Proc. 12th International Conference on Antennas & Propagation (ICAP 2003), pp. 1-4, Exeter, U.K., 31 March - 3 Apr. 2003

CHALLENGES FOR BROADBAND MOBILE TECHNOLOGY

F Adachi
Tohoku University, Japan

ABSTRACT

A global wireless system is presented that provides broad ranges of services to cellular and nomadic users everywhere. A Giga-bps wireless access using DS-CDMA and MC-CDMA is discussed. Wireless links are severely power-limited for such a Giga-bps wireless access. A virtual cell system concept that allows flexible installation of distributed wireless ports is presented.

INTRODUCTION

Convergence of mobile communications, computing and Internet is on the way. This will be the driving force towards a broadband wireless multimedia society. Since the present cellular systems (often referred to as 2G cellular systems) are optimized to real-time voice services, they have quite limited capabilities in providing broadband multimedia services because of their slow data transfer rates and small displays on the portable phones. The IMT-2000 systems, called 3G cellular systems, are under deployment with much faster data rates of up to 384kbps (2Mbps in the later stage) and better representation than the present 2G cellular systems [Adachi et al (1)].

Information transferred over the Internet will become increasingly rich. Broadband multimedia services will soon be in full force in fixed networks based on the next generation Internet technology. However, the capabilities of 3G cellular systems will sooner or later be insufficient to cope with the increasing demands for broadband multimedia services. Most of the services may contain high resolution and short delay streaming video combined with audio. Broadband wireless access will definitely be required that is optimized to broadband IP packet transport over the air.

In this paper, we first present a global wireless system concept to provide broad ranges of services to cellular and nomadic users everywhere. Then, we will address the broadband mobile technology. Robust broadband wireless access techniques under severe frequency selective fading environments need to be developed. Since wireless links are severely power-limited for broadband wireless, adoption of the well-known and long-time used cellular concept may not be applied. We will also address this problem in this paper.

TABLE 1-Evolution of cellular systems

	1G	2G	3G	4G
Wireless Access	Analog	Digital	Digital	Up to 1 Giga bit/s
	FDMA	TDMA, DS-CDMA	DS-CDMA	OFDM, CDMA based access
Major Services	Voice	Voice	Voice	Broadband rich Internet
		Internet (text only)	Internet (text, images)	
Core-network	Circuit-switched	Circuit-and packet switched	Circuit-and packet -switched	Broadband IP-based

EVOLUTION INTO A GLOBAL WIRELESS SYSTEM

Cellular systems have been evolving according to advancements in wireless technologies and changes in user demands as shown in Figure 1. Table 1 shows how the cellular systems have evolved from 1G to 3G and will evolve to 4G. In line with an explosive expansion of Internet traffic in the fixed networks, demands for broad ranges of services (in terms of data rate, quality, traffic type, etc) are becoming stronger even in mobile communications networks. The so-called 4G cellular systems that will support extremely high data rates than 3G cellular systems (W-CDMA, cdma2000) are expected to emerge around 2010.

Systems that support such extremely high data rates (e.g., ~1Gbps) services may not be able to provide a nationwide coverage. Places where users require such extremely high data rates services may be in small hot spot areas, e.g., homes, shopping areas, railway stations, airports, hotels, etc. It may be almost impossible to build a single super wireless system to meet all the demands. An important issue is how to offer both cellular and nomadic users broadband multimedia services everywhere. Some new ideas are necessary.

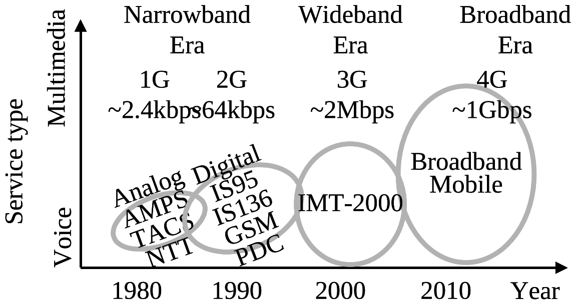

Figure 1 Evolution of cellular systems.

Global Wireless System

A good solution may be an introduction of a global wireless system concept that efficiently inter-connects many dedicated wireless systems (e.g., 2G/3G/4G cellular systems, wireless LANs, broadcasting systems, etc), each optimized to different communications environment, using broadband Internet technology. This concept allows each wireless system to evolve independently of each other as indicated in Figure 2. The cellular systems provide nationwide coverage, while wireless LAN type system will cover only hot spot areas but with extremely higher data rates than cellular systems. Broadcasting systems may have nationwide coverage to provide cellular and nomadic users with one-way streaming video programs and high-fidelity music programs, etc. Close coordination of 2G/3G/4G cellular systems, wireless LAN systems, broadcasting systems and other wireless systems will be of paramount importance for providing seamless nationwide services.

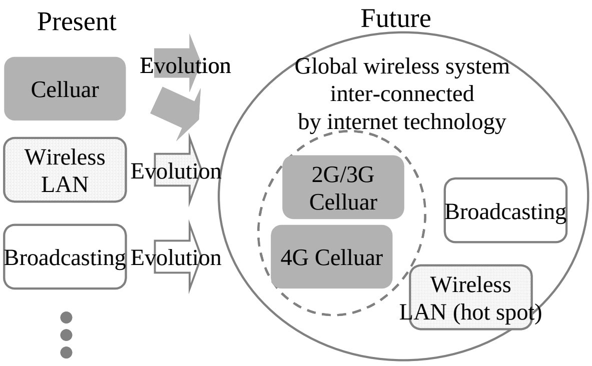

Figure 2 Global wireless system.

Data Rate Requirements

Demands for downloading of ever increasing volume of information will become higher and higher. Flexible data multiplexing of much broader range of information rates than today's 3G cellular systems and wireless LANs is required for forward links (base-to-mobile). A 100M~1Gbps class wireless access (we call this technology a *Giga-bps wireless access*) may be necessary. Required data rates may be:

- ☐ Hot spots and pedestrian environments: 100M~1Gbps
- ☐ Vehicular environments: ~100Mbps

A very high spectrum efficiency of ~ 10 bps/Hz may be required because of very limited available bandwidths. For achieving this, multiple-input multiple-output antenna systems (MIMO) will play an important role.

Wireless Access Network

IP packet traffic will dominate over the circuit switched traffic in the near future. Figure 3 illustrates a conceptual configuration of 4G cellular systems. The wireless part of 4G cellular systems will become closer to a wireless LAN, but with wide area mobility management as in the 2G/3G cellular systems. Cellular systems require many call control functions and distributed database. All of these functions will be inter-connected via all IP network. Voice traffic can be transferred as IP packets (i.e., VoIP) but how to guarantee different QoS requirements and reduce latency is a major technical issue.

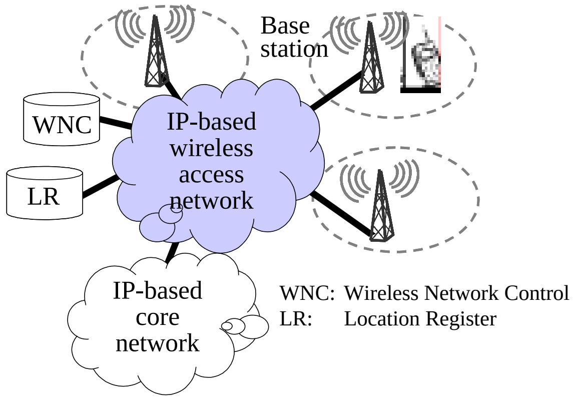

Figure 3 Conceptual configuration of 4G cellular systems.

WIRELESS TECHNOLOGY

Proper understanding of propagation mechanism is important before system development. We first look at the broadband propagation channel and then discuss Giga-bps wireless access techniques.

Propagation Channel

In wireless communications, many obstacles (e.g., buildings) reflect and diffract the transmitted signal and create a multipath propagation channel. When multiple paths with different time delays are present, the frequency response of the channel is not anymore constant over the signal bandwidth, and results in the frequency selective fading and distorts the received signal spectrum. Furthermore, the channel frequency response rapidly varies in a random manner over a short distance.

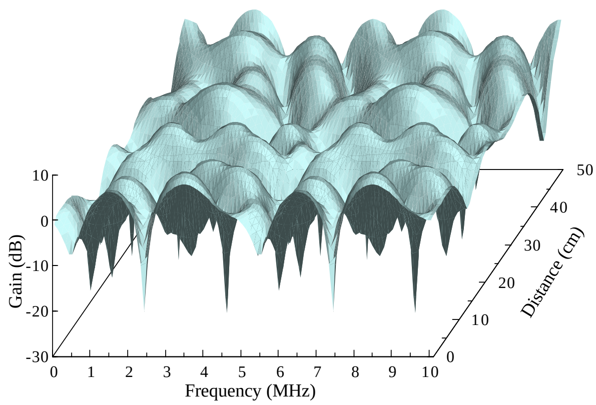

Figure 4 Frequency response of multipath channel.

Figure 4 shows how the channel frequency response varies in the frequency-distance plain for a multipath channel having a 4-path uniform power delay profile with a time delay separation of 200ns and a carrier frequency of 2GHz. When a mobile terminal is moving, the time selective fading is produced; the channel response at any frequency is subjected to Rayleigh fading in most cases. The challenge is to transmit data with high quality at high speed (close to 1 Gbps) under such a severe fading environment.

Proc. 12th International Conference on Antennas & Propagation (ICAP 2003), pp. 1-4, Exeter, U.K., 31 March - 3 Apr. 2003

Giga-bps Wireless Access

The Giga-bps wireless access is a core of 4G cellular systems. There may be two approaches: from direct sequence code division multiple access (DS-CDMA) and from multicarrier CDMA (MC-CDMA) [Helard et al, Hara and Prasad]. The former uses the time-domain spreading technique, while the latter uses the frequency-domain spreading technique, as illustrated in Figure 5. MC-CDMA is under extensive development [Atarashi and Sawahashi]. Recently, we have found that both DS-CDMA and MC-CDMA can provide almost the same bit error rate (BER) performance if proper frequency domain equalization techniques are employed [Adachi et al (2)]. Figure 6 compares the computer-simulated average BER performances of DS-CDMA and MC-CDMA both with a spreading factor (SF) of 256 for various numbers *C* of simultaneous users. An 8-path frequency selective Rayleigh fading channel is assumed that has a uniform power delay profile with a time delay separation of $T_s/32$, where T_s represents the QPSK data symbol duration. The results suggest that either DS-CDMA or MC-CDMA can be used.

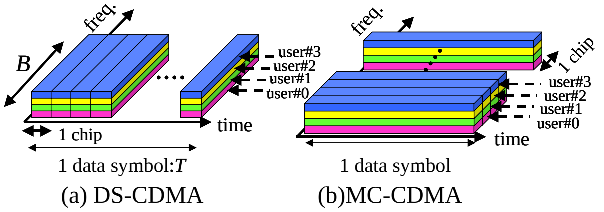

Figure 5 DS-CDMA and OFDM-CDMA.

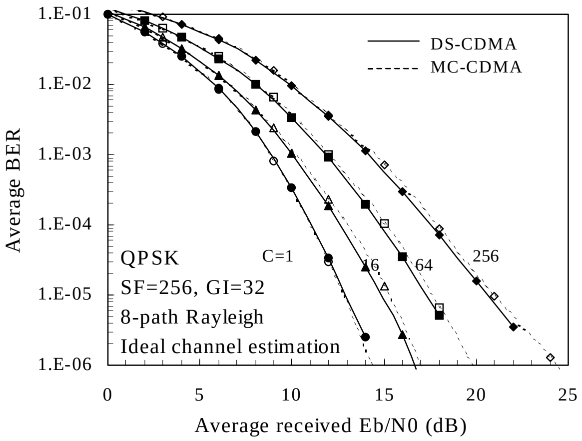

Figure 6 Performance comparison of DS-CDMA and MC-CDMA.

CDMA spreads the transmitting data over the available bandwidth, e.g., 100MHz. For packet transmissions, hybrid automatic repeat request (ARQ) combined with CDMA and rate compatible punctured turbo (RCPT) coding seems to be the most promising error control scheme [Garg and Adachi]. The spreading factor can control the transmission data rate and the number of simultaneously transmitting users. The computer-simulated total throughput performance in bps/Hz of type II RCPT hybrid ARQ using DS-CDMA is plotted as a function of *SF* in Figure 7 for a 4-path frequency selective Rayleigh fading channel. Interestingly, almost the same throughput can be achieved with and without spreading.

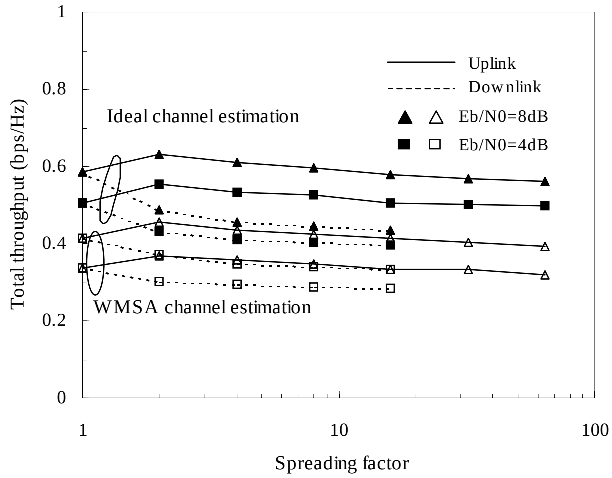

Figure 7 Throughput of type II RCPT hybrid ARQ using DS-CDMA.

The use of orthogonal variable spreading factor (OVSF) spreading codes [Adachi et al (3)] allows construction of spread and non-spread systems using DS-CDMA, as illustrated in Figure 8 (note that a similar design can be applied to MC-CDMA [Atarashi and Sawahashi]). The use of *SF*>1 allows cellular systems with single-frequency reuse similar to 3G cellular systems, while *SF*=1 can be used to cover hotspot areas, resulting in a single-cell system similar to wireless LAN using OFDM. Real time and non-real time services with relatively low data rate per user are provided in cellular system with *SF*>1. On the other hand, non-real time services with very high data rates per user are provided with *SF*=1 in hot spot areas. A fast scheduling mechanism is required to determine which user to be served in the given time interval. Higher priority of services can be given to users in better channel conditions, but a certain degree of fairness among users should be kept. Of course, the *SF*=1 system can be extended to a cellular system with the aid of fast selection of transmit base station and adaptive antenna array.

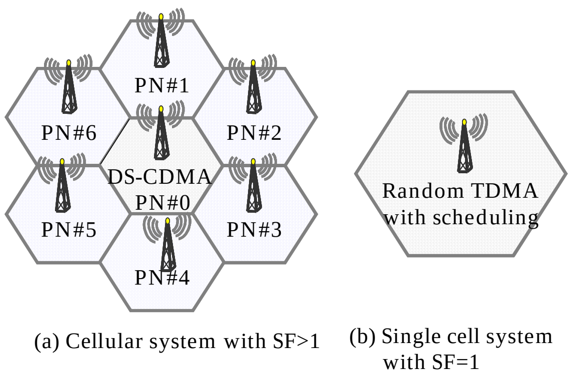

Figure 8 Spread/non-spread systems using DS-CDMA.

Virtual Cell

The frequency bands for the 4G cellular systems will most likely lie above 5 GHz. Since the propagation loss is approximately in proportion to 2.6th power to the carrier frequency [Hata], the links are not only interference-limited but also become severely power-limited for a Giga-bps wireless access. This suggests that a nano-cell or even a pico-cell structure must be adopted. Propagation statistics are strongly influenced by microscopic structure of nearby propagation environments and dynamically change from cell to cell. 4G cellular systems may need to be designed apart from the present cellular concept that relies on the statistical properties of propagation channels. One idea to cope with increasing path loss is to adopt a virtual cell system concept [Adachi]. This is illustrated in Figure 9.

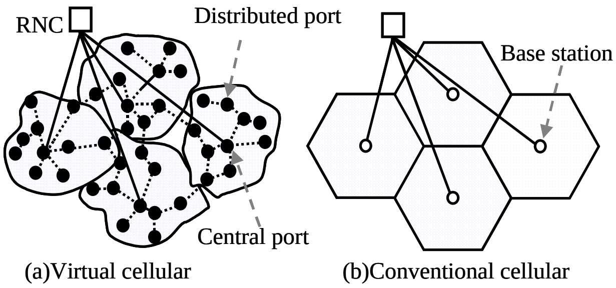

Figure 9 Virtual cell system.

This concept is particularly suitable to non-real time IP packet transfer, which obviously does not require transmit and receive functions at the same base station. Each virtual cell consists of many distributed wireless ports. The receive-only ports can be distributed in each virtual cell together with transmit & receive ports. They can be installed where needed and removed when not needed; they are connected to each other in a self-configuring way to transfer IP traffic. Central ports with large transmit powers can be co-located with the 2G/3G system base stations. The 2G/3G cellular network will be the primary network, which can be overlaid with the above virtual cell network in the hot spot areas. Since coverage areas of virtual cells may not overlap each other, close coordination with 2G/3G systems is necessary. This requires inter-technology mobility management between the 2G/3G and virtual cell networks, a dynamic IP routing algorithm, and so-called software radio technology. The last is to make a single mobile terminal capable of accessing 2G/3G and 4G cellular systems.

CONCLUSION

Broadband mobile technology was discussed. The global wireless system concept was presented that provides broad ranges of services to cellular and nomadic users everywhere. A Giga-bps wireless access close to 1Gbps will be necessary. This can be achieved by using either DS-CDMA or MC-CDMA. Since the expected frequency bands will be above several GHz, wireless links are severely power-limited for such a Giga-bps wireless access. Probably, adoption of the well-known and long-time used cellular concept may not be applied. Adoption of virtual cell system concept that allows flexible installation of distributed wireless ports may be a better solution.

References

1. Adachi F, 2001, "Wireless past and future - evolving mobile communications systems", IEICE Trans. Fundamentals, E84-A, 55-60
2. Adachi F, Sawahashi M and Suda H, 1998, "Wideband DS-CDMA for next generation mobile communications systems", IEEE Commun. Mag., 36, 56-69
3. Adachi F, Sao T and Itagaki T, "Performance of multicode DS-CDMA using frequency domain equalization in a frequency selective fading channel", submitted to Electronics Letters
4. Adachi F, Sawahashi M and Okawa K, 1997, "Tree-structured generation of orthogonal spreading codes with different lengths for forward link of DS-CDMA mobile radio", Electron. Lett., 33, 27-28
5. Atarashi H and Sawahashi M, 2001, "Variable spreading factor orthogonal frequency and code division multiplexing (VSF-OFCDM)", 2001 Third International Workshop on Multi-Carrier Spread Spectrum (MC-SS 2001) & Related Topics, 113-122
6. Garg D and Adachi F, 2002, "Effect of limited number of retransmissions of RCPT hybrid ARQ for DS-CDMA mobile radio", The 5th International Symposium on Wireless Personal Multimedia Communications
7. Hara S and Prasad R, 1997, "Overview of multicarrier CDMA", IEEE Commun. Mag., 126-144
8. Hata M, 1980, "Empirical formula for propagation loss in land mobile radio services", IEEE Trans. Veh. Technol., VT-29, 317-325
9. Helard M, Le Gouable R, Helard J-F and Baudais J-Y, 2001, "Multicarrier CDMA techniques for future wideband wireless networks", Ann. Telecommun., 56, 260-274