



Application of Software Defined Radio (SDR) in Satellites

H. Kashi

PhD student of Satellite Technology Group, Department of New Technologies,
Iran University of Science and Technology (IUST), Tehran, Iran

M. Nasiri Sarvi

Assistant Professor of Satellite Technology Group, Department of New Technologies,
Iran University of Science and Technology (IUST), Tehran, Iran

Abstract

Nowadays, electronic and telecommunication systems play a significant role in human life. It can be claimed that the mentioned systems have penetrated almost all parts of the world and hardly anyone can be found who does not use this technology. Almost all the telecommunications devices around us use Software Defined Radio (SDR) technology in some way. In this article, we will first introduce software defined radio, introduce its various components, advantages and disadvantages, then describe its use in the satellite industry with regard to its most important advantage, which is reconfigurability.

Keywords: Software Defined Radio, Satellite, Reconfigurability, Flexibility, Responsibility.

1- Introduction

The ever-increasing progress of science and the increase in demand for wireless communication and the subsequent emergence of different communication protocols have caused the need for a telecommunication system that can work with different protocols and standards to be felt more than ever. It is clear that implementing such a system using hardware will cause many problems, including large volume and high cost. On the other hand, with the increase in computing power and speed of processors and the flexibility of software and digital systems, these systems are rapidly expanding and replacing analog systems. One of these changes is the introduction of a concept called software defined radio. By using software defined radio, it becomes possible that instead of common hardware in transmitter and receiver systems, high-speed processor chips by running the appropriate software and digital signal processing play its role. In this way, a software defined radio system can be used by using software codes for different telecommunication standards and different frequency bands. At the same time, the cost of producing and upgrading the system and services for the manufacturers of transmitter and receiver devices as well as for operators is reduced. Software defined radio was first proposed in 1991 by Joseph Mitola and the first article about it was published by him in 1992. Since that date, with the expansion of hardware technologies and software implementation techniques, the scope of software defined radio research has increased. Today, many transmitter and receiver systems, including mobile phones, are designed and marketed based on the principles of this technology. The use of software in the structure of the radio system provides the possibility of intelligentizing the behavior of the radio in different dimensions. For example, the radio system can act based on environmental changes and conditions in a way that quickly reacts appropriately based on the different needs of its users, increasing the efficiency of using the frequency spectrum and managing it, and reducing communication costs. The existence of the software allows all these optimizations to be done automatically without user intervention. [1]

2- What is Software Defined Radio (SDR)?

A radio is a device that sends and receives signals wirelessly to transmit information in the RF band. With this definition, all types of telecommunication transmitters and receivers are in a way a radio. All radio systems consist of relatively fixed parts that appear with differences in structure depending on the type and application. In general, radios are composed of similar components including antenna, amplifier, mixer and modulator.

Older radios are limited for multiple uses. The main reason is that in these systems, the performance can only be changed by changing the hardware, which results in a large cost imposed on the manufacturer and reduced flexibility. If a radio (for example, a mobile phone) needs to exchange information with different standards, if software is not used, new hardware facilities must be added to the system for each telecommunication protocol, which increases the complexity of the system, power consumption, volume and its price.

Software defined radio technology is a solution for this problem and makes it possible to have multi-band, multi-mode and multi-purpose telecommunication systems that can be improved with software upgrades; In this way, all telecommunication operations such as modulation, demodulation, etc. are performed by the software. The main advantage of this method is that instead of using additional circuits to access all kinds of radio signals, it is enough to use a suitable program. With this, a device based on the type of programming can be an AM radio or a cordless phone or act as a digital video, Wi-Fi or Bluetooth broadcasting system. This software flexibility provides the power to do difficult or even impossible tasks by traditional radios.

In fact, software defined radio is a type of technology that tries to increase the contribution of software in the implementation of telecommunication systems. According to Figure (1), in the ideal case, this contribution can be increased to the lowest physical layers and the closest position to the antenna, so that in the receiver's path, after receiving the signal from the antenna and amplifying it, the signal immediately Convert analog to digital and the rest of the operation is done by the software. In the same way, on the way of the transmitter, after all the work is done by the software, the digital samples are converted to analog and delivered to the antenna for sending. Of course, there are currently limitations for this work, including the limitation of the working rate and frequency of analog-to-digital and digital-to-analog converters, therefore, in practical cases, it is generally necessary to convert the analog signal to digital and vice versa in frequency Lower levels should be done and some processing should be done in the analog field.

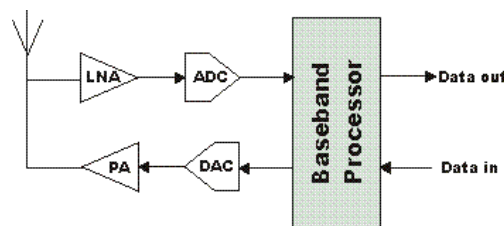


Figure (1): Ideal implementation of software defined radio

The key point in the capability of software defined radio is the ability to program the software, which provides the possibility to change the basic characteristics of the radio, including the type of modulation, operating frequency, bandwidth, and encryption and decryption algorithms. The platform for software implementation and execution in a software defined radio can be DSP, FPGA and embedded processors or even personal computer processors. [2]

2-1- Software Defined Radio Levels

In order to realize software defined radio, it is necessary to first convert the analog waves received in the receiver into digital symbols, after being transferred to the low frequency band, using analog-to-digital converters. In the transmitter units, the output of the software parts is converted into the analog signal sent using digital to analog converters. These converters are the border between hardware and software.

Among the characteristics that are of interest in these converters are sampling frequency, bit resolution, signal-to-noise ratio, power loss, linear behavior domain, etc., to reach the ideal state, the used converter must meet the specifications required by the designer.

For example, in order to convert discrete-time to continuous-time without losing information, it is necessary to observe the Nyquist rate, that is, at least twice the highest frequency of the analog signal in sampling. On the other hand, in order to implement the ideal software of all parts of the radio, analog-to-digital and digital-to-analog converters should be moved to the closest part to the antenna as much as possible, so that a larger part of the structure of the radio should be realized in the digital field. But analog signals are located near the antenna at relatively high frequencies. Therefore, due to the limitations of choosing converters and processors, converters may be placed in middle frequency classes. In this way, a smaller share of the implementation will reach the software units.

Therefore, as shown in figure (2), according to the amount of software usage, three different levels for software defined radio implementation are defined as follows:

- If digitization is done after RF signal transmission to intermediate frequencies, it is called Software Defined Radio (SDR). It is clear that on the transmitter side, the digital to analog converter is placed in a similar position.
- If analog to digital conversion is done immediately after the antenna or very close to it, it is called Software defined radio (SR), which requires the use of high-speed converters and fast digital processing.
- If intelligence capability is added to SR in such a way that it can make decisions according to the used environment and adapt itself to the environment, it is called Adaptive Intelligent Software defined radio (AI-SR). [2]

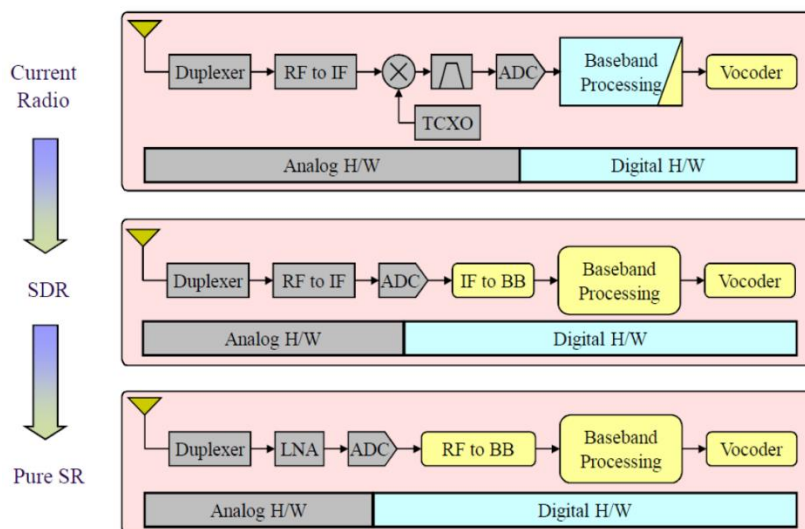


Figure (2): Comparison of the share of software and hardware in conventional radio and SDR and SR [2]

2-2- Software Defined Radio Advantages

Software defined radio will have many benefits for telecommunication equipment manufacturers and consumers. The most important of these benefits are:

- Price reduction: Usually, due to the reduction in the number of required parts and the possibility of reusing previous designs, the cost of software defined radio systems is lower than hardware systems. Especially in mass production, this difference will be more noticeable.
- Ease of design, construction and upgrade: in general, the equipment that works in the RF range, due to the high working frequency, has complex behaviors, and as a result, their construction requires great precision. Now, if we have several systems with different hardware and we want these components to work optimally with each other, it will be equally difficult. This issue makes the stages of designing, manufacturing and implementing a new device longer. In case of using software defined radio, the earlier the digitalization of the signal happens in the receiver, the less the need to coordinate the hardware components and the simpler and faster the design cycle of a new product. and

it will be possible to reuse previous designs. Also, upgrading a software-based system is much easier than a hardware-based system. In these systems, the efficiency and performance of the system can be improved only by updating the software.

- Support of different standards: In traditional radios, both sides of the communication must follow a single standard, and the lack of compatibility between the two sides prevents communication. In addition, telecommunication systems in different geographical areas use different standards for providing services, which, if compatibility is established between different areas, the coverage of services in wider areas is convenient. It happens more. It is easier to provide compatibility between different communication standards in software environments and through processing algorithms, and by using software defined radio, a system can meet different needs in this field. [3]

2-3- Software Defined Radio Limitations

In addition to the mentioned advantages, this technology also has disadvantages and limitations, which can be mentioned as follows:

- Due to the use of processors and hardware designed for general use, power consumption may increase.
- If the tasks of different parts of the system become more complex, the amount of software that must be stored in digital processors increases and the time of software storage and execution becomes longer. With the increase in the volume of software, management and considering the appropriate architecture for it will be very necessary and a specialized matter.
- Due to the multiple standards of the system and the existence of different frequency bands, broadband antennas and RF class with wide bandwidth are needed. As a result, designing the RF layer and choosing the right antenna is very important in software defined radio. It should be noted that due to the limited bandwidth of antennas, it may be necessary to use several antennas, which is not very desirable in mobile terminals.
- Due to the multi-mode and multi-standard nature of software defined radio, as well as the wide bandwidth of the RF layer, the dynamic range of the received signal is greater than that of conventional systems. As a result, due to the limited dynamic range of existing analog-to-digital converters, a compromise must be made in system design and converter selection.
- In the software stored in the system, the system specifications and all kinds of skills and techniques used by the programmer, including optimization methods and calculation algorithms can be obtained in software form and this it is possible that these skills are illegally discovered by competitors.
- Software programming and the possibility of tampering by non-responsible persons can cause problems and these devices can be used for anti-security purposes. [3]

3- Software Payloads in Satellites

Software defined radio has been a hot topic for more than a decade and has found several interpretations over the years. IEEE recently provided this definition of software defined radio: A radio is considered a software defined radio if some or all of the baseband or RF signal processing is performed through the use of digital signal processing software. and can be edited after production.

For space applications, the concept of software defined radio is a software-based payload that remains limited to simple or low-rate functions as it can be for space exploration applications, for example. In this framework, NASA is active in the development of software defined radio technologies. In particular, NASA is developing an open architecture framework to achieve highly efficient software defined radio architectures (specifically for telemetry links). NASA is also funding space radiation tests of an SRAM-based FPGA (manufactured by Xilinx). Also, in the Electra radio that was sent to Mars, a software defined radio method was used for the TT&C system.

But taking into account the payload of new telecommunication satellites, software defined radio is much more challenging. First, everyone can ask themselves what is the added value of software defined radio in telecommunication satellite networks. The following can be mentioned in the answer:

- By using software defined radio in telecommunication cargoes, the on-board processor can be adapted to the new wave specifications.
 - Using software defined radio, you can implement reconfigurable satellite payloads, terminals and gateways.
 - Using software defined radio, terrestrial and satellite networks with different standards can be more easily integrated.
- The first requirement for software payloads is a flexible front-end section in the RF band, followed by an analog-to-digital conversion. In fact, the flexibility of the baseband alone cannot be fully exploited unless it is accompanied by the flexibility of the front-end part of the RF band. The most difficult issue in achieving flexibility is that the satellite payload can accommodate a limited number of high-power elements such as high-power amplifiers. Figure (3) shows the block diagram of a software package.

Reconfigurable antennas on the receiving side can adapt the needs of the covered area and beam shape to the desired traffic and services. Recently, active antenna is used for this purpose. After transferring to a low frequency band to a suitable IF frequency, analog to digital conversion is done. At this stage, software defined radio technologies come into play. Initially, digital beamforming and channelization operations do not require reconfigurability. This enables effective implementation of these functions in ASIC technology. DSP algorithm design embedded in ASIC elements can provide the required level of on-the-fly reconfigurability. Although the ASIC design cannot be edited on the fly, by controlling the digital beamforming coefficients and frequency demultiplexer settings from the ground, the satellite

antenna beam layout, frequency reuse scheme, and frequency allocation of each beam can be controlled. edited Digital beamforming network can also be used to support pointing error corrections in electronic antennas.

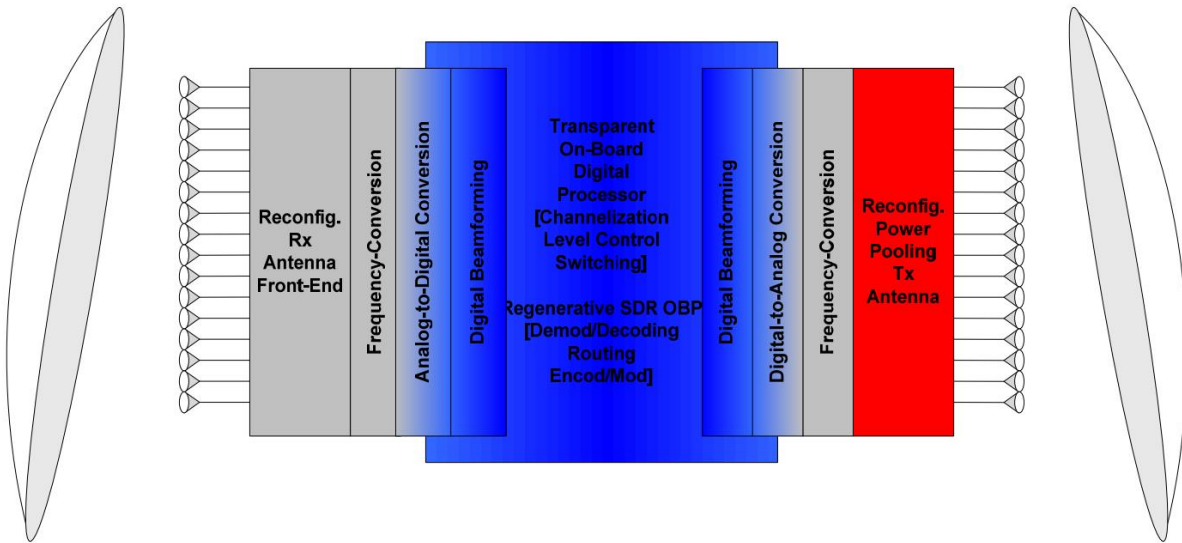


Figure (3) block diagram of telecommunications payload architecture with software payload support [4]

Operators currently prefer the use of transparent satellite transponders (bent tube) to have the maximum useful use of the cargo in the future. It is also clear that the multi-star architecture in a satellite network with bent tube transponders meets the needs of a wide range of applications. Despite the wide application of flexible transparent payload architecture, there are cases where network architectures are required. [4]

4- Reconfigurability, Flexibility and Responsibility in Satellite Payloads

The need for the reconfigurability of the shipments arose as soon as they became more complex. Beam-forming antennas and multi-beam antennas provide greater gain and reduce interference from one system to another, but limit the freedom in allocating bandwidth and RF power sources. . In multi-beam shipments, it is also possible to connect beam to beam.

In order to meet the evolving requirements of a highly unpredictable market during the lifetime of a satellite, techniques and technologies have been developed over the years.

But the evolution of mission requirements is not the only reason for the move towards flexibility, another very important issue is that with the advent of digital telecommunications, technology obsolescence has become more apparent.

One of the obvious features of digital telecommunications is the continuous evolution of air interfaces (i.e. the conversion of protocols and formats of the physical layer to the OSI layer). What on earth can lead to expensive upgrade of software and possibly physical components of a network in the worst case, in satellite systems can lead to a much more costly reality: obsolescence. Unless that satellite is based on transparent cargo.

Today, satellites are designed and built for a lifespan of fifteen years or more in orbit. In fact, fifteen years means several generations of software and hardware evolution. The rapid evolution of digital hardware technologies, software, modulation and coding standards, telecommunication protocols and formats, is one of the reasons why there is little demand for remanufactured shipments. Transparent bent tube transponder architectures or transparent digital signal processing transponders can adapt to evolving modulations, protocols and formats, provided that the operating frequency and channel bandwidth change. Don't make it noticeable.

As a result, the answer to the obsolescence problem can be in two ways: simple shipments or flexible shipments. However, the need for flexibility arises from many other conditions, including the specialization of the satellite telecommunication market. [5]

Today, satellite operators are more concerned about investment, flexibility and reliability than technological developments. There are also concerns from space insurance companies about the reliability of newly designed components and emerging technologies. As mentioned earlier, flexibility in the circuit is necessary to adapt to changing business conditions or to face critical situations. Customer needs are moving towards more ERIP, more bandwidth, reconfigurable coverage areas, higher reliability and flexibility to adapt to digital standards. The main challenge is to achieve higher payload flexibility and efficiency without significantly increasing complexity and cost. On the other hand, satellite manufacturers expect significant benefits due to the use of multi-purpose payloads, mainly in terms of development planning and reduction of recurring costs.

The main concepts of reconfigurability and flexibility are evolving and merging into a more general concept, which we call "Responsibility". Responsibility in satellite telecommunication payloads can be defined as "the ability to react

to various forms of uncertainty" that includes a wide range, from geopolitical operational requirements to technology obsolescence to technical failures.

The need for accountability can lead to a revolution in the design of satellite payloads. In addition to focusing on technical requirements, which has happened so far, the development of highly customized (and expensive) solutions, architectures with inherent reconfigurability and flexibility should be considered.

Technological progress can play a savior role this time. Because according to Moore's law, the efficiency of digital microelectronic technology on the board doubles every 18 months. This means that in the next few years, we will witness the use of digital bent pipe shipments for broadband applications. Similarly, we can expect software defined radios in use to revive remanufactured payloads by overcoming technical obsolescence and incompatibility with evolving air interfaces. [6]

5- Technological bottlenecks of software payloads implementation in satellites

The possibility of realizing the digital part of a software shipment depends on technological advances in a number of key areas, which are mentioned below:

- ASICs technology resistant to heavy particle radiation: According to the predictions of the International Semiconductor Technology Roadmap, the width of CMOS gates is steadily decreasing from micrometers to nanometers. As a disadvantage, the supply voltage is currently decreasing to 1 V, which leads to a decrease in the efficiency of DC to DC converters, an increase in ohmic losses, and a higher sensitivity to noise. Also, in low dimensions, the cost of making photolithography masks increases drastically.
- DSP and FPGA technology: DSPs, which are considered as fully programmable processors, are able to implement an unlimited number of functions at the cost of limited speed and complexity (per device). Also, FPGA-based solutions can be an intermediate method between fully programmable DSPs and hardware ASICs. The reconfigurability of an on-board DSP/FPGA includes performance, management and control functions, such as: software transfer (download), storage, installation, testing, failure reporting, etc.
- Analog-to-digital and digital-to-analog converters with high speed and low power consumption: analog-to-digital and digital-to-analog converters play a key role in the transition between the analog and digital domains. Unfortunately, the speed of development of converter technology is lower than the speed of ASIC technology development.
- High-speed serial links: Along with the processing capabilities of ASIC cores, it is necessary to increase the efficiency of data transfer (between ASICs, boards and equipment) using a high-speed serial link. To connect over long distances, you can use a high-speed serial connection with an electrical interface but with an optical transmitter and receiver, or replace the copper cable with an optical fiber.
- High-Density Modular Packaging: High density and thermally efficient packaging is required to meet the demand of integrating increasing functions on a single chip. The sensitivity of packaging technology is increased due to the need to control interference effects for high-speed serial link intermediate connections.
- Simultaneous design and optimization of architecture and algorithm: it is clear that the ability to reconfigure the software load may be obtained at the cost of increasing power, mass and complexity. Therefore, full use of all degrees of freedom in design is mandatory. This goal can only be achieved by simultaneous design and optimization of cargo architecture and algorithm. [7]

6- Conclusions

In this article, we first introduced Software Defined Radio and its different types, and then introduced its various components, advantages and disadvantages. After that, we described the requirement of reconfigurability, flexibility and responsibility in satellite payloads and showed the compatibility of these requirements with the features of software Defined radio, and then We examined the technological bottlenecks of implementing software payloads in satellites.

References

- [1] Enrico Mioso, Mattia Bonomi, "An SDR-based Reconfigurable Multicarrier Transceiver for Terrestrial and Satellite Communications", IEEE, 2017
- [2] Nivin R, Dr. J Sheeba Rani, Vidhya P, "Design and Hardware Implementation of Reconfigurable Nano Satellite Communication System Using FPGA Based SDR for FM/FSK Demodulation and BPSK Modulation", 2016 International Conference on Communication Systems and Networks (ComNet), 2016
- [3] Michael Caffrey, Michael Wirthlin, William Howes, Daniel Richins, Diane Roussel Dupre, Scott Robinson2, Anthony Nelson and Anthony salazar, "On-Orbit Flight Results from the Reconfigurable Cibola Flight Experiment Satellite (CFESat)", IEEE Symposium on Field-Programmable Custom Computing Machines, 2009
- [4] Piero Angeletti and Riccardo De Gaudenzi, Marco Lisi, "From Bent Pipes to Software Defined Payloads: Evolution and Trends of Satellite Communications Systems", American Institute of Aeronautics and Astronautics, 2008



- [5] Jon Hamkins and Marvin K. Simon, Editors, “Autonomous Software-Defined Radio Receivers for Deep Space Applications”, NASA, Ch 2, 2006
- [6] Mamatha R. Maheshwarappa, Christopher P. Bridges, “Software Defined Radios for Small Satellites”, 2014 NASA/ESA Conference on Adaptive Hardware and Systems (AHS), pp. 172-179, 2014
- [7] Chi-Yuan Chen, Fan-Hsun Tseng, Kai-Di Chang, Han-Chieh Chao and Jiann-Liang Chen, “Reconfigurable Software Defined Radio and Its Applications”, Tamkang Journal of Science and Engineering, Vol. 13, No. 1, pp. 29-38, 2010