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AN ONTOLOGY FOR A FAULT TOLERANT TRAFFIC INFORMATION SYSTEM

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Abstract. *In a traffic information system, a vehicle communicates with other vehicles, requesting information about road traffic. The conductor of the vehicle, which can be a human conductor or an autonomous agent, uses the information to decide about the better route for a specific place. This kind of system is typically implemented as a multi-agent system, where the agents communicate through a vehicular network. In these networks there are no communication guarantees, as the vehicles continuously move, and the communication links are dynamically modified. An interesting alternative to construct fault tolerant traffic information systems is to use semantic replication, while requesting information. In such a system, a vehicle requests the same information to many other vehicles, depending on the type of information and the situation. In this paper we present a road traffic ontology, to be used by a traffic information system with a semantic replication mechanism. The ontology represents the knowledge of road traffic, traffic scenarios, and specific information to help determine how critic a situation is. Our approach to fault tolerant multi agent systems is distinct from others, as we use semantic knowledge and semantic replication instead of status replication.*

Keywords: *Traffic information systems, Multi-agent systems, Ontologies, Semantic replication, Fault tolerance*

1. INTRODUCTION

VANETs (Vehicular Ad-Hoc Networks) are computer networks dynamically constructed by computers embedded in vehicles. The vehicles use wifi technology to communicate. The topology of the network is dynamically modified, as vehicles move in roads or streets (Karagiannis *et al.* (2011); Kakarla *et al.* (2011); Willke *et al.* (2009)). Using VANETs it is possible to develop applications to help the conductor to decide the best routes, to help conductors to drive without accidents, or to in practice drive the vehicles. An application that provides information to help the conductor is named a Traffic Information System.

A Traffic Information System (TIS) is a distributed application embedded in vehicles, which produces and manages information about traffic in roads and streets (Seredynski and Bouvry (2011)). This information becomes available to every vehicle. The information can be about the weather in a specific region, the traffic in a segment of a road, or the situation in, for example parking places and toll plazas. The information is used by vehicle conductors to decide for the best routes to a specific destiny.

A conductor may need information about the traffic situation in an intersection, or in a tool plaza, to decide between continuing in a road or taking a secondary road. A conductor may also need to know if a parking place in the road isn't busy. Conductor may also need information about accidents in the roads. Sometimes, the need for this information may be critical. An ambulance may be rushing to help in an accident, and needs to know the fast route to arrive at the accident.

This type of application is frequently developed using multiagent systems (MAS), although it can be developed using other computer technologies (Wooldridge (2009)). In a multiagent system autonomous agents cooperate in a domain to obtain better results to all. In a TIS developed as a MAS the agents autonomously decide about the information to be collected and distributed. It uses the type of the vehicle, the situation of the vehicle, its location and direction, and the place it needs to arrive. The agents may also be controlling the vehicles. And in this case, the agent decides, based on the traffic information, the better routes.

In many situations, the information needed is critical for the conductor, and must be delivered to the conductor in real time. An ambulance rushing to help in an accident is a critical situation. For these scenarios, the TIS must execute in a reliable way. The traffic information must be delivered in time, for the conductor to make its route decisions. The system must tolerate the occurrence of faults, and it must execute without delays. A fault tolerant multiagent system can be used to construct this system (Bora and Dikenelli (2009); N. Faci (2006)). FT MAS usually uses replication as a mechanism to provide reliability.

To correctly analyze all these scenarios and situations, and deliver the correct information in time, the Traffic Information System must be developed based on an ontology. An ontology is a formal representation of the type of information to be processed, associated to its semantics (Chen *et al.* (2004); Gu (2005)). Usually, ontologies are composed by classes, properties, relations between classes, restrictions, attributes, and other types of information. There are both generic on-

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tologies and ontologies developed for specific domains.

Some ontologies have been developed for traffic systems. They are used in the construction of Traffic Information Systems, and also to Intelligent Traffic Systems (ITS) (Khekare and Sakhare (2013)). Some ontologies are specifics for some scenarios, such as road intersections, and other ontologies are more generic for traffic information.

In this paper we present an ontology for a fault tolerant Traffic Information System. The TIS that is being developed is based on fault tolerant multiagent systems. The system uses contract net as e protocol to negotiate information. It also uses semantic replication, as a way to provide fault tolerance while executing the contract net protocol. The proposed ontology provide a way to develop rules with the aim of analyzing the criticality of each situation. The critical level of the situation is used by the system to set the replication mechanism.

The rest of the paper is organized in 5 sections. In Section 2 we discuss the Traffic Information Systems. In Section 3 we show some ontologies developed for TIS. In Section 4 we present some aspects of our reliable TIS, and the proposed ontology. In Section 5 we present some conclusions.

2. TRAFFIC INFORMATION SYSTEMS

A traffic information system (TIS) is a kind of vehicular network application, in which a group of intelligent, autonomous agents executing over a vehicular network send and ask for information (Seredynski and Bouvry (2011)). The agents maintain a traffic information base which is accessed by them. Information such as the weather, traffic conditions in a specific point of a road, and additional information can be accessed. The vehicles add information to this base, based on its local view of the traffic. All agents access the information base.

Traffic Information System are developed over Vehicular Ad-Hoc Networks (VANETs) (Karagiannis *et al.* (2011); Kakarla *et al.* (2011); Willke *et al.* (2009)). A VANET is a kind of network dynamically constructed over vehicles using wifi links. The communication routes between the vehicles are created and destructed during the execution, as the vehicles move down the streets.

For Traffic Information Systems, the loss of communication messages or a delay in this communication is not critical. Drivers use the information system to make decisions about the best route to a specific destiny. The system can also be used by autonomous agents controlling a vehicle. The aim of this application is to optimize transportation and traffic, in general.

This kind of application is classified as group 1 vehicular application by Willke *et al.* (2009). In this group, applications do not present critical communication requirements. The application is based on multiagent systems. The agents can use GPS devices (Willke *et al.* (2009); Quitadamo and Zambonelli (2008)). A problem generated by the use of VANETs is the small bandwidth provided by these networks. In some TIS the vehicular agents process the information before sending it to the database, in small messages. There are also solutions for TIS based on the use of mobile phones and smart phones (for example TomTom, PeerTis).

Traffic information systems are developed based on two distinct approaches: centralized and decentralized. Centralized information systems maintain a central information base. This system uses a road infrastructure, composed of interconnected sensors distributed over the roads. The sensors collect traffic information, which is transmitted to a central unit. This unit analyses and processes the information. The traffic information can be used by drivers when these drivers access the central unit. Every information collected by vehicles and sensors is transmitted to the central unit over the network.

In the decentralized approach, each vehicular agent is responsible to detect and collect information. The agents transmit their knowledge about the traffic, over the vehicular network. Every agent maintain a local knowledge base. Vehicles must, locally, analyze information to decide if the information must be included in its local knowledge base. Agents change information about the road traffic, through messages transmitted over the network.

An advantage of the decentralized approach is that in this case, it is not necessary to construct an infrastructure composed by a network of traffic sensors distributed over the roads. The system becomes flexible. The traffic information base is decentralized. The information is distributed among the vehicular agents.

There are different Traffic Information Systems proposed. Next we are going to analyze some of these systems.

The Sotis (Wischhof *et al.* (2003)) is a decentralized traffic information system which executes over a vehicular network. Each vehicle has a Sotis hardware, which collect local traffic information and send this information to other vehicles. The collected information is filtered and analyzed, before it can be transfered to other vehicles. The system uses GPS mechanism and other sensors. Each vehicle has its local database. Each database maintains traffic information related to the vehicle's region. The roads are divided into segments. The information is related to a road segment. The system is not reliable.

The PeerTIS (Rybicki *et al.* (2009)) is also a decentralized traffic information system, which executes over a peer-to-peer network, executed in smartphones. The use of smartphones is justified as this mechanisms have GPS, and in this case the vehicles communicate by a mobile network. The information is collected and distributed using the peer-to-peer network.

The TomTom system (TomTom (2013)) collects information using mobile phones. The information is transfered to a

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central unit which maintains a central traffic information base. Information about the location and the movement speed of mobile phones is used to infer the traffic situation on main intersection roads. Results are sent back to users using UMTS (Universal Mobile Telecommunications System).

The TrafficViewIn is presented in (Nadeem *et al.* (2004)). TrafficView is a traffic information system based on VANETs. It uses a specific hardware, which is installed in each vehicle. This system is part of a larger project, named e-Road. Traffic information is dynamically presented to users over static GPS maps.

Our traffic information system is also decentralized, but vehicles only send information when it is needed. Our system is reliable, as it sends replicated information, when the need for the information is critical. An ontology and a local knowledge base in each vehicle is used to determine when information is necessary, and how critical this information is. Our TIS is presented in Section 4. In the next section we are going to present some traffic ontologies.

3. ONTOLOGIES FOR TRAFFIC INFORMATION SYSTEMS

An ontology provides conceptual information to systems. Ontologies are fundamental building blocks to provide communication in multiagent systems. Agents use communication protocols, such as FIPA ACL (Wooldridge (2009)). These protocol provides the communication between autonomous agents based on domain ontologies.

Ontologies are developed using specific languages. Languages such as XML, KIF and OWL can be used (Wooldridge (2009)). Many ontologies use the OWL language (Antoniou and van Harmelen (2003)). OWL provides the representation of classes, its attributes and properties, and also the relationships between classes. An ontology can be inserted into the implementation of an agent as a library. The knowledge base of an agent is constructed based on its ontologies.

There are some ontologies developed for traffic information systems or to vehicle systems. These ontologies represent distinct levels of vehicles and traffic information. Some ontologies are more global, and do not represent specific situations. Other ontologies are specific, and represent only few types of scenarios. for example, there are ontologies that represent information related to traffic intersections.

We are going to discuss some ontologies in the next paragraphs.

Feld and Müller presented in (Feld and Müller (2011)) an automotive ontology which represents concepts and characteristics associated with both drivers and the vehicles aspects. The ontology also represents roads and its infrastructure. The main objective of this ontology isn't the road traffic. Due to this, the ontology isn't appropriate to the development of a reliable traffic information system.

The Primary-Context Model and Ontology has been presented in (Lee and Meier (2007)) by Lee and Meier. PCOnt formally specify concepts and relations between concepts, which are refereed by the Primary Context Model. Model and Ontology are components of the iTransIT system. The semantic meaning of information provided by the iTransIT system is based on types and relationships defined by the ontology. The ontology is composed by many global ontologies used in the iTransIT system and by local ontologies associated to specific systems, like parking systems. Although PCOnt is a wide ontology, it is not adequate to represent specific traffic scenarios, and its occurrences.

Hülsen et all present in (Michael Hülsen (2011)) a situation description ontology for traffic intersection. The ontology performs the reasoning on traffic rules. The ontology is modular and can have its expressiveness changed, connecting other ontologies. The ontology is specific for traffic intersection, and it is not applicable for road traffic.

Our ontology has been developed to represent traffic in highways. Its aim is the construction of a reliable Traffic Information System. The ontology provides information about roads, traffic, and scenarios related to vehicles in the roads. It also provides ways to the TIS to analyze how critical a specific situation is.

4. RELIABLE VEHICULAR INFORMATION SYSTEMS

A reliable Traffic Information System should provide guarantees related to the change of information between the vehicular agents. These guarantees must be proportional to the level of criticality of the information being requested. We have been developing a reliable Traffic Information System based on contract net protocol (Wooldridge (2009)) and semantic replication Bora and Dikenelli (2009); Xiaoqi and Klusch (2013). In our system we replicate information requests, which are sent to distinct vehicular agents. As we have many requests for one information, we guarantee the reception of the information required. The criticality of some information is defined by the agent after analyzing its situation, by executing rules over its knowledge base and the ontology. The criticality level is used to set the replication mechanism. The ontology represents information about road traffic, with the aim of providing an analysis of the criticality of the requested information.

In the next subsection we are going to present the ontology developed for our system. The ontology is based on Traffic and Transport Systems. It represents relationships of properties of traffic situations. The representation has been developed to be part of an intelligent system based on logic. in this system, sets of rules are executed using information based on the ontology.

The ontology is also used to represent relational dependencies, which are used to compose the semantics of each traffic situation. It then represents the context of the autonomous vehicular agent (Simone Fuchs and Kyamakya. (2008)).

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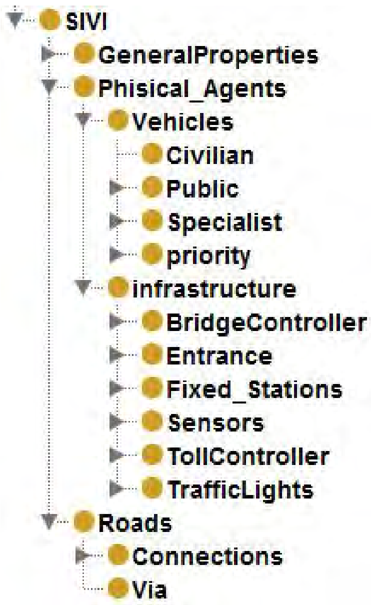

Figure 1. Based structure of the Ontology.

Figure 2. General properties of a road.

4.1 Reliable TIS Ontology

We assume a vehicular environment where each vehicular agent is autonomous, and has their own objectives. Both the vehicular agents and the roads have properties, characteristics and states. Each agent makes its decisions based on its state, and on information about the state of the roads. The agents have rules to make their decisions, which are based on the semantic of the state information represented. The semantics are analyzed using the information and the ontology. An agent also determines how critical its own state is. The semantics of every possible state and property, of all situations, are represented in the ontology.

The ontology we propose in this paper is presented in Figure 1, which shows the structure of the ontology. In the next subsections we are going to present details of this ontology.

4.2 Physical agents

The class Physical Agent is divided into Vehicles and Infrastructure subclasses.

The class InfraStructure represents physical stations which occurs in the roads. Infrastructure objects are linked to the roads using the attribute KM-Road, which is declared in the General-Properties-Road subclass. The KM-Road attribute is used to relate each infrastructure instance with its position in a road instance. The General-properties-Road class is a subclass of General-Properties.

Figure 2 presents the General-Properties-Road class. The relation of this class with infrastructure is presented in the Figure 3.

The subclasses of the Infrastructure class are:

- **Gateway**

  This subclass represents entrances for restricted places, like parking places. Instances of this class represent the gateway of this specific places, and are related to Roads instances using the attribute KM-Road. The Gateway-Control attribute indicates the kind of access to the place.

- **Fixed-Stations**

  This class indicates fixed places in roads, like parkings, gas stations, mechanical services, and so on. Its subclasses are: Parking, No-Parking-Place, Toll-road, Gas-Station and Machine-Shop.

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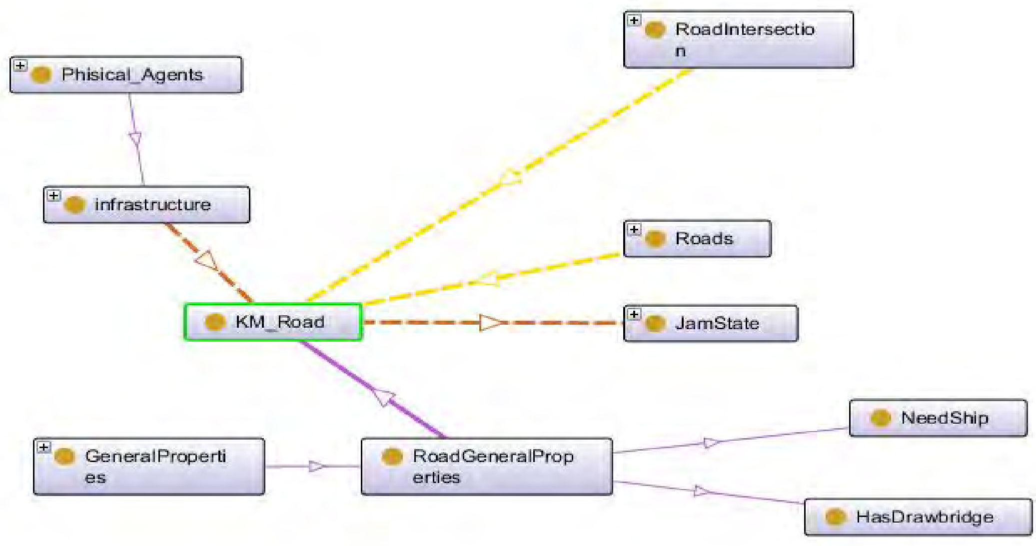

Figure 3. Relation between the classes General-Properties-Road and Infrastructure.

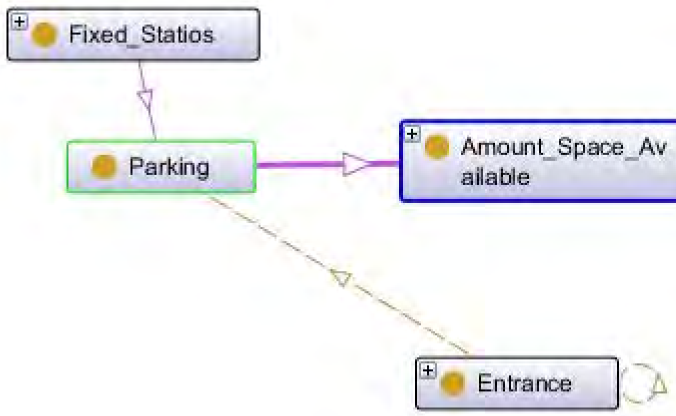

Figure 4. Relationship between the classes Parking and Entrance.

- **Parking**

  This class represents parking places in a road. Its attributes are: Amount-Space-Available and KM-Road. An agent which executes the entrance control of the parking sends information about the available parking to the information systems.

- **Gas-Station and Automotive-Services Subclasses.**

  The instances of these classes represent information about available gas stations and mechanical services in the roads. Its attributes are described in Figure 5.

- **Toll x Toll-Controller.**

  Instances of the class Toll-Road indicate places in the roads with a toll. The class Toll-Control is related to Toll through the Toll-Tax attribute.

- **Traffic-Lights.**

  Instances of these class indicates places in a road where there is a traffic light. Its attributes are: Traffic-Light-State, Traffic-Light-Current-Time-State and Traffic-Light-Time-State.

- **Sensors.**

  Sensors are infrastructure agents, linked to attributes such as speed and weight.

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Figure 5. Attributes of the Gas-Station and Automotive-Services classes.

Figure 6. Toll-Road and Toll-Control.

- **Bridge-Controller.**

  Represent information about bridges in roads.

4.3 Vehicle

The information system is composed by agents executing in the vehicles, which are travelling on a road. An instance of the class vehicle represents the vehicle agent, with its type and situation. Other instances of this class represent other vehicles on the roads. The agent uses its state and situation to analyze the criticality of the information that is being searched.

The class Vehicle is related to the class General-Property-Vehicle (Propriedades-Gerais-Veiculos). Vehicles are divided into four subclasses:

- Priority Class: vehicles with a high priority to travel on roads, as police cars, firefighter trucks and ambulances; linked to the Priority-Vehicles-General-Properties class, using the HooterState attribute;
- Public Class: public vehicles;
- Civilian Class;
- Specialist Class.

4.4 Roads.

Instances of this class represent roads. By using this class it is possible for an agent to analyze routes, to ask for specific information in the roads, and to decide for an adequate route to a destination. The set of roads and its infrastructure represent a scenario for the travelling vehicle.

Figure 9 represents the intersection between roads. Figure 10 represents a traffic jam on a road, and its position related to the road.

4.5 Critical scenarios

The analysis of the level of criticality of each situation is executed by a set of rules. The rules analyze the type of the vehicle asking for the traffic information, and the current status of this vehicle. The rules also analyze the kind of information that is being asked for. This analysis is possible considering the relations between the vehicle and its current

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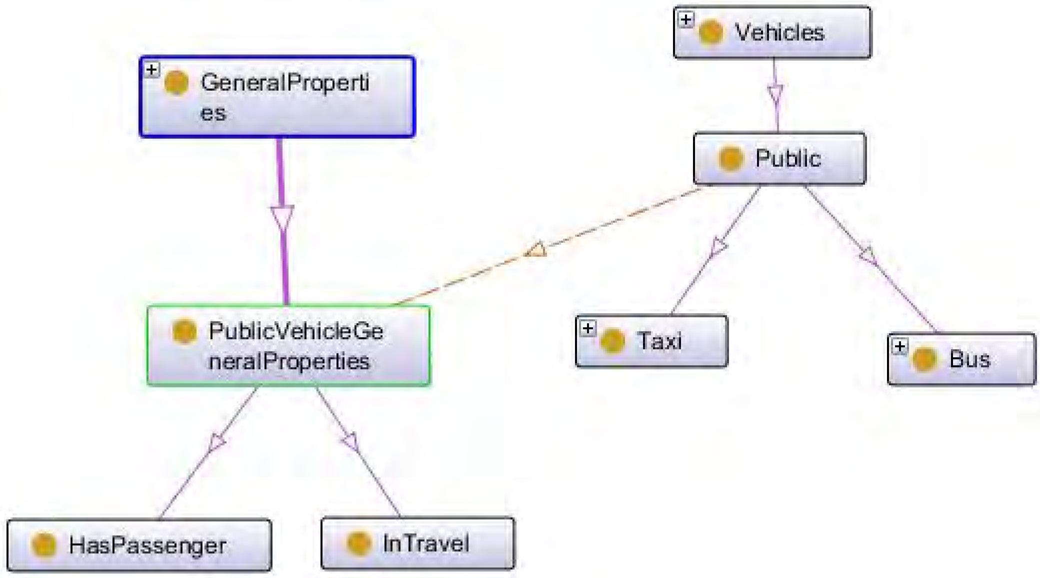

Figure 7. Public Vehicles Properties.

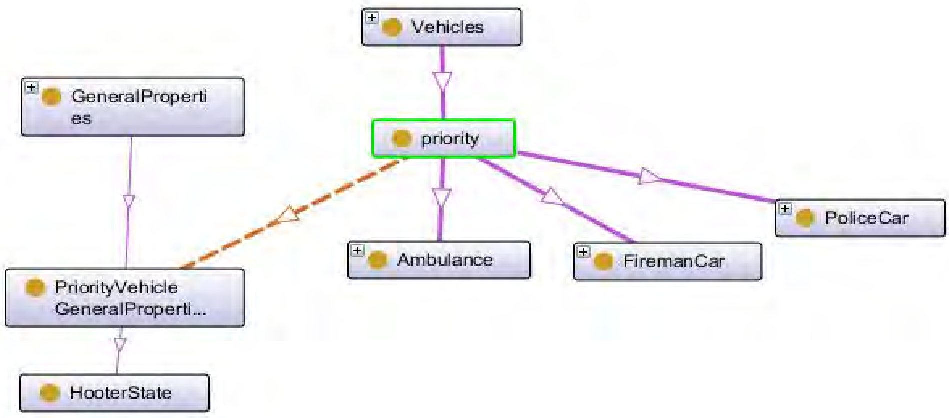

Figure 8. Priority Vehicles Properties.

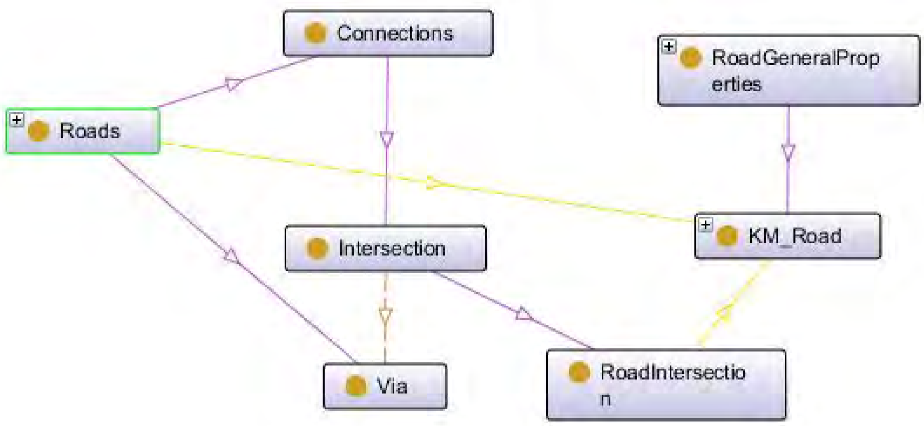

Figure 9. Intersection between roads.

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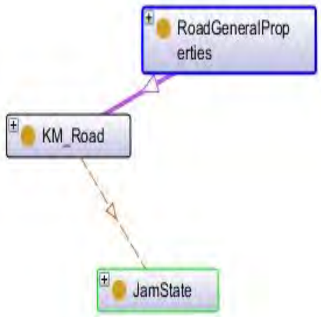

Figure 10. Traffic jam on a road.

status, and also between the current location of the vehicle and the location of the information source. This location depends on the information that is being required.

For example, an ambulance may need to know about the congestion status of a toll plaza. Requesting this information is critical if the ambulance is moving to the scene of an accident. On the other hand, if a common vehicle is moving through a road without hurry, then its information requested is not critical.

5. Conclusions

In this paper we have presented a new ontology for a reliable Traffic Information System. The ontology is based on road traffic, and on possible scenarios of vehicles traveling in a highway. The ontology had been developed in OWL. It is composed by classes, properties, attributes and relations between classes.

The ontology must be included in each agent executing the TIS. Each agent may ask for traffic information based on the ontology, and also based on its knowledge base.

The ontology provides a way for the system to analyze different scenarios, with distinct levels of criticality. The criticality is used to set up the semantic replication mechanism, providing fault tolerance to the system.

Our FT TIS is a work in progress. It is being developed, based on rules, in Jade.

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