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The Future of C2

C4ISR Multimedia Framework for Situational Awareness Improvement

Topic: C4ISR/C2 Architecture

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Abstract

C4ISR systems will be one of the bases of the Network Centric Warfare (NCW) approach in future symmetric and asymmetric confrontations. The C4ISR framework described in this paper is based on COTS philosophy and it is fully standards compliant. The main technological contributions of this framework are the following: the introduction of high quality video streaming in the communications architecture, the single-element detection through GPS, the data fusion gathered through biosensors and the integration of different wireless communication systems with large bandwidth requirements. i.e. IEEE 802.11, IEEE 802.15 (ZigBee), Bluetooth, GSM/GPRS, UMTS and satellite communications which will make up the networks at different command levels which will be described in the present paper. The basic objective of the inclusion of high quality video streaming is to improve the Situation Awareness in every step of the command chain within a multi-resolution representation scheme. This SA enhancement will be tested in an emergency management environment in order to translate the learned lessons to a military environment.

Keywords: situational awareness, network-centric warfare, C4ISR architecture, COTS, real-time Linux, real-time CORBA, data fusion, distributed systems, multimedia, biomedical monitoring.

1. Introduction

The final goal of a C4 system is to gather the adequate data to construct a proper vision of the operations theatre that will help the command and control staff make the correct decisions and subsequently transmit their orders, on time. However, this goal is hard to achieve as many technical challenges arise, most of them tightly coupled. Moreover, the emergence of new kinds of operations and battlefield scenarios (peacekeeping operations, asymmetric confrontations, etc) requires new solutions and/or approaches to the command & control topic.

In asymmetric confrontations in traditional land battlefields and also in peacekeeping operations, the tactic information systems in general, and the C2 in particular, have their capabilities very limited due to bandwidth constraints of the communication networks available. Additionally, the radio electric environment is most of the times hostile due many factors associated to these kind of operations: absence of communications infrastructure, environmental hazards or electronic countermeasures. The later case points out the strict communications security requirements, which considerably affect the available bandwidth to deliver data to the command and control loop.

Both reasons restrict available bandwidth. These bandwidth limitations drive to a restriction onto the amount of information delivered to command and control decision makers, which impacts in the quality of the Operations theatre vision they made. This can be not properly correlated to the real situation. Subsequently, decision-making can be wrong or inadequate and can lead to catastrophic consequences.

On the other hand, in most of current C2 systems the information is managed at battalion level. As a consequence, no information is gathered or treated in an automatic way from lower levels. In the new types of asymmetric confrontation (i.e. a street fight against a highly mobile and familiar with the ground, but not well-armed enemy), in peace maintenance tasks and in a wider application of the NCW concept to both the security environment and the emergency management (terrorist attacks, natural disasters, etc..) the person in command of a tactical operation requires specific information from specific battlefield points. This means acquiring and managing information from lower echelon units in the military hierarchy in “useful time” (before the deadline time which invalids the information). Currently, in existing solutions, the command and control loop operates at a higher level and this will be another contribution of our proposal, to investigate and develop C4ISR systems more fine-grained than battalion level.

So, tactical decisions affect directly to high value personnel, elite soldiers, security forces or even civil people, in the major part of the previously mentioned situations: asymmetric confrontation, peace maintenance operations, terrorist attacks or catastrophic forest fires. In addition, the tactical decisions have to be made in hard real time since human lives (soldiers and civil people) depend directly on them and, never forget the success of the mission, either. To permit these real time decisions, all the steps involved in the cycle: information gathering, data fusion and elaboration (which requires the proper coordination among different data sources) and decision-making staff orders transmission must be done in hard real time.

In order to provide the adequate COP, the following requirements should be fulfilled:

- Enough bandwidth to deliver and process the required information to construct the COP. This includes, in our opinion, the inclusion of multimedia video flows.
- The appropriate granularity or resolution of the Vision of the Operations Theatre, scalable to any level from a brigade to the entire army
- The hard real-time nature of: the information acquisition, the Operations Theatre Vision construction and the order delivery processes. Missed deadlines on any element of the chain lead to improper OTV construction which conducts to wrong decisions and subsequently to the loss of human lives and/or mission failure.

In these scenarios, the person in charge needs many times to “see through his own eyes” the operation scene, so as to obtain the correct Situation Awareness (SA). This requires the inclusion of multimedia flows in the C4 architecture which will improve, dramatically, the vision of the operations theatre of the decision-making officials. As a result, available bandwidth must be increased, something achievable nowadays to the required extent in non-military networks.

Once the SA has been clarified, the person in charge can make the appropriate command decisions. The traditional vocal communications via radio supported by current combat networks are mostly insufficient to obtain an adequate SA or the adequate Common Operational Picture (COP) which allows the coordination within reduced teams (a platoon or a firemen brigade) and the coordination among teams in a common tactical environment. The traditional C2 systems do not handle information with enough granularity for supporting these kinds of situations. Additionally, existing C2 systems do not integrate all the information flows in an IP network-centric manner and do not handle all of them in real time.

2. Problem Outline

Therefore, to obtain the adequate SA, it is required to produce a proper representation of the operations theatre, which requires:

1) An adequate GIS (Geographic Information System) focusing on the hot-spot area, and a continuous and real-time acquisition of location-awareness of all the agents involved in an operation. To achieve this goal, identification of the exact position of the work teams and the individual elements inside the battlefield is obtained through the inclusion of a GPS receiver in each singular element. This information must be transmitted in real-time through the network

2) Multimedia information capture, mainly video, from each singular element through a video or IR camera in order to “see through his own eyes”. This requires that video stream must be high-quality and at an acceptable rate.

3) Moreover, and taking into account the high value of the elements involved, it would be helpful to be able to collect from them biomedical information such as ECG or body temperature. This kind of information would be obtained through biometric sensors allocated in each singular element.

All this information acquired from each element has to be fused and transmitted to the first tactical decision node through the combat network. It must be properly fused and synchronized to deliver a real time vision of the operations theatre to the decision-makers. Raw data will be transformed by means of these fusion processes to elaborated knowledge and useful information. Once the information has been acquired by the first command node, it will be transmitted to the upper levels, when appropriate. The upper level information redistribution process will be completely automated, transparent to users which, when required, will focus on specific information, on demand.

In the proposed architecture, decision support mechanisms are included at each command level, thus offering the relevant information with the adequate degree of elaboration in order to help the decision making. The information to be transmitted and processed will be very high due to its multimedia character. In general, both the combat and tactical networks available for most occidental armies (even in the security forces and firemen) are not capable of handling all these flow of information.

So, proposed work tries to solve the following dilemma: is it necessary to incorporate multimedia flows in C4 systems in order to achieve a better COP? As a consequence, how will this enhancement transform command and control military doctrines and procedures?

Then, the concept of managing in a C4ISR individual multimedia information (location, video or IR images, and vital data) complemented by a general vision of the situation acquired from an aerial means endowed with a video or IR camera and a sensor network distributed in the operation scenario attached to human actuators and/or deployed as Unattended Ground Sensor (UGS), it is obviously attractive and, above all, useful in present non-conventional operations, opening the way for new operative procedures, leading us to the eternal dilemma of the "hen and the egg": so, as current combat systems and networks are not able to provide support to these new operative procedures, we will never be able to check the viability of command and control procedures over individual elements or reduced very mobile teams with a high individual value, if the adequate networks to support the information system are not available previously, in order to check the procedures over them.

To break the dilemma, we propose a C4ISR architecture with the three DoD standard definition levels: operational, systems and technological, with an initial application to civil environment, specifically to emergency scenario management, due to the availability of more bandwidth and less use constrains than in military scenarios. The architecture will be used to evaluate command and control procedures by dealing with multimedia information from individual elements. The blocking point of the dilemma (the non-availability of enough bandwidth in the combat and tactical networks) is solved by means of IP networks and systems following the COTS principle currently used in the dual development civilian/military environments.

Then, if the hypothesis is successfully proved onto civil scenario, and it is feasible to include massive multimedia flows into C4ISR architectures and allow them to be more fine-grained, it can be considered its translation to the military area, leading to a new range of technical and doctrine research fields. Moreover, it must be pointed out that evident operative similarities exist between command and control needs of military armies in the battlefield and civil emergency command and control, making feasible the translation from one domain to the other included into our dilemma-breaking procedure.

We can imagine the next scenario:

"A phone call to 911 number alerts an on guard firefight official about the detection of a wildfire with various fronts. The message carries out the approximate wildfire position. Quickly, a reconnaissance helicopter carrying Infrared (IR) and video cameras yields to the wildfire area. Concurrently, three land units depart to the hot-spot.

The helicopter locates over the fire area and transmits, in an automated, digital, continuous and real-time fashion, to the official in charge (who stays at the headquarters) the following values: GPS position, video and IR image of the hot-spot, speed and direction of the wind. This information is pre-processed at the control computer and helps the official to get a precise idea of the magnitude and exact location of the disaster.

Automatically, the command and control computer: 1) extracts the hot-spot map from a GIS, 2) isolates and represents the wildfire fronts onto the digital map, 3) transmits, throughout a wireless terrestrial link or a satellite link, the previously generated hot-spot map to the tactical computer on each terrestrial vehicle driven by a fire brigade official, heading to the hot-spot area, 4) sends a message to the hydroplane on guard with the exact position of the wildfire, 5) sends an alert message to the traffic *authority computer in order to cut highways close to the fire area, 6) the wildfire is substantial and close to inhabited areas, a message is sent to the medical authorities to dispatch ambulances to the area.*

On hot-spot arrival, each terrestrial unit has received the optimal exact position where its command and control post must be located. Each unit, coordinated by an officer, deploys a wireless network infrastructure which will bring connectivity to three fire extinction brigades, composed each one by one officer and four firefighters. Every firefighter carries external and internal temperature sensors, as well as electromyographic sensors. Additionally, all of them will carry a GPS receiver. Two of them carry a video camera attached to the helmet, and the other two an IR camera. Sensors and cameras are connected by a PAN (Personal Area Network) to a SBC (Single Board Computer) or a PDA which also has a microphone and a VoIP (Voice over IP) earpiece plugged-in. The VoIP, or radio software, allows the vocal communication between fire brigade members and their officer. All the communications infrastructure is deployed as a mobile ad-hoc network. The officer's PDA displays a real-time schematic version of the extinction area assigned to its brigade. This PDA has a wireless link with the hierarchy's next echelon tactical computer, and acts as a gateway for the fire brigade members real-time data: GPS positions, biomedical data, and video flows. If this link fails, automatic processes and protocols detect the event and elect another gateway among the firefighters PDAs or SBCs.

All the data flows received at the tactical computer are processed and the most relevant are sent to the central computer which fuses them with data received from other tactical computers and, for instance, sends a message to the hydroplane with the optimal coordinates where to drop next water load. Command and control staff know, at any time, where their men are located because they are represented as points that move over a digital map of the area. If any of the firefighter sensors exceeds an alarm threshold, its point becomes red and the officer sends the vocal order "regroup and leave the area immediately". This order is transmitted with maximum priority to the firefighters of the brigade".

This futuristic scenario can be real in few years. It describes a civilian usage of command and control C4ISR system, with multimedia communications integration. It will be the basis of our architecture development, and the basement for the hypothesis test aiming present paper.

3. Proposed Architecture

3.1General overview

3.1.1 Systems theory view

As stated in the outline, the proposed architecture considers a command and control system as a closed feedbacked control algorithm. Agents, who can be firemen or soldiers, act both as sensors and actuators. On the one hand act as sensors (ECG, temperature, video, GPS) and, on the other hand, act as actuators as they carry out orders received from command and control personnel, over the operating environment. Command & control posts, particularly the whole composed by systems and decision making staff, behave like the control algorithm. Additionally there are "passive sensors" such as UGS, as they do not act onto the system.

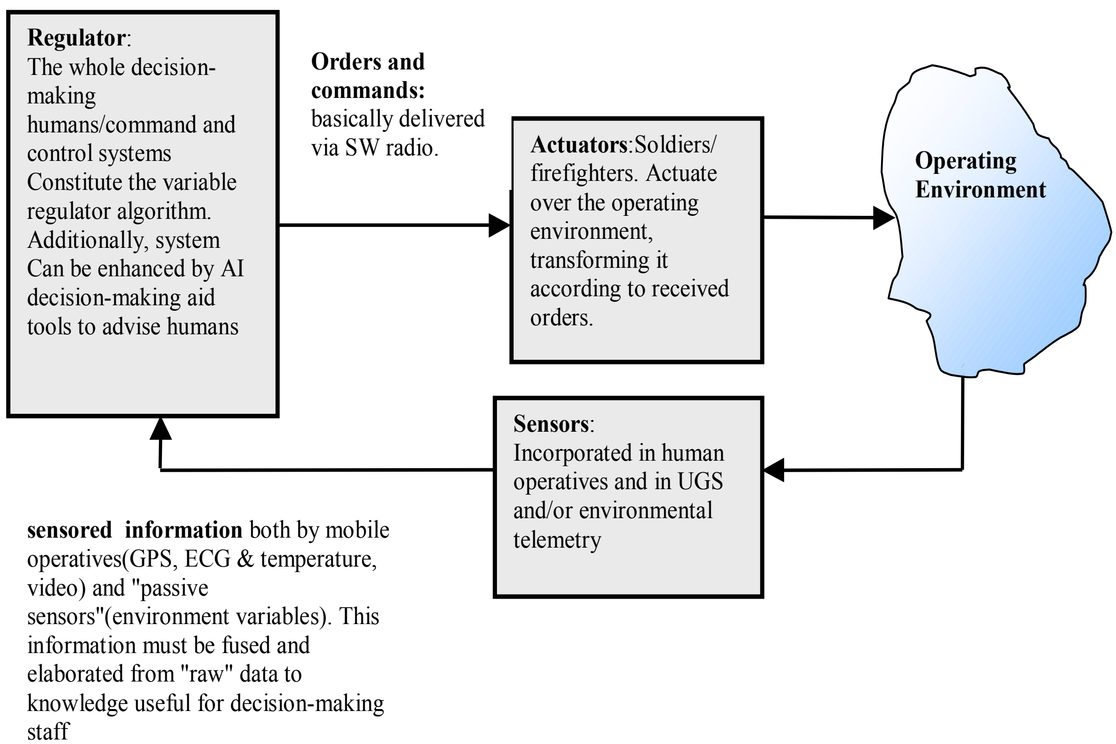

Figure 1: Systems theory view of a C4ISR system

Conceived this way, the system behaves, globally, adaptively respect to a dynamic and unpredictable environment. From this perspective, there are various control loops, one for each roster in the command and control hierarchy and obviously priorized by the rank order.

The inclusion of real-time adaptive feedback scheduling mechanisms onto individual nodes and in wider scheduling domains (such as combat/field network) enforces the adaptability and real-time response of the system respect to the non-ergodic external environment (enemy, natural hazard, relation our forces-enemy)

3.1.2 Cognitive view

It is not the objective of the proposed architecture to solve the numerous and complex cognitive problems related to the command and control topic. But, the main goal of our architecture is to enhance situation awareness and consequently the cognitive loop by means of the inclusion of massive multimedia flows. So, cognitive matters must be addressed.

A relevant element of the architecture, from the cognitive point of view, will be the separation of concerns; each agent involved in an operation receives exactly the information that it requires in order to:

- Acquire enough data to properly make up the situation picture in an incomplete and messy information scenario, as it is a battlefield or a disaster environment
- Minimize the cognitive overload [1], which can be worse in many cases than underload. Soldiers and firefighters must follow precisely their orders and, have no need to know what other operatives are doing or if weather is going to change. Avoid overwhelming them with tons of data (even fused and elaborated) about the environment or the operation.

We can extend system's correction dimensions with a third one added to logical and temporal correctness. So, it can be stated as:

- Logical correctness: System behaves properly and delivers correctly the specified outputs for a given set of inputs.
- Temporal correctness: System delivers outputs on time (with the specified tolerance), not before, nor later.
- Cognitive correctness: Each agent on the system receives the information that it requires: not more, nor less. The question is which items must each agent process and this must be clockwork crafted for every agent, in an ad-hoc fashion in order to avoid cognitive overload.

The separation of concerns, also relates to security and hierarchy matters so that a mid-rank official will not receive the same COP as an low-rank official and also, different agencies that potentially could dynamically plug into the architecture in a mission course will not share all the information acquired through their network and systems with other agencies.

Thus, data access and SA construction is considered in a hierarchical fashion, so that a low-level official achieves a COP from its brigade and their environment (combat network), a mid-level official achieves a COP related to its low-level officials and their brigades (tactic network), a high-level official can have a vision of the operations theatre of all its mid-level officials, and so on. Also, on demand, each commander can focus on a particular subset of the operatives under its command and on particular features (position on map, video flows, biomedical and temperature monitoring) or any high level fused data that the system could deliver.

From the cognitive point of view, an additional argument appears for the inclusion of high-quality multimedia video flows. Related to the definitions of well-balanced reactive systems from authoritative researchers from the reactive cognitive systems community [2][3][4] there must be an equalization between acquired data, processing power and actuation degrees of freedom in order that the cognitive loop acts properly. It can be seen that, both processing power and actuation degrees of freedom are very powerful, as conducted by human beings, and that information gathered, if multimedia video is not included, is some magnitude orders below (Notice that the problem is not located at sensors but at the underlying network infrastructure that does not provide enough bandwidth to carry out those flows). Thus we must leverage the three cognitive components (sensors, processors and actuators) to be equivalent by including real-time high quality video.

3.1.3 DoD C4ISR compliance

Currently, our architecture is designed with the DoD´s C4ISR specification[5][6] in mind and is described from the operational view, systems view, and technical view. Also, linkages between different views and relational matrixes for many products are created to help developers and architects.

This standards fulfillment will guarantee interoperability, evolvability and evolvable development (using products such as Systems Technology Forecast (SV-9) and Standards Technology Forecast (TV-2)), proper project development management and improve architecture development and maintenance (with the usage of the Overview and Summary information (AV-1), System-to-System Matrix (SV-3) and Systems Functionality Descriptions (SV-4)).

Also, the architecture is enhanced through the use of the C4ISR specs by means of easing users-to-developers communication (Integrated Dictionary (AV-2)), proper correlation between operative, systems and technical goals (by means of using Information Exchange Matrices y and System Interface Description).

3.1.4 Technical view

STANDARDS-BASED

Following the DoD C4isr directive, the system is developed using rigorous standards on each area of development: video coding and transport standards (MPEG-4 compression standard), European medical information transmission standards, standard-based operating system (Linux, RT-linux based on POSIX definitions and real-time extensions[7]), Real-time CORBA (based on OMG specification)[8], TCP/IP and IPv6 for networking stack, RTP/RTSP for real-time networking, NMEA 0183 [9] for GPS data and SQL for database access.

Moreover, hardware is also selected if it fulfils commercial or engineering standards such as Bluetooth[10], IEEE 802.11 a/b/g or PC104+[11].

INTEROPERABILITY

One of the main aims of the DoD C4isr specification is that systems that follow its architecture achieve high interoperability degree. The proposed architecture will guarantee interoperability by means of different approaches, basically CORBA/RT-CORBA middleware and web based technologies.

Thus, when an operative belonging to a different agency approaches the hot-spot area, its systems and applications can be integrated, in a plug-and-play fashion, to the whole C4ISR architecture, transparently to the user. By means of CORBA technologies, approaching systems can discover existing services and apply for information delivery. Using common shared objects, methods and communication primitives, video, GPS, biomedical signals and SW radio orders will be received by approaching operative sets as they are dynamically integrated in the architecture with no human intervention in the process. Additionally, being the system standards-based will enforce the interoperability concern.

Obviously, a strict validation and authentication process are necessary due to the logical requirements (military environments) and the vulnerabilities of some of the means used (radio links, etc) before a system can be plugged to the global architecture.

Moreover, following DoD´s C4ISR architecture, each software/hardware component is defined as an abstract object with its particular interfaces and time relationships, so as to allow developers replace it with new versions, redefine subsets of systems or share them with other agency developers/architects in order to interoperate.

COTS

The proposed architecture is based on COTS philosophy. All hardware components are COTS and all software components are also COTS but, especially, they are reusable.

On the one hand, and, as stated in preceding point, the system allows component reuse by means of an abstract object definition that can be replaced if interface specifications are fulfilled. It is important to point out that object-defined architectures are not silver-bullets, and every component reuse must be carefully studied avoiding black-box philosophy, mainly for real-time and safety critical applications and systems.

On the other hand, most of the architecture follows OSS (Open Source Software) philosophy, so source code is available. Due to this, existing software components can be reused, replaced or redesigned at any time to extend existing ones or to fulfil new needs and challenges.

Besides reusability, source code availability allows developed systems validation conforming strict international standards for safety critical systems development, such as ESA (European Space Agency) ECCS-Q-80-01 and ECSS-E-40-06[12][13].

3.1.5 Multimedia flow inclusion

The main contribution of the present work is the inclusion of multimedia flows in a C4ISR architecture. The application of the system to a civil environment (emergency management), has showed that situation awareness is dramatically improved as decision-making staff can "see through his own eyes" and, all the better, can "see through his own eyes" what is going on simultaneously in different places, with flows synchronized.

This is achieved by means of the inclusion of COTS IP networks (with IPv6 as core element). Besides, efficient compression systems, multicast to guarantee system scalability, real-time protocols and network architectures that guarantee quality of service to some extent, have been used. Real-time protocols, such as RTP, RTCP or RTSP to enforce temporal correction in multimedia flows transport, reproduction, adaptation and synchronization are, additionally, reinforced by real-time resource management and scheduling policies, both at local node level and at a distributed level.

Moreover, applying a real-time multimedia system is only feasible in a corporate environment, i.e. the one where the designer has control over all resources (applications, protocols and infrastructure) and is not restricted by nor has to share resources with others. That is the environment we found in our development and that is the environment where military systems exist, so, in that sense, feasibility is guaranteed.

3.2 Communications Architecture

As it has been showed, a critical element of all the architecture is communications infrastructure, particularly if real-time multimedia flows are included. So it has to be clockwork, wisely designed and specified, to support all the features and requirements of our proposal and help us to break raised dilemmas.

Communications architecture fulfils the following requirements:

- Fault tolerance: As stated below, there are mechanisms to enhance network resilience and robustness.
- Incorporation of real-time protocols like RTP/RTCP/RTSP enforced by OS real-time scheduling and resource management strategies on each individual node and distributedly.
- Mobility in the combat network: by means of MANET particular algorithms and techniques usage to support dynamic topologies and continuous reconfigurations.
- Interoperability in the tactical network: due to CORBA, abstract object definitions, web technologies...
- Global coverage in the operational network: as massive data flows are supported by fiber optic links.
- Enough bandwidth availability for the exchange of command and control information and downlink communications by means of messages and IP radio software.

The available technologies for communications are: terrestrial trunk networks, satellite networks, WLAN technology (i.e.: IEEE 802.11 a/b/g) for the interconnection of individuals and equipment through ad-hoc networks, Bluetooth for sensor interconnection in terms of wearable computers philosophy, robust terminals (industrial PDA and SBC), fiber optic links owned by the organizations or leased from network operators, mobile networks like UMTS or GPRS, and IPV6 as core protocol of the network (using UDP for real-time flows, obviously).

As can be figured out, selected communications technologies and associated IP stack protocols, allow bandwidths up to 54 Mbps at mobile networks (combat/field and tactical) and Gigabit order magnitude at the operational network, enough for the inclusion of multimedia flows to prove our hypothesis.

The network has been designed with a hierarchical structure, to reflex command chains and to isolate operational needs and data/orders flows. It presents the following structure:

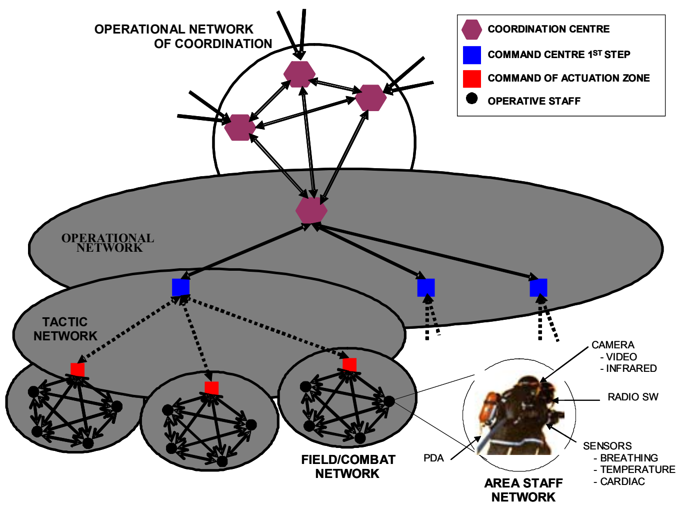

Figure 2: Communications Architecture

- ***Personal Area Network (PAN)***, in charge of the interconnection of the sensors carried by the individual elements (firemen or soldiers), which includes biomedical and GPS. This kind of networks uses Bluetooth technology, mainly. Video signal is carried out by coaxial cable, due to bandwidth limitations of Bluetooth specification (<1Mbps. The new BT 2.0 specification promises rates up to 3Mbps so it will be considered in further versions). Many different sensors can be plugged-in, managed in a master-slave fashion by the corresponding soldier SBC or PDA. Additionally, sensors can be plugged-in automatically so, if an individual node's SBC fails, its sensored data can be carried out by another node and delivered to the next command post. Moreover, if a brigade arrives to a hot-spot where non-networked casualties exist, their biomedical information can be incorporated to the network immediately.

- ***Combat/Field Network***, is used to connect the personnel operating in the actuation zone among them and with the first command level, who is located close to the operative elements in the hot-spot area. Technically, nodes at this level will be the SBC or PDA carried by individual elements. These networks must support all the multimedia and sensor flows in the uplink (from individual nodes to the first command level) and VoIP orders in the downlink (from commanders to soldiers/firefighters. Many orders will by-pass lower level command echelons). Moreover, these networks are mobile ad-hoc networks (MANET) with all their features and problems. We will benefit from the dynamic nature of those networks to adapt to a changing environment, but also suffer associated problems (see below). Wireless technology, mainly WLAN, will be used.

- ***Tactical Network***, connects the first level command personnel with the personnel in charge of the operative units, in order that the superior level has an adequate COP of the whole situation. These nodes will agglutinate all the lower echelon uplink data flows, so enough bandwidth (particularly for all video flows it must support) must be provided. There is more processing power and lesser restrictions than in lower echelon networks, so more complex processes can be done. Wireless technology (WLAN), mobile commercial networks or satellite communications are used, depending on the coverage and deployment of the operative units.

- ***Operational Network***, connects the coordination center of a certain organization with the personnel in charge at the first command level. Satellite or fiber optic links are mainly used here. In case of the existence of several operational networks, there should be an information flow between the coordination centers of higher level, so the existence of an operational network of global coordination could be considered. Additionally, this network can provide computing units that support heavy processing and/or massive storage, as can be located at corporate facilities where there are no restrictions for power consumption, size and computing power. For instance, complex data fusion or Artificial Intelligence processes can be applied to situation/operation data collected at lower echelons, to anticipate or predict the enemy (which can be a natural disaster or an army) next movements and deliver elaborated advise to corresponding command and control decision-makers. This, regardless to simpler data fusion, but more critical data fusion processes that would be done on site, in combat/field or tactical network.

Combat/Field network and tactical network currently are the key point of the architecture and the most technically challenging ones. Both must support all the operatives, belonging to different platoons and carry out sensored data and orders, operating in a hostile and dynamically changing environment.

Combat/Field network and tactical network, will be deployed in an ad-hoc fashion when arriving the hot-spot. This mobility feature makes the system designer pay an important price. On one hand, it is required special mechanisms and algorithms to manage the network dynamically changing configurations at each level of the defined network stack.

On the other hand, there are considerable restrictions due to the mobile and ad-hoc nature of the network. First, mobile devices (which include handhelds, SBC, communications infrastructure devices and sensors) are limited by their processing power and storage capacity. Second, and much important, all devices have a limited lifetime battery and, obviously, cannot run out in the middle of an operation as they support safety-critical information flows. As the operation duration is unpredictable, some safety schemas have been introduced in the architecture. Second, mobile ad-hoc networks experience continuous and unpredictable topology changes which affect the connectivity of a given link, with dramatic consequences for real-time flows. To solve all this problems, solutions as path redundancy, real-time enforcement for critical flows (using a differentiated traffic schema) and real time scheduling at node level and at distributed level, are used.

All these problems related to mobile communications will impact considerably on multimedia video transmission due to the particular nature of video flows and human vision perception affecting delays, jitter and synchronization, mainly. At this point, usage of well-known transport and streaming IP protocols, as well as, operating systems real-time scheduling and resource management and network resource reservation and/or traffic differentiation policies and, mobile link state prediction techniques, allows us to provide real-time video.

To acquire the adequate network resilience and robustness there are automatic mechanisms that detect connection failure and other troubles and switch from an IEEE 802.11 network connection to a UMTS network connection among nodes.

There are also other types of network fault tolerance mechanisms such as dynamically added redundant paths for every information flow and usage of special algorithms that manage the detection of failures and adaptively reconfigure the different field networks electing new leader/gateway nodes.

4. Developed prototype

An operative prototype that proves the main concepts of the described architecture is currently under development. Every developed software object is reusable and could be applied both to the military and the civilian fields, due to the utilization of the DoD data structure for C4ISR systems enhanced with civilian object types for emergency management scenarios. Besides, interoperability and real-time performance of the distributed system are guaranteed by using RT-Linux and RT-CORBA.

Currently, a working prototype has been developed, including the node to command and control posts stage, and consequently the combat/field network management infrastructure.

Each node is composed of a PAN (Personal Area Network), video camera and a SBC (Single Board Computer). The SBC manages real-time data acquisition from sensors and network communication among different nodes and information delivery between nodes and command and control posts. Also it signals real-time alarms when detects abnormal values on sensored data. It is limited to just these tasks (sensoring and alarm triggering) to simplify system and enforce real-time and in order to keep low power consumption (consider that it must codify video by software) to extend time between battery replacement. The SBC is a ruggerized PC-104+ compliant, 400Mhz x86 architecture computer.

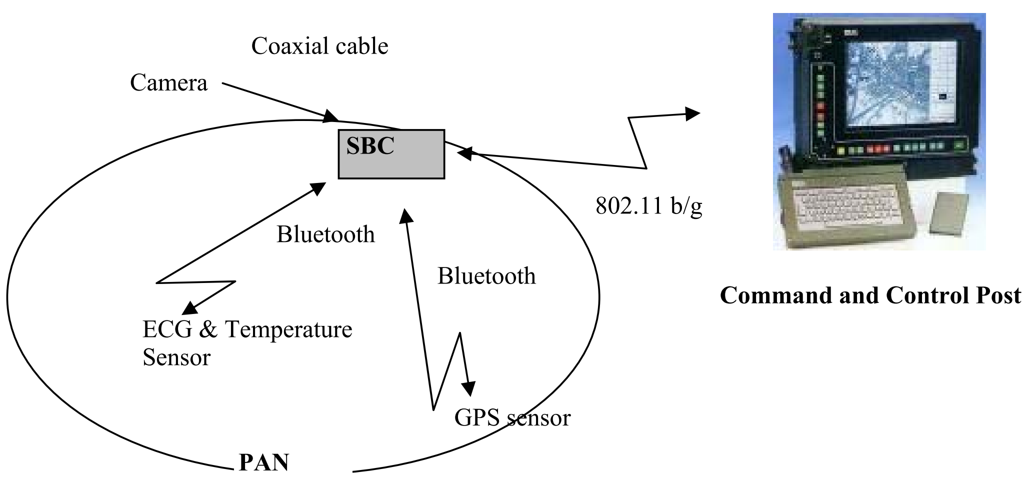

Figure 3: Single node technical architecture

All the involved elements, both hardware and software, are COTS. This includes sensor devices, SBC, and network hardware. On the software side, every piece is COTS but coming from OSS (Open Source Software) community. This introduces important tones, as it can be considered more related to OSS-ON (Open Source Software- Off the Network) than to COTS which makes the project development and management quite different from the traditional COTS perspective [14] .

This includes the real-time operating system (currently real-time linux [15]), the software for network management and data communication, the database system (currently MySQL[16]), the video adquisition and streaming system[17] and the GIS infraestructure (Mapserver[18]). All these components come from the OSS community, and are tailored and properly reprogrammed to our needs. Additionally, all the custom developed software is done using OSS IDEs and tools.

On each node, the PAN (Personal Area Network) is composed by several sensor devices that communicate with the SBC and among them by means of Bluetooth technology. Currently there are sensors for ECG (ElectroCardioGram), body temperature and high spatial resolution GPS. The video stream is captured with a 1.3 Mpixels camera and transmitted to the SBC through coaxial cable. It is envised to add radiation and toxic gas concentration sensors at short-term.

The operating system is a custom implementation of a real-time linux distribution, tailored to the operating environment. The SBC and the command and control posts communicate throughout 802.11, with the appropriate access protocols and the later coordinates the communication among nodes of the same combat/field network. Moreover, there is a protocol to detect leader failures and to elect substitutes.

The command and control posts are less memory, storage and energy consumption restricted. As a result, more processing and storage can be located on them so they contain the database system, web servers, network management agents and, fundamentally, COP representation systems (GIS and related decision-aiding applications).

Sensored data (biomedical, GPS) are stored in a database for an eventual later forensic reconstruction. Additionally, it is envised the possibility of storing selected video fragments on demand. This data is located in the command and control posts in an increasing size as command and control hierarchy increases.

The command and control software visualization system is based on web technologies. As a result, using a web browser, different command and control platforms can visualize the same web page (dynamically generated by the server application) showing the brigades position. In case of a physical hazard, alarms are signalled to top level C2 posts across the network and represented in real time in the web page. At any time, the position of an operating node can be clicked bearing to another page where video and biomedical data is represented, in real-time, for this worker. The main reason for using web technologies is due to the interoperability needs.

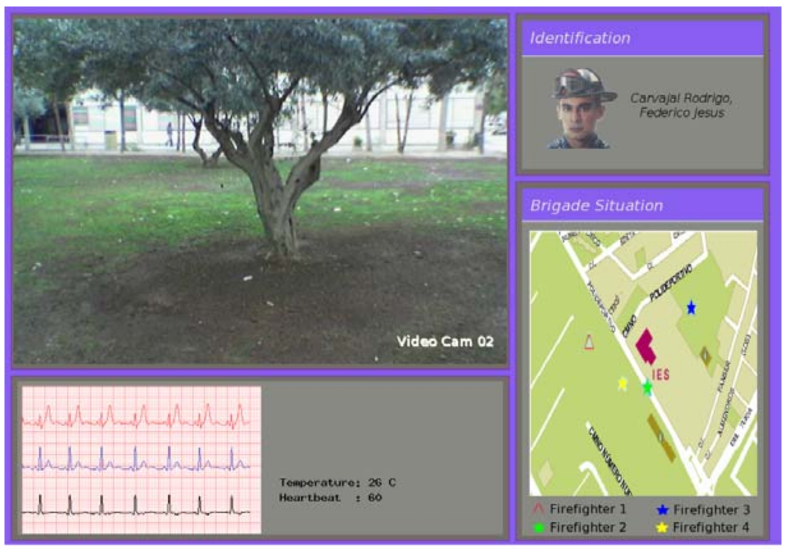

Figure 4: Individual node information page

The video server/clients are well-known OSS solutions, customized to our needs. Mpeg-4 encoding is used and also, software agents monitor each node's processes to check out service failure to automatically raise fallen ones, as system must be self-recoverable.

Tests have been carried on to study the interference between Bluetooth and 802.11, which affects more considerably the later as the former applies a frequency hopping scheme 1600 times per second, becoming more resilent to interferences. Nowadays, the system transmits each video flow at a rate of 1 Mbps, experiencing no problems with the Bluetooth interaction. For higher video rates, migration to 802.11a is considered. This will bring 54Mbps to each link and no interference with Bluetooth or other systems that operate on the ISM band, as is located at the 5Ghz band.

Additionally, a middleware implementation, by means of CORBA technology, is used to transfer and coordinate different software objects. It enforces and coordinates real-time distributed scheduling among nodes by means of the usage of RT-CORBA2.0 [19] distributable threads.

Moreover, it also enforces interoperability concerns by encapsulating common components as CORBA objects. This way, cooperating agencies can implement, independently, those objects as long as the interface definition is concerned. This independency relates to hardware (equipment, configuration) and software systems (programming language, inner characteristics) and is abstracted by the middleware layer.

5. Added Value of our proposal

The described C4ISR architecture, introduces innovative concepts for this kind of systems, mainly the inclusion of high quality video streaming and its fusion and synchronization with different data sources, as well as the information representation and processing coming from individual elements who act as sensors/actuators of the system. Besides, our approach investigates how this multimedia flow inclusion and synchronization can be done in real-time, particularly in hard-real time in a distributed, mobile and hostile environment, in order to improve situation awareness.

Another contribution of our work is to focus on finer-grained resolution rather than battalion level, which we consider significant as it wasn't set before and also we found necessary for many environments, mainly newly emerged scenarios such as civil emergency management and new asymmetric confrontation kinds. Then we focus importance and value over individuals (soldiers, firefighters) and civilians. Also, new command and control power is brought to low echelons (such as corporal or officer) of the agency hierarchy so higher echelons can delegate command and control efforts onto them.

Additionally, proposed architecture is based on COTS, with all the interoperability and evolvable design benefits. Particularly, it is based on OSS, which brings strict control over the developed system. If we have source code we can verify and validate properly the system, mainly for safety critical environments, as ours is.

The advantages of using the system, working with civilian networks with more available bandwidth and lesser restrictions, will provide very useful information in order to translate the developed and evaluated concepts to the strictly military environment.

6. Conclusions and future work

Proposed system has been applied into a civil environment (emergency management) showing that the inclusion of multimedia flows: (i) is feasible by means of designing underlying network infrastructure with COTS IP hardware and software, allowing enough bandwidth and protocols and mechanisms to manage massive real time flows, (ii) improves dramatically situation awareness as decision-making staff can "see through his own eyes" or, all the better, can "see through his own eyes" what is going on simultaneously in different places, with flows synchronized, fused with other data sources and in real time.

The next step would be to apply the architecture into a military environment to verify if lessons learned could be translated to the military world, with its particularities, and check out dilemma-breaking hypothesis.

There are many research areas involved in this project. We outline some of them:

- Inclusion of multi agent architectures (particularly real-time multi-agent architectures) on top of the middleware architecture, to achieve independent data gathering and dissemination besides network and system autoconfiguration by applying autoorganization principles underlying to the interaction nature of the agents systems.

- Feasibility investigation and Inclusion of new real time paradigms and frameworks for distributed systems, such as those related to adaptive real-time scheduling, path based real-time systems, utility function-based real-time systems and reflexive middleware.

- Inclusion of artificial intelligence elements such as prediction of the evolution of the enemy/dynamic natural disaster to assess decision-makers. Collected data should be directed to specialized servers that process information and tries to bind the evolution of the event whenever unpredictable.

- Inclusion of SW Radio management systems based on event-driven middleware architectures.

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