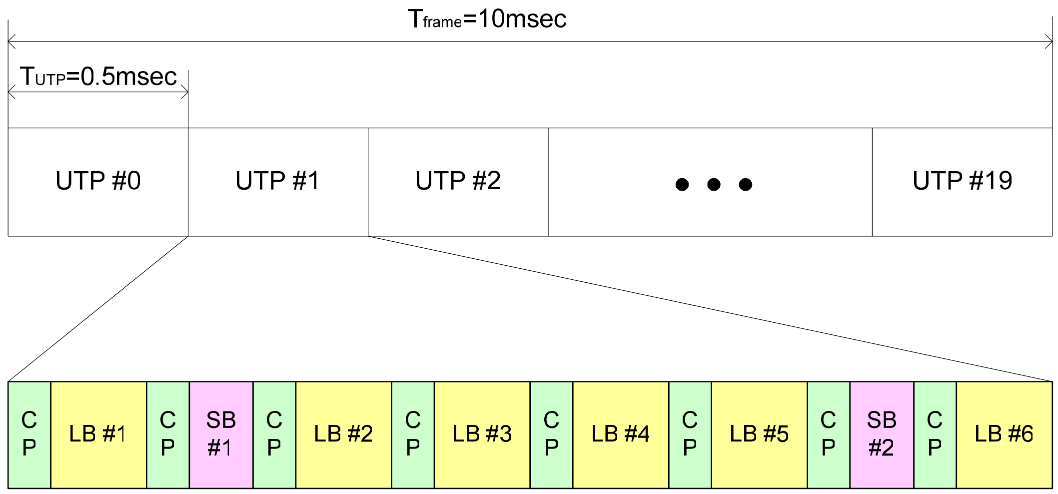

Figure 3-2. Uplink frame structure.

3.3 Channel Multiplexing

3.3.1 Pilot Structure

In this proposal, we present time division multiplexed pilot structure. TDM pilot is advantageous to keep low PAPR. Two main usages of the pilot signal are 1) channel quality measurement for time-frequency domain scheduling, and 2) channel estimation for coherent detection. Pilot symbols are alternatively transmitted via SB #1 and SB #2 in order to meet half-length pilot structure. The proposed pilot structure support both localized and distributed channel types.

3.3.2 Physical Channels

Major physical channels in uplink are as follows

- Shared Physical Data Channel (SPDCH): transmit data traffic and some data-dependent control signals.
- State Control Physical Channel (SCPCH): transmit control signal for state management of user equipments.
- Uplink ACK Channel (UACH): transmit ACK/NACK information responding to downlink SPDCH.
- Uplink Feedback Channel (UFCH): transmit feedback information for downlink transmission.
- Path-loss Feedback Channel (PFCH): transmit path-loss information of UEs for uplink interference coordination.

3.3.3 Multiplexing of Shared Channels

Figure 3-3 shows channel multiplexing scheme. Main features of this structure are as follows:

- TDM pilot structure is used
- Data-independent control channels are multiplexed in frequency domain
- UE data and data-dependent control are multiplexed in time domain

This structure is very advantageous to keep low PAPR and to assist channel estimation for coherent detection at receiver site.

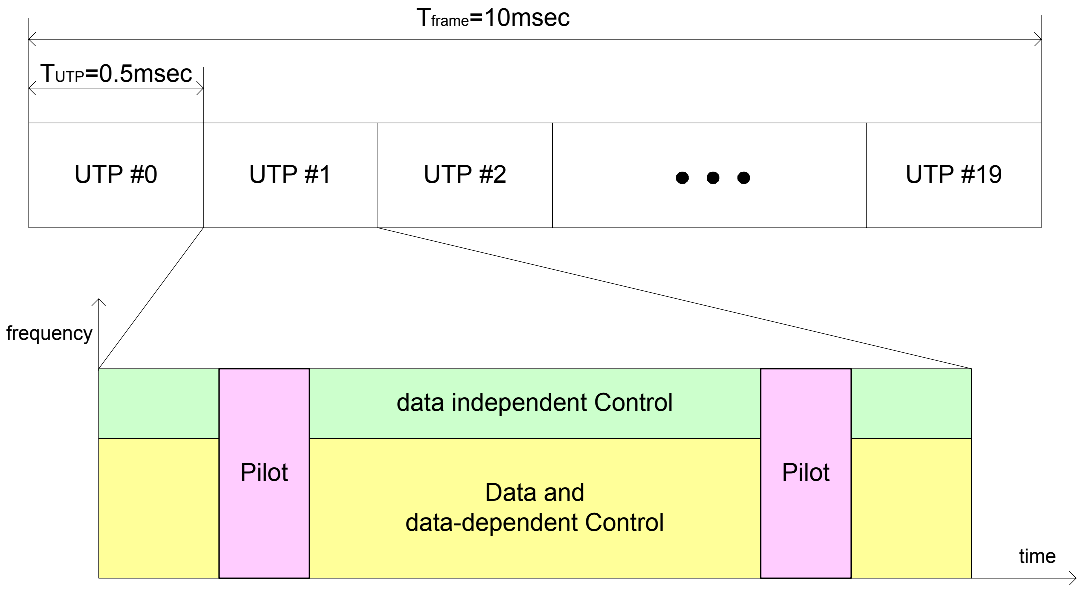

Figure 3-3. Uplink channel multiplexing in logical domain

3.4 Link Adaptive Modulation and Coding Scheme

Proposed specifications provide link adaptive transmission schemes with various combinations of modulation, coding, multiple transmit antenna schemes.

3.4.1 Modulation

QPSK, 16QAM and optional 64 QAM are supported

3.4.2 Coding Scheme

8-state tail-biting Turbo and structured LDPC codes with expansion for multi-length and multi-rate compatibility for various codeword sizes and code rates are supported

The mandatory coding method is LDPC coding, and convolutional Turbo coding is optional.

3.4.3 Hybrid ARQ

Both *Incremental Redundancy* and *Chase Combing* are supported. Also, IR with ACK reporting the information that is desired to be retransmitted by receiver is supported.

3.4.4 MIMO

Up to two transmit antenna in uplink transmission is supported. Supported MIMO schemes are: $N_T \times N_R$, $N_T = 1,2$, $N_R = 1,2,3,4$ where N_T denotes the number of transmit antennas and N_R denotes the number of receive antennas, respectively. STBC, single user spatial multiplexing, and multi-user MIMO transmission can be selected by link quality and required QoS.

4 Salient Features

4.1 Virtual MIMO & resource allocation

4.1.1 Coordinated symbol repetition technique

In the conventional approach, in order to provide reliable data transmission to cell-edge users, very low-rate coding is used through symbol repetition, which is done without coordination among cells. However, if the symbol-repetition is coordinated among cells, the symbol detection performance can be greatly improved by employing interference cancellation in the detection process. This Coordinated Symbol Repetition (CSR) technique seems to be a promising solution for ICI problem since it neither sacrifices the full frequency reuse nor requires a complicated multicell planning.

The key idea of the CSR method is that for cell edge users, the data symbol is repeated on a number of resources, which are identically allocated among different cells. Then, the transmission of the desired symbol from the serving cell and interfering symbols from neighboring cells coupled with respective channel responses can be considered as a “virtual” MIMO system, for which a variety of MIMO detection techniques such as Zero Forcing (ZF), Minimum Mean Square Error (MMSE), Parallel Interference Cancellation (PIC), Successive Interference Cancellation (SIC) etc. can be used to extract the desired symbol or cancel the interfering signals from the received signals.

4.1.2 Resource allocation

4.1.2.1 Resource partitioning

In this section, we describe a resource partitioning and allocation scheme for the CSR. In an OFDM system, the basic resource unit that carries one OFDM symbol is specified by the tone and the symbol time in the frequency-time resource space.

Figure 4-1 depicts the resource partitioning, which only illustrates a logical arrangement and actual physical resource allocations in the frequency-time resource space can be specified through a separate mapping procedure. The entire resource space is partitioned into two large resource blocks; one for traffic channels (type-A resources) and the other for control channels (type-B resources). In our scheme, the type-A resource block is further split into subblocks A1 and A2. The subblock A1 is for UEs relatively free from interference; cell center UEs, while the subblock A2 is for UEs susceptible to interference from other cells; cell-edge UEs. Further, in case all the resources in A2 are used up, a part of resources in A1, denoted A11, is reserved for further resource use for interference-susceptible UEs. Each cell adopts the same resource allocation scheme, while the size of the resource blocks A1 and A2 in each cell can be adjusted by taking into account interference-susceptible traffic through inter-cell coordination.

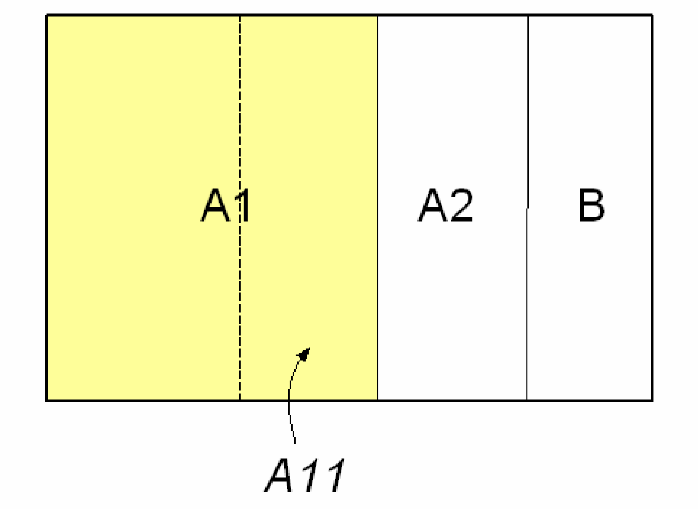

Figure 4-1: Resource partitioning (logical)

Figure 4-2 illustrates geometrical resource allocation of the resource subblock A1 and A2 in the two-dimensional hexagonal cellular geometry. The resource allocation by the Node-B is done as follows: The UE estimates the signal to interference ratio (SIR) and the noise strength and reports them to their serving Node-B. If the UE has a large SIR, the resources belonging to the subblock A1 are assigned as traffic channels for the UE. Otherwise, the resources in the subblock A2 are assigned. In contrast, the resource allocation for the resource block B, which is used for control channels, is uniform throughout the cells as shown in Figure 4-3.

4.1.2.2 Resource allocation for repetition symbols

In this section, the allocation of the repetition resources in the subblocks A2 and B is described. The subblock A2 is divided into K disjoint resource sets A2-1, A2-2, …, A2-K consisting of N_1, N_2, … , N_K resources, respectively. The A2-k contains N_k/G_k unit repetition blocks, each consisting of G_k repetition resources, which are used for transmission of one symbol and occupy exactly the same positions in the frequency-time resource space for all cells.

The unit repetition block of the resource set A2-k can take three different allocation patterns called comb, random, and cluster types, respectively, which differ from each other in the way of assigning G_k resources. Depending on the allocation type, the G_k resources are allocated as follows.

Comb or random type: The G_k repetition resources are spread uniformly as much as possible in the frequency-time resource space in order to obtain a maximum frequency/time diversity gain and to minimize the correlation between G_k subcarrier channels connecting the Node-B and the UE.

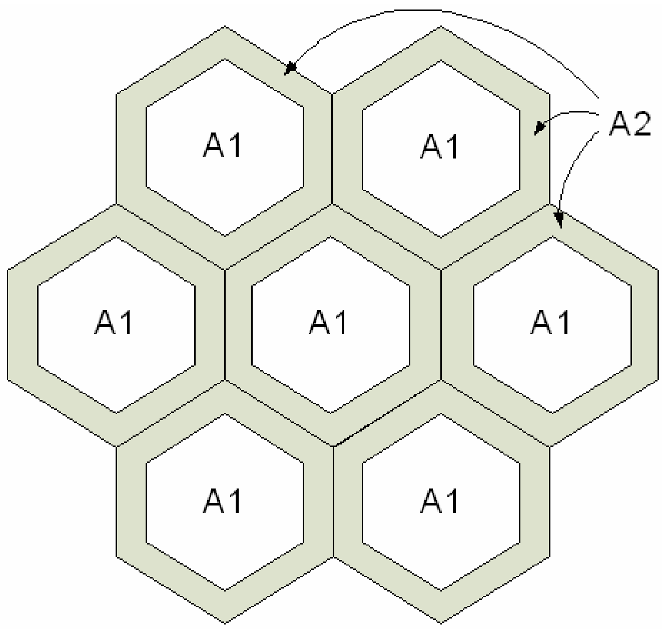

Figure 4-2: Resource allocation for traffic channels (geometrical)

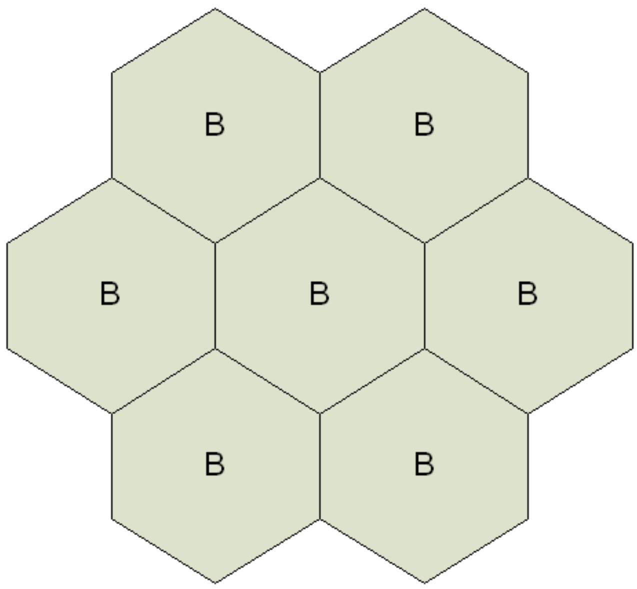

Figure 4-3: Resource allocation for control channels (geometrical)

Cluster type: The G_k repetition resources are localized so that they form a connected block in the frequency-time resource space.

The three types of resource allocation pattern are illustrated in Figure 4-4.

The allocation for the subblock B, which is used for control channels, is done in a similar way; The subblock B is divided into R disjoint resource sets B-1, B-2, …, B-R consisting of M_1, M_2, … , M_R resources, respectively. The B-k contains $M_k/G_{c,k}$ unit repetition blocks, each of which consists of $G_{c,k}$ repetition resources occupying exactly the same positions in the frequency-time resource space for all cells. However, in the allocation of repetition resources, only comb or random type allocation is considered to maximize frequency/time diversity gain.

4.1.3 Transmission and reception

4.1.3.1 General process

In this section, we discuss the transmission and reception processes for the CSR in detail. Assuming Nc neighboring cells, the received signals for a channel belonging to resource block A2 or B can be written as below.

$$Y(n) = \sum_{i=1}^{N_c} H_i(n) X_i(n) + N_w(n), \ \text{n} = 0, 1, \ldots , \text{N-1}, \qquad (1)$$

where $X_1(n)$ and $X_i(n)\ (i \neq 1)$ represent the desired transmit symbol and the interference symbols from the i-th adjacent cell, respectively, and N is the total number of subcarriers in the channel. $N_w(n)$ denotes an AWGN with zero mean and variance σ^2. Assuming that every symbol is repeated G times over G subcarriers, Eq. (1) can be rewritten in a vector-matrix relation;

$$\mathbf{Y}(m) = \mathbf{H}_i(m)\mathbf{X}_i(m) + \mathbf{N}_w(m), \ m \in \{0, 1, \ldots , \text{M-1}\}, \qquad (2)$$

where m indicates a resource block consisting of G subcarriers and M = N/G. M corresponds to the total number of data or control symbols being transmitted .

The received signal vector $\mathbf{Y}(m)$, the channel matrix $\mathbf{H}(m)$, the transmit signal vector $\mathbf{X}(m)$, and the noise vector $\mathbf{N}_\mathrm{w}(m)$ are expressed as below.

$$\mathbf{Y}(m) = [Y(J_{m1}), Y(J_{m2}), \cdots, Y(J_{mG})]^T, \qquad (3)$$

$$\mathbf{H}(m) = [\mathbf{H}_1(m), \mathbf{H}_2(m), \cdots, \mathbf{H}_{\mathrm{N_c}}(m)], \qquad (4)$$

$$\mathbf{X}(m) = [X_1(m), X_2(m), \cdots, X_{N_c}(m)]^T, \quad (5)$$

$$\mathbf{N_w}(m) = [N_w(J_{m1}), N_w(J_{m2}), \ \cdots, N_w(J_{mG})]^T, \quad (6)$$

where J_{mg} indicates the g-th subcarrier of the m-th resource block. The m-th symbol for the i-th UE $X_i(m)$ experiences the channel $\mathbf{H_i}(m)$. The physical allocation of G subcarriers is indicated by indices J_{mg} and depends on the allocation type, i.e., whether it is cluster, comb, or random-type allocation. The index assignments for the three allocation types are given below;

$$J_{mg} = G \cdot m + g - 1 \quad \text{(cluster)} \quad (6)$$

$$J_{mg} = M \cdot (g-1) + m \quad \text{(comb)} \quad (7)$$

$$J_{mg} = M \cdot (g-1) + rand(m, g) \quad \text{(random)} \ (8)$$

where $g \in \{1, \cdots, G\}$ and rand(m, g) is a random integer ranging from 0 to M-1. As illustrated in Figure 4-4, the G subcarriers are adjacent in cluser-type allocation, separated by M carriers in comb-type allocation, and randomly positioned in random-type allocation.

$\mathbf{H_i}(m)$ in Eq. (4) denotes the i-th column vector of $\mathbf{H}(m)$ and represents the channel response between the Node-B of the i-th cell and the UE, for the subcarriers in the m-th resource block;

$$\mathbf{H_i}(m) = [H_i(J_{m1}), H_i(J_{m2}), \cdots, H_i(J_{mG})]^T. \quad (9)$$

Assuming that $\mathbf{H_i}(m)$'s are mutually independent, the symbols can be extracted by employing various detection techniques including linear detection processes such as ZF and MMSE, and nonlinear detection processes such as PIC, SIC, and Maximum Likelihood (ML). For example, in the linear detection, the following weight matrix $W(m)$ is multiplied to the received signal vector to obtain the decision statistic

$$\widehat{\mathbf{X}}(m) ; \widehat{\mathbf{X}}(m) = \mathbf{W}(m)\mathbf{Y}(m), \quad (9)$$

where

$$\mathbf{W}(m) = (\mathbf{H}(m)^* \mathbf{H}(m))^{-1} \mathbf{H}(m)^* \ \text{(ZF)} \quad (10)$$

or

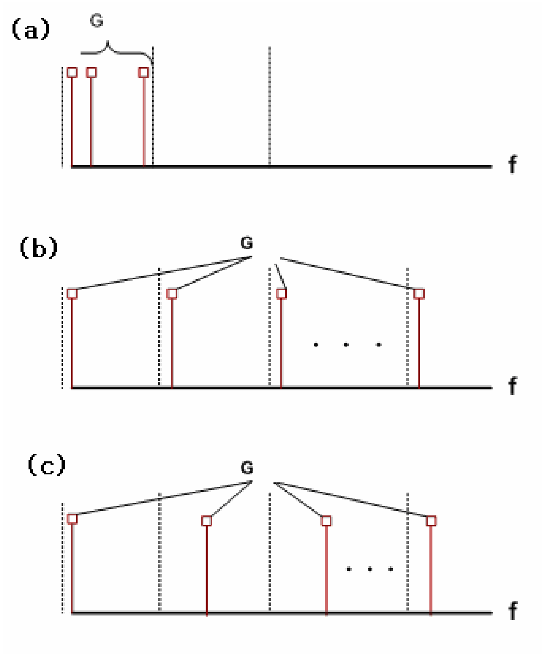

Figure 4-4: Three types of repetition resource allocation

(a) Cluster type, (b) Comb type, and (c) Block-random type

$$\mathbf{W}(m) = (\mathbf{H}(m)^{*}\mathbf{H}(m) + \sigma^{2}\mathbf{I}_{\mathbf{G}})^{-1}\mathbf{H}(m)^{*} \text{ (MMSE)}, \qquad (11)$$

where $\mathbf{H}(m)^{*}$ denotes the conjugate transpose of $\mathbf{H}(m)$, σ^{2} is the noise variance normalized by the transmit power, and $\mathbf{I}_{\mathbf{G}}$ is the G x G identity matrix.

4.1.3.2 Signature randomizers

If the subcarriers carrying the repetition symbols are highly correlated to each other, we cannot obtain a full transmit diversity effect, which results in degradation in the performance of the interference cancellation. Thus, in order to minimize the possibility of high correlation between the subcarrier channels, we multiply a signature randomizer to each repetition symbol, which effectively leads to randomization of the channel responses of the subcarriers thereby inducing the diversity. As an example, one may use the following set of random phasers as signature randomizers.

$$c_i(n) = \exp[j\pi/4 \cdot rand(i,n)], \quad rand(i,n) \in \{0,1,\cdots,7\},$$

where *rand(i, n)* is a random integer ranging from 0 to 7, and thus, $c_i(n)$ is one of 8PSK weights, which is multiplied with the symbols before it is transmitted over the *n*-th subcarrier. With the above random phasers, the effective channel matrix $\mathbf{H}_{\mathbf{Vi}}(m)$ can be represented as below;

$$\mathbf{H}_{\mathbf{Vi}}(m) = [c_i(J_{m1})H_i(J_{m1}), c_i(J_{m2})H_i(J_{m2}), \cdots, c_i(J_{mG})H_i(J_{mG})]^T .$$

Note that cell-specific scrambling codes can be used as signature randomizers without introducing additional signature randomizers. In this case, high-order M-ary phasers with M > 4 are recommended for sufficient signature randomization. Additionally, in order to separate the signals transmitted from different sectors within a cell, sector-specific orthogonal codes are multiplied to each of the repetition blocks for localized subchannels. For distributed subchannels, either orthogonal code sequences or sector-specific randomizers can be used depending on the cell-environment.

4.2 Uplink Inter-Cell Interference Management Using Whispering Resource Region Concept

In uplink, inter-cell interference (ICI) from a neighboring cell can be either small or big. Big ICI values determine the denominator of signal-to-interference ratio (SIR). Figure 4- explains that there is a neighboring base station receiving big ICI in uplink of a mobile terminal.

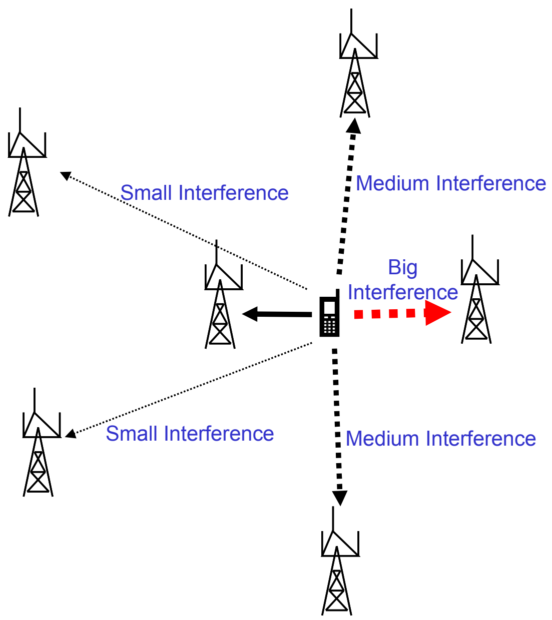

Figure 4-5. ICI in uplink of a mobile terminal

Existence of direction for big ICI is regarded as “directivity of interference” without both of directional beamforming and smart antenna. In conventional uplink, each link suffers from the mixture of big ICIs and small ones at random. Therefore, many links of mobile terminals have at least one big ICI source from neighboring cells. Here we concentrate big ICI sources into a small amount of resource. Then, heavy ICI is inevitable for that resource. However, ICI level is kept very low for the most remaining resource. Figure 4-6 shows these examples.

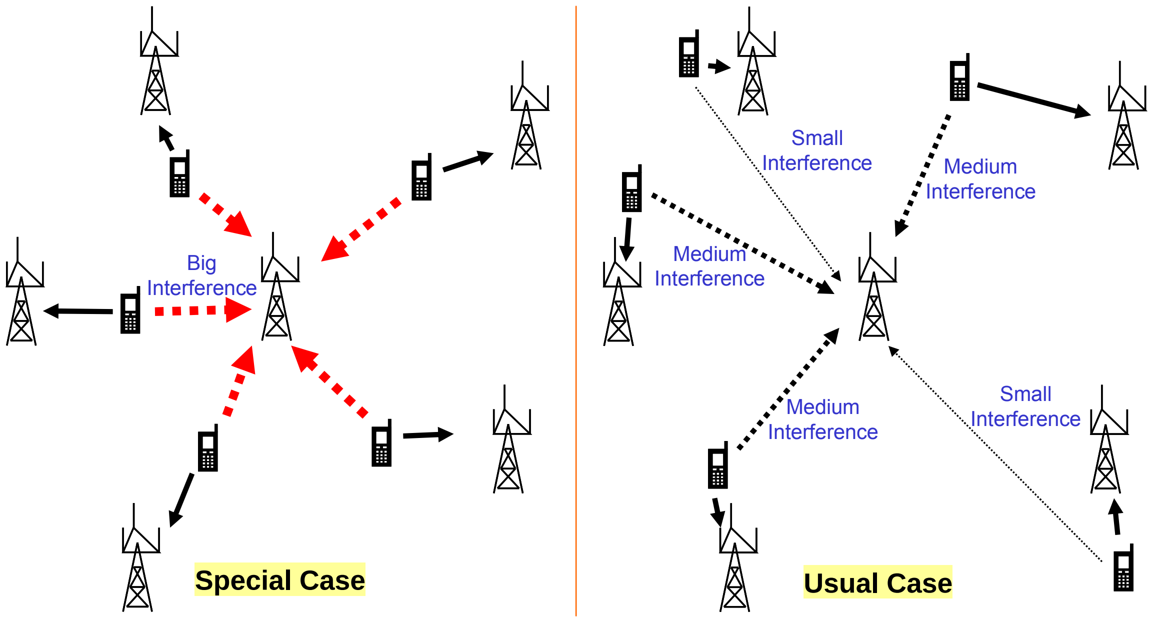

Figure 4-6. Concentration of interference

In the left figure under high ICI, a mobile terminal with good channel condition is allocated in the center cell. On the other hand, a mobile terminal with bad or medium channel condition is assigned in the right figure. Then, mobile terminals with bad channel conditions in cell boundaries are categorized into the right figure. This results in a great increase of SIR for cell boundary users and fairness among users. It is the first aspect of the ICI management scheme enlarging spatial capacity in cellular systems by concentrating dominant interferers into a small resource region in uplink.

Each mobile terminal reports a few pilot path loss values to its serving base station. Each path loss value is accompanied by the corresponding base station identifier. Assuming long-term channel reciprocity taking only distance loss and shadowing into account, this information tells how much interference the mobile terminal makes toward the corresponding neighboring base station. By concentrating big ICI sources (mobile terminals) of neighboring cells into a specific resource region, the most remaining resource becomes relatively free from ICI. A specific resource region suffering from big ICI is called a "whispering" resource region, and the remaining resource regions are called "speaking" resource regions. In a speaking resource region, ICI from a neighboring cell is kept below a certain value, and thus, the total ICI can be suppressed and estimated. This is the second aspect of whispering concept reducing the variance of the total ICI and helping to estimate SIR.

For a whispering resource region of the center cell, neighboring cells allocate mobile terminals making big ICI toward the center cell. At this moment, neighboring cells are using speaking resource regions. Figure 4-7 depicts whispering (W) and speaking (S) resource regions considering only distance loss in hexagonal cellular geometry. Resource of a cell is divided into 7 orthogonal pieces such as time or frequency in this example. Resources with the same number are activated concurrently.

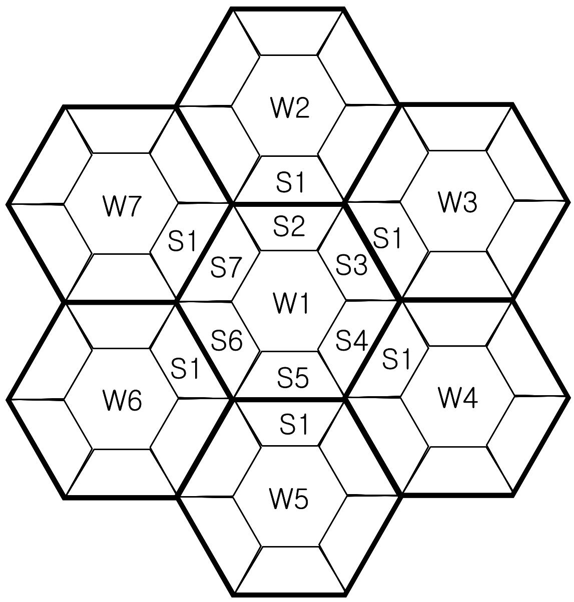

Figure 4-7. Whispering and speaking resource regions with pattern 7

Figure 1-8 illustrates a distribution of whispering resource regions in hexagonal cellular geometry. For a specific resource number, it tells which cells are assigned to whispering resource regions, and the remaining cells are all speaking resource regions.

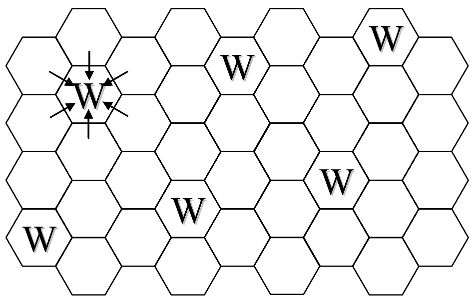

Figure 1-8. Distribution of whispering resource regions when concentrating dominant interferers into a cell

In this example, 1/7 of all cells are assigned to whispering resource and 6/7 are speaking resource. For a cell, 1/7 of the entire resource is whispering resource and the remaining is speaking resource.

Cell edge bitrate can be increased using whispering resource concept. This scheme enlarges spatial capacity in cellular systems by concentrating dominant interferers into a small resource region in uplink. It also suppresses a high variance of inter-cell interference in uplink.

4.3 Multiuser MIMO

The multiuser precoding MIMO scheme named Per User and Stream Rate Control based on Successive interference cancellation (S-PUSRC) is characterized by successive interference cancellation (SIC) based multiple stream reception and the feedback of decoding order for efficient multiuser scheduling.

S-PUSRC exploits the multiuser diversity in the spatial domain by transmitting precoded multiple data streams simultaneously to multiple co-channel users. Each data stream forms an independent coding block and the SINR estimation and the rate control are done on a stream by stream basis. The use of independently coded streams has the advantage in performance by allowing reliable successive interference cancellation based on post-decoding symbols at the receiver, which is not permitted in the conventional single-stream transmission. The choice and multiplicity of the precoding matrices may vary depending on cell environment. For example, a cell may use a single precoding matrix (or a set of precoding vectors), which is pre-informed to all UE's in the cell. When multiple precoding matrices are employed in one cell, the UE may choose a precoding matrix depending on channel condition and identify the precoding matrix with additional feedback bits.

4.3.1 Precoding MIMO techniques

It is preferred to use precoding MIMO technique with a predetermined set of multiple precoding matrices. In previously suggested schemes such as Per-Antenna Rate Control (PARC), Selective Per-Antenna Rate Control (S-PARC), Per-User Unitary Rate Control (PU^2RC), and Per-Stream Rate Control (PSRC), a set of unitary matrices including the identity matrix was suggested as precoding matrices. By employing a predetermined set, excessive feedback overhead may be avoided and by allowing multiple precoding matrices, the performance can benefit from adaptive transmission by adopting cell-specific precoding matrices well suited for given channel environment.

One common feature shared by these precoding MIMO schemes is that each data stream forms an independent coding block and thus, the SINR estimation and rate control can be done on a stream by stream basis. The use of independently coded streams also has the advantage in performance by allowing reliable SIC based on post-decoding symbols at the receiver, which is not permitted in the conventional single-stream transmission.

PARC, a single-user MIMO scheme employing a separate data stream for each transmit antenna, was shown to achieve open-loop MIMO capacity when it is coupled with SIC and decoding at the receiver. In contrast to the PARC, as a modified scheme, PSRC performs precoding with a unitary matrix before transmitting to a user. Meanwhile PU^{2}RC was designed as a multiuser MIMO scheme transmitting multiple data streams to multiple users simultaneously to utilize the multiuser diversity in the spatial domain. In this multiuser scheme, a maximum performance can be achieved by allocating each stream to a "good" UE with the aid of SINRs of the data streams reported by all UEs.

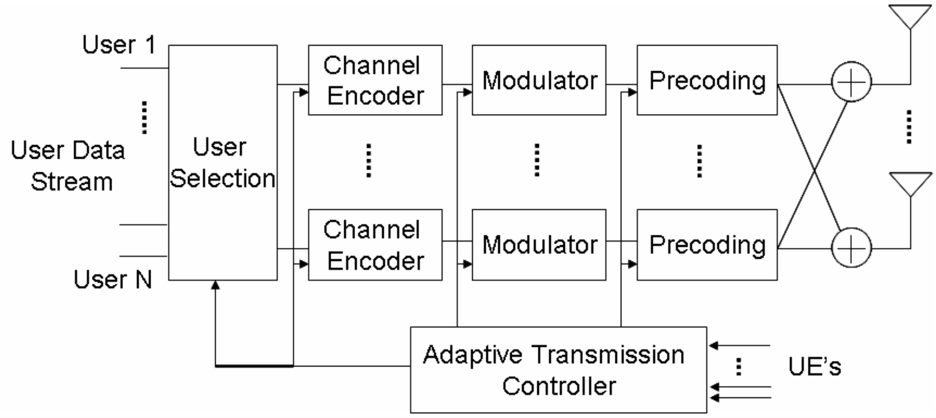

Figure 4-9. Transmitter structure of S-PUSRC

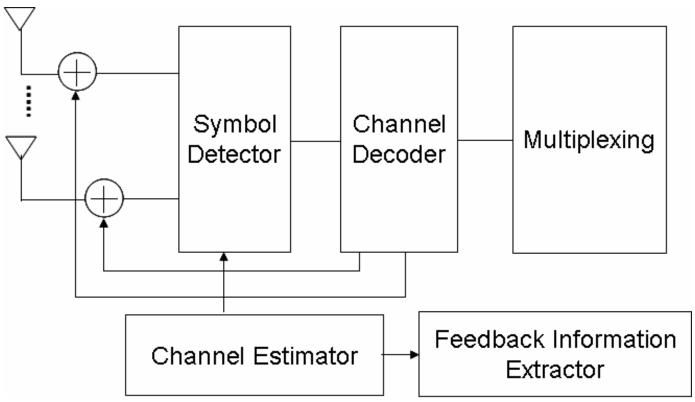

Figure 4-10. Receiver structure of S-PUSRC

4.3.2 Transmitter and receiver structure

Figures 4-9 and 4-10 show schematic diagrams of the basic transmitter and receiver structure of S-PUSRC, respectively, which are much similar to those of PARC, PSRC, and PU^2RC. At the transmitter in Figure 4-9, depending on stream allocation, the user data is directly fed to the encoder as a single stream or branched into a number of low-speed data streams, which are encoded and mapped to a series of constellation symbols. These symbols are further either multiplied by a precoding vector or mapped separately to transmit antennas. The selection of users and precoding vectors is controlled by the feedback information from UEs.

At the receiver in Figure 4-10, the Channel Estimator estimates channel coefficients from pilot symbols, from which SINRs for each data stream are estimated. Note that the estimated SINRs can vary depending on the detection algorithm even with the same received signals. In the case of multiple stream reception, the SIC based on decoding symbols is performed on a stream-by-stream basis; the decoder proceeds to one data stream after another. Once the data stream is decoded, the symbols are reconstructed from the decoded bit stream, multiplied by channel coefficients and subtracted from the received signals. The decoding, and cancellation processes are repeated until all the data streams are recovered.

The choice and multiplicity of the precoding matrices may vary depending on cell environment. For example, a cell may use a single precoding matrix (or a set of precoding vectors), which is pre-informed to all UEs in the cell. When multiple precoding matrices are employed in one cell, the UE may choose a precoding matrix depending on channel condition and identify the precoding matrix with additional feedback bits.

4.3.3 S-PUSRC

4.3.4 Basic description

S-PUSRC is compatible with any MIMO transmission schemes employing independently coded multiple streams and a predetermined set of precoding matrices or vectors and hence we do not presume the specifics of the precoding matrices or vectors here.

In the multiuser MIMO scheme PU^2RC, the UE reports back the SINR's for each data stream for a given unitary precoding matrix and an index to the unitary matrix. The SINR's for data streams can be obtained after estimating MIMO channel coefficients using pilot symbols. Although the receiver itself may employ SIC as in PARC when more than one data streams are allocated to the UE, the estimation of the SINR's that are reported back by the UE is solely based on the detection of the received signals without incorporating SIC process and information regarding the stream ordering for decoding and cancellation is not provided to the BS.

In S-PUSRC, the receiver is assumed to perform SIC based on decoding symbols, and *the feedback information consists of the decoding order and the post-detection SINR's for* *each data stream estimated under the assumption of perfect cancellation of preceding streams in SIC.* In more detail, the decoding order and the post-detection SINRs are obtained through following processes. First, post-detection SINRs for each data stream are calculated using the estimated channel coefficients, and the data stream with the largest post-detection SINR is chosen to be at the top of the decoding order list. Assuming that the decoding and cancellation process at the receiver exactly removes the interference due to the selected stream from the received signals, post-detection SINRs are re-estimated for remaining data streams. Again, the stream with the largest post-detection SINR is selected as the next stream in the decoding order. Repeating this process, the decoding order and its associated post-detection SNRs are obtained.

The benefit of the feedback of the decoding order and SIC-based SINRs, in combination with an appropriate multiuser scheduling algorithm, is that multiuser diversity can be fully exploited in stream allocation and simultaneously, the SINR gain due to the SIC process at the receiver when more than one data streams are allocated to one UE brings about improvement in system performance. Once the stream allocation is decided, the modulation and coding scheme (MCS) for the allocated data streams can be determined using the corresponding reported SINRs.

4.3.5 Multiuser scheduling

In this section, the multiuser scheduling process in S-PUSRC is described. The UE is required to feed back the decoding order in addition to SINRs for a predetermined number of data streams. The BS decides on which data stream is to be allocated to which user by taking into account the feedback information collected from all active users but under the following constraints.

1. One data stream cannot be allocated to more than one user.

2. The i-th data stream can be allocated to a certain user only when the data streams that precede the i-th stream in the decoding order list of the user have been allocated to the same user.

As an example of such user scheduling, consider four transmit antennas at the BS and three active UE's. Assume the following decoding order was reported by the UEs.

.

UE	Decoding order of data streams
UE1	3 1 4 2
UE2	2 3 1 4
UE3	4 2 1 3

If data streams 2 and 3 have been allocated to UE2, data stream 4 can be allocated to UE3. However, the remaining data stream 1 cannot be allocated to UE1 without breaking the constraints because data stream 3 has not been allocated to UE1. However, if the data streams 3 and 1 have been allocated to UE1, data stream 2 can be allocated to UE2 and the remaining data stream 4 can be allocated to UE3.

The MCS of a particular stream is chosen based on the reported SINR of the stream. When a multiple number of data streams are allocated to a user, the User Selector breaks the user's bit stream into parallel streams and assigns each to one of the data streams. At the receiver side, when multiple streams have been allocated, the UE employs stream-by-stream SIC and decoding following the decoding order in the feedback information.

4.4 Additional Macro Diversity in Multicast/Broadcast

Multi-cellular soft combining provides a good opportunity for multi-cellular multicast/broadcast assuming inter-cell synchronization. Transmitting the same symbol through the same resource (time and frequency) from multi-cells has been basically considered. This achieves energy gain but cannot increase diversity order. To promote more diversity order, it is possible to use space-frequency (or space-time) transmit diversity such as Alamouti's scheme for single antenna each cell. For multiple antenna transmission, antenna rotation concept is adopted to obtain diversity within a coding block.

When a mobile terminal is located at the border of cells, it receives signals from all neighboring base stations. By applying SFBC (space-frequency block code) (or STBC: space-time block code) it is possible to increase diversity order at the border. SFBC can be applied for two or more multiple antennas, but we explain only the case of two antennas in this document since it achieves rate-1 through Alamouti's scheme and more antennas may make the channel estimation complicated.

All cells are divided into 2 cell groups to apply order-two SFBC. Figure is an example of cell planning for 2 cell groups. A mobile terminal receiving signals from both of S_0 and S_1 can achieve diversity gain as explained in Figure 4-12.

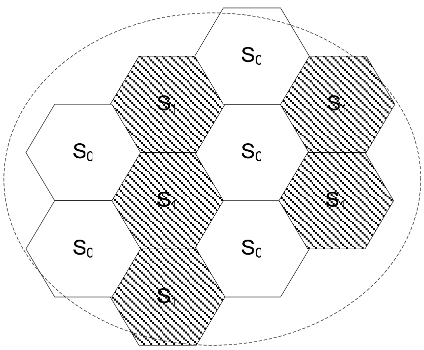

Figure 4-11. Cell planning for 2 cell groups

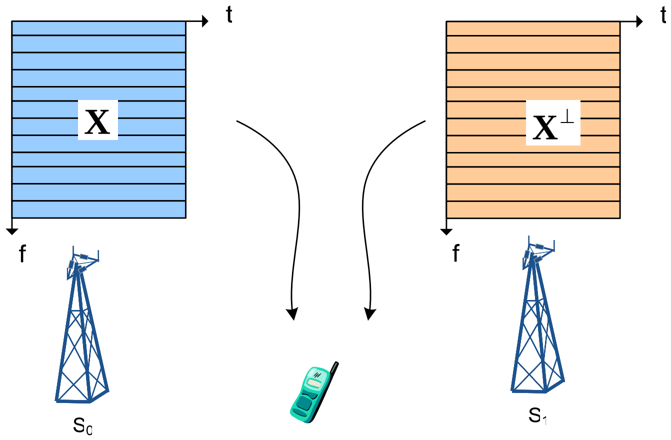

Figure 4-12. SFBC (STBC) with 2 cell groups

$$\mathbf{X} = \{\ldots, X(2k), X(2k+1), \ldots\}$$

$$\mathbf{X}^{\perp} = \{\ldots, -X(2k+1)^{*}, X(2k)^{*}, \ldots\}$$

Two cell group division provides diversity gain for mobile terminals at the border of S_0 and S_1, but boundary terminals of only one cell group cannot obtain diversity gain. Therefore, 3 cell groups are introduced to average diversity gain for all boundary terminals. Figure 4-13 and Figure 4-14 illustrate an example of cell planning for 3 cell groups and how to average diversity gain, respectively. Since diversity order is still two, only two different SFBC (STBC) streams are allowed at each time and frequency resource. In Figure 4-13, the entire resource is divided into 3 sub-regions, and order-two grouping is rotated. Any boundary terminal can achieve order-two diversity over 2/3 of its entire symbols. A coding block should cover the rotation of patterns.

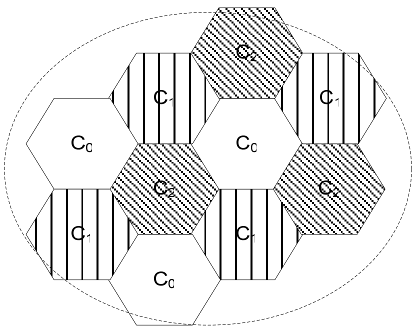

Figure 4-13. Cell planning for 3 cell groups

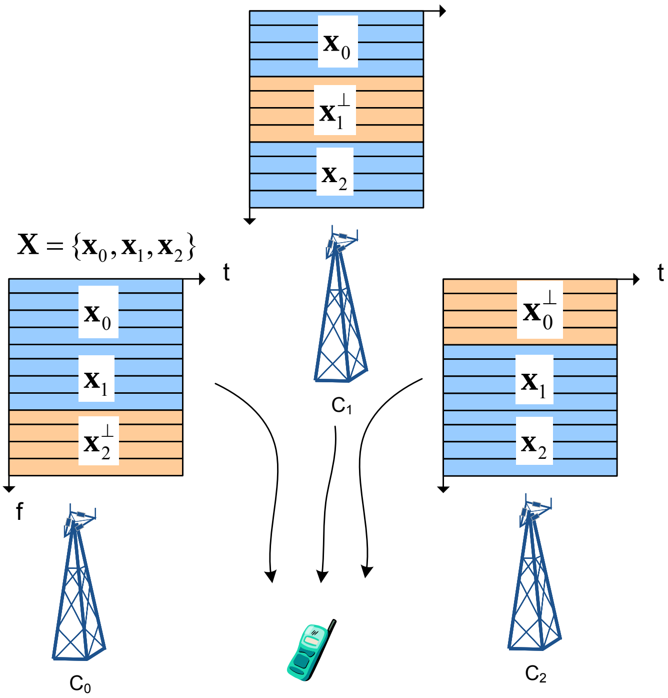

Figure 4-14. SFBC (STBC) with 3 cell groups

When more than one antenna exist in a cell, SFBC or STBC may be already used. For macro diversity, each cell transmits the same SFBC streams with the same antenna configuration. To achieve more diversity gain inside a coding block, antenna rotation concept is adopted. We consider only two antenna case here. (Two antenna selection either in random or scheduled can be added for systems with more than two antennas.) Figure 4-15 and Figure 4-16 illustrate the conventional method and the new one, respectively. Each cell transmits in the same way in Figure 4-15, and the antenna combining combination pattern is rotated to achieve more diversity in a coding block in Figure 4-16. This method does not increase diversity for a symbol, but gives diversity to a decoded symbol after channel decoding. In addition, this method for two antenna case does not increase pilot overhead even though the space-frequency transmit diversity method for single antenna may introduce an increase in overhead.

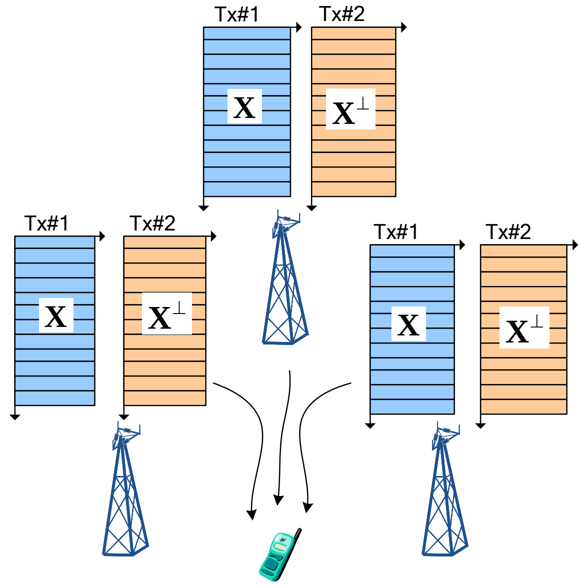

Figure 4-15. The conventional two antenna transmission

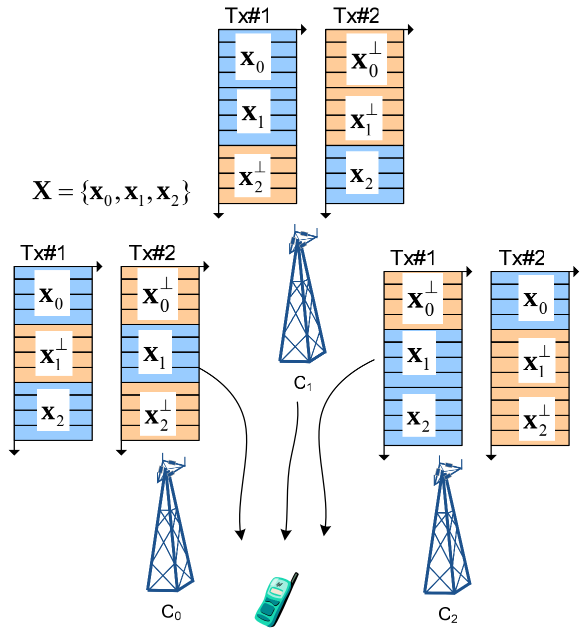

Figure 4-16. The new two antenna transmission with pattern rotation

SFBC or STBC has been applied to downlink single antenna multicast/broadcast. It gives much diversity gain with increased pilot overhead. For multiple antenna case, antenna pattern rotation concept has been presented to achieve diversity in a coding block. It produces performance gain without an increase in pilot overhead.

Synchronization is basically required for the above schemes which can be used for both of inter-sector and inter-BS (base station). For inter-sector case, synchronization is natural. For inter-BS case, synchronization is preferred and it can be implemented by GPS, network signaling, or assistance of mobile.

4.5 Cell search using pilots

The cell search is performed using common pilot symbols without additional resources allocated for cell search. The cell search is comprised of two steps. The first step searches for the cell-group and the second step identifies the cell-ID within the cell-group. By changing the number of pilot symbols that are used in cell search procedure, the UE can adjust the performance and computation complexity. The pilot symbols are multiplied with cell-group specific codes and cell-specific scrambling codes.

Figure 4-17 shows the frame structure of downlink in an OFDM-based cellular system. Let the total number of subcarriers and the subcarrier spacing be denoted by N_t and Δf, respectively. The number of usable subcarriers for a particular UE can vary depending on the capability of the UE. For example, if the bandwidth of the UE is B, the total number of the usable subcarriers N_f is given as

$$N_f = B/\Delta f.$$

Since N_f can vary depending on the UE capability, the synchronization and cell search scheme should be able to support the bandwidth scalability of the UE. A single frame consists of N_{sub} subframes and each frame consists of L OFDM symbols. In each subframe, pilot symbols are located at one or more OFDM symbols and the spacing between pilot symbols along the frequency axis is N_{ps} and the total number of pilot symbols is N_0. If the pilot spacing N_{ps} is chosen to be narrower than the coherence bandwidth, the adjacent pilot symbols can be considered to experience the same channel.

To reduce computational load in cell search, a number of neighboring cells are grouped into a cell-group. In the first step of cell search, the UE performs cell-group search and identifies the cell-group that it belongs to and then finds its serving cell-ID by searching cells within the cell-group.

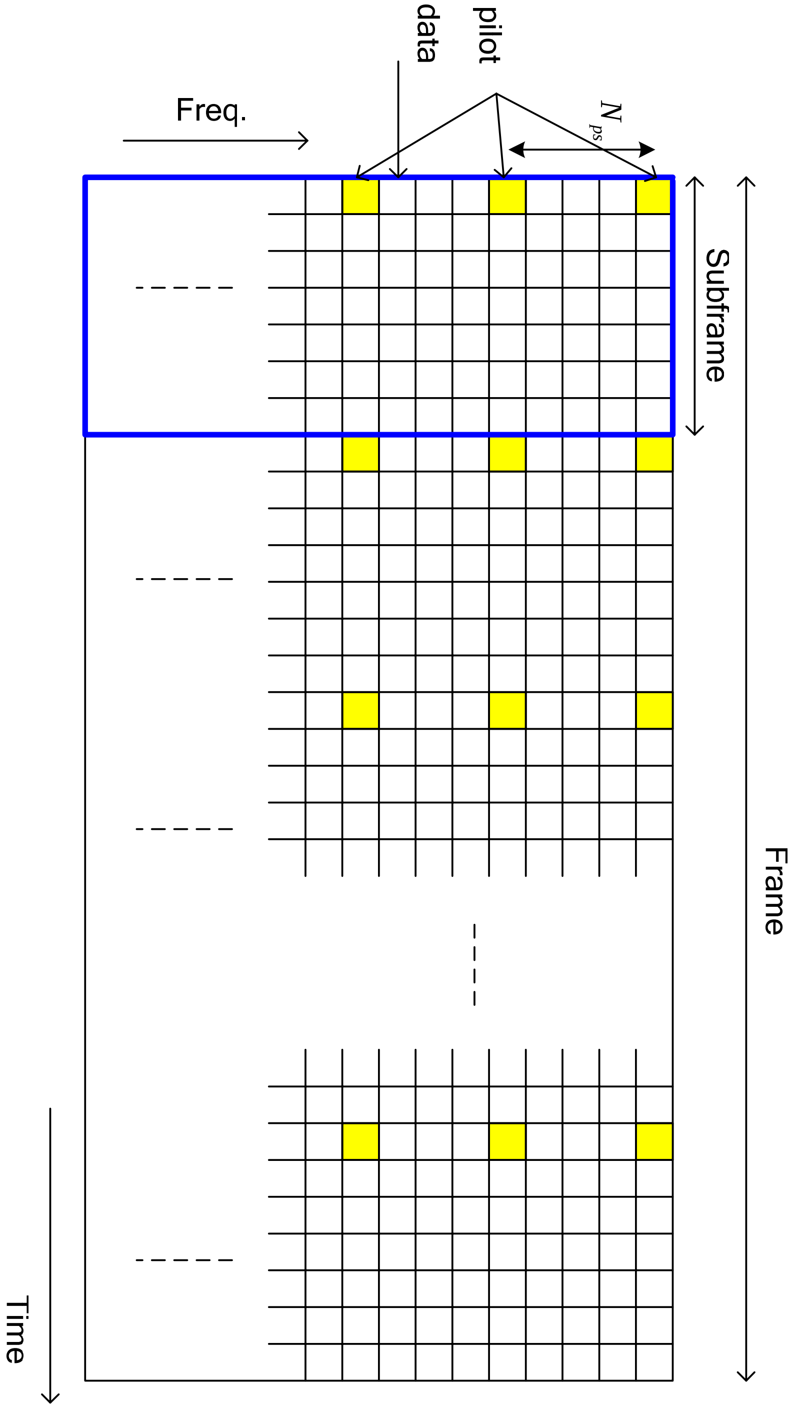

Figure 4-17. Frame structure

Figure 4-18 shows the pilot symbol structure of the m-th subframe of the i-th cell. Let $p_n^{(i)}(m)$ be the n-th pilot along the frequency axis. $p_n^{(i)}(m)$ is given by the product of the scrambling code for the i-th cell $s_n^{(i)}$ and the cell-group specific code for cell-group g $a_n^{(g)}(m)$;

$$p_n^{(i)}(m) = s_n^{(i)} a_n^{(g)}(m) \quad , \quad n = 0,1,\cdots,N_0 - 1$$

where $\{s_n^{(i)}\}_{n=0}^{N_0-1}$ is a cell-specific scrambling code and is the same for all the subframes in the cell. The cell-group specific code $\{a_n^{(g)}(m)\}_{n=0}^{N_0-1}$ $(m = 0, 1, \ldots, N_{\text{sub}}\text{-}1)$ for cell-group g is different from subframe to subframe, as indicated by the index m.

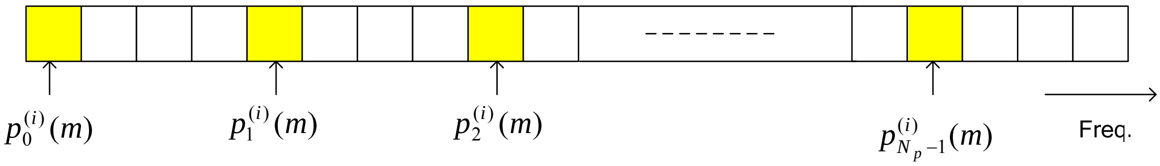

Figure 4-18. Pilot OFDM symbol

Let $b_n^{(g)}(m)$ be the product of $a_n^{(g)}(m)$ and $a_{n+1}^{(g)}(m)^*$.

$$b_n^{(g)}(m) = a_n^{(g)}(m) a_{n+1}^{(g)}(m)^* \quad , \quad n = 0,1,\cdots,N_0 - 2 \, ,$$

where * denotes the hermitian transpose. Let $c_n^{(g)}(m)$ be given by multiplying $b_n^{(g)}(m)$ and $b_n^{(g)}(m+1)^*$.

$$c_n^{(g)}(m) = b_n^{(g)}(m) b_n^{(g)}(m+1)^* \quad , \quad n = 0,1,\cdots,N_0 - 2$$

From the relation between the codes $a_n^{(g)}(m)$, $b_n^{(g)}(m)$, and $c_n^{(g)}(m)$, the following relation holds for any pilot symbol $p_n^{(i)}(m)$.

$$p_n^{(i)}(m) p_{n+1}^{(i)}(m)^* p_n^{(i)}(m+1) p_{n+1}^{(i)}(m+1)^* = c_n^{(g)}(m)$$

A set of sequences $c_n^{(g)}(m)$s appearing within one subframe can be represented by a vector;

$$\mathbf{c}^{(g)}(m) = [\, c_0^{(g)}(m), c_1^{(g)}(m), \cdots, c_{N_0-2}^{(g)}(m) \,].$$

Let $\mathbf{c}^{(g)}(m)$ be one of J elements in the basic code set $\{\mathbf{e}_0, \mathbf{e}_1, \cdots, \mathbf{e}_{J-1}\}$;

$$\mathbf{c}^{(g)}(m) \in \{\mathbf{e}_0, \mathbf{e}_1, \cdots, \mathbf{e}_{J-1}\},$$

where each element is a sequence of length N_{0-1};

$$\mathbf{e}_l = [e_{l,0}, e_{l,1}, \cdots, e_{l,N_0-2}].$$

For instance, if $\mathbf{c}^{(g)}(m)$ for cell-group g is associated with codeword {5, 2, …, 7}, we have the following relation.

$$[\mathbf{c}^{(g)}(0), \mathbf{c}^{(g)}(1), \cdots, \mathbf{c}^{(g)}(N_{sub}-1)] = [\mathbf{e}_5, \mathbf{e}_2, \cdots, \mathbf{e}_7].$$

The following should be taken into account in designing the codebook that contains all the possible codewords associated with $\mathbf{c}^{(g)}(m)$ s. For any codeword, the phase-shift versions of the codeword should be different from anyone of the other codewords. The minimum distance of the codebook, which includes the codewords and all the possible phase-shift versions of the codewords, should be maximized. The symbol distance between two codewords is defined as the number of coordinates in which the two codewords differ. The minimum distance is the minimum symbol distance between all distinct pairs of codewords. One example codebook that satisfies the above property is Comma-Free Reed-Solomon (RS) codes. For an arbitrary prime q and an arbitrary positive integer m, an RS code is a q^m-ary code of length $q^m - 1$. The RS code is a maximum distance separable code that achieves the maximum limit of the minimum distance known as the singleton bound. The symbol distance is given by $q^m - 1 - k + 1$.

The RS code has the property that any cyclic shift of a codeword results in another codeword. This property may hinder the timing synchronization by inducing tendency towards an incorrect codeword. Thus, it is necessary to choose a set of codewords that do not result in another codeword in the set. If the total number of cell groups is G_{gr}, we need to determine q, m, and k satisfying $(q^m)^k \le G_{gr}$. To maximize the symbol distance, k should be minimized as much as possible and thus, q^m should be maximized. Since $q^m - 1 \le N_{sub}$, possible q and m s are limited. If there are no q's and m's satisfying the condition, we need to adjust the number of cell groups or the length of codewords. One may choose q to be near but larger than N_{sub} and shorten the codeword length to equate its length to N_{sub} but, in this case, the number of the elements in the codewords increases. Thus, it is desirable to choose a large q with $q^m - 1 \le N_{sub}$. In this case, the codeword length can be enlarged to N_{sub} by attaching a copy of a certain part of each codeword at the end of the codeword.

The receiver process for synchronization and cell search is described below. The UE estimates the initial timing and frequency offset by measuring the correlation between the guard interval and the corresponding repeated part in the OFDM symbol. After performing FFT for the received signal, the n-th subcarrier signal at the l-th received OFDM symbol can be written as below.

$$r_n(l) = H_n^{(i)}(l) X_n^{(i)}(l) + W_n^{(i)}(l)$$

Here, $H_n^{(i)}(l)$ represents the channel coefficient of the i-th cell, and $W_n^{(i)}(l)$ represents the interference from other cells and additive noise. If $X_n^{(i)}(l)$ is the transmit signal in the *m*-the subframe,

$$r_n(l) = H_n^{(i)}(l) s_n^{(i)} a_n^{(g)}(m) + W_n^{(i)}(l) .$$

To acquire subframe synchronization, the two adjacent received pilot subcarrier signals are multiplied to obtain $u_n(l)$ and in a similar way, $u_n(l+L)$ is obtained for the received pilot subcarrier signals that are L OFDM symbols away in symbol time. Then, $y_n(l)$ is obtained by multiplying $u_n(l)$ and $u_n(l+L)$:

$$u_n(l) = r_n(l) r_{n+1}(l)^* \quad , \quad n = 0, 1, \cdots, N_p - 2$$

$$y_n(l) = u_n(l) u_n(l+L)^* ,$$

where L is the total number of OFDM symbols in the subframe,.

The correlation between $\{y_n(l)\}_{n=0}^{N_p-1}$ and the basic codes $\{\mathbf{e}_0 , \mathbf{e}_1 , \cdots, \mathbf{e}_{J-1}\}$ is obtained using J correlator banks.

$$Z^{(j)}(l) = \sum_{n=0}^{N_p-2} y_n(l) e_{j,n}{}^* \quad , \quad j = 0, 1, \cdots, J-1$$

For each of L OFDM symbol durations, the following sum of the J correlations is computed.

$$P(l) = \sum_{j=0}^{J-1} | Z^{(j)}(l) | \quad , \quad l = 0, 1, \cdots, L-1$$

The symbol time l giving the maximum P(l) is taken as the first symbol position of the subframe $\hat{l}_{sub}$;

$$\hat{l}_{sub} = \arg\max_{l} \; P(l) \quad , \; l = 0, 1, \cdots, L-1$$

After finding the first symbol position $\hat{l}_{sub}$, the cross correlation between $y_n(l)$ and the basic codewords is computed as follows.

$$Z_k^{(j)} = \sum_{n=0}^{N_p-2} y_n(\hat{l}_{sub} + kL) e_{j,n}^{\;*} \quad , \; j = 0, 1, \cdots, J-1, \;\; k = 0, 1, \cdots, N_{sub} - 1$$

By decoding $|Z_k^{(j)}|$, $j = 0,\ 1, \cdots,\ J-1$, $k = 0,\ 1, \cdots,\ N_{sub} - 1,$ the frame synchronization is acquired and the cell-group is identified.

After finding the cell-group, the following process is performed for the cells belonging to the cell group. The products of the two adjacent received pilot subcarrier signals are multiplied with the code $a_n^{(\hat{g}_0)}(k)^* a_{n+1}^{(\hat{g}_0)}(k)$ corresponding to the estimated cell group $\hat{g}_0$:

$$v_n = \sum_{k=0}^{N_{sub}-1} \{ r_n(\hat{l}_{sub} + kL) r_{n+1}(\hat{l}_{sub} + kL)^* \} \, a_n^{(\hat{g}_0)}(k - \hat{m}_{frame})^* \, a_{n+1}^{(\hat{g}_0)}(k - \hat{m}_{frame}) \; , \;\; n = 0, 1, \cdots, N_p - 2$$

Here, $\hat{m}_{frame}$ is used for consideration of the starting position of the frame. In the above equation, normalization can be performed to reduce the effect of channel variation in the time-frequency space. Further, v_n is multiplied with a cell-specific scrambling code.

$$Q^{(i)} = \sum_{n=0}^{N_p-2} (s_{n+1}^{(i)} s_n^{(i)^*}) \, v_n \quad , \; i \in \{\text{cell IDs belonging to cell-group } \hat{g}_0 \}$$

Finally, the cell-ID $\hat{i}_0$ is obtained as follows.

$$\hat{i}_0 = \arg\max_{i} \left| Q^{(i)} \right|, \;\; i \in \{ \text{ cell IDs belonging to cell-group } \hat{g}_0 \}.$$

To further enhance the cell search performance, $Q^{(i)}$ can be replaced with a combination of $Q^{(i)}$ s from multiple subframes.