(2) Broadband Packet Wireless Access

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Packet access in the Radio Access Network (RAN) is essential to reducing network cost and to achieving high-capacity multimedia mobile communications capable of high-resolution video communication services. This article presents targets and key techniques of the broadband packet wireless access system that we propose, enabling seamless support of both cellular systems and isolated-cell environments such as hot spot areas and indoor offices employing the same air interface through efficient packet access. The article also describes high-efficiency packet access technology for guaranteeing Quality of Service (QoS) including handover in the RAN on both the data-link layer and the physical layer.

1. Introduction

A maximum information bit rate of 2 Mbit/s or greater has been specified as the requirement of Third-Generation (3G) mobile communications called International Mobile Telecommunications-2000 (IMT-2000) in the Radiocommunication sector of the International Telecommunication Union (ITU-R). In this regard, we have experimentally demonstrated high-speed data transmission greater than 2 Mbit/s with high quality at an average Bit Error Rate (BER) less than 10^{-6} using a 5-MHz frequency bandwidth in the downlink, applying three-code multiplexing with a spreading factor of SF = 4 using 2-branch antenna diversity reception. Meanwhile, the 3rd Generation Partnership Project (3GPP) has completed specifications focusing on high-speed packet data transmission in the downlink called High-Speed Downlink Packet Access (HSDPA) based on a Wideband-Code-Division-Multiple-Access (W-CDMA) wireless interface [1]. In HSDPA, a much higher peak throughput than 2 Mbit/s is possible with low latency and high efficiency by employing Adaptive Modulation and channel Coding (AMC) including 16 Quadrature Amplitude Modulation (QAM), Hybrid Automatic Repeat reQuest (H-ARQ) with packet combining in the Medium Access Control (MAC) layer, and fast packet scheduling (i.e., user diversity). Moreover, we have shown that a peak throughput near 10 Mbit/s is possible with 5MHz-bandwidth by applying a MultiPath Interference Canceller (MPIC) or chip equalizer even in the multipath fading channel. However, anticipating the current and future tremendous increases in the amount of data traffic, new broadband wireless access must establish broadband packet transmission with a maximum data rate above 100 Mbit/s in the forward link using an approximate 50 to 100-MHz bandwidth (note that the target information bit rate corresponds to an approximately 10-fold increase over that achievable in HSDPA with a 5-MHz bandwidth). In addition, this broadband wireless access must flexibly support both isolated-cell environments such as hot spot areas and indoor offices as well as cellular systems from the standpoint of further reducing the cost of radio access networks. Furthermore, since it is presumed that the signal format in the wireless channel takes on a packet format, the service offered is basically based on the best-effort type according to the channel condition of each user and traffic conditions within the cell, where minimum throughput is guaranteed with the required Quality of Service (QoS), i.e., delay and residual Packet Error Rate (PER), etc.

In this article, we present targets in the broadband packet wireless access system called Systems beyond IMT-2000, and overview key techniques of the proposed broadband wireless access system. In the proposed system, both the cellular system with a multi-cell configuration and local areas (isolated cell environments) such as hot spot areas and indoor offices can be supported by the same air interface by having to change only major radio parameters. The rest of this article is organized as follows. First, Section 2 describes the targets of broadband packet wireless access. Section 3 then explains the RAN configuration that we propose, and Section 4 presents proposed broadband packet wireless access techniques focusing on wireless access schemes. After that, Section 5 briefly presents efficient packet access techniques, and Section 6 discusses multiple-antenna transmission techniques, which are essential for enabling wider cell coverage area and improving achievable throughput.

2. Targets of Broadband Wireless Access

Figure 1 shows the concept of the proposed broadband packet wireless access system. In the future RAN, further

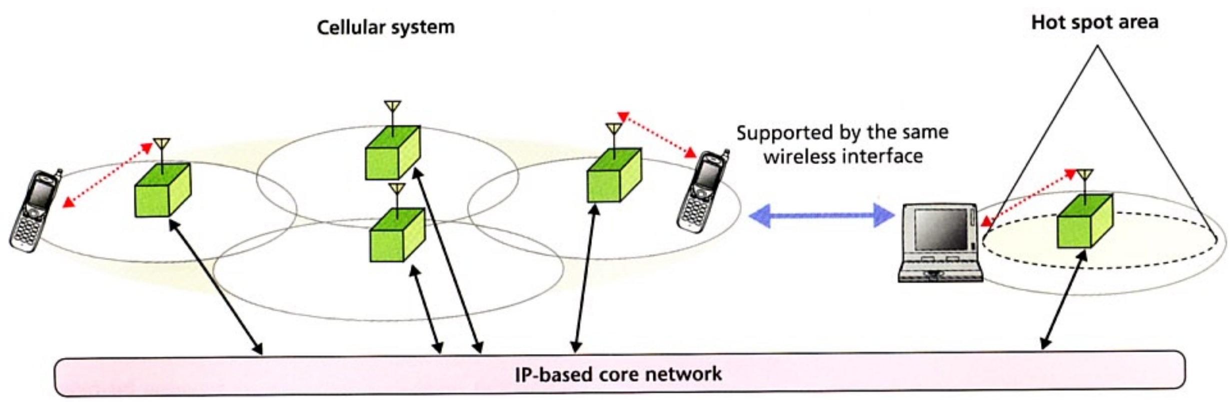


Figure 1 Concept of the broadband packet wireless access system supporting a cellular system and local areas by the same air interface

decrease in the network cost is a very important requirement for offering rich multimedia services to customers via wireless communications. Therefore, in the proposed concept, the cellular system with a multi-cell configuration and local areas such as hot spot areas and indoor office environments are supported by the same air interface (i.e., the same carrier frequency, frequency bandwidth, and radio frame structures, etc.) and only by changing major radio parameters such as spreading factor (*SF*), data modulation scheme, and channel coding rate. Then, by changing the radio parameters according to the cell configuration, channel load, and channel condition of each user, the maximum system capacity is achieved based on the same air interface, that is, the same broadband wireless access scheme.

In the proposed broadband packet wireless access system, the target of the peak throughput for the downlink in a cellular environment is 100 Mbit/s, which is approximately 10 times the peak throughput forecasted for HSDPA using a 5-MHz frequency bandwidth. Achieving a throughput of 100 Mbit/s will of course help to reduce network cost but will also enable large-capacity data downloads and high-resolution video communication services among multiple users. However, local areas such as hot spot areas and indoor office environments characterized by clustered traffic (in general, short-distance and short-time-dispersion environments) will probably require throughput in excess of 100 Mbit/s. We therefore target a maximum throughput of 1 Gbit/s (frequency usage efficiency: 10 bit/s/Hz) for these types of areas and aim to support throughput flexibly according to the environment in question using the same wireless interface (in terms of number of carriers, frequency bandwidth (about 100 MHz), wireless frame configuration, etc.).

For the uplink, the frequency usage efficiency targeted for hot spots and indoor environments is 7 bit/s/Hz. This would come to a maximum throughput of 300 Mbit/s for a frequency bandwidth of 40 MHz. For a cellular environment, a maximum throughput of 20 Mbit/s per sector is targeted.

In the broadband wireless access system, the basic plan is to give all signals a packet configuration, i.e., on the Radio Access Network (RAN) to transmit both Real-Time (RT) and Non-Real-Time (NRT) traffic data as packet signals. Here, channels can be allocated to multiple access users in a cell on the basis of Time-Division Multiplexing (TDM) using a shared-channel, common-channel, or dedicated-channel packet format. This will significantly reduce the number of physical radio devices making up base-station equipment compared to the circuit-switching transmission system that allocates a separate physical channel to each user.

3. Radio Access Network Configuration in Broadband Wireless Access

3.1 Inter-cell Synchronization

A broadband wireless access system must be able to support expansion of a seamless service area covering not only a cellular environment but also hot spots in underground shopping centers, airports, hotel lobbies, and indoor environments like offices. Here, to achieve flexible expansion especially to indoor environments, an asynchronous inter-base-station system closed to the wireless access system is thought to be advantageous over a synchronous inter-base-station system based on time synchronization.

A mobile terminal needs to establish a wireless link with the base station that minimizes the propagation loss between the base station and mobile terminal. In a wireless access system that supports a multi-cell cellular system, this criterion of minimizing propagation loss is nearly the same as the criterion of

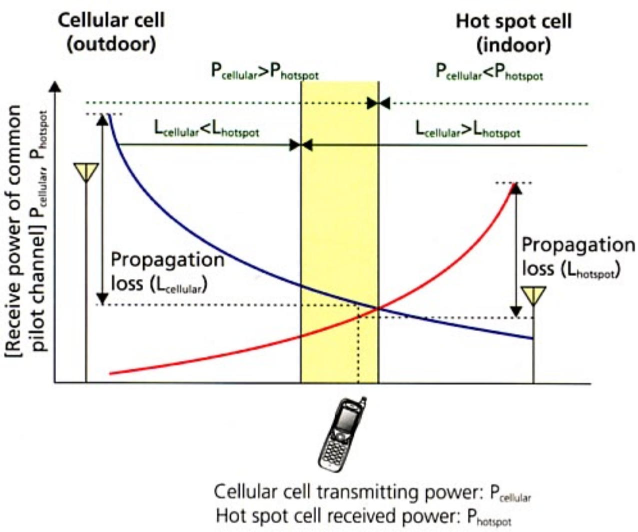


Figure 2 Cell selection when cellular cells and hot spot cells coexist

finding the reference signal in the downlink with the highest received level (in W-CDMA, the common pilot channel is used for this purpose). Thus, in W-CDMA, the cell/sector whose common pilot channel in the downlink has the highest received power is selected as the optimal cell/sector. The situation is somewhat different, however, in a broadband wireless access system that supports both cellular and isolated cells, as shown in **Figure 2**. Specifically, the base-station transmitting power of cellular cells differs from that of hot spot cells, which means that the cell with the most powerful common pilot channel in the downlink is not necessarily the cell with the lowest propagation loss between the base station and mobile terminal. In the example shown in the figure, the received power of the pilot channel from an outdoor cellular cell is highest but the cell with the lowest propagation loss is an indoor hot spot. Establishing a wireless link with the indoor cell makes for maximum reduction in the transmission power required by the mobile terminal.

In the above way, a search must be performed for the cell/sector having the lowest propagation loss between the base station and mobile terminal in a system where isolated environments like hot spots and offices coexist with a cellular environment. This cell search can be broadly divided into three types: (1) initial cell search, (2) call-in-progress cell search, and (3) standby (idle mode) cell search. For the call-in-progress and standby types of cell searches, the currently connected cell (sector) informs the mobile terminal about the transmission power and cell type (cellular or isolated) of neighboring cells so that the terminal can search for the optimal cell having the lowest propagation loss between it and the base station.

For the initial cell search, two methods can be considered. In the first method, which is similar to the method used in conventional cellular systems, the mobile terminal first establishes a wireless link with the cell whose downlink pilot channel has the highest receive power. The terminal then receives and decodes a report on neighboring cells from that cell, and if a neighboring cell exists with a propagation loss less than the reporting cell, the terminal switches its wireless link to that neighboring cell. In the second method, each cell is allocated beforehand with a unique scrambling code indicating a cellular or hot spot cell [2]. As a result, a mobile terminal in an initial cell-search stage can identify cell type and therefore search for an optimal cell with lowest propagation loss through processing on the physical layer only.

Of the above three types of cell searches, the initial cell search takes the most time. To reduce search time, three-step cell search algorithms have been proposed using Orthogonal Frequency and Code Division Multiplexing (OFCDM) or Orthogonal Frequency Division Multiplexing (OFDM) [3], [4]. In the first step, the system detects OFCDM symbol timing, and in the second step, it detects the group that a cell-specific scrambling code belongs to as well as frame/slot timing. As a means of detecting this information, a method that uses synchronized channels [3] and one that uses a time-multiplexed common pilot channel [4] have been proposed. In the third and final step, the system detects the optimal cell scrambling code from among the scrambling-code candidates belonging to the scrambling-code group detected in the second step.

3.2 Handover

In addition to handover between cells/sectors in a cellular system, a function for achieving handover between a cellular cell and an isolated cell such as a hot spot or office is vital to achieving seamless cell expansion. A handover function on the data-link layer or below employs macro diversity between cells or between sectors, and it is this macro diversity that guarantees required QoS on the data-link layer or below. On upper application layers, consideration must be given to both data delay on wired transmission paths (Internet Protocol (IP) network portion of the system) and to control-signal delay corresponding to the mobility of the mobile terminal. In W-CDMA, the mobile terminal opens up separate channels with multiple cells/sectors, and achieves a diversity effect by performing a soft handover in which the same information is transmitted to the mobile terminal via multiple cells/sectors on the downlink and received by multiple cells/sectors on the uplink. This macro-diversity effect between cells/sectors in a soft handover results in high-quality channels in circuit-switching mode.

A broadband wireless access system, however, employs transmission-slot allocation (packet scheduling) and ARQ, which means that an optimal handover algorithm on the data-link layer or below must take the effects of packet scheduling and ARQ into account.

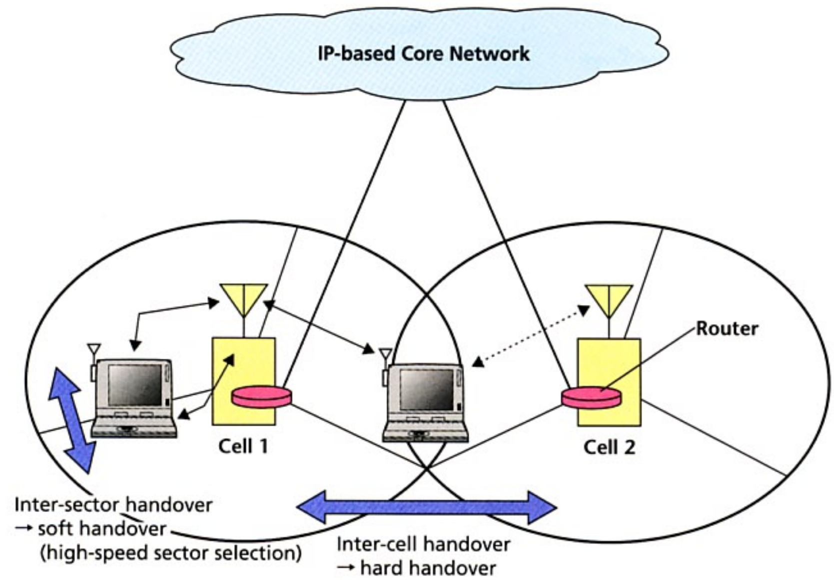


Figure 3 Handover control

In this regard, a study has been performed on throughput characteristics versus cell selection/switchover period during inter-cell macro-diversity reception for OFCDM on the downlink [5]. For a cell selection/switchover period of 500 ms or greater, cell-select updating cannot keep up with shadowing variation. This results in the selection of a cell with a small Signal-to-Interference power Ratio (SIR), i.e., a large propagation loss, and increase in the signal-energy-per-bit to background-noise-power-spectrum-density ratio (E_b/N_0).

Figure 3 shows the proposed method of handover control for the data-link layer and below. When taking high-speed packet scheduling and ARQ into account, a short hard handover with a cell switchover period of about 100 ms is considered to be appropriate for inter-cell handover. A hard handover can simplify control of the core network between different cells compared with a soft handover.

As for handover between sectors, processing within the base station makes it easier to distribute and synthesize data sequences. A soft handover (including high-speed sector selection on the downlink) is therefore expected to have a traffic-dispersion effect when traffic becomes concentrated in a particular sector.

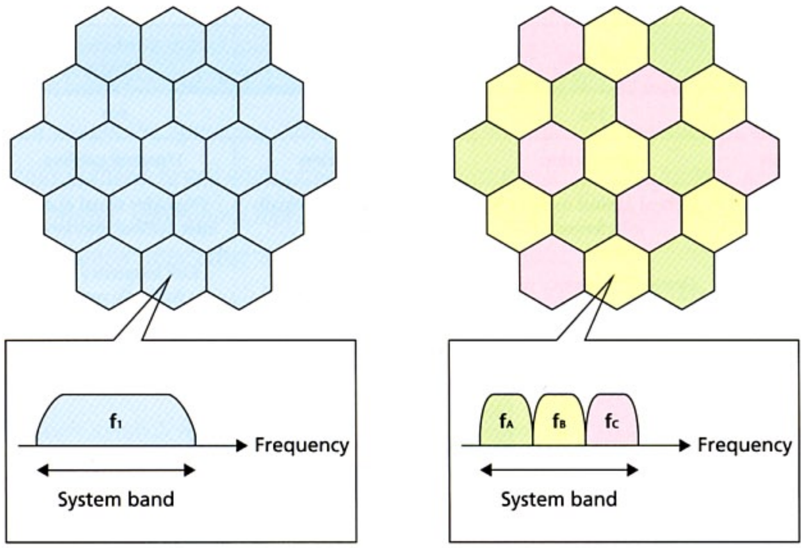
4. Broadband Wireless Access Schemes

4.1 Duplex

Two well-known duplex systems are Frequency Division Duplex (FDD) and Time Division Duplex (TDD). The latter system has the advantage of not requiring a pair of bands to operate although it does require that base stations to be synchronized (frame synchronization) for application to a cellular system. In an isolated cell environment, moreover, TDD can perform flexible slot allocation for each link by varying the transmission/reception slot-allocation ratio on the uplink and downlink using the same frequency band. A cellular system featuring a cluster of cells, though, requires that uplink/downlink slot allocation be the same throughout. The FDD system, on the other hand, while requiring a pair of bands for the uplink and downlink, does not require base-station synchronization and is therefore considered to be preferable to TDD from the viewpoint of flexible cell expansion. While both will probably have to be supported in the end, a system configuration based on a single wireless interface (frame configuration) is desirable.

4.2 Cell Frequency Reuse

Figure 4 shows the frequency usage efficiency in a cellular system for one-cell frequency reuse and three-cell frequency reuse. For one-cell frequency reuse shown in Fig. 4 (a), the system band expands by spreading the time or frequency domain while the despreading process decreases interference and noise components by the inverse of the spreading factor on average, which means that a spreading gain can be expected. In ordinary Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA), however, three-cell frequency reuse as shown in Fig. 4 (b) becomes necessary to reduce same-channel interference. As a result, the effective fre-



(a) One-cell frequency reuse (b) Three-cell frequency reuse

Figure 4 Comparison between one-cell frequency reuse and three-cell frequency reuse

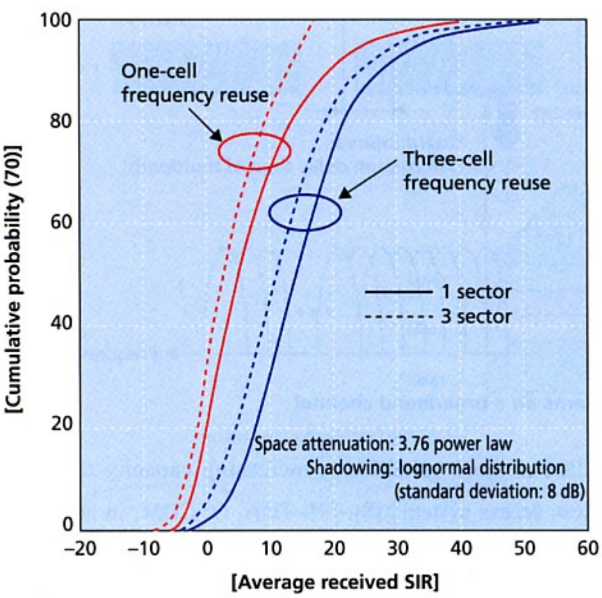


Figure 5 Cumulative distributions of average received SIR for one-cell and three-cell frequency reuse

quency band per cell/sector is 1/3 the full system band. In short, one-cell frequency reuse is an essential condition for increasing system capacity in a cellular system.

Figure 5 shows cumulative-distribution plots of average received SIR, here the ratio of desired-signal power to interference power from neighboring cells, for one-cell and three-cell frequency reuse on the downlink of a cellular system. It is assumed here that cell radius is the same for all cells and that transmit power is the same for all sectors. Space attenuation follows a 3.76 power law while shadowing variation follows a log-normal distribution with a standard deviation of 8 dB. Now, on examining the 50% values of these cumulative-probability plots for either 1-sector or 3-sector configurations, it can be seen that received SIR for one-cell frequency reuse is about 10 dB less than that for three-cell frequency reuse, which means that one-cell frequency reuse needs "gain" to suppress about 10 dB of interference from neighboring cells. Spreading of the time or frequency domain can easily achieve one-cell frequency reuse by effectively reducing interference from neighboring cells. In addition, to prevent each information symbol from being affected by same-pattern interference from the physical channel of neighboring cells in the cell configuration of one-cell frequency reuse, it is essential that the effects of signal interference from neighboring cells be averaged out by cell-specific (or user-specific) scrambling (i.e., multiplying the scrambling code).

4.3 Downlink Wireless Access Scheme –VSF-OFCDM–

Table 1 compares broadband wireless access systems on the downlink and **Figure 6** compares DS-CDMA and multicarrier transmission systems on a broadband channel. These systems can be broadly divided into those that perform spreading using user-specific spreading codes and those that do not.

With broadband, a radio propagation path can be decomposed into an extremely large number of arriving waves (paths). If spreading is applied to the 5-MHz frequency band of W-CDMA based on the time-domain-spreading approach taken by DS-CDMA, the number of paths that can be decomposed increases, but at the same time, paths having different delay times generate interference (multipath interference) negating the Rake diversity effect. If SIR of each despread path is very small, the signal after Rake combining cannot achieve the required SIR. A wireless access system robust against multipath interference is therefore essential to achieving high-quality signal transmission on a broadband channel. In this regard, a multicarrier transmission system first subjects a high-speed data stream to a serial-parallel conversion generating many subcarrier signals whose symbol length is sufficiently longer than multi-

Table 1 Comparison of wireless access systems on the downlink

Access System	Single/Multicarrier DS-CDMA	OFCDM	OFDM	Single/Multicarrier TDMA
Spreading	Yes	Yes	No	No
Number of carriers	1/several carriers	Many carriers	Many carriers	1/several carriers
Effects of multipath interference	Degrades signal by negating Rake diversity effect	Robust against multipath interference	Robust against multipath interference	Degrades signal due to inter-symbol interference
Frequency reuse	One-cell frequency reuse	One-cell frequency reuse	Cell frequency reuse basically needed	Cell frequency reuse basically needed

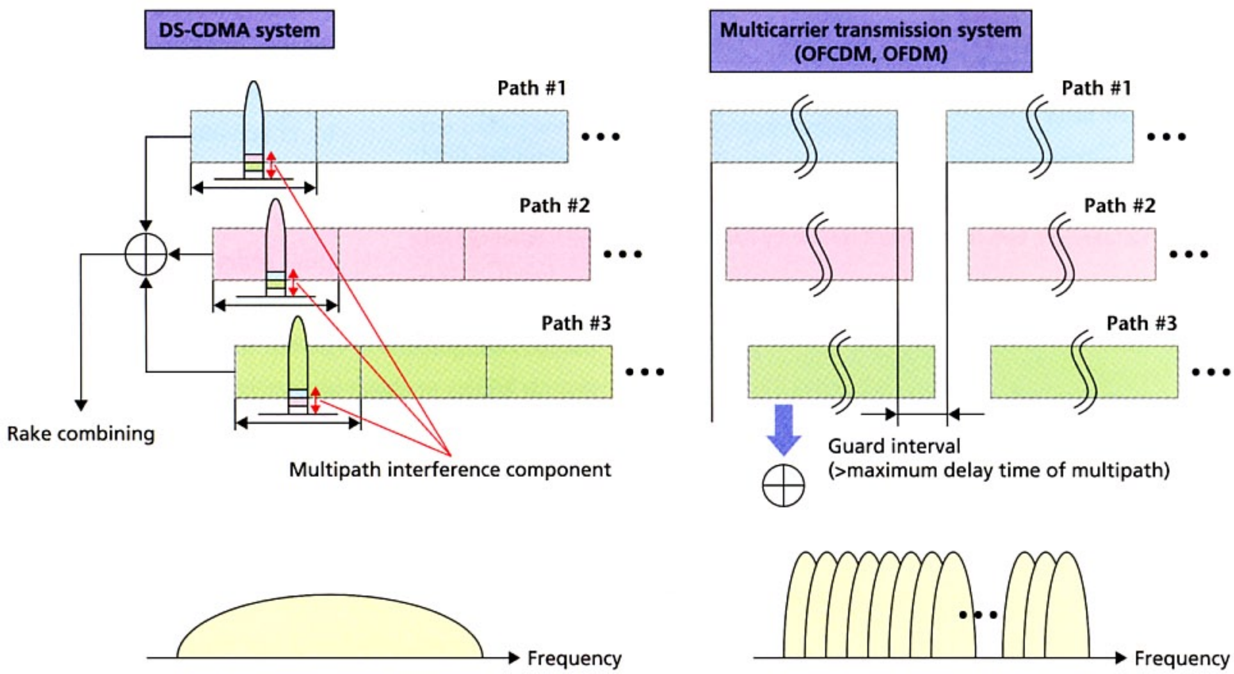


Figure 6 Comparison of wireless access systems on a broadband channel

path propagation delay time. It then proceeds to transmit these low-symbol-rate data streams in parallel. In multicarrier transmission, the wireless band is divided into a large number of narrow-band signals resulting in small bandwidth per subcarrier. This means that amplitude and phase variation within a subcarrier can be treated as flat fading and that the effects of waveform distortion caused by frequency-selectivity fading can be reduced. Even if a subcarrier exists whose received power has dropped due to fading, its decoded error can be compensated for by applying error-correction channel coding across multiple subcarriers whose received power has not dropped, resulting in high-quality reception.

On the downlink of a cellular system, OFCDM, which is based on Multi-Carrier CDMA (MC-CDMA) [6], [7], can reduce the effects of multipath interference while obtaining a frequency diversity effect by spreading and mapping channel-coded symbols across all subcarrier bands. For this reason, OFCDM is more suitable for increasing capacity than other wireless access systems [8], [9]. Thus, OFCDM, in addition to being robust against multipath fading characteristic of multicarriers, it can achieve one-cell frequency reuse in a flexible manner and increase system capacity by applying spreading in either the time or frequency domain. In an isolated cell environment, however, interference from neighboring cells is small and system capacity can generally be increased in the domain that does not use spreading. The reason for this is that when spreading in the frequency domain, code orthogonality among multiplexed code channels collapses due to frequency-selectivity fading caused by multipath interference. Similarly, when spreading in the time domain, amplitude fluctuation occurs in the time domain within a high-speed Doppler environment giving rise to inter-code interference that in turn causes orthogonality to collapse in the time domain. In either case, the number of code channels corresponding to the band expansion factor cannot be multiplexed.

To deal with the above situation, OFCDM with a Variable Spreading Factor (VSF-OFCDM) has been proposed [10], [11]. This system adapts the spreading factor in the OFCDM time and frequency domains to cell configuration, propagation conditions (delay spread, maximum Doppler frequency, and magnitude of interference from other cells), channel load, wireless parameters (data modulation system, channel coding rate), and other conditions. **Figure 7** shows a conceptual diagram of VSF-OFCDM applied to two-dimensional spreading. Here, one data modulation symbol will be spread across SF_{Time}-number of consecutive OFCDM symbols and SF_{Freq}-number of consecutive subcarriers with the total spreading factor represented as $SF = SF_{Time} \times SF_{Freq}$ (where SF_{Time} and SF_{Freq} denote spreading factor in the time and frequency domains). As indicated in Fig. 7, two-dimensional VSF-OFCDM can (1) control the total spreading factor in accordance with cell configuration (the mobile terminal sets the spreading factors based on control information from the base station), (2) adaptively control SF_{Time} and SF_{Freq} in accordance with propagation conditions, channel load, and wireless parameters, and (3) maximize channel capacity for both a cellular system and an isolated cell environment such as hot spots and indoor cells.

4.4 Uplink Wireless Access Scheme –VSCRF-CDMA–

Table 2 compares broadband wireless access systems on the uplink. From the viewpoint of low mobile-terminal power consumption, the most important requirement on the uplink, the DS-CDMA approach is more advantageous than the multicarrier approach as in OFDM and OFCDM that use many subcarriers having a large Peak-to-Average Power Ratio (PAPR). The uplink, moreover, requires a separate pilot channel for each mobile-terminal physical channel to perform synchronous detection and demodulation. Consequently, for OFDM and

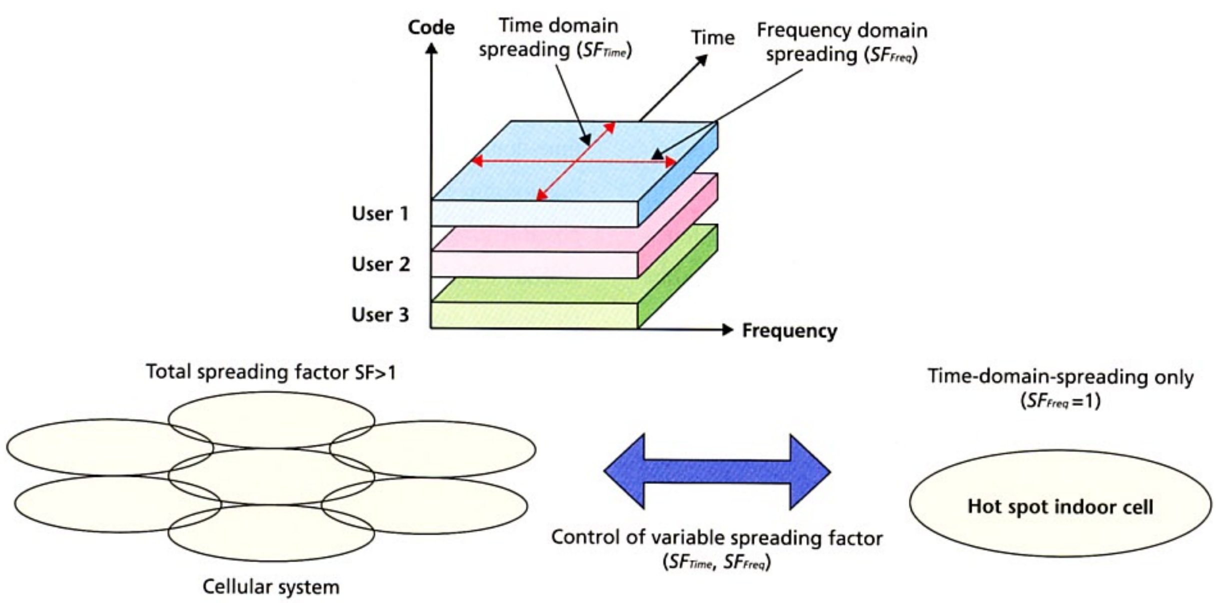


Figure 7 Concept of VSF-OFCDM using two-dimensional spreading

Table 2 Comparison of wireless access systems on the uplink

Access System	Single/Multicarrier DS-CDMA	OFCDM	OFDM	Single/Multicarrier TDMA
Spreading	Yes	Yes	No	No
Number of carriers	1/several carriers	Many carriers	Many carriers	1/several carriers
Low power-consuming terminal	Low peak-power transmission possible by spreading	Large peak power	Large peak power	Large peak power
Large capacity	Characteristics improve by Rake diversity	Accuracy of channel estimation degrades	Accuracy of channel estimation degrades	Signal degrades due to inter-symbol interference
Frequency reuse	One-cell frequency reuse	One-cell frequency reuse	Cell frequency reuse basically needed	Cell frequency reuse basically needed

OFCDM that use many subcarriers, channel estimation must be performed for each subcarrier, and if pilot power is the same throughout, pilot-channel signal power per subcarrier is small compared to that of DS-CDMA. As a result, the DS-CDMA system has been reported to excel in channel-estimation accuracy, to reduce the received E_b/N_0 which satisfys the required packet error rate compared with multicarrier systems, and to be capable of increasing link capacity [12]. In DS-CDMA, moreover, a band exists that can minimize required transmission power (i.e., received E_b/N_0). This optimal subcarrier band is determined on the basis of a tradeoff between improved and degraded reception characteristics, where the former is achieved by Rake diversity after broadening the frequency band and increasing the number of paths that can be separated, and the latter is caused by an increase in multipath interference. When given propagation characteristics like delay profile model and number of paths and spreading factor as parameters, it has been reported that received E_b/N_0 required can be reduced the most by a subcarrier band with a width from 20 to 40 MHz [12]. Accordingly, a multicarrier/DS-CDMA system configured on the basis of this optimal subcarrier in accordance with the system band is a promising wireless access system from the viewpoint of link capacity.

The DS-CDMA system can achieve one-cell frequency reuse in a flexible manner through spreading in the time domain. The advantage of one-cell frequency reuse diminishes, however, in an isolated cell environment for which interference from neighboring cells is small. Link capacity here turns out to be 20-30% of the spreading factor when using no voice activation. To therefore support a single wireless interface for both multi-cell and isolated-cell environments using DS-CDMA, link capacity needs to be increased for isolated cells. Since interference from other users and multipath interference make it difficult to achieve orthogonalization (absence of mutual correlation) in the code domain even when broadening the band, orthogonalization between simultaneous users in the frequency or time domain must be established.

Figure 8 shows a conceptual diagram of a proposed system called Variable Spreading and Chip Repetition Factors-CDMA (VSCRF-CDMA) [13]. In a multi-cell environment, the norm is to perform spreading in the time domain only making one-cell frequency reuse easy to achieve, while in an isolated-cell environment, the principal of symbol repetition is applied to the spread chip sequence and chip repetition is performed. Here, *SF* denotes the spreading factor for total band broadening. Its value is determined by the symbol rate of the physical channel. In an isolated-cell environment, *CRF* is set to 1 or greater and the time-domain spreading factor $SF_{hotspot}$ is made small based on the relationship $SF = SF_{hotspot} \times CRF$. This kind of control makes it possible to allocate received signals of a *CRF*-number of simultaneous users to a set of subcarriers mutually orthogonal in the frequency domain. In the method proposed here, *CRF* and

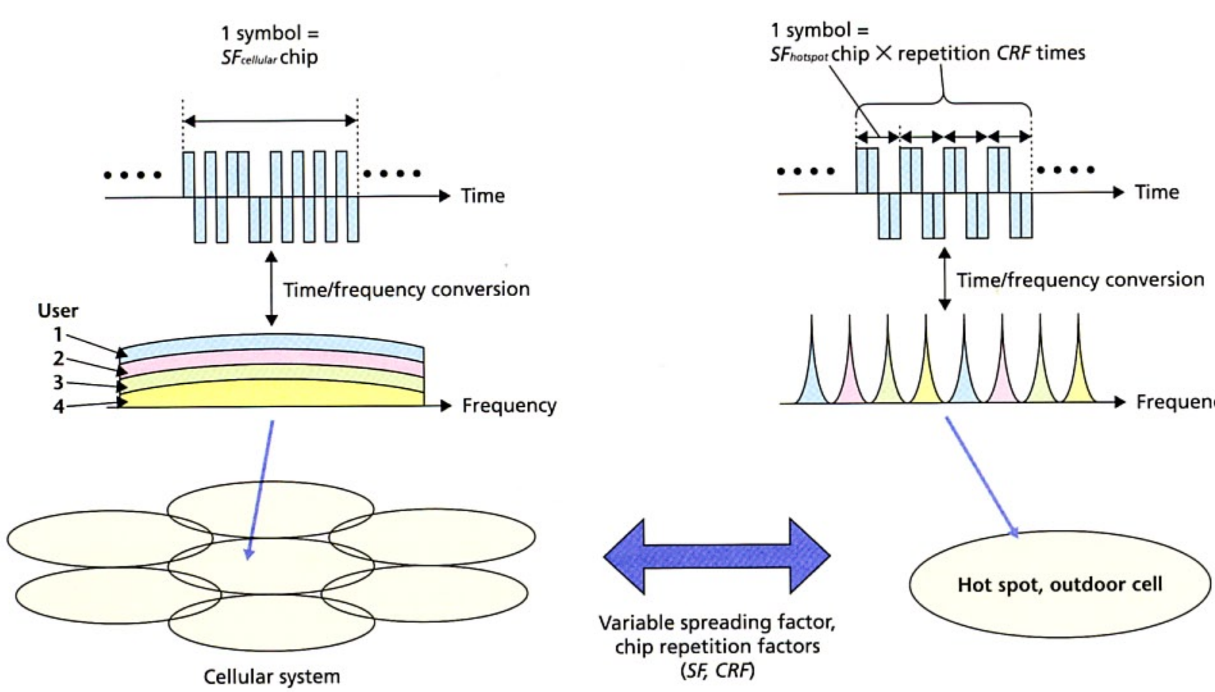


Figure 8 Concept of VSCRF-CDMA

$SF_{hotspot}$ are varied adaptively according to cell configuration (multi-cells or isolated cell), number of simultaneously accessed channels, and propagation condition (number of multipaths).

4.5 Physical Channel Configuration

Figure 9 shows the configuration of physical channels. First, the common control channel transmits broadcast and paging information at a fixed level of transmission power. This channel uses a fixed modulation system, Quadrature Phase Shift Keying (QPSK), and a low coding rate so that reception can be performed at required quality and at required coverage within the cell. Next, the shared packet channel transmits high-speed packet data likewise at a fixed level of transmit power. It applies AMC using a modulation system and channel coding rate appropriate for the received SIR and provides a maximum information rate to guarantee the required received-packet error rate. Finally, the associated control channel sends control information for the physical and data-link layers to facilitate high-quality transmission on the shared packet channel. It features a fixed modulation system, QPSK, and coding rate and applies transmission-power control to compensate for fluctuating received level due to variable fading.

5. High-efficiency Packet Access Techniques

Table 3 lists RT and NRT traffic requirements [14], [15]. The transmission of RT traffic data such as audio and video broadcasts must guarantee receiving quality at or under the required residual packet error rate while maintaining delay requirements. In contrast, NRT traffic data such as file transfer and WWW browsing must keep delay to within several seconds, a less stringent requirement than that of RT traffic data. Here, however, data transmission must be error free within this delay requirement. **Figure 10** shows packet control on the data-link and physical layers [16]. On these layers, scheduling is performed to satisfy required delay and IP packet loss rate on the RAN in accordance with the traffic data in question. On the downlink, efficient transmission-slot allocation (scheduling) is performed according to the received SIR and type of traffic data (RT or NRT) of each mobile terminal. On the uplink, each terminal sends a reservation packet beforehand to advise the base station of QoS requirements of subsequent data packets, data size, received-channel state, etc., and the base station performs transmission-slot allocation on the data packet channel for each mobile terminal based on this information. The system also applies MAC-layer ARQ to the data packet channel according to required delay time. The above approach can reduce required transmission power by a time diversity effect especially in the case of NRT traffic data [17].

6. Multi-antenna Transmission/Reception Techniques

6.1 Multi-antenna Transmitter/Receiver Configurations

A broadband wireless access system is expected to have high carrier frequencies to support high-speed information bit rates, and if such a service is to be provided to a wide area,

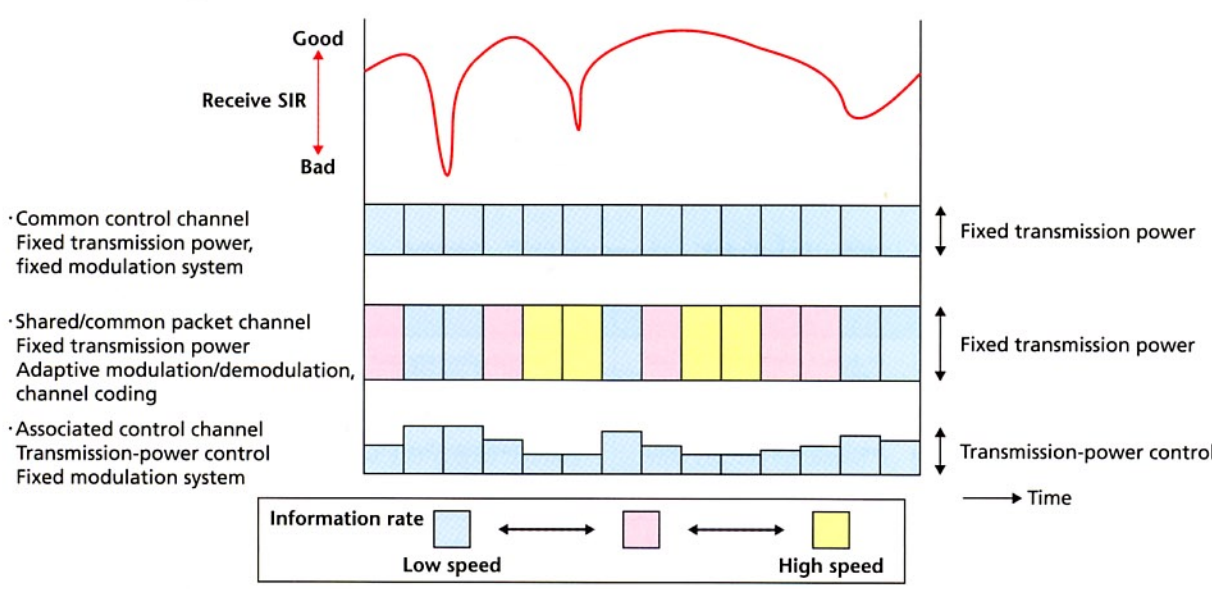


Figure 9 Physical channel configuration

small zones (micro cells) and low required received E_b/N_0 will be indispensable. An adaptive antenna array that can generate directional beams in the angular direction of each user is one would be effective.

At the same time, a Multiple-Input-Multiple-Output (MIMO), spatially multiplexed multi-antenna transmitting /receiving scheme is effective for raising information rate (frequency usage efficiency). This scheme uses multiple transmitting /receiving antennas and radio devices and transmits different data streams from each transmitter. On the downlink given VSF-OFCDM wireless access with a frequency bandwidth of 100 MHz, a peak information rate of 200/300 Mbit/s can be achieved here by combining 16QAM/64QAM data modulation and a channel coding rate of 3/4. A 4-antenna MIMO, for example, could possibly achieve 1 Gbit/s transmission (frequency usage efficiency: 10 bit/s/Hz) for a frequency bandwidth of 100 MHz in an isolated cell environment.

Table 4 compares multi-antenna transmitter/receiver configurations from the viewpoint of improving frequency usage efficiency.

The following three configurations are compared in this article.

- MIMO multiplexed method that transmits different data streams on independent radio propagation paths using the same frequency band and time slot [18],
- MIMO diversity method that codes and transmits data streams amongst multiple antennas [19],
- Adaptive-antenna-array transmission method that performs directional transmission using multiple transmit antennas.

Figure 11 (a) shows a MIMO transmitter/receiver configuration (MIMO multiplexed method). This method performs serial/parallel conversion on a modulated data stream to produce *N* separate streams and transmits these streams by spatial parallelism. Since different data streams are transmitted here on the same frequency band and time slot, the receive signals carrying these *N* data streams must be separated at the receiver. To this end, the following methods have been proposed using the sig-

Table 3 Traffic requirements

Service class	Example	QoS requirements (examples)	
		End-to-end delay	Packet loss rate
Real time (RT)	Audio and video broadcasts	< 150 ms	0.5% or less
Non real time (NRT)	File transfer, WWW browsing	< 2-3 sec	0%

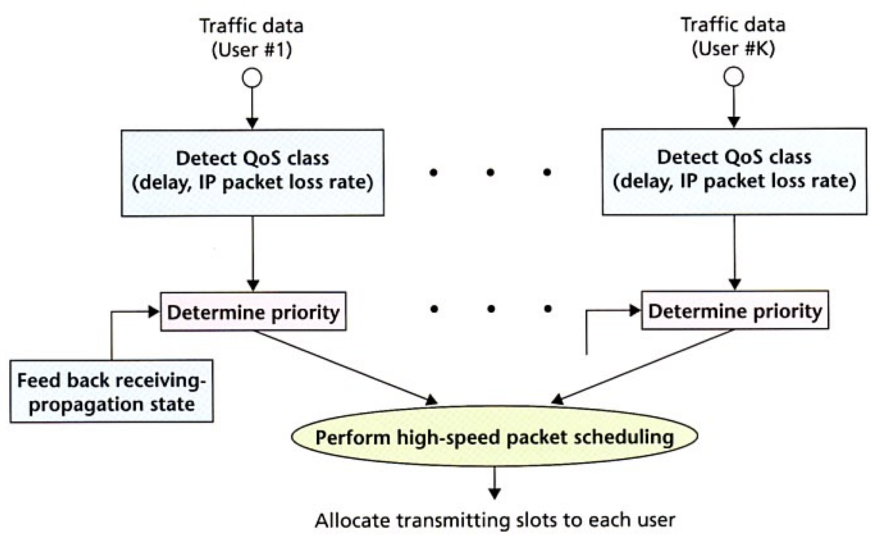


Figure 10 Packet control on the data-link layer and physical layer

Table 4 Comparison of multi-antenna transmitter/receiver configurations

		MIMO multiplexed	MIMO diversity	Adaptive-antenna-array transmission
Effect		Increases information bit rate	Increases diversity gain	Increases average receive SIR
Required transmission-antenna interval		Large		Small
Inter-antenna fading correlation	Large	Small signal-separation ability	Small transmission-diversity gain	Large antenna gain
	Small	Large signal-separation ability	Large transmission-diversity gain	Small antenna gain
Own-cell/other-cell interference-suppression effect		No		Yes
RF circuit calibration		Unnecessary		Necessary

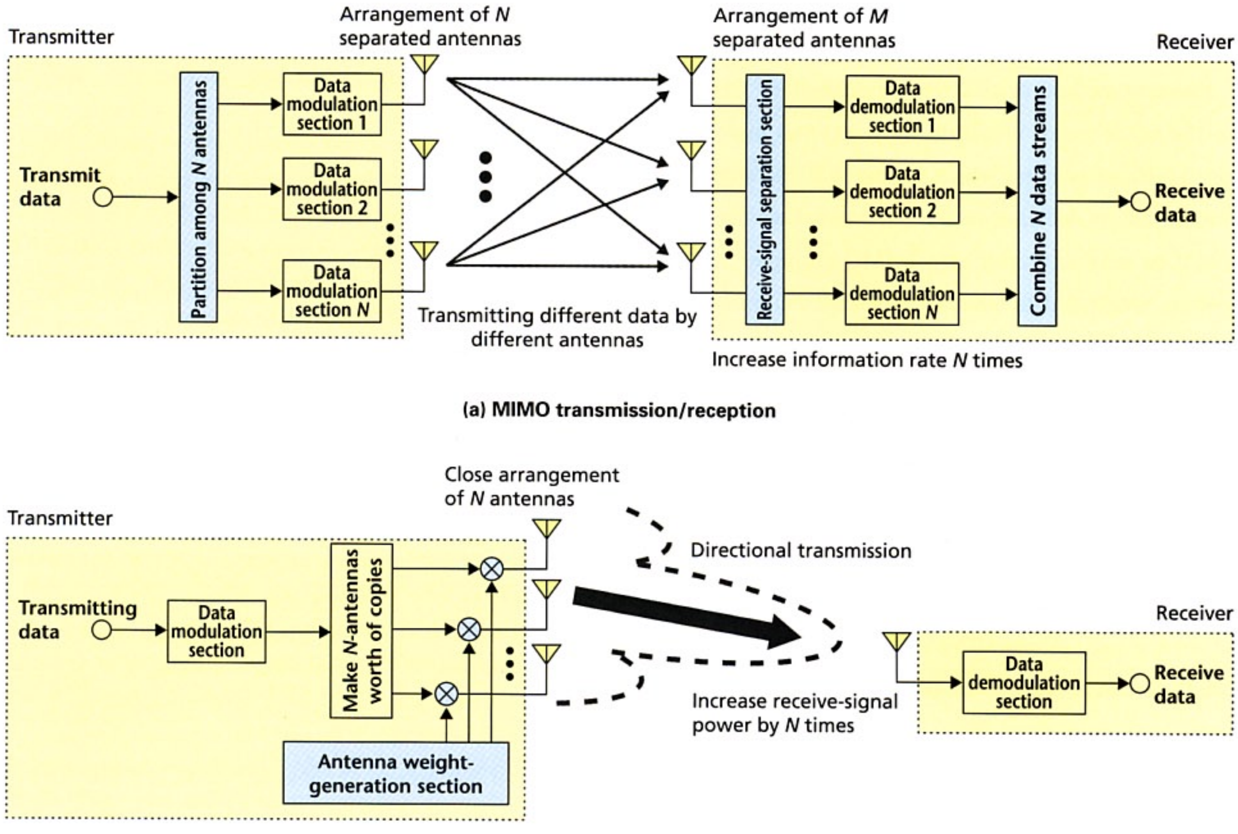


Figure 11 Multi-antenna transmission/reception technologies

nals received from all receiving antennas after channel estimation by pilot symbol has been performed.

- Separate signals by Maximum Likelihood Detection (MLD)
- Combine received signals by weighting so as to minimize mean square error
- Successively extract regenerated data replicas from received signal (Bell Laboratories Layered Space Time (BLAST)) [18]

Turning to the MIMO diversity method, the transmitter performs Space Time Block Coding (STBC) [19] after information bits have been channel coded and data modulated, and generates and transmits *N* streams of coded data. The receiver performs STBC decoding at each antenna and then performs antenna-diversity reception through Maximal Ratio Combining (MRC).

Next, Fig. 11 (b) shows a transmitter/receiver configuration for performing adaptive-antenna-array transmission. In this configuration, the system subjects a data stream to channel coding and modulation (including data modulation and spread modulation), copies the result *N* times corresponding to the number of antennas, and multiplies each stream by a weight unique to each antenna branch (antenna weighting). The weights are generated adaptively by first estimating the direction of a signal received from the target user on the uplink and then computing them so that the main beam of the transmitting antenna pattern is directed the user's direction [20]. On the receiving side, the system performs antenna diversity reception by MRC. This type of adaptive-antenna-array transmission can ideally increase antenna gain by N-times where *N* is the number of transmitting antennas.

6.2 Comparison of Multi-antenna Configurations for Ultra-high-speed Signal Transmission

As shown in Table 4, the MIMO multiplex method, which transmits information in parallel via multiple transmitting antennas, can increase information rate by simply increasing the number of transmitting antennas. This stands in contrast to MIMO diversity and adaptive-antenna-array transmission, which do not increase information rate by increasing the number of transmitting antennas. For these methods, information rate can be increased by either expanding multivalue encoding in modulation or raising the channel-coding rate. Given VSF-OFCDM wireless access with a frequency bandwidth of 100 MHz and assuming four antennas for both transmission and reception, the MIMO multiplex method can achieve a high-speed, high-efficiency information bit rate of 1 Gbit/s (10 bit/s/Hz) using 16QAM or 64QAM data modulation. The MIMO diversity method or adaptive-antenna-array transmission, on the other hand, would have to expand multivalue encoding significantly here, which means that characteristics deterioration due to decrease in the minimum Euclidean distance would be severe. Overall, the MIMO multiplex method that transmits multiple data streams by spatial multiplexing is most appropriate for achieving high-efficiency transmission such as 10 bit/s/Hz [21].

7. Conclusion

This article described the overview of broadband wireless access technology featuring seamless support of a broad range of communication environments from cellular systems to isolated cells like hot spots and offices all by a single wireless interface.

In future research, we plan to perform indoor and outdoor experiments to measure propagation characteristics and evaluate packet-signal transmission on a broadband channel.

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ABBREVIATIONS

3GPP: 3rd Generation Partnership Project
AMC: Adaptive Modulation and channel Coding
ARQ: Automatic Repeat request
BER: Bit Error Rate
BLAST: Bell Laboratories Layered Space Time
DS-CDMA: Direct Sequence Code Division Multiple Access
E_b/N_0: Signal energy per bit to background noise power spectrum density ratio
FDD: Frequency Division Duplex
FDMA: Frequency Division Multiples Access
HSDPA: High-Speed Downlink Packet Access
IMT-2000: International Mobile Telecommunications-2000
IP: Internet Protocol
ITU-R: ITU Radiocommunication sector
MC-CDMA: Multi Carrier CDMA
MIMO: Multiple Input Multiple Output
MLD: Maximum Likelihood Detection
MRC: Maximal Ratio Combining
NRT: Non Real Time
OFCDM: Orthogonal Frequency and Code Division Multiplexing
OFDM: Orthogonal Frequency Division Multiplexing
OVSF: Orthogonal Variable Spreading Factor
PAPR: Peak to Average Power Ratio
PER: Packet Error Rate
QAM: Quadrature Amplitude Modulation
QoS: Quality of Service
QPSK: Quadrature Phase Shift Keying
RT: Real Time
SF: Spreading Factor
SIR: Signal to Interference power Ratio
STBC: Space Time Block Code
TDD: Time Division Duplex
TDM: Time Division Multiplexing
TDMA: Time Division Multiple Access
VSCRF: Variable Spreading and Chip Repetition Factors
VSCRF-CDMA: Variable Spreading and Chip Repetition Factors-Code Division Multiple Access
VSF: Variable Spreading Factor
VSF-OFCDM: Variable Spreading Factor-Orthogonal Frequency and Code Division Multiplexing
W-CDMA: Wideband Code Division Multiple Access