REPORT ITU-R M.2064

Software-defined radio in the land mobile service

(Question ITU-R 230-8)

(2005)

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, 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. The requirements from, and application to, IMT-2000 are covered in a separate report (Report ITU-R M.2063).

3 Related documents

ITU-R Recommendations:

M.622	Technical and operational characteristics of analogue cellular systems for public land mobile telephone use
M.1032	Technical and operational characteristics of land mobile systems using multi-channel access techniques without a central controller
M.1033	Technical and operational characteristics of cordless telephones and cordless telecommunication systems
M.1073	Digital cellular land mobile telecommunication systems
M.1221	Technical and operational requirements for cellular multimode mobile radio stations
M.1450	Characteristics of broadband radio local area networks
M.1453	Intelligent transport systems – Dedicated short range communications at 5.8 GHz
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
M.1678	Adaptive antennas for mobile systems

Reports:

M.740 General aspects of cellular systems

M.742 Public land mobile telephone systems

M.1021 Equipment characteristics for digital transmission in the land mobile services

M.1024 Personal radio system

M.1025 Technical and operating characteristics of cordless telephones

M.1156 Digital cellular public land mobile telecommunication systems (DCPLMTS)

M.1157 Integration of public mobile radiocommunication systems

M.2014 Spectrum efficient digital land mobile systems for dispatch traffic

M.2033 Radiocommunication objectives and requirements for public protection and disaster relief

M.2038 Technology trends

M.2040 Adaptive antennas concepts and key technical aspects

M.2063 The impact of software-defined radios on IMT-2000, the future development of IMT-2000, and systems beyond IMT-2000

Handbooks:

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

Land Mobile (including Wireless Access) Volume 3: Dispatch and Paging Systems

4 Definition

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.

5 Characteristics of software-defined radios

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:

a) Bridging between multiple air interfaces.

b) Allowing a subscriber to enable his equipment to implement a specific service according to his/her requirements.

c) 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:

1 The air interface specifications are made public so that every radio vendor can implement and offer them on their radio.

2 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 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 control of the air interface. A description of the cognitive control mechanisms which can be used for software-defined radios can be found in Annex 1.

The SDR abstraction includes a full chain of baseband 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 baseband 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's. The baseband 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.

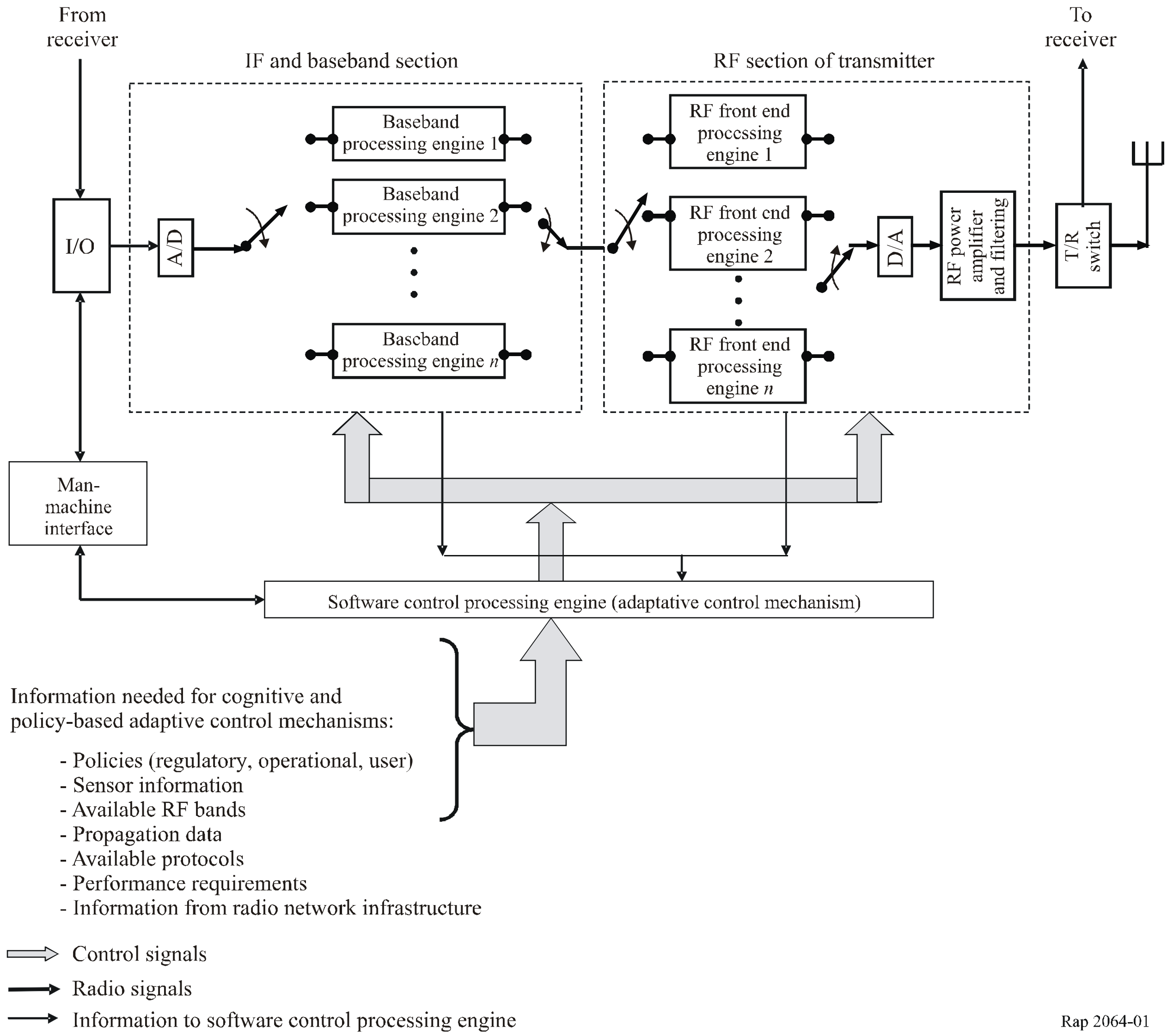
At an international level, work has been done on the hardware and software architecture for a flexible SDR system, with strong interest in flexible radio systems to promote efficiency in their use of assigned channels, interoperability and lower costs. A software architecture specification called "Software 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 control[1]. Such an example of standardized architecture of hardware and software will lead to generic, flexible radio systems

[1] 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).

which may be loaded with applications to suit particular operating scenarios. They may later be reloaded and reconfigured to suit new opportunities. Some software-defined radios 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.

FIGURE 1

Example of SDR concepts



6 Potential regulatory implications

6.1 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.

6.2 Spectrum management

Current spectrum management techniques provide for designating specific frequency bands for each mobile radio service. 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.

6.3 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 software-defined radios 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.

6.4 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 software-defined radios. 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.

7 SDR application to specific mobile systems

This section addresses the application and implications of SDR to various land mobile systems. Details of the requirements from, and application to, IMT-2000 and systems beyond IMT-2000 are specifically addressed in Report ITU-R M.2063 – The impact of software-defined radio on IMT-2000, the future development of IMT-2000 and systems beyond IMT-2000.

SDR offers advantages for many mobile systems at the functional level. Original equipment manufacturers (OEMs) serving increasing complex and diverse market conditions may be attracted by the ability to configure a standard product platform to address multiple markets. The benefits include lower costs, faster-to-market new products and better-tailored products for target markets. Thus the concept of a highly (re)configurable base station or handset is exceedingly attractive to radio OEMs even before consideration of multiband, multimode functionality, or in-use over-the-air reconfiguration.

7.1 Wireless access systems (WAS) including radio local area networks (RLAN)

WAS devices can operate on a licensed or licence-exempt basis. In addition to widespread deployment for networking computers in companies and for personal computers in private homes, many international carriers and service providers are offering service via "hot-spots". This has been termed "heterogeneous roaming" – staying connected to the same operators, but roaming between different air interfaces.

However, operations on a licence-exempt basis may raise some special considerations. Such operations can be localized and varied in nature. Such devices have traditionally been used for personal, localized purposes, rather than for widespread commercial services by major carriers or service providers. Thus, case-by-case treatment with regard to operating parameters may materially raise costs in the manufacturing and certification of the devices; uncertainty in product planning; and unreliability of QoS in operation. Many of the variations are small; the use of WAS is still allowed and viable but needs to be slightly different because of local needs. Examples are variations in power restrictions because of other devices sharing spectrum.

SDR will permit the manufacturer to develop a product once and then have it deployable globally, allowing jurisdictions to tailor it to fit local needs.

7.2 Public protection and disaster relief (PPDR)

A primary challenge which is often faced by the people and agencies responsible for PPDR operations is the incompatibility of the communications equipment that they use. It is frequently the case, even within a particular city, that the police, fire, and ambulance forces use incompatible equipment with incompatible protocols in incompatible bands. The situation is typically even worse across jurisdictions. This challenge reaches its height in the face of a large-scale emergency that requires the cooperation of first responders from multiple agencies and multiple jurisdictions. Larger emergencies increase the likelihood of non-interoperability and incompatibility of the communications systems used by the people and agencies whose cooperation is crucial to saving lives and resolving the crisis effectively.

Public safety and emergency responders need standards that lead both to interoperability and to cost-effective equipment and services for both routine and extraordinary operations. It is important that authorities and organizations around the world collaborate in the development of these standards for PPDR communications and that they share information on emerging technologies and services. Resolution 646 (WRC-03) – Public protection and disaster relief, was adopted to promote harmonization of spectrum for PPDR applications, and efforts are underway to develop harmonized standards for these bands. However, more can and should be done to address the existing problem of incompatible communications used by public safety agencies.

Enhancing voice communications is a critical component of PPDR operations. However, new data and video services will play an increasing important role in the future deployment of PPDR. Wideband and broadband applications that are dependent on the use of spectrum-efficient technologies will be an essential component.

Software-defined radios represent a strategic opportunity to meet many of these requirements. By allowing the dynamic reconfiguration of radio operational characteristics, SDRs provide a communications mechanism through which:

– individual agencies can function independently in normal operations, without interference from the equipment of other agencies; and
– agencies can communicate when cooperation is necessary.

7.2.1 Interoperability

Public safety systems can communicate across networks today, but only with difficulty. Such communications are currently accomplished by use of the dispatch operator and console cross-patch, or by bringing separate patch panel equipment to the field site, and attempting to connect to one of each kind of the field radio. This technique does not provide the sophisticated policing of priority-of-service rules required in multi-agency and multi-jurisdiction emergency situations. SDR technology in portable/mobile radios will be a prime enabler of more efficient and reliable cross-network communications in such situations. When fully implemented, SDR can lower the total cost of ownership of public-safety wireless communications while also improving system responsiveness to interoperability issues.

An aspect of SDR that is important to PPDR interoperability is the SDR-enabled flexibility to allow operation with multiple air interfaces as was described in sections above. The software in an SDR portable allows the user to easily select the RF band, air interface, and group affiliation. It presents these selections to the user in terms that can be easily understood. The benefit of SDR technology is increased when portable/mobile SDR equipment is used with an SDR-enabled system employing a cross-networking interface. The SDR-enabled infrastructure brings all of the participants of the group into the call when this is desired, regardless of the location, system, RF band, or air interface they are using.

Using SDR technology, public safety agencies can effectively achieve interoperable communications across a broad range of systems operating in different frequency bands and with different technologies. This challenge and approaches for addressing it are being pursued internationally. SDR technology provides the potential for operation/interoperability across multiple radio interface standards and bands of operation. This would enable interoperability among public safety agencies on multiple air interfaces, overlaying existing systems without disruption, upgrading legacy systems, including possible transition from one radio interface to another, and the easy selection of RF band, air interface, and group affiliation by users of portable SDR equipment.

7.2.2 Enhanced functions

Enhanced functions for the user are also possible with SDR technology that uses computer software to generate its operating parameters, particularly those involving waveforms and signal processing. This is currently in use by some government agencies and in some companies' products. In addition to SDR's ability to span multiple bands and multiple modes of operation, in the future it may be capable of adjusting its operating parameters, reconfiguring itself in response to changing environmental conditions. SDR systems could be capable of transmitting voice, video and data, and have the ability to incorporate cross-banding to communicate, bridge, and route communications across dissimilar systems.

7.2.3 Remote control

SDR systems could be remotely controlled and may be compatible with new products and backward-compatible with legacy systems. By building upon a common open architecture, this SDR system will improve interoperability by providing the ability to share waveform software between radios, even radios in different physical domains. Further, SDR technology could facilitate public protection organizations to operate in a harsh electromagnetic environment, to be less detectible by scanners, and to be protected from interference from sophisticated intentional interference and hacking. Additionally, this system could replace a number of radios currently operating over a wide range of frequencies and allow interoperation with radios operating in disparate portions of that spectrum.

7.3 Intelligent transport systems (ITS)

Various kinds of radio services are provided to vehicles at present. This includes, for example, broadcasting services such as FM radio, as well as TV, and ETC (electronic toll collection) services. VICS (vehicle information and communication service) are also provided in some regions. In addition to these radiocommunication services, other land mobile services such as cellular phones and radio LANs are also used for ITS applications such as traffic and traveller information, and emergency call notification.

Other applications include crash-avoidance technology which depends on a continuous, real-time understanding of the vehicle's driving environment. This understanding can clearly be enhanced and enlarged by using data derived from sources external to the vehicle, including land-based information centres and other vehicles. Real-time remote vehicle diagnostics depend on a similar data communications capability.

SDRs, therefore, will be an essential component of future suites of in-vehicle technologies.

The clear trend for the delivery of ITS messages is that they will be data messages, not voice technology messages. They will be handled by a dedicated, and possibly integrated in-vehicle data communication unit (DCU) that is completely separate and isolated from the vehicle's multimedia system (that handles general information and entertainment services) and from any personal communication devices that link wirelessly to the multimedia system (e.g. via Bluetooth) or through a docking cradle.

The communication technologies through which ITS-related messages will be transmitted and received are evolving and will undoubtedly continue to evolve. A collection of umbrella protocols will allow for transparent in-vehicle data communications via a variety of wireless media, for example 2.5 and 3rd generation cellular data messages, short-range microwave, millimetre wave, mobile wireless broadband, two-way satellite, etc. This collection will be expanded and refined with the arrival of new technologies and the improvement of existing ones. Some technologies may fall out of use over time.

7.3.1 Space considerations

Due to space and radio environments peculiar to vehicles, SDR is a very useful and effective technology to realize a multimode mobile terminal to handle a variety of radio systems in a vehicle.

In a vehicle, interior space is a very important factor and ensuring that this space is safe and comfortable for drivers is an important design issue. SDR technology, which makes it possible to integrate several kinds of radiocommunication equipment into one radio device, can contribute to the effective use of interior space of the vehicle.

7.3.2 Power considerations

Another consideration in the application of SDR to vehicles is that it is not necessary to be too concerned with the power consumption of the SDR equipment. In order to implement multiple-radio accessible functions into SDR equipment, large and high speed digital devices such as GPP, DSP and FPGA are required, and they consume much electric power. However, in-vehicle use, batteries and an electric power generator mounted in the vehicle can be used as the power source for the SDR equipment.

7.3.3 Reconfiguration considerations

Static reconfiguration of SDR equipment may be executed in the event that an existing radio system is enhanced or a new radio system is added as part of a vehicle service. For such remodelling of equipment, an adequate amount of digital devices should be estimated in advance.

Dynamic reconfiguration is required for the "vertical handover" among multiple heterogeneous radiocommunication systems. In this case, the ability to complete the reconfiguration quickly is one of the key factors in the design of SDR equipment.

Dynamic reconfiguration of ITS mobile terminals is particularly important to enable interoperability among ITS services. These services and technologies could include satellite positioning, mobile communications and 5.8 GHz microwave technologies SDR based on-board equipment designed to support all these possible services will enable users to avoid the need to have a multitude of on-board equipment within the vehicle.

Another issue to be considered is how to give SDR equipment the ability to handle multiple services simultaneously, that is, how to enable SDR equipment to process multiple radio services such as FM radio and ETC simultaneously. It is especially important to realize the road traffic safety and convenience of peer-to-peer and multipoint communication between vehicles and the roadside.

7.3.4 Service life considerations

Another key factor for the implementation of SDR in vehicles is the service life of private passenger cars which could average 12 years or more. Some vehicles have even longer service lives. The DCU must be functionally available for the entire service life of the vehicle. A significant burden is placed on in-vehicle SDRs' ability to remain upgradeable over a significant time span, for example throughout many generations of RF technologies. For example, the probability of encountering an avoidable crash situation and the probability of a remotely diagnosable fault increase with the vehicle's age. Therefore, the value of SDRs to remain upgradeable and reconfigurable increases in the later years of service. Advance planning and careful strategizing will be needed to enable a lifespan for in-vehicle SDRs that is far longer than non-vehicle radios. In-vehicle requirements imply the need for SDRs that are reconfigurable.

The physical longevity of the DCU is not the primary issue, although some steps may be needed to keep it in good working order. The important issue is for an aging DCU to be able to continue communicating through multiple generations of communications technology.

7.3.5 Cost considerations

The cost of maintaining the necessary longevity of the DCU can be significantly reduced by making the operating characteristics of the DCU software reconfigurable and remotely updatable, allowing it to adapt:

– to the mobile communications technologies currently available in the area that the vehicle is operating, and

– to changes in the characteristics and membership of this family of technologies.

7.3.6 Special requirements for software-defined radios in the vehicle

Some specific capabilities for SDRs are necessary to assuring the widest possible continuing availability of these ITS services. The radios may include software-controlled antenna filters to allow the use of new frequencies as they come online, and the software in in-vehicle SDRs must be kept up to date to the extent practical. This has two implications:

The first is that SDRs in vehicles should be capable of having their software updated and upgraded. The second is that this capability should be available for these radios without requiring physical maintenance (e.g. the replacement of a DSP or its 20-years-from-now equivalent). For vehicle manufacturers and vehicle equipment manufacturers as well as owners and drivers, updating of software will be more economical than physical component replacement. However, well-focused design and planning is required to make this capability available.

These requirements imply that the software for an in-vehicle SDR is not only updatable, but downloadable. It may be possible to transmit this software to the vehicle via the same mechanism used to deliver other ITS-related data messages – and the in-vehicle radio may be capable of receiving and installing these software updates.

These capabilities will maximize the ability of all equipped vehicles to communicate with one another and the infrastructure, and they will moderate the burden on the land-based communications utility to be infinitely backward compatible.

7.4 Other land mobile systems

Over the years, the development of better electronic equipment has allowed the channel spacing employed by the land mobile radio service to be decreased. Because of the need for backward compatibility, however, most of the land mobile radio services cannot take full, immediate advantage of the increased spectrum use for narrower channels. For example, legacy equipment does not have the capability to tune to the interstitial channels. Moreover, transition of these services from analogue to digital modulation techniques, which can support a more flexible and efficient use of the spectrum, has been difficult because of the backward compatibility requirement. SDR could facilitate this transition in channelization and modulation schemes in the land mobile radio service. By being able to switch modulation/detection schemes, to switch frequencies and bandwidths of operation, and possibly sense the characteristics of received signals and to institute actions based on these characteristics, SDR could operate in this transitional environment.

Annex 1

Technical characteristics of cognitive control mechanisms

The term "cognitive" has been used in the radio world to describe radio control mechanisms with varying levels of adaptive capability. In this Report, the definition of cognitive-based control mechanisms is drawn from technical definitions from the AI world along with specific considerations of the radio control domain.

The term "cognitive" comes to the radio community via the AI and computer science realm. The study of intelligence and reasoning systems in the AI sense can be shown to fall into two broad categories:

1 systems that think and act like humans; and

2 systems that think and act in a purely rational (e.g. "logical") manner.

In the AI literature, the term "cognitive" is consistently applied to systems that exhibit human-like qualities in its processing. Cognitive science is concerned with modelling machine reasoning processes in accordance with those exhibited by humans. The human-like processes are not limited to purely rational ones, but can encompass processes that are inconsistent with strict rationality when reasoning, problem solving, planning, and learning. Furthermore, the inputs, outputs, and internal behaviours of a cognitive system are consistent with human behaviour in both conduct and timing.

In this sense, a rational system obeys the well-defined laws of inference and logic in processing information. It may use a combination of deductive and inductive processes for reasoning, problem-solving, planning, and learning.

Clearly, a radio control mechanism that is useful and supportable must be deterministic insofar as it will obey a set of rules or policies that govern its behaviours, i.e. do the "right thing". These rules may be regulatory in nature (e.g. ensure the radio is not harmful to other radios) or optimizing (e.g. maximize or minimize a certain aspect of the radio's operation). Within that deterministic bound, the radio control mechanism may be free to adapt by whatever processes are deemed appropriate. These processes may be purely rational and deterministic or may incorporate non-rational processes for learning and adaptation.

In 1950, Alan Turing proposed a set of tests (known as the "Turing test") for a system to possess intelligence:

– natural language processing: communicates in human-understandable language;

– knowledge representation: store information (in an ordered manner);

– automated reasoning: answer questions and develop new conclusions;

– machine learning: adapt to new circumstances and detect/extrapolate new patterns.

Looking at the Turing test criteria, three of the four criteria are applicable to establishing the characteristics of cognitive-based control mechanisms. Control mechanisms with appropriate memory, software, and processing capabilities can store information (knowledge representation), reasoning in an automated manner to develop new conclusions, and employ machine learning processes. Radios, however, do not communicate with each other using human-understandable languages.

Applying practical considerations to the AI definitions of cognitive, the characteristics of a cognitive-based control mechanism emerges:

– maintains knowledge representation, automated reasoning, and machine learning capabilities in accordance with the Turing test;
– automated reasoning can be purely rational (deterministic) or can be inconsistent with strict rationality when reasoning, problem solving, planning, and learning;
– for practical implementations, the degree of inconsistent (non-deterministic) rationality must be limited by a deterministic bound such that it consistently obeys a set of rules or policies that govern its behaviour.

The use of "cognitive" throughout the wireless communications community spans the spectrum of dynamic radio control capabilities. It has been used to describe systems that mechanically adapt in a fixed fashion as well as ones that learn from past experiences and adapt how they operate accordingly.