Critical Communication Scenarios Description based on Ontological Analysis

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Abstract. *Critical communication scenarios require a huge modeling effort to represent reality as accurately as possible and independent of their implementation. To reach an accurate model for this domain and provide a decision support, it is necessary to use modeling techniques that contribute to high semantic expressiveness, such as ontological analysis based on foundational ontologies. This work presents a rich and real example that illustrates how useful the application of ontological analysis can be in coping with such complexity. Moreover, it also contributes to the cognitive-driven communication technologies domain, with a clear and unambiguous specification of events and situations in critical communication scenarios.*

1. Introduction

Conceptual modeling can be a challenging task. A semantic rich conceptual model needs to provide the necessary elements to represent reality as accurate as it can be in a way that turns to be understandable as well as independent of implementation. As stated in [Verdonck et al. 2019], ontological conceptual data modeling can bring substantial benefits when compared to traditional conceptual modeling, as larger and more complex an information system becomes. In their empirical study, they observed that novice modelers (modelers without previous data modeling knowledge) using ontological analysis techniques brought higher quality models when compared to the ones brought by novice modelers using a traditional technique. Besides that, they have not found any noticeable effort variation in both groups while using different modeling techniques.

In the last decades, there has been significant advances on using ontological analysis to provide a sound foundation for conceptual models development, in order to reach better representations of computational artifacts, specially conceptual schemas [Guizzardi 2012]. Ontological analysis is based on the use of foundational ontologies (also called top-level ontologies), which provide a set of principles and basic categories [Guarino 1998], independent of any particular domain, such as space, time, matter, object, event, action etc..

One of the most representative foundational ontologies is the Unified Foundational Ontology (UFO). It has been successfully applied[1] to the conceptual modeling of a variety of domains, bringing more real world semantics to modeling elements. Due to its wide usage, UFO is constantly evolving and, more recently, new constructs have been added, such as scenes and multi-level representation elements. Thus, we envision the critical communications domain as a relevant use case to be analyzed, especially when the communication nodes are empowered by cognition. Hence, this work presents a UFO application example in this rich and challenging operational environment. It shows UFO constructs benefits, contributing to their understanding and similar application to other domains. Moreover, it also contributes to the mission critical communications domain, with a clear and unambiguous specification of the situations that should be mapped within this scenario.

2. Literature Review

2.1. Critical Communications

Communication systems can be classified in many ways, from technological choices to operational scenarios. In this work, we use a classification based on the criticality of a situation. Based on the referenced literature [Ulema 2018, Ferrus and Sallent 2015], a situation is critical when human lives, their assets or the environment are at risk, whether being caused by natural or man-made events. Therefore, communication systems can be classified as non-mission critical or mission-critical.

Traditionally, the deployment of a mission critical communication network is based on mobile communications systems such as P25, TETRA, DMR etc. [Kumbhar et al. 2017]. Although these technologies proved to be robust over the years, they are no longer suitable for data intensive applications. According to the International Telecommunication Union (ITU), current 4G mobile communication system stands as a promising new platform for critical communication networks [ITUM2291 2016].

Besides pointing out the next step for critical communications networks, ITU foresees the use of Software Defined Radios (SDR) technology for this operational scenario[ITUM2377 2017]. This radio technology allows operational flexibility, as many radio functions can be changed by software, as opposed to the monolithic hardware-based solution. Broadly stating, every network node is becoming more ”softwarized”, bringing a new communication environment known as Software Defined Network (SDN)[Cho et al. 2014].

Cognitive Radios(CR) and Cognitive Networks(CN) are considered the next technological cycle for SDRs and SDNs. Respectively defined by [Mitola and Maguire 1999] and [Thomas et al. 2006], these technologies add reasoning capabilities to every communication node in a self-adjustable wireless network. Several advances have already been achieved in the cognitive-driven communications domain, mainly in spectral sensing and sharing. However, spectral analysis and decision making proposals for the proper use of the electromagnetic spectrum remains an open issue. Thus, foundation ontologies utilization arises as a way to represent knowledge to support cognitive communications usage, specially in mission critical communication scenarios.

[1]https://nemo.inf.ufes.br/projetos/ufo/

2.2. Foundation Ontologies

Foundation ontologies represent nonspecific aspects of reality for any domain, using formal theories to describe knowledge about reality, regardless its language or a particular state of affairs. Their goal is to provide a better and precise representation of the real world elements.

The Unified Foundation Ontology(UFO) [Guizzardi 2005] is a descriptive ontology that represents universals (types) and particulars (substantials or individuals), endurants, and perdurants incorporating ideas from other ontologies such as GFO and DOLCE, as well as from the OntoClean methodology. UFO has three main fragments: UFO-A (Ontology of Endurants), UFO-B (Ontology of Perdurants), and UFO-C (Ontology of Social and Intentional Entities). The modeling applied in this work focuses, initially, on the use of UFO-A and UFO B constructs.

UFO-A refers to objects and entities from the real world, with focus on structural aspects. It is the main UFO fragment and represents Universals (types) and Individuals of these types. In UFO-A, a *Situation* represents a slice of the real world in a specific point of time. *Objects* (existentially independent) and *Tropes* (existentially dependent) are distinct *Endurants* that are part of the *Situation*. On the other hand, UFO-B represents *Events* acting on *Situations*, *Dispositions*, *Time Points*, as well as the connections between *Endurants* and *Perdurants* [Guizzardi et al. 2013].

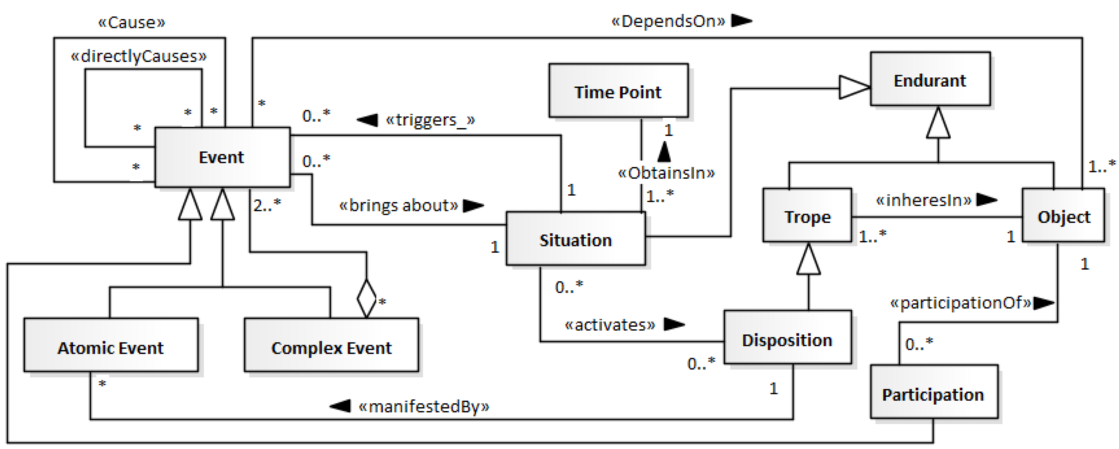

Figure 1. UFO-B fragment, based on [Guizzardi et al. 2013]

As shown in Figure 1, a *Situation* is a part of the world obtained at a particular point of time, modified or created by an event that has mereological features and can be classified as atomic or complex. An *Atomic Event* has no proper parts and depends on a unique object. On the other hand, *Complex Events* are aggregations of at least two disjoint *Events*. Both event types are related by using axioms, as described in [Guizzardi et al. 2013]. It is important to note that *Events* can be caused by other *Events*, directly or indirectly. For instance, a snooker stick hitting the white ball to hit the red ball leading it towards the hole is an example of indirect causality. Also, *Atomic Events* can be manifestations of *Dispositions*, a construct that is inherent to an *Object* and existentially dependent of it. ,

Disposition is a type of *Trope* that represents an abstract and latent property of a real-world object (i.e., the fragility of the glass, the conductibility of the wire, the magnetism of the magnet etc.) and might be manifested or perceived. When it happens, it is manifested by an *Event* (i.e., the glass breakage, the electric current flux or the magnetic attraction) and it only occurs if the objects involved in the same contextual situation have reached certain properties thresholds. In the case of the magnetism (*Disposition*) of a magnet (*Object*), it could only be perceived (manifested) by an attraction (*Event*) of a metallic object, if some properties such as the distance between them or the mass of each one had reached their thresholds values.

3. Military Theater of Operations

Extending the conventional Brazilian military operations, we have a particular type of operation called Law and Order Guarantee (GLO in Portuguese) [DO 1999, DO 2004]. In this operation type, military forces support local authorities in order to manage major social disruptions caused by unexpected events such as a police force strike or a major criminal outbreak.

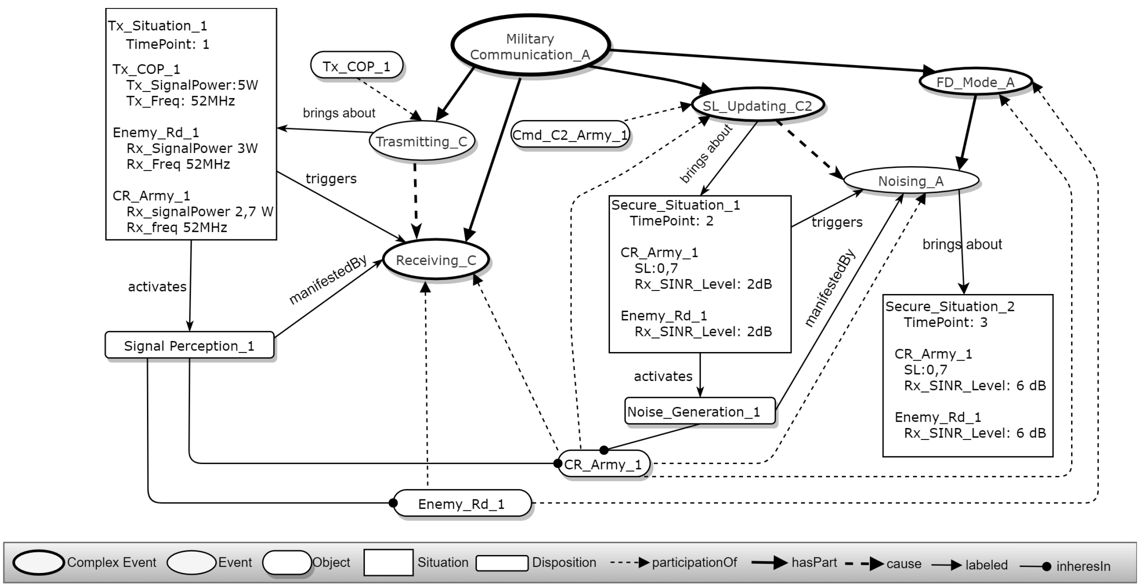

Figure 2. A Military GLO Communication Scenario

Figure 2 presents some events, using UFO-B constructs, that may happen in a hypothetical military communications environment during a GLO operation. The central object of this communication system is a military cognitive radio (*CR_Army_1*), which is able to modify its behavior whenever it perceives any relevant change, either in the communication environment or in the security policies. Additionally, the communication environment also includes a local law enforcement radio station (*Tx_Cop_1*), one enemy radio (*Enemy_Rd_1*), and a Command and Control Center Chief (*Cmd_C2_Army_1*), who defines the security policies for each operational context. In this hypothetical scenario, the military communication system has two objectives: (i) to stop or mitigate military and law enforcement messages interception by the enemy radios; and (ii) to interfere or block the enemy forces communications.

In this scenario, the *Military Communication_A* event is a complex event that is composed by five sub-events. Each of these events may change the characteristics of the participating objects, bringing about new situations. These situations represent slices of real world characteristics in three different moments (time points). Each disposition represented in Figure 2 is a trope that is inherent to one or more objects. A disposition is activated by a situation when some trope of an object, that takes part on that situation, satisfies a given proposition[2]. Consequently, that situation triggers an event, which manifests the activated disposition.

The initial event of the presented scenario is the *Transmitting_C* event. It indicates that the law enforcement equipment (*Tx_COP_1*) starts a transmission (*Tx_SignalPower=5W*; *Tx_Frequency=52MHz*). This event brings about the *Tx_Situation1* situation, which comprises the current transmitting status of *Tx_COP_1*, the receiving status of the *Enemy_Rd_1* radio (*Rx_SignalPower=3W*; *Rx_Frequency=52MHz*), and the receiving status of the *CR_Army_1* cognitive radio (*Rx_SignalPower=2.7W*; *Tx_Frequency=52MHz*). Both radios are able to perceive communication signals according to the dynamic range proposition (*Rx_SignalPower>2W*; *50MHz<=Rx_Frequency<=52MHz*), which means the (*Signal_Perception_1*) disposition is activated and manifested by the *Receiving_C* complex event.

Subsequently, the Command and Control Center Chief (*Cmd_C2_Army_1*) updates the security level of the GLO operation (*SL=0.7*), represented by the *SL_Updating_C2* event. As a consequence, this event brings about the *Secure_Situation_1* situation, presenting the current noise ratio (SINR) measured by both radios *Enemy_Rd_1* and the security level (SL) of *CR_Army_1* (*SINR=2dB*; *SL=0.7*). Once the SL value for the *CR_Army_1* satisfies the proposition (*0.5 <= SL <=* 1.0), this activates the *Noise_Generation_1* disposition, which is manifested by the *Noising_A* event. This event provokes a power noise level increase in the wireless communication environment, as a defense measure to block enemy communication. As a consequence, it brings about a new situation (*Secure_Situation_2*) at time point 3, where the overall noise ratio is raised to 6 dB.

4. Discussion and Related Works

The previous analysis showed how communication nodes can deal with changes in their operational environment and how they can adapt to provide the most suitable user experience. Different from current communication nodes, future communication nodes should have the ability to proactively reason not only about their internal data, but also about data that come from different domains and sources, especially in critical situations.

However, reasoning about such a diverse amount of data can be challenging and easily become a complex conceptual modeling task. Therefore, using ontological analysis for conceptual modeling seems to be more adequate and precise than using traditional conceptual modeling. In the scenario described in Section 3, this UFO ability was highlighted. We were able to express how and when internal and external information can support the communication nodes cognition. Elements such interference level and the intelligence and security doctrine were accurately represented. Their influence on the system behavior was described and now can be processed by the communication nodes. Thus, as more scenarios are covered, it is possible to envision that communication nodes will be able to deal with changes in their operational environment and adapt themselves to provide the most suitable user experience in critical communication scenarios.

[2]Proposition is an UFO-C construct not included in this work for simplicity and space limitation.

Moreover, although we analyzed a particular scenario, the ontological analysis approach could also be used to describe and integrate other communication scenarios in the same context. In this sense, causality relationships between micro (radio) and macro (network) systems could be identified, as well as the combined impact of internal and external informational elements. Additionally, it is worth to mention the benefits of such broader view to the critical communication domain.

Some works showed interesting contributions to describe situations and events in communication scenarios. In [Moreira et al. 2018], the authors applied UFO-B to a real-time scenario that could have also included the notions of situation and disposition. In [Moreira et al. 2015], the authors proposed a framework that combines a core ontology and a model language to represent situation types, both of them based on foundation ontologies. This work could also be extended to contemplate events and causality relationships.

5. Conclusions

Nowadays, critical communication scenarios are facing the rapid changing of technology as organizations around the world are pointing to cognitive-driven communications solutions as the main assets to be used in those scenarios. However, such solutions shall be preceded by a proper behavior configuration, anticipating critical situations and specific conditions prior to decision making and related action. These situations are typically complex and their modeling is not an easy task. Here is where this work contributes by performing an ontological analysis on a critical communication scenario, by applying UFO to illustrate and reinforce its constructs usage.

As a further step, UFO-C and KIPO (the Knowledge-Intensive Process Ontology) [Santos França et al. 2015] constructs, such as social relators, normative descriptions, and rules, could be used for a more thorough analysis of complex situations. Moreover, future works include the modeling of a core ontology on the critical communication domain, which will facilitate the modeling of scenarios such as the ones illustrated in the present work. In addition, even more complex scenarios will be described, identifying causality relationships between micro (radio) and macro (network) systems.

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