

REPORT ITU-R M.2117

**Software defined radio in the land mobile,
amateur and amateur satellite services**

(Question ITU-R 230/8)

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1 Introduction

Radio technology continues to migrate towards software reprogrammable radios, which can be reconfigured to adapt to changing communications protocols and frequency bands.

This technological evolution to software defined radios (SDR) may have a profound effect on interoperability, on spectrum utilization and allocation in general, and on all technology partners from chip vendors and service providers to users. The impact of SDR could be far reaching with possible applications in government systems, emergency response, medical communications, automobile sensors, commercial wireless systems and more.

2 Scope

This Report addresses the application and implications of SDR to land mobile systems, including, but not limited to, IMT-2000 and systems beyond, dispatch systems, intelligent transport systems (ITS), public mobile systems including public protection and disaster relief (PPDR), and first and second generation cellular systems including their enhancements. It addresses issues on the efficient use of spectrum using SDR techniques and adaptive control mechanisms, frequency sharing issues relating to SDR and general technical issues.

3 Related texts ITU-R Recommendations

- ITU-R F.1399 – Vocabulary of terms for wireless access
- ITU-R M.687 – International Mobile Telecommunications-2000 (IMT-2000)
- ITU-R M.1032 – Technical and operational characteristics of land mobile systems using multi-channel access techniques without a central controller
- ITU-R M.1033 – Technical and operational characteristics of cordless telephones and cordless telecommunication systems
- 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 bands¹ 806-960 MHz², 1 710-2 025 MHz, 2 110-2 200 MHz and 2 500-2 690 MHz
- ITU-R M.1073 – Digital cellular land mobile telecommunication systems
- ITU-R M.1450 – Characteristics of broadband radio local area networks
- ITU-R M.1453 – Intelligent transport systems – dedicated short range communications at 5.8 GHz
- ITU-R M.1457 – Detailed specification 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

¹ Some administrations may deploy IMT-2000 systems in bands other than those identified here.

² The whole band 806-960 MHz is not identified on a global basis for IMT-2000 due to variation in the primary mobile service allocations and uses across the three ITU Regions.

- 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
- ITU-R M.1678 – Adaptive antennas for mobile systems
- ITU-R M.1797 – Vocabulary of terms for the land mobile service.

ITU-R Reports

- ITU-R M.1021 – Equipment characteristics for digital transmission in the land mobile services
- ITU-R M.1024 – Personal radio system
- ITU-R M.1025 – Technical and operating characteristics of cordless telephones
- ITU-R M.1156 – Digital cellular public land mobile telecommunication systems (DCPLMTS)
- ITU-R M.1157 – Integration of public mobile radiocommunication systems
- ITU-R M.2014 – Digital land mobile systems for dispatch traffic
- ITU-R M.2033 – Radiocommunication objectives and requirements for public protection and disaster relief
- ITU-R M.2038 – Technology trends
- ITU-R M.2040 – Adaptive antennas concepts and key technical aspects

Handbooks

Land Mobile (including Wireless Access) Volume 1: Fixed Wireless Access – Second Edition.

Land Mobile (including Wireless Access) Volume 3: Dispatch and Advanced messaging Systems.

4 Definition

Software defined radio (SDR): 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 (see Recommendation ITU-R M.1797).

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.

5 Characteristics of SDR

5.1 Functional characteristics

The ability of a radio to emulate multiple air interfaces, add new ones as they are developed, and even act as a bridge between incompatible ones stems naturally from the SDR-supported ability to

add or reconfigure air interfaces by using software. SDR may lengthen the useful life of legacy systems, diminish the barriers to communications and ease the transition from legacy radios to new ones. The level of interoperability will develop incrementally as SDR technology advances and expands the universe of standards, frequency bands, and modulations over which SDR-enhanced equipment can operate reliably, and as other infrastructure issues that might hinder interoperability are resolved.

There are some practical considerations which may limit the use of SDR for a particular communication system, including power limitations, cost, size and weight. Technology advances may diminish these limitations with time. As the processing power of computer chip technology has allowed smaller and lighter computers with increased functionality, the same technology advances will allow more functions to be integrated into radio devices, including handheld devices.

An SDR capable of emulating a number of air interfaces today will still be able to emulate those same air interfaces over many years. However, SDR technology does not guard against eventual hardware obsolescence. There will come a point in time when future applications are too complicated to run on specific generation of hardware.

5.2 Operational characteristics

SDR can provide an effective means to bridge operational requirements involving multiple bands and protocols. However, unless the air interfaces are standardized or the software framework used to implement SDR is common, there will always be interoperability issues between radio vendors. These air interface protocols establish a language that the portable radio will use when speaking with the system. These standardized air interface protocols identify features, such as encryption, authentication, scanning, priority, emergency, caller-ID, and define how they will work. Radios developed using different proprietary air interfaces will not be able to communicate unless the air interfaces can be exchanged from one radio platform to another one. This exchange can be achieved if the air interfaces have been developed using a common software framework.

Services and applications can be implemented with SDR to facilitate interoperability in any of several ways. The specific method chosen will be market-driven, but the following are possible ways that interoperability can be achieved:

- 1 Bridging between multiple air interfaces.
- 2 Allowing a subscriber to enable his equipment to implement a specific service according to his/her requirements.
- 3 Device reconfiguration that includes everything from enabling tokens to entire protocol stacks and air interfaces. The specific reconfiguration process could itself take one of several possible forms, including:
 - over the air transmission;
 - infrared link;
 - download from a personal computer;
 - reconfiguration while in a battery charger;
 - factory authorized update at local kiosks; or
 - memory card insertion by a network operator.

The ability to reconfigure an SDR radio and system will require protection mechanisms. The radio must be protected from being reconfigured to transmit in an inappropriate way. The radio and system should be protected from reconfiguration by individuals with malicious intent and from inadvertent reconfiguration by authorized technicians.

An aspect of SDR that is important to mobile system interoperability is the SDR-enabled flexibility to allow operation with multiple air interfaces, given the use of available specifications, and across multiple RF bands. An SDR enabled portable device can be used in many different systems by employing its capability to operate in the particular RF band and over the particular air interface that is in use by the system. This allows a user with an SDR enabled portable device to roam into various different systems and communicate with the local users on that system. When an SDR enabled portable radio is used in conjunction with a system employing a cross-networking interface, a capability to communicate with local system users and remote users on other systems is established. The software in an SDR portable allows easy selection of the RF band, air interface, and group affiliation. The selection could be done automatically if the radio has policy-based or cognitive capabilities.

The ability described above, to allow heterogeneous radios to communicate together by changing their air interface, could be further enabled by the following items:

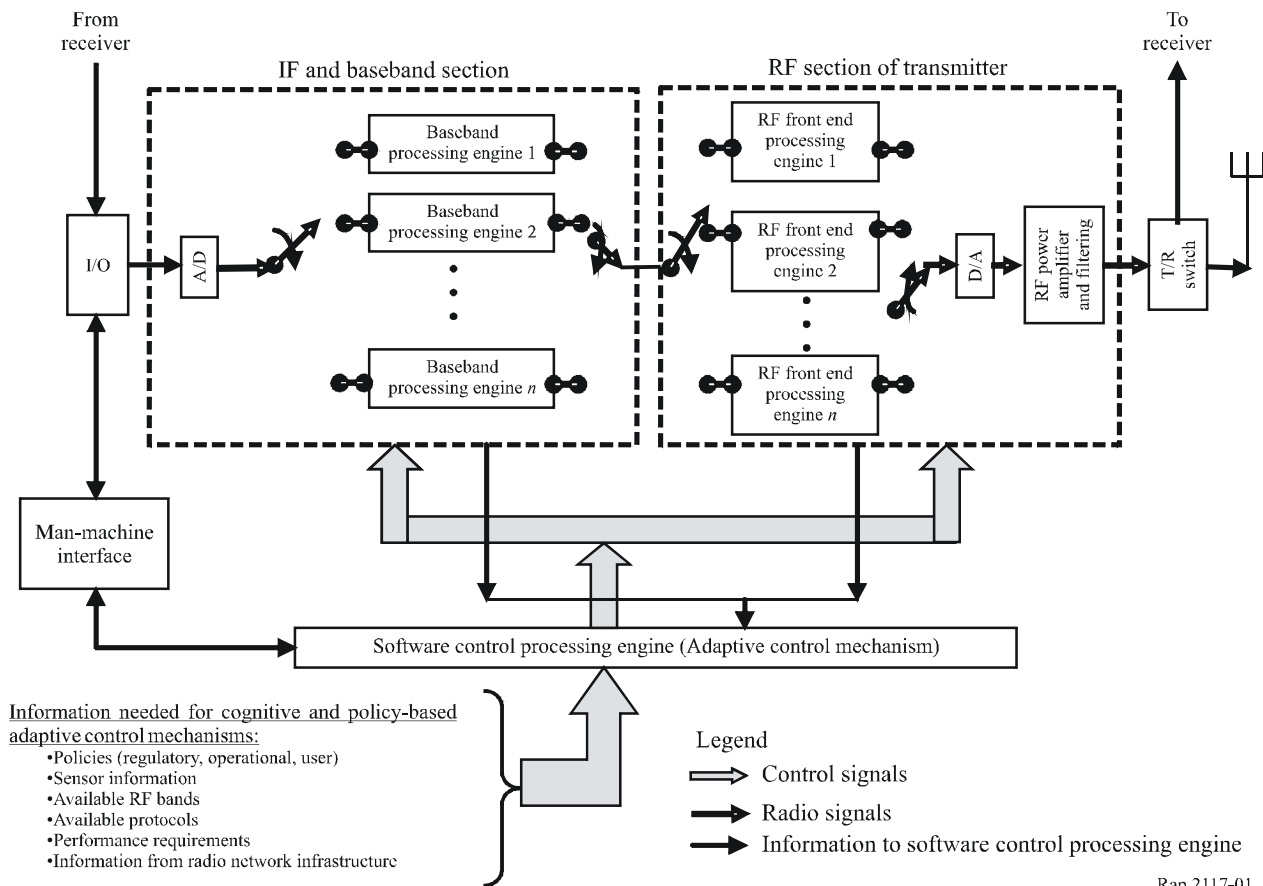
- The air interface specifications are made public so that every radio vendor can implement and offer them on their radio.
- The software architecture(s), on which the air interfaces are built, allows air interface software developed by Company A to be used on a Company B's radio.

5.3 Technical and architectural characteristics

Consistent with the definition of SDR provided in this report, a radio is considered to be a SDR if some or all of the baseband or RF signal processing is accomplished through the use of digital signal processing software and can be modified post manufacturing. This functionality is depicted in the upper portion of Fig. 1.

The air interface selection functionality, depicted in the lower portion of Fig. 1, is the control mechanism that selects the proper air interface to establish the communications and modifies the transmit/receive parameters accordingly. While this selection can be done manually, two adaptive control mechanisms have been identified: policy-based or cognitive. The difference between the two resides in their approach to derive to control the proper air interface. A description of the cognitive control mechanisms which can be used for SDR can be found in Annex A.

FIGURE 1
Example of SDR concepts



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The SDR abstraction includes a full chain of base-band hardware, signal-processing, interfaces and computing elements supported by suitable RF conversion and antenna technology. The RF components may be designed specifically for the individual frequency bands of interest for the particular system implementation. However, the base-band elements conform to the standardized architecture and software interface such that the waveform application software can be directly ported to another hardware platform with similar RF capabilities. This portability of waveform software among platforms and manufacturers is a key feature of this new generation of SDR. The base-band devices may include general purpose processors (GPP), digital signal processors (DSP) and field programmable gate arrays (FPGA) and are supported by the applications programming interface (API) of the radio software system (SCA). The SDR may thus include traditional sequential “turing machine” software sequences as well as coded hardware functions that are optimized for the particular desired waveform. The “software” of the SDR may thus include both traditional program coding as well as logic gate coding.

Systems developed that follow a standardized architecture will benefit from the economies of scale from a cross-industry user base for both hardware costs and software development. SDR systems are distinguished by following the standardized hardware and software architecture while the programmable digital radios follow a proprietary format.

At an international level, work has been done on the hardware and software architecture for a flexible SDR system, with strong interest in flexible radio systems to promote efficiency in their use of assigned channels, interoperability and lower costs. A software architecture specification called “software communications architecture” (SCA) provides a real-time software operating-system environment to support the dynamic waveform generation and signal processing aspects of a radio

as well as the administrative aspects for radio installation and change control³. Such an example of standardized architecture of hardware and software will lead to generic, flexible radio systems which may be loaded with applications to suit particular operating scenarios. They may later be reloaded and reconfigured to suit new opportunities. Some SDR may be flexible enough to operate in several modes at the same time and some may be capable of changing or adding modes while continuing operation in other modes.

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 the 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.

³ The SCA is not an operating system in itself, but a common set of features, interfaces and capabilities that are built on a real time operating system (RTOS).

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 Annex C, different organizations outside 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 system which is installed on a terminal to use their services.

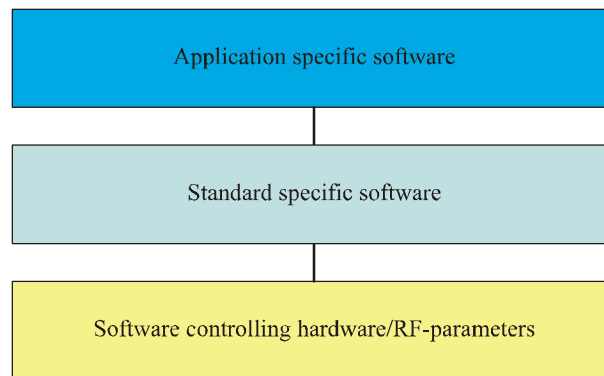
It is noted that output of ITU-T Study Group 17 on security aspects is relevant to this.

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 quite 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 manufactures normally offer suitable layer 1 software for the chips. In the long term it is conceivable that chip manufacturer 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 Potential regulatory implications

8.1 Interference considerations

The ability of an SDR to dynamically modify its operating parameters represents an asset of SDR in managing interference; however the potential for causing interference to other authorized radio services cannot be overlooked. The primary concern would come from SDRs that are remotely programmable and have the hardware capability to transmit in critical frequency bands in which they are not authorized.

The adequacy of the security requirements for SDR software is a key factor in ensuring equipment operates within its allowable parameters to avoid the emission of harmful interference. Recurring media reports of security flaws in software packages and operating systems highlight a concern that the software based security mechanisms employed in SDR could also be vulnerable. The main security issues related to SDR that have been identified include: who has the authority to control the reconfiguration of the communications equipment; protection of the reconfiguration signalling; privacy of the reconfiguration information; the correctness and availability of the information on which the reconfiguration is based; and secure download of the software required for reconfiguration and issues related to the radio emission and associated conformance requirements of radio equipment.

8.2 Spectrum management

Current spectrum management techniques provide for designating specific frequency bands for each mobile radio services. SDR provides legacy emulation of current radio implementations. As more services are added, there will come a time when spectrum allocations become more difficult.

There are portions of spectrum that are unused when considered on a time and geographical basis, i.e. used only in certain geographical areas or only for brief periods of time. Studies have shown that even a straightforward reuse of such spectrum can provide improvement in available capacity. SDR using cognitive or policy-based control mechanisms is one approach for achieving better spectrum utilization, dynamic spectrum management, and flexible spectrum use.

A growing number of regulatory agencies around the world believe that there is a need for a new approach to spectrum management, spectrum allocation and spectrum utilization. The new spectrum paradigm is driven, in part, by the increasingly keen competition for spectrum – a problem common to many parts of the world and to all segments of the communications industry: government, commercial wireless, public safety, etc.

The magnitude of the spectrum management task of not only comprehending all of the dynamic or temporal and spatial or geographical sharing requirements, but also anticipating changes to all of these sharing arrangements in order to code them into the devices *ex ante*, makes a strong case for devices to have the ability to have their operating parameters modifiable via software in the field. Equally important is the need to be able to change the policies that dictate the radio's behaviour.

In addition to current uses, SDR can assist to provide access to those bands already allocated to a particular service, as well as assisting in allocation of additional harmonized frequency bands for services. While the operating frequency and other channel parameters such as modulation type, error coding scheme and power could be manually selected, this would most likely be much too slow and be prone to errors which would result in unacceptable interferences.

Adaptive control mechanisms allowing dynamic access to spectrum such as policy-based and cognitive could be beneficial. In those cases, the radio would be made aware of its environment and automatically establish its operating parameters. The selection would be based on a number of rules-set to avoid interference. The input information to the control mechanism may include, for example:

- Policies (regulatory, operational, user).
- Sensor information.
- Available RF bands.
- Propagation data.
- Available protocols.
- Performance requirements.
- Information about the radio network infrastructure.

The main difference between the two mechanisms comes from their decision process. In the policy-based approach, a deterministic mechanism is used whereby the selection process is repeated for every new situation. In a cognitive approach, the mechanism is closer to Artificial Intelligence (AI) whereby a learning mechanism is implemented and the selection is based on past experience, therefore speeding up the process.

There are a number of research challenges to this adaptive spectrum management including:

- Wideband sensing.
- Opportunity identification.
- Network aspects of spectrum coordination when using adaptive spectrum management.
- Traceability so that sources can be identified in the event that interference does occur.
- Verification and accreditation.

8.3 Implications for certification and conformity

The impacts to certification arise from the fact that historical certification regimes have been developed based on an *ex ante* determination that the operating parameters of the device are in accordance with local regulations. Such regimes have no mechanisms to deal with a fundamental capability attributed to SDRs – that such devices can change their operating parameters *ex post* of its certification or declaration of conformity.

Administrations have also recognized the conformity issues and have begun activities to examine and/or modify conformity regulations to enable SDR devices to be deployed.

Common themes and questions are being addressed, including modifying existing conformity regulations to authorize the use of SDR and adaptive control mechanisms.

Certification and conformity issues:

- Enabling such radios to be reconfigured in the field by establishing rules to allow for equipment identification, recertification or declaration of conformity of such terminals post deployment.
- Conformance certification.
- Software installation issues such as:
 - Installation rights.
 - Installer certification.
 - Media delivery.

- User and operator installation.
- Installation procedures and mechanisms.
- Recovery from installation failure.
- Roaming and reconfiguration mechanisms.
- Prevention of unauthorized software changes.
- Prevention of harmful interference.

8.3.1 IMT-2000 technical considerations necessary to insure conformance with ITU Recommendations and Radio Regulations

World-wide 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 – Global circulation of IMT-2000 terminals.

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/marketing, 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.

8.4 Implications for circulation

In order to address the new scenarios introduced by SDR, it may be necessary to review the technical basis for circulation.

Common themes and questions arise when administrations examine existing conformity regulations to authorize the use of SDR. However, though common themes and questions are being addressed, different approaches might be taken by different administrations to achieve the desired effect.

For instance one administration may require a specific type approval for SDRs, requiring that the manufacturer take steps to ensure that only software that has been approved with a SDR can be loaded into such a radio. The software must not allow the user to operate the transmitter with frequencies, output power, modulation types or other parameters outside of those that were approved. Administrations with other conformity regimes might require different procedures.