Towards Active C3I Systems

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(invited paper)

Abstract - **This survey paper focuses on some important advanced research directions in key enabling technologies for building modern C3I systems. Special attention is given to communication and intelligent aspects of such systems. Finally, our research experience and future directions in C3I systems development are also shown.**

Keywords - **CSCW, C3I, active technologies, mobile agents, active databases, nomadic computing**

I. Introduction to the C3I Systems

As we go further into an information age, applications requirements become stronger then ever. As we are going closer to 21st century we witness that any human activity is supported by computers. From education to entertainment, from personal digital assistants (PDA) to massive parallel computing, from simple word processing to management information systems, from single isolated personal computer to Internet, everything is supported by computers. In addition, there are very few applications which are not communication oriented. Communications without any limitations, regardless to distance or geographical distribution, operating system, hardware, data, or whatever we can see as potential limitation, are becoming usual.

This paper concentrates on one of the most important computer applications usually known as C3I (Command, Control, Communication and Intelligence) systems. Such applications have an important common feature: they serve to save human lives. There are many examples of their usage, the typical ones being are national defense, fireguard systems, hail suppression, healthcare, air-traffic control, rail road control, anti-criminal and so on.

From a general point of view C3I systems support prediction, prevention and intervention against any potentially dangerous situations caused by humans (aggression, terrorism, traffic accidents, etc.) or natural catastrophes (earthquake, floods, fires, etc.). To accomplish such complicated task those systems require a lot of people to work together sitting with each others and/or at the different places. This cooperative work on the same data, usually known as CSCW [1], requires very complex interaction between C3 system and its environment as shown in Fig.1.

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This interaction can be compared with "neural arc" with number of points where human experts make decisions [2]. An intelligent command and control system has to provide appropriate tools in decision making. Sensors, the "eyes" and "ears" in the area of responsibility of such system, are giving real-time inputs which then combine with description of the system mission and its goals. After several activities, such as estimation of the situation, options generation, choosing the best one, planning and instruction (orders) generation, system is ready to act into the area of responsibility.

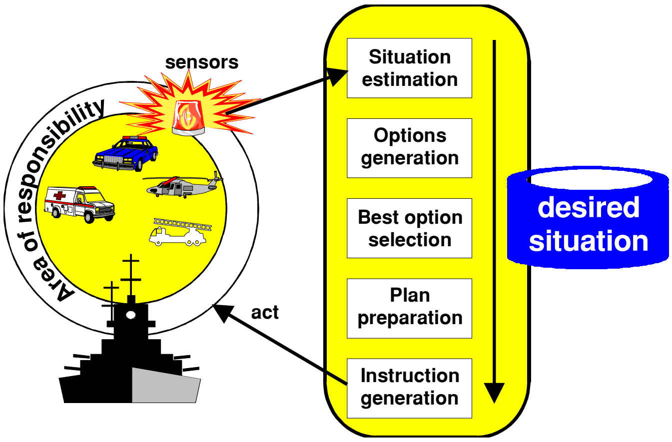

Figure 1. Command and Control System

Depending of the degree of artificial intelligence of such systems the decision making process can be less or more automotive, from simple support to offering a decision. This process is very often distributed, both the functionally as well as geographically. Also, it is often necessary to provide some kind of cooperation with other C2 (Command and Control) systems, for example to exchange some current situation data or to synchronize the common activities on the field. Therefore, it is necessary to include network components and provide distributed computing support. Such systems are known as C3I systems, as in Fig. 2.

The communication abilities of such systems have to be very high. The communication network and appropriate services have to carry different real-time or near-real-time data such as graphics, image, video, voice or any alphanumeric data. The mobility of both, either potential users or the whole system host, have to be supported as well. In those circumstances, the network security, safety, and efficiency are of crucial importance. Any network failure or bottleneck can produce a lot of problems including a total system failure disabling its decision making and command and control functions, due to the lack (delay) of data or even of their corruption. Those issues will be discussed later on.

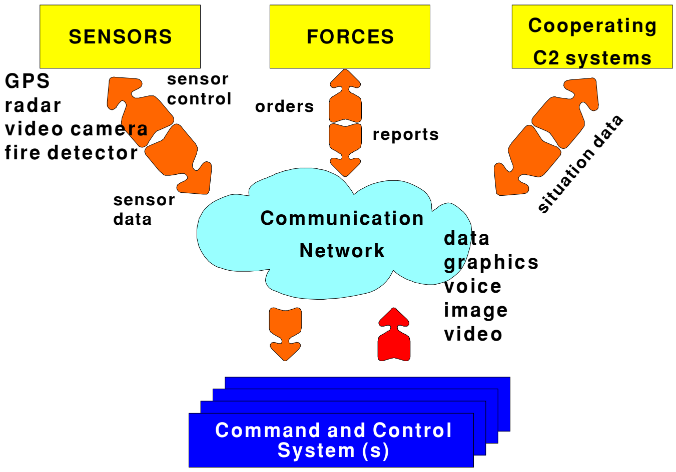

Figure 2. Command, Control and Communications System

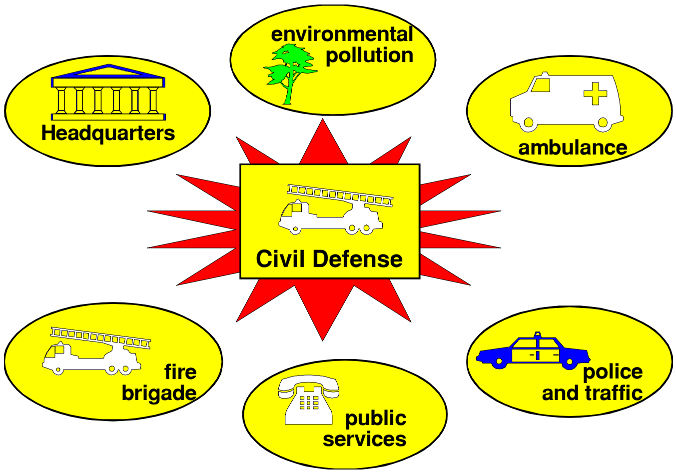

Figure 3. Civil defense example of distributed cooperation

The rest of the paper is organized into four sections. Section two gives the brief overview of necessary communications technologies, especially of high speed networks and wireless networks. Section three explains intelligent aspects of C3I systems and includes active databases and intelligent software agents. Finally, sections four and five give a short overview of our C3I systems development at Computer Graphics and GIS laboratory, Faculty of Electronic Engineering in Niš and some research all over the world.

II. UNDERLYING COMMUNICATIONS

There are at least, five C3 features which we have to highlight here. Firstly, C3I systems are *real-time systems*, so the communication imperative is based on very strong specific requirements: how to get right message to the right people at the right place and time [3]. There are a lot of people which depend on that. We may save many lives if we can act just in time in such unpredictable environments such as earthquake, flood, or fire. The next, very important, issue is *mobility*. There is no future to C3I systems without possible mobility of any subject involved, from mobile users (clients) to mobile hosts (servers). Finally, C3I systems are usually *distributed*. They also have be able to share some useful information with other information systems with common interest, and coordinate in action if necessary, as shown in fig. 3, in case of C3 system for civil defense. This ability requires a C3 system have to work in an *heterogeneous environment* with different operating systems or DBMSs. Furthermore, such CSCW real-time applications must be able to use *all kinds of data*. This ability produces additional communication problems, i.e. how to deal with multimedia data in real-time, heterogeneous distributed and mobile environment.

Some of the imperatives given above, in local and static environments (LAN, MAN) can be accomplished using some of available fast communication technologies. Today, high-speed LANs is based on FDDI, Fast Ethernet, HIPPI or Fibre Channel. Their usefulness in such kind of CSCW applications is described elsewhere [1].

Due to its priority marked small cells, ATM standard is recognized as a useful technology to provide real-time isochronous communications, especially with SONET together in a fixed network area. Regardless of the potential ability of such combination to work on high rates in Gb speed domain, the communication bottleneck and/or application processing overhead are still possible. Those problems can extremely grow if an application such C3 needs huge amounts of data or depends on real-time distributed multimedia data, etc.[3].

Another challenge addressed here is the spring of nomadicity potentials. The *nomadicity* is a new computer and communication paradigm related to a possibility that client and server can move from one place to another, giving an application the illusion that everything is happening on a single site. From the general point of view, mobility is usually viewed as wireless communications or mobile PDA palmtops weekly connected at stop [4]. From the C3 systems point of view, mobility is the strategic and tactical issue. It is of crucial issue that their mobile computers can either be disconnected, poorly connected by low speed wireless networks or fully-interconnected by some high-speed network. Such *heterogeneity* causes additional problems. The *mobility* also implies that the mobile hosts will connect from different access points holding their connectivity while on the move, if necessary. Both, the client and host mobility, require a powerful system support providing a rich set of computing and communications capabilities during their migration from place to place in a transparent, integrated and convenient form [5]. In the case of dealing with CSCW multimedia requirements QoS aspects are becoming more and more important due to the lower transmission quality, limited communication bandwidth and an *apriory* unknown user location [6].

Additional problems can also appear if some part of C3 system has been broken or damaged in the case of enemy fire, terrorist actions, or some unpredictable natural phenomena. In such circumstances an unpredictable sum of micro seconds delay of application processing can resume as an unrecoverable minutes or hours delay. The key point, here is to minimize the potential delay using adaptive services offered by artificial intelligence (AI) as much as possible. Such *active DAI based* applications will be able to tailor their behavior according to changes in their distributed environment.

Future network evolution depends on several important challenges [7], such as new models for layering and functional modularity, active objects in distributed environment and new communications paradigms for interaction among remote application elements, reliability, performance, safety and security on the network, network control, new media such as wireless networks, etc.

III. THE C3 INTELLIGENCE

Following the keywords given above we have to say that AI is an crucial element of C3I systems. Up to day, C2 systems have a common trend: whatever it is possible leave it, step by step, from human responsibility to machine responsibility. In order to explain what is happening today and what can happen tomorrow we will turn to database intelligence and appropriate software agents, related to enabling active technologies in this field, as following.

A. Active Database Systems

C3 applications rely on continuously changing databases that represent the states of real systems (e.g., the area of responsibility of a fire brigade). Since the system's data is supported to reflect the environment being controlled, they must be updated frequently to maintain temporal validity. Today's C3 systems are implemented on conventional database systems (relational, object-oriented or object-relational) which are passive in operation, that means a system waits for a user to initiate a query and then evaluates it to produce results. Some commercial database systems (e.g., Oracle 7, Informix, Ingres) provide user defined triggers, which can be activated on a limited set of database operations such as insertions into a table.

The new trends are in using active databases (ADB). *Active database systems (ADBS)* have been a hot research topic for several past years. Many different systems and models have been proposed, HiPAC [8], Alert [9], Ode [10], but it is still unclear what the term really means. The ACT-NET Consortium [11] defines "mandatory features that are needed to qualify as an active database system, and desired features which are nice to have" (see Table 1). The basic concept of an ADB is ECA-rule (*event-condition-action rule*) that defines the next state: when an *event* occurs, check the *condition* and if it holds, execute the *action*. Once a set of rules has been defined, the ADBS monitors the events, evaluates conditions associated with events, and triggers the relevant rules.

The *active database management system (ADBMS)* provides mechanisms for ECA-rule definition and execution. An ADBMS can support different event types, such as database events (update, deletion, quering, rule definition, transaction boundaries and other administrative operations), temporal events (periodic, at-a-particular-time, relative-timing, options) or general application signals. An event type may be primitive or composite. All ADBs have primitive event types, but some of them have composite as combinations of primitive or composite events.

There are many options for scheduling of events: immediate (executed directly after the event has been signaled), deferred (executed at the end of the triggering transaction), decoupled (executed as a separated transaction or after a particular time interval). Scheduling algorithms define coupling modes between triggering and triggered transactions. An action formulates the reaction to an event and is executed after the rule has been triggered and its condition determined to hold. An action may refer to a transaction, it may affect the database itself by performing some corrective or data retrieval operations or some arbitrary actions ranging from a complex application program to sending a series of signals.

TABLE 1
CHARACTERISTICS OF ADBMS

Feature No	ADBMS Feature
1.	An ADBMS is a DBMS
2.	has an ECA-rule model
2.a.	has to provide means for defining event types
2.b.	has to provide means for defining conditions
2.c.	has to provide means for defining actions
3.	must support rule management and rulebase evolution
3.a.	has to support rulebase management
3.b.	has to support rulebase evolution
3.c.	has to support enabling and disabling of rules
4.	has an execution model
4.a.	must detect event occurrences
4.b.	must support binding modes
4.c.	must be able to evaluate conditions
4.d.	must be able to execute actions
5.	must offer different coupling modes
6.	ADBMS must implement consumption modes
7.	must manage the event history
8.	must implement conflict resolution
9.	should support a programming environment
10.	An ADBMS should be tunable

An ADBMS should at least be possible to use DML-commands in actions. The set of rules defined at a given point in time forms the rulebase. The rulebase should be managed by an ADBMS. An active database system derives its power from a variety of events it can respond to and the kinds of actions it can perform in response. The important aspects of the systems are the use of incremental and parallel processing to meet the real-time performance requirement, and the concise specification of temporal conditions.

There are different directions to build ADBS. For the majority of users the most interesting one is building systems using a commercial off-the-shelf database management systems. Some research projects use that philosophy [12],[13]. They develop rule-processing components that can be incorporated into existing database management systems.

Using rule system, users are able to specify conditions that need to be monitored in real systems and actions to be taken upon occurrence of these conditions.

Which features should an ADBMS for C3I systems have? The above mentioned ACT-NET consortium suggests the following classes of ADBMS: (1) for monitoring in homogeneous information systems; (2) for control in homogeneous information systems; (3) for control in heterogeneous information systems. We think that the ADBMS for C3I systems is from the third class for the following reasons. First, the C3I systems information is typically distributed among multiple heterogeneous database management systems (see Fig. 3). The heterogeneity exists at three basic levels. The first is the platform level. Database systems reside on different hardware, use different operating systems and communicate with other systems using different communication protocols. The second level of heterogeneity is the database management system level. Data is managed by a variety of database management systems based on different data models and languages. Finally, the third level of heterogeneity is that of semantics since different databases have been designed independently. Second, the C3I systems monitor and control the area of responsibility using different sensors and actors (see Fig. 1).

TABLE 2
FEATURES OF ADBMS FOR THE C3 SYSTEMS

Feature	Instantiation
events (2.a)	DML-operations, external events, composite events
conditions (2.b)	boolean functions, predicates on database state
actions(2.c)	DML-action, user notification, external programs, contingency actions
rule management (3)	create/delete, modification, enable/disable
coupling modes (5)	immediate, deferred, decoupled, causal dependencies
consumption mode (6)	choice, including chronicle
execution	not fully under local control

Some C3I applications need real-time or near-real-time information processing activity which has to respond to externally generated input stimuli within a finite and defined delay. For the class of C3I applications, the C3I systems interface directly to some physical equipment or plant and are dedicated to monitoring or controlling the operation of that plant. Typical examples of this kind of application are hail suppression system, traffic control and air defense. Therefore, C3I systems need active mechanisms to integrate heterogeneous and autonomous database systems and must be able to detect events from external devices and critical situations in other cooperative information systems. Also, ADBMSs need be able to specify the timing constraints for rule execution and complex relationship among application steps. Summary of the ADBMS features required by the C3I systems is presented in Table 2.

The C3I systems use data coming from very different sources constantly in evolution. Therefore, data management is a key concern in these systems. Research should concentrate on how intelligent agents can contribute to the organization, distribution, transportation, and fusion of massive amounts of data available from a wide variety of information sources. Other research issues include assurance of data integrity and caching strategies for managing information flow. In the C3I systems, knowledge has to be treated dynamically allowing it to develop according to new acquisitions or political and legal decisions. This is the reason why knowledge cannot be considered a static element but something which need dynamic updating.

B. Intelligent Software Agents

The concept of intelligent agents has been investigated almost ten years ago, especially in the field of AI. The general letter of intend how to and when to use intelligent agents may include network management, business process re-engineering, data mining, electronic commerce, learning from examples, e-mall related agents, searching digital libraries, smart databases, as well as C3I systems. In addition, agents are investigated in different research areas such as operating systems, communication networks, programming languages, AI, distributed systems etc. For instance, nowadays, it is hard to find out the volume, even the issue, of any computer related journal without an article addressing some kind of an agent research.

After such wide open application field of agents, a general definition of just an agent is supposed to be has not been reached yet. Agent theory research have offered a variety of definitions, each of them tray to explain its own point of view (it is better to say the view of research people involved). We accept the following one. An agent can be defined as a component of software and/or hardware which is capable of acting in order to accomplish tasks on behalf of its user [14]. In order to simplify and to make a closer view to the readers about theory and practice of intelligent agents we are going to start with a short overview to different agent types as shown in Fig. 4.

The *collaborative* agents are typical DAI agents. They should be able to act rationally and autonomously in an open multi-agent environment. There are several motivations for having them in C3I systems. They can provide solutions to inherently distributed problems such as distributed sensor networks and/or they can assist where the expertise is distributed. In addition they are the key intelligent components for interconnecting and inter operation of multiple decision support systems as well as for communication network control and management [14], [15].

Instead of collaborating with other agents, *interface* agents allow cooperation with the user. Actions taken by users are observed and monitored by an interface agent. As result, an agent can propose the better way to the user to do a specific task. So, interface agents learn from the user but sometimes they can also ask for an advice from another agent. The learning process is based on imitating user's actions, positive and negative feedback received from user as well as the explicit instruction given by the user [16]. The usefulness of such kind of personal assistants in C3I systems is not so obvious as in the case of collaborative agents. It can vary from accommodation of novice users, better scheduling i.e. to reducing user's workload, to helping users to perform some demanding tasks. Generally, interface agents will help to free HCI from limited direct manipulation currently UI metaphor [17].

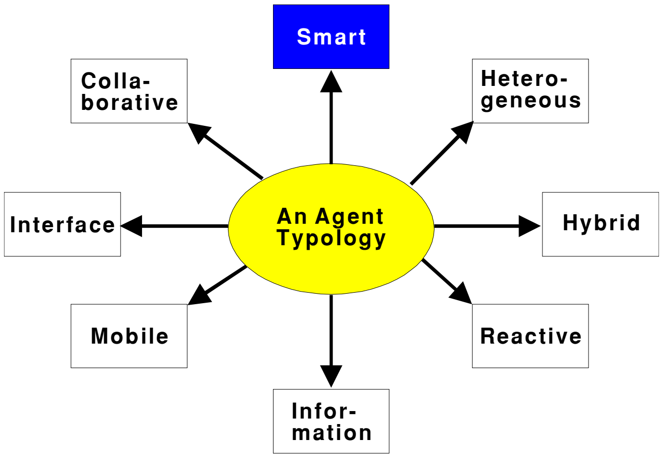

Figure 4. A Classification of Software Agents, [14]

Information agents are referred to as software tools for managing the growth of available on-line information. They manage, manipulate or collate information from many distributed resources. Today, main research in this field of agents is concentrating on WWW and Internet [18], but is not limited to. Information agents give each particular user the ability to put a high-level request for some specific information (s)he needs and which is expected to be somewhere in the distributed environment.

According to the subject matter, we can see that information agents are an important part of C3I systems. Firstly, in the development phase they can serve as fast source providers to answer what is happening on and where, who is working on that and how, etc. The second, in run-time C3I environment, information agents can act as fast filtering mechanism for the responsible people involved, to help them to decide what to do, for example stay here, move there, switch on fire, or something else.

Reactive agents act/respond in a stimulus-response manner to the present state of the environment in which they are embedded [14]. Furthermore, we have to note that *smart* agents, coded in Fig. 4 with different color then the rest of agent typology shown there, are just the scientific vision. As the matter of fact, truly smart agents do not yet exist. The *hybrid* agents are obviously exploring some combination of the rest of agent world. As always, the point is to maximize the strengths and minimize the difficulties of the most relevant technique for a particular purpose.

C. Itinerant Agents for Lightweight and Mobile Computing

The last type of agent mentioned above is a mobile one. *Mobile agents* are intelligent software agents capable to move from one place to another, interact with foreign host, act on behalf of its owner and then come back 'home" having finished the dedicated task. Their usefulness, in such demanding communication oriented applications as C3 systems are, for example, is one of hot topics research all over the world [3], [15], [19], [20], [21], [22], [23], [24]. We think that the whole idea about mobile agents is based on simple (in fact, very hard) question: how to provide lightweight communication between two or more parties involved ?

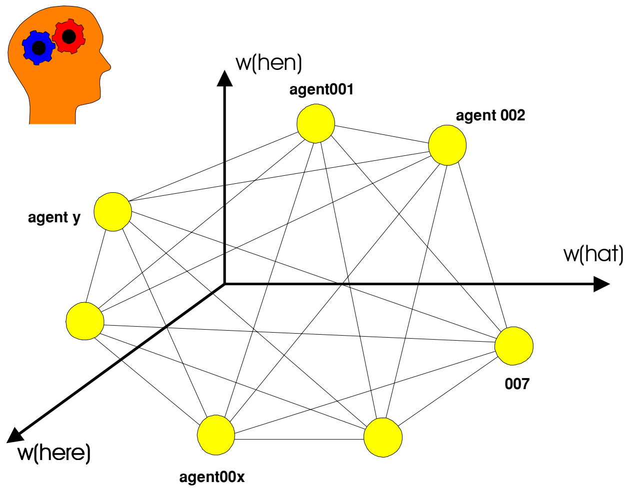

Figure 5. The agent navigation in 3w space

The term *lightweight* is treated here as a goal to accomplish traffic reduction. Several relative individual and cumulative mobile agents advantages have been recognized to warrant their usefulness in client/server applications and services [3],[20],[23]. The key issue here is to delegate a task to an agent and send its to execution to another machine and then leave the communication line free. Mobile agents can also be resident on particular server just waiting to be activate.

In order to support services from a number of servers mobile agents have to navigate through to network [3]. They have to know where to go, what to do and when, as shown in Fig. 5. as the navigation in *3w(where, what, when) space*. They can suspend there execution, pick up the temporally results, move its code and state to another server and finish the dedicated task. Furthermore, such kind of autonomy supposes that mobile agents have the ability to "meet" other agents and that they can collaborate with each other. This ability of mobile agents gives them an additional attribute: itinerant [20].

In the field of C3 applications this kind of mobile agents have to support very sensitive communication traffic over the low-bandwidth and high-latency networks typically employed by mobile computers. In addition, such agents allow mobile computers to interact with heavyweight rigid applications having knowledge of total network offer, rather then having knowledge of particular server capabilities on that network.

On the other hand, itinerant agents are not going to shame to engage in high-bandwidth communication. Instead, its cooperation with, for example, an active database management system and related agents on remote server on high-speed to mine large spatial database, is of one of the key C3 issues.

We note that last year the United States Department of Defense (USDoD) announced the competition for the Multidisciplinary Research Program in order to enhance universities' capabilities to perform research and related education in science and engineering areas critical to national defense [21]. One of hot topics is the field of intelligent agents for wireless computing with five objectives as follows:

- to determine how to build mobile agents and use them in the creation and evaluation of secure, highly reliable networks for use in C2 systems;
- to determine how AI technology inherent in the design of such agents can be used in the management of these dynamic networks;
- to define appropriate coordination structures for mobile agents in a wireless networking environment;
- to develop techniques for security and fault-tolerance assurance in wireless networks using intelligent agents; and
- to devise a unified, comprehensive framework for using intelligent agents in wireless network operation.

This is just an illustration what C3 systems users can expect from that emerging technology in the future. In addition, USDoD is ready to pay $1M per year for this research. The fact is that are a lot of research projects related to mobile agents that are directly supported by governmental organizations such are USDoD, DARPA in USA, or the like elsewhere in the world, with primary interest to C3 field.

In addition to lightweight communications, mobile agents will take a significant role in future networks infrastructure and their management [15], [25], [26]. This will have a lot of impact on the architectures and related protocols of existing communication systems. Such networks, also known as *active networks* [3], [26], will be able to support new services in a very efficient way. It will be enough to develop a new mobile agent supporting particular service and send that agent to act.

We cannot say that development of such agent is easy, especially not today. The research field of mobile agents is wide open. There are lot of challenges to solve such as mobility, authentication, security, privacy, performance and so on [3]. But, the majority of research community investigating mobile agents has already survived a dilemma from the past: "Objects and Agents: Love at first sight or Shotgun wedding", representing by the title of the ECOOP'95 Workshop held a couple of years ago.

IV. Our Experiences and Future Directions

Over years in the Computer Graphics and GIS laboratory at the Computer Science Department of the Faculty of Electronic Engineering in Niš we have been continuously researching and developing C3I systems, corresponding technologies and applications. All the time we have been concentrating on special parts of such systems related to spatial data and geographic information systems (GIS). We passed several steps, improving from the closed proprietary platform to an open object-oriented platform [27], [28], to build several C3 applications and the like [29], [30], [31]. Our experience is based on our development of GinisNT system and applications based on that.

The GinisNT system is an open-architecture collection of GIS tools [2],[27]. It supplies user interface functions, input, storage, retrieval and display of data about spatial objects. Two basic ideas underlying its design are: unified object-oriented data model is used for storing all data in the spatial database [28], [32] and a visual context is obtained by using raster maps and situation plans. GinisNT also includes powerful tools for scanning and vectoring maps and drawings. This can be used for capturing information from existing paper maps, operating plans and blueprints of special risk buildings, photographs, etc.

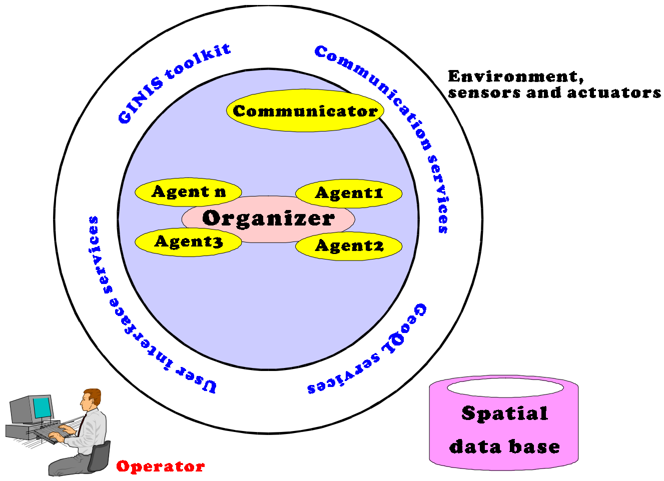

Figure 6. The MapSys architecture

GIS based systems are of widely use in all areas where there is a need for documenting, organizing and using different geographic information. A GIS is defined as computer-based information system which that captures, stores, manipulates and displays spatially referenced data in different points of time for solving complex research, planning and management problems [33]. GIS found special application in C3 systems for monitoring and management of spatial objects.

Our first step considering active technologies has been taken during the development of MapSys: the spatial objects control system [2]. The MapSys architecture is based on a set of intelligent agents which use some knowledge to perform specific tasks on behalf of their users (see Fig. 6). Agents communicate by message passing. Messages are generated from input influences of certain events which are happening on the system. In order to reduce multi agent communications and particular knowledge of each agent a special agent named Organizer is introduced. This special agent has a knowledge about whole system goals and also it is familiar with dedicated task of other agents in the neighborhood.

Another special agent, involved here, is Communicator. It is in charge of communication with the rest of the environment and between geographically distributed agents. This part of MapSys is still under development considering most of the open problems in research field mentioned above. The Communicator agent development is only one of the tasks which we are going to do in the future to develop and use active technologies. We also expect that some results of active technologies implementation on commercial system will appear soon on the market. This expectations are especially oriented towards operating systems, ADBMS and active networks development.

A. The FireGuard System example

The *FireGuard* is the first C3I system developed for civil defense in CG&GIS Lab at Computer Science Department of the Faculty of Electronic Engineering in Niš [29]. The main task of the system is to provide computer support in fire & rescue protection, prevention and monitoring process. The system provides real-time command and control of fire & rescue actions, as well as storage, processing, analyzing, searching and representing of spatial data relevant for fire & rescue brigades and their inspection services. The system consists of three subsystems as described bellow.

The aim of the F*ire & Rescue* subsystem is to provide computer support in gathering and checking of fire calls, preparing, planning and leading the action, to make reports of the action and to analyze previous actions. This subsystem gathers some intelligent agents that generate first plan of fire & rescue action, based on knowledge base, tactics and current situation. To provide automatic positioning of object location and shortest route (and alternative routes, if needed) to event/incident place, the system incorporates 1:25000 topographic maps of area of responsibility for background referencing, 1:1000 urban area maps, 1:2500 and 1:5000 rural area maps of the area of operation for precise positioning. It assists in identifying incident locations, position of fire hydrants, near water courses and any area classified as special risk (electrical station, gas station, chemical plants, etc.). The C2 center in fire brigade station is the place where all send and reported data is transmitted, processed and presented to executives, where decisions are made and orders transmitted to the fire forces. The subsystem is capable of providing any information related to the situation, for example, the history of the incidents over the area of responsibility, the location, composition and equipment of the fire brigade forces acting on the event/incident place, position and nature of important places, transportation, water supply points, etc. This data is presented on a detailed map of the event/incident area with symbols or in numerical forms (see Fig. 7).

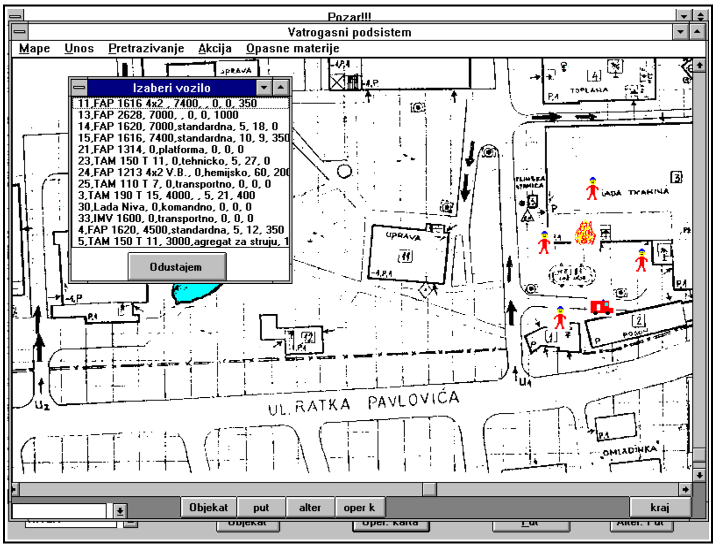

Figure 7. Action plan by FireGuard system

The purpose of the *Inspection subsystem* is to support monitoring of all activities connected to fire & rescue area. These actions consist of establishing all documents connected to area, planning and monitoring of all examined objects in sense of presence of the fire & rescue regulations, inspections of dangerous materials transport, examine the causes of fire and fire statistics handling, etc. This subsystem use geospatial data from relevant databases and is based on the Yugoslav lows of the fighting and prevention. The expert systems for dangerous materials and fire causes recognition are also the parts of this subsystem.

The *Training subsystem* covers all the activities for education monitoring of staffs as in the Fire Brigades as well as in the Inspection Services. It also helps in training new staff and in process of further training more experienced staff. This intelligent subsystem uses an original algorithms and modules from machine learning and student modeling area [34] The problem generation process is governed by existing knowledge of staff performance, advantages and known problems. Special attention is going to be devoted to interface design, since this is an area where GUI with simulation of real-life situation can be of invaluable importance for learning.

B. The Hail Suppression Information System example

*The Hail Suppression Information System (*HASIS) [30] is the C3I system developed for the Republic Hydro Meteorological Service of Serbia (HMS). Twelve Radar Centers (RC) and 1600 Hail Suppression Stations (HSS), adequately distributed all over Serbia, represent the framework of the HASIS. Command of the system and coordination in hail suppression activities are performed by HMS's Operational-Methodological Center in Belgrade. Each RC is supplied by meteorological radar Mitsubishi RC34A. The use of a large antenna provides good sensitivity and high resolution needed for long range observations of precipitation. HSS is supplied by launching pads and rockets with sending materials.

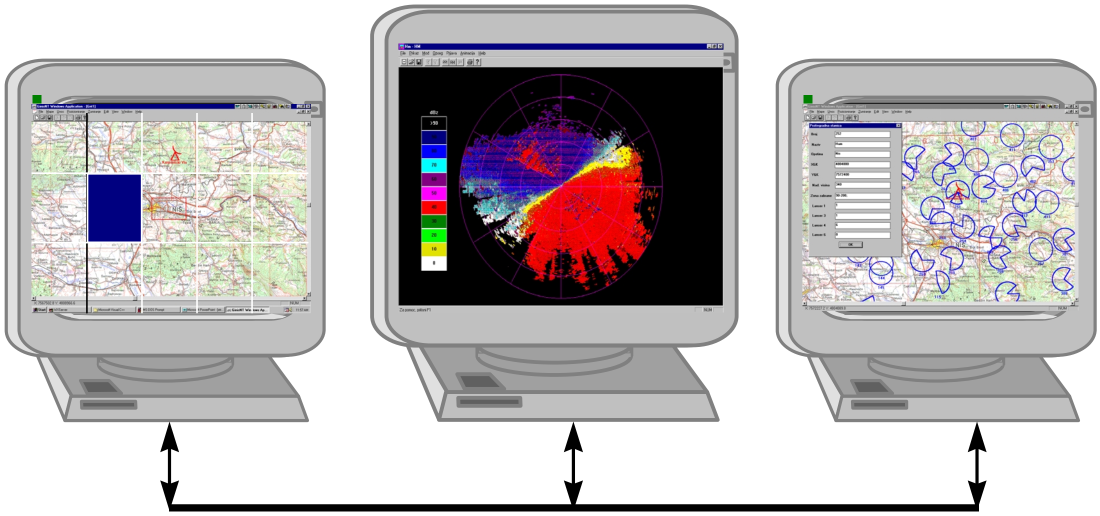

Figure 8. One view to the HASIS in action

One view of HASIS in action on the area of responsibility is given by Fig.8. Based on the organization structure to be supported, HASIS hardware include the following: *main workstation* for processing, displaying and analyzing radar signal, *workstation* for coordination with the Command Center, *workstation* for coordination with HSSs *and intelligent microwave link* for communication between RCs. All workstations are PC based. Main workstation has two additional cards: radar log-video signal digitalization card (A/D converter) and DSP (Digital Signal Processing) card with two digital signal processors. The basic functions of HASIS are:

- continuous observation of clouds (24 hours per day, from April to September)
- detection of cumulonimbus clouds that indicate the approach of a hailstorm
- measurement of relevant parameters of hail cells in clouds
- displaying of collected data in a chosen mode
- analyzing of collected data for hail cell prediction
- control and manipulation of the antenna
- support hail suppression command and control process
  - select the best fitted HSSs according to the parameters
  - determine launching elements (azimuth, elevation and timing) for selected HSSs
  - require permission to act from the National Fly Control Center
  - transmit task order to HSSs
  - keep track of the action progress and store action reports for later analyses
  - collect and process reports from HSSs
- management of equipment and forces
- recording, play-back and simulation of incoming information and results
- updating the system databases

The research work and full implementation on HASIS are still underway. It's beta version now is under careful investigation by end users. The experiments undertaken in the last two years in real-time environment shown that we are on the right way.

V. Related Research

Nowadays, scientists all over the world were called upon to take greater role in areas critical to national defenses. The term national defense as a global goal close to any C3 system aim. In this section we will present some of this solicitations. Also, we will present some research and development activities from industry.

A. DoD's Multidisciplinary research program

USDoD announces the FY97 competition for the Multidisciplinary Research Program, one element of the University Research Initiative (URI). This initiative is going to enhance universities' capabilities to perform research and related education in science and engineering areas critical to national defense. Awards will be made in 11 research topics, one of which is Intelligent agents for wireless computing, as we discussed above.

B. Information System Office of DARPA [35]

The DARPA has announced soliciting proposals in 14 research topics associated with the Information System Office, two of which are of particular relevance to C3I systems:

1. *The Battlefield Awareness and Data Dissemination (BADD).*"The goal of BADD is to empower warfighters at echelons from the Task Force Commander down to Battalion, and possibly below, and especially mobile warfighters, by providing them with advanced battlefield awareness applications that are driven by near-real-time

data that is delivered by advanced data dissemination methods".

2. *High Performance Knowledge Bases (HPKB).* " The goal of the HPKB program is to produce the technology needed to enable system developers to rapidly (within months) construct large (100K-1M axiom/rule/frame) knowledge-bases that provide comprehensive coverage of topics of interest, are reusable by multiple applications with diverse problem-solving strategies, and are maintainable in rapidly changing environments".

C. Office of Naval Research [36]

The Office of Naval Research announced a research initiative in *Tactical Picture Agent* which is "intelligent software agents that can dramatically improve future Naval capabilities for achieving common, consistent, coherent Tactical Picture among Naval decision-maker at sea and ashore". The Tactical Picture is the totality of the information relevant to a Naval commander that "need to be able to understand as accurately as possible all important factors regarding their own situation, including but not limited to the disposition of Allied, Neutral, and non-combatant entities, geographical, oceanographic, and meteorological characteristics in the areas of interest, and of course, the disposition of an adversary if one exists".

D. NIMA University Research Initiative [37]

The National Imagery and Mapping Agency (NIMA) announced its FY97 University Research Initiative with 7 research topics including: (1) *Intelligent Agents for Geospatial Information Discovery and Retrieval* and *(2) Like-Feature Detection.* The objectives of the first program are : (1) to determine how to build intelligent, mobile agents and use them for discovery and retrieval of geospatial information; (2) to develop techniques to enhance the reliability and relevance of geospatial information discovered using intelligent agents; (3) to define appropriate coordination structures for roving agents in a networked environment; and (4) to devise a unified, comprehensive framework for using these intelligent agents. The objectives of the second program are: (1) to develop an operational capability to detect probable 'identity' between corresponding features in multiple data sets and can eliminate false pairing; (2) to develop ways in which such an operational capability can 'learn' as new data sets are presented to it; and (3) to demonstrate ways in which the capability can be used to expedite various data integration and data maintenance tasks.

E. Industry News

Logicon [38] works on a number of classified programs for U.S. government customers in the communications and intelligence area, some of which involve command and control of various military satellite systems. Logicon also has become well known in developing technical interfaces between the C2 systems and the computer simulation models that simulate the testing and training events. Logicon integrated shelter systems with government and commercial off-the-shelf computer hardware and software to a field a mobile U.S. Army weather forecasting and analysis system. Its drug network project for the four southwestern border states links the computer systems of federal, state and local law enforcement agencies so they can share information on drug trafficking and other criminal activity.

Alcatel offers integrated C2 and C3I systems which include functions ranging from data collection and data fusion to situation management, and C2 operations [39]. The systems integrate all incoming communications, from the police department's private mobile radio network, emergency phone calls, to video surveillance cameras monitoring strategic locations. Alcatel provides C2 centers for police, civil security and specialized units such as drug enforcement squads. Alcatel has developed ALCIDE software platform for development and execution C2 and C3I systems.

MITRE Corporation [40] provides technical assistance, system engineering, and acquisition support to large organizations, especially U.S. Government agencies. Data management research at MITRE Corporation includes information integration, security and privacy, active and responsive systems, metrics and digital libraries. MITRE has built a new kind of semantic gateways that allows clients to use their own data semantics when accessing foreign databases and repository to manage domain knowledge for information integration. MITRE has demonstrated the utility of information integration in C2 systems. Much research in the active and responsive systems has focused on the support active behavior for real-time C2 applications. There are several research projects, some of which are: Distributed Object Management Integration System (DOMIS), Global Command and Control System (GCCS), Data Integrity Between C3I Systems (DIBCIS), Evolvable System Initiative for Real-Time C3, and Integrated View of the Battlespace.

VI. Conclusions

This paper has addressed the one of the most important and demanding computer application, C3I system. In particular we have focused on the emerging active technologies as a key technologies to improve efficiency, reliability, communication abilities and intelligence of such systems.

Although this paper has concentrated on active C3I systems, we expect that a lot of problems addressed here are of wider interest. A new approach to their development, presented here is expected to be an of the key computing and communications paradigms over the next ten years. In addition to Nwana's words "as we move further and further into the information age, any information-based organization which does not invest in agent technology may be committing commercial hara-kiri" [14], we can say that any communication oriented application which will not be able to use active technologies sooner or later will disappear from the market.

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REFERENCES

[1] Kajan E., Djordjevic-Kajan S., "Gigabit Networks for Open Computer Supported Cooperative Work" *TELSIKS '95*, 10-12 October 1995, Nis, Yugoslavia, pp. 384-387.

[2] Mitrović,D.; Djordjević,S., et all., "MapSys - Spatial objects control system",. *The 3rd Int'l Conference on Automation, Robotics and Computer Vision ICARCV'94*, 9-11 November, 1994, Singapore, pp. 93-97.

[3] Kajan E., "Towards the Key Issues in Client/Server Computing for the Year 2000 and Beyond", *Proceedings of TELSIKS '97*, Niš, Yugoslavia, 10-12 October 1997.

[4] Imielinski T., et all., "Wireless Computing", *CACM*, Vol. 37, No 10, October 1994., pp. 19-28.

[5] Bagrodia R., et all., "Vision, Issues, and Architecture for Nomadic Computing", *IEEE Personal Communications*, Vol. 2, No 6, December 1995, pp. 14-27.

[6] Spaniol O., et all., "Impacts of Mobility on Telecommunication and Data Communication Networks", *IEEE Personal Communications*, Vol. 2, No 5, October 1995, pp. 20-33.

[7] Clark D., Pasquale J., et al., "Strategic Directions in Networks and Telecommunications", *ACM Computing Surveys*, Vol. 28, No. 4, December 1996, pp. 679-690.

[8] Dayal U., et all, "The HiPAC project: Combining active database and timing constraints", *SIGMOD Record*, Vol. 17, No 1, 1988, pp. 51-70.

[9] Schreier U, et all., "Alert: An architecture for transforming a passive dbms into an active dbms, *ACM-SIGMOD International Conference on Management of Data*, September 1991, pp. 469-478.

[10] Gehani N., Jagdish H.V., "Ode as an active database: Constraints and triggers, *ACM-SIGMOD International Conference on Management of Data*, September 1991, pp. 327-336.

[11] ACT-NET Consorcium, "The Active Database Management System Manifesto: A Rulebase of ADBMS Features", *SIGMOD Record*, Vol. 25, No 3, September 1996, pp. 40-49.

[12] Krishnan, M.R., Bever K.S., "Implementation of a prototype of active database", *http://www.cs.wisc.edu/ ~krishnan/etc/ academic/adb/adb.html*

[13] Sistla P.,Wolfson O., "Temporal Trigers in Active Database", *IEEE Trans. on Knowledge and Data Engineering*, June 1995, pp.471-486.

[14] Nwana H.S., "Software Agents: An Overview", *Knowledge Engineering Review*, Vol. 11, No 3, September 1996, pp. 1-40.

[15] Magedanz T., et all., "Intelligent Agents: An Emerging Technology for Next Generation Telecommunications?", *INFOCOM '96*, March 24-28, 1996, San Francisco, CA.

[16] Maes P., "Agents that Reduce Work and Information Overload", *Communications of the ACM*, Vol. 37, No 7, July 1994, pp. 31-41.

[17] Morse A., Reynolds G., "Overcoming Current Growth Limits In UI Development", *Communications of the ACM*, Vol. 36, No 4, April 1993, pp. 73-81.

[18] Etzioni O., Weld D.S., "Intelligent Agents on the Internet: Fact, Fiction, and Forecast", *IEEE Expert*, August 1995, pp. 44-49.

[19] Harrison C.G., et all., "Mobile Agents: Are they a good idea?", *IBM Research Report* RC 19887, 1994.

[20] Chess D., Grosof B., et all., "Itinerant Agents for Mobile Computing", *IEEE Personal Communications*, Vol. 2, No 5, October 1995, pp. 34-59.

[21] Qian X., "Scientists Called Upon to Take Actions, *ACM-SIGMOD RECORD*, Vol. 25, No 3, Sept. 1996, pp. 77-80.

[22] Gray R.S., "Agent Tcl: A flexible and secure mobile-agent system", *Dr. Dobb"s Journal*, March 1997, pp. 18-26.

[23] White J., "Mobile Agents White Paper" General Magic, *www.genmagic.com/Telescript/whitepapers/wp4*, 1996.

[24] Lingau A., Drobnik O., "Making Mobile Agents Communicate: A Flexible Approach", *1st Annual Conference on Emerging Technologies and Applications in Communications (etaCOM'96),* Portland, Oregon, 7-10 May 1996.

[25] Tennenhouse D., et all., "Towards an Active Network Architecture", *Computer Communication Review*, Vol. 26, No 2., April 1996, pp. 5-18.

[26] Tennenhouse D. L., et all., "A Survey of Active Network Research", *IEEE Communication Magazine*, Vol. 35, No 1, January 1997, pp. 80-86.

[27] Mitrović,D.; Djordjević,S. "An open GIS architecture for inexpensive hardware platforms", *AM/FM European Conference X*, Heidelberg, October 18-20,1994, pp. 185-189.

[28] Mitrovic A., Mitrovic D., et all., "A Scalable, Object-Oriented GIS Framework", *Workshop on New Developments in Geographic Information Systems*, Milan, Italy, 6-8 March 1996, pp. 20-21.

[29] Djordjević-Kajan,S.; Mitrović,D.; et all., "Intelligent GIS for fire department services", *Eurocarto XIII*, Ispra, Italie, 2-4 October, 1995, pp.185-196

[30] Djordjevic-Kajan S., Milovanovic B., et all., "Hail Suppression Information System of a Radar Center", GIS/LIS '95/'96, Budapest, Hungary, June 1—14 1996, pp 102-111.

[31] Petković,M.; Djordjević-Kajan,S.;et all,. "Maps in vehicle navigation systems", *18th ICA/ACI International Cartographic Conference*, Stockholm, Swedish, 22.6.-28.6.1997.

[32] Mitrovic A., Djordjevic-Kajan S., "Object-Oriented Paradigm Meets GIS, a New Era in Spatial Data Management", *YUGIS*, Belgrade, YU, 14-15 March 1996, pp. 141-148.

[33] Fischer M.M.,, "From conventional to knowledge-based Geographic Information Systems", *Computer, Environ. and Urban Systems*, Vol. 18, No.4, pp.233-242, 1994.

[34] Mitrovic A., "Reconstructive Approach to Student Modeling in Intelligent Educational Systems", PhD Thesis, *Computer Science Department, University of Niš*, Yugoslavia, 1994

[35] *http:/ www.arpa.mil/ baa/#iso*

[36] *http://ksi.cpsc.ucalgary.ca/course/ 547-5/entley/navyagents.html*

[37] *http://164.214.2.57/. NIMA/URI.html*

[38] http:/www.logicon.com

[39] Carcagano D., Suslenschi P., "ALCIDE - The Alcatel C3I Development and Execution Platform", *Electrical Communication*, 2nd Quarter 1994, pp. 111-117.

[40] Rosenthal A, et all., "Data Management Research at The MITRE Corporation", *SIGMOD RECORD*, Vol. 24, No 3, September 1995, pp. 77-82.