Challenges for Broadband Wireless Technology

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1. INTORODUCTION

Convergence of mobile communications, computing and Internet is on the way. This will be the driving force towards a wireless multimedia society in 21st century. Unfortunately, since the present mobile communication systems (often referred to as 2G 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 [1], [2] called the 3rd generation (3G) systems, are under deployment in Japan with much faster data rate of 384kbps and better representation than present 2G systems. We are now entering into wideband era. However, the capabilities of 3G systems will sooner or later be insufficient to cope with the ever-increasing demands for broadband multimedia communications.

Broadband multimedia services will soon be in full force in fixed networks based on the next generation Internet technology. Information transferred over the Internet will become increasingly rich. It is expected that the 4G systems should emerge around 2010; a major objective is to offer mobile users with broadband multimedia services. Demands will become stronger and stronger for downloading of ever increasing volumes of information. Giga-bit wireless technology (up to 1G bps) will be required that is optimized to broadband IP packet transport over the air. For wireless access, a random and reservation packet access and flexible wireless resource assignment between forward and reverse links will be required. The technical requirements for 4G wireless may be:

- Pedestrian environment: 100M~1Gbps
- Vehicular environment: ~100Mbps
- Spectrum efficiency: ~10 bps/Hz

The 3d requirement is of paramount importance because of very limited available bandwidths. This paper looks at the broadband wireless technology that will be a core of 4G systems.

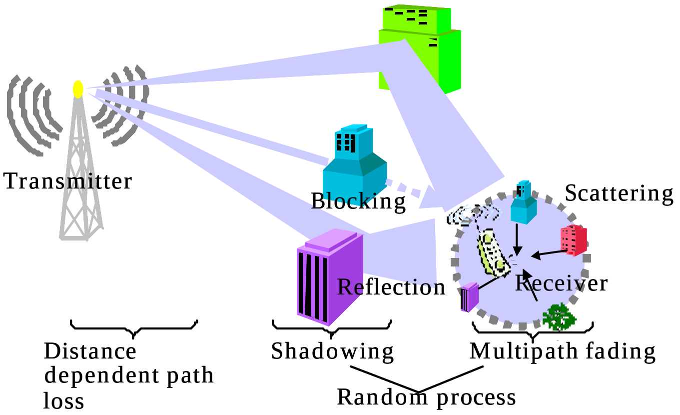


Fig. 1 Propagation channel model.

2. BROADBAND PROPAGATION CHANNEL

Proper understanding of propagation mechanism is important for broadband system development. A wireless propagation channel model is illustrated in Fig.1. The transmitted signal is reflected and diffracted by obstacles, e.g., buildings, resulting in a multipath channel.

For a broadband channel, fine propagation structure can be seen and propagation parameters change dynamically and rapidly. A series of impulses are received with different time delays when one impulse is transmitted from a transmitter at time *t*, as illustrated in Fig. 2. Such a multipath channel can be viewed as a time varying linear filter of impulse response $h(t,\tau)$. Hence, wireless propagation channels can be characterized as doubly (frequency-time) selective fading channels. When multiple paths with different time delays are present, the received signal spectrum is distorted, resulting in the frequency selective fading. Furthermore, since the path gains measured at any frequency are spatially distributed in a random manner, as illustrated in Fig. 3, time selective fading is produced when a mobile terminal is moving; each frequency component is subjected to Rayleigh fading in most cases. To overcome the above-mentioned severe doubly selective fading problem, more than one wireless technique must be combined:

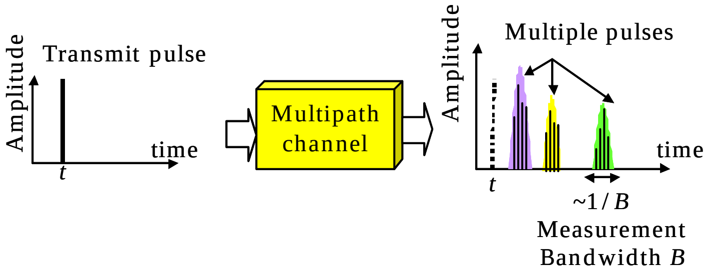


Fig. 2 Linear filter model of propagation channel.

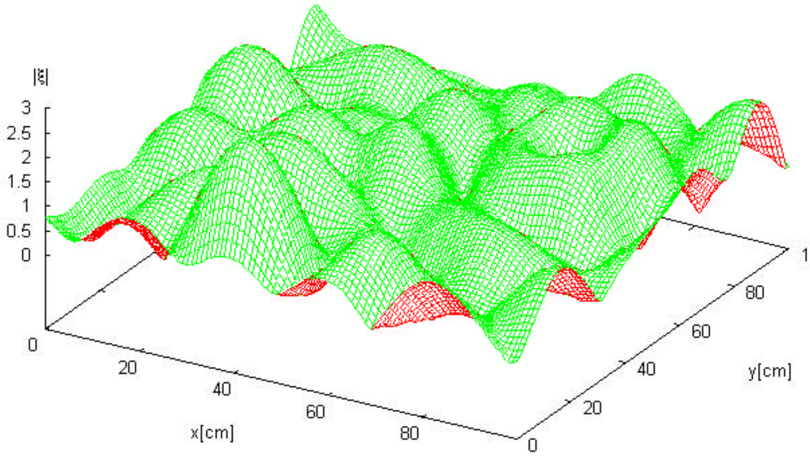
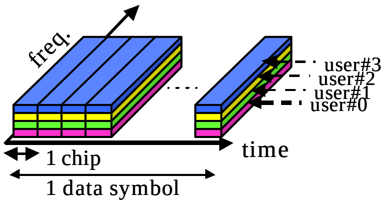


Fig. 3 Spatial distribution of channel gains at f_c=800MHz.

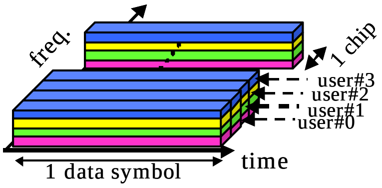
- Bandwidth efficient modulation techniques
- Powerful channel coding techniques
- Multiple-input and multiple-output (MIMO) antenna techniques

3. BROADBAND WIRELESS TECHNOLOGY

Giga-bit wireless technique is a core of 4G systems. The challenge is to transmit data packets of as many users as possible with high quality at high speed (close to 1 Gbps) under severe frequency-selective fading environments. Proper choice of wireless access techniques is important. Any wireless technique has its own limitations: too long delays to equalize in TDMA, too weak paths to Rake combine in DS-CDMA, and no multipath diversity and large peak-to-average power ratio in OFDM. When many narrowband channels are used in parallel, small performance degradations can be achieved in a severe frequency selective channel. Recently, multicarrier CDMA (MC-CDMA) technique is attracting increasing attention



(a) DS-CDMA



(b)OFDM-CDMA

Fig. 4 Comparison of DS-CDMA and OFDM-CDMA.

and is extensively considered as 4G wireless access [2]. There will be two approaches to realize Giga-bit wireless: from DS-CDMA [2] and from MC-CDMA [4], [5], [6]. The former uses time-domain spreading sequences, while the latter uses frequency-domain spreading sequences as seen in Fig. 4. In the following, these two approaches are discussed.

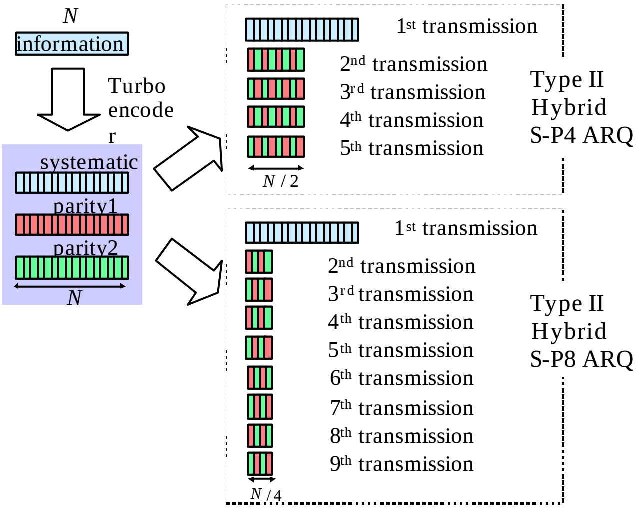


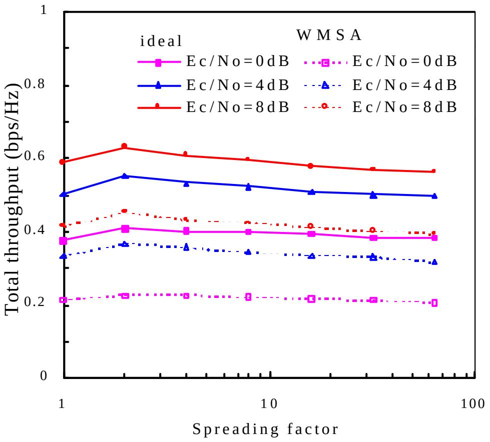
Fig. 5 RCPT hybrid ARQ

3.1 DS-CDMA approach

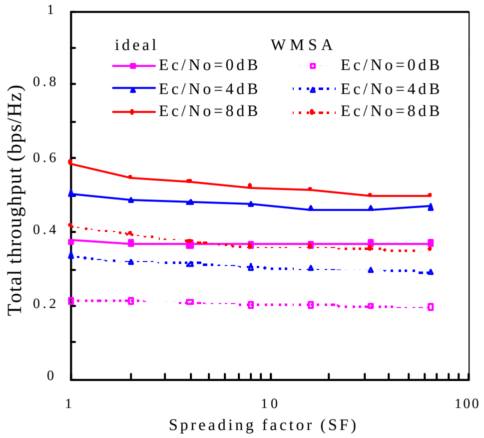
DS-CDMA spreads the data over the available bandwidth. The spreading factor (SF) can control the transmission data rate and the number of simultaneously transmitting users. ARQ combined with DS-CDMA (spread ARQ) seems to be the most appropriate error control scheme. However, spread ARQ alone cannot work satisfactorily. Spread ARQ can be combined with forward error control technique to form spread hybrid ARQ, in which the information data is first forward error coded and then spread to transmit. One promising solution is to use spread hybrid ARQ with rate compatible punctured turbo (RCPT) coding [7]. How the data transmission proceeds is illustrated in Fig. 5. The computer simulated performance of RCPT hybrid ARQ in a four-path (L=4) frequency selective fading channel is plotted in Fig. 6. The throughput obtained with and without spreading is found to be almost the same. Interesting question is: what should be the spreading factor? Is it necessary to spread? Both can be used. The use of orthogonal variable spreading factor (OVSF) spreading code [8] allows flexible system design between spread and non-spread systems.

(a) *When spread*: spreading allows multiple users to communicate at the same time. Each user is provided continuous transmission but the time taken for transmission is longer. Total throughput is divided among the users, hence, each user's throughput is lower. This may be optimum for real time communication with a constant data rate.

(b) *When not spread*: High throughput is given to a single user at each moment. After completing the transmission of one user, channel is assigned to another user. Users need to wait for channel being assigned. This scheme may be optimum for non-real time data communications.



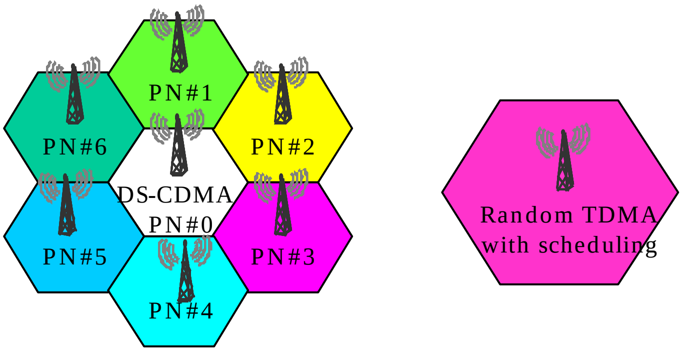
(a) Downlink



(b) Uplink

Fig. 6 Total throughput of SF users as a function of spreading factor. L=4.

A possible non-spread wireless system may be a random TDMA system with appropriate scheduling, while a possible spread system is just an extension of present 3G cellular system based on DS-CDMA (see Fig. 7). 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, in hot spot areas (isolated cells), non-real time services with very high data rate are provided with *SF*=1.



(a) Cellular system with SF>1

(b) Isolated cell system with SF=1

Fig. 7 Packet DS-CDMA system. PN sequences are used as scrambling codes to separate cells.

3.2 MC-CDMA approach

MC-CDMA wireless access can cope with severe frequency-selective fading and allows multi-rate transmission using OVSF spreading codes (when orthogonal sub-carriers are used, it is called OFDM-CDMA). MC-CDMA can fill the gap between OFDM and DS-CDMA. The former can overcome frequency selective fading by adopting a relatively low-complexity receiver (a simple one-tap equalizer per sub-carrier), while the latter gives multi-access capability, multi-rate transmission, single-frequency reuse, etc. The received signal suffers from frequency distortion and thus, partial orthogonality destruction is produced, thereby producing large multi-access interference (MAI). A number of multi-user interference suppression techniques have been proposed: orthogonal restoration combining (ORC), controlled equalization combining (CEC), minimum mean square error combining (MMSEC) and threshold detection combining (TDC) [4], [5], [6], [9]. The computer simulated BER performances of MC-CDMA achievable with ORC, CEC, TDC, and MMSEC are compared with that of DS-CDMA in Fig. 8. MC-CDMA achieves better BER performance than DS-CDMA.

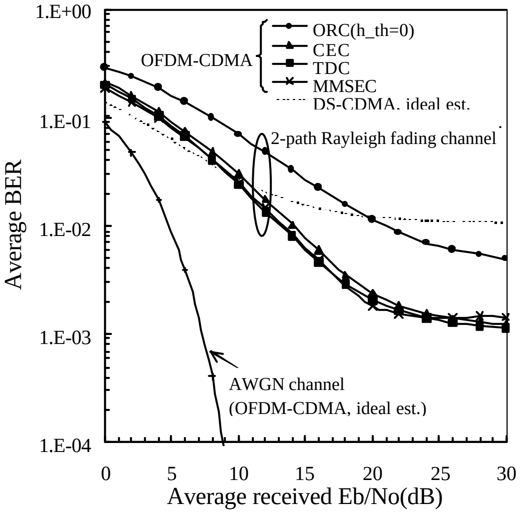


Fig. 8BER performances with pilot-aided channel estimation for various fading maximum Doppler frequency. N=128 users, L=2 paths, and $f_D T_{slot}$=0.032.

MC-CDMA allows flexible system design between cellular systems and single cell systems for covering hotspot areas. The use of *SF*>1 allows single-frequency reuse similarly to 3G, while *SF*=1 can be used to cover hotspot areas, resulting in a single-cell system using OFDM [3], resulting in the similar system design illustrated in Fig. 7.

3.3 Virtual cell concept

The frequency bands for the 4G systems will most likely lie above 5 GHz. Since the propagation loss is in proportion to 2.6th power to the carrier frequency [10], the links are not only interference-limited but also become severely power-limited. This suggests that a nano-cell or even a pico-cell structure must be adopted. It is almost impossible for 4G systems to provide nationwide coverage; only hot spot areas, such as business centers, shopping areas, airports, etc, with high multimedia traffic can be covered. In hot spot areas, data transport can be done almost instantly at speeds of 100M~1Gbps. In other areas, however, data transport can be done using conventional cellular systems. Due to the nano/pico-cell structure, propagation statistics are strongly influenced by microscopic structure of nearby propagation environments and dynamically change from cell to cell. 4G systems may need to be designed apart from the cellular concept that relies on the statistical properties of propagation channels.

One idea to cope with increasing path loss is to adopt virtual cell concept [11]. This is illustrated in Fig. 9. Each virtual cell consists of many distributed micro base stations. 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. Hence, the receive-only micro stations can be distributed in each virtual cell together with micro transmit & receive stations. 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 base stations with large transmit powers can be co-located with the 2G and 3G systems' base stations. Since coverage areas of virtual cells cannot overlap each other, close cooperation with 2G and 3G systems is necessary. The 3G cellular network will be the primary network, which can be overlaid with the above virtual cell networks in the hot spot areas. This requires inter-technology mobility management between the 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 to access both 3G and 4G systems.

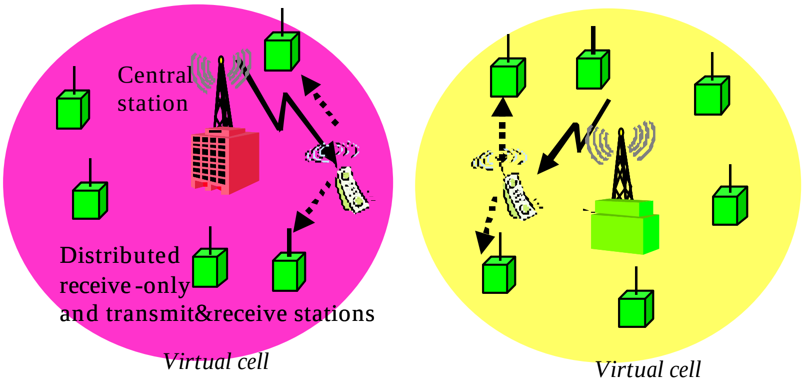


Fig. 9 Virtual cell.

4. CONCLUSION

4G systems will emerge around 2010; a major objective is to offer mobile users broadband multimedia services. In this paper, wireless technology was discussed and Giga-bit wireless and virtual cell concept were presented. The expected frequency bands will be above several GHz and data throughput over the air will be close to 1Gbps. There will be two approaches to realize Giga-bit wireless: from DS-CDMA and from MC-CDMA. Since wireless links are severely power-limited for such a Giga-bit wireless, adoption of the well-known and long-time used cellular concept may not be applied. Adoption of virtual cell concept that allows flexible installation of micro base stations may be a better solution. Before the realization of the wireless society, very difficult but interesting technical challenges are waiting for us.

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