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C4ISR Multimedia System for Emergency Management TIN2004-03588

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Abstract

C4ISR systems (Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance) are one of the most classical examples of critical real-time distributed systems. The origin of these systems falls under the scope of military research. Usually they are embedded systems with particular purpose and ad-hoc designed. The project proposes the migration of the technological and operative concepts presented in the DoD and NATO standards and developed in the C4ISR military systems to the civil environment. In special, emergency management since it has a large social impact. (flood, fire, terrorist attacks, dumping of toxic waste and so on). Additionally, the project proposes the massive inclusion of multimedia flows as a main technological innovation with regard to the military systems. The main project objectives are the following: (i) Generic C4ISR system architecture definition for emergency management. The defined architecture follows the DoD and NATO standards in the operational, system and technological plane and are based on the COTS (Commercial- of-the-self) development principle. (ii) Validation of the proposed concept through the development and assessment of a test application for fire management based on RT-LINUX as a particular case of a generic emergency management system. In order to guarantee the correct working of the distributed real time system and due importance of the communication (protocols, network technologies) another one of the main project objectives will be the analysis and detailed definition of the project communication architecture based on IP and wireless mobile networks. Moreover, from hard and soft requirement integration point of view it is important to emphasize the novel aspect and the added difficulty due to the massive inclusion of multimedia flows.
Keywords: Command and control information systems, emergency management, wireless networks, high quality video streaming, GPS, biometric sensing

1 Project goals

The main project goals fall under the National Plan of Informatics Technologies priority line "Real-time distributed systems. Modelling, development, verification and validation of critical systems. Architectures, platforms and interoperability. Fault tolerance" of the section "Open and Distributed Systems".

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The project goals were proposed in order to fulfil the needs of the following scenario:

"A message from 112 emergency number, alerts the firemen officer about the detection of a forest fire with several fronts. The message contains the approximate fire position. Fast, a reconnaissance helicopter equipped with a video camera and an infrared (IR) camera takes off and goes directly to the fire area. In parallel, three terrestrial units drive to the same zone. The helicopter places above the fire area and sends to the commanding officer (who is at the firemen building in the general headquarters) information in digital format, automatically, continuously and in real-time. This information is: (i) GPS reference position; (ii) video images from the area; (iii) IR images from the area; (iv) wind speed and direction. This information is pre-processed and fused at the control computer and help the officer to know the exact size and location of the disaster. Automatically the control computer at the headquarters: (i) extracts from a GIS the map of the disaster area; (ii) isolates and represents the fire fronts onto the map; (iii) sends through a terrestrial wireless or satellite link the map to the tactical computer available at each terrestrial vehicle commanded by a firemen NCO, driving to the fire area; (iv) sends a message to the duty seaplane indicating the exact fire position; (v) sends a message to the traffic management authorities in order to cut roads in the fire area; (vi) fire is serious and it is located close to inhabited areas, then the computer sends a message to the health authorities in order to send paramedics to the area.

By the time each land unit arrives to the fire area, they have received the exact optimal position to install their advanced command posts. Each unit, coordinated by a firemen NCO, would install a wireless network base, which would provide service to three fire extinction brigades formed by a corporal and four firemen. In the brigade, every firemen wears outside and inside temperature sensors; so as vital electromiographic sensing equipment. All of them are equipped with a GPS receiver. Two of the firemen wear a video camera installed over the helmet, and other two wear an IR camera. All the devices worn by each fireman are connected by means of a PAN (Personal Area Network), to an SBC equipped with a wireless transceiver, including also a microphone and an earphone to be used with VoIP. The SBC carried by the corporal, includes a display, which represents in real-time the updated and schematic version of the fire-fighting area assigned to his brigade. In the tactical computer of the first level C2, every received information is processed and the most relevant are retransmitted to the following level C2 system, which fuses them with the all the information received from the tactical C2 computers, together with the information received from the helicopter. The result is, for example, the transmission of a message to the specialized seaplane to indicate the crew where to drop the following water charge. The NCO knows at every time where the fire-fighters under his command are because they are blue points which move over the digital map of the area. If any point turns red because any vital sensor has surpassed the alarm threshold, the NCO gives the vocal order "group and abandon the area!", this order has maximum priority and is sent to every fire-fighter in the brigade. All the communications are IP-supported."

The initial proposed goals of the project, which have been kept during the whole duration of the project, are the following:

1. To define the architecture of a generic C4ISR system for emergency management, following the COTS development philosophy,
   - Application of the DoD standard working framework for the definition of C4ISR systems, to the emergency management systems.
   - Modification of the working framework in order to include multimedia flows with analysis of the implications in the three planes of the architecture definition (operational, systems, and technological).
   - Definition of the architecture operational plane
   - Definition of the architecture systems plane

- Definition of the technological plane
- Definition of the CADM (Core Architecture Data Model) of the C4ISR architecture for emergency management, by means of the data model NATO C2IEDM modification, including and modifying the objects related with emergency management

2. To define the emergency management system communications architecture
   - Definition of the communication hierarchical layers: operational, tactical, field and personal.
   - Definition of the network topology for each hierarchy level and level interconnection
   - Definition of the protocol architecture for each hierarchy level
   - Definition of the technologies for each hierarchy level

3. To validate the defined generic C4ISR architecture
   - Analysis and development of a reduced application for fire-fighting management
   - Systems integration
   - Functional evaluation of the application
   - Performance evaluation of the application

Every goal has been accomplished, except from the performance evaluation of the system through exhaustive and systematic field trials executions. The developed prototype under the SIMAGEM (**SI**stema de **MA**ndo y control para **G**estión de **E**mergencias **M**ultimedia) denomination. Throughout this paper to refer to the full system we will use this name: SIMAGEM.

In the development of the project we have achieved nearly all the foreseen goals in the first two years. We still have another year to continue with the development and we have decided to enlarge these goals with the following tasks:

- To introduce the representation of each brigade members position over a PDA for each brigade chief
- To use WIMAX wireless technology for giving support to the tactical network. This support could be extended to the combat field network when equipment compliant with IEEE 802.16e standard was available with mobility support.
- To introduce vocal communications based on VoIP which will be directly supported on system wireless networks.
- To introduce a system for automatic risk objects designation, by mean on integration of binocular telemetric devices.
- To introduce an automatic system for positioning own forces (Blue Force Tracking), with indoor positioning capabilities for complementing GPS information.
- To achieve international and interagency interoperability based on the Multilateral Interoperability Program (MIP) specifications for Command and Control Information Systems. These specifications include the addition of a common data interface for the system.

2 Success Level Reached in the Project

2.1 Statement of the Project

As we have indicated, in the first two years of the project development we have accomplished nearly all the initial goals, extending them with new additional goals, assumed within the project tasks and work packages. And proposing the follow-up of the project in the 2007 call of the "Plan Nacional de I+D+I", including fixed and mobile wireless sensor networks.

Regarding the stated goals:

- It has been defined a command and control information system architecture, specifically applied to emergency management, whose functionalities are described in a following section.
- It has been defined a communication architecture with four network layers: operational, tactical, field and personal.
- It has been developed a new system prototype: SIMAGEM, and a subjective evaluation of its functionalities has already been performed by expert personnel in tactical emergency management.

The development of the previous goals is stressed in the following sections.

2.2 C4ISR system architecture and functionality

Generally, the aim of military command and control information systems is to elaborate the Common Operational Picture (COP) at a high hierarchical level, i.e, from battalion level and upwards.

Moving this functionality to the civilian emergency management, it is needed to generate the COP at operating units of smaller size, e.g. fire-fighting brigades or specialized rescue teams, usually formed by a chief and a reduced amount of individuals, not surpassing the number of ten individuals.

In such a kind of operations, from the command and control point of view, it is fundamental to acquire a global vision of the situation (Situational Awareness, SA) by means of sharing each unit situation perception. Starting from the perception sharing among units (Shared Awareness), collaboration among them and a better effectiveness in reaching the mission goal are obtained.

Nowadays, this situation sharing is reached through unit's direct vision, maps, and vocal communications using the tactical radio combat network. In general, obtained SA is quite poor. Then, it will be extremely useful a command and control tool which: a) Allows obtaining the COP at fire brigade or rescue team level, virtually locating friend individual units over an operations theatre cartographic database with the suitable scalability at each level; b) Facilitates command and control decisions from one or from many tactical command and control locations, forward or rear; c) Allows self synchronization among fire brigades or rescue teams, shared awareness based. d)

Acquires individualized data from individual units, which therefore will act as sensors and actors simultaneously.

To develop all these objectives, we will start from two hypotheses: a) Availability of a field network capable of delivering digital data with the appropriated bandwidth; b) Automated information acquisition for COP generation. This process must be performed transparently to the individual units (fireman, member of a rescue team), that is, without their intervention in the information elaboration process and without interfering in their tasks.

In these scenarios, the person in charge, so as to obtain the enriched situation awareness, needs many times to "see through his own eyes" the operation scene, to make the proper tactical decisions. This requires the inclusion and fusion of multimedia flows, gathered from different sensors, particularly video flows.

The system architecture consists of various C2 nodes connected among them and to individual nodes with sensor/actuator functionality, by means of a wide capacity (tenths of Mbps) wireless data network, based in IEEE 802.11 WiFi standard in the current functional prototype. It is planned the migration to IEEE 802.16 WiMax.

The functional approach of the system can be summarized in the following points:

- Each individual member carries a SBC (Single Board Computer) which fuses data sensored from different sensors (video or infrared camera, GPS, biometric sensor, telemetric binoculars) and generates a unique information stream per individual element.
- Each individual unit SBC of a brigade is connected to the others by means of a wireless network, which access point is located at this brigade C2 post.
- First level C2 application generates the COP at fire brigade level since it receives data flows from individual units that constitute the brigade. The first level C2 post can manage a single brigade or a group of brigades, and usually will be installed in a tactical communications vehicle.
- C2 node can receive and fuse streams from other non-human sensor sources such as managed aerial vehicles (helicopter flying over operations theatre) or non managed (UAV) or fixed sensors distributed in the operations field (cameras with streaming capacity, presence sensors, etc).
- A brigade/group level C2 node can operate in the following three ways:
    1. Isolated from the others when, due to dimension of the mission, no more C2 levels are required. A unique COP at brigade/group level is generated.
    2. In an self-synchronized manner with other C2 nodes involved in the operation. In order to achieve this mode of operation, full wireless connectivity among involved C2 nodes is required. The COP is generated by the different C2 nodes, by mean of automatic replication of each node tactical database.
    3. Under the hierarchy of a higher level C2 post that coordinates several brigade/group level C2 nodes. Then, groups of brigades COP is automatically generated, at this high level C2 post.

Four screenshots of the current prototype application are included below to get a more graphic view of the ideas explained.

a) Group level, b) Brigades group level, c) Brigade level,
d) Individual element level

2.3 Network architecture

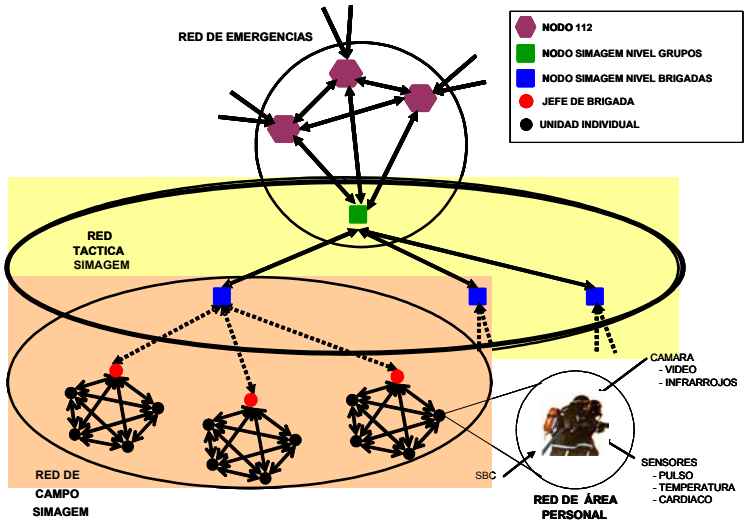
The main components of the SIMAGEM network architecture are the following:

- Personal Area Network, interconnect the sensors of each individual unit (brigade chief and fire-fighter) with his SBC. The PAN is implemented with Bluetooth and coaxial cable.
- SIMAGEM field network. IEEE 802.11 technology for the interconnection between the brigade chief; the individual units and the C2 Headquarters, where the wireless access point would be installed.
- SIMAGEM tactical network, interconnects C2 nodes of brigade group level among them and with the upper level C2 node. Currently the network is deployed using IEEE 802.11.

Some points have to be highlighted to the defined architecture:

- As an improvement of the prototype, we foresee the migration of the SIMAGEM field network to IEEE 802.16 WiMax. Mainly of the links between the C2 nodes of brigades group level and each brigade chief. The reason for this migration is twofold: (i) increase the radio coverage of the WiFi links (less than 1Km) to several Km using WiMax (5 Km without LOS and until 15 Km with LOS, although these values are an estimation and they depend on each vendor); (ii) improvement of indoor propagation, because with WiFi is nearly null.
- Due to the foreseen flexibility for the configuration of SIMAGEM, the C2 node of the brigades group level (or even a C2 node of brigades level if the operation has a reduced size) could be installed remotely with regard to the action scenario, e.g.: in a back headquarter, with the possibility of deploying the tactical network using satellite links, E1 links if available, or if the adequate bandwidth is available the regional or national emergency management radio network.

The C4ISR system network architecture is shown in the following figure:



SIMAGEM network architecture

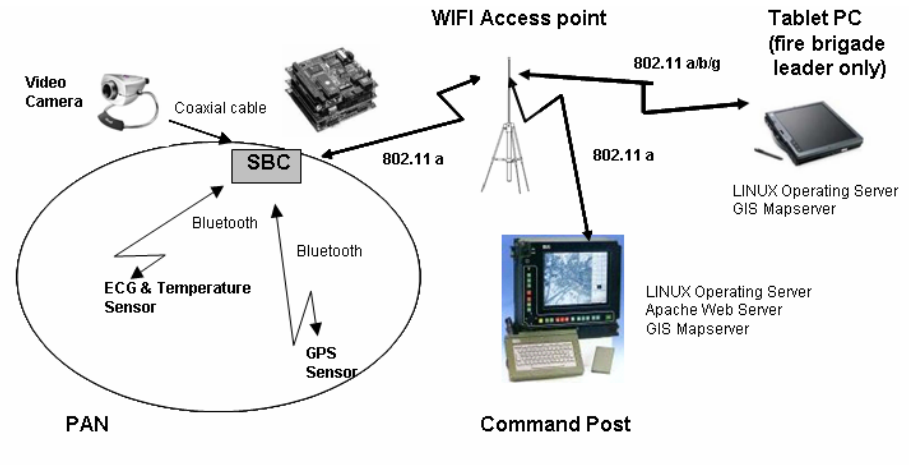
2.4 System prototype

Prototypes of a C2IS node and of the individual equipment for each individual unit, have been developed. Prototypes include the following technologies, all of them COTS and open source:

- Video cameras and grabbing cards.

- Biosensors: electrocardiogram (ECG), pulse and temperature.
- GPS.
- SBC with Linux operating system (distribution with minimal components).
- MPEG-4 codification and streaming software module.
- Data fusion module.
- Bluetooth and coaxial connectivity.
- C2 node computer with Linux operating system.
- Apache web server.
- Mapserver GIS.
- IEEE 802.11 WiFi connectivity, with immediate inclusion of IEEE 802.16 WiMax.
- Tablet PC with Linux, with Mapserver GIS, for fire brigade chief.

All these technologies are summarized in the following figure.



System prototype components

A first version of the system has been evaluated by command and control experts during a field demonstration (see annex with pictures of this demonstration), where video quality and overall system operability subjective aspects were evaluated. Some numeric results from this evaluation are (0 worst, 5 best):

Video quality at command post	4.5
Situation awareness improvement at command post	4
Decision support improvement	4.5
Application usability	4.5

3 Results Indicators

The project results till today have been published in the most renowned international conference in the field of command and control systems for civilian and military applications

- I.Pérez, C.Palau, M.Esteve, F.Carvajal, I.García-Juliá. "C4ISR Multimedia Framework for Situational Awareness Improvement". 10thICCRTS: International Command and Control Research and Technology Symposium. Malean, Virginia. EEUU. June 2005.
- F. Carvajal, I. Pérez, C. Palau, M.Esteve, "Adaptation of C2IEDM for Civil Crisis Management". 2006 International Command and Control Research and Technology Symposium San Diego, California. EEUU. June, 2006.
- Manuel Esteve Israel Pérez, Carlos Palau, Federico Carvajal "Command and Control Information Systems for Little Units: SIMACOP, a Research System to Test New Concepts" 11th ICCRTS: Coalition Command and Control in the Networked Era. Cambridge, UK. September, 2006.

The experience acquired in the previous project, has allowed the inclusion of the research group in three European projects related with command and control systems applied to emergency management. The projects are next briefly described. All of them are funded by EU 6th Framework Program. We have to highlight that in these projects, we are currently working with the main industrial companies of the sector, so as with the most prestigious universities in Europe in the scope of information systems, communications and emergency management.

MARIUS (Mobile Autonomous Reactive Information system for Urgency Situations). PASR Program (Preparatory Action on Security Research).
Project co-ordinated by EADS France, with the participation of Thales, Eurocopter, Selex, Marconi, Amper Programas and Cranfield University. The project began on the first week of March 2006, and its main goal is the development of a aero-transported tactical headquarter, for the management of the first hours of an emergency scenario. The headquarter will integrate and fuse information from different origins: UAV, video and IR from a helicopter, individual terrestrial video cameras); a C2IS for resources management (Zodiaco system from AMPER) and a modulus for decision support. One of the underlying goals of the project is the viability proof of using military technologies in the scope of joint civilian-military applications, within Europe or in detachments outside Europe (peace-keeping missions, catastrophes like tsunamis or earthquakes). UPV is responsible of the integration of terrestrial video cameras system integration, which is a direct result of the project.

DIVYNE (Dinamic Visual Networks). Programa IST (Information Society Technologies).
Project also co-ordinated by EADS France with some partners in common with MARIUS and other companies and universities leading the research in the C2IS field, like Catholic University of Leuven; University of Surrey and EPFL. The project started in September 2006, the main goal of the project is the development of a system allowing the interconnection and joint management from a headquarter and the management of the visual sensor networks of a certain city or a region (mainly video cameras) in case of a catastrophe.

CITRINE (Common Intelligence and Traceability for Rescues and IdentificatioN operations). PASR Program (Preparatory Action on Security Research).
Project co-ordinated by Thales, with other relevant partners like EADS, Selex, Galileo Avionica and Skysoft. The project started in January 2007. The main goals of the project can be summarized in: (i) development of a first version of a modular and scalable system of damages valuation in a catastrophe scenario from the data acquired by different sensors and other sources of human information (messages, reports,…), composing a synthetic picture of the situation that can help in the process of decision making on the catastrophe management; (ii) development of a support tool for decision making for the operational catastrophe management allowing the coordination of the different groups involved by means of task assignment, routes,…

Currently, the following researchers are working in their PhD Thesis in the field of command and control for emergency management, with activities directly related with the described research project. The researchers, the title of the PhD Thesis dissertation and the expected defence date follow:

- Israel Pérez Llopis. "Arquitectura C4ISR multimedia architecture for emergency management". July 2007.
- Federico Carvajal Rodrigo. "Adaptation of the tactical data model C2IEDM for command and control information systems applicable to emergency management". December 2007.
- Luis Ernesto Hernández Blanco. "Wireless data networks for command and control information systems for emergency management". July 2008.

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Manuel Esteve Israel Pérez, Carlos Palau, Federico Carvajal "Command and Control Information Systems for Little Units: SIMACOP, a Research System to Test New Concepts" 11th ICCRTS: September, 2006.

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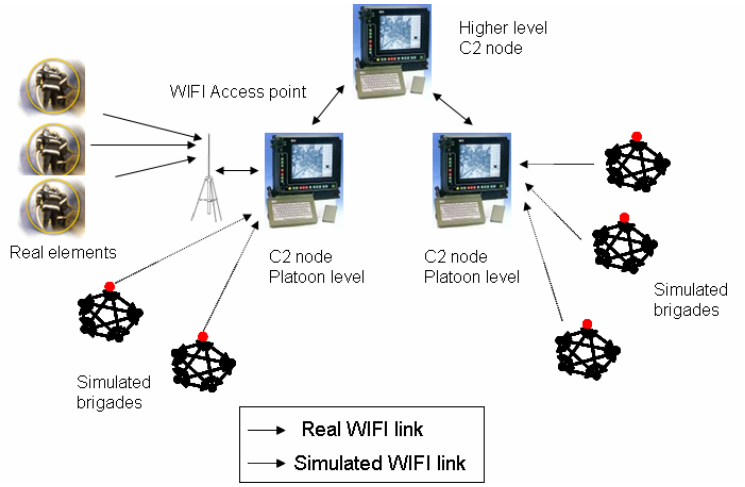
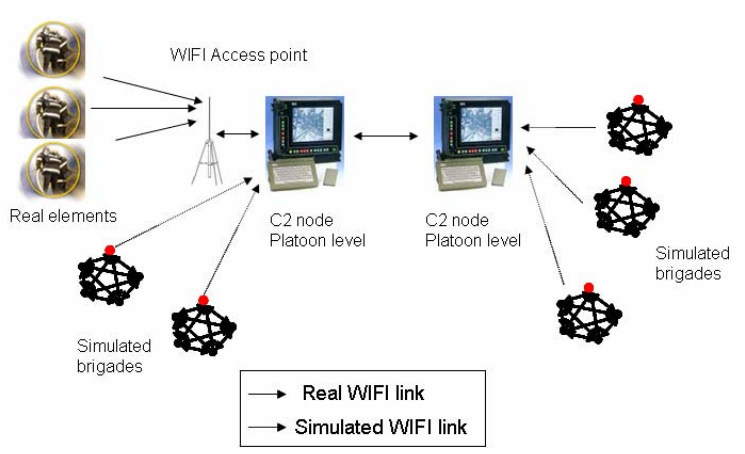
Annex:

Configuration and pictures of C4ISR multimedia system field demonstration



Self-synchonized configuration



Hierarchical configuration


WiFi access points at C2 post


WiFi antennas


SBC with WiFi card and video camera mounted on helmet


Application running at C2 post