Design and Experiment of a Collaborative Planning Service for NetCentric International Brigade Command

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Abstract

Complex operational environments require improved tactical mission command capabilities with a high level of interoperability among coalition control and command (C2) systems. This paper focuses on two areas of interest: decision support based on automated planning and Service Oriented Architecture (SOA) for rapid service development. Previous experiments were performed bilaterally by US, France and Germany to focus on collaborative mission planning using Web Services (WSs). The results reported herein were obtained from a unified experiment performed by US, France and Germany involving a common scenario. The operational benefit from the experimentation has been to improve mutual understanding among allied forces, to dynamically plan for assistance among ground support troops (logistics, MEDEVAC, and other areas) as well as to improve their coordination. The effort addressed system design, and integration within an experimental framework. It enabled the evolution of the CERDEC Mission Command Gateway (MCG) architecture as well as a constraint based planner ORTAC, developed by French DGA and Sagem. It takes into account near real-time multimodal Situation Awareness and readiness status from tactical edge units. The trilateral experiment, entitled From Data to Decision included Net-Centric manned and unmanned assets from all three nations (France - Germany - US) operating as a cohesive coalition force while preserving command and support relationships as required through their respective chains of command.

Introduction

During coalition in operations, plan safety and flexibility, mutual support and understanding are critical challenges. Command and Control (C2) systems must rely on smart tactical exchanges across the chain of command at brigade level and below. Thanks to the improvement of IP-based networking radios as well as C2 software, it is now possible to share a consistent situation awareness among commanders at different echelons. However, when planning a Course of Action (CoA) collaboratively, conflicting actions may occur among friendly forces. This is particularly the case when planning support actions for a friendly unit in coalition.

In previous work (Guettier et al. 2011), the US/FR project has focused on Service Oriented Architecture (SOA) and decision support based on optimizing web service agents. In particular, the collaborative mission planning Web Service (WS), named ORTAC (Optimization of Resources and Tactical Action Control) provides automated processing of a CoA and associated routes to the command team. ORTAC web service can dynamically plan for assistance among ground support troops (logistics, MEDEVAC, and other Warfighting functions) as well as to improve units coordination. At the operational level, the value gained from experience led to the acceleration of the decision-making process, thereby improving mutual understanding among allied forces. This experimental mission planning service relies on two main software components:

- the CERDEC[1] Mission Command Gateway (MCG) architecture (see (Mayk et al. 2011) for related works), taking into account near real-time multi-media situation awareness and readiness status from the tactical edge entities (Vehicles, unmanned vehicles, dismounted infantry)(Mayk et al. 2011). MCG allows a set of commanders to draft coordinated mission plans collaboratively, to submit to their hierarchy and to commit once they are consistent.
- ORTAC planning tool, which combines constraint solving techniques with advanced search strategy in order to solve, optimize or deconflict plans automatically. ORTAC is wrapped into a Web Service (WS) to be activated automatically or on-demand during the experimental collaborative planning process.

Previous experiments were bilaterally conducted between the USA and France as well as between the USA and Germany at Fort Dix and between USA and Germany at Roethenbach. These experiments highlighted the benefit of operational Web Service, automated decision support, and assessed shared awareness involvement in the joint tactical planning processes. Current operational policies mandate interoperability at the brigade and possibly at the Battalion level. Nevertheless, research projects, nationally and jointly conducted under Project or Technical Arrangements have explored new ways to manage tactical interactions at lower echelons. For instance, the German (GE) project SPRINT,

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the US project Mission Command Gateway (MCG), and the French (FR) demonstrator TACTIC merged into one multinational (GE/US/FR) experiment named *From Data to Decision*. It marks the conclusion of five years of experimentation efforts conducted in Germany, USA and France under bilateral agreements. Initial projects were all focused on new information technologies to support commanders interactions at the tactical level during combined joint operations. In order to provide live data and to represent lower echelons, the experiment integrated the German Vetronics/Systronics Demonstrator called "SAMSON", as well as German tactical Unmanned Aerial Vehicles (UAV). A french soldier platoon (using the system "FELIN") was also integrated, as well as an Unmanned Ground Vehicle (UGV) system. Results show the feasibility of seamless and effective end-to-end command, in spite of diverse international cultures and engineering methods.

The following section provides details on the operational context and the experimental framework developed in an international Limited Objective Experiment (LOE). The following two sections also provide an overview of the collaborative planning process, and a description of service architecture integration. Results are presented before concluding with the two remaining sections.

Operational Context

Operational Challenges

Two different practices can illustrate current collaborative planning methods. The first approach is to perform the planning process in a top-down manner using detailed battle command principles. The high level commands can provide resources and time constraints for all actions to include relevant timelines down to the squad or lowest tactical edge unit. The second approach is to perform the planning process more hierarchically whereby decisions are taken using the mission command principles. This means that a given command level gives objectives to the immediate lower level, abstracting away other lower level actions.

In both cases, the different plans may be conflicting or loosely coordinated. Therefore, elaborating a complex action plan can be difficult and may take a long time. Moreover schedule of events must be found in order to evaluate mission feasibility. Information on both plan and schedule are represented in an "Operational Order" (OPORD). The definition of an OPORD is the result of a collaborative task within the given Task Organisation. Of course, when unexpected threats or contingent events occur during the mission, the tactical situation is updated and both plans and schedules must be adapted. In general, the initial order is a brief warning order (WARNO) followed by a more detailed OPORD. The OPORD however may be overcome by events and the commander has to issue a fragmentary order (FRAGO) to replan and update any obsolete order along the chain of command.

When operating in coalition, initial plans and their subsequent updates must be shared, mutually understood and agreed, without ambiguity or erroneous data. Because of the difficulty of constructing operation plans in the right tempo, joint operation plans are all elaborated at the division level. This involves three different levels of complexity. Firstly, respective national plans must be consistent with the mission objectives, current positions, and global situation awareness. The commander must define an Axis of Advance (AoA) with safe routes, the Course of Action (CoA) and task / organize their own units. Secondly, at the international level, the different plans must not conflict with each others and some actions must be defined collaboratively. Conflicts can be resolved using temporal (e.g., timing conditions or scheduling constraints) and spatial (e.g., geographic boundaries and areas) constraints that are specified in the orders (OPORD or FRAGO). These conflicts generally result from different interpretations and understanding of the tactical picture. Lastly, information exchanges (situation awareness, plans, orders, reporting) must be consistent, in spite of heavy dataflows. For instance, in many cases, situation awareness is updated during the planning activity.

Echelon	Time for P&S decision	Nb of Units commanded
Division	6 to 8 hours	1500
Brigade	1 to 6 hours	300
Battalion	1 hour	70
Company/Squadron	5 to 15 mins	16
Team/Squad	second to 5 mins	4

Figure 1: Usual times for planning or replanning

The figure 1 gives a *rough* order of magnitude in terms of number of units and time to take OPORD or FRAGO decisions.[2] In both cases, planning and scheduling automation is required to facilitate and expedite decision making while alleviating commander and staff workload and related stress.

The goal of the experiment is to assess decision making delays, reduction of fratricide risks, and to improve mutual support among Joint and coalition units. Mutual understanding can be improved by automatically detecting and pointing out conflicting plans to the users.

Situation and Battle Order Example

In the scenario (see Fig. 2) the 4th International Brigade Combat Team (IBCT) is under US command, integrates FR and GE battalions (BN) as well as US support and logistic units. The OPORD is portrayed in this section.

Although for practical reasons, the experimentation is located south of Paris, the actions take place in a fictitious area for a peace keeping mission. Informally, the battle order is depicted in the following:

Opponent Forces: Opponent forces opposing 4IBCT consist of "LEXOVIAN" insurgents and militia. Primary enemy unit opposing 4IBCT is in the vicinity of ORY and MSY.

During the last 3 days, the LEXOVIAN have attacked several civilian areas, destroyed administration buildings and have ambushed peace keeping forces. LEXOVIAN Hostile forces include

[2]The battalion level combines multiple arms of land forces (artillery, cavalry, infantry, ...), while brigade level or "joint" is the upper tactical level, that also includes air and naval forces. Indeed, real data depends on the country and the mission.

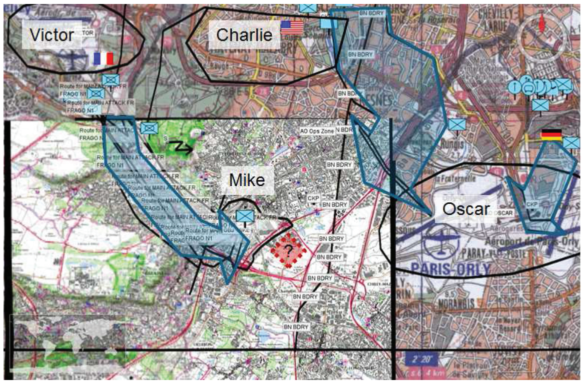

Figure 2: Graphical view of the operational order, friendly positions and friendly AoA definition in blue for the three FR / GE / US Battalion. Conflicts between two plans may occur at the boudaries of an AoA.

squad sized anti-coalition insurgent elements. Hostile operations focus on hit and run ambushes (rockets, snipers and light mortars) with pedestrian or pickup vehicles, from concealed positions in urban areas and heavily compartmentalized terrain. LEXOVIAN intention is to disrupt, delay and harass coalition forces. For that purpose, the opponents conduct Improvised Explosive Devices (IED) or direct convoy attacks, using hit and run attacks. In case of failure, they are able to apply indirect fire on the airport, on the civilian rescue collection area and BN Headquarters(HQ). The LEXOVIAN enemy opposing the 4IBCT is probably disseminated north and south of the axis between MSY and ORY.

Friendly Forces: Defined in terms of location, objectives (OBJ) and Area of Responsabilites (AoR). The Area of Operation (AO) includes AoR CHARLIE and VICTOR, objectives (OBJ) OSCAR, and MIKE.

- French mechanized INFantry (INF): (3) MECH BN(FR) Located in Velizy (AoR VICTOR)
- German infantry: (2) INF BN(GE) Located in 5kms west Massy north (OBJ MIKE)
- US infantry:(1) 1-44IN BN(US) Located 10kms north Orly (AoR CHARLIE).

Mission

In Order To (IOT) conduct the evacuation operation of civilian refugees from OBJ MIKE (in Massy) to OSCAR, the 4IBCT must

- Deploy and secure the area between AoR VICTOR and CHARLIE, OBJ MIKE and OBJ OSCAR.
- Organize 2 collection points for civilian refugees within OBJ MIKE.
- Reconnaissance and secure the axis from OBJ MIKE to OBJ OSCAR.
- Ensure convoy evacuation on road axis from OBJ MIKE to OBJ OSCAR

Liaison among OBJ OSCAR, AoR VICTOR, OBJ MIKE across the AO

Be Prepared To (BPT):

- Prevent LEXOVIAN attack in the AO and particularly route axis
- Evacuate civilian refugees to Airport in case of contingencies.

Execution

- Commanders Intent: IOT enable a fast and secured evacuation of civilian refugees, threatened by LEXOVIAN militia and insurgents, the 4IBCT favor an evacuation through OBJ OSCAR.
- Concept of Operation. The operation is conducted in Three (3) phases:
  1. Secure all deployment areas in the AO.
  2. Simultaneously: create two collection points for refugees, conduct reconnaissance (RECCE) missions and secure two axes from OBJ MIKE to OBJ OSCAR.
  3. From OBJ MIKE, ensure evacuation of civilian refugees and their safety up to the boarding in OBJ OSCAR.

BPT evacuate civilian refugees to Airport in case of security concerns.

Task to Manoeuvre Units

FRench MECHanized Infantry: 3MECH BN(FR)

1. From current positions, CONTROL OBJ OSCAR and main inbound axis. Conduct RECCE missions for all planned sites. SECURE hand-over Point; Deploy UAV and UGV for aerial surveillance and IED inspection.
2. PREPARE and COORDINATE with 2INF BN(GE) incoming convoys from OBJ MIKE. Conduct RECCE missions for all planned sites. Provide Liaison (LIAISE) with 2INF BN(GE). Duty 2 INF BN(GE) to ensure refugees collection on hand-over point.
3. PROTECT convoying in 3MECH BN(FR) AO and organize with local airport authorities civilian refugees boarding. BPT support convoy evacuation to airport in case of contingency.

GErman INfantry 2IN BN(GE)

1. From current positions CONTROL OBJ MIKE and main inbound axis. Conduct RECCE missions for all Planned Sites.
2. ORGANISE civilian refugees collection points on two distinct sites. Recce and secure two axis between OBJ MIKE and OBJ OSCAR. LIAISE with 3 MECH BN(FR). Duty 2 INF BN(GE) to protect dismounting of refugees on hand-over Point.
3. EVACUATE civilian refugees to OBJ OSCAR using road convoys onto two secured axes.

US infantry (1) 1-44IN BN(US)

1. ESTABLISH Main Supply Route from AoR VICTOR to OBJ MIKE. BPT to conduct MINE BREACHING in OBJ MIKE. BPT to conduct RECCE in OBJ OSCAR with LIAISE 3MECH BN(FR).
2. BPT permanently support 2INF BN(GE) and 3MECH BN(FR) in IED Destruction.
3. IOT protect joint forces after evacuation, On Order (O/O), clear obstacles on bridges on the national road in the AO.

Support Service

Support Concept, Material and Services are not detailed. Battalion Service provides all classes of supply to include field services in the AO and will establish the base GOLF in vicinity of OBJ OSCAR during Phase 3. Supplies will be pushed forward to Forward Support Companies. For Health Service Support, Battalion Medical Platoon will establish aid station within on phase 1 then on forward operation base OSCAR 2 during Phase II. Units need to coordinate mass casualty evacuation plans using non-standard evacuation assets. BN Medical Platoon will coordinate ambulance exchange points.

Collaborative Planning

A simplified and informal input specification can be expressed using terrain structure, initial conditions, mission objectives, unit capabilites and coordination constraints. The following elements are known off-line and characterize this input specification:

- Terrain structure is defined as a set of positions, related by progression axis. Each position has a geographical location and two adjacent positions are separated by a given distance.
- Initial conditions correspond to the resources initially available per unit, the initial positions of friendly and hostile units.
- Some of the positions can correspond to secondary or primary objectives, with mandatory actions.
- Unit capabilities are formulated using mobility constraints (the minimum and maximum possible speeds on a progression axis), actions that can be realised on a given position and resources required and consumed by a given action. Also, some positions or progression axes are more or less dangerous according to the unit.
- Coordination constraints, resulting from expected effects and Rules of Engagement impose synchronisations among units and to exscute actions in parallel.

Plan submission and commit process

The MCG distributed planning process allows any commander to draft a plan and to submit it to its own hierarchy. In turn, the hierarchy can commit the proposal or send some feedback by suggesting updates. Once all the plans of subsidiaries are committed, the hierarchy can issue orders, which are then propagated down to the chain of command in charge of national battalions. This collaborative planning approach faces two challenges. The first is that plans must be constructed concurrently to be efficient, and multiple access to shared variables are necessarily implemented in WS. The engineering must guarantee no deadlock and no "livelock". The second is that situation awareness is evolving during the planning process itself. Also, users must not be overloaded and must converge towards a shared operational solution. Therefore, beyond data consistency, this collaborative paradigm needs automatic support to reinforce plan coordinations and de-confliction in due course. The following paragraphs present an optimization approach to conflict resolution.

Mission planning model

The mission planning model has been widely presented in (Guettier 2007), (Lucas et al. 2010) and (Lucas and Guettier 2012). It can model basic infantry and cavalry actions such as maneuvres, observations, fire and logistics management. To be executed, each action must satisfy a set of preconditions (in terms of resources, timing and location). A logical coordination language enables synchronisation of the different units in time and space. In (Guettier 2007), three kinds of coordination logics have been demonstrated:

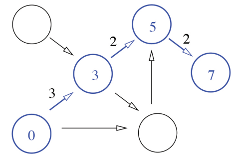

Figure 3: On the graph, blue edges are positive flows that indicate the planned route, and propagate operational metrics (time, resources)

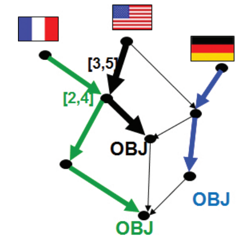

Figure 4: Assuming the blue route may conflict with the black one, respective passing dates must belong to safe intervals (resp. [2,4] and [3,5], with $W_x = 1$) to avoid conflicts

- Support action: a unit must execute an action on a location, if another unit can support it.
- Composite actions: two units perform two respective actions in the same time window.
- Exclusive actions: two units cannot perform two respective actions simultaneously (using an exclusive time window) on some predefined locations.

In the scope of this paper, extensions of the approach are presented to cope with conflicting itineraries among all units.

The terrain key positions and available routes are represented using a directed graph $G(X, U)$ where the set U of edges represents possible paths and the set X of vertices are navigation points (see Fig. 3). A vertex is denoted x, while an edge can be denoted either u or (x, x').

The itinerary of the mission plan is defined by the set of positive flows over edges. The set of variables $\varphi_u \in \{0, 1\}$ models a possible path from $start \in X$ to $end \in X$, where an edge u belongs to the navigation plan if and only if a decision variable $\varphi_u = 1$. The resulting plan, can be represented as $\Phi = \{u | \ u \in U, \ \varphi_u = 1\}$. From an initial position to a final one, path consistency is enforced by flow conservation equations, where $\omega^+(x) \subset U$ and $\omega^-(x) \subset U$ are outgoing and incoming edges from vertex x, respectively.

$$\sum_{u \ \in \ \omega^+(start)} \varphi_u \ = \ 1, \qquad \sum_{u \ \in \ \omega^-(end)} \varphi_u \ = \ 1, \tag{1}$$

$$\sum_{u \ \in \ \omega^+(x)} \varphi_u = \sum_{u \ \in \ \omega^-(x)} \varphi_u \leq 1 \tag{2}$$

Since flow variables are $\{0, 1\}$, equation (2) ensures path connectivity and unicity while equation (1) imposes limit conditions for starting and ending the path. This constraint provides a linear chain alternating flyby way points and navigation paths along the graph edges. We use a path length formulation (3) where variable D_x is expressing the time at which the unit reaches a position x (see example in Fig. 3). Assuming that variable $d_{(x',x)}$ represents the time taken to perform the maneuvre from position x' to x. The time D_x

cumulates action duration and navigation between two waypoints. We have:

$$D_x = \sum_{(x',x)\,\in\,\omega^-(x)} \varphi_{(x',x)}(d_{(x',x)} + D_{x'}) \quad (3)$$

$$\forall (x,x') \in U,\ d_{(x,x')} \in \mathbb{N},\ l_{(x,x')} \leq d_{(x,x')} \leq u_{(x,x')} \quad (4)$$

Bounds $u_{(x,x')}$ and $l_{(x,x')}$ are problem constants, occuring in (4, and may differ between two edges. If a unit does not take vertex x at all, then $D_x = 0$. As presented in previous works (Guettier 2007), coordination constraints and different cost functions can be adressed.

Conflict detection, plan and schedule resolution

Let i and j be two different units, they are conflicting when their passing date overlaps within a predefined window $[-W_x, W_x]$. A $\{0,1\}$ variable C_x acts as boolean to provide a global awareness for X on conflicting itineraries (see Fig. 4). The final cost function $\Omega(X)$ is the total amount of conflicts detected (6) for all nodes X.

$$C_x \Leftrightarrow \exists (i,j)$$

$$\left[D^i_x - W_x, D^i_x + W_x\right] \cap \left[D^j_x - W_x, D^j_x + W_x\right] \neq \emptyset \quad (5)$$

$$\Omega(X) = \sum_{x\,\in\,X} C_x \quad (6)$$

Search Strategy for deconfliction optimization

All problem formulations and search strategies have been implemented in the Constraint Logic Programming framework over Finite Domain algebra CLP(FD), with the SICStus prolog library. The search strategy relies on previous works in the same area (Lucas and Guettier 2012)(Guettier 2007) and uses a hybrid solving technique. It is a global search technique which guarantees completeness, solution optimality and proof of optimality for the end-user. It combines a global constraint-solving method with a stochastic approach in order to save the number of backtracks and to quickly focus the search towards the most promising solutions.

The first part of the algorithm consists in constructing a probe. It is an Ant Colony Algorithm (ACO) that solves a relaxed version of the initial problem(Lucas et al. 2010). ACO generates a population of ants through the state space and iteratively improves the search, based on a guiding heuristic and a collective memory model called *pheromone*. ACO generates a path for each unit, by relaxing scheduling constraints and conflicts.

The second part of the algorithm consists in designing the tree search according to the problem structure, revealed by the probe. Designing a good global search technique consists in finding the right variable ordering and value filtering, accelerated by the probe guidance. Once the solution to the relaxed problem is available, the probe construction consists of two steps. Firstly, a metric (e.g minimal distance) between problem variables and the solution to the relaxed problem is computed. The second step uses these results to sort problem variables in ascending order. At the global solving level, the relaxed solution is useless, but problem variables will be explored following this order. This method has polynomial complexity and still guarantees the global solver completeness. Then, the algorithm performs concurrent constraint solving over all problem variables, using Arc-Consistency (AC) techniques to reduce their domain. Here, all problem constraints are considered, including scheduling ones. The global search relies on three main algorithmic components:

- Variable filtering with correct values, using specific labelling predicates to instantiate problem domain variables. AC being incomplete, value filtering guarantees the search completeness.
- Tree search with standard backtracking when variable instantiation fails.
- Branch and Bound (B&B) for cost optimization, using minimize predicate.

The B&B minimizes the number of conflicts between plans, which corresponds to cost function $\Omega(V)$. The strategy favours timeline deconfliction, and therefore backtracks at first on timing variables. When all timing alternatives have been explored, the search explores routes alternatives by selecting conflicting edges using the probe guidance.

Experimental framework

The operational architecture emulates full international GE-US-FR command chains from the Brigade level down to the lower tactical level (squad). This command chain enables vertical communication of orders and reports. Battalion and Brigade commands were using the MCG tool suite, while company levels were using French and German experimental C2 software.

Operational organisation and related communications

The international brigade command involves three battalions: US, France and Germany and is depicted in Fig. 2. MCG instances were operated by the national battalion commander and the Brigade commander. MCG provides collaborative working functionalities to draft, share and commit on tactical data related to mission plans. MCG instances were used in combination with the ORTAC web service that provides decision support to the brigade staff. To represent operational activity on the field, two real sub systems were fielded and able to receive orders and to send reports in the command chain. Other simulated units were completing the friendly forces.

- The French system was representative of dismounted combat. French soldiers (led by a platoon leader) were equipped with "Felin" system and Deter UGV (able to report positions and to detect hostile fires). The platoon leader was equipped with a dismounted version of a C2 system. The Deter can detect shots and automatically prepare a report, to be controlled and sent by the platoon leader.

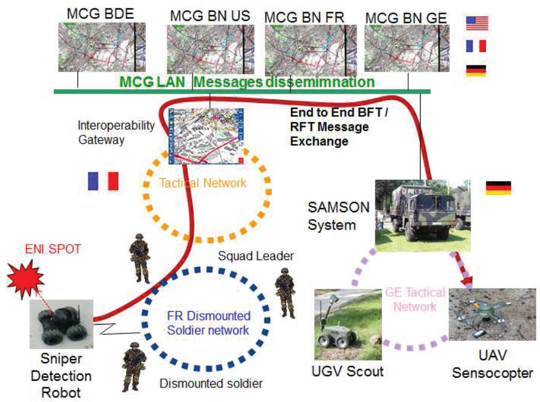

Figure 5: Networking architecture, includes three levels of networking: the Brigade / Battalion LAN, tactical network mainly for mounted units, UAV and UGV, as well as the platoon dismounted soldier network with robot.

- The German system was representative of mounted combat. German C2 system "Samson" was able to deploy and control a quadrirotor UAV as well as an observation UGV. Again these two systems can automatically prepare a report to be sent by platoon or company commanders.

In spite of many simplifications, the experimental operational architecture was representative of a complete brigade and below command chain. This architecture enabled the whole team to experiment with two main capabilities:

- End-to-end seamless information: tactical data (position, reporting, plans and orders) were shared on the fly by all members of the brigade staff ;
- Collaborative planning, including distributed decision support: tactical plans could be commonly elaborated, using decision support, shared and disseminated along the command chain.

To ensure end-to-end communications among actors at different echelon levels, an heterogeneous network has been deployed (see Fig. 5). It consists of tactical radio networks for French dismounted and German mounted systems. At the higher level, a LAN Ethernet Networks interconnects the different C2 systems. The French interoperability gateway and the German System are both connected to radio and wired network in order to disseminate and to filter messages to avoid network collapsing at the low tactical level. All these networks enable IP communications, which facilitates tactical message exchanges. Different types of traffics were supported by this network: multicast (used for alerts, position, tactical reports, and uncorrelated data exchanges, mostly passed over the air) and unicast (used for web service, plans and orders, mostly passed within the wired LAN). Note that multiple unicast traffics can also be occasionally generated.

Service Architecture Overview

The concept of Service Oriented Architecture concept is simple: a software application is divided into several inter-

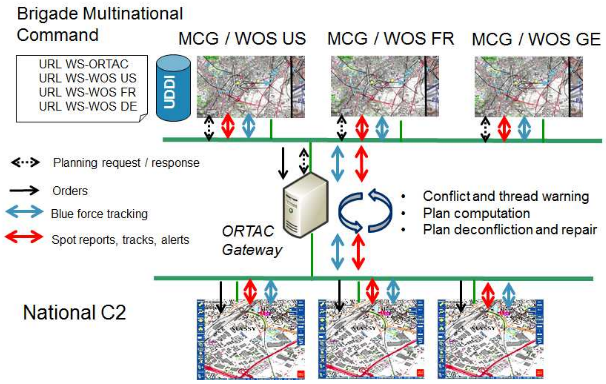

Figure 6: The service architecture, with communications with the gateway, situation awareness, and collaborative planning

operable and independent services. A service corresponds to a bundle of functions and is defined by its external interfaces or in other words a service is defined by a contract, which can cover different topics: input and output data models, service properties related to guarantees or quality, or service policies (e.g. the maximum time to respond to a request for a service). Independence of services is achieved through a loose coupling: to initiate and execute a service, it is not necessary to know the location and resources used by other services. A service discovery mechanism is used to dynamically initialize services parameters, configuration and localization at system/services startup. New services can be dynamically constructed by composing other services during the execution of the application.

Collaborative planning is performed at the multinational level. Plans can be checked automatically or on user demand by the ORTAC web service, which also acts as gateway with national chains of command. Data on both friendly (so-called "blue") position awareness and enemy (so called "red") are filtered and analyzed by the gateway. The ORTAC web service automatically detects dangers and potential conflicts in the different on-going plans.

The Workflow Orchestration Service (WOS) is a component of the MCG system. WOS manages the communication for internal and external services (see Fig. 6), bridges the gap between different technologies (publish/subscribe middleware, web services) and handles the data model. For this experimentation, WOS allows the following services interactions : ORTAC is activated through the MCG, by the user interface or automatically, resulting from the situation awareness analysis. Indeed, ORTAC automatically retrieves situation awareness data from MCG.

Situation awareness

During the mission, the tactical situation (friendly and enemy positions, AoA, AO, AoR,) evolves and needs to be shared within the brigade unit. In addition to having its own comprehensive data model to represent efficiently plans and orders as well as various tactical reports, MCG translates messages from one system format to another as required.

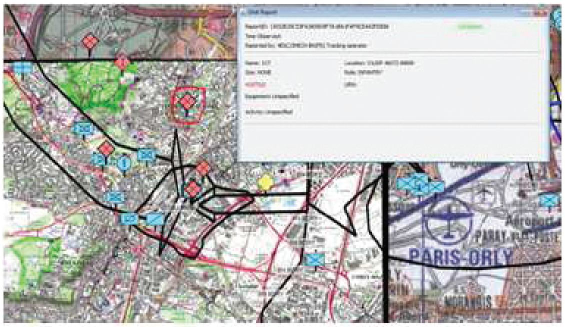

Figure 7: Situation awareness with blue positions and red spot reports.

Most messages consist of blue positions and observed red force position messages. In addition, MCG provides a rich set of overlay messages to include a wide variety of route reports. However, in contrast with blue positions, the French system handles tracks while US system handles uncorrelated spot reports for red force data. The experimentation showed that it is difficult to have these two different paradigms in a same command chain for different reasons:

- Spot reports (or uncorrelated tracks) have to be translated in red tracks and vice-versa.
- Using correlated red tracks instead of uncorrelated spot reports generates background traffic, which is a bandwidth overhead.
- User interpretation of red awareness and mindset are different when following tracks, compared to spot reports.

The differences in data semantic is representative of real interoperability problems, and in this specific case, we had to recast track representations in uncorrelated data. When the situation changes, essentially due to a spot report occurence, the command chain must replan some missions and issue FRAGOs. Spot reports may require to replan a complete route for an AoA, while avoiding conflicts with other blue coalition units (see Fig. 7).

Collaborative planning

Collaborative planning is achieved by allowing the concurrent drafting, obtaining feedback as well as final commitment of OPORD and FRAGO. ORTAC can be activated upon user request or automatically, when some conflicts or dangers are detected by the situation awareness modules (updated thanks to red spot report or/and blue positions). ORTAC provides decision support for planning, schedules and routes. It is parametrised automatically by other C2 systems data, through MCG. Main data are terrain structure, current positions of friendly forces, objectives, mandatory way points, spot reports as well as potential conflicts with existing routes or blue units. While drafting the plans, any user could request a route to actually fill the OPORD, for instance along an AoA. ORTAC optimizes route computation in order to minimize conflicts with other existing routes or to minimize mission completion time. But ORTAC also acts as an intelligent *gateway* and encapsulates the planning support functionality by passing route requests and answering a route response. The gateway also analyzes tactical situation to warn users or trigger replanning. It is designed as a multi-user web service, which can handle concurrent access to terrain, situation awareness, enemy and existing routes information. When requesting a route, the decision support functionality can automatically detect and resolve conflicts with existing ones. This functionally is of interest to prevent from conflicting plan that can yield fratricide fires. Red force data can also constrain routes computation either to be targeted (this has not been evaluated) or to find safe way points. The route request comprises:

- Starting and ending way points,
- Existing routes (already commited by users),
- Terrain trafficability information,
- Spot reports.

ORTAC web service shall be strongly persistent, since previous requests and commitments have to be considered while resolving a conflict or, for instance, when computing a new route along an AoA. This is a complexity overhead since additional constraints must automatically be added for route resolution.

Results

The experimentation by itself took 3 days of complete planning and execution activities from an initial OPORD to live FRAGO. The experimentation was involving some stimulating data produced by fielded systems. The resulting traffic matrix was dense, due to blue force position awareness which was generating a background many-to-many broadcast trafic. Network loads had no or limited effects on situation awareness updates and decision making latencies. The figure (8) presents the experiment execution for the second day (in about 5hours of experimentation), which is way below usual decision making timelines.

The ORTAC web service has mainly been used to define AoA associated to an order. Mandatory way-points were used occasionally, in particular to follow the shape of axis of advance. The figure (9) relates the number of planning requests with decision making. The figure shows that several trials are necessary before submitting and comitting on a planning successfully. Conflict detections and successful resolutions have been observed twice during the experimentation between 1-44IN BN(US) and 3MECH BN (FR) the second day and between US 1-44IN BN and 2IN BN (GE), the third day. To fully use the deconfliction schema in the collaborative environment, the concept of draft / issued route is important to trigger conflict detection and resolution. Solving time are compatible with end user expectation, although optimization of de-conflictions is more processor demanding. During the experimentation conflicting plans have been set up once and not detected by ORTAC, after changing a battalion AoR. This shows that the service is not sufficient to cover the whole deconfliction problem. During the entire experimentation period, the web service approach has also been showed efficient to dynamically parametrize ORTAC

H	**4 IBCT** **4 IBCT**	**OPORD Issue,** **Ambassy evacuation**
+1h00 +1h05	All BN FR MECH BN FR MECH BN	Planning Orders, OPORD Issue Recce Movement to OBJ OSCAR RECCE Spot Report
+1h10	**4 IBCT** **4 IBCT**	**FRAGO1 Issue,** **2 INF BN ambassy evacuation**
+2h10 +3h42	All BN GE IN BN GE IN BN	FRAGO Issue Move to link up point OBJ MIKE Spot Reports
+4h00	**4 IBCT** **4 IBCT**	**FRAGO2 Issue,** **2 INF BN ambassy evacuation**
+4h30	US 1-44IN BN US/FR FR MECH BN US 1-44IN BN	FRAGO Issue conflict resolved FRAGO Issue Movement to OBJ MIKE

Figure 8: The experimentation of day 2; the planning process follows BDE OPORD. FRAGO are issued whenever a mission is replanned. A conflict was detected and resolved between US and French battalions.

web service functionalities or to reconfigure its deployment through the WOS.

Day	1	2	3	Solving time
Planning (OPORD)	3	3	3	$< 0.5s$
Replanning (FRAGO)	4	4	2	$< 0.75s$
Deconflicts (FRAGO)	0	1	1	$< 30s$
Total ORTAC requests	18	22	25	

Figure 9: Planning activities: the three first lines show the number of time ORTAC is invocated and yields a decision (OPORD or FRAGO). The last line shows the total number of planning invocations.

Conclusion

This work represents a unique LOE since it defines a US - German - French command with a C2 integration at the Brigade and below levels for the first time in the history. Only very few works, such as (Allsopp et al. 2003), can be put in comparison. Compared to the 2010 experimentation (Guettier et al. 2011), new route deconfliction / resolution functionalities have been used. This function detects potential conflicts and guarantees space and temporal deconflictions of the new route with previous ones. Results may appear to be controversial with respect to current operational doctrines. Nevertheless, from the technical point of view, the experimentations among our three nations demonstrated the feasibility of this new approach, on the basis of innovative services. The Brigade could improve its mission command process by significantly reducing the data-to-decision delays, and better than todays practice. Moreover, soldiers safety, operational coordination, and deployment costs strongly depend on such tactical interactions. Further work should be pursued to extend the approach, integrate with deployed tactical systems for practical evaluations, as well as tackle the cyber security information assurance issues. This three year iterative experimentation in a field environment in an operational context with live assets, has shown our ability to develop successful multinational cooperation on the basis of multiple bilateral Project Agreements or Technical Arrangements.

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