Network-Centric Operations for Crisis Management Due to Natural Disasters

B. Lazarov, G. Kirov, P. Zlateva, and D. Velev

***Abstract*—The paper discusses the application of the network-centric operations (NCO) approach in the context of crisis management due to natural disasters. The study identifies some shortcomings of the traditional approach to crisis resolution and identifies areas in which NCO could bring advantage and enable faster and more accurate response to potential threats as natural hazards. The paper also proposes a technical implementation based on the Data Distribution Service (DDS) standard, which allows for fast development of network-centric applications which can provide the required real-time information exchange needed for the implementation of the NCO approach in the framework of the crisis management due to natural disasters.**

***Index Terms*—Network-centric operations, data distribution service, crisis management, natural disasters.**

I. Introduction

The increasing number of crises due to natural disasters in many regions of the world has changed irreversibly the security environment and made the countries define in a new way their responsibilities for security guarantee on national levels. The need to develop capacities for adequate prevention and timely response to natural hazards, and for minimization of possible consequences has imposed the necessity of transforming the existent crisis management mechanism into integrated package of special capacities [1].

A natural disaster crisis can quickly cross functional, temporal and even political borders and thus have an effect over multiple domains [2]. In order to mitigate those increasing effects, an increasing number of resources are required, as well as the participation of multiple organizations which must operate in close coordination in order to minimize human, economic and ecological losses.

Key to this cooperation is the effective, real-time information exchange between the participating responsible institutions and the ability to quickly make adequate decisions and organize a coordinated response.

The aim of this paper will be to analyze how the network-centric approach can be applied in order to provide the mechanisms for such information exchange and what benefits it will bring to the process of the crisis management due to natural disasters.

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II. Conventional Approach to Crisis Management

The response to a typical crisis usually involves multiple different organizations, each with its own capabilities and responsibilities during the aftermath of an incident. These organizations are further characterized by their specific internal structure, communication capabilities and protocols. Examples for such organizations are emergency medical services (EMS), police, fire brigade, search and rescue, civil defense etc.

At the scene of a large incident, these organizations are usually represented by one or more teams of their respective first responders, who are the ones who actively interact with the environment and are the prime source of information regarding the critical situation. Teams belonging to the same organization usually report to a coordinator, who works as the connecting link between the field assets and the operational level, where the decision making takes place (Fig. 1). Information is passed hierarchically from the first responders, through the coordinator, to the operational level, typically by means of status reports. In the opposite direction, once the situation has been evaluated at the operational level, orders are forwarded down to the field assets for execution [3].

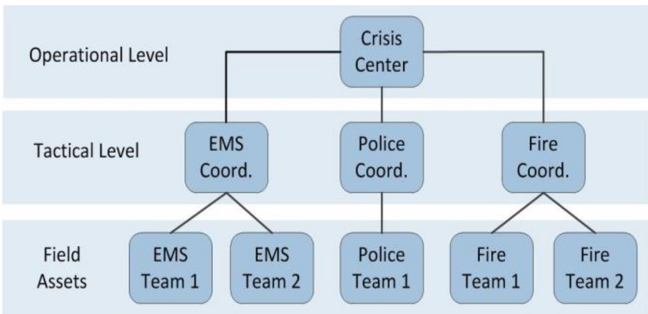

Fig. 1. Hierarchical operational structure during a response to a crisis.

One characteristic of this approach is that the higher level in the crisis management hierarchy the more non-real time the information becomes. This is due to the fact the information undergoes some form of processing (summarization, preparation of status reports) before being forwarded to a higher level.

During a critical event as natural disaster, the situation could change dramatically in a very short time frame, therefore creating the risk that until a decision is taken and respective reaction is generated, the response is no longer adequate to the progression of the crisis. In addition, if a new organization has to join the crisis management effort, it needs to be brought “up to speed” with the situation. This requires additional time and there is often the problem that not all parties involved have access to all the required information.

All these factors add up to additional time required to include another organization effectively in the crisis management mechanism.

At the Field Assets level, information exchange is mostly limited to sharing between different teams belonging to the same organization. On one hand, this is due to the different communication channels specific to each organization.

For example, EMS and police voice communications usually operate on different frequencies, and in some cases communications equipment used by one organization is incompatible with the one used by the other.

On the other hand, even if equipment constraints are resolved (e.g. one organization lending communication equipment such as radio stations to the other), the different communication protocols, habits, as well as specific professional terminology make the efficient exchange of information very challenging [3]. Therefore, most of the information sharing between different participating organizations happens at the tactical level, between the respective team coordinators, which then forward any information of interest to the first responders. Naturally, this limits the amount and type of the exchanged information as well as introduces delays and the possibility of introducing errors.

In summary, the hierarchical organization of the information flow during a critical event does not facilitate data exchange between first respondents from different organizations, and also introduces delays in forwarding information up the command chain to the operational level. At the Operational Level (and, to a smaller extent, at the Tactical Level as well) this results in limited situational awareness, creating the risk that decisions become outdated even before they reach the execution level. In order to overcome this, improvements in information collection and sharing are required. The following sections of this paper discuss how Network-centric Operations can be applied to crisis management in order to create efficient information exchange mechanisms.

III. Network-Centric Approach and Operations

The term network-centric (NC) is introduced by the U.S. Department of Defense (DoD). In military connotation the NC is frequently associated with a term Net-centric Operations (NCO). The Concept of the NCO is to establish the architectural model for integrating all DoD information systems into Global Information Grid (GIG). The purpose of the NCO is to achieve shared awareness, increased speed of command, higher tempo of operations, greater, increased survivability, and a degree of self-synchronization and standardization [1], [2], [4].

The basic concept is based on the idea of representing management interactions with the help of the network model. In the context of crisis management the network points can be illustrated with the various ministries, agencies and organizations, including specialized action units, analysis centers, etc. The nodes' basic functions are to elaborate assessment of the crisis and to propose particular measures for tackling a concrete situation or accident. To understand what is the new in network centric systems (NCS) and to be able to understand the increased power that is associated with it, one has to concentrate on four levels (Fig. 2) and on their interactions - information level, cognitive level, physical level, and the social level [5].

- *Physical domain* – it is the place where the NCS seek to influence. In the context of crisis management, it includes the physical domain where the critical even has occurred, including all infrastructure and field assets. According to experts [6], all organizational units must be networked and should support connectivity and interoperability between each other.
- *Information domain* – it is the place where information is created, gathered, transmitted, and shared. It includes information exchange between territorially separated participants. The collaboration aspect aims at taking into account the opinions of all participants in the crisis management process before the most appropriate decision is made.
- *Cognitive domain* - it regards the awareness and understanding of the critical situation. Individuals need not only to develop their own situational awareness, but they will need to share this awareness with a wide range of participants. This domain takes into account a level of training and experience.
- *Social domain* – it regards the ability of organizations to conduct collaborative decision-making and formulate adequate responses to the unfolding situation. This includes considering the impact which decision-making may have on tasks performed by other organizations.

Different organizations during the management of a crisis usually pursue their individual goals – EMS must treat wounded, police is in charge of maintaining the peace and order at the scene, conduct search and rescue etc.

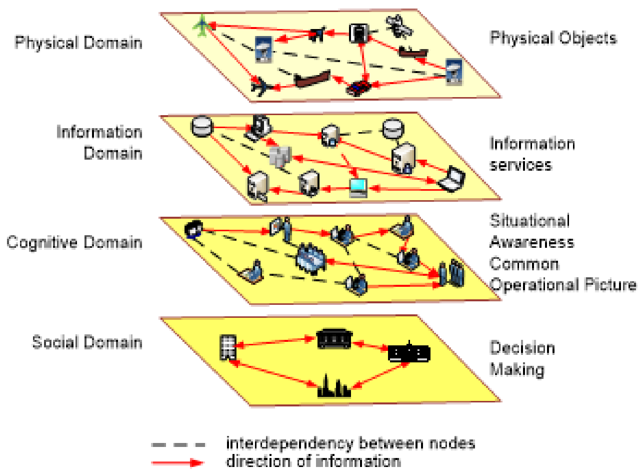

Fig. 2. Conceptual network-centric model.

In the traditional approach, each of these organizations would follow their own action plan. In a complex environment, however, this approach is not optimal, because it does not consider the effects that one team's actions might have on the other team.

For example, police deciding to block access on certain roads might influence or disrupt transportation of victims by the EMS, if the decision is not coordinated or communicated in timely fashion between the teams. Therefore, it is better for organizations to agree on a common action plan rather than follow individual agendas. The Social Domain of NCO envisions the ability to conduct cooperative decision-making, which in turn requires that the goals on the lower levels of the model have been reached. Ultimately, it comes down to the ability to share information and share agreement on its meaning.

IV. Enhanced Crisis Management through NCO

This section focuses on a short example of how the network-centric approach can be applied in practice and what quantitative and qualitative improvements it can bring to the crisis management effort. A similar study has been documented [3] and some of the observations are discussed here as well.

In the example, we assume a combined search and rescue attempt by teams from different organizations. We compare the two scenarios – a traditional one, where teams from different organizations rely only on voice communications with their own controller at the tactical level, and a scenario where the voice communication is supplemented by a network-centric application. The application provides a GIS interface with real-time position of all participating teams, as well as the ability for each user to enter points of interests (POIs) with short descriptions - for example location and state of a victim. Data entered by one user is automatically synchronized to all participants.

We assume a situation where a first response team from one organization wants to share information with the rest of the rescues – for example, a police search and rescue team has come across an injured person. Fig. 3 depicts the information flow in a scenario where only voice communications are available. In order for the information to reach the EMS personnel on field, it has to be transmitted by the police team to their coordinator at the tactical level. The information is then forwarded to the EMS controller, who informs the EMS responders.

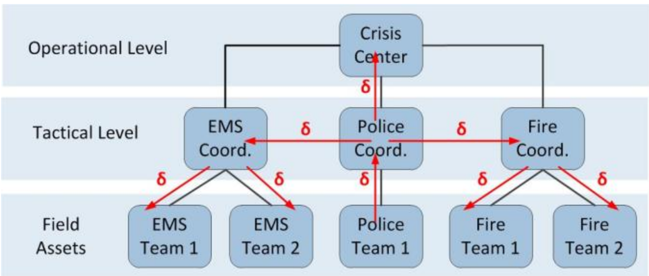

Fig. 3. Information flow with voice-only communication.

For simplification, we assume that the time needed to forward data about one victim from over one link is $t = \delta$ and remains constant, regardless of the specific participants in the link. Therefore, relying on voice only, it would take $t = 3\times\delta$ before the EMS team is informed about the victim.

On Fig. 4, the same situation can be observed, this time taking advantage of the available NCO application. Upon discovery, the police team enters the data as POI in the NCO application.

The data is transmitted in real-time simultaneously to all participants using the application. For simplification, it is assumed that the amount of time required to interact with the application and enter the data is the same as the time needed to transmit all necessary details over a voice channel.

The time required for the actual transmission can be neglected. The result is reduction of the reaction time compared to the traditional approach by 2/3rds. Furthermore, simultaneous to informing the EMS team, the information is also transmitted up the functional hierarchy to the Operational Level. In the traditional scenario, Operational Level is usually updated about the situation by means of status reports, resulting in a static, non-real-time snapshot of the event. The proposed NCO enhancement allows real-time updates to be provided to the decision-making authority, thus improving the quality and accuracy of the response actions.

In addition to the quantitative improvement, the application of NCO to the crisis management procedure also improves the data exchange qualitatively. Going back to the discussed example, in the voice-only scenario, the police team will transmit the information about the victim as a description of where the victim is found, in the best case perhaps with exact coordinates. Upon receiving the information, the EMS coordinator at the tactical level will have to process the update, locate the victim on a map of the area, select the closest team and direct them to the location or forward the coordinates and let them find the best route.

Besides introducing further delays, using this approach it is much harder to create a comprehensive overview of the situation. For the first responders, who might be visiting the location for the first time, it can be hard to orientate themselves based only on a description of the location or even based on coordinates.

Use of the proposed NCO application and having a readily available GIS representation of the information can improve both the processing at the Tactical and Operational Levels as well as the response of the field personnel.

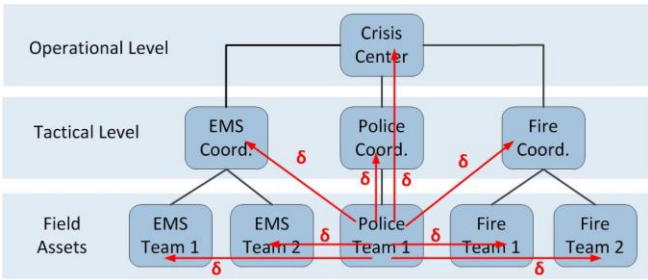

Fig. 4. Information flow with NCO applications.

V. Technological Implementation of Network-Centric Operations

The analysis of the current capacities has shown that the crisis management mechanism is of insufficient operational compatibility with the international practices and systems. In order the scientific potential to be used to the maximum of its capacity in view of the accomplished research work and the investments made, an information and communication infrastructure is necessary to be built providing operational compatibility of all segments within the crisis management system. The information and communication infrastructure will provide structural methodology, standards and instruments for the integration of geographical separated software applications in a common information and communication environment. These way administration officials of various institutions will be equipped with a tool to quickly exchange updated information on current changes in a particular situation, granting them the opportunity to come up with adequate solutions and coordinate in appropriate and timely mode the cooperation among the institutions in charge.

In this section, we propose a technical solution for development of network-centric applications, which can be used to develop software that could assist in implementing NCO for the purposes of crisis management.

The principles of the network-centric approach for complex system management assume that the information environment consists of two parts [7] – transportation and management (see Fig. 5). The transportation part provides communication functions and services for synchronized information exchange. It defines structural methodology, standards and interfaces for integration and implementation of territorially separated information systems each of which services a particular organization within a common information and communication environment. The management part includes a set of software applications which provide the persons in charge with the needed functionality according to their competences and duties in the crisis management process. The standards and interfaces defined by the transportation part leave the system open allowing for new applications to be added on a modular base.

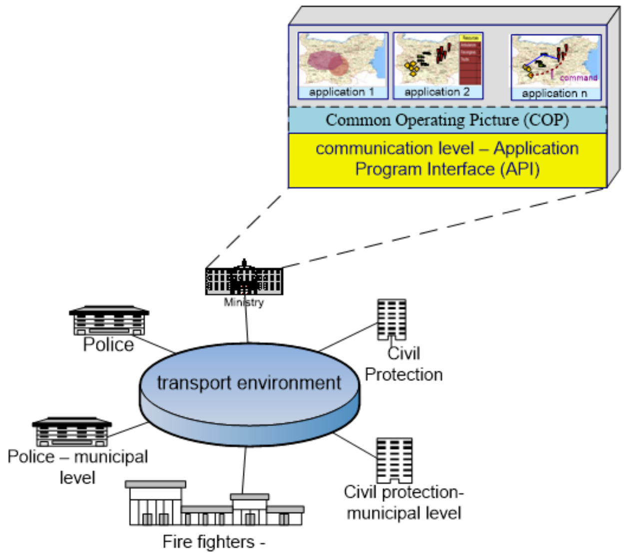

Fig. 5. Network-centric information environment.

The proposed network-centered information environment provides an opportunity for obtaining a Common Operational Picture (COP) which includes:

1) A common picture of the particular situation being received in each organization as a result of exchange and summary of operational information from various sources;
2) Total awareness of the objectives of the strategic management levels and of the policies for their attainment;
3) Passing on organizations' objectives and tasks to lower executive levels in a comprehensible mode;
4) Drawing plans for coordination the actions of all operational units without changing or distorting the specific purposes of separate organizations;
5) Monitoring the performance of lower levels so as to intervene, if necessary, in view of correcting observed shortcomings and weaknesses;
6) Providing feedback between tactical executives and organizations' managements; drafting recommendations for changing objectives, tasks, techniques and procedures with regard to the observed changes in the environment.

The principles of network-centric approach considering the opportunities for decision-making at lower levels and intense information exchange put specific requirements towards the network-centric environment architecture. On the one hand, software applications have to be designed to sustain the functional requirements of a particular organization, on the other – these applications must exchange information to provide common operational picture (COP). This necessitates the implementation of a distributed architecture which can provide transport infrastructure and offer interface standardization between different organizations' applications.

A. *Software Modules*

This part of environment architecture includes a set of software applications assisting the employees' work within a particular organization, participating in the crisis management process. This set of applications provides specific services, which are different for each organization, depending on its functional responsibilities and duties. All applications share a common feature - COP, allowing the creation of a common idea about the situation and the use of remote application services. Software applications are usually used for planning the available resources, decision-making, assigning tasks, etc. The major advantage of these applications is their ability to exchange information and use databases of different organizations, this way providing officials with opportunities for joint services and mutual analysis of various alternatives before taking actions. The main characteristic features of the applications can be summarized as follows:

Ability to collaborate – It means information exchange between territorially separated applications. The collaboration aspect aims at taking into account the opinions of all participants in crisis management before the most appropriate/ right decision is made.

Ability to synchronize actions – The network-centric approach requires that entities be able to rapidly synchronize among themselves, independent of direction from superiors. This will enable them to flexibly adapt actions, to take advantage of opportunities and minimize impacts of changing or emerging threats.

Ability to share situational awareness - Individuals will need not only to develop their own situational awareness, but they will need to share this awareness with a wide range of participants. They will need to see how others perceive the situation, and be capable of processing information from many sources while remaining focused on current tasking.

Ability to conduct collaborative decision-making - The ever-changing nature of crisis environment requires that commanders involve many elements, including other commanders and non-traditional communities of interest, in the decision-making process. This allows taking into account the impact which decision-making may have on tasks implemented by other organizations.

Ability to accomplish joint operation – Availability of formal rule sets which allow for combining the potential of multiple services and organizations to achieve maximal effect and optimal resource allocation.

B. Transport Infrastructure

The demand of attaining compatibility, integration and service virtualization, taking into account users' preferences, requires a new approach to distributed information systems implementation. In network-centric approach the information coming from different sources must be distributed to all participants according to their demands and preferences (QoS). Basic rule concerning the exchanged information is 'the right data at the right time in the right place'. In other words, a user is more interested in a particular type of information rather than in the initial sources providing it [8].

The concept of network-centric environment is based on the idea of providing structural methodology, standards and instruments for integration of separate applications into a common information and communication environment. This architecture provides a technical framework for development of a network-centric environment that allows operation compatibility and provision of services for all applications. In the proposed architecture the different applications interoperate through a common transport environment or standard mechanism for data distribution - DDS (Data Distribution Service). DDS provides communication functions and services that exempt the programmer from the procedures needed for integration of software applications and their interrelated communication [1], [2]. The applications communicate through Application Program Interface (API). This way each application can call the communication functions and services from DDS.

C. Data Distribution Service (DDS) Standard

Data-Distribution Service (DDS) is emerging specifications created by the Object Management Group (OMG) in response to the need to standardize a data-centric publish-subscribe programming model for distributed systems. The purpose of the specification is to provide a common application-level interface that clearly defines the data -distribution service [9]. DDS defines a set of services for efficiently distributing application data between participants in a distributed application [10], [11]. The specification provides a platform independent model (PIM) that can be mapped into a variety of concrete platforms and programming languages. DDS provides formal definitions for the Quality of Service (QoS) settings that can be used to configure the services [10]. The service is divided into two levels of interfaces: the Data-Centric Publish-Subscribe (DCPS) layer and an optional Data Local Reconstruction Layer (DLRL). The DCPS layer transports data from publishers to subscribers according to Quality of Service constraints associated with the data topic, publisher, and subscriber. The DLRL allows distributed data to be shared by local objects located remotely from each other as if the data were local. The DLRL is built on top of the DCPS layer.

The overall Data-Centric Publish-Subscribe (DCPS) model consists of the following entities [10]:

Domain – It is a basic DCPS building unit. All DDS entities that belong to the same domain can interact with each other.

Topic - A fundamental means of interaction between publishing and subscribing applications. Each topic has a unique name and a specific data type that it publishes. When publishing data, the publishing process always specifies the topic. Subscriber requests data via topic. The association between publications and subscriptions is accomplished by means of Topic objects.

Publisher - It is responsible for the dissemination of publications to all relevant subscribers in the domain. The Publisher decides what information is to be published at what time.

DataWriter - It is a type specific interface for the Publisher. It allows an application to offer samples (data) for a specific topic to the Publisher, which will then perform the actual transmission of these samples. The DataWriter is responsible for marshalling the data and passing it to publisher for transmission.

Subscriber - It is responsible for collecting information coming from various publications. The Subscriber decides what information is to be retrieved at what time.

DataReader - It is a type specific interface for the Subscriber. It allows an application to access samples of a specific topic from the Subscriber, which actually collects all incoming samples. The DataReader takes the data from subscriber and de-marshals it into the appropriate type for a topic.

Fig. 6 illustrates an example application using DCPS to distribute data from a single publisher process to a single subscriber. The application uses a publish subscribe technology that is based on a powerful concept of a fully distributed global data space in which publishers and subscribers asynchronously produce and consume data.

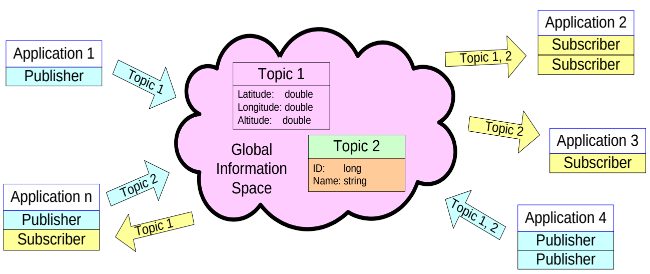

Fig. 6. DDS publish-subscribe software architecture.

Applications that want to write data are "publishers" for a topic [12]. Whereas, applications that want to read data from a topic are "subscribers". The DDS middleware is responsible to distribute the information between a variable number of publishers and subscribers.

It is important to emphasize that DCPS model only transmits data structures (Topic). For this reason it cannot be used to exchange additional information such as data processing methods and data dependencies. A possible answer to these challenges is the extending of the existent DCPS mechanism by using the object-oriented design.

The acquired experience in the DDS systems (air traffic control, transport, energy, SCADA, network-centric systems) has called for carrying out in-depth analysis as to what extent the DCPS mechanism is fitting the contemporary challenges and requirements. The conclusions are indicative of the following trends:

1) The DCPS makes it easy to connect applications, but not so easy to find, access, and work with the information from object-oriented applications;
2) Lack of an object-oriented infrastructure of the DCPS that would provide effortless component integration;
3) The DCPS does not effectively address data abstraction and information hiding.

The paper aims at developing an object-oriented layer (OOL) providing a high-level mechanism for DCPS data exchange through local objects. Manipulating these objects (i.e., create, modify, delete), the applications can work directly at the DCPS level. This will eliminate the complex network programming for DDS distributed applications. OOL allows intense information exchange in a comprehensible format among distributed participants while following the principles of information security, regulated information access and coordination.

VI. Software Architecture for Crisis Management System

The main goal of the proposed software architecture for DDS applications is to provide functions and services for working with the DCPS Data Model [10], [11], [13]. Once this is done, we can write the business logic on-top of these abstractions.

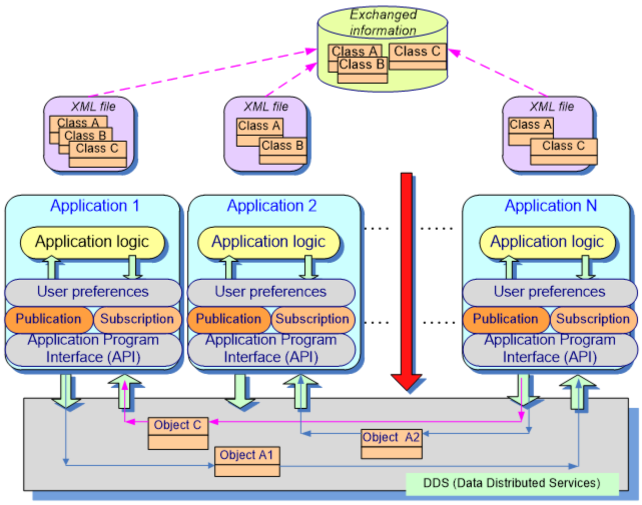

Fig. 7. Architecture of the network-centric environment.

Our aim is to develop an object-oriented architecture that reduces the lines of code that need to be written for a DDS application (see Fig. 7). It has a publish-subscribe communication architecture that supports object modelling and the notion of disseminating updates to DDS object instances. The architecture allows exchanged data to be described not only in terms of attributes, but also in terms of methods and relationships with other objects.

A common information standard is used to implement and control the information exchange between different applications. It includes the following services:

Declaration management services – allow the applications to declare their demands for data delivery to and from other applications; provide a mechanism for information exchange based on publication, subscription, and supporting control functions.

User-centered services – provide a mechanism for data exchange taking into account user's preferences. It means that data can be received selectively by subscribing applications on the basis of publicizing applications' values or characteristics.

Time management services – provide a mechanism for coordination of distributed applications (time setting, time synchronization and time modification). DDS is meant for real-time data exchange.

The remaining of this chapter aims to apply the previously mentioned features of DDS for a crisis management application. For a purpose of the investigation is used a SIMD library, which is an open source C++ API intended to simplify the use of DDS [14]. Our purpose is to develop an architecture model based on SIMD that reduces the lines of code that need to be written for a DDS application. Figure 8 presents a simplified view of the model.

As it can be seen in the diagram all classes use templates. The new element of the model is a class StandAlone. It provides the ability to be configured all classes that accomplish a communication between the applications.

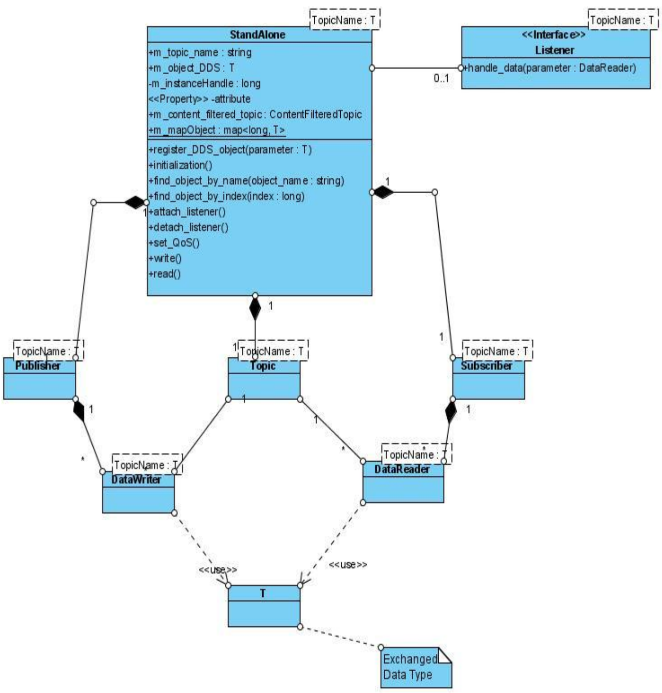

Fig. 8. Model of the software architecture for DDS application.

The StandAlone class template allows exchanging different data types (topics) without being rewritten a new class for each topic. The parameter T is the topic name exchanged between the communicating participants. An instance of the class provides methods to refresh write and read a topic. It can be created in "read" mode to provide an access to data without blocking the incoming updates or in "write" mode in order to send the new data samples.

The publishing side of the communication model is represented by the association between a Publisher and one or more DataWriter objects. The application uses this object to send data of a given type T, which then triggers the Publisher to issue the data according to the Quality-of-Service settings. The subscriber side of the communication model is represented by the association between a Subscriber and one or more DataReader objects.

The Subscriber is responsible for receiving published data T and making it available according to the QoS-settings. The application can access the received data by DataReader objects generated for T type. The important element of the model is a Listener. It is an interface that has to be implemented by a programmer to be aware of incoming updates on the objects belonging to one particular data type T. The last samples of the exchanged data objects are stored in a static map – values, with integer key (ID) management. The association between publications and subscriptions is accomplished by means of a Topic class template. A Topic associates a unique name, a data type T and Quality-of-Service settings related to the data T.

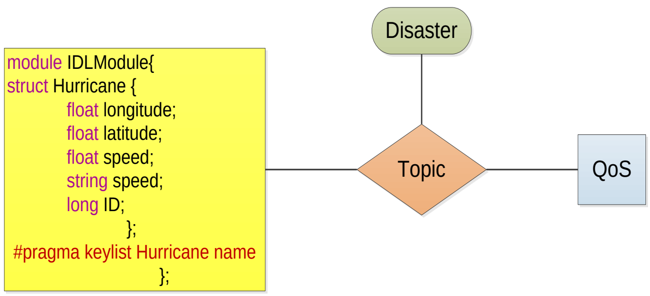

Fig. 9. Topic definition.

TABLE I: EXAMPLE OF USE OF THE STANDALONE CLASS

Publishing application

```
StandAlone< IDLModule::Hurricane > * objectWrite = NULL;

objectWrite = new StandAlone<IDLModule::Hurricane>
("Disaster",StandAlone<IDLModule::Hurricane>
::OperationMode::WRITE_ONLY);

IDLModule::Hurricane trackPt;

objectWrite->m_object_DDS = trackPt;
objectWrite->write();
```

Subscribing application

```
StandAlone< IDLModule::Hurricane > * objectRead = NULL;

objectRead  = new  StandAlone< IDLModule::Hurricane >
("Disaster",
StandAlone<IDLModule::Hurricane> ::OperationMode::READ_ONLY);

objectRead->m_dataReader->on_data_available_signal_connect(
boost::bind(&StandAlone::handle_data,
this,
_1) );
```

The proposed software model is illustrated the with a simplified example application in the field of the crisis management. For the sake of simplicity, the different software applications will exchange a sample data structure. It contents the disaster data that need to be published by an application supporting specific functional requirements of an organization. The subscribing applications separated into different organizations have to receive the published data. As an example, Fig. 9 shows the data structure for a disaster according to the Interface Definition Language (IDL).

Based on these IDL type definitions, the source code for all DDS entities are automatically generated in the specified programming language. The generated classes can be used in applications by the StandAlone class template (Table I). The next C++ lines of code show how to use StandAlone by publishing and subscribing applications to exchange (write and read) information through a DDS environment.

The next C++ lines of code show how to use StandAlone by publishing and subscribing applications to exchange (write and read) information through a DDS environment. An instance of the StandAlone class automatically registers a topic, creates a DataWriter, DataReader and sets the QoS.

The above example shows that DDS can be used with 2-3 lines of code for development network-centric software systems.

VII. CONSIDERATIONS

The transition from the traditional approach to crisis management to a system that implements network-centric mechanisms is not just a matter of finding a technical solution to the challenge of information sharing. In a network-centric environment, it is expected that organizations will work in close cooperation with each other on all hierarchical levels. Due to the nature of work of the organizations involved in this field, changes to the legislature might be required in order to accommodate sharing of information, resources and know-how. In addition, extensive joint trainings will be required before teams can efficiently leverage the benefits of the network-centric mechanisms. A similar study has been conducted and documented [3] during which were observed problems such as people using specific professional jargon when entering information or concerns that by having all information available to everyone people might start interfering with other teams' work. Issues like these can be resolved by extensive training and educating and encouraging professionalism when working in a multi-team environment. Only after the people learn the fundamentals of network-centric operations will they be able to act in a network-centric.

VIII. CONCLUSIONS

Modern-day crises due to natural disasters are characterized by their large-scale impact on multiple domains. The traditional hierarchical information exchange during the response to a crisis cannot efficiently cope with the dynamics with which the situation can change. In order the best counter-actions to be taken. It is necessary to be able to make fast, well-informed decisions. Network-centric operations provide a model for efficient information generation and exchange, which results in better situational awareness and coordinated decision-making. The proposed technical solution based the DDS standard enhanced by an object-oriented layer can be used to implement the network-centric approach in applications that can provide the necessary communication for an efficient network-centric based crisis management.

The paper presents a model of network-centric information environment providing operational compatibility between all segments within the crisis management system. This allows officials from various institutions to exchange updated data on current changes in a particular disaster situation, to come up with adequate solutions, as well as to pass on instructions for their interaction. The effect from the proposed environment aims at transforming the crisis management mechanism into an integrated information package, which is able to provide communication functions and services within an ICIE.

The results are in accordance with recommendations for operation compatibility of the natural disaster crisis management mechanism with the innovative practices and systems and use of the scientific potential in the maximum of its capacity in view of the accomplished research work and the investments made.

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REFERENCES

[1] G. Kirov and V. Stoyanov, "Network-centric architecture for crisis management system," in *Proc. 11th. International Conf. on Computer Systems and Technologies - CompSysTech'10*, Sofia, Bulgaria, 2010, pp. 161-167.

[2] G. Kirov, V. Stoyanov, and B. Lazarov, "Abstract model of an object-oriented layer for distributed systems based on the DDS standard," in *Proc. 12th International Conf. on Computer Systems and Technologies - CompSysTech'11*, Vienna, Austria, 2011, pp. 75-81.

[3] V. Ven, R. Rijk, P. Essens, and E. Frinking, "Network centric operations in crisis management," in *Proc 5th International ISCRAM Conference*, Washington, DC, USA, 2008, pp. 764-773.

[4] A. Benssam, J. Berger, A. Boukhtouta, M. Debbab, S. Ray, and A. Sahi, "What middleware for network centric operations?" *Knowledge-Based Systems*, vol. 20, pp. 255–265, 2007.

[5] S. Ahvenainen, "Backgrounds and principles of network-centric," National Defence College, Course of Network-Centric Warfare for Post-Graduate Students, 2003.

[6] A. S. David and H. E. Richard, *Planning: Complex endeavors, DoD Command and Control Research Program*, Washington, DC, 2007.

[7] G. Kirov, "Contemporary approaches to management of complex heterogeneous systems," *Perspectives*, National Library of Serbia registration, Belgrade: CIP – 316.4, pp. 87-101, 2015.

[8] W. Y. Chang, *Network-Centric Service-Oriented Enterprises*, Published by Springer, 2007.

[9] R. Joshi and G. Castellote, "A comparison and mapping of data distribution service and high-level architecture," Real-Time Innovations, Research Program, Washington, DC, 2004.

[10] A. Corsaro, L. Querzoni, S. Scipioni, S. Tucci-Piergiovanni, and A. Virgillito, *Global Data Management*, IOS Press, 2006.

[11] N. Wang, D. Schmidt, H. Hag, and A. Corsaro, "Toward an adaptive data distribution service for dynamic large-scale network-centric operation and warfare (NCOW) systems," in *Proc. IEEE Military Communications Conference MILCOM*, 2008, pp. 1-7.

[12] M. Ryll and S. Ratchev, "Precision Assembly Technologies and Systems," *Four International Precision Assembly Seminar IPAS*, Chamonix, France, 2008, pp. 359-369.

[13] A. Chigani and J. Arthur, "The implications of network-centric software systems on software architecture: A critical evaluation," in *Proc. 45th Annual Southeast Regional Conference*, Winston-Salem, North Carolina, USA, March 23-24, 2007, pp. 70-75.

[14] *OpenSplice C++ Tutorial*, PrismTech Corporation, September, 2009.

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