An Electronic Warfare Meta-Model for Network Centric Systems

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***Abstract*— In this paper we present a domain meta-model that formally defines the semantic of the entities, and related relationships, involved in an electronic warfare scenario. The presented meta-model can be exploited as common ontology by human and computer based entities involved in a network centric system. The goal is the sharing of a common understanding of the battle-space arena.**

I. Introduction

As soon as the exploitation of the EM environment has become one of the core capabilities of a military force, electronic warfare techniques [17][18] have been developed aimed at controlling the usage of the EM spectrum [3]. Electronic warfare deals with: Electronic Attack (EA) and Electronic Support Measures (ESM). EA consists of all those techniques having the purpose to degrade the efficiency of the enemy to exploit the EM spectrum. ESM is instead aimed at searching for, intercepting, identifying and locating source of intentional and unintentional radiated EM energy for the purpose of threat recognition, targeting and planning. Both EA and ESM techniques can be considered part of an invisible war aimed at achieving the *Information Superiority* [4]. In [4], Alberts et al. define *Information Superiority* as a state which is achieved when a competitive advantage (e.g., full-spectrum dominance) is gained from the ability to exploit a superior information position.

The achievement of information superiority is supposed to increase the speed of command decision, to pre-empt adversary options, to create new possibilities, and to improve the effectiveness of the selected options. A key element to the achievement of this condition is the adoption of a *network-centric* paradigm aimed at creating a shared situational awareness, enabling collaboration and self-synchronization, and enhancing sustainability and speed of command.

In contrast with this paradigm, Figure 1 depicts the model of a self-consistent platform equipped with: sensors, providing strategic information, and actuators (e.g. electronic counter measures, weapons, etc.), enabling a warfighter to contrast perceived enemy platforms. Sensors transform perceived signals into information exploitable by the warfighter and the installed weapons. Warfighters can only communicate by voice to share their own perception of the EM environment.

This constraint can significantly degrade the development of a shared context awareness because of several reasons such as: the voice channel's low throughput; the intrinsic ambiguity of the natural language, etc.

In a network centric system instead (Figure 2), capabilities for sensing, commanding, controlling, and engaging are robustly networked through digital data links.

The source of the increased power derives from the increased content quality, timeliness of information flow and by the fact the synthesis of all the information is delegated to the on board processing units and not to the operators.

One of the main requirements for the realization of such information centric system is the capability of the involved entities, both humans and processing units, to share common semantics for the data management. As described in section II, this requirement is a *knowledge representation* issue typical of the Artificial Intelligence (AI) research area. Solutions adopted by researchers of this topic should therefore be applied to the domain of electronic warfare in order to enable the realization of autonomous electronic warfare expert systems able to communicate, share and integrate information.

In order to provide a contribution toward the achievement of this objective, in this paper we present a meta-model describing the entities involved in an electronic warfare scenario.

The presented meta-model is a simplified version of an ontology designed during the development of the Elettronica S.p.A. product, named EW-Manager.

The EW-Manager aims to be an integrator of all the information provided by on-board and distributed sensors, enabling sensor data fusion also in network centric (NC) operations.

Through the designed ontological representation each platform can:

- relate its own sensed and retrieved information to high level concepts shared with the cooperating platforms;
- integrate the data retrieved by the cooperating platforms in its own knowledge base;
- infer new information to share.

Moreover, because it is a formal representation of a domain, it is flexible enough to be exploited for different purposes. For instance it can be used to generate domain specific languages [5] for the definition of mission libraries, or as a grammar for mission data automatic post analysis and documentation.

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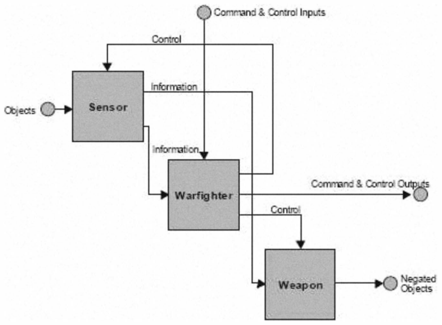

Figure 1: The Model of a Platform Centric System [4]

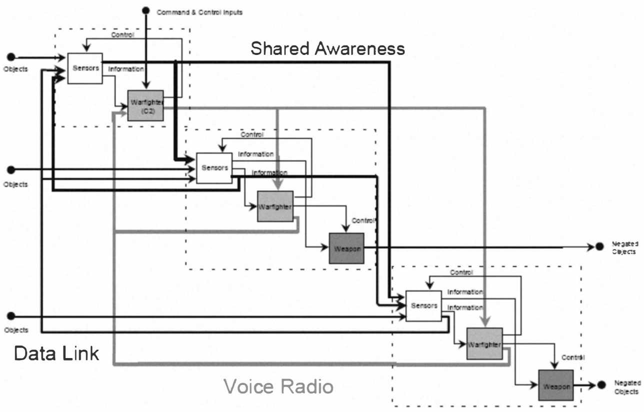

Figure 2: The Model of Network Centric System [4]

II. THE USE OF ONTOLOGIES IN COMPUTER SCIENCE

In computer science, an ontology (or domain meta-model) can be defined as a formal explicit specification of a shared conceptualism [2]. It provides a shared vocabulary which can be used to model a domain, that is: the existing objects and concepts; their properties and relationships. Ontologies are used in Artificial Intelligence since mid-1970s as a form of knowledge representation [6]. Several domain ontologies have already been designed and published [7] [8] [9] such as *BioPax* [8], an ontology for the exchange and interoperability of biological pathway, or *Wordnet* [9], a lexical reference system. This kind of formalism is strongly required when dealing with systems based on distributed autonomous agents called Multi-Agent Systems (MAS) [10]. MASs consist of distributed software components that are capable of taking decision autonomously and addressing complex tasks by cooperating through communication acts. A Net-Centric operation can be imagined as a multi-agent system consisting of autonomous agents each one expert in a particular aspect of the warfare domain. Because of this similarity with MASs, several organizations interested in NC warfare, have started designing their own ontologies representing specific aspects of the warfare. However, because of the practical impossibility to realize a unique domain meta-model suitable for any military organizations [11], the US DoD has recently adopted an approach based on *Communities of Interest* (COI) [12]. COIs represent an approach for developing the agreements necessary for meaningful information exchange among the *entities* of a *community*. Each COI consists of a collaborative groups of entities who must have a shared vocabulary to exchange information in pursuit of their shared goals, interests, missions or business processes. With respect to the COI approach our work represents a baseline for the design of ontologies for COIs dealing with Electronic Warfare. For the design and specification of the electronic warfare meta-model we have exploited the Object Management Group (OMG) [13] Meta Object Facility (MOF) [14]. The MOF is the OMG standard language providing means to define models' structures and data. We have chosen MOF for several reasons: first of all because it is an OMG widely adopted standard whose syntax and semantic is formally specified in [14], moreover it is a graphical easy-to-learn language by means of which the UML [15] itself has been defined. Finally because there already exist open source frameworks, like the Eclipse Modeling Framework (EMF) [16], enabling the MOF meta-modeling and model transformations.

III. A DOMAIN META-MODEL OF THE ELECTRONIC WARFARE

In this section we introduce the electronic warfare domain meta-model by means of a MOF specification. We use the term *meta* because our aim is to describe a domain. As a consequence the modelled elements are concepts (i.e. Platform, Sensors, etc.), not specific entities (i.e. that aircraft, the radar installed on that aircraft, etc.). The latter, also called *concept* instances, are instead objects of those models derived from an application of the meta-model to the description of a specific scenario. When referring to elements of the meta-model the italic case is adopted. Figure 3 depicts an high level overview of the main concepts of the EW meta-model. The *EWEntity* concept is the abstract concept representing a first order entity in the Electronic Warfare domain. Five elements of the meta-model extend the *EWEntity* concept: *Platform* (section. III-A), *Weapon* (section III-D), *CounterMeasure* (section III-C) *Sensor* and *Active Sensor*'s *Mode* (section III-B). For sake of simplicity the attributes characterizing each of these concepts have been omitted in Figure 3 but will be described in the specific sections.

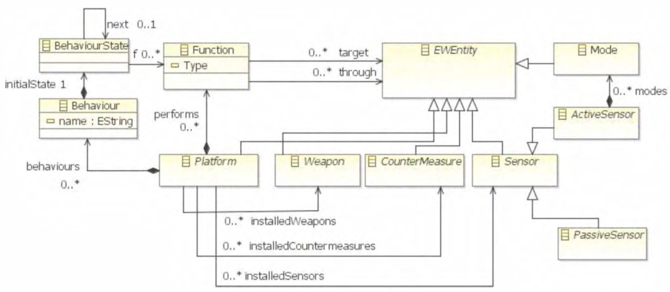

Figure 3: An overview of the EW meta-model

A. The Platform Concept

The *Platform* can be considered as the main concept of the meta-model. It extends the *EWEntity* abstract concept and represents a physical platform involved in an EW scenario. As depicted in Figure 3 a *Platform* instance can have several relationships with instances of the *Sensor*, *Weapon* and *CounterMeasure* concepts. They respectively represent the sensors, weapons and countermeasures installed on the modelled platform. Figure 4 depicts a more detailed representation of the *Platform* concept, its attributes and concrete realizations (i.e., Aircraft, Tank, Ship, etc.). Within a model, each platform has to be uniquely identified by a name, represented by the *Name* field, and a type, represented by the *Type* field. The *Type* field can assume the following values:

- *Friend*: if it has to be considered friendly and thus cooperating platform;
- *Neutral*: if it has to be considered a neutral platform;
- *Hostile*: if it has to be considered an enemy platform;
- *Informationsource*: if it has to be considered the source of the modelled data.

Only one platform within a model can have *INFORMATIONSOURCE* as type value. It represents the origin of all the modelled data and, consequently, their point of reference. The *Function* concept represents an activity that a platform can perform *by means of* one or more *EWEntities* (i.e. sensors, weapons, other platforms, etc.) with respect to a set of *targets*, that are represented by one or more *EWEntities* (i.e. sensors, platforms, etc.). The field *Type* of a *Function* instance can assume the following values:

- *Search*: the related platform is trying to detect the presence of *target* platforms in the environment. This function can be performed *by means of* *Passive Sensors* and *Active Sensors*;
- *TargetTracking*: the related *platform* is trying to track a detected *target platform* by means of *passive sensors* and *active sensors*;
- *ActiveContrast*: the related *platform* is trying to reduce the efficiency of a *target sensor*, or an *active sensor*'s *mode*, for instance by means an *active countermeasure* (i.e. flares, ECM, Towed Decoy, etc.);
- *PassiveContrast*: has the same objective and *target* of the *ActiveContrast* function, but is passively performed for instance *by means of* passive countermeasures as chaff or maneuvers;
- *HardKilling*: the related platform is trying to destroy a *target platform by means of* the use of *weapons*;
- *Cooperation*: associates a *platform* with a set of other *target platforms* in order to represent an existing collaboration among them;

Behaviours can finally be defined for each *platform* as a state machine of *Functions* modelled by means of the *Behaviour* and *BehaviourState* concepts.

A *Platform* instance can have associated information about its position. Such information can be absolute, by means of the *Latitude*, *Longitude* and *Altitude* fields, or relative to the platform that is the information source within the model, by means of the *RelDOA*, *RelElevation* and *RelRange* fields. An asset information can also be provided by means of the *Roll*, *Pitch* and *Yaw* fields. As depicted in Figure 4, several classes of platform exist (i.e. Air, Land, Water, etc.). For instance the *Missile* is modelled as an *Air Platform* that is a *Weapon* too. The reason for this modelling approach is that a missile can be considered a platform with its own sensors, both passive and active, performing its own functions, such as *TargetTracking* or *Cooperation* with the firing platform in the case of semi-active guide, its own position and asset.

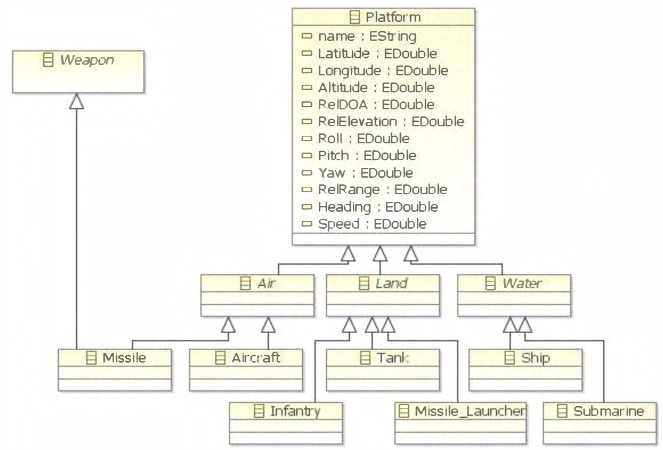

Figure 4: A detailed view of the Platform concept

B. The Sensor Concept

In our meta-model a sensor is an *EWEntity* enabling platforms to detect other platforms: directly in the case of *Active Sensors*, or indirectly in the case of *Passive Sensors* that detect the EM emissions coming from other platforms. Typical examples of *Active Sensors* are: the Radar (*RDR*) and LADAR (*LDR*); while Radar Warning Receiver (*RWR*) and Laser Warning System (*LWS*) are examples of passive sensors aimed at detecting emissions coming from other radars and ladars respectively. In our meta-model sensors are uniquely identified by a name and characterized by the measurement resolutions they provide (i.e. angular, elevation and range). Active sensors can also be specified by means of the set of their functional modes. As depicted in Figure 5 and *Figure 6*, a *Mode* consists of a set of emitted waveforms. In the meta-model, a *Waveform* is characterized by a type which can take value *CW* or *PULSED* if it is respectively a continuous or pulsed waveform. In both cases a description of the emitted radio frequency can be provided by means of the *RFDomain* concept. Only in the case of *PULSED* waveforms a description of the pulse width (PW), of the pulse repetition interval (PRI), and of the modulation on pulse (MOP) can also be provided by means of the *PWDomain*, *PRIDomain* and *MOP* concepts. The *DomainModel* concept is an abstract concept with those characteristics shared in the definition of RF, PRI and PW parameters.

These are:

- (*BandMin*, *BandMax*): define the domain of existence in which the parameter can assume values;
- (*RangeMin*, *RangeMax*): given a reference value, contained within the domain defined by *BandMin* and *BandMax*, the *RangeMin* and *RangeMax* pair define the upper and lower bounds relative to the reference value, in which the related parameter can assume values.
- (*PeriodMin*, *PeriodMax*): parameters can assume different values in time according to periodic rules. In this case an information about the period can also be associated by means of the PeriodMin and PeriodMax parameters.

A waveform can have associated a set of possible scanning modes. The *ScanningMode* concept represents the way the active sensor exploits the emitted waveforms to physically monitor the surrounding environment. It is characterized by a *ScanNotation* field that can assume the following values:

- *CRC*: for circular scanning mode;
- *SCT*: for sectorial scanning mode;
- *LOCK*: for tracking mode;

We refer to [18] for a detailed explanation of the cited scanning approaches and parameters. The other *ScanningMode* parameters can be exploited to provide a further characterization of the scanning mode:

- (*ASPMin*, *ASPMax*): represent the range of values for the antenna scanning period;
- (*BWAzMin*, *BWAzMax*): represent the range of values for the angular beam width;
- (*BWElMin*, *BWElMax*): represent the range of values for the elevation beam width;

A Passive sensor can instead be modeled by means of:

- (*RFMin*, *RFMax*): the frequency range in which it can detect an emitted waveform;
- *Sensitivity*: the minimum signal level perceived by the sensor where the detection takes place;

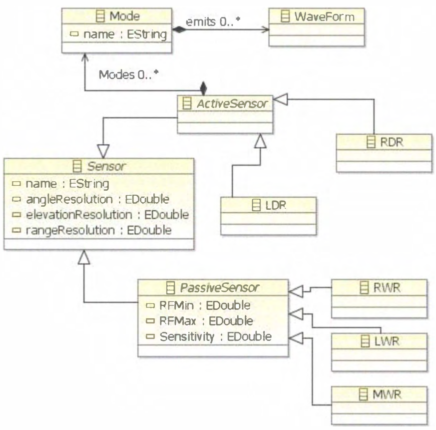

Figure 5: The Sensor Model

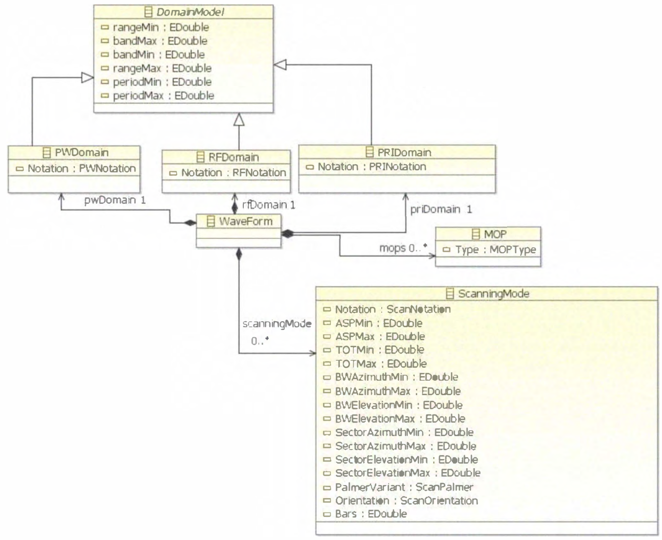

Figure 6: The Waveform Model

C. The CounterMeasure Concept

Figure 7 depicts the *CounterMeasure* concept. Similarly to the *Sensor* concept we have identified two classes of countermeasures: *Passive* and *Active*. The former encompasses all those countermeasures that do not require the emission of waveforms in the EM spectrum. An example of this class are chaff and maneuvers. Active countermeasures are instead based on the emission of waveforms, in a range of frequency specified by means of the *RangeMin* and *RangeMax* fields, and *Amplitude*, tailored to reduce the effectiveness of specific sensors. An example of this class are ECM and flares. ECM consists of all techniques reguarding the emission of energy in the spectrum. We have finally defined a third type of counter measure class: the *ArtefactsLauncher*. This entity acts as container and dispenser of those countermeasures based on cluster of artefacts dispensed in the environment when the countermeasure is activated. An artefact launcher is characterized by the number of dispensable artefacts (*AvailableArtifacts* field) each one characterized by the number of singular elements contained in the related cluster (*NumberOfElements* field).

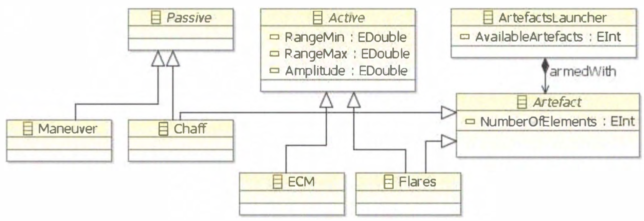

Figure 7: The *CounterMeasure* Model

D. The Weapon Concept

Even though the weapon concept, intended as a device aimed at damaging a platform, is not strictly related to the electronic warfare domain, we have decided to introduce it into the meta-model in order to provide a further confirm of its flexibility. This decision is moreover motivated by the fact there are weapons that can be equipped with sensors in order to perform target tracking functions (i.e. semi-active of active missiles). This particular class of platform represents one of the most important target of the EW activities aimed at reducing or inhibit the efficiency of missiles' seekers.

IV. Examples of Application Scenarios

Several use cases are possible for the designed meta-model. They can be arranged into two classes: *offline* and *runtime*.

The offline class encompasses all those cases in which the meta-model is exploited for the definition or the elaboration of data before or after a mission. For instance the meta-model can be used for the definition of mission libraries used by a platform during a mission for the purpose of platforms identification. Figure 8 depicts an XML representation of a possible mission library, compliant to the described meta-model. In the depicted library only one Radar is modelled, named *RDR1*, consisting of two possible modes: *S1* and *T1*. The former mode consists of a FIX RF emission at 9Ghz, with a FIX PRI of 1000msec, a FIX PW of 10 micro seconds and a CIRCULAR scansion having a period of 10 seconds. The T1 mode consists of a FIX RF emission at 10Ghz with the same PRI and PW of the former mode but having a SECTORIAL scansion with a period of 1 second. Such library can be for instance used by a platform (P1) in order to compare, during a mission, the data of the detected waveforms with those contained in the library and recognize the presence of the *S1* or *T1* mode within the EM environment (a process called *identification*). If the *S1* mode is detected and identified, the platform P1 can exploit the other parts of the mission library to automatically infer relevant information. As an example that the detected mode belongs to a radar installed on another platform, precisely an aircraft, named *EnemyAircraft* which is currently performing a *SEARCH* function. Moreover it can automatically infer that this function belongs to an hostile behaviour that will probably evolve with the activation of a *TargetTracking* function by means of the *T1* radar mode. As soon as the *T1* mode is also detected and identified, the *P1* platform might assumes itself to be the target of the *EnemyAircraft* platform .

The runtime class encompasses all those cases where the meta-model is exploited as a shared ontology for the exchanging of data between the cooperating platforms of a network centric army. Suppose the platform P1 is part of a network centric operation with another cooperating platform P2. As soon as P1 recognizes to be target of an enemy platform it might decides to share this information with the other friendly platforms involved in the same scenario. To this end, the information inferred through the identification process can be enriched with other data. For instance P1 can associate to the *EnemyAircraft* identity also information about its position obtained, for instance, by means of the P1's radar. In order to share semantically correct data, the information sharing itself has to be performed with communication acts compliant to the shared meta-model. For instance the XML message presented in Figure 9 depicts an example of dynamic data produced by the *P1* platform on behalf of the other cooperating platforms. In this message the *P1* platform is modelled as the source of the information (the *type* field has value *InformationSource*). It provides detailed data about its current position, speed and orientation and assesses that there is another platform, named *EnemyAircraft*, hostile, which is currently performing a *TargetTracking* function on the *P1* platform itself. The message also provides, to the cooperating platforms, a description of the radar mode through which the *EnemyAircraft* is performing the *TargetTracking* function. Moreover a description of the *EnemyAircraft* current position is provided by means of *DOA*, *Range* and *Elevation* measurements relative to the P1 platform (the information source of this message).

```
<ewmodel:Model>
<modeledSensors>
  <sensor xsi:type="ewmodel:RDR" name="RDR1">
   <Modes name="S1">
    <emits>
     <rfDomain rangeMin="9.0E9"
       rangeMax="9.0E9" Notation="FIX"/>
     <priDomain rangeMin="1000.0"
       rangeMax="1000.0" Notation="FIX"/>
     <pwDomain rangeMin="10.0"
       rangeMax="10.0" Notation="FIX"/>
     <scanningMode Notation="CIRCULAR"
       ASPMin="10.0" ASPMax="10.0"/>
    </emits>
   </Modes>
   <Modes name="T1">
     <emits>
      <rfDomain rangeMin="1.0E10"
       rangeMax="1.0E10" Notation="FIX"/>
      <priDomain rangeMin="1000.0"
       rangeMax="1000.0" Notation="FIX"/>
      <pwDomain rangeMin="10.0"
       rangeMax="10.0" Notation="FIX"/>
      <scanningMode Notation="SECTORIAL "
       ASPMin="1.0" ASPMax="1.0"/>
     </emits> </Modes> </sensor>
 </modeledSensors>
 <modeledPlatforms>
    <platform xsi:type="ewmodel:Aircraft"
       name="EnemyAircraft" type="Hostile">
    <performedFunction
    modes="//@modeledSensors.0/@sensor.0/@Modes.0"
    type="SEARCH"/>
    <performedFunction
    modes="//@modeledSensors.0/@sensor.0/@Modes.1"
    type="TARGET_TRACKING"/>
    <beaviours name="HostileBehaviour">
        <initialState
        functions="//@modeledPlatforms.0/@platform.0
        /@performedFunction.0">
        <next
        functions="//@modeledPlatforms.0/@platform.0
        /@performedFunction.1"/>
         </initialState>
     </beaviours> </platform>
  </modeledPlatforms>
</ewmodel:Model>
```

Figure 8: An example of model instance for static use

```
<ewmodel:Model>
<modeledPlatforms>
<platform xsi:type="ewmodel:Aircraft"
        name="EnemyAircraft" type="Hostile"
        RelDOA="123.0" RelElevation="-10.0"
        RelRange="2000.0">
```

```
        <performedFunction
          modes="//@modeledSensors.0/@sensor.0/@Modes.
          0" type="TARGET_TRACKING"
          target="//@modeledPlatforms.0/@platform.1"/>
    </platform>
    <platform xsi:type="ewmodel:Aircraft"
          name="P1" type="InformationSource"
          Latitude="30.1" Longitude="50.9"
          Altitude="6000.0" Heading="23.5"
          Speed="350.0"/>
    </modeledPlatforms>
    <modeledSensors>
     <sensor xsi:type="ewmodel:RDR" name="RDR1">
     <Modes name="T1"> <emits>
        <priDomain rangeMin="1000.0"
           rangeMax="1000.0" Notation="FIX"/>
        <rfDomain rangeMin="1.0E10"
           rangeMax="1.0E10" Notation="FIX"/>
        <pwDomain rangeMin="10.0"
            rangeMax="10.0" Notation="FIX"/>
        <scanningMode Notation="SECTORIAL "
         ASPMin="1.0" ASPMax="1.0"/>
        </emits> </Modes> </sensor>
      </modeledSensors>
</ewmodel:Model>
```

Figure 9: an example of model instance used to share information

```
<ewmodel:Model>
<modeledPlatforms>
    <platform xsi:type="ewmodel:Aircraft"
          name="P1" type="InformationSource"
          Latitude="30.1" Longitude="50.9"
          Altitude="6000.0" Heading="23.5"
          Speed="350.0"/>
    <platform xsi:type="ewmodel:Aircraft"
          name="P2" type="Friend"
          installedCountermeasures="
          //@modeledCountermeasures.0/@contains.0">
       <performedFunction type="PASSIVECONTRAST"
          counterMeasures=
          "//@modeledCountermeasures.0/@contains.0"
           target="//@modeledPlatforms.0/@platform.2"/>
   </platform>
   <platform xsi:type="ewmodel:Aircraft"
          name="EnemyAircraft" type="Hostile"
          RelDOA="123.0" RelElevation="-10.0"
          RelRange="2000.0"/>
    </modeledPlatforms>
    <modeledCountermeasures>
      <contains xsi:type="ewmodel:ArtifactsLauncher"
          Name="ChaffLauncher"/>
    </modeledCountermeasures>
</ewmodel>
```

Figure 10: an example of model instance used for platforms coordination

Activities coordination is another important issue related to data exchange in NC systems. Figure 10 depicts an example of XML data, compliant to the EW meta-model, that the P1 can produce to coordinate activities with the cooperating P2 platform. In this example P1, which is modelled as the information source. It asks to the cooperating platform P2 the activation of a *Passive Countermeasure*, named *ChaffLauncher*, against the *EnemyAircraft* platform.

V. CONCLUSION

Modern warfare operations are ever more based upon a continuous flow of strategic information. Nowadays processing and communication technologies enable the possibility to share and integrate information among the different entities of a distributed army. This technological condition only represents a base line for the realization of network centric operations. The next fundamental step for the achievement of this objective, consists of a knowledge engineering work aimed at defining ontological representations of the scenario perceived by the different network centric cooperating entities. These will represents shared domain vocabularies enabling seamless communication and cooperation among sensors, weapons and platforms made in different times by different organizations. In this paper we have presented a simplified version of a meta-model describing the Electronic Warfare domain we have realized for the knowledge base structure of an Elettronica S.p.A. product called EW-Manager. The EW-Manager is an enhanced processing unit aimed at integrating, in a unique picture, all the information provided by the different sensors installed on a platform and those retrieved from cooperating platforms.

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