REPORT ITU-R M.2063

Software defined radio in IMT-2000, the future development of IMT-2000 and systems beyond IMT-2000

(2005)

1 Introduction

International Mobile Telecommunications-2000 (IMT-2000) systems are third generation mobile systems, which provide access to a wide range of telecommunication services, supported by the fixed telecommunication networks (e.g. PSTN/ISDN/IP), and to other services, which are specific to mobile users.

Key features of IMT-2000 are:

– high degree of commonality of design worldwide;
– compatibility of services within IMT-2000 and with the fixed networks;
– high quality;
– small terminal suitable for worldwide use;
– worldwide roaming capability;
– high-speed data;
– capability for multimedia applications within a wide range of services and terminals.

The capabilities of IMT-2000 systems are being continuously enhanced in line with market and technology trends.

The specifications for the initial releases of IMT-2000, which are defined in Recommendation ITU-R M.1457, have been completed, and the commercial deployment of IMT-2000 has begun.

Radio functionality previously confined to fixed hardware implementations continues to migrate to software running on processors, e.g. by use of software defined radio (SDR). This technological evolution of the increasing use of software may have a significant impact on the future development of IMT-2000 and systems beyond IMT-2000.

Software defined radio: A radio in which the RF operating parameters including, but not limited to, frequency range, modulation type, or output power can be set or altered by software, and/or the technique by which this is achieved.[1]

In its most basic form, SDR may be viewed simply as an implementation technique in which signal processing hardware is replaced by programmable devices such as digital signal processors or field programmable gate arrays (FPGA). In the broader perspective, software defined radio is a collection of hardware and software technologies that enable reconfigurable wireless infrastructure and user terminals. It is an enabling technology that is applicable across a wide range of areas within the wireless industry.

This Report addresses the potential implications of SDR on the future development of IMT-2000 and systems beyond IMT-2000. It addresses radio network and terminal issues and describes high-level technical aspects such as the latest areas of research and the state of technology development. Market developments and other aspects are also considered. It documents existing activity in these and related areas and correlates these to IMT-2000.

SDRs may ease the frequency allocation process, but are not anticipated in the foreseeable future to reduce the need for harmonized or "quasi-harmonized" frequency arrangements.

Many aspects of SDR, including detailed technical specifications for software download to wireless devices, are being developed by other organizations such as standard development organizations, universities, and industry organizations, and with partnership projects, forums, consortia, and research collaborations. The ITU has cooperative agreements with many of these organizations and

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[1] See definition and notes in § 4.

is seeking to enhance these synergistic working relationships. This Report does not seek to duplicate this work but makes appropriate references to these external activities.

In addition to the standards of the IMT-2000 family, there is a trend of integrating more and more standards like Bluetooth, IEEE 802.11, GPS, DVB and DAB into terminals. SDR is not specific to IMT-2000 or cellular architectures. SDR technology will be equally applicable for all existing and future wireless systems.

2 Scope

This Report addresses primarily the increasing use and implementation of software in a radio network and terminal for the future development of IMT-2000 and systems beyond IMT-2000.

It describes high-level technical aspects such as the latest areas of research and the state of technology development. Market aspects are also considered.

It documents existing activity in these and related areas and correlates it to IMT-2000.

The primary focus is on the terrestrial component of IMT-2000 and systems beyond IMT-2000; special considerations for the satellite component are not explicitly addressed.

The requirements from, and application to, the land mobile service in general are covered in a separate report (Report ITU-R M.2064).

3 Related Recommendations

ITU-R F.1399	Vocabulary of terms for wireless access
ITU-R M.687	International Mobile Telecommunications-2000 (IMT-2000)
ITU-R M.1035	Framework for the radio interface(s) and radio sub-system functionality for International Mobile Telecommunications-2000 (IMT-2000)
ITU-R M.1036	Frequency arrangements for implementation of the terrestrial component of International Mobile Telecommunications-2000 (IMT-2000) in the bands 806-960 MHz, 1 710-2 025 MHz, 2 110-2 200 MHz and 2 500-2 690 MHz
ITU-R M.1073	Digital cellular land mobile telecommunications systems
ITU-R M.1450	Characteristics of broadband radio local area networks
ITU-R M.1457	Detailed specifications of the radio interfaces of International Mobile Telecommunications-2000 (IMT-2000)
ITU-R M.1579	Global circulation of IMT-2000 terminals
ITU-R M.1580	Generic unwanted emission characteristics of base stations using the terrestrial radio interfaces of IMT-2000
ITU-R M.1581	Generic unwanted emission characteristics of mobile stations using the terrestrial radio interfaces of IMT-2000
ITU-R M.1645	Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000
ITU-R M.1652	Dynamic frequency selection (DFS) in wireless access systems including radio local area networks for the purpose of protecting the radiodetermination service in the 5 GHz band

4 Definitions

In addition to a definition of software defined radio, IMT-2000-specific definitions on have been developed and agreed.

Software defined radio: A radio in which the RF operating parameters including but not limited to frequency range, modulation type, or output power can be set or altered by software, and/or the technique by which this is achieved.

NOTE 1 – Excludes changes to operating parameters, which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard.

NOTE 2 – SDR is an implementation technique applicable to many radio technologies and standards.

NOTE 3 – Within the mobile service, SDR techniques are applicable to both transmitters and receivers.

IMT-2000 radio: A radio that operates according to one or more of the IMT-2000 radio standards defined in Recommendation ITU-R M.1457,

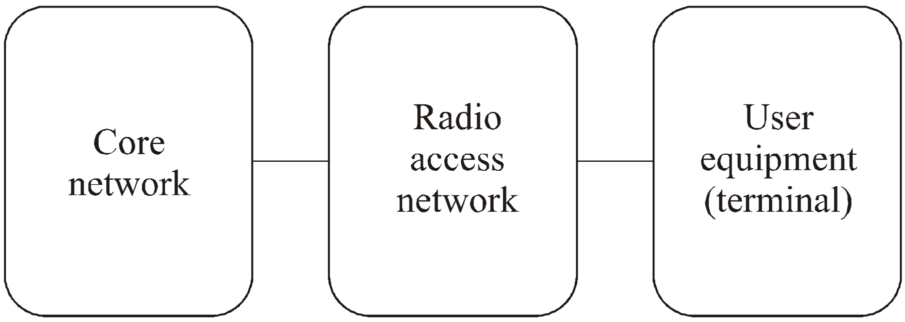
Systems beyond IMT-2000 radio: A radio that operates according to standards subsequently developed for systems beyond IMT-2000.

5 Application of SDR to future developments of IMT-2000 and systems beyond IMT-2000

Recommendation ITU-R M.1035 deals with the concept of IMT-2000, including core elements and radio interface characteristics, and is a useful guideline for this section. Looking at an IMT-2000 system architecture from a principle point a view, the following sub-systems can be identified, as in Fig. 1:

FIGURE 1

Principle system architecture of an IMT-2000 system



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SDR will have some impact on these sub-systems and on the interworking between them.

– In particular the user equipment (terminals) and their network interface are most affected since the different standards have to be implemented in the terminal. Implementation of the various IMT-2000 radio interface standards leads to different technical requirements in regard to the terminal capabilities e.g. storage capacities, computing power and power consumption. The main target for introducing SDR technology into the base station and its controllers of a mobile radio access network (RAN) is to increase flexibility of radio access networks.

Moving the reprogrammable elements as close to the front-end as possible allows introduction of very flexible platforms that can be (re)configured by software for different air interface standards and multiple frequency bands.

The use of SDR potentially enables the base station to be "reconfigured" which could include a change of functionality, for instance changing from one IMT-2000 radio access technology to another, as well as the partial modification or update of certain aspects of a radio access technology, such as the introduction of an optional capability or a new version.

Terminal reconfiguration favours worldwide roaming and interoperability, because, ideally, one single terminal might be reconfigured to employ any radio access technology and/or access differing frequency bands. Likewise, it enables the separation of services offered to the user, and the technology used to provide them. It also makes the correction of software errors easier and more effective, as the physical need for recalling defective terminals is substantially reduced or eliminated through software based changes.

5.1 User benefits

Modern high-performance mobile terminals are becoming more and more complex due to an increase in terminal capabilities and an increased amount of software (application as well as operational software). For the user, SDR terminals that can be upgraded or enhanced in their capabilities at a later date may be a great benefit and a criterion for buying. In the long-term the user's terminal will be upgradable or reconfigurable via download over the air.

Implementation of an SDR base station and terminals may bring benefits for the user such as improved roaming and interoperability.

5.2 Manufacturer benefits

Some driving forces behind the developments towards SDR are reduction of time-to-market of devices, reduction of development and manufacturing costs, wider market access and multi-standard capability.

For the terminal manufacturers SDR offers the possibility of using one and the same terminal platform for different applications. In particular manufacturers can start the development of terminals at an earlier stage in the development of the standard. Ideally, adoptions of changes to standards can easily be performed without modifying hardware components.

In addition to the standards of the IMT-2000 family, there is a trend of integrating more and more standards like Bluetooth, IEEE 802.11, GPS, DVB and DAB into future terminals. SDR technology may facilitate this integration of existing and future standards.

6 Software download

Software download of air-interfaces or radio standards, in particular over the air, is one of the most important SDR topics as already mentioned above. The download of application software is not included within SDR, as that software does not directly relate to radio regulation. The download of radio software is not really a new topic in mobile phones. Due to the complexity and rapid evolution of standards, a program code is kept in non-volatile memory and can, probably in the majority of the devices currently on the market, be reloaded or modified after manufacturing. Security mechanisms such as signed code (digital signature) are needed. It is probably in the interest of the industry to standardize this aspect up to the extent that "due diligence" in this area is clearly defined (especially relevant for horizontal market models). Since progress is also expected for security solutions, it does not make much sense to prescribe details in advance. If an adequate level of security is assured, the method, medium and time of software download should not be of any concern from a regulatory point of view.

In the context of software download, it might be useful to distinguish between downloads of code and download of air-interface parameters.

– Download of code may be defined as the download of the complete executable code, parameters, standard description, etc. which implements a certain air-interface standard or serves as the update or replacement of some of its modules. This feature is useful and will be extended within the next few years so as to allow for upgrades of device capabilities. A user may, for instance, buy support for a newer version of a standard or for an additional standard. A European customer may want to upgrade his device for use in the United States of America, or vice versa, by adding new software. Operators may distribute upgrades of original manufacturer software. A variety of methods and media can be employed to this end, ranging from memory cards, CD-ROM and Internet or over-the-air download.
– Download of air-interface parameters may be defined as the selection from pre-defined operational modes or the re-parameterization of functionality, relating, e.g., to transmit frequency, power, modulation, burst structure, encoding, timing, certain aspects of the protocol, etc., which can be described by parameters or templates. This does not in general require the exchange of executable code. Only a concise set of well-defined and easily standardized parameters or descriptive information has to be transmitted.

In general, the radio links, download and reconfiguration management and maintenance for a terminal can be either more user-controlled or network-controlled. Potential upgrades for a terminal should be managed by the network, service provider and/or manufacturer based on a clear split of responsibilities.

6.1 Security aspects

An essential aspect for the acceptance and the success of the SDR concept is the security aspect. It has to be ensured that neither the radio functionality of an SDR terminal or base station is altered unintentionally nor that unauthorized sources have access to SDR-related components. As pointed out before, a secure configuration/reconfiguration of the terminals is seen to be feasible by cooperation of the involved parties.

Nonetheless, aspects of rollback mechanisms and fault management have to be considered and developed. Regarding rollback mechanisms, it has to be ensured that after incomplete or faulty download of a new standard the terminal can switch back to a safe starting position.

As stated in § 9, different organizations outside the ITU, are currently working on secure software download aspects since it is and it will become an important topic for telecommunication devices. Since this aspect is essential and vital for all involved parties, sophisticated solutions for secure download mechanisms will be provided by the industry.

Accordingly, there are technical study items regarding the assurance of security. These are examples of such study items that may facilitate secure operation:

– how to assure integrity of the software, and how to prevent malicious software (malware) such as Trojan horses and computer viruses from being installed by hackers;
– how to protect private information;
– how to authenticate the identity of individuals intending to install software;
– how to identify the consistency between terminal and software;
– how to recover from a failure of installation.

When a number of systems are installed in a terminal, there are study items regarding terminal addressing and user management:

– whether every system has different addresses for identification;

– how to manage the address resource and how to avoid duplication of addresses and shortage of the address resource;

– how operators gather information about the the system which is installed on a terminal to use their services.

It is noted that the output of Standardization Study Group 17 on security aspectsare relevant to this.

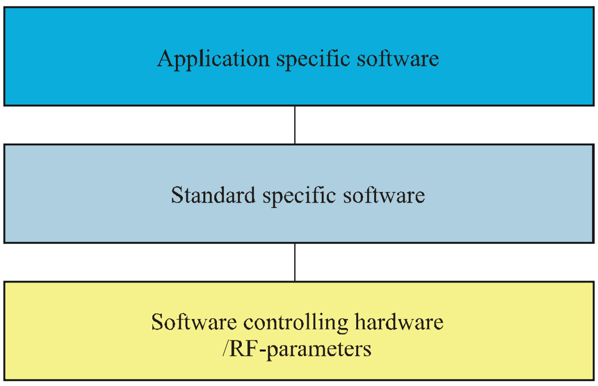
7 Deployment considerations

7.1 Vertical, horizontal industry models

The aspect of software download will play an important role for SDR technology, therefore, a differentiation of the diverse types of software might be useful for the discussion. Figure 2 shows a possible (rough) graduation of software present in SDR terminals or base stations. As will be explained in more detail subsequently in the document, a distinction has to be made between software that has influence on or controls RF/air-interface parameters and software that has no influence on such parameters. Only radio-related software needs further consideration.

FIGURE 2

Schematic of different types of software present in an SDR terminal or base station



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Due to the complexity of technology and due to security aspects there might be a stepwise SDR market evolution. In a first step the vertical model seems to be a near-term industry model. Here "vertical" means that all hardware and software components are under responsibility of only one entity (e.g. via contracts or certification processes) which is responsible for the conformity and faultless functioning of both. This well-defined responsibility ensures that the devices will operate within the given regulatory limits.

In a horizontal model the situation is more complex since many different independent companies will develop and offer SDR hardware and/or software components based on open interfaces. A close cooperation of all involved parties is a prerequisite for a successful SDR market evolution. In particular, mechanisms have to be elaborated to ensure that the hardware of company X is compliant with the software of company Y. Before new software or hardware components are offered to the market these components have to pass through validation processes and have to perform test cycles successfully. It sounds reasonable that this validation process can be performed by the involved industry players self-dependently. Special security mechanisms may have to be applied to reduce the risk of unintended or criminal modification of radio functionality. For instance by using appropriate security processes, adequate safeguards from software manufacturers can be installed on hardware platforms, which can be used by those concerned to verify that the downloaded and encrypted software modules originate from the original software manufacturers.

It is of vital interest to software and hardware manufacturers to ensure that functional products will be offered. Due to this fact many industry players are already working on suitable and powerful solutions in different organizations and projects to develop secure software download mechanisms (see e.g. SDR Forum or European Projects like TRUST, SCOUT and E2R). These secure download mechanisms are not a special feature of SDR, but are and will become more important for other technologies.

7.2 Timing and dependencies (business, technical)

The introduction of SDR technology will take place in different phases. Among other things, it will depend on the evolution of suitable and powerful hardware components like the base band processing unit, tuneable front-end filter and antenna systems. A high-performance and marketable SDR technology will also depend on the commercial availability of suitable software, compliant with the particular hardware. At present and in the near future, layer 1 software is strongly related to the specific hardware chips which means that the chip manufacturers normally offer suitable layer 1 software for the chips. In the long term it is conceivable that chip manufacturers will offer a standardized high-level description of the hardware so that other companies can offer suitable layer 1 software. In contrast to the layer 1, a variety of commercially available higher layers, e.g. transport and network protocols (radio resource control, TCP/IP stacks, etc) may appear sooner.

8 Technology aspects

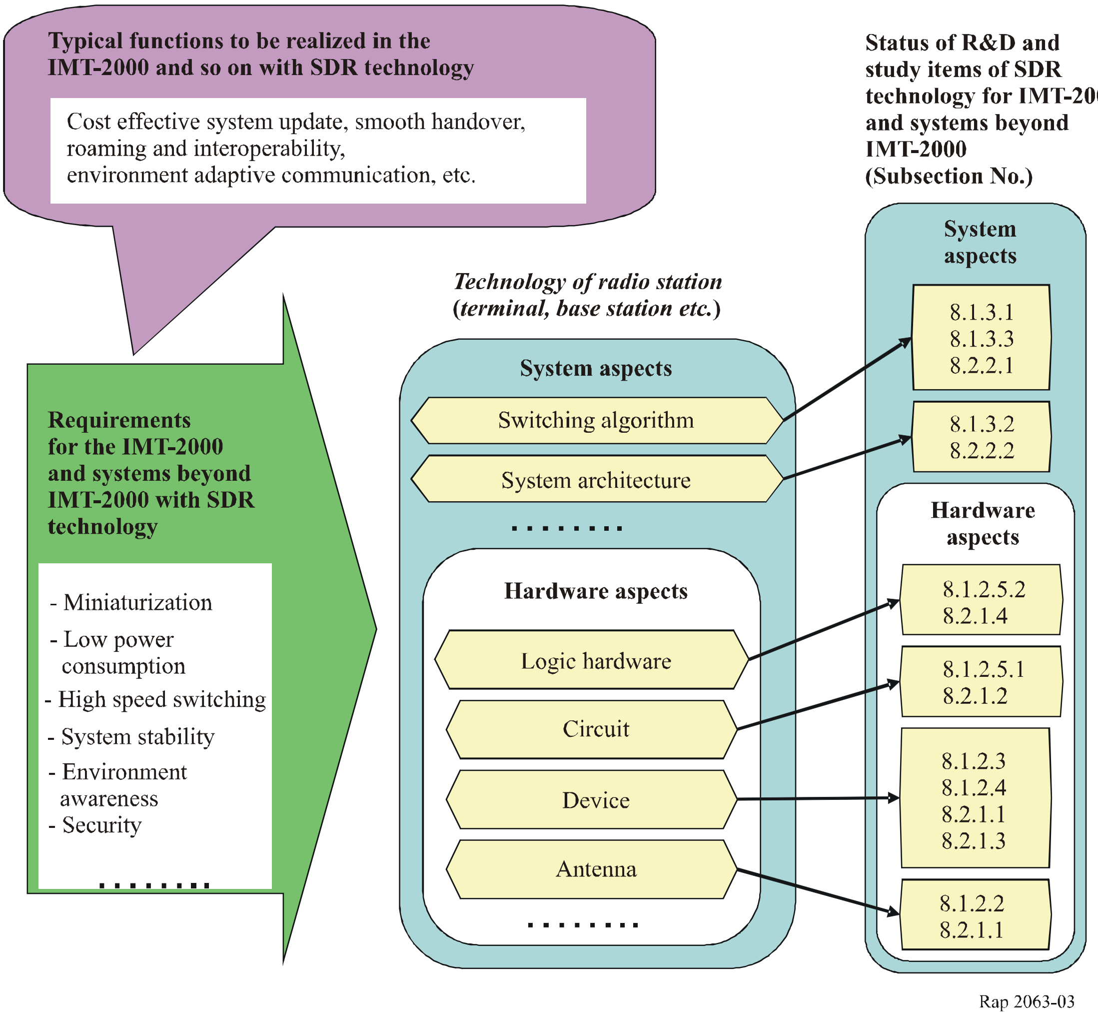
IMT-2000 and systems beyond IMT-2000 may demand an extremely wide diversity of functionality and spectral flexibility and may technically stretch the SDR technology to the limits of scientific knowledge.

As shown in Fig. 3, system update, smooth handover, roaming, interoperability, high speed switching, miniaturization, and low power consumption are important areas in which SDR may be a means to realize cost effectiveness.

This section describes how SDR might satisfy such requirements and consists of the present status of R&D and study items of related technologies to be developed in the future.

FIGURE 3

System and hardware aspects of SDR's impact on system requirements for IMT-2000 and systems beyond IMT-2000



8.1 Status of R&D

There are several technologies that can contribute to the increasing realization of SDR's potential especially for IMT-2000. The R&D status of these technologies categorized into the aspects of hardware and system are given below.

It is envisaged that the use of SDR in commercial wireless communications systems such as IMT-2000 and systems beyond IMT-2000 will develop gradually as hardware, software and cost-tradeoffs mature.

8.1.1 Hardware aspects

8.1.1.1 Hardware overview

Looking at an SDR terminal from a basic architecture point of view the following figure can be drawn.

FIGURE 4

Basic architecture of SDR

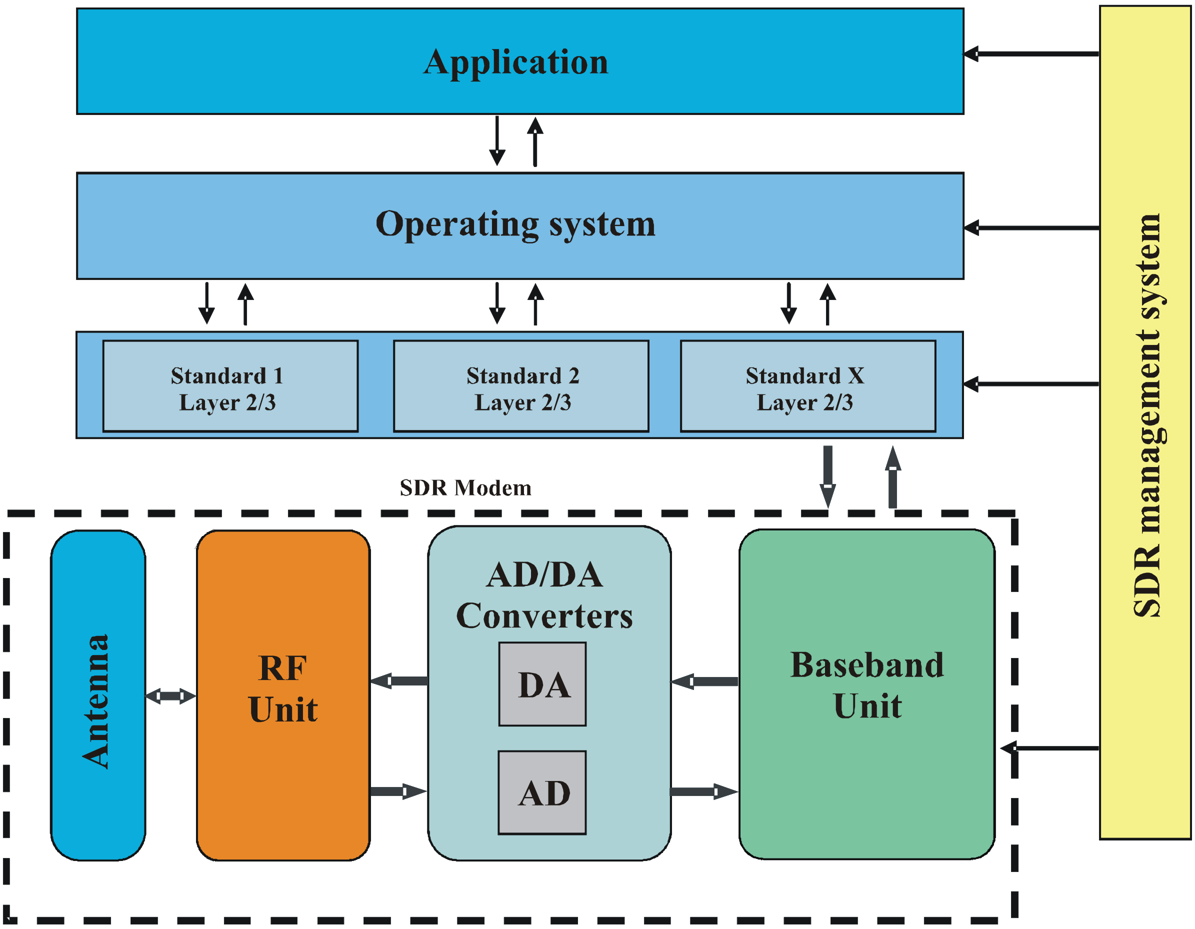


Figure 4 shows the functional SDR hardware elements baseband unit (BBU), "AD/DA converter unit", "RF-unit (RFU)" and the antenna system.

Within the RF-unit the receiver, transmitter and the front-end unit are included.

The RFU may perform the frequency down-/up-conversion etc., for the frequency range needed to support the future development of IMT-2000 and systems beyond IMT-2000. The BBU performs several functions such as high-speed signal processing (sampling rate conversion, filtering, etc.), modulation/demodulation for each system, transmission control, and modem control (reconfiguration function).

These hardware elements are standard independent, i.e. almost any air interface standard can be processed after the download of the respective software. The responsible entity for the proper and faultless implementation of a standard is the SDR management system. It is the central software component for SDR devices and has terminal-wide control of the SDR procedures, reconfigurations and transactions. This includes the device reconfiguration as well as management of the terminal resources. It also provides a high-level control interface for mode switching. The SDR management system has an interface to the BBU.

8.1.1.2 Aspects of antenna systems

Future antenna systems are expected to support a wide range of frequencies. A small size antenna achieving wide bandwidth is essential to realize different radio access technologies in different bands in hardware, while it is challenging since the small size and wide bandwidth could contradict each other.

Furthermore, the antenna system should be capable of supporting parallel reception and transmission of different radio bands, where an optimum beamforming algorithm and a multi-user detection algorithm are essential. At present there are many research and development activities ongoing.

8.1.1.3 RFU

In applying SDR to the future development of IMT-2000 and systems beyond IMT-2000, in order to correspond to multi-band/multi-mode communication systems, selecting an RFU architecture suitable for SDR is very important. Moreover, circuits such as amplifiers and mixers that compose an RFU are required to have a broadband characteristic. Filters for reducing interference from other communications systems need to vary their pass band corresponding to the frequency of a received signal.

8.1.1.4 AD/DA converters

In applying SDR to the future development of IMT-2000 and systems beyond IMT-2000, AD/DA converters are expected to require a 10 bits or higher resolution and 100 Msample/s or higher sampling rate for SDR. The reason for 10 bits is that some potential new modulation schemes such as orthogonal frerquency division multiplex (OFDM) have large PAPR (peak-to-average power ratio). The systems beyond IMT-2000 may have signal bandwidth of several tens of MHz, and over-sampling is required for baseband AD conversion. These figures need to be obtained with low power dissipation for battery-powered terminals.

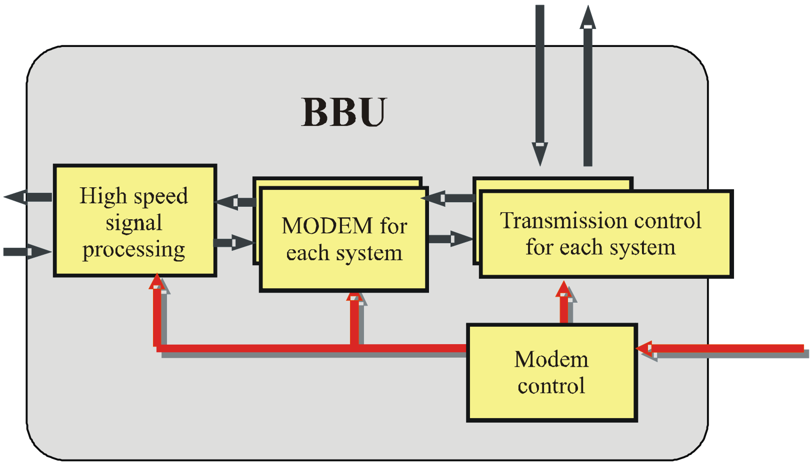
If higher performances are required, major improvements not only in power dissipation of AD/DA converters but in precision (or jitter) of the clock source are needed.

8.1.1.5 Baseband unit

In Fig. 5, the BBU performs several functions such as high-speed signal processing (sampling rate conversion, filtering, etc.), modulation/demodulation for each system, transmission control, and modem control (reconfiguration function).

FIGURE 5

Baseband unit



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8.1.1.5.1 Sampling rate conversion filter

In applying SDR to the future development of IMT-2000 and systems beyond IMT-2000, simultaneous reception of different radio access systems is required for multimode mobile terminals in case of inter-system handover, so the digital signal processing design of the terminals should be independent of the A/D sampling rate. Therefore a function that converts the sampling rate of the ADC output signals to a suitable one for modulation is needed between the ADC and the modulation unit.

8.1.1.5.2 Reconfigurable baseband processor

One of the biggest problems in achieving the digital baseband part with SDR applied to the future development of IMT-2000 and systems beyond IMT-2000 is that the processing performance demanded of each generation of mobile telecommunications increases rapidly. Nearly one thousand times the processing power is required as compared with the previous generation of mobile communications.

The use of a hybrid architecture of the processor is significant, consisting of reconfigurable circuits with high and restricted flexibility for programming and dedicated hardware for common purposes, in order to achieve the high processing performance especially required in systems beyond IMT-2000.

8.1.2 System aspects

8.1.2.1 High-speed software switching

The performance of switch software in SDR significantly depends on the devices to be used, such as digital signal processor (DSP), field programmable gate array (FPGA) and others. For example, a system using DSP may be reconfigured relatively easily and switched at high speed. When FPGA is used in the system, the switching time is longer than for DSP because FPGA currently must be fully reconfigured whenever the system is switched. Some technologies will reduce the switching time like multiple FPGAs used as a cache.

8.1.3.2 Simultaneous multiple communication

Especially for IMT-2000, simultaneous multiple communications may be a necessary function of SDR terminals. As the number of radio communication systems implemented in one terminal increases there is a point at which SDR clearly has advantages of body size, cost and flexibility of system update. Items for further study include how to store each system's software and how to realize simultaneous communication. For example in some case the entire software of each system may be downloaded, in others a common part of the software may be shared among the systems.

8.1.3.3 Communication system selection

A user with an SDR based terminal may have thethe possibility of selecting a wireless system that best meets his or her requirements. Thus, a way to identify a user's requirements is crucial. Some information to define the requirements can be obtained in the terminal, and some other information cannot. Examples of the former information are the received signal strength indicator (RSSI), bit error ratio (BER), frame error ratio (FER), transmission power consumed for each system, and the number of transistors and gates in the digital signal processing unit. The latter information may be transmission speed, charge of usage and data reliability. All this information may be used to select and switch the systems.

8.2 Items for future study

The following technologies may be required study items for SDR in future development of IMT-2000 and systems beyond IMT-2000. Several technologies are being developed to a certain extent as shown in § 8.1. There are technical items that should be further studied and developed as follows. Study items regarding software download including over-the-air software download are described in § 6.

To assist in applying SDR to the future development of IMT-2000 and systems beyond IMT-2000, the development of technology for the hardware element is encouraged as follows:

– Further development of analogue signal processing devices such as antenna, RFU, AD/DA converters further. Especially for terminals, miniaturization and low power consumption are needed. Furthermore, software controlled frequency band-switching or multi-band characteristics without hardware switching are required for the multi-mode/multi-band terminal.

– With regard to baseband processing devices, such as baseband processors, although the complexity depends on the type of radio systems, very high performance will be necessary, while the mobile communications system will become large-scaled and highly advanced in the future. Furthermore, stability improvement, and especially for terminals, low power consumption are future study items.

Examples of specific study items:

– *Adaptive antennas and RFUs* – Programmable multiband antennas and RFUs are expected to satisfy the requirement for several frequency bands in the future development of IMT-2000 and systems beyond IMT-2000. The technical specification of transmission power, spurious emissions, sensitivity etc. need further study as well.

– *Tuneable filters with steep attenuation characteristics* – To study the challenge of achieving a very steep attenuation characteristic for the filters in the RFU, especially, in the duplexer for separating the transmit and receive signals.

– *High-speed ADC/DAC with wide dynamic range* – SDR requires high-speed semiconductor devices, and deep sub-micron CMOS technology is suitable. Such devices operate with low power supply voltage, and the low supply voltage limits the dynamic range of the analog part. ADCs with low supply voltage and high resolution (i.e. wide dynamic range) should be studied especially.

– *High performance baseband processors* – To realize inter-system handover, baseband processors must handle baseband processing of both systems at the same time. Baseband processors require very high processing capabilities and high speed task switching capabilities.

– *System switching and inter-system handover* – Examples of study items are development of system architecture, further high-speed real time operating systems, commonly used software description language and development of adaptation method in response to the radio environment. Especially for the mobile terminals, simultaneous miniaturization and low power consumption are necessary.
– *Environment adaptive communication* – To achieve lower power consumption of terminal equipments, a technique which can adaptively vary the communication algorithm according to the communication environment is necessary.

9 Relevant external bodies

Other organizations such as standard development organizations, universities, and industry organizations, and partnership projects, forums, consortia and research collaborations are currently working on SDR related topics, e.g. flexible, reconfigurable terminal/base station software architectures, and security mechanisms for software download.

Some of these bodies are described in Annex 2.

10 Technical considerations necessary to ensure conformance with ITU Recommendations and Radio Regulations

Worldwide roaming, one of the key features of IMT-2000 systems and systems beyond IMT-2000, requires the global circulation of terminals.

Flexible terminal implementation including that offered by SDR, enables a single terminal to support multiple standards, facilitating world-wide roaming.

Flexible implementations of IMT-2000 terminals and (e.g., those implemented by SDR, etc.) will be subject to the same procedures as conventional IMT-2000 terminals, i.e. global circulation and interference performance is covered by Recommendation ITU-R M.1579.

SDR technology may have some impact on the procedures for conformity assessment of terminals because they may work in several different ways. A number of administrations are therefore considering how the current procedures might be enhanced to address the considerations related to SDR.

However, common principles would facilitate the global circulation of such flexible terminals.

Examples of issues which are being addressed:

– equipment identification/marking, re-certification or declaration of conformity of such terminals post deployment;
– software/hardware configuration issues;
– security and integrity issues;
– prevention of unauthorized software changes;
– prevention of harmful interference.

11 Summary and conclusion

Within this Report aspects of software defined radio with respect to IMT-2000 and systems beyond have been addressed. This comprises a definition of SDR as well as some considerations on the potential impact of SDR technology on IMT-2000 and systems beyond.

As one major topic, technical aspects, such as the principal system overview as well as some latest areas of research and the state of technology development, have been briefly described. Since SDR comprises many different and evolving technical aspects, this Report should be seen as an initial technical report.

The Report also addresses issues like market development and external bodies that are working on SDR related topics.

Technical implementations are being developed by the industry. Examples can be found in Annex 1.

Annex 1

Technical aspects

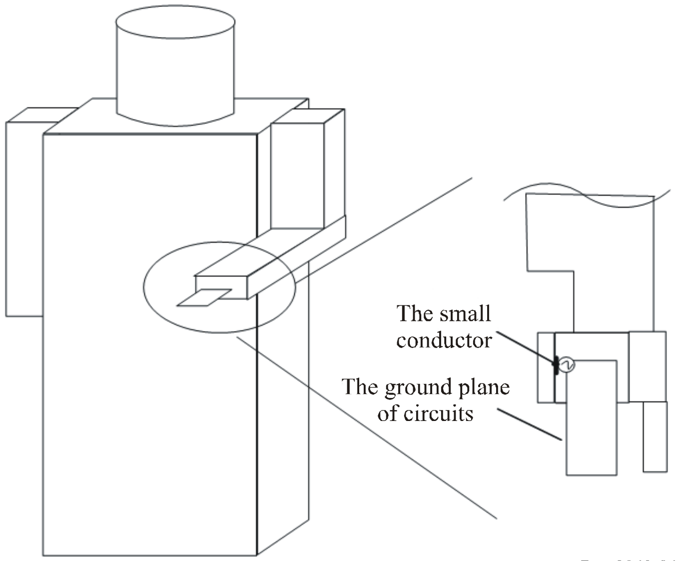
1 Aspects of antenna systems

1.1 Monopole antenna using human body

Although small size and multi-band characteristics are mutually exclusive in general, this antenna can achieve both of them [Fukasawa, *et al.*, 2003]. This antenna is a monopole antenna using the human body as a ground plane (Fig. 6). The radiation element is a ground plane of internal circuits. So, by using only a small conductor contacted with the human hand, this antenna does not require the conventional resonance element with a quarter wave length.

FIGURE 6

Monopole antenna using human body



This antenna can achieve very wide bandwidth available for multi-band use. For example, a voltage standing wave ratio (VSWR)<3 for 0.5 to 2.5 GHz (Fig. 7) and efficiency of more than –4 dB (Fig. 8) are obtained.

FIGURE 7

VSWR characteristics of the antenna

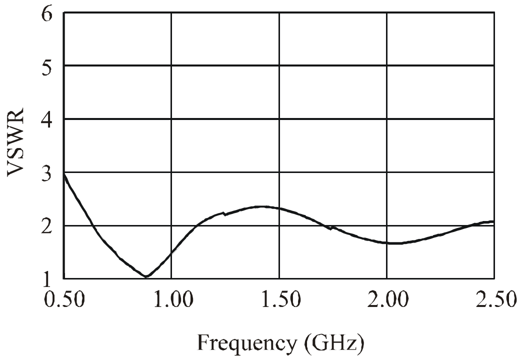
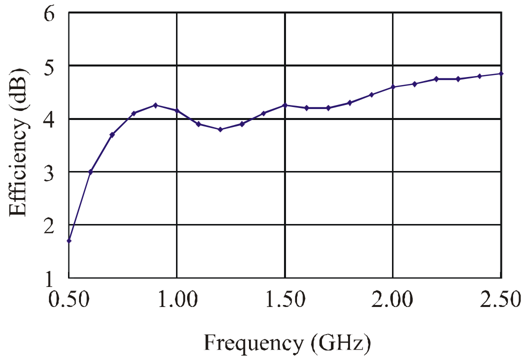


FIGURE 8

Efficiency of the antenna



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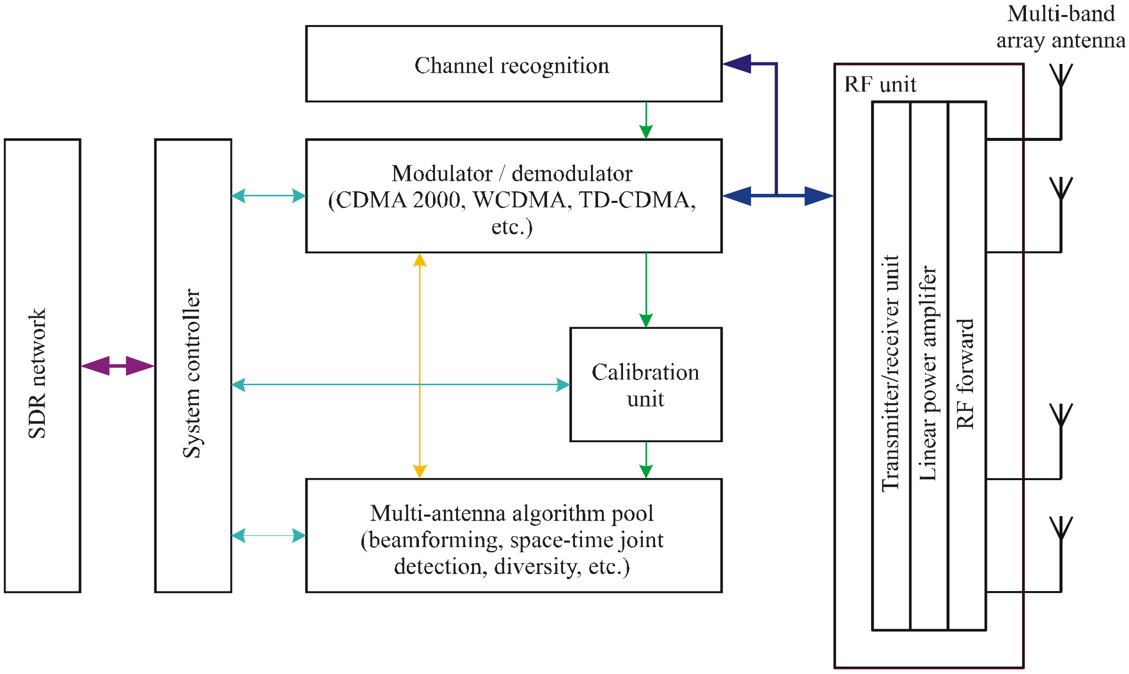
1.2 Software adaptive antenna

A software adaptive antenna takes advantage of the space diversity of the time-varying propagation environment by using the optimum multi-antenna algorithm. To implement the algorithm, the adaptive antenna system has to change adaptively with respect to the time varying fading environment. The software adaptive antenna implementation discussed here overcomes the limitations of each individual algorithm by employing channel recognition, modulator/demodulator, calibration unit, multi-antenna algorithm pool, system controller and SDR network, etc. Therefore, in a sense, this software adaptive antenna can sense the environment at any time. The architecture of a software adaptive antenna is shown in Fig. 9.

FIGURE 9

Architecture of software adaptive antenna



1.2.1 Application of IMT-2000 and systems beyond IMT-2000 software adaptive antenna system

The technology overcomes the shortcoming of the traditional adaptive array antenna algorithm which is limited in its area of use. It adopts software adaptive antenna technology so that the system can be used in a multifarious environment.

1.2.1.1 Software adaptive antenna in IMT-2000 CDMA direct spread

An example is shown of the implementation of software adaptive antenna used in IMT-2000 and systems beyond IMT-2000 for mobile communication. Specifically, Fig. 10 is a schematic illustration of the software adaptive antenna for IMT-2000 CDMA Direct Spread systems. The inputs are baseband signals that come from the antenna elements and after A/D conversion. With the input data, it is able to estimate the numbers of desired signal, delay spread, spatial spread, and inband spectral power, etc. Using the estimated values, the software adaptive antenna can select the beamforming algorithm and determine the multiple user detection algorithm. Therefore, with the desired beam directed to the expected user and suppressing the interferences, the software adaptive antenna can increase the possible capacity of the cellular system and improve the quality of the wireless communication in low-*S*/*N* ratio environments as well.

It comprises:

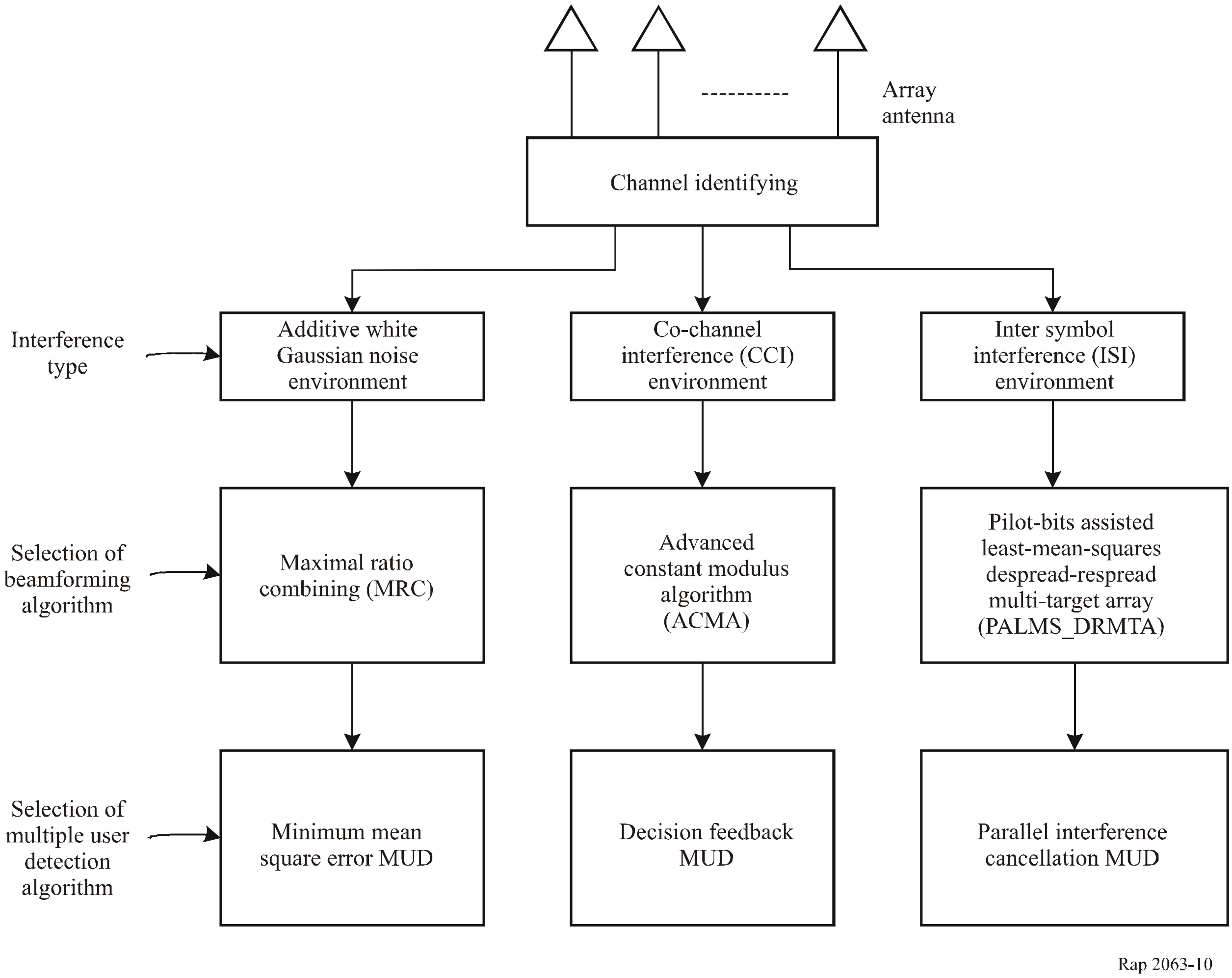
– A function for evaluating changes in the environment and identifying interferences.

– A pool of beamforming algorithms for a variety of possible countermeasures, and a function for finding the optimum beamforming algorithm at any time.

– Multiple user detection (MUD) by the results of environment sensing and recognition.

FIGURE 10

Configuration of software adaptive antenna in IMT-2000 CDMA direct spread

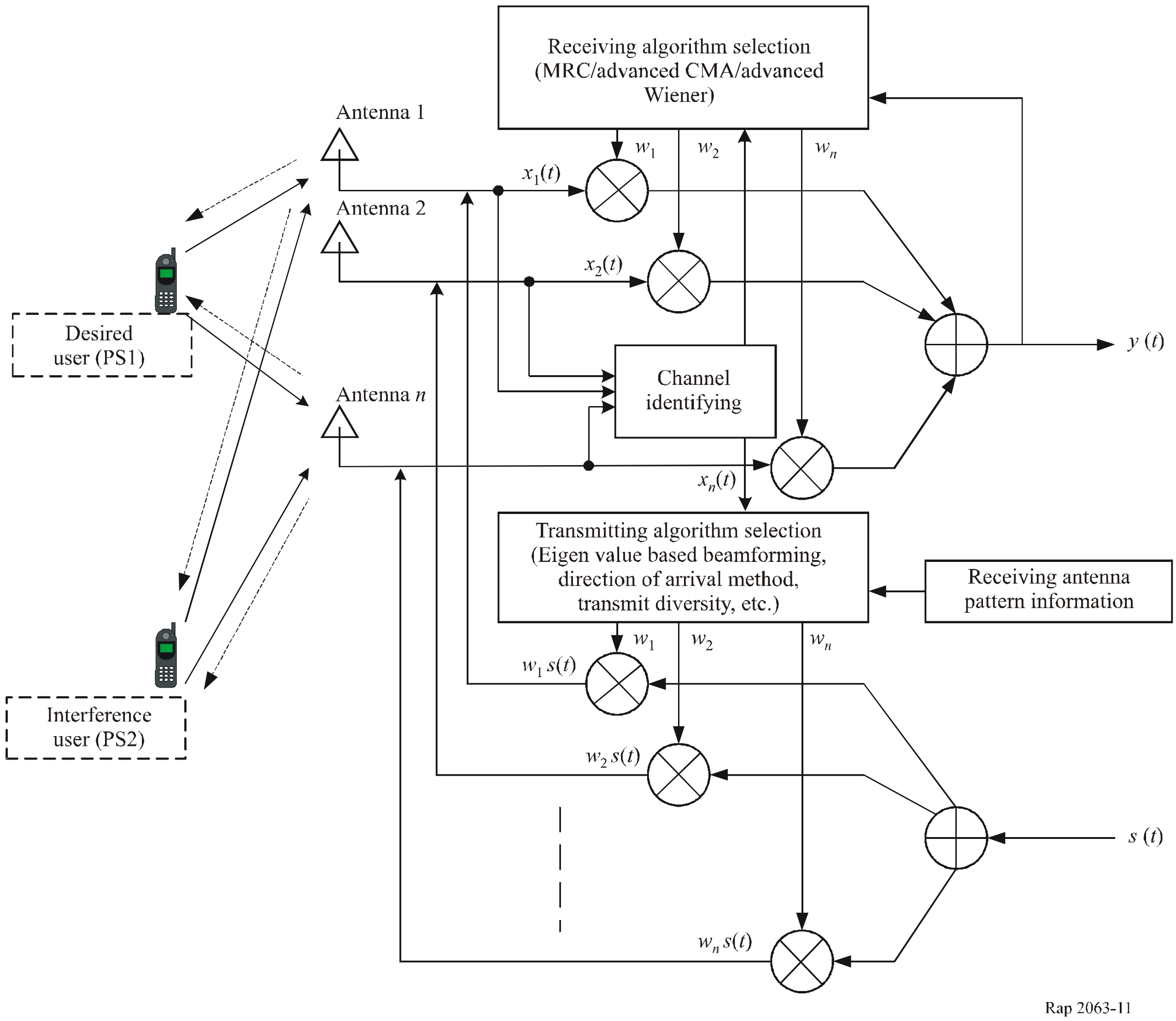


1.2.1.2 Software adaptive antenna in IMT-2000 CDMA TDD

Figure 11 is the configuration of software adaptive antenna for TD-SCDMA, which has the function of runtime reconfiguration by means of an adaptive algorithm based on radio environmental recognition in space and time.

FIGURE 11

Configuration of software adaptive antenna in TD-SCDMA

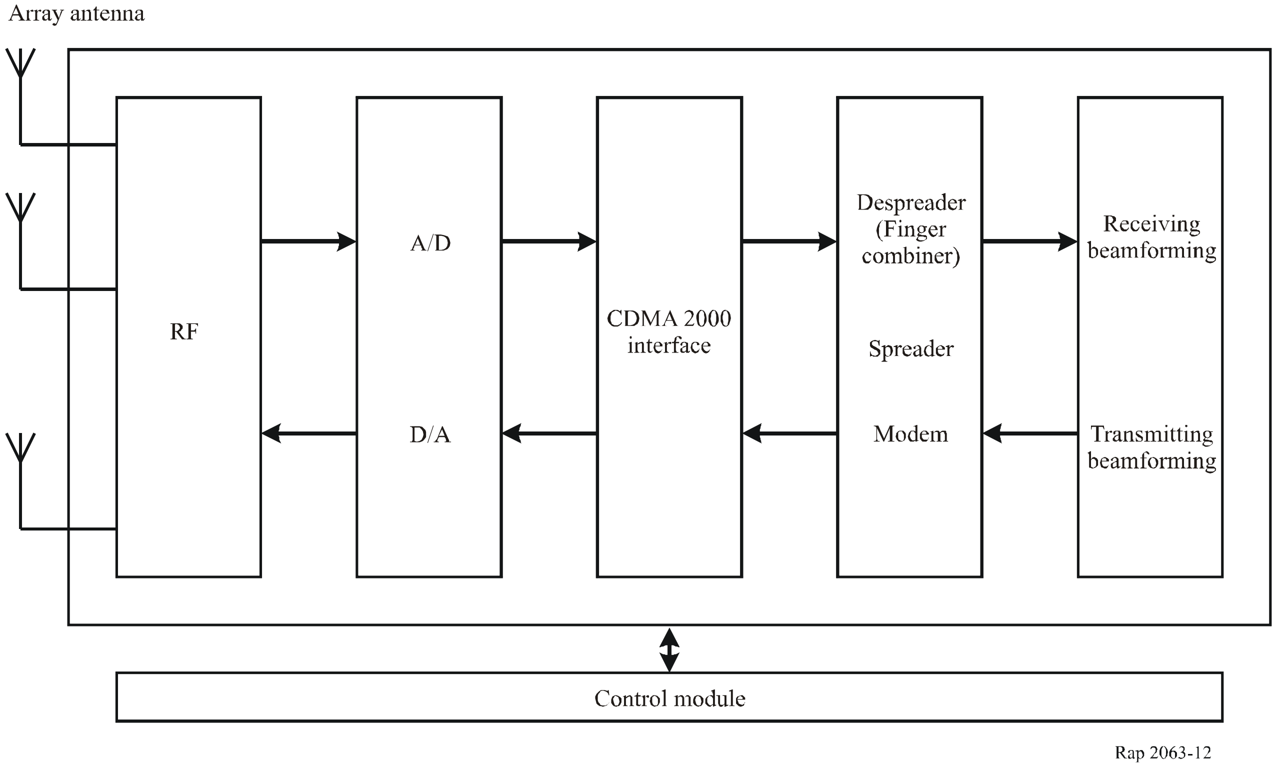


1.2.1.3 Software adaptive antenna in IMT-2000 CDMA multi-carrier

Figure 12 is the configuration of software adaptive antenna for IMT-2000 CDMA multi-carrier.

FIGURE 12

Configuration of software adaptive antenna in IMT-2000 CDMA multi-carrier



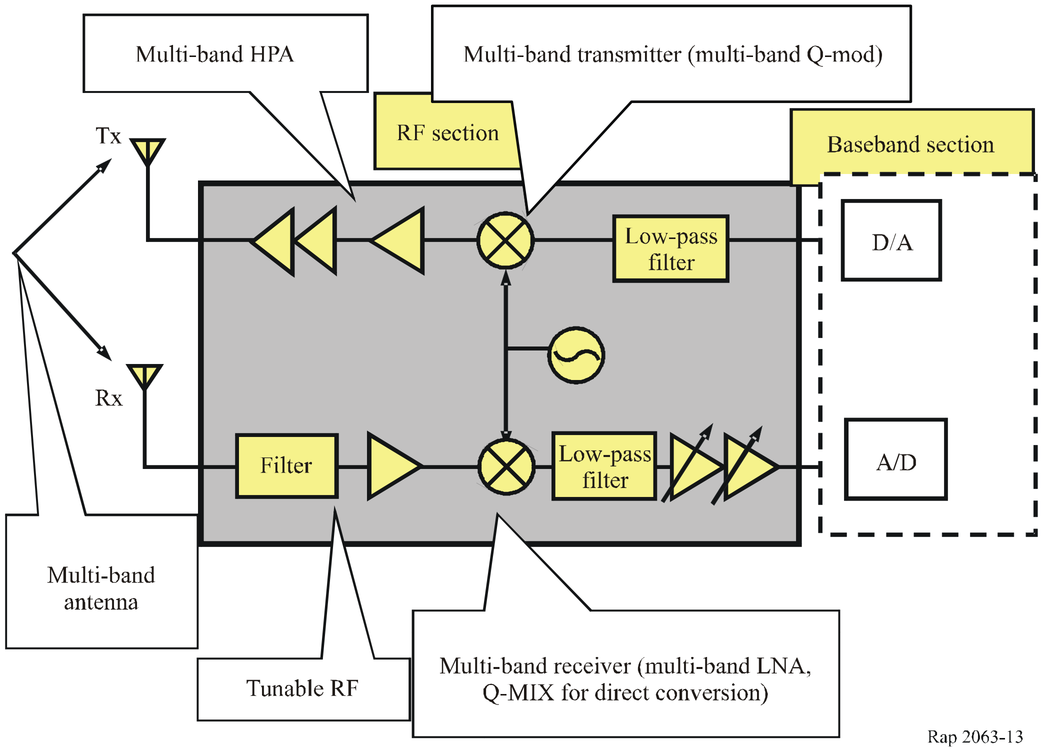
1.3 RFU

In order to correspond to multi-band/multi-mode communication systems, selecting an RFU architecture suitable for SDR is very important. A direct conversion architecture (Fig. 13) that can achieve miniaturization is chosen as the receiver architecture [Kawashima, *et al*., 2002], since an image rejection filter and IF band-filter becomes unnecessary. The direct modulation architecture is very promising since this can simplify composition to the transmitter. However, it is necessary to perform transmitting power control with a large dynamic range. Composition examination including power control at a local signal of a quadrature modulator is performed.

Circuits, such as a low noise amplifier (LNA), a RF quadrature mixer and a driver amplifier that compose a RFU, are required to have a multi-band characteristics. With a multi-band RF quadrature mixer for a direct conversion receiver, achievement of good amplitude and phase balance is difficult. To improve the accuracy, a 90° phase shifter employing a divider circuit is currently proposed. In order to reduce the interference from other communication systems, the receiving RF filter needs to vary its pass band corresponding to the frequency of a received signal. With a high power amplifier (HPA), all of the frequency bands are not covered by a single device, but efficiency of the HPA is improved by using two or more devices.

FIGURE 13

Direct conversion architecture



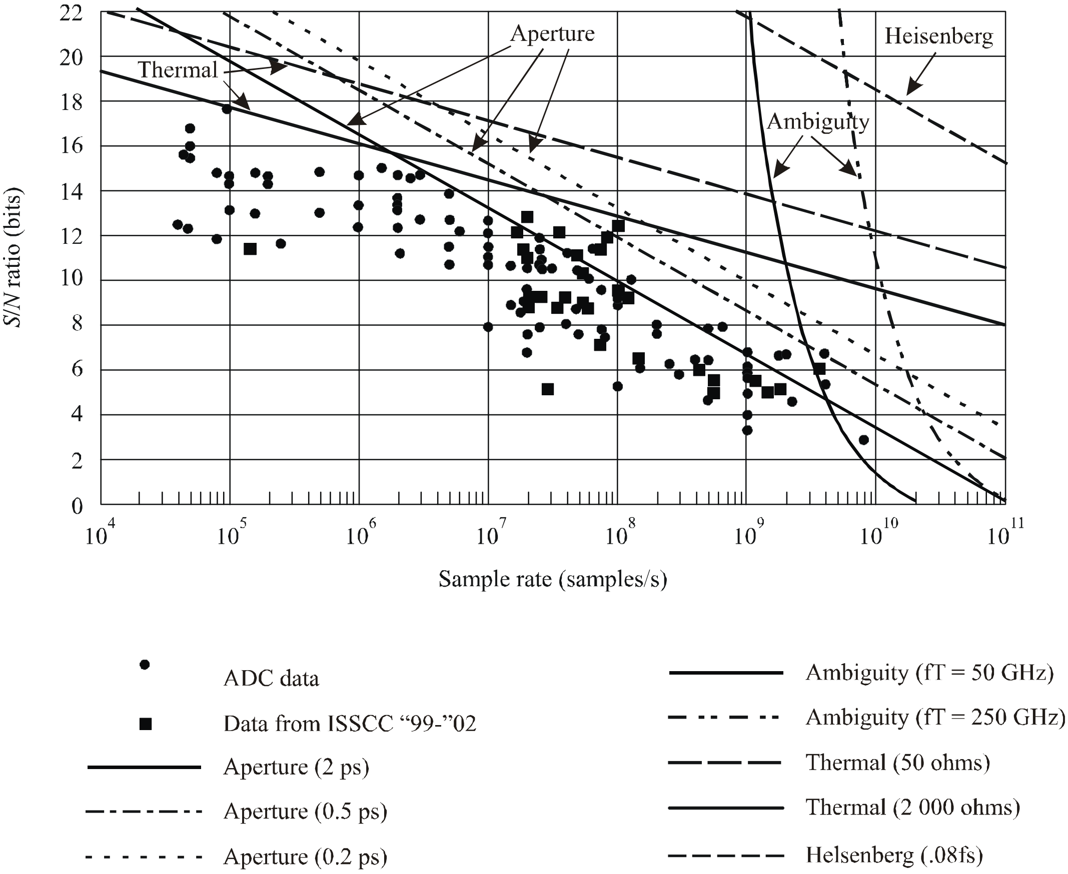
1.4 AD/DA converters

In applying SDR to the future development of IMT-2000 and systems beyond IMT-2000, AD/DA converters are expected to require a 10 bits or higher resolution and 100 Msample/s or higher sampling rate for SDR. The reason for 10 bits is that some potential new modulation schemes such as OFDM have a large PAPR. The systems beyond IMT-2000 may have a signal bandwidth of several tens of MHz, and over-sampling is required for baseband A/D conversion. These figures need to be obtained with low power dissipation for battery-powered terminals.

If higher performances are required, major improvements not only in power dissipation of the AD/DA converters but also in the precision (or jitter) of the clock source are needed, as discussed in [Walden, 1999]. Figure 14 is the reported ADC data plot, and shows that the aperture jitter limits the *S*/*N* ratio for the target sampling frequency range.

FIGURE 14

Reported ADC performance



Based on Robert H. Walden, IEEE J., Selected Areas in Communications, 1999.

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1.5 Sampling rate conversion filter

As mentioned earlier, simultaneous reception of different radio access systems, as in the case of inter-system handover, is needed so digital signal processing design of the terminals should be independent of the A/D sampling rate. Therefore the function that converts the sampling rate of the ADC output signals to a suitable one for the modulation is needed between the ADC and the modulation unit.Ω

Figure 15 shows an implementation example of a sampling rate conversion filter for multi-radio access technology (RAT) mobile terminals [Motoyoshi, *et al.*, 2003]. This filter is implemented by use of a delay time-variable pulse-shaping filter with a polynomial approximation technique [Farrow, 1988] and is intended to perform pulse-shaping signals and sampling rate conversion at the same time. The sampling rate conversion ratio can be finely controlled only by controlling delay-time of the filter without changing the filter's structure or coefficients.

FIGURE 15

Implementation example of sampling rate conversion filter

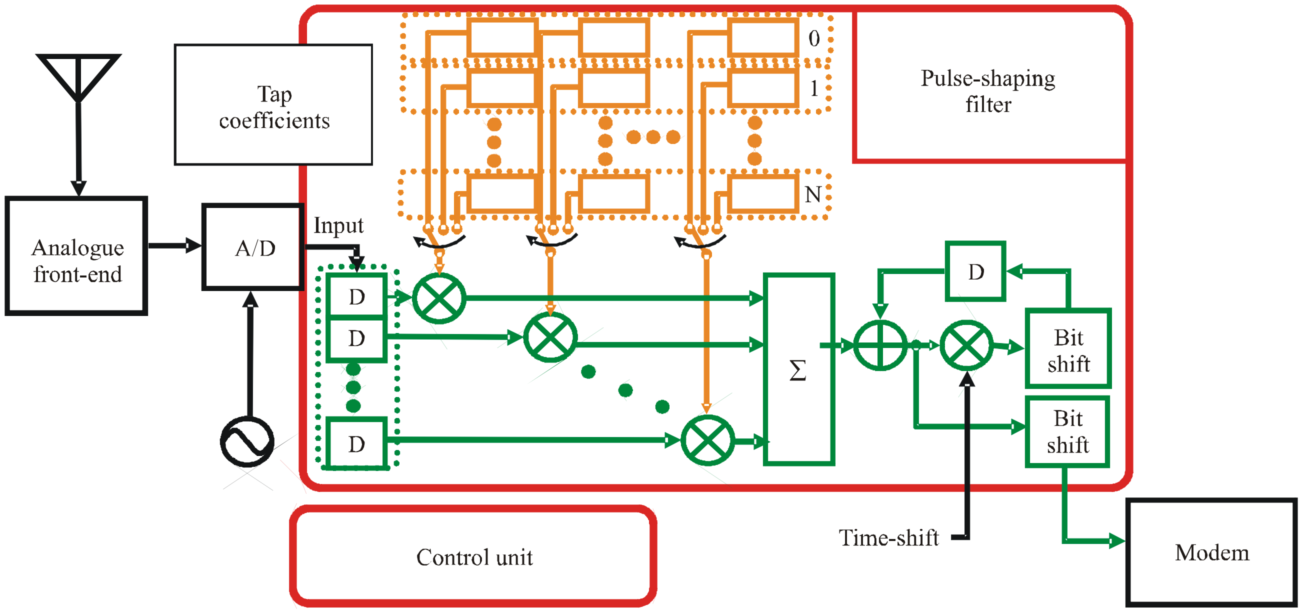

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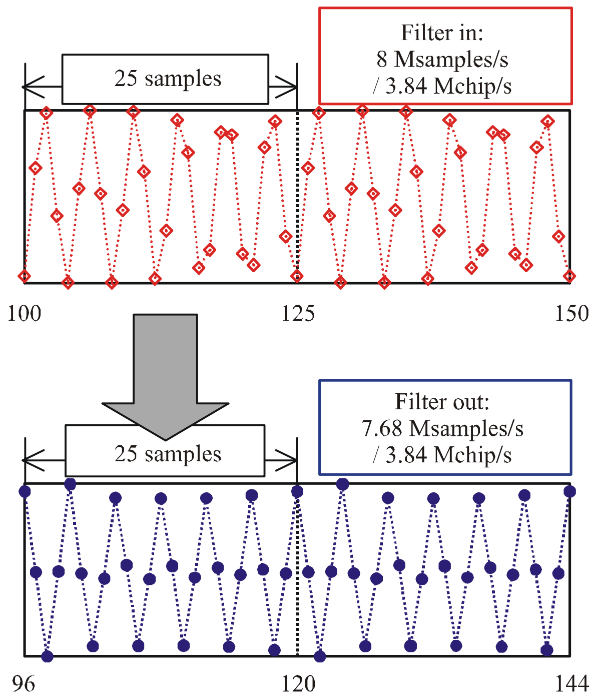
Figure 16 shows an example of how the filter works. The graph at the top of of Fig. 16 shows the A/D output of an IMT-2000 CDMA Direct Spread signal sampled at 8 Msamples/s, which is not an integral multiple of the chip rate (3.84 Msamples/s). The graph at the bottom of Fig. 16 shows the output of the filter. In this filter, the sampling rate of the input signal is converted from 8 Msamples/s to 7.68 Msamples/s, which is 2 times the chip rate.

FIGURE 16

Example of sampling rate conversion filter behaviour



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By use of the filter, one can obtain an optimum sampling rate for modulation. Moreover, this process is not so heavy for terminals because this can be shared with the digital pulse-shaping process usually needed for single-carrier RAT systems, which need less processing power than high-speed RAT systems (e.g. OFCDM) relatively.

1.6 Reconfigurable baseband processor

One of the biggest problems in achieving the digital baseband part for SDR applied to the future development of IMT-2000 and systems beyond IMT-2000 is that the processing performance demanded of each generation of mobile telecommunications increases rapidly. For the systems beyond IMT-2000, transfer rate increases from 384 kbit/s to 100 Mbit/s and the introduction of new techniques such as MIMO will require more than 1 000 times the processing power compared with former generations

On the other hand, the processing performance of processors executing baseband processing is increasing with a growth rate a little less than Moore's law: namely four times per every 3 years.

The growth rate of processor performance is lower than that of the baseband processing requirement.

An approach that provides all the baseband processing only by DSPs is not realistic. An approach that provides the baseband processor by a combination of restricted flexibility circuits with the complementary functions corresponding to the characteristics needed for baseband processing becomes important.

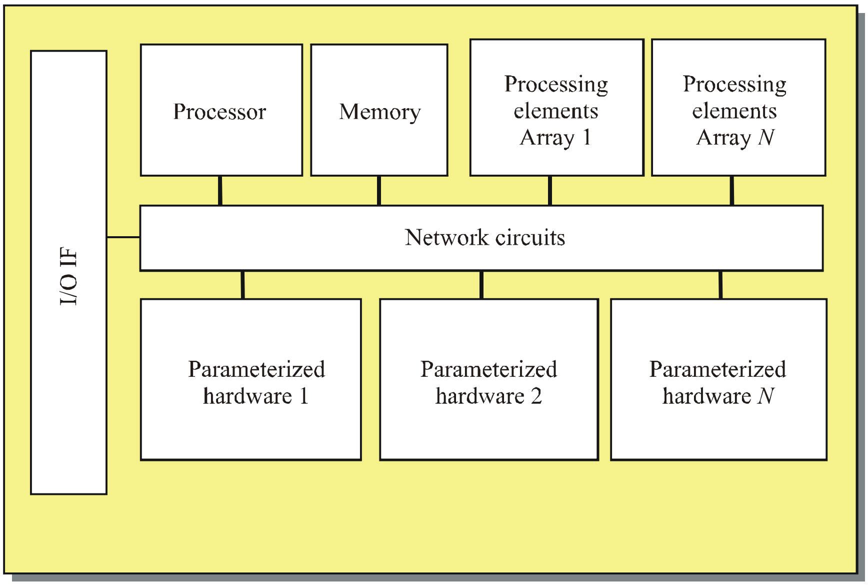
In other words, for realization of SDR, a LSI circuit that has a hybrid architecture consisting of the following components may be necessary:

– arrays of processing elements such as ALUs (arithmetic logical units) which achieve a high degree of programmability;
– special purpose reconfigurable circuits (or parameterized hardware) that achieves higher processing performance by restricting the flexibility of programmability;
– dedicated hardware such as general purpose CPU’s or memories.

Commonly used functions such as fast fourier transport (FFT) are candidates for parameterized hardware that can economically realize a matched filter and a decoding function. It may be more advantageous to achieve the function with dedicated hardware and give flexibility to apply it also for other uses than to achieve the functionality with a complex, processing element array from the perspective of circuit area (i.e. cost) and power consumption. The architecture of a reconfigurable baseband processor for SDR is shown in Fig. 17. It uses several arrays of processing elements to execute processing which requires higher programmability, and several parameterized hardware elements to execute a commonly used function or functions which require very high processing performance. The number of processing element arrays or kind of the parameterized hardware changes according to the wireless communication systems to be realized as SDR.

FIGURE 17

Reconfigurable baseband processor architecture



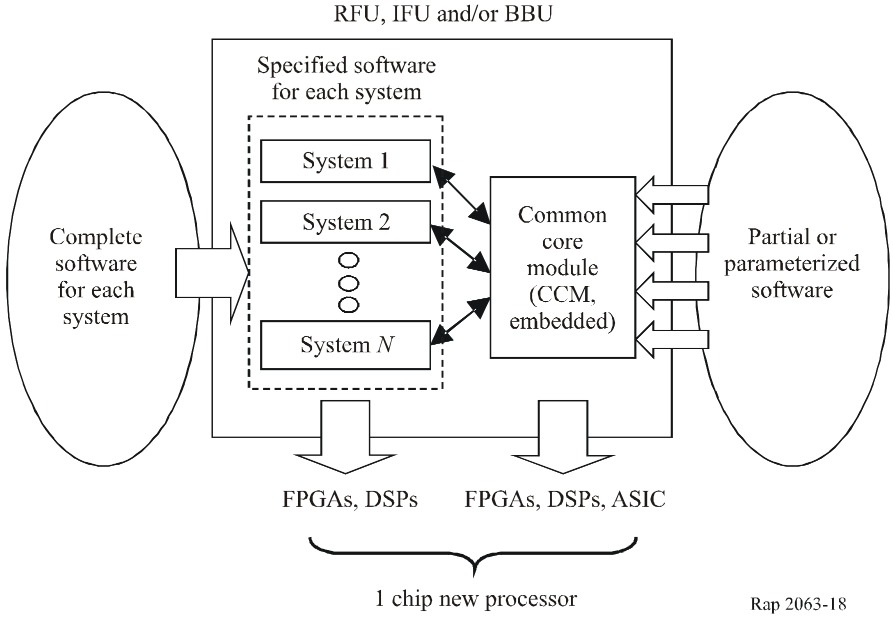
1.7 High-speed software switching

The performance of switch software in SDR depends significantly on the devices to be used, such as DSP, FPGA and others. For example, systems using DSP may be reconfigured relatively easily and switched at high speed. When a FPGA is used in the system, switching time is longer than for DSP because FPGA currently must be fully reconfigured whenever the system is switched. Some technologies will reduce the switching time, like multiple FPGAs used as a cache.

Figure 18 shows one concept where a communication functionality block is programmed into the reconfigurable digital signal processing hardware units, and a desired modulation/demodulation scheme can be selected by only the parameter information. An experimental prototype has confirmed feasibility of the technology in which it was possible to change the modulation/demodulation scheme among ASK, QPSK, BPSK, GMSK, and π/4-QPSK in less than 1 ms [Kawashima, *et al*., 2002; Walden, 1999]. The communication functionality block is a common core module (CCM) for all of communications systems, however there are some parts that are dependent on communication systems in the software.

FIGURE 18

Parameter controlled software radio



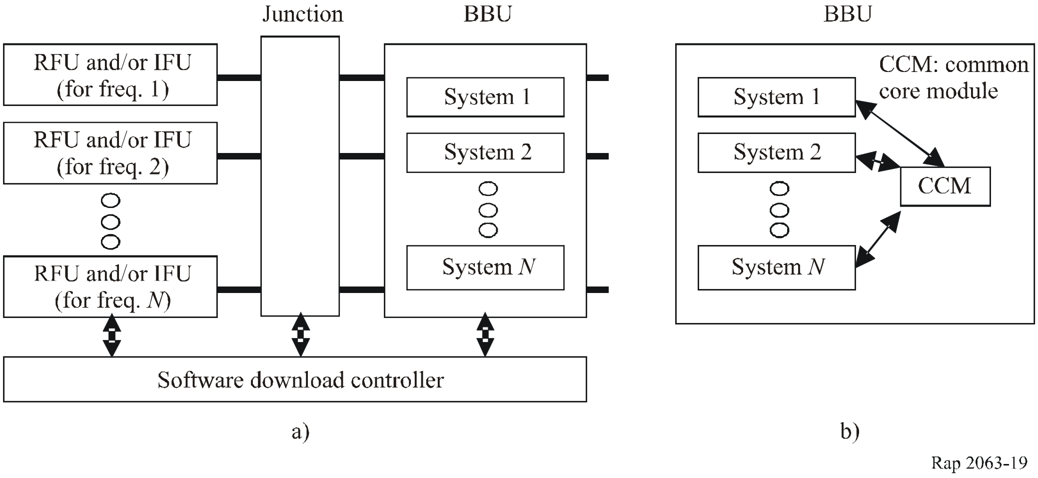
1.8 Simultaneous multiple communication

Especially for IMT-2000, simultaneous multiple communications may be a necessary function of SDR terminals. As the number of radio communication systems implemented in one terminal increases there is a point at which SDR clearly has advantages of body size, cost and flexibility of system update.

Shown in Fig. 19 is an example of a typical implementation of simultaneous multiple communication. In the future multi-mode and multi-service terminal, the RFU, intermediate frequency unit (IFU) and BBU (baseband digital signal processing unit) will be connected via a multi-port junction circuit. The RFU and IFU must cover as wide a bandwidth as possible. The BBU comprises a single or several hardware units for digital signal processing. Software to implement two or more communication systems is downloaded on demand to the hardware units for digital signal processing by the BBU using multi-mode and multi-task software radio (MMSR) technology [Harada *et al.*, 2002; Harada, 1999]. All of the software may be downloaded individually, as shown in Fig. 19a). Otherwise, as shown in Fig. 19b), part of the software may be shared among the systems in the processing to implement multiple systems.

FIGURE 19

Examples of system architecture for simultaneous multiple communication

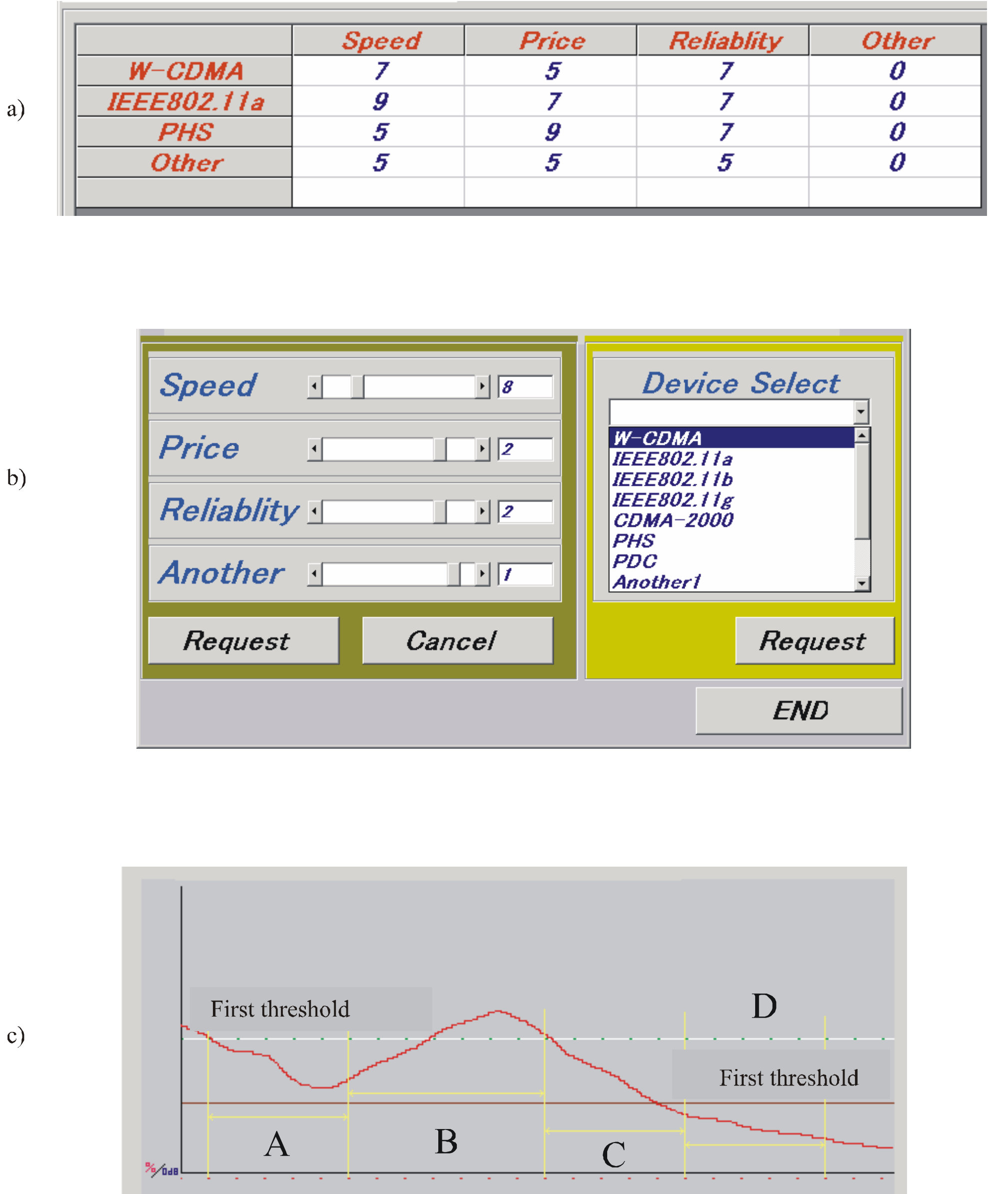


1.9 Communication system selection

A user with an SDR based terminal may have a possibility of selecting a wireless system that best meets his or her requirements [Farrow, 1998]. Thus, a way to identify a user's requirements is crucial. Some information to define the requirements can be obtained in the terminal, and some other information cannot. Examples of the former information are the received signal strength indicator (RSSI), BER, FER, and transmission power consumed for each system. The latter information may be transmission speed, price (charge of usage) and data reliability. In Figure 20a), systems are evaluated in terms of speed, price, and reliability. Figure 20b) shows the priorities needed in the entire communication process using this terminal, before starting communications. While communicating, information on RSSI, BER, or FER is obtained at the terminal, as shown in Fig. 20c), where the vertical axis represents lower values of RSSI, BER or FER. If a value falls below the first threshold, the operability of the other services is checked. The check result may be obtained by measuring RSSI of other communication systems. If the second threshold is passed, there should be a change. To change systems, the systems are prioritized based on the information shown in Figs. 20a) and b). A system is selected according to the priority.

FIGURE 20

Example of communication system selection



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Annex 2

External Organizations

Industry consortia and IMT-2000 interaction

The Software Defined Radio (SDR) Forum

An international non-profit organization dedicated to promoting the development, deployment and use of SDR technologies for advanced wireless systems.

– The SDR Forum addresses different aspects of an SDR system such as market, technical and regulatory topics. It has established formal liaison activities with standardization development organizations such as the 3GPP and OMA. More detailed information is provided at www.sdrforum.org.

The Open Mobile Alliance (OMA)

The mission of the Open Mobile Alliance is to facilitate global user adoption of mobile data services by specifying market driven mobile service enablers that ensure service interoperability across devices, geographies, service providers, operators, and networks, while allowing businesses to compete through innovation and differentiation.

– OMA developments of specifications regarding security mechanism (e.g. OMA wireless public key infrastructure), rights management (OMA Digital Rights Management) or device management for terminal configuration are related to SDR implementation. More detailed information is provided at www.openmobilealliance.org.

The Third Generation Partnership Project (3GPP)

The scope of 3GPP includes producing globally applicable Technical Specifications and Technical Reports for a 3rd Generation Mobile System based on evolved GSM core networks and the radio access technologies that they support (i.e., universal terrestrial radio access (UTRA) both frequency division duplex (FDD) and time division duplex (TDD) modes).

Technical Specification Groups (TSG) develop specifications on various technical aspects in areas such as:

– Core Network and Terminals (TSG CT)
– Service and System Aspects (TSG SA)
– WG3 Security – responsible for the security of the 3GPP system
– Radio Access Network (TSG RAN).

More detailed information is provided at www.3gpp.org.

The Third Generation Partnership Project 2 (3GPP2)

Provides a collaborative third generation (3G) telecommunications specifications-setting project comprising North American and Asian interests developing global specifications for ANSI/TIA/EIA-41 Cellular Radiotelecommunication Intersystem Operations network evolution to 3G and global specifications for the radio transmission technologies (RTTs) supported by ANSI/TIA/EIA-41.

Technical Specification Groups (TSG) develop specifications on various technical aspects in areas such as:

– TSG-A (Access Network Interfaces)
– TSG-C (cdma2000®)
– TSG-S (Services and Systems Aspects)
– TSG-X (Core Networks).

More detailed information is provided at www.3gpp2.org.

IEEE Standards Association

More detailed information is provided at standards.ieee.org/sa/index.html. There are currently three working groups within the IEEE P1900 Standards structure related to SDR:

IEEE P1900.1 Working Group

Objective document: Standard Terms, Definitions and Concepts for Spectrum Management, Policy Defined Radio, Adaptive Radio and Software Defined Radio.

IEEE P1900.2 Working Group

Objective document: Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems.

IEEE P1900.3 Working Group

Objective document: Recommended Practice for Conformance Evaluation of Software Defined Radio (SDR) Software Modules.

More detailed information for the IEEE P1900.1, P1900.2, and P1900.3 Working Groups is provided at standards.ieee.org/board/nes/approved.html.

Research Projects and Initiatives

Various research projects and initiatives which impact SDR technology development are:

– European End-to-End-Reconfigurability Project (E^2R).

  – E^2R is an Integrated Project addressing the core of the strategic objective "Mobile and wireless systems beyond 3G". The key objective of the E2R project is to devise, develop and trial architectural design of reconfigurable devices and supporting system functions to offer an expanded set of operational choices to the users, application and service providers, operators, regulators in the context of heterogeneous Mobile Radio Systems. More detailed information is provided at www.e2r.motlabs.com

Examples of successful cooperation between different industry players in the area of modular base station architecture are:

Common Public Radio Interface (CPRI™) initiative

The Common Public Radio Interface (CPRI™) is an industry cooperation aimed at defining a publicly available specification for the key internal interface of radio base stations between the Radio Equipment Control (REC) and the Radio Equipment (RE)

– CPRI specifications are freely available. More detailed information is provided at www.cpri.info

The Open Base Station Architecture Initiative (OBSAI)

The Open Base Station Architecture Initiative (OBSAI) aims to create an open market for cellular base stations. An open market will substantially reduce the development effort and costs that have been traditionally associated with creating new base station product ranges.

– The OBSAI is comprised of over a hundred companies, spanning base station manufacturing, module manufacturing and component manufacturing. More detailed information is provided at www.obsai.org