10.53477/2284-9378-21-26

RADIO SPECTRUM MANAGEMENT IN MODERN MILITARY ACTIONS

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Due to the continuous development of civil and military communications and information technology services, in an era of digitalization in which the need to allocate, allot or assign a much larger number of frequency bands is essential, it is necessary to adopt national and international rules and guidelines for sharing and efficiently managing the radio spectrum. The use of modern and / or emerging technologies involved in current or future military actions is dependent on the use of radio spectrum in an increasingly congested, contested and constrained electromagnetic operational environment.

Keywords: radio spectrum management; UAS; radio communications; spatial frequency spectrum; 5G; CEMA.

The fact that radio spectrum is a valuable, necessary but limited resource must be effectively managed and capitalized by each responsible structure.

Due to the peculiarities of radio wave propagation, they can go beyond the borders of a state and can interfere with those of neighboring states, which is why it is necessary to ensure proper management and strict compliance with common standards and regulations at national and international level.

From a military perspective, land, naval, air, cybernetic and cosmic operations are based on technological capabilities that use and consume radio spectrum resources. In order to successfully complete the missions, it is necessary to optimize the way in which the own equipment benefits from the radio spectrum, but at the same time limits the access of the enemy in the own radio networks.

Starting from the desideratum presented above, through this article I set out to analyze the importance of radio spectrum management beginning with the national and international organizations that regulate it and to clarify its implications in current and future military actions.

National and international organizations

The International Telecommunication Union – ITU is a UN agency that aims to regulate radio spectrum worldwide. ITU organizes world conferences to update Radio Regulations and Regional Conventions on the use of radio spectrum, ensures cooperation in the field of telecommunications to eliminate interference between communications of different states, approves technical characteristics and operational procedures of radio communication services and systems, promotes international cooperation with on the allocation of satellite frequencies, advocates for the improvement of the global communications infrastructure, etc.

ITU divided the world into 3 regions according to Figure 1, Romania being in region 1, along with most NATO member states (except Canada and the USA).

The allotment of frequency bands in each region is not similar, which raises a number of issues that require regional discussion forums and world radio communication conferences to find solutions. From the perspective of coalition forces, ITU maintains good cooperation among international frequency band allotments, the host country and the area of interest.

At European level, the intergovernmental organization *European Conference of Postal and Telecommunications Administrations* (CEPT) brings together the administrations and regulators in the field. Its main duties are to establish scenarios on the electromagnetic spectrum, taking into account the development of technology and the market, the adoption and promotion of joint European proposals in the ITU, the harmonization of regulations in the field of telecommunications and postal services, etc.

In NATO, the structure that has authority in the field of radio management is *NATO's Spectrum*

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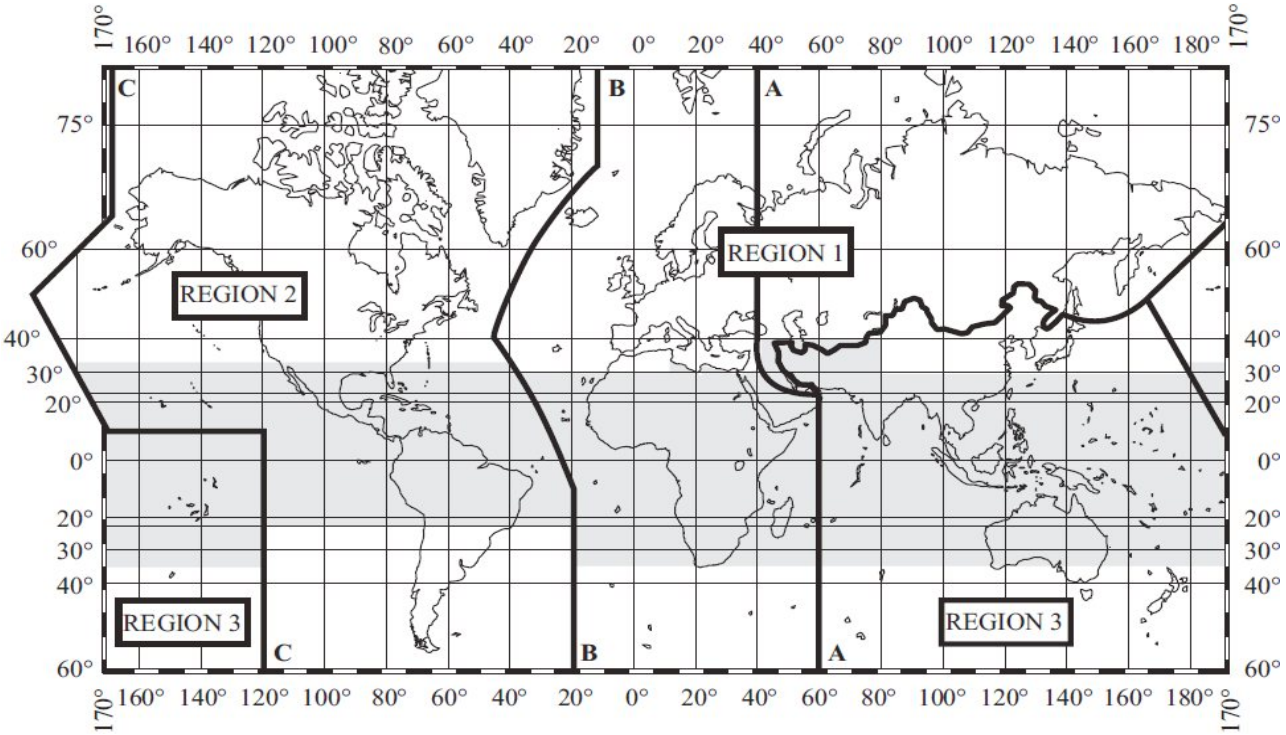

Figure 1 *Harmonization of frequency bands worldwide*[1]

and C3 Infrastructure Branch (SC3IB). The NATO Joint Civil / Military Frequency Agreement (NJFA)[2] regulates NATO's access to the spectral resource, establishes and allocates the necessary frequency bands to military equipment, which member countries include in their national allocation tables. As an observation, NATO is not a member of the ITU and cannot send representatives to decision-making forums, but its interests are represented by the member states of the Alliance.

NATO structures are not allowed to use the radio spectrum allocated for the territory of a state, even if it is a member of the alliance, without requesting Radio Frequency Support. This is a mandatory step for NATO in authorizing and allocating frequencies on the territory of a state.

The NATO doctrine clearly specifies the difference between the responsibilities of radio spectrum management and radio frequency management. In the *ACP-190 NATO Supp-1*, spectrum management (SM) represents the totality of "process of identification and efficient use of the available RF electromagnetic spectrum for military purposes"[3], and frequency management (FM) is "a sub-process of SM to provide coordinated frequency assignments & allotments to military users and to resolve interference"[4]. Radio spectrum management ensures the planning, coordination and management of the use of electromagnetic spectrum, allowing military radio equipment to operate without limitations or to be affected by the interference from the radio systems of its own or partner forces. Radio frequency management aims to streamline frequencies in the *Area of Responsibility* (AOR).

According to ITU regulations, each Member State has national radio frequency management agencies intended to manage the electromagnetic spectrum within its borders and to cooperate with international organization in the field. In Romania, the National Authority for Management and Regulation in Communications (ANCOM) ensures electromagnetic compatibility, manages the radio spectrum specific to electronic communications and controls the radio equipment on the market. As the radio spectrum is considered a sovereign good, each state has a National Table for Frequencies Allocation (TNABF) through which it efficiently manages its frequency bands in the national interest, but without contradicting regulations of the organizations to which it belongs.

The Military Agency for Radio Frequency Management (AMMFR) is the structure of the Romanian Army having as field of responsibility the management of radio spectrum resources by the armed forces on the national territory, of

cooperation with similar structures for participation in joint actions outside the country, which establishes the principles and general rules in the field of electromagnetic compatibility.

Implications of radio spectrum management in military actions

Radio spectrum management is an analytical, procedural and political challenge to plan and use frequency bands. The military has become increasingly dependent on wireless communications, navigation and surveillance systems, long-distance connections, cyber and electronic actions, to support a wide variety of operational missions. The most important resource that any wireless system needs is the radio frequency through which to communicate. The unallocated radio spectrum has become very limited and as a result its commercial value has continuously increased. Government agencies competing with private companies are finding it increasingly difficult to purchase new frequency bands for modern systems and equipment and even retain those they have used for years.

When we talk about military actions in AOR we agree that the Electromagnetic Spectrum (EMS) makes the connection for all 5 domains, which must ensure the efficient and timely command and control process. For NATO, the electromagnetic spectrum is an essential part of military operations and is seen as an operational environment in which alliance forces benefit from its effects to support the commander's intention. Electromagnetic Battle Management ensures dynamic monitoring, plans and coordinates joint operations in the electromagnetic spectrum, integrates data and information from sensors, technology and fighters to ensure a Recognised Electromagnetic Picture of the battlefield. Spectrum needs result in an increasingly *congested, contested and constrained*[5] electromagnetic operating environment, generically called *complex*. According to the *Electromagnetic Spectrum Superiority Strategy*, the electromagnetic operating environment is:

- *congested* because military and civilian EMS-dependent systems continue to crowd the spectrum and increase the amount of unintentional interference;
- *contested* because enemy activities detect, disrupt, exploit, degrade, deny, deceive or destroy friendly EMS capabilities for military gain;
- *constrained* due to domestic and international regulations that reduce the spectrum available for military access.

Radio frequency spectrum refers to electromagnetic radiation which, depending on the frequency or wavelength, can be used in different

Frequency (Hz.)	Abbreviation	Band
3 kHz – 30 kHz	VLF	Very Low Frequency
30 kHz – 300 kHz	LF	Low Frequency
300 kHz – 3000 kHz (3 MHz)	MF	Medium Frequency
3 MHz – 30 MHz	HF	High Frequency
30 MHz – 300 MHz	VHF	Very High Frequency
300 MHz – 3000 MHz (3 GHz)	UHF	Ultra High Frequency
3 GHz – 30 GHz	SHF	Super High Frequency
30 GHz – 300 GHz	EHF	Extremely High Frequency
300 GHz – 3000 GHz	THF[6]	Tremendously High Frequency

Figure 2 *Radio frequency spectrum*[7] *– adaptation*

civilian or military fields (Figure 2). The radio frequency spectrum comprises 9 frequency ranges between 3 kHz and 3000 GHz.

Radio spectrum management in Romania is based on TNABF which contains information about: allocation of radio frequency bands on radio communication services at ITU, CEPT and national level, their uses at European and national level, regulations applicable in CEPT and Romania for different bands of frequencies and usage status.

Aiming to maximize radio spectrum resources and minimize overlaps, but also to prevent unauthorized or improper use, radio spectrum management is "the combination of administrative, scientific and technical procedures necessary to ensure the efficient operation of radio communication equipment and services without causing prejudicial interference"[8]. The objective of the frequency manager is to adopt optimal decisions for the operation of communication networks in concrete conditions, sometimes uncertain in the electromagnetic environment. It ensures compliance with military policies, rules and procedures for regulating local radio, and the application of effective *Electronic Counter Measure* (ECM) practices.

In modern combat actions, the commander is supported in making the decision by a large number of systems/equipment that mostly use radio spectrum. Without proper management of radio frequencies, saturation will soon be reached which will lead to compromises in the full exploitation of resources and will affect the performance of the mission. The commander and staff must also understand that the spectrum allotted to a mission is limited and must be used effectively to multiply combat power, without interfering with their own equipment and to conduct command and control during military operations.

Communications and IT systems planners design and implement the communications networks needed to conduct an operation, and the frequency manager uses this design to determine the frequency requirements, to provide operational support by deconflicting and resolving interference.

Radio spectrum management is responsible for the development and maintenance of radio communications infrastructure, as well as the introduction and development of new C2 defence capabilities in an environment where the density of equipment and systems is constantly increasing. Along with traditional radio communications, current and future challenges come from the area of 5G technology, satellite links, UAS, cyber and electromagnetic activities, etc. Next I will present four pillars of the field of communications from the perspective of radio spectrum management, in optimizing the access of own systems / equipment to radio bands, in the conditions of the presence of the enemy in electromagnetic environment.

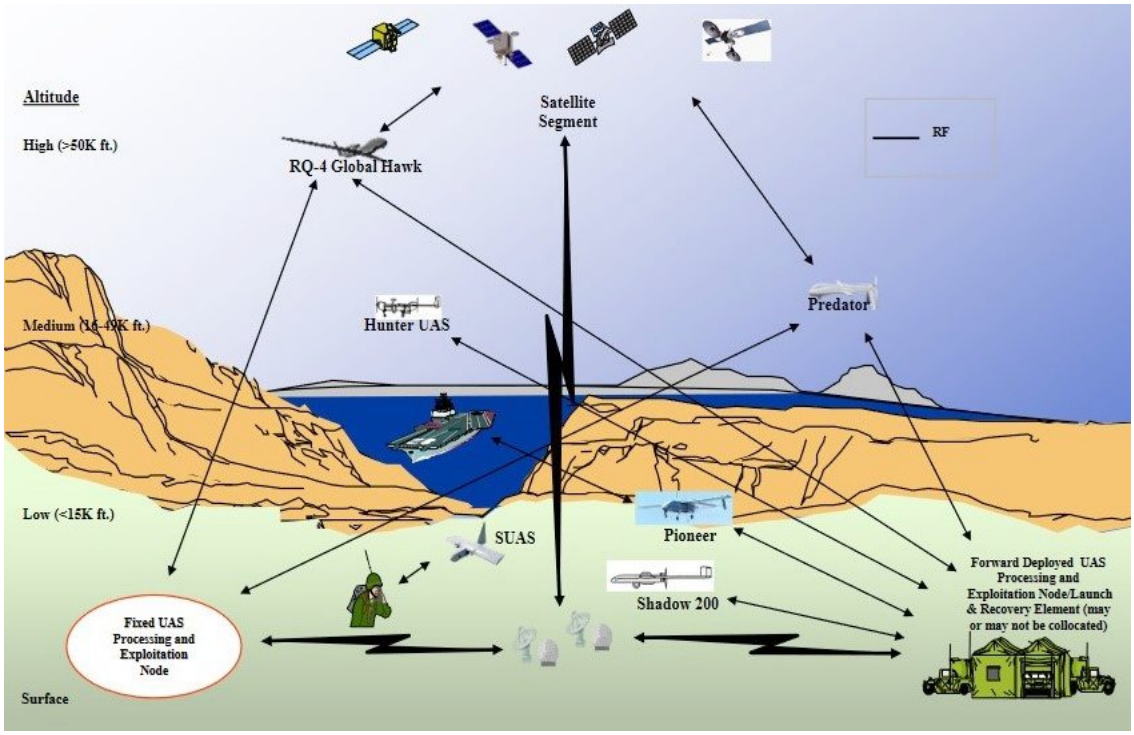

Figure 3 *UAS Architecture*[10]

Satellite frequency band	Frequency band (GHz)	Satellite services
L	1-2	Mobile Satellite Service (MSS), Radionavigation Satellite Service.
S	2-4	Radars, MSS, Broadcasting Satellite, Space Research.
C	3,4-7	Fixed Satellite Service (FSS), VSATs, Direct-To-Home (DTH).
X	7-10	Radars, Satellite Imaging, Space Research.
Ku	10-15	FSS, VSAT, MSS, Broadcasting Satellite.
Ka	17,7 -21,2 27,5-31	FSS broadband, inter-satellite link, MSS, military/commercial FSS.
Q și V	42,5-52,4 37,5-50,2	FSS broadband, inter-satellite link, MSS, military/commercial FSS.

Figure 4 *Satellite frequency bands*[11]

UAS – Unmanned Aircraft Systems

Unmanned Aircraft Systems need secure and interference-free communications because they are in a network that also includes ground control stations, air traffic control systems, satellite systems, other UAS, etc.

NATO categorizes UAS into 3 dedicated classes[9]: Class I for micro, mini and small ones, Class II for medium-sized tactical systems, and Class III for those flying at Medium and High Altitude, but also with Long Endurance. Depending on the size, the altitude at which it flies, the duration of operation, etc. it requires different approaches to using the radio spectrum in which it works. In the UAS architecture model presented in the US Army, the spectrum needs represent a challenge for a frequency manager in a joint operation like the one in Figure 3.

UAS can be used in gathering information from the electromagnetic spectrum, performing SIGINT – Signal Intelligence services, artillery guidance, with the role of radio relay, jamming of enemy communications, etc. The sensors are installed on UAS platforms for locating, identifying and intercepting radio transmitters.

The electromagnetic environment ensures the realization of specific UAS communications, using radio frequencies, both on direct wave (Line Of Sight – LOS) migrating to the 14/15 GHz band for some of the medium or large systems, and on indirect wave (Beyond Line Of Sight – BLOS) – mainly military satellite links (SATCOM) in the 20/30 GHz band, being considered the best solution. The most used radio frequency bands for UAS communications are: L, C, X, K_u, K.

From the point of view of radio spectrum, the UAS problem is related to the absence of international dedication and protection of frequencies against harmful interference, so that they are able to maintain a high level of integrity and availability.

Spatial frequency spectrum

Due to the increase in the number, use and size of satellites, congestion of lower frequency bands has become a problem. A real challenge is the discovery of new technologies through which satellite links can be made through higher frequency bands. Figure 4 shows the frequency bands and satellite services that are generally used for satellite links.

The frequency bands are indicative, they are adjusted according to each region according to the division of ITU-RR, but also by the allocation of the frequency bands according to the relevant

TNABF at the level of each state. For example, the transmission frequency for the X-band is the reception frequency for the neighboring K_u-band, which may cause interference to certain satellite services. European states for military satellite services "have employed more secure frequency bands such as S, X and K_a to isolate such commercial applications"[12].

5G technology

5G technology is also a challenge in the field of radio spectrum management. At the 2019 World Radiocommunication Conference (WRC-19), additional radio frequency bands needed for the IMT-2020 (IMT – International Mobile Telecommunications) standard were identified, which will facilitate the development of 5G mobile networks. Thus at WRC-19 they were identified "frequency bands 24,25-27,5 GHz, 37-43,5 GHz, 45,5-47 GHz, 47,2-48,2 and 66-71 GHz. In total 17,25 GHz of spectrum have been identified for IMT by the Conference, in comparison whit 1.9 GHz of bandwidth available before WRC-19"[13].

High frequency bands higher than 6 GHz allow information transfer speeds of up to 10 Gbps and an almost instantaneous response time. The band of high waves is subject to rain attenuation, causing large losses during radio propagation and requires conditions of direct visibility.

Medium frequency bands between 1.5 and 6 GHz provide protection against rain attenuation, ensure information transfer speeds of up to 490 Mbps and allow the installation of 5G equipment in the same locations as previous 4G LTE equipment.

Low frequency bands below 1 GHz provide extensive coverage and long propagation distances, but do not ensure the same information transfer speeds as above, reaching 100 Mbps (about 20% higher than 4G anyway).

The 5G Strategy for Romania states that "the 700 MHz, 3.4-3.8 GHz and 24.25-27.5 GHz bands (26 GHz band) are key bands for the implementation of 5G in Romania, similar to the other Member States of the European Union"[14]. 5G technology offers a number of opportunities in the military field such as: Virtual Reality / Augmented Reality facilities - in training, cloud computing and edge computing – in CIS (Communications and Information Systems), the decision-making process through Situational Awareness – in C2, autonomous remote-controlled cars – at a tactical level.

Starting from the question of what frequencies would be useful to cover 5G an area of operations at the level of a tactical unit, but also the fact that ANCOM is preparing to auction[15] the 800 MHz, 2600 MHz and 3400-3600 MHz frequency bands, I consider that the Romanian army should ensure its spectral resource in time.

Electromagnetic and cybernetic actions

Some NATO member countries have adopted at the national level the integration of cyber and electronic warfare actions and have assimilated them under the concept of *Cyber and Electromagnetic Activities* (CEMA).

Having as a starting point the fact that CEMA are "activities leveraged to seize, retain, and exploit an advantage over adversaries and enemies in both cyberspace and the electromagnetic spectrum, while simultaneously denying and compromising them, at the same time protecting the mission command system"[16]; they are integrated and synchronized through cyber operations, electronic warfare and spectrum management actions. "The continuous planning, integration, and synchronization of cyberspace and EW operations, enabled by spectrum management operations, can produce singular, reinforcing, and complementary effects"[17], in support of the kinetic effort of the operation.

Radio spectrum management is a pillar of integrated cyber and electronic warfare actions. Drawing attention to the importance of using electromagnetic spectrum in different fields (SIGINT, ISR, ISTAR, BSM), LTC Panagiotis Stathopoulos stated that "there is a need to integrate and unify all the EMS capabilities, entities and disciplines under a single domain of operations, the EMS including Cyberspace"[18].

One direction of future development is tactical operations in cyberspace, which are dependent on the spectrum. In the future, the military will fight in an area of cyber spectrum operations, which is currently another space in the process of being known. To prevent this problem, the structures of communications and informatics, electronic warfare and radio spectrum management must collaborate and integrate actions to achieve these objectives and present them to decision makers.

The management of the frequency spectrum of this new combat space could be the key to success in future military actions.

Conclusions

Freedom of action in the electromagnetic spectrum, at the place, time and parameters we choose, is a necessary precursor for the successful conduct of operations in all areas. The electromagnetic spectrum is a fundamental component of the natural environment, and the Electromagnetic Spectrum Operations is the framework in which military actions take place. The Electromagnetic Spectrum Operations is an area of maneuver, combat, but also a competition between the military and non-military activities. In modern warfare, the advantage of efficient EMS management is a key indicator in ensuring superiority in the air, on land, at sea, in space, or in cyberspace.

As radio spectrum is a limited resource, poor management will often not be able to meet the requirements of all spectrum users. Complex exercises such as joint or multinational ones are the best opportunity to become aware of this reality and identify solutions.

A radio spectrum manager is and will continue to be essential in the conduct of military operations, and for this the use of updated software tools and a good training of human resources are mandatory. The radio spectrum manager must be proactive in enabling decision-makers to maintain initiative and continuity in conducting military operations.

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