System Configuration for Multiband MC-CDM Systems

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***Abstract*— This paper studies efficient structure of multiband mobile communication system which can support both high data rate services and wide coverage. First, we show design criterion of appropriate bandwidths in multiple frequencies. Second, we show a realistic scenario of smooth migration from singleband system to multiband system, considering investment risk and frequency license problem. Third, we study multiband MC-CDM system for downlink, that is a multiband system combined with MC-CDM system. The presented multiband MC-CDM system includes efficient structures of pilot signals, two dimensional spreading, and simplified receiver.**

I. Introduction

Recently, much interest has been devoted to fourth generation (4G) mobile system to provide high data rate services, according to the rapid growth of mobile subscribers and high data rate applications such as data transfer, pictures, and video. In 4G mobile system, it is essential to establish a system configuration to support not only high data rate transmission but also wide service coverage. Since the service coverage area is dependent on radiowave propagation characteristics, the frequency used in 4G systems is an important issue to be discussed.

Indeed, propagation characteristics are much different depending on operating frequency. In general, lower frequency has more diffraction and more penetration to non-line-of-sight (NLOS) or indoor locations. Therefore, low frequency band such as 800MHz is more popular in mobile communications because of its wide coverage area. On the contrary, higher frequency band has more difficulty to support NLOS or indoor locations, which results in less popularity.

Apart from this problem, 4G mobile system is supposed to use 50 or 100MHz bandwidth on downlink to support more than 100Mbps. Globally, several hundreds MHz or 1GHz bandwidth will be required for several operators to provide 4G mobile services. However, it will be difficult to allocate much of low frequency band (e.g. less than 1GHz), because there is no frequency band to meet the requirement of bandwidth. Therefore, it is inevitable to allocate higher frequency bands as main resources, although service coverage becomes smaller. Consequently, a large risk in business will occur that consumers are not satisfied with the smaller service coverage of the higher frequency.

To deal with these problems, we have so far studied a multiband mobile communication system (hereafter multiband system), which can support both high data rate services and wide service coverage [1]. The multiband system employs separated multiple frequency bands and active terminals basically use higher frequency band prior to lower frequency band. The lower frequency band is allocated to terminals not covered by the higher frequency band. According to terminal's channel condition, frequency handover is performed quickly by physical (PHY) and medium access control (MAC) layers. Since the use of low frequency band is limited to a few terminals uncovered by high frequency, the low frequency band is effectively used to support the service area missed by high frequency. Consequently, the multiband system can support both wide coverage area and high data rate transmission as if all resources have low frequency.

In this paper, we study further the system configuration of the multiband system. First, we present criterion of appropriate frequencies and bandwidths for high performance, including numerical examples. Next, we show a realistic scenario of smooth migration from singleband system to multiband system, considering investment risk and frequency license problem. Finally, we present multiband MC-CDM system, that is the multiband system combined with MC-CDM system [2]–[4]. The presented system structure handles the different bandwidths with low hardware cost using partially common transceiver structure for different frequencies. The frame format for pilot signals, two dimensional spreading, and paging channel is also presented.

II. Design of bandwidths and frequencies

A. Multiband System

We explain the basic concept of the multiband mobile communication system [1]. Figure 1 shows an example of frequency bands in the multiband system. Figure 2 shows coverage area of each frequency band. Figure 3 shows the service area supported by each frequency band in the conventional singleband systems and the multiband system. In figure 3(a), the singleband systems are composed of independent systems using one frequency band. In this case, a singleband system with low frequency band has wide coverage area, whereas the other singleband system with high frequency band has small coverage which may not satisfy users.

In contrast, the multiband system is a single wireless system employing multiple frequency bands. Terminals are allocated

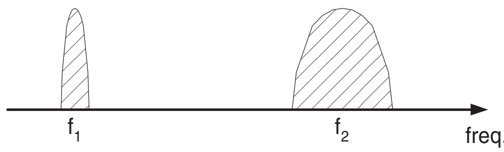

Fig. 1. Frequency bands used in multiband system.

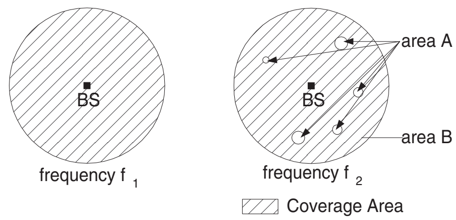

Fig. 2. Coverage area of each frequency band

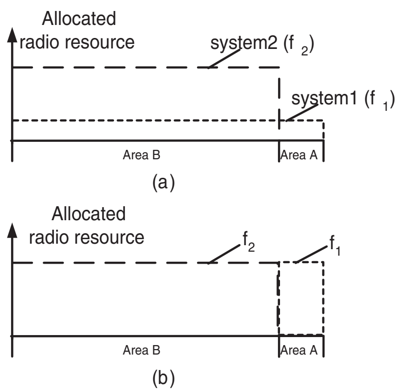

Fig. 3. Service area supported by each frequency band (a) in case of singleband systems (b) in case of multiband system.

to high frequency band prior to low frequency band. The allocation of low frequency resources is restricted to the terminals uncovered by high frequency as seen in figure 3(b). Since the low frequency supports only a few terminals, the multiband system can support both wide service area and high data rate services using different frequency bands.

B. Design of bandwidths

In the multiband system, it is essential to use appropriate frequencies f_i ($f_1 < f_2$) and bandwidths W_i ($i = 1, 2$) for high performance. So, we present design criterion of (f_i, W_i).

Define the rate of coverage area in frequency f_i to the target area as R_i ($R_1 > R_2$) and assume the same spectrum efficiency in each frequency. Based on [1], the multiband system has equivalent performance with singleband system of (f_1, $W_1 + W_2$), if

$$\frac{R_1 - R_2}{W_1} \leq \frac{0.9R_1}{W_1 + W_2}. \quad (1)$$

Therefore, the multiband system is designed to have equivalent performance with singleband system of (f_1, W_{req}) by

$$W_1 \geq \frac{(R_1 - R_2)W_{req}}{0.9R_1}, \quad W_2 = W_{req} - W_1. \quad (2)$$

TABLE I

BANDWIDTHS AND COVERAGE RATES IN SINGLEBAND SYSTEMS AND MULTIBAND SYSTEMS.

System	Freq.	Bandwidth	Effetive BW	Coverage
Singleband 1	800MHz	6MHz	4.5MHz	99.99%
Singleband 2	3.5GHz	90MHz	67.5MHz	97%
Multiband System	800MHz	6MHz	72.0MHz	99.99%
	3.5GHz	90MHz		

For wide coverage rate of the multiband system R_1, it is important to set the frequency f_1 as low as possible. For small bandwidth W_1, it is important to select f_2 with small $R_1 - R_2$ and with large applicable bandwidth W_2.

C. Numerical Examples

Let us show examples of bandwidth allocation using (f_1, W_1, R_1)=(800MHz, 6MHz, 0.9999) and (f_2, W_2, R_2)=(3.5GHz, 90MHz, 0.97). Note that these coverage rates are supposed as a probable example. In actual wireless environments, the guard band is placed to avoid the potential interference from other services using nearby spectrum. Using the loss of efficiency $\eta(< 1)$ due to guard band, the effective bandwidth is given by $W_{eff} = \eta W_0$ where W_0 is the total allocated bandwidth.

Table I lists bandwidths and coverage rates in the singleband systems and multiband system with guard band of 25%. In the singleband systems, effective bandwidth satisfying coverage rate of 99.99% is 4.5MHz. On the other hand, the multiband system achieves effective bandwidth of 72.0MHz satisfying coverage rate of 99.99%. Therefore, the multiband system greatly enhances effective bandwidth to meet coverage rate of 99.99%.

D. Other Advantages

In future 4G mobile communications, allocated spectrum may be distributed to several separated frequency bands to coexist with other existing wireless services [6]. Then, the multiband system has another advantage of integrating the separated frequency bands flexibly. Therefore, the multiband system is still useful for separated frequency bands with similar propagation characteristics.

III. GRADUAL MIGRATION TO MULTIBAND SYSTEM

In the previous section, we presented an ideal multiband system as final goal. However, in real business process, some other problems such as investment risk or difficulty to obtain multiband license may arise. To solve these problems, we show a more realistic scenario to introduce the multiband system smoothly.

A. Financial and License Problems

The deployment of new mobile communication services requires years of efforts and large amounts of investment to make infrastructure. Specifically, the following issues are essential in real business process.

- Under future uncertainty of demand for a new service, there is a large investment risk in making all infrastructure

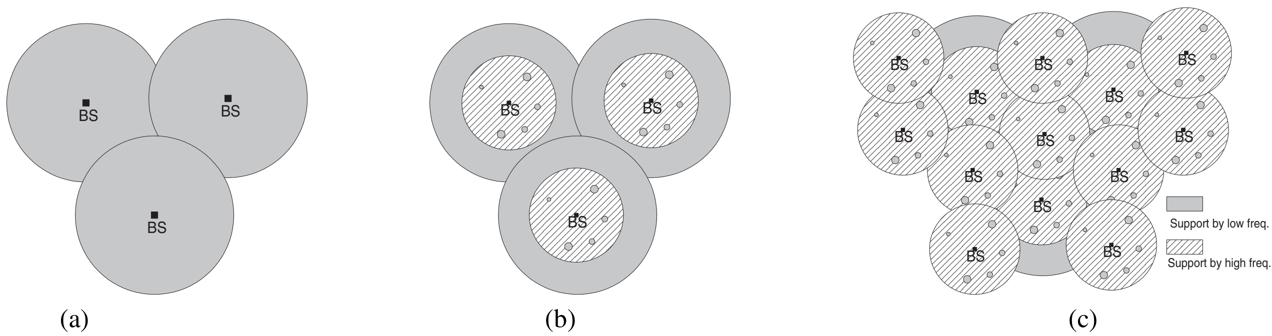

Fig. 4. Gradual migration to multiband system. (a) Initial service by singleband system (b) Partial migration to multiband system (c) Multiband system with completed infrastructure.

at once for a high speed mobile system. The deployment of infrastructure requires large amounts of investment and long delay until accommodating subscribers or obtaining economic returns.

- Licenses for multiple frequency bands may not be obtained simultaneously, which depends on spectrum allocation policy. Then, it is unrealistic to wait all licenses for multiple frequency bands without starting mobile services.

The first problem also occurs in the conventional 4G mobile system. To solve these problems, we present a more realistic scenario to introduce a multiband system, where a singleband system is initially launched and migrated to a multiband system gradually.

B. Gradual Migration to Multiband System

We propose the procedure to introduce a multiband system, which is composed of three processes.

1) Singleband system with low data rate services is initially launched using a low frequency band (e. g. 800MHz).
2) The existing base stations are changed to multiband system. Subscribers change gradually their mobile terminals for singleband system to ones for multiband system (hereafter, multiband terminal). Multiband terminals enjoy high data rate services in limited areas near base stations using high frequency band.
3) According to demand for high data rate services, more base stations for multiband system are deployed.

Figure 4 shows arrangement of base stations and coverage areas in each process. We show more details of each process.

1) Lower frequency band, which has smaller propagation loss, can support wider area [1]. Therefore, operators can start mobile services using smaller number of base stations compared to the case of higher frequency band, as shown in Fig. 4(a). Since feasibility of low frequency band for mobile system has been already granted by past mobile market, operators can establish reliable fundamental system.
2) Migration of the existing base stations to a multiband system will be achieved in low cost by exchanging transceiver circuits to new ones. However, high frequency band (e.g. 3.5GHz) has difficulty in supporting the same service area with low frequency band due to large propagation loss. Therefore, high data rate services are limited to areas near base stations as shown in Fig. 4(b), where multiband terminals can use high data rate services. Since low data rate services are supported everywhere, number of users unsatisfied with connections will not be so significant.
3) If consumers' demand for high data rate mobile services is large, more base stations are deployed to increase capacity and to support high data rate services in wide area as shown in Fig. 4(c). When base stations are so dense that high frequency band covers all service areas, each frequency band has interference-limited environments, where all frequency bands in a base station support inside of the boundary with near-by base stations. Consequently, low and high frequency bands supports the same target area, although high frequency band has some poor locations to support in the target area.

Since the above processes always support low data rate services even when high data rate is not supported, many users will not feel unsatisfied with connections. Also, operators can accommodate subscribers before constructing all infrastructure for high data rate mobile system. Operators can construct more infrastructure for high frequency band, examining demands for high data rate services. Furthermore, singleband system can be mitigated to the multiband system at the time when license for a second frequency band is obtained.

In the presented processes, gradual migration from low data rate services to high data rate services is performed, which is effective to decrease investment risk and to solve the license problem. On the other hand, in the conventional processes that infrastructure is straightforwardly constructed using a single high frequency band, it is required to complete infrastructure for a high frequency band before the mobile services are launched. If base stations are not deployed sufficiently, there

[1] In general, the propagation loss is proportional to square of operating frequency f [7][8]. Therefore, higher frequency has smaller coverage area in noise-limited system. However, in interference-limited system, low and high frequency bands support the same target area, which is defined as inside of the boundary with near-by base stations.

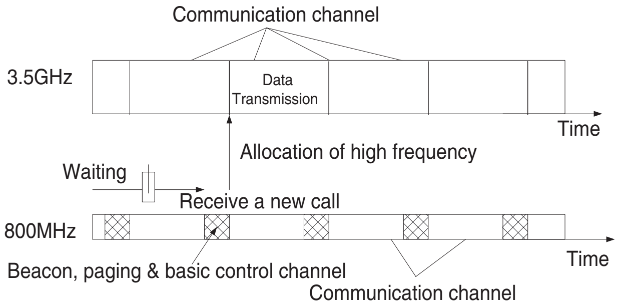

Fig. 5. System design for gradual migration to multiband system.

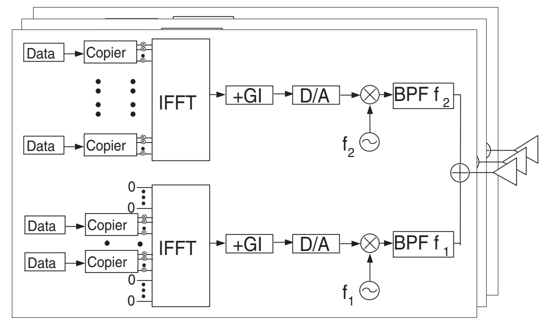

Fig. 6. Base station structure for downlink in multiband MC-CDM system.

are risks in business that the system cannot support no-line-of-sight (NLOS) or indoor locations and that users will feel unsatisfied with connections. The proposed processes can solve these conventional problems.

C. System Architecture for Gradual Migration

We present system configuration to achieve a gradual migration processes to a multiband system.

Figure 5 shows the system architecture to achieve the gradual migration. In the presented system architecture, the base station transmits beacon to identify the base station, paging channel to inform a new call arrival, and basic control channel to inform allocated frequency band in starting a connection using low frequency band. The stand-by terminal receives only low frequency band to check for a beacon and paging information. Since lower frequency band has wider coverage area, the mobile system can send essential information to all terminals with high reliability. The basic control channel inform a new terminal of the allocated frequency band in the beginning of the connection. The terminal changes frequency band for connection according to the base station's signaling. In this process, the base station identify types of terminals and allocates the high frequency band to a multiband terminal while does not allocate it to a legacy singleband terminal.

In this architecture, operators can start mobile services initially using singleband system with low frequency band. Then, the base station allocate the low frequency band to all terminals through the basic control channel. As the system is migrated to the multiband system, the base station allocates the high frequency band to capable terminals. Thus, the low frequency band conveys basic control channel and terminals shift operating frequency to make active connections. The presented system has flexibility to include a new frequency band and achieves smooth migration to more sophisticated system.

D. Flexible Adaptation to Spectrum Restructuring

In wireless communications, according to transition of ages, restructuring of spectrum allocation may be required by public institutions. The multiband system can deal with the restructuring flexibly without stopping the mobile services if low frequency band transmitting essential information is remained. In the process of restructuring, the base station stops to use frequency band to be restructured and includes a newly allocated frequency band. Although supportable data rate may temporally decrease, subscribers can enjoy the continuous mobile services without withdrawing and initializing their service contracts. Therefore, the presented multiband system is effective to continue one mobile service long time adapting to spectrum restructuring. Consequently, the presented multiband system has additional advantages of smooth migration to evolutional system and flexible adaptation to spectrum restructuring in addition to support of wide coverage and high data rate transmission.

IV. Multiband MC-CDM System

In the multiband system, simple and efficient transceiver architecture is required to deal with multiple frequency bands with different bandwidths. In the following, system configuration of the multiband MC-CDMA system is presented.

A. Base Station

Figure 6 shows the transmitter structure of base station in the multiband MC-CDM system. The spreading signal multiplied by orthogonal sequences is mapped into several subcarriers and time symbols. The resultant OFDM symbol with guard interval is converted to analog signal, upconverted to radio frequency (RF). The transmit signals for multiple frequency bands are made in parallel and combined in RF field.

The same OFDM symbol duration and symbol timing are used in different frequencies. Since the multiple frequencies have different bandwidths, the number of used subcarriers is different depending on the operating frequency [9]. Figure 7 shows the subcarriers used for pilot and data transmission. A larger number of subcarriers are used in higher frequency The remaining subcarriers are not used with no energy.

B. Pilot Signals

Figure 8 shows the placement of pilot signals in each frequency band. As Doppler frequency becomes larger in higher frequency band, pilot signals must be inserted in shorter periods to track faster varying carrier phase. For instance, in case of dual band system with 800MHz and 3.5GHz, high frequency band has about 4.4 times larger Doppler frequency

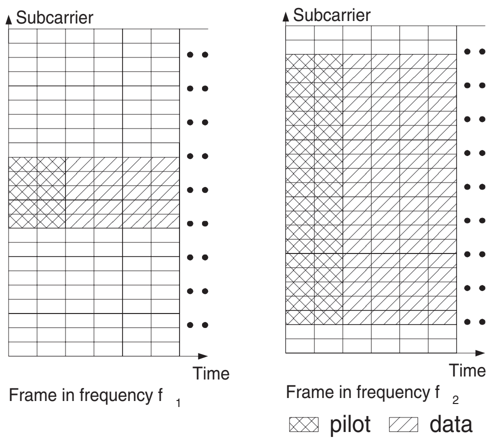

Fig. 7. Frame format for multiple frequencies.

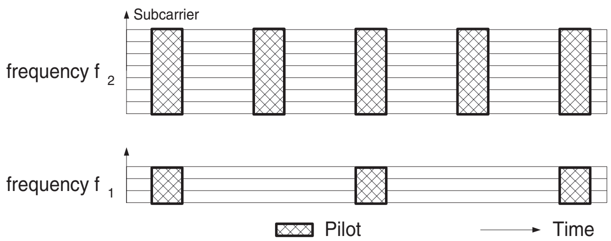

Fig. 8. Placement of pilot signals in multiple frequencies.

than low frequency band. In Figure 8, low frequency band has the same starting point of pilot signals with high frequency band, which helps a terminal's timing synchronization in both high and low frequencies.

C. Control Channel

Beacon, paging channel, and basic control channel are transmitted in low frequency band, which has been also shown in [9]. Using this architecture, essential information is sent widely to service area including a number of stand-by terminals. This architecture is also suitable for smooth migration from singleband system to multiband system.

D. Two Dimensional Spreading

In MC-CDM systems, two dimensional spreading, which spreads data symbol into time and frequency domains, has been studied to maintain good orthogonality between multiplexed signals [4]. The orthogonality will deteriorate in time domain as Doppler frequency increases.

Fig. 9 shows time symbols and subcarriers to perform two dimensional spreadings. The signals are spread over different units of time and frequency domains in multiple frequencies, because time correlation is smaller in higher frequency. Therefore, higher frequency band uses smaller number of time symbols for two dimensional spreading to maintain good orthogonality.

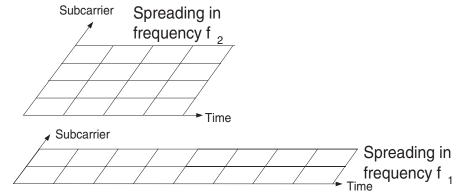

Fig. 9. Two dimensional spreading in multiple frequencies.

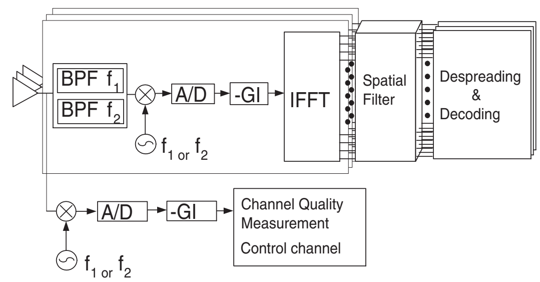

Fig. 10. Receiver structure of multiband MC-CDM system.

E. Terminal Structure

Figure 10 shows the receiver structure of a terminal. The terminal is equipped with a local oscillator of controllable frequency, analog filters for different bandwidths, and common digital circuits.

The received signal is passed through analog bandpass filter, and multiplexed by a local oscillator, frequency of which can be adjusted to operating frequency plus intermediate frequency (IF) by controllable frequency synthesizer. Thus, the received signal is downconverted and sampled by analog-to-digital converter (ADC). The architecture presented here uses the same ADC with constant sampling clock for all frequency bands. The sampling clock is designed for widest frequency band, which can be applied to other frequency bands without additional hardware cost. In the digital circuits, the sampled signals are fed to identical FFT. The number of extracted subcarriers are controlled according to the operating frequency. The extracted signals are despread, de-interleaved, and decoded based on specification of each frequency band. Thus, the terminal uses the common digital circuits for multiple frequency bands, which will decrease the hardware cost.

F. Channel Quality Measurement

A terminal measures channel conditions of multiple frequency bands by changing the frequency of local oscillator and analog filter. Usually, the channel condition is measured in terms of the average received power or the average signal-to-interference-plus-noise (SINR) of pilot signals, which are obtained by averaging the received power or SINR of each subcarrier over subcarriers to reduce the multipath fading effect. The terminal decides availability of each frequency band by checking whether the measured channel parameter is above a threshold.

V. Conclusions

We studied efficient structure of multiband mobile communication system to support both high data rate services and wide coverage. First, we showed design of appropriate bandwidths. Next, we showed a realistic scenario to introduce the multiband system gradually considering investment risk and frequency license problem. In this process, it is possible to add or modify the allocated spectrum, which makes flexible system migration to new generation mobile system. Third, system configuration of multiband MC-CDM system is presented for downlink. The presented structure will be practical from hardware point of view.

The multiband system structure has flexibility of system migration and will be practical from both investment and technical points of view.

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