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Model-Driven Engineering Applied to Radio Cognition in Military Operations

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ABSTRACT: The dynamic nature of the military communications environment makes cognitive radio a promising alternative due to its versatility in sensing the environment and changing its operation mode autonomously. These changes must be grounded in military doctrine and telecommunications standards, which may vary from different military scenarios. In war situations, quick reaction and adaptation to new rules and conditions are desirable to avoid or prevent fratricide. This research applies Model-Driven Engineering (MDE) techniques to achieve fast adaptation, by using Domain-Specific Languages (DSL) and source code model transformations applied to cognitive radios in military operations. In a study case, these concepts were applied, speeding up the update of rules and employing a sliding windows strategy.

KEYWORDS: Cognitive Radio. Military Operations. Model-Driven Engineering. Domain-Specific Language.

RESUMO: O dinamismo do ambiente de comunicações militares faz dos rádios cognitivos uma alternativa promissora, em virtude de sua versatilidade para sensoriar o ambiente e mudar seu modo de operação de forma autônoma. Essas mudanças são baseadas em regras fundamentadas na doutrina militar e nas normas de telecomunicações, que podem mudar em função de alterações no cenário militar. A capacidade de reagir e se adaptar, com rapidez, às novas regras e condições é um diferencial que, em situações de guerra, pode evitar ou prevenir o fratricídio. Buscando atingir essa rapidez, esta pesquisa usou técnicas de engenharia dirigida a modelos, como Linguagens Específicas de Domínio (DSL) e transformações de modelos em código fonte aplicadas a rádios cognitivos, em operações militares. Estes conceitos foram aplicados em um estudo de caso, agilizando a atualização das regras e empregando uma estratégia de janelas deslizantes.

PALAVRAS-CHAVE: Rádio Cognitivo. Operações militares. Engenharia Dirigida a Modelos. Linguagem Específica de Domínio.

1. Introduction

Among the various means of communication used in military communications systems, the electromagnetic spectrum is shared by radios, radars, weapons systems, and other types of devices. During military operations, these systems ensure communicability between command and troop, supporting Command and Control (C2) systems. The diversity of types of operations may require changes in the behavior of communication means, considering technical (signal quality, range, susceptibility to noise, etc.) and tactical requirements of an operation (when the radio must operate at low power to avoid enemy detection). The combination of capabilities of software-defined radio (SDR) and cognitive radio (CR) [1, 2] emerge as an alternative to meet the variations of these requirements, with the agility required by a war environment.

As far as it was possible to investigate, there are studies focused on streamlining the configuration of SDR in military operations, but still without contemplating the definition of rules for autonomous decisions of cognitive radio [3]. On the other hand, other studies in the areas of disaster management [4], medical emergencies involving Internet of Things sensors [5], or even in business, [6] indicate that the use of *Model Driven Engineering* (MDE) could be appropriate in environments that require agility in updating rules that define actions to be performed.

This study proposes the use of an MDE-based approach as an alternative to streamline the construction of rules that will define the behavior of cognitive radios in a military communications system. In this context, a *Domain Specific Language* (DSL) was developed, which facilitates the description of rules, favoring the transformation of models and the automatic generation of codes. In this experimental environment, the technical and tactical information sensed by the equipment was submitted to the rules that defined the radio's mode of operation.

This study is organized as follows: Section 2 presents a literature review on command and control systems, and communications in military operations, SDR, CR and MDE; Section 3 presents some related work, indicating the potential for the employment of MDE in military communications systems; Section 4 describes a case study; then there are the final considerations and indications of further studies in Sections 5 and 6, respectively.

2. Literature review

In this section, concepts involving military communications in operations are discussed.

2.1 Military operations

Military operation is the name given to the set of actions employing military forces and means, coordinated in time, space and purpose, following a directive, plan or order. It can occur in moments of peace, war, or in crisis situations, under the responsibility of a military authority [7]. In war operations, there is armed conflict and military power manifests itself with the use of violence. In peacetime operations, this power is employed in tasks unrelated to combat, except in special circumstances [8].

Military operations can be classified according to the forces employed and their purpose. As for the use of forces, they can be singular (developed by only one armed force), joint (employs ponderable means of more than one singular force) or combined (composed of ponderable elements of multinational armed forces, under a single command).

Under the finalistic bias, they can be classified as basic or complementary [7]. Basic operations, in situations of war, can be offensive, defensive or in cooperation and coordination with agencies, the latter being more common in situations of peace. Complementary operations, on the other hand, can be divided into seventeen different types of operations aimed at expanding, improving and/or complementing basic operations. The scope of this study does not include detailing the various operations; however, one should note there is a set of rules and restrictions to be adopted by the personnel and communications resources involved for each operation, in line with the context and military doctrine in force. In other words, during a specific operation, a radio may have to operate at a certain frequency, with low signal power, by contextual and doctrinal force.

2.2 Command and Control Systems (C2) and Communications Systems

Command and Control Systems (C2) form an environment where leaders manifest command intentions and perform actions to achieve objectives in a controlled manner. In addition, they can determine roles and responsibilities, as well as establish rules and restrictions to the context and subordinate elements [9]. These actions characterize behaviors defined based on the understanding gained by monitoring and evaluating the context of the environment. Agility in this understanding is a relevant factor for successful decision-making in a timely manner, and may represent an advantage over the enemy.

In the Brazilian Army (EB), through the C2 system supported by communications and information systems, aligned with the communications employment doctrine [10], the commander plans, directs and controls forces and operations [11].

A Communications System is a mesh of devices deployed in an action zone to meet the elements of an echelon. This structure enables the flow of data, voice and images through a network of nodal centers interconnected by various means of communication. Considering radio as a means of communication, different forms of link can be employed, such as satellite, microwave in direct sight or tropo-diffusion, using different waveforms.

Military doctrine [10] defines the means, forms of operation, and the use of communications resources. Such conditions and circumstances may involve tactical, doctrinal and physio-graphic issues, as well as technical limitations and the role of each equipment in operations.

In military communications systems, range, capacity and mobility are relevant factors [12], which make up the so-called Compensation Triangle, which is a simple way to assess the relevance of using a means of communication.

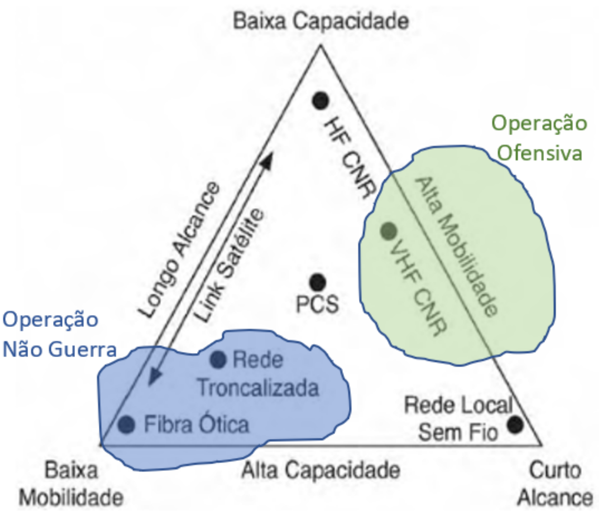
In Table 1, in each example operation (offensive and not war), the technology to be used varies according to the requirements defined, doctrinally, for each of the factors associated with the communications equipment used.

Table 1 - Compensation Triangle Factors applied to Subsystems.

Subsystem	Radio 1	Radio 2
Operation	Offensive	No War
Scope	Average	High
Mobility	High	Low
Capacity	Average	High
Technology	VHF	Trunked Network

Considering the requirements of each operation described in Table 1, they are represented in the compensation triangle as shown in Figure 1.

Figure 1 - Compensation Triangle, Adapted from [12]



Technologies such as software-defined radios and cognitive radios are appropriate to these variations in requirements.

2.3 Software-defined Radio (SDR)

An SDR is a type of radio whose majority of physical components are built using software [1, 2], and which can use virtual machines and intelligent agents [13]. This is considered an evolution of traditional radios, since functions such as modulation, demodulation, and filtering can be implemented by software rather than hardware. Reconfigurability, flexibility, and modularity are hallmarks of SDR, which can be reconfigured without hardware changes [14].

These possibilities make communication systems capable of operating in more than one mode, with different waveforms, with the same hardware [15]. A waveform carries from information describing security mechanisms in data transmission, source coding (voice, image and video compression), to re-transmission mechanisms and modulation and demodulation techniques, among other functionalities [16].

2.4 Cognitive Radio (CR)

A cognitive radio (CR) is an SDR capable of sensing the environment, changing its characteristics and its functioning, being able to adapt its operation to achieve objectives such as performance improvement, energy savings, and adaptation to the operational conditions in the place where it is inserted [2, 15]. The CR is also able to learn from past behavior, employing machine learning techniques to improve its functioning over time, analogous to what a human would do [17].

According to Doyle [18], the CR is a device that perceives inputs or views of the real world and, based on their understanding, makes autonomous decisions, being able to self-configure itself for communication tasks. This type of understanding is divided into four main areas: environment; communication requirements; policies, rules, and doctrines; and the radio's own capabilities.

The understanding of the environment is characterized by the correct detection and decoding of signals that are captured by the antenna, as well as by the knowledge of the operation in which it is inserted and its role in it.

Communication requirements are linked to which capabilities the equipment must have to meet the demands of communications systems (quality of service, tolerated noise level, etc.)

Policies and rules involve both standards for the exploration and use of the electromagnetic spectrum and manuals of military communications doctrine [12].

Knowing one's own capabilities means knowing the limits of equipment perception and operation, such as maximum power or sensed or transmitted waveforms.

Different types of cognitive methods can be applied to cognitive radios; some, such as those based on mathematical models or machine learning algorithms presented by Xu et al [19], could be suitable for definitions of radio behaviors related to technical issues as energy saving, noise level reduction, among others. On the other hand, when the decision is based on rigid doctrinal rules, rule-based models would be appropriate [19], whose knowledge structures, such as tables and decision trees, are desirable.

2.5 Model-Driven Engineering

In the context of software engineering, a model is a form of graphical or textual representation of a system, in which the abstractions and relationships employed are described by a metamodel [20].

Models are useful in a software project because they provide everyone involved, whether in the technical area or not, with a concrete, clear, and common view of the system to be designed [21].

Model-driven engineering (MDE) employs methodologies that conceive models as elementary artifacts in the software development process and not just as documentation of a project [21]. In other words, the model is part of the system and, even undergoing transformations, will always be aligned with its physical implementation.

Comparing MDE with approaches such as structured programming and object-oriented programming, there is greater simplicity in the propagation of changes. This characteristic is justified by the automatic generation of executable code from the system models, through the combined use of meta-modeling techniques and transformations between models (M2M) and from model to text (M2T) [21].

Model-to-Model transformations allow the transformation of one model into another, usually to a lower level of abstraction than the original, or simply so that the new model is more convenient to those involved in the project. On the other hand, *Model-to-Text* transformations generate software artifacts from the models through a technique called code generation. Defining a domain-specific language (DSL) enables the use of M2T transformations.

A DSL is created specifically for a particular application domain, such as languages used to search databases (CSQC) or languages that markup text for Web presentation (HTML). This type of language is close to the universe of understanding of domain users, contributing to the agility in the process of building this level of abstraction.

3. Related works

taking advantage of the characteristics of software-defined radios, in [3] the authors propose a tool that facilitates the configuration of radio equipment that will participate in a military operation. In this case, different software-devised configurations can be distributed to each equipment using a standard configuration file, but without exploring the use of a cognition method on the radio, enabling changes in operation from environment understanding and prior planning definitions.

On the other hand, studies focusing on decision support contexts applied MDE in environments of similar complexity to the communications scenario in military operations, such as bank fraud detection, public health and safety, disaster management, among others. In these environments, the understanding time of the observed information is also an important factor. In addition, the cognitive model is based on rules that can classify and identify perceived situations, which can generate understanding about the environment and support decision-making.

The study by Costa et al. [22] presents a scenario where the system is able to identify situations and react to the environment in which it is inserted. In this context, a DSL applied to the description of real-world situations (*Situation Modeling Language* - SML) serves as the basis for building a set of rules that run on a centralized, rules-based software platform (DROOLS). This platform allows for analyzing data collected from the environment within a time frame of observation. To validate the proposal, a case study was conducted, focusing on the detection of possible bank fraud in a mobile banking system. The research by Moreira et al. [4], aimed at disaster and emergency management, uses MDE in the conversion of texts expressed in SML (the same used by Costa et al. [22]) into rules processable into executable code. In addition, it also addresses the issue of data interoperability, justified by the interaction between the agents involved. The use of ontologies is pointed out as a favorable alternative in conceptual modeling, in applications based on situational awareness.

Brambilla's book [23] presents a DSL used specifically to favor interaction with users in the development of software applications.

Soleymanzadeh et al. [24] created a graphical environment to facilitate the understanding of domain users in the construction of business rules to be met by an application. The study applies MDE techniques in the translation of the rules created into the structure closest to the application domain. In addition, a case study was carried out in the area of collection of attorney's fees.

In this context, the MDE approach has shown good possibilities of use in the conversion of models and in the use and development of domain-specific languages that can help the understanding of the user who will insert the business rules. These initiatives demonstrate that the use of a DSL can favor agility in the elaboration of rules. However, no studies applied to cognitive radios have yet been observed, in favor of agility in the construction and configuration of rules applicable to sensed data. In addition, the approaches evaluated so far also do not address competing rules or establish priorities for them.

4. Modeling rules in cognitive radio systems

this study presents an MDE-based approach to streamline the construction of cognitive radio behavior rules in a military communications system. These rules will be transformed into intelligible code by the equipment and, from them, the radio will be able to change its own behavior (mode of operation) if there are significant variations in the environment that can be perceived and understood by it.

Initially, a small hypothetical scenario will be described, demonstrating cognitive radios acting in military operations, employing varied modes of operation.

In the scenario described by the sequence diagram in Figure 2, we have three radios involved in two operations (A and B). In operation A, there are the radios of the operation commander and of an operator, while in operation B there is only the radio of the operation commander.

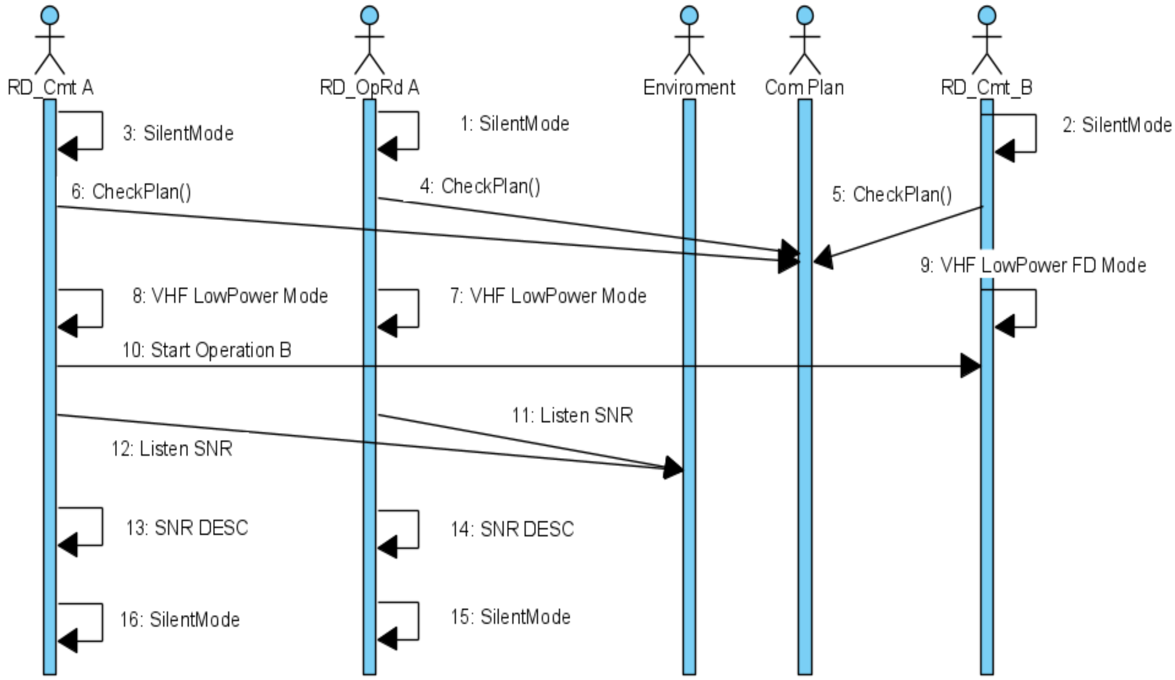
In this environment, three operating modes are used: 1- the Silent mode (*SilentMode*), in which the equipment is turned on, but does not emit any signal; 2 - the low power VHF mode (normal mode); and 3 - the low power VHF mode FD. In the latter, the acronym FD means that the equipment can operate in the Full Duplex In-band mode, in which the radio transmits and receives at the same frequency simultaneously, producing interference on its own signal and increasing safety in the physical layer [8].

The communications plan *(Com Plan)*, accessed by the radios, contains details about the operations in which the equipment participates. It describes the type of operation, the role of the radio, and its possibilities.

From the signal level and noise level readings present in the environment, the *Signal-to-Noise Ratio* (SNR) can be established, i.e., the relationship between the received signal level and the perceived noise level in the electromagnetic environment. A drop in SNR may be caused by a drop in the received signal level or by the increase in the perceived noise level.

The electromagnetic environment (*Environment*) illustrates the environment sensing action performed by the radios. Initially, they all work in silent mode. Then, a communications plan check application is performed and information such as *Security Level*, which depends on the criticality of the operation [25], the role of the equipment in the operation (Operational Role), the frequency of the channel used (Carrier Frequency), among others, can be collected.

Figure 2 - Communications in operations



From this information, the radio will be able to define its mode of operation, together with predefined rules. In this example, the mode set was low power VHF. In the sequence, messages are exchanged between the radio equipment of the Cmt of operations (RD_Cmt_A and RD_Cmt_B). In addition, the equipment of operation A checks the environment and realizes that the SNR ratio shows a decrease (SNR DESC), that is, there was a loss in the quality of the received signal. In this case, the rule defines that there is a change in the operating mode, and it starts to operate in the VHF low power FD mode.

One can classify this type of change as technical, as they aimed to improve the quality of communications. On the other hand, they could have been motivated by tactical issues, such as preparation for an attack, in which silence could be established, characterizing a tactical change.

4.1 Research Overview and Scope

Through BPMN notation[1], Figure 3 presents an overview of the approach we are proposing in this work, highlighting tasks and some results produced in each of the steps.

Two *swimlanes* of the BPMN notation are represented, so that one of them represents a system dedicated to communications planning, in which the communications officer prepares the communications plan that will determine the behavior of the cognitive radio.

1 BPMN- from the English: Business Process Model and Notation [26]

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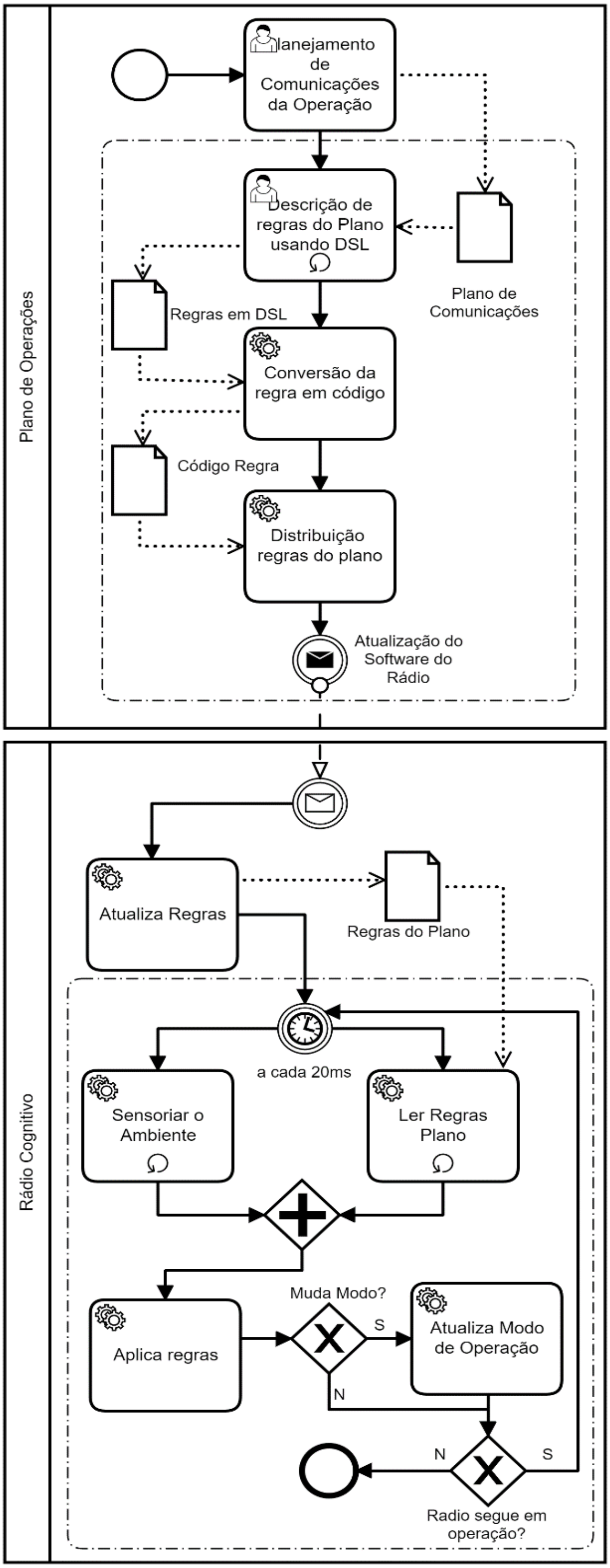
Figure 3 - Approach Overview



Once the settings and rules are defined in the Communications Plan, the rules will be described through a DSL language specially designed for this context. The expressed rules are converted into the code of a programming language compatible with the cognitive radio software and hardware platform. At this point, the radios need to be "updated" with the new code, so that the rules take effect and determine their behavior during operation. When entering into operation, the cognitive radio, in a cyclical manner, senses the environment and reads the communications plan, in addition to applying the rules and, as the case may be, changing its mode of operation.

The dashed parts of Figure 3 indicate the scope of what has been implemented in this work. In the planning system, techniques based on MDE were applied; in the cognitive radio, a simulation of environment sensing, plan reading, and the application of rules and definition of the mode of operation was carried out autonomously.

It is worth noting that the set of rules can be changed, and the proposed scheme can make it easier to make changes in an agile way.

In this study, as a validation alternative, a case study simulated the sensing of the environment and the application of rules, defining the radio's mode of operation.

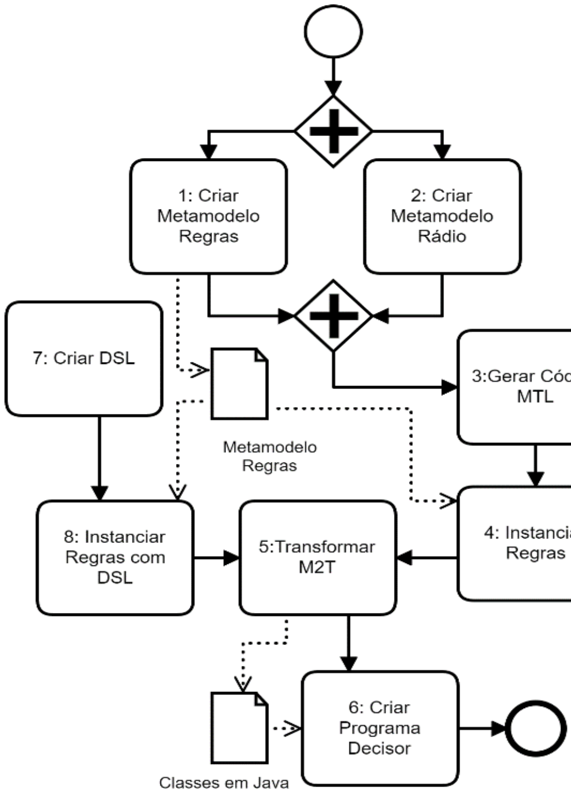
4.2 Applied methodology

Figure 4 describes the methodological procedures of this work, in which a metamodel describing a cognitive radio in an operational environment (step 1) and a metamodel describing the structure of formation and construction of rules that determine the mode of operation of the radio (step 2) were developed.

Then, a code (*template*) in MTL transformation language was developed, based on the rule formation metamodel (step 3).

After this step, rules were instantiated, based on the *template* metamodel (step 4).

Figure 4 - Applied methodology



From the code model and the created rule instances, the M2T transformation tool was used for the automatic generation of a class in Java language for each of the rules (step 5), based on the developed template. In the last step, the classes of all the generated rules are inserted into a Java language decision program. At that moment, the final artifact of the work is ready, that is, the executable decision program (step 6).

To make the process of elaborating the rules simpler and more agile for the user, different from the use of the template generated in step 3, a DSL was developed, i.e., a domain-specific language was created (step 7), which can be used for a more compact representation of the rules (step 8).

4.3 Metamodeling

The metamodel of Figure 5 represents, in a simple way, some concepts of a cognitive radio and a communications plan. In addition, it represents the elements involved in the operation of the cognitive radius. The *Transceiver* class corresponds to the radio equipment. The *Environment* class expresses the environment that the radio can sense, that is, signals and noise, in addition to deriving the signal/noise ratio (SNR). The *Communication Plan* class represents the communications plan of a given operation in which the radio is inserted. The plan informs the frequency of the signal carrier (*Carrier Frequency*), the role of the radio operator (*Operational role*), which can be "*commander*" or "*soldier*", and the security level of the operation in progress (*Security Level*).

In addition, the plan includes a set of rules that determine the operation of the radio. For example, it may contain a rule that says that if the SNR is decreasing, then the mode of operation must be changed. For simplicity, the rules were not represented in this metamodel, but in another, presented in Figure 6.

The *LogEntry* class represents the collection of information from the environment and the communications plan at each instant in time. Each *LogEntry* instance contains the SNR, *Security Level*, *CarrierFrequency* and *OperationalRole*. Finally, the Log class acts as a sliding window, which collects the most recent readings (for example, the last three) from *LogEntry*. Based on these readings, the cognitive radio (*Transceiver*) should refer to the rules of the Communications Plan to see if it should change its mode of operation.

In this composite rule, operators and operands connect, setting a mode of operation for the radio.

The SNR value and the last observed values of the other concepts present in the *Log* (the most recent data perceived) are the basis for the description of the rules and decision of the radio.

Motivated by the rule-based models of Xu et al [19] and inspired by the initiative of Costa et. al. [22] and the work of Horrocks et.al.[27], a set of rules (*ruleSet)* has been devised, and can be composed of a single or many rules. Each of them (*rule*) has an identifier (IDENTIFIER) and a priority. In addition, it consists of a single antecedent (*LeftSide*) and a single consequent (*RightSide*). The left side of the rule is composed of expressions, which can be simple (*SimpleExp*) or compound (*CompoundExp*). Each type of expression has its *operand*(s) and operators, which can be mathematical, logical or comparison. The operands can be attributes or values.

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Figure 5 - Cognitive radio metamodel

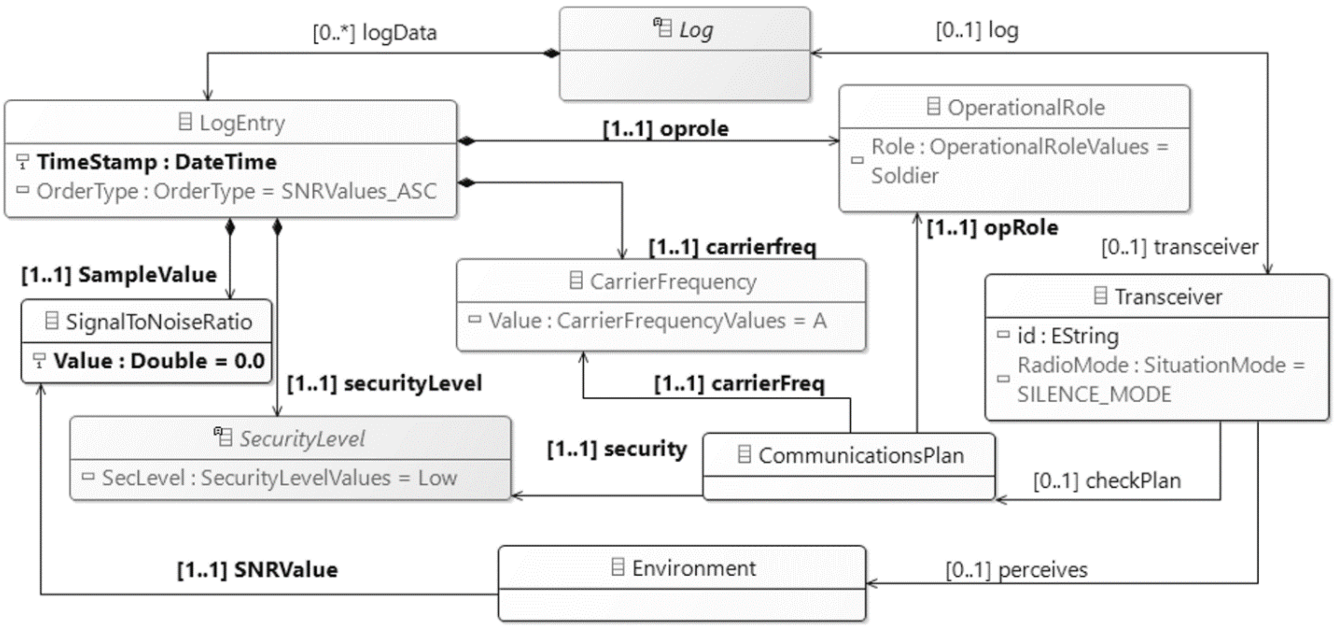
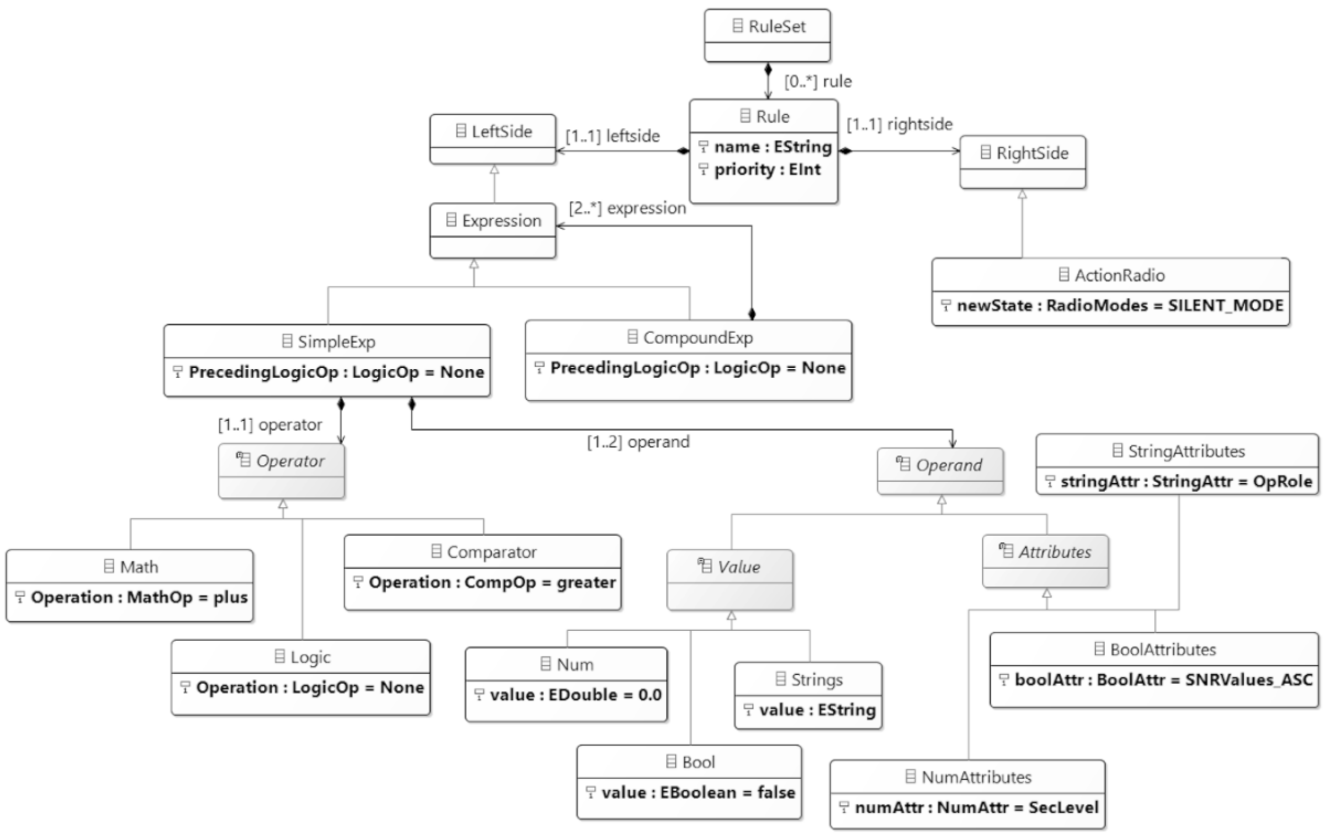


Figure 6 - Rules construction metamodel



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The metamodel described in Figure 6 represents the way the rules are structured. Based on this model, a small grammar was developed, represented in Figure 7, employing the formalism of the Backus-Naur Form (BNF) representation.

Figure 7 - Clipping of the BNF grammar

```
<rule> ::= "{" priority, <leftSide> "→"
<rightSide> "}"
priority ::= ( [0.0-1.0]+)
< rightSide > ::= "normal" | "default FD" |
"silence" | "alert"
<leftSide> ::= <expression>
<expression> ::=< simpleExp> | <compoundExp>
<compoundExp> ::= ( < expression >, < expression
>+\, )
<simpleExp> ::= <Boolean> <expr>
<boolean> ::= True | False | |ε|
<expr> ::= <operand> | "(" <operand> <operator>
<operand> ")"
<operand> ::= <value> | <attribute>
<operator> ::= <math> |<logic>|<comparator>|
<Math> ::= "+" | "-" | "*" | "/"
<logic> ::= "AND" | "OR"| "NOT" | "NAND"|
"NOR"|"NXOR" | "XOR"
<comparator> ::= "=" | "<" | ">" | "!="
<value> ::= <number> | <string> | <boolean>
<number>::=(^\d*[0-9](\.\d*[0-9])?$)
<string>::= ([A-Za-z][A-Za-z0-9]*)
<attribute>::= <numAttribute>
|<stringAttribute> |<boolAttribute>
<numAttribute> ::= "securityLevel" |
"carrierFrequency"
<stringAttribute>::= "sampleValue" |"operationalRole"
```

In our example, we represent the universe of attributes that belong to the cognitive radio model presented in Figure 5, which participate in our usage case.

Rule (1) demonstrates a possible use of this grammar in the construction of rules in the domain of cognitive radios.

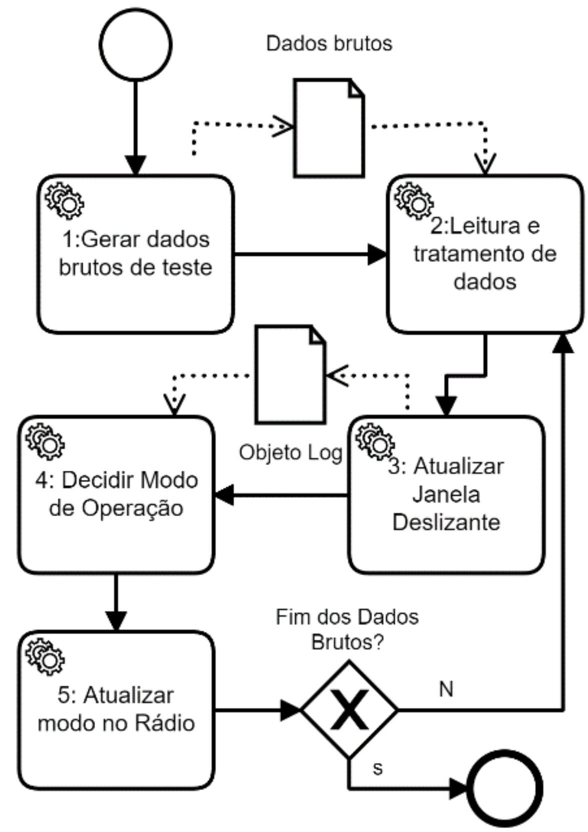
{0,2 True (True(sampleValue ="DESC") AND True (securityLevel < 0.5) AND False(carrierFrequency =100.0) AND (operationalRole ="soldier"))→ normal} (1)

When a rule is created, it receives a single priority value between 0 and 1, with 1 (one) being the highest priority. In this case, the priority is just a simplified strategy of dealing with possible competing rules, where two or more rules could be met simultaneously.

5. Case Study

This case study verifies the feasibility of the approach described in Section 4. According to Figure 8, a raw data file is generated from a test file generator program, which simulates readings of information from the electromagnetic environment and the communications plan, with intervals of 20 milliseconds, simulating a cycle of sensing the environment on a real radio (step 1) [28].

Figure 8 - Stages of the Simulation/Testing Process



From these data, another program reads, validates (step 2), and instantiates them in a class called Log, which represents a set of samples of the environment

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sensed or perceived by the device in each simulated reading (step 3). In the next step (step 4), the decision program applies the rules that have been constructed by means of a DSL, resulting in a decision that can determine a new mode of operation for the radio (step 5).

Table 2 is a decision table, which represents the knowledge structure that describes the rules that were simulated in the experiment, representing those related to the doctrine of military communications.

Table 2 - Simulating Rules of military doctrine.

Tipo	Objeto	Atributo	Domínio	ST_1	ST_2	ST_3	ST_4	ST_5	ST_6	ST_7
Entrada	Sample Signal	Sample Value	ASC	true		true		true		false
			DESC		true		true		true	false
		Security level	>=0,5	true			true			
			< 0,5		true	true				
	transceiver	Carrier Frequency	50MHz	true			true			
			100MHz		true	true				
		Operational Role	Cmt	true		true				
			Soldado		true		true			
Saída		Modo Tx	normal							
			padrão FD							
			Silêncio							
			Alerta							
			Sit_Ant							

Taking as an example the rule determined by the context ST_1 of Table 2 (column ST_1), if the trend of the last three values of the received SNR is ascending (i.e., the SNR value of the last three perceived instants is increasing), the channel security level is greater than or equal to a threshold (0.5 in this case), the transmission frequency is 50 MHz and the "operational role" of the radio in question is that of commander ("Cmt"), the mode of operation to be used in the equipment will be the silence mode.

During the experiment, the Eclipse IDE was used, using the Eclipse Modeling Framework (EMF). The Sirius extension of Eclipse was used in the development of metamodels. In step of M2T transformation of the model into a Java program, the Acceleo tool was used.

The rule-building interface is not trivial for a user with no programming experience. To simplify the process of instantiating the rules metamodel, the Xtext tool [29] was used to generate and edit a DSL. This DSL allows the user to instantiate the rules of the radios without having to know any programming language, writing the rules in a simple way. Figure 9 shows a code fragment, demonstrating the description of two rules in the DSL. *Rule_ST1* has priority 1 and describes the conditions for the *Silent Mode*.

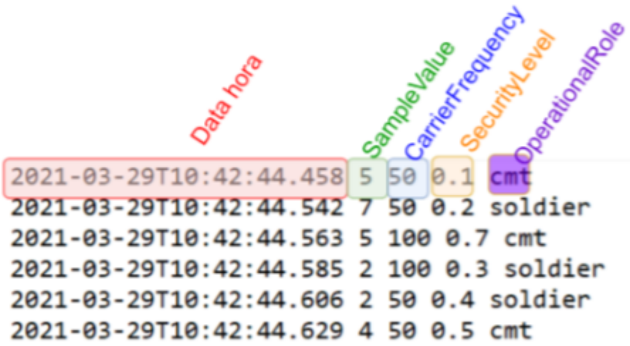
Figure 9 - DSL usage fragment

```
RuleSet{
    Rule 'Rule_ST1' {
        priority = 1
        rule = _[ _(SNRValues_ASC=true) and [_(SecurityLevel>=0.5)
               and(CarrierFrequency=50.0)and(OperationalRole="Cmt")]]
               --> SILENT_MODE
    },
    Rule 'Rule_ST2' {
        priority = 2
        rule = _[ _(SNRValues_DESC=true) and [_(SecurityLevel<0.5) and
               (CarrierFrequency=100.0)and(OperationalRole="Soldier")]]
               --> NORMAL_MODE
    },
```

5.1 Results obtained

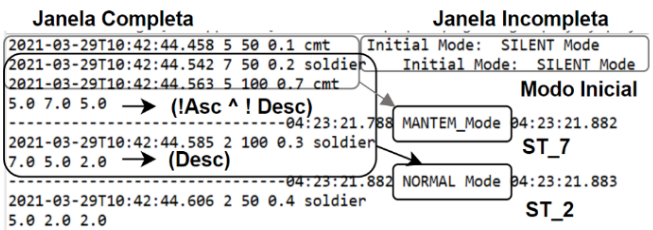
Figure 10 shows a small fragment of the input log, where the data that would be sensed is simulated. Each line represents values of the environment at an instant in time.

Figure 10 - Input log



After the execution of the rules, an output log file is generated, recording all sensed data and each decision made based on the application of the rules on the data contained in the sliding window of the last three observations of the environment. As shown in Figure 11, at the beginning of the execution, while the window is not yet filled, the operating mode of the equipment will always be the silent mode.

Figure 11 - Output log



When the window is filled, the rules are applied, that is, the last three *sampleValue* values are checked to identify whether they are ascending (ASC) or descending (DESC), along with the other values of the most recent reading. It is also possible to observe the changes in the operating mode, at times when the rules ST_7, which maintains the current mode (Silent Mode), and ST_2, which changes to *Normal mode*, are met.

6. Final Considerations

The diversity of types of military operations requires dynamism in changes in media behavior. Cognitive radios are a promising alternative, being able to adapt their operation to the technical and tactical needs of operations.

This study presented an alternative capable of supporting the variations of communications requirements during operations in an agile manner. In this experiment, only one piece of equipment operating in a single operation was simulated, but it was possible to verify its variations in behavior, based on technical and tactical rules. From this initial experiment, the modeling can be extended to a universe compatible with a real operation. The description of rules employing DSL, as well as model transformations and automatic code generation can contribute to agility in updates, in addition to maintaining alignment between the physical implementation and the conceptual model.

As contributions, we can highlight the proposed methodology that enables the replication of this experiment. The use of a sliding observation window can reduce the amount of data to be processed, consuming less computational resources, since the radio has limited computational power. Indirectly, the resource savings in the decision task will make more resources available for tasks that can be performed by machine learning algorithms.

As far as it was possible to observe, many studies have already made use of DSL and automated code transformations in environments that require urgency, however, the particularities of the military communications environment and the domain of cognitive radios were not considered.

Cognitive radios can be part of command and control systems, which operate in an integrated manner. In this context, interoperability between systems is a necessity and ambiguities in the understanding of concepts should be avoided. A failure to understand a concept may represent an error in the construction of rules involving communication systems, causing unwanted operation of equipment during an operation and causing, in some cases, fratricide.

Some studies [4, 22] indicate that the use of ontologies can favor syntactic and semantic interoperability between the various systems. In this sense, ontology-based interoperability will be explored in the next stages of this research, in addition to a possible integration with the mission planner proposed by Souza et al. [3]

The focus of this study is the benefit of the use of the language by the end user, streamlining the decision-making process and reducing the need for knowledge in programming languages. The use of this methodology in systems for performance evaluation and error handling mechanisms is recommended as future work.

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