IMT-2000 and Beyond IMT

- Radio Technologies toward Future Mobile Communications -

Fumio Watanabe, Ph. D.
KDD Corporation
3-2, Nishishinnjyuku 2, Shinjyuku-ku, Tokyo, Japan

Abstract

The field of mobile communications has continued to spread with astonishing speed in recent years. The expansion of mobile communications and the Internet has not only brought changes to communications services but also exerted huge effects on the economy and daily life. IMT-2000, International Mobile Telecommunications, is the next generation system for mobile communications systems currently being implemented. Standardization and development of IMT-2000 are in much progress under international frameworks to start commercial service by around the year 2001. This paper focuses in particular on radio transmission technology, giving an overall view of IMT-2000 standardization and technological status, as well as future technical directions extending beyond IMT-2000.

1. Introduction

The number of mobile communication subscribers worldwide reached approximately 430 million by the end of 1999. Even just in Japan, the number of subscribers is reaching 53 million and by the end of March of this year has exceeded the number of fixed telephone users. The first generation of systems in field of land mobile communications started out in the 1970's as car telephone systems using analog technology (Figure 1). The second generation of systems mainly in the 1990's centered on digital technology. System capacity drastically improved thanks to advances in digital technology and the use of hand-portable terminals spread at an explosive rate thanks to a compact size and low power consumption. The development and improvement of the second generation systems is still continuing.

Mobile communication continued to develop in first and second generation systems mainly in terms of voice communications. In recent years however, a trend has started towards "voice plus data" types of information services in mobile communications such as short message service, mail service, and Internet access service. An even greater variety of Internet type multimedia communications are expected to appear from hereon including images and video. However, the second generation systems still lack sufficient capability for providing full multimedia communications. There is also a rapidly approaching upper limit on the number of subscribers that can be taken in the system. These limits on performance and capacity are serving as a spur to develop and use a third generation of systems oriented towards the multimedia world.

This third generation of mobile communication systems is called IMT-2000 and work has proceeded for more than 10 years towards its development and standardization. Service is scheduled to start in Japan and other countries from the year 2001 onwards. With the implementation of IMT-2000 as a firm goal, research and development for mobile communications oriented towards the next generation beyond IMT-2000 is needed.

2. Standardization of IMT-2000 Radio Interfaces

2.1 Initiation

Studies on IMT-2000 were first started back in 1986 by the ITU (International Telecommunications Union) while the second generation of systems was still under development. Even at this time, in the digitized second generation systems, it was expected that different region around the world would have their own types of mutually incompatible systems, such as GSM in Europe, PDC in Japan and the USA systems, etc. So to achieve terminal mobility in

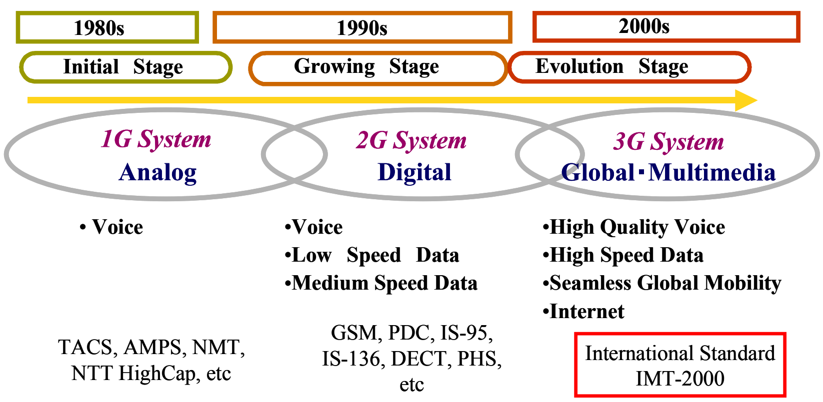

Fig. 1 Evolution of Mobile Communication System

communications essentially "able to communicate from your own mobile terminal anytime and anywhere", the need for standardization within an international framework was recognized. ITU-R (ITU Radio Sector) established an interim working party in 1986 to promote study of FPLMTS[1] (Future Public Land Mobile Telecommunications Systems) [1].

In order to develop a mobile communication system in which a terminal can be carried around and used anywhere in the world, a radio frequency band common in the world had to be defined. Preliminary calculations made by the ITU-R Study Group in 1990, mainly for voice and voice band data communications, advised obtaining spectrum band width of a 170 MHz for vehicles and 60 MHz for personal communication, or in other words a total of 230 MHz. World Administrative Radio Conference held in 1992 determined a frequency allocation for FPLMTS use of 230 MHz of the band from the 1885 MHz to 2025 MHz and from 2110 MHz to 2200 MHz from the year 2000 onwards. A portion of this 230 MHz was also assigned to mobile satellite communications.

Standardization of IMT-2000 as a third generation mobile communication systems had proceeded towards the following goals (Figure 2)[2]:

- capable of use throughout the world,
- providing high quality equivalent to fixed networks,
- capable of use in various radio environments (indoor to outdoor, urban to rural, walking to high-speed trains, etc.) having compatibility in terrestrial systems and satellite systems,
- providing a communications infrastructure not only for developed countries as well as developing countries,
- being capable of "roaming" so a user can use the same number across the world,
- capable of approximately 2 Mbits/s of data transmission in order to provide multimedia service not limited to just voice.

By following these guidelines, IMT-2000 can provide in principle, a global multimedia mobile communications service free of the "telephone-centered service" or "mobility limited service" of second generation systems.

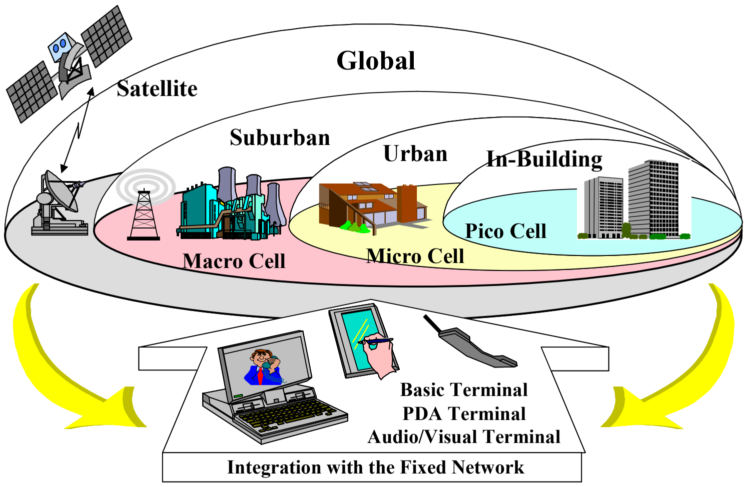

Fig. 2 Vision of IMT-2000

The concept of IMT-2000 of those days has the goal of achieving mobile communications compatible to the ISDN fixed network services. However, due to the explosive growth of the Internet, the outlook for IMT-2000 is shifting more toward a mobile Internet approach that stresses operations linked with the Internet.

2.2 Proposal and Evaluation

At the ITU a Recommendation [3] for "Guidelines for evaluation of radio transmission technologies for IMT-2000" was agreed to in April 1996. Various common conditions were established (such as propagation model, multi-path fading model, cell deployment model, traffic model, quality of service and grade of service) for evaluation of radio transmission technology (RTT) focusing on the four radio environments of indoor, pedestrian, vehicle, and satellite. Evaluation of RTT was implemented based on seven criteria, spectrum efficiency, coverage efficiency, technological complexity - effect on cost of installation and operation, quality, flexibility of radio technologies, implications for network interfaces, and hand-portable performance optimization capability.

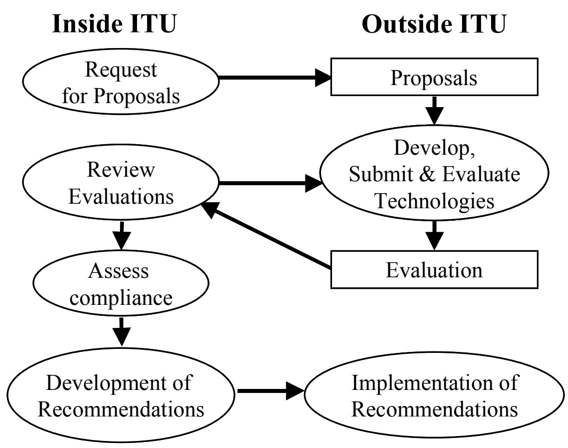

Fig. 3 ITU-R IMT-2000 Standardization Procedure

[1] ITU used the name 'FPLMTS' since 1986. However as work in standardization and system development took on a more real shape, the name was changed to IMT-2000 from 1996. The "2000" part of IMT-2000 implies to plans to implement the system around the year 2000, frequency use at 2000 MHz and a user information rate of 2000 kbits/s, etc.

The minimum performance capabilities necessary for providing the technology proposed as IMT-2000 were also agreed to. For instance, a data bit rate provided to a user should be greater than 2 Mbits/s for indoor office environments, 384 kbits/s for pedestrian environments, and 144 kbits/s for vehicular environments.

Implementing to finalize the Recommendation for detail specification of RTT was acknowledged as both indispensable and necessary from the point of view of efficiency not only within the ITU but also by cooperating with regional standardization organizations. A development process for an IMT-2000 RTT was agreed to under the assumption of cooperative action between the ITU and regional standardization organizations (Fig. 3). A standardization schedule establishing detail specifications of the radio system by the end of 1999 had been agreed to. In April 1997, ITU-R issued a circular letter to the worldwide requesting proposals for a radio system for IMT-2000 [4][5].

There were a total of ten proposals for terrestrial systems [6], of which eight utilized CDMA (code-division multiple access) as shown in Table 1. 14 evaluation groups registered to ITU evaluated those proposals, and they submitted evaluation reports in September 1998. At the ITU conference in November 1998, all the proposed RTTs were acknowledged as meeting the minimum performance conditions for IMT-2000 and it was agreed these would constitute the final candidates [7].

Table 1 IMT-2000 Terrestrial Proposals

Proposal	Description	Environment			Source
		Indoor	Pedestrian	Vehicular	
DECT	TDMA	X	X	-	ETSI DECT
UWC-136	TDMA	X	X	X	TIA TR45
WIMS W-CDMA	Wideband CDMA	X	X	X	TIA TR46
TD-SCDMA	TD Synchronous CDMA	X	X	X	CATT (Chaina)
W-CDMA	Wideband CDMA	X	X	X	ARIB (Japan)
Global CDMA II	Asynchronous DS-CDMA	X	X	X	TTA (Korea)
UTRA	Wideband CDMA (FDD), TD/CDMA (TDD)	X	X	X	ETSI SMG
WCDMA/NA	Wideband CDMA	X	X	X	ATIS T1P1
cdma2000	Wideband CDMA	X	X	X	TIA TR45
Global CDMA I	Synchronous DS-CDMA	X	X	X	TTA (Korea)

2.3 Harmonization Activities

One of the important objectives of IMT-2000 is to establish a global system allowing use a terminal throughout the world, so various activities such as conferences among standardization organizations and operations were held to unify and harmonize the systems. Two new organizations were started to help draft specification more efficiently. A joint project for drafting specification called the 3GPP (Third Generation Partnership Project) was founded in December 1998 as an effort among six standardization organizations constituted by ARIB/TTC (Japan), CWTS (China), ETSI (Europe), T1 (USA), and TTA (Korea). 3GPP makes its specification based on the enhancement of GSM core-network and the Japanese/European proposal UTRA/WCDMA as the radio transmission system. The ARIB/TTC, CWTS, TIA (USA), and TTA on the other hand, founded a project called 3GPP2 having the same nature as 3GPP in January 1999. This project utilized an enhancement of the USA ANSI-41 standards for the core-network, and the USA proposed cdma2000 as the radio system (see Figure 4). The regional standardization organizations participating to these 3GPPs activities promised to adopt the specifications agreed in 3GPPs as their own standard to ensure compatibility of standards of various participating organizations.

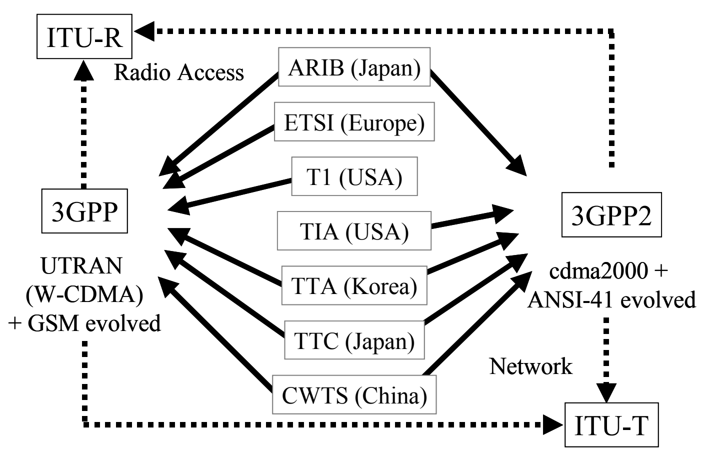

Fig. 4 3GPPs and ITU

From among the eight CDMA systems proposed to the ITU in June 1999, the Operator Harmonization Group (OHG) having the goal of further unification of CDMA systems, proposed a three mode concept consisting of DS (Direct Spread) CDMA, MC (Multi-carrier) CDMA and TDD (see Figure 5). OHG proposed the harmonized parameter of CDMA technologies. Proposed chip rate was 3.84 Mcps for DS-CDMA and TDD, and 3.6864 Mcps for

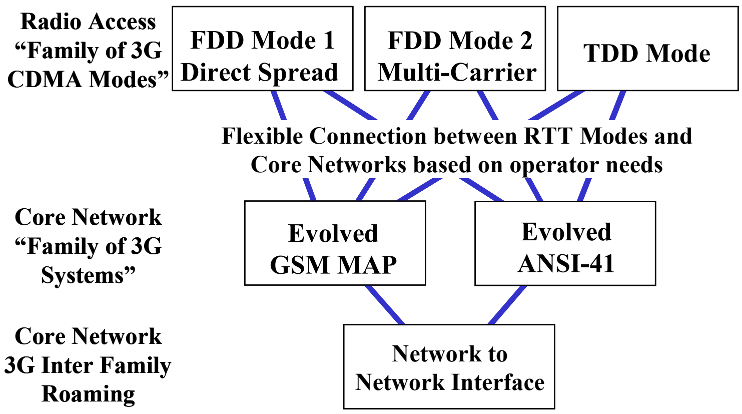

Fig. 5 Harmonization Concept

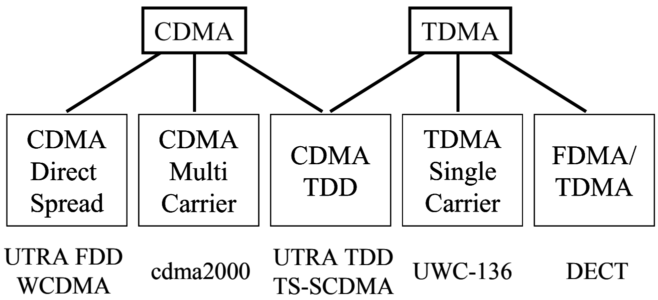

Fig. 6 IMT-200 Terrestrial Radio Interfaces

MC-CDMA in the case of a 5 MHz band. OHG also proposed additional functions such as connections to two different types of networks, GSM enhanced network and ANSI-41 enhanced network, in whatever mode of CDMA. The ITU, 3GPP and 3GPP2 all welcomed the OHG proposal and showed their support.

2.4 Recommendation for Radio Interface

In November 1999, the ITU agreed the Recommendation of 'Detailed Specifications of the Radio Interfaces of IMT-2000' comprised of the five terrestrial interfaces and the six satellite interfaces as shown in Figure 6, and officially approved in May 2000 [8]. Table 2 indicates major parameters of DS-CDMA and MC-CDMA interfaces. The Recommendation does not include contents of detail specifications, but it has a reference list hyper-linked to the standards established by external standardization organizations. This was the first time the ITU-R had approved such a format of Recommendation. Since the contents of the standards given as a reference are also a portion of the Recommendations, ITU member allowed to procure their entire contents even he is not a member of the external standardization organization.

As mentioned above in section 2.2, of the ten terrestrial systems proposed to the ITU, eight were based on CDMA technology. Also, of the five interfaces recommended by the ITU, three were based on wide-band CDMA technology. Clearly, CDMA technology is an extremely significant technology for IMT-2000.

Several reasons why CDMA technology was chosen are:
(i) higher capacity,
(ii) lower transmission power for mobile terminals,
(iii) less frequency management: frequency reuse pattern = 1,
(iv) soft and softer handover,
(v) inherent immunity to multipath,
(vi) flexible data service: variable data rate,
(vii) flexible QpS control,
(viii) dynamic resource allocation, and etc.

The main reasons for selecting the wide-band CDMA system which has a band width three to four times wider than the currently used cdmaOne system of 1.25 MHz bandwidth are (i) higher bit rate data service, (ii) improved multipath resolution; higher capacity, (iii) higher interference averaging effect, and etc.

In the wide-band CDMA technology, the path-diversity of the RAKE receiver, soft-handover or in other words, the site-diversity, and also the transmission power control play an extremely vital role. Wide-band CDMA would never have become possible without enormous efforts and results of researches on mobile propagation which allow predicting behavior of broadband signal in various mobile propagation environments, and especially methods such that allow estimating multi-path fading.

3. Beyond IMT-2000

Commercial service of IMT-2000 is scheduled to start in Japan and Europe from around the year 2001. Research and development of land mobile communications is tending towards expanded improvements of the IMT-2000 system, and focusing on systems following up on IMT-2000. This section will boldly describe future trends in land mobile communications over the ten-year span after IMT-2000.

3.1 An Analysis of IMT-2000

As mentioned previously, over 10 years were spent in standardizing of IMT-2000. The frequency band for use was procured in 1992. Previously existing radio systems should be moved to clean up the radio spectrum in order for the IMT-2000 system to make use of the selected portion of the spectrum, so the fact that ten years were required to obtain commercial use of that frequency band is perhaps only natural. USA instead assigned a portion of the radio spectrum planed for IMT-2000 for PCS usage from 1996 onwards. Although this makes it difficult to obtain a worldwide common band for IMT-2000, it is quite natural that each administration has to deal with its own particular circumstances and requirements when using the radio spectrum.

The basic concepts and essential requirements for IMT-2000 were decided upon in 1994. The main concept until then was "to provide mobile ISDN service", since this period was prior to the amazing boom of the Internet. The rapid expansion of the Internet brought about social and cultural changes as well as economic effects, amounting to a kind of communications revolution. To keep pace, commercial IMT-2000 is making a rapid shift to operations linked with the Internet, and a vital goal now is "to provide mobile Internet service".

IMT-2000 was planned with the goal of providing all types of mobile communications in an integrated nature as the next generation mobile communications. System goals included mobile communications over a wide range of requirements and various radio environments ranging from voice to high speed data service at 2 Mbits/s, circuit switched service and packet switched service, real-time service and non-real time service, and indoor to high speed vehicular environments. The key to attaining a radio transmission technology capable of handling such a wide range of requirements is wide band CDMA that offers excellent versatility and flexibility.

There are several reasons why IMT-2000 was designed to play a center role as an integrated system incorporating a wide range of conditions.

- Flexibility is needed to deal with an unpredictable, fluctuating market.
- Customers want to carry just one terminal.
- Existing operations take most of their profits by voice service and have been unconfident of mobile multimedia market.
- Systems specializing in mobile data communications have failed in the past.
- Existing operators are being drawing into the existing 'legacy' network.

3.2 Position of "Beyond IMT-2000"

IMT-2000 can be considered the "department store of mobile communications" as an integrated system providing a wide range of service. By contrast with this interpretation the conclusion of this paper is that future years will bring a "shopping mall type" or a cluster of mobile communications. "Beyond IMT-2000" will perhaps be a cellular layer system within that cluster.

One interpretation to the various positions of mobile communication systems is shown in Figure 7. IMT-2000 will provide low mobility through high mobility communications at their various respective data transmission rates. Though limited to low mobility and quasi-static status, broadband radio access systems such as MMAC and BRAN have a higher speed data transmission capability 10 times greater than IMT-2000. The successor to the third generation of system will probably be a fourth generation system combining the high speed mobility of IMT-2000 with the high speed data transmission capability of MMAC/BRAN. The author though, assumes the slightly different scenario as shown in Figure 8. Though IMT-2000 was planned to provide indoor office environment services, it is certainly not the best communications tool for an indoor office environment. The true value of IMT-2000 appears most in hand-portable communications where IMT-2000 has a continuous and dense coverage area. Systems such as MMAC and BRAN having poor area coverage density show off their true value in high

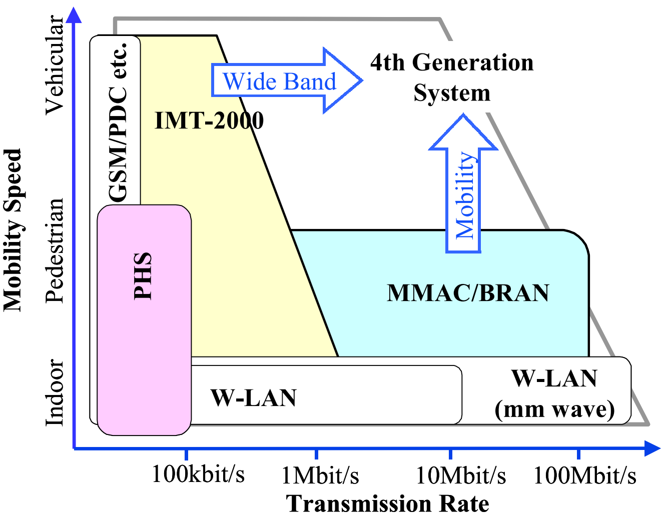

Fig. 7 Various radio Systems and "4th Generation"

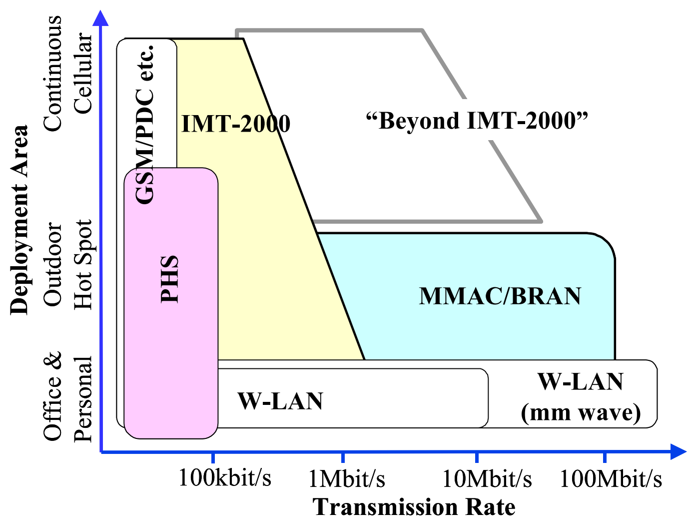

Fig. 8 Target of "Beyond IMT-2000"

speed data transmission services in hot spot zones. Future of mobile communications would not direct the concept of the almighty fourth generation of system if considered in this way. Up until now a clear step was drawn indicating the system generation such as IMT-2000, which is called the third generation, but the clear generation step may disappear as shown in Figure 8. So the term "fourth generation of mobile communications systems" may not be an appropriate title.

Mobile communications with the clustered configuration will have a radio network structure consisting of scaleable layers, and mobility management will be performed for the user and terminal across the various radio systems. This will allows delivery of seamless and gap-free services utilizing various types of radio systems. A concept view of the layered structure of the mobile communications system is shown in Figure 9. Here, a variety of mobile systems will be linked together, with IMT-2000 and 'Beyond IMT' for continuous area coverage, DSRC (Dedicated Short Range Communication) for development along roads, MMAC/BRAN for providing high speed communications in hot spot areas, and wireless LAN including Bluetooth for indoor office and home environments. What should be noted is that these layers are not divided according to mobility speed but rather the type of service coverage or in other words, differences how deploy base stations.

Figure 10 is an image showing the network structure for the concept view in Figure 9. Here, different radio access networks (RAN) are connected on a shared core network. Typically, a 'stupid' core network serves as the high speed transmission network and all types of services are implemented not in the core network but as service nodes. Terminal mobility management or user mobility management is performed that spans across many RAN. The various types of services and contents are used along jointly shared RAN, so that the user can take advantage of seamless type services without being consciously aware of these RANs. If desired by the users, the same contents can be provided in different formats by means of a transcoder according to user preferences (for instance, users wanting high quality, or low cost), terminal capability (for example, size of display) and of course according to the capability of RAN (see Figure 11).

3.3 Technology for Beyond IMT-2000

In the system of Figure 10, services that can be provided are determined mainly by the capabilities

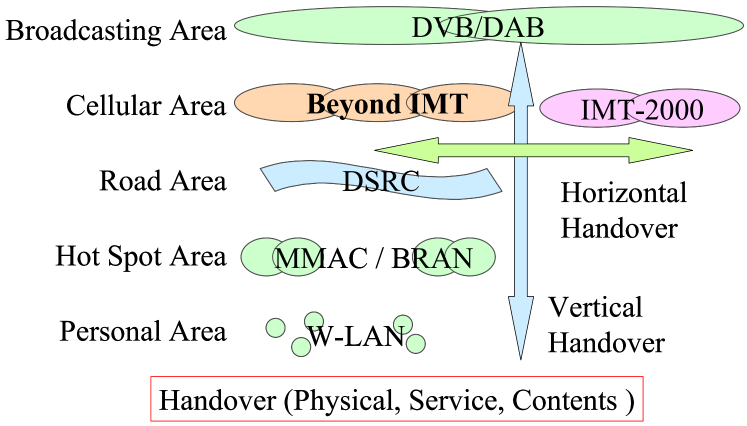

Fig. 9 Hierarchical mobile systems

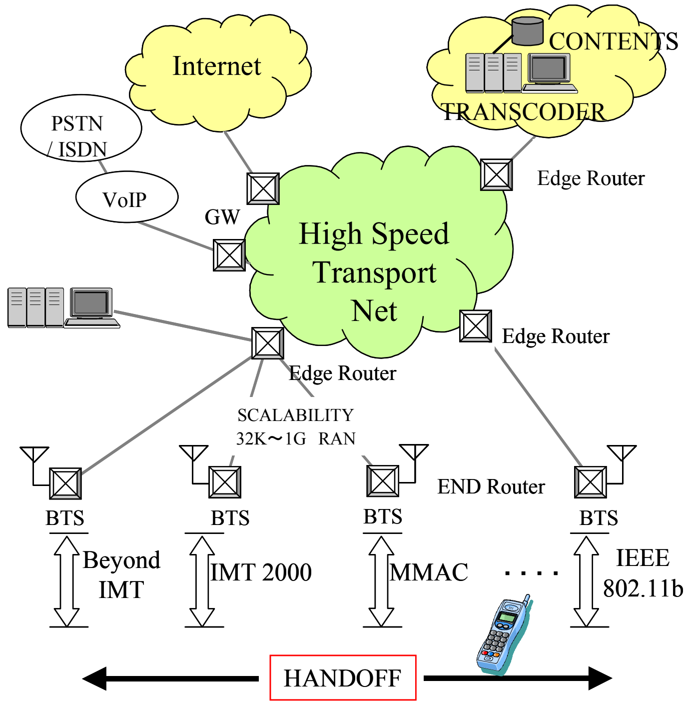

Fig. 10 Seamless Mobile Network

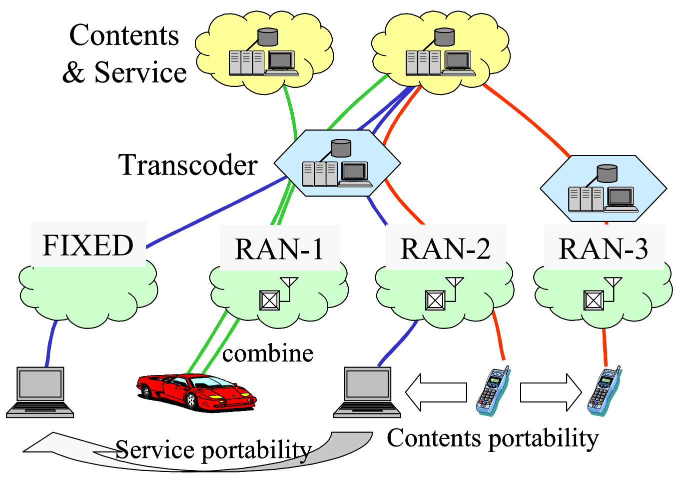

Fig. 11 Contents Transfer and Service Portability

of the terminal and the service node. The mechanism for providing a service and its contents must be configured independently to the core network and the RAN. The core network and RAN must be kept as nearly "transparent" to the service as possible. This means that the terminal must have a high range of functions and multi-band and multi-mode terminals are indispensable. In other words a "re-configurable" type terminal is essential to achieve the clustered mobile system. A so-called 'Software Radio' incorporating technology such as software defined signal processing, flexible and adaptive RF front-end, link adaptation technique will prove the key to achieving such a terminal.

ITU's World Radiocommunication Conference 2000 (WRC'00) held in Istanbul May 2000 agreed to allocate new spectrum as possible extension band for IMT-2000. The additional bands identified for the terrestrial component of IMT-2000 are: 806-960 MHz, 1710-1885 MHz and 2500-2690 MHz. It does not preclude the use of these bands for other types of mobile applications or by other services to which these bands are allocated. Administrations will be able to develop their own transition plans and best migration path tailored to meet their specific conditions and market demands. While the decision of the Conference includes uncertainty of the globally common usage of the spectrum, each country will decide on the timing of availability of the particular spectrum at the national level according to need. The agreement of WRC'00 on additional spectrum for IMT-2000 also hints at the importance of research and development of multi-band terminals.

What form the radio system following up on IMT-2000 such as 'Beyond IMT-2000' with its cellular layer will take are not known, but the author envisions the following features based on the above mentioned "shopping mall type" concept.

- Optimized design for a continuous and dense coverage area not for a hot spot area.
- Higher transmission data rate (e.g. 10 Mbits/s)
- Elimination of variety of transmission rates (e.g. concentration on short burst packet transmission)
- Increased variety in transmission delays
- Non-uniform throughput within the coverage area
- Connection-less
- No diversity handover
- Asymmetrical uplinks and downlinks
- Efficient use of the spectrum not dependent on traffic density of each cell

Since 'Beyond IMT-2000' will have high speed data transmission capability, it will handle the wider-band signals than IMT-2000. What frequency band will be available for use is not clear but it could be a higher frequency band. Propagation losses and multipaths will of course increase, leading to increased output power. This will cause problems in terms of compact mobile terminals and battery life. An increased power output from these terminals is not desirable because of the effects on human beings. Technologies should be developed to meet demands for larger capacity, high speed communications, reduction of transmit power and reduction of cost.

Among the research and development targets regarded as indispensable for achieving a radio transmission system of the 'Beyond IMT-2000', particularly important topics relating to antenna and propagation technologies are listed below.

- Adaptive signal processing antenna for base stations
- Multi-spot beam antenna
- Adaptive antennas for mobile terminals
- Re-configurable software radio
- Flexible and adaptive RF frontend
- Software defined signal processing
- High speed and low power consumption DSP
- Super conductive amplifier and filters
- Terminal synchronization technology
- Link adaptation technologies
- Propagation path prediction technology for link adaptation
- High precision propagation path prediction technology applicable to wide-band, short burst transmissions

4. Summary

The paper overviews the concepts and the state of international standardization of the third generation mobile communications systems "IMT-2000" scheduled to start in the world from the year 2001 onwards mainly focusing on radio transmission technology. Nearly ten years have passed since frequency band allocation and basic concepts for IMT-2000 were established. Though a first version of the international standards is in place, faced with rapid change of market demands, the future appears certain to bring periodic modifications and improvements to these standards.

Studies of all aspects of a 'fourth generation system' to follow up on IMT-2000 have begun amidst commercial IMT-2000 services next year. The typical image of a fourth generation system is to provide higher bit rate than IMT-2000 at every possible ranging from indoor office environment to high speed vehicular environment. This paper, however, discussed another typical scenario of future mobile communications, from the standpoint that clear divisions marking the generation of a system such as a fourth generation system will not appear in the future. The paper further suggests that different radio access networks such as IMT-2000 effective in wide and continuous coverage area, MMAC/BRAN like system effective in hot spot areas, and wireless LAN for indoor environments will be connected to 'stupid core network' seamlessly and future mobile communications will provide seamless services to the user by combination of those clustered radio systems. The follow-up to IMT-2000 here called 'Beyond IMT-2000', which is a part of the clustered mobile system, will provide a cellular type continuous service area. Technical trends toward 'Beyond IMT-2000' were also described.

A tremendous amount of research and technical breakthroughs are needed to achieve the goals of 'Beyond IMT-2000'. Researches on antennas and propagation field will be a key element to achieving future. Hopefully, the paper contained some useful hints for future directions.

References

[1] M. Callendar, "IMT-2000 Standards Efforts of ITU", IEEE Personal Communications, Vol. 4, No. 4, pp. 6-7, August 1997

[2] K. Buchanan et al., "IMT-2000: Service Provider's Perspective", IEEE Personal Communications, Vol. 4, No. 4, pp. 7-13, August 1997

[3] Recommendation ITU-R M.1225, "Guidelines for evaluation of radio transmission technologies for IMT-2000'

[4] ITU-R BR Circular Letter 8/LCCE/47, "Request for Submission of Candidate Radio Transmission Technologies (RTTs) for IMT-2000/FPLMTS Radio Interface", 4 April 1997

[5] R. Carsello et al., "IMT-2000 Standards: Radio Aspects", IEEE Personal Communications, Vol. 4, No. 4, pp. 30-40, August 1997

[6] A. Sasaki et al., "Standardization Activities on FPLMTS Radio Transmission Technology in Japan", IEICE Trans. Fundamentals, Vol. E79-A, No. 12, pp. 1938-1947, Dec. 1996

[7] S. Okasaka, Y. Furuya and F. Watanabe, "Radio transmission technology for IMT-2000", IEICE, Vol. 82, No. 2, pp. 123-130, Feb. 1999

[8] Recommendation ITU-R M.1457, "Detailed Specifications of the Radio Interfaces of IMT-2000

Table 2 Major Parameters of DS-CDMA and MC-CDMA

Major Parametors	DS-CDMA	MC-CDMA
Multiple Access Technique	CDMA	CDMA
Duplexing Scheme	FDD	FDD
Chip rate	3.84 Mcps	N × 1.2288 Mcps (Currently N = 1 and 3 is specified, and N can be easily extended to N = 6, 9, 12)
Frame Length	10 ms	5, 10, 20, 40, 80 ms
Inter Base Station Operation	Asynchronous Synchronous (Optional)	Synchronous operation is required.
Pilot Structure	(UL) Dedicated pilots (DL) Common and/or dedicated pilots	(UL) Code division dedicated pilot (DL) Code division common pilot (DL) Code division common or dedicated auxiliary pilot
Modulation	Spreading: QPSK	Spreading: (UL) HPSK (DL) QPSK Data: BPSK, QPSK
Channelization Code	Orthogonal Variable Spreading Factor (OVSF) codes	(UL) Walsh codes and Long codes (DL) Walsh codes or quasi-orthogonal codes
Spreading Code	Gold codes	Long code and Short PN code
Channel Coding	Convolutional coding with K=9, R=1/2 or 1/3 Turbo coding with K=8, R=1/3 No channel coding	Convolutional code with K=9, R=1/2, 1/3, 1/4, or 1/6; Turbo code with K=4, R=1/2, 1/3, or 1/4.
Uplink Power Control	Closed loop (1500 Hz update) Power control steps: 1 dB, 2 dB	Open loop Closed loop (800 Hz or 50 Hz update) Power control steps: 1.0, 0.5, 0.25 dB