A C2 Framework for Dynamic Battlespace Resource Management Based on Networking Concepts and a 'Post and Smart Pull' Approach

C4ISR/C2 Architecture

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Abstract

The effective networking of the warfighting enterprise enables Network Centric Warfare (NCW) concepts to be developed, namely the capability for self-synchronization and direct collaboration between battlespace entities, increasing the operational effectiveness. One of the advantages brought by self-synchronization is the potential for a more efficient use of often scarce resources at the force's disposal, by allowing faster responses to battlespace developments and thus a more effective exploitation of fleeting opportunities. However, care must be taken to limit the required information flows (transactions) between decision entities by means of appropriate tools and procedures, otherwise self-synchronization may lead to extra burden of decision entities with the consequent inefficiency in the accomplishment of time-critical tasks. This paper presents a C2 framework that facilitates self-synchronization through dynamic allocation and tasking of resources. By extending the *post and smart pull* concept to the management of resources other than information (e.g., ISTAR assets, warfighting platforms, formations, etc.), the proposed C2 framework allows a seamless and efficient transfer of resources between friendly battlespace entities for employment where they are in greater to respond more promptly and effectively to opportunities and contingencies.

Keywords

Network Centric Operations, Network Enabled Capability, Self-synchronization, Dynamic Resources Management, Communication Networks QoS.

Introduction

Information Age warfare will be characterized by the decoupling of sensors, actors and their carrying platforms, increasing the connectivity among these entities as well as with decision makers, allowing every entity to access information generated by any other entity within the warfighting enterprise. However, information is not the only resource required for mission accomplishment. Other resources cannot be easily or timely replicated and thus must be allocated with care in order to maximize the guarantees of successful mission accomplishment. Command in the Information Age involves creating all the conditions for success, including the selection of a vision (desired endstate), and associated goals, the development of objectives, the setting of priorities, the allocation of resources, and the establishment of constraints. These must be allowed to change and adapt as the battlespace evolves. In order to allow a more effective dissemination of congruent command intent, command should be exercised in a decentralized way. On the other hand, control should be kept as flexible as possible, increasing responsiveness to contingencies and opportunities arising in the battlespace [1].

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[1] D. S. Alberts et al, '*Power to the Edge*'. CCRP, DoD, Washington DC, USA, 2003.

As stated above, resource allocation is intrinsic to the command process and thus becomes dependent on the operational plan agreed by the deciding actors. When a contingency or opportunity arises that was not planned for, collaborative processes must take place to adapt the plan to the new battlespace operational situation, which may include the establishment of new resource assignments. However, collaboration is shown to have a cost in terms of decisionmaking time – specially when decisions must be made under stress[2] – which makes it is desirable to increase the capability for self-synchronization, and to minimize the number of collaborative interactions. Ways to achieve this objective rely on extensive training, development of flexible plans, increased contingency planning, as well as the development of appropriate collaborative tools and processes that increase the quality and efficiency of interactions between decision entities. The Web-based Battlespace Resource Management (WBRM) framework proposed in this paper integrates all these elements to achieve dynamic battlespace resource management with minimum cost as far as the operational situation is kept within well-defined bounds.

The basic principles of the proposed WBRM framework can be better grasped by looking at the way the Information resource is disseminated in a networking environment. The Web-based *post and smart pull* approach frees the information owner from having to know the identity and specific needs of the information consumer, at the same time enabling the latter to choose the nature and source of the information he needs[3]. Although the information owner and consumer are in fact collaborating on the process of information dissemination, this collaboration requires a minimal degree of interaction between participants, making it more efficient and thus leading to an increase of operational "tempo".

The proposed WBRM extends the *post and smart pull* approach to encompass the on-demand allocation and task organization of physical domain resources such as Intelligence Surveillance Target Acquisition and Reconnaissance (ISTAR) assets, processing nodes, weapons, platforms, force structures, etc. A good example for the urgency and usefulness of the WBRM framework is the realization of the ISTAR C2 Model proposed by Graham Le Fevre [4]. In order to allow the tactical level of command to benefit from investment in operational and strategic systems, while enabling tactical assets to be employed and exploited at best effect, this model allows ISTAR assets to be controlled/tasked from levels of command that stay above and below the levels of command to which they are organic. This model could be straightforwardly integrated in a WBRM instantiation. But the possibilities behind WBRM go much further allowing the implementation of resource management policies across all domains of the warfighting enterprise.

Definition of Web-based Battlespace Resource Management

The main WBRM procedures are illustrated – albeit in a simplified way – in Figure 1. The WBRM Core is embedded in the warfighting enterprise infostructure, such as the Global Information Grid (GIG) in development by the U.S. DoD. The WBRM Core serves as main repository and access controller of battlespace resources. In the example, at some point in time, the Headquarters (HQ) of unit **u2** decides that its organic UAV (**a1)** shall be consigned to the reserve. From its WBRM application front-end, the commander of **u2** places the UAV in reserve notifying the WBRM Core by means of a POST procedure/command in which the UAV is properly identified. The WBRM uses this information to place the UAV in standby mode, as part of the global resource repository. Some time later, the HQ of unit **u3** independently decides that an organic battery (**f1)** and a spare robotic reconnaissance vehicle (**r1)** shall be consigned to the reserve and its commander orders the respective POST procedures/commands. Later on, during the pursuit of its currently assigned objective, the HQ of unit **u1**, having all of its organic force committed, finds out that it needs extra artillery fires (one battery in size) to perform a deep strike on enemy rescue forces behind the enemy's frontline, which should be assisted by an extra reconnaissance platform used to better monitor the effect of those artillery fires. From its WBRM application front-end, the commander of **u1** finds that UAV **a1** and battery **f1** are in standby mode in reserve and that the HQ of **u1** has the required privileges to allocate and use them. The commander of **u1** summons those resources by means of a PULL procedure/command. The WBRM Core automatically task organizes **u1**, placing **a1** and **f1** in its Order of Battle (OOB) and hence under direct control of **u1**'s HQ. Once those

[2] D. S. Alberts et al, '*Command Arrangements for Peace Operations*'. National Defense University Press, Washington DC, USA, 1995.

[3] See footnote 1.

[4] D. Potts, '*The Big Issue: Command and Combat in the Information Age*'. CCRP, DoD, Washington DC, USA, 2004 (reprint). The ISTAR C2 Model is proposed in chapter 11.

resources cease to be needed for **u1**'s mission accomplishment, or when the allowed time budget or force expenditure rates are used up, **a1** and **f1** are again POSTed to the WBRM resource repository, allowing their allocation by other decision entities.
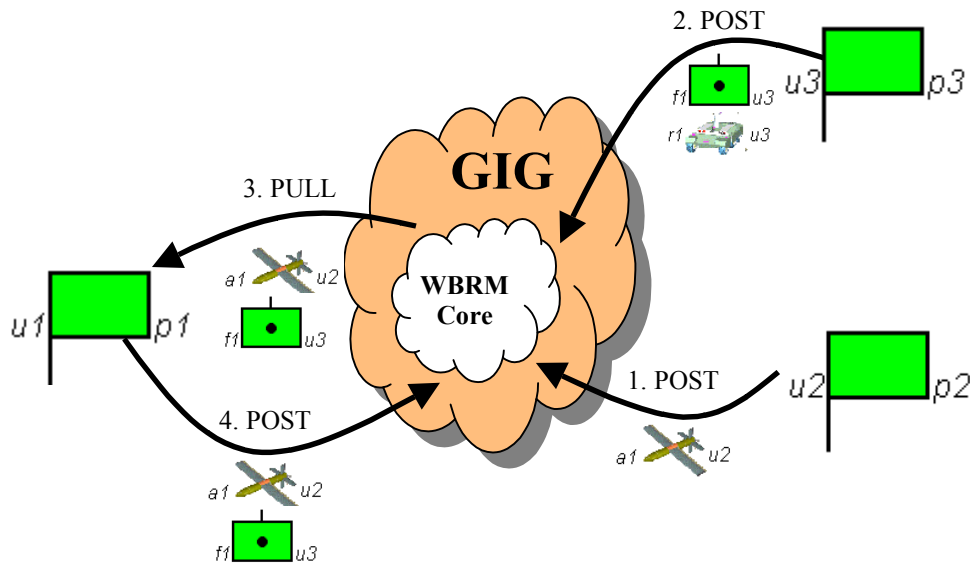
Figure 1. The WBRM *post and smart pull* approach to battlespace resource management.

As illustrated in the example, WBRM allows resource allocation adjustments to be performed by resource consumer decision entities transparently to other decision entities, without significant collaboration overhead, allowing each decision entity to concentrate on its specific objectives. The straightforward and efficient way in which battlefield resources are shared is reminiscent of Web-based information sharing. However, some important differences apply, which must be borne in mind:

1. Physical domain resources have only one instantiation and cannot respond to more than a limited number of tasks at a time. This brings the issue of access deconfliction, which must be resolved by mechanisms such as prioritization, preemption and time-sharing.

2. Physical domain resources are usually subject to expenditure/degradation, loosing capability due to attrition, supply constraints/limits and/or other factors. This expenditure may be reversible or not. This in turn brings the need to limit the expenditure of the available resources on behalf of each user in a way that maximizes the overall performance of the force (as an analogy, we can compare this to the maximization of the returns for a given investment).

3. Physical domain resources are subject to physical domain constraints and overheads. These may significantly affect opportunity time-windows, resource availability and performance in the accomplishment of the assigned tasks. They have also implications on the resource's task commitment status (e.g., a resource can be assigned to the reserve, tasked, maneuvering, acting, engaged, suppressed, disbanded, etc.), which can further constrain re-allocation and re-tasking.

In some way this makes WBRM more akin with the e-Commerce paradigm, where constraints are imposed by the limited product availability and need for shipping arrangements. In fact, the WBRM system offers a storefront where decision entities are able to browse and to allocate/deallocate battlespace resources to/from their operational shopping chart with the same ease that ordinary users are able to browse, buy or sell products at a virtual store. The analogy goes as far as to allow operational costs and allocation/deployment overheads in the battlespace to be comparable with product costs and shipping overheads in a virtual store.

The flexibility that is inherent to WBRM implies that decision entities are themselves resources that can be explicitly or implicitly allocated and used by other decision entities (e.g., if the resource is a company unit, it is implicitly associated in a permanent and inextricable way with the respective company HQ). However, the system should keep track of and take into account echelon relationships, limiting the available degrees of freedom. As an example, it should not be possible for a given company HQ to automatically allocate and task an entire division, brigade, battalion or company. However, depending on the configured resource management rules, that company HQ could be allowed to automatically allocate

and task a platoon or smaller formation that is organic to its or other division, brigade, battalion, or to another company. In this way, WBRM allows the force to be tailored beforehand to operate in any configuration, spanning from a traditional strict hierarchy to a totally flexible and dynamic hierarchy where decision entities at one level have unconstrained access to all resources at the levels below. This also brings new flexibility to the employment of "reserves" because in WBRM reserve resources can be allocated on-demand and shared by a set of decision entities according to battlespace evolution, instead of being a priori subordinated (as per the operations order) to specific decision entities.

There are also situations where the allocation of one resource can only make sense when accompanied by the allocation of other resources to form a coherent mission package, establishing resource allocation dependencies. When several users simultaneously try to allocate resources from the common resource pool, conflicts may arise that lead to mission package incompletion with consequent inefficiency due to resource reposition overhead or allocation inconsistency towards command intent. The WBRM system should be able to cope with this issue by supporting atomicity of mission package *pull* transactions, where the *pull* transaction is aborted and all its resources are automatically left free if any dependency is not satisfied during its execution.

Architecture of the WBRM System

A possible WBRM system architecture is depicted in Figure 2. Decision entities use Web browsers to access WBRM Web Sites, through which they interact with the WBRM Core. The latter is represented by a cloud.
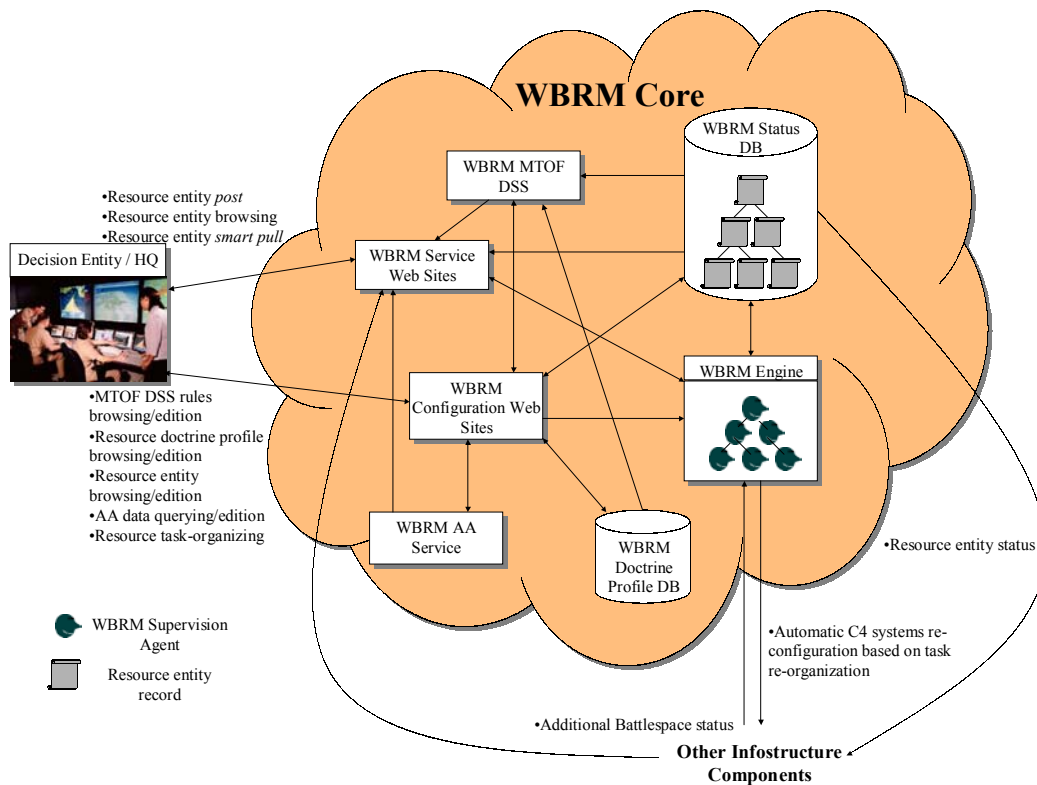
Figure 2. Reference model of the WBRM architecture.

This architecture borrows Data Warehousing concepts and comprises the following main elements:

- **WBRM Authentication and Authorization (AA) Service.** This service defines the privileges of decision entities to access the WBRM services, keeping AA data about each decision entity. Authorization data defines what services a decision entity can access at WBRM Service Web Sites and WBRM Configuration Web Sites, and which resources and databases the latter can affect.

- **WBRM Mission Task Organized Force (MTOF) Decision Support Service (DSS).** This system provides decision support on the choice of mission packages to accomplish a given mission task. This is done taking into account the currently available resources, whose

information is retrieved from the WBRM Status Database (DB). The WBRM Service or Configuration Web Sites can use it to assist or even automate the processing of decision entity requests.

- **WBRM Doctrine Profile DB.** This is the repository where the resource allocation and usage rules are kept (see below). The WBRM Doctrine Profile DB is distributed for redundancy and scalability reasons, but it appears as a single and coherent entity. A number of resource entity doctrine profiles is defined, each profile containing an independent set of rules that specify the following:

    o Resource doctrine profile identifier (unique).

    o Resource qualifier stating whether this kind of resource is a decision entity (see below).

    o Assigned echelon for resources of this doctrine profile within the force's hierarchy.

    o Rules that further constrain the allocation and usage of resources with this doctrine profile by other decision entities in a quantitative way, i.e. the allocation and usage budgets.

    o Rules that further constrain the allocation and usage of resources with this doctrine profile by other decision entities in a qualitative way, i.e. the allowed forms of use.

    o Rules of Engagement (ROE) that delineate the circumstances and limitations under which the force constituents (resources, which can be or not decision entities) will initiate and/or continue combat engagement with other forces encountered[5], translated in WBRM as specific resource allocation and usage rules that can override all other rules depending on the mission or operational situation.

    Moreover, if this profile defines resources that correspond to decision entities, the following information should also be present:

    o Rules that further constrain the quantity and quality of resources that this kind of decision entity can allocate and use, i.e. the allocation and usage budgets.

    o Rules that further constrain the ways that resources in general can be allocated and used by this kind of decision entity.

    The existence of doctrine profiles greatly simplifies the configuration of the WBRM system, as they avoid having to configure resource management rules separately for each resource.

- **WBRM Status DB.** This is the main WBRM information repository, where a snapshot of the internal status of the resource entity supervision agent (see below) is kept at all times for sake of access efficiency. The WBRM Status DB is also distributed for redundancy and scalability reasons, but it appears as a single and coherent entity from the WBRM Engine point of view. A resource entity record should encode the following data:

    o Resource identifier (should be unique across the entire span of the warfighting enterprise).

    o Reference to the resource's supervision agent running in the WBRM Engine (see below).

    o Resource description.

    o Resource's doctrine profile.

    o Identifier of the decision entity that is its owner by default (it may be useful to rule configuration privileges).

    o Allocation and commitment status, including the identifier of the decision entity or entities to which it is currently allocated (if any).

    Moreover, if the resource is itself a decision entity (which is stated in its profile) the following information should also be present in the respective record:

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[5] U.S. DoD, '*Department of Defense Dictionary of Military and Associated Terms*'. JOINT PUB 1-02, U.S. DoD, 23 March 1994 (as amended through 7 December 1998).

o   Decision entity's currently assigned priority.

- **WBRM Service Web Sites.** These Web sites constitute the service access points for decision entities. The WBRM Service Web Sites interact with the WBRM AA Service in order to authenticate and obtain the required authorization on behalf of the requesting decision entity, after which browsing, *post* and *pull* requests can be executed. For resource browsing requests, these Web sites interact with the WBRM MTOF DSS, WBRM Status DB, the WBRM Engine and other infostructure components to gather information about resources, filtering it according to user parameters/constraints and then packaging and presenting it to the user in a suitable format. For *post* and *pull* requests, the WBRM Service Web Sites interact directly with the resource supervision agents running in the WBRM Engine, whose references are obtained from the WBRM Status DB. All these functions can be assisted or even automated by consulting the WBRM MTOF DSS, which can suggest mission packages that are best suited to accomplish the mission task assigned to the requesting decision entity.

- **WBRM Configuration Web Sites.** These Web sites are used by authorized decision entities to configure and tailor the WBRM system according to current command intent. They serve as mediators between decision entities and the WBRM Engine for the creation, edition, deletion and task organizing of the respective supervision agents (see below), as well as the management of the WBRM MTOF DSS, management of the WBRM Doctrine Profile DB, and the management of authentication and authorization data at the WBRM AA Service.

- **WBRM Engine.** This distributed processing system runs special service agents called resource supervision agents. Each configured resource entity is represented by a supervision agent that actively exercises resource allocation and usage control on behalf of that resource. Supervision agents are themselves organized in a logical hierarchy that mirrors the C2 hierarchy of the resources they represent. Their autonomous processing functions are carried out based both on internal status (which includes the resource entity record, WBRM doctrine profile, as well as other time varying information) and additional battlespace status retrieved from infostructure components external to the WBRM Core. As already mentioned, supervision agents also keep a snapshot of their internal status updated at the WBRM Status DB. Processing of requests received from WBRM Service Web Sites may change the task organization and the allocation of resources, which is reflected in the hierarchy of supervision agents. In this case, supervision agents are responsible for the re-configuration of other C4[6] systems (possibly by means of other specialized service agents operating elsewhere in the global infostructure) in order to materialize the exercise of C2 according to the changes introduced in the resource task organization. It should be noted that supervision agent creation and deletion are triggered by the WBRM Configuration Web Sites, closely following the creation/deletion of the resource entities they represent.

## Networking Approach to Battlespace Resource Management

The limited availability of battlespace resources may at times be greater than demand, which brings the need to distribute resources according to a mission set of resource management rules. In the architecture proposed above, these rules are defined in the WBRM Doctrine Profile DB and constitute an intrinsic part of the internal status of supervision agents.

Some of the issues encountered in WBRM resource management are also found in a networking context. Although the precise definition of resource management rules is left for future work, the networking Quality of Service (QoS) paradigm may provide invaluable hints to the kind of resource management rules and algorithms that can be used in a WBRM system. Lets first consider a typical scenario where a set of user sessions have the mission task of transmitting locally generated multimedia streams (formed by constant or variable size data packets) to a server node through a network interface (see Figure 3).

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[6] C4 is the acronym of Command, Control, Communications and Computers and can be used to define the complete set of both decision making and infostructure entities.
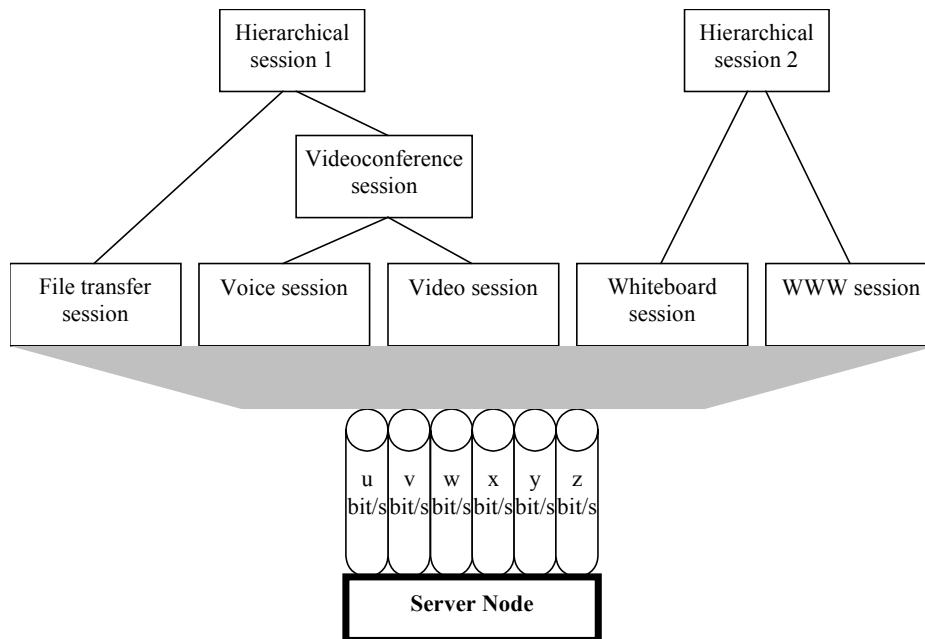
Figure 3. Networking scenario where multimedia data sessions contend for the limited available resources (bandwidth-limited communication channels) in order to transmit their data packets to a Server Node.

The user sessions can be organized hierarchically since composite sessions can be formed by a number of subordinate aggregate or elementary sessions. The channels that compose this network interface are characterized by a limited amount of bandwidth that corresponds to a given data rate, variable over time. Each of the user sessions can allocate one or more channels at a time, being able to transmit its packets at the aggregated data rate that results from the sum of the data rates of individual channels. Furthermore, each traffic stream has its own set of QoS requirements/constraints for the transmission of its packets, defined by a set of QoS parameters. Some of the most commonly used QoS parameters are the following[7]:

- *Mean Rate.* This defines the expected amount of data that will be generated by the session per unit time. It is usually enforced by a Token Bucket[8]. Its battlespace counterpart is the average amount of battlespace resources/capability required by a decision entity to successfully accomplish its mission.

- *Peak Rate.* This defines the expected maximum amount of data that will be generated by the session per unit time. Like the Mean Rate, it is usually enforced by a Token Bucket. Its battlespace counterpart is the maximum amount of battlespace resources/capability that a decision entity will need to simultaneously allocate during mission accomplishment.

- *Delay Bound.* This defines the absolute maximum delay that a packet may experience from the time of its generation at the user session, to the time when it is successfully received by the server node. Packets whose overall transmission time violates this figure are discarded and contribute to the overall packet loss count. The transmission delay of packets can be decreased at the cost of more bandwidth. Its battlespace counterpart is the time-span of a window of

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[7] A. Grilo, *'Quality of Service in IP-based WLANs'*. PhD thesis, Instituto Superior Técnico, Technical University of Lisbon, June 2004.

[8] The Token Bucket abstraction defines a structure that is filled with tokens/permits at the Mean Rate (ρ) and has a Maximum Size (σ). The transmission of an amount of data causes a corresponding decrease of the amount of tokens in the Token Bucket and the traffic source is only allowed to transmit until the Token Bucket becomes empty. When the traffic source transmits with a data rate that is lower than ρ for some time, the Token Bucket may become full, in which case excess tokens are discarded. From these definitions results that the maximum amount of data that can be transmitted during time interval t by a Token Bucket controlled source is $\rho \cdot t + \sigma$.

opportunity arising in the battlespace, i.e. the time interval within which enough resources must be assigned to allow the decision entity to successfully exploit the opportunity.

- *Priority* or *Precedence.* This parameter is normally related with the *Delay Bound*, but defines a relative rather than absolute delay constraint i.e. high priority packets should be transmitted earlier than low priority packets, thus experiencing lower delay. Another function of this parameter is to serve as a criterion for packet transmission preemption, which is specially important in military networking QoS [9]. The battlespace counterpart of priority is the order of assignment of shared resources when there is simultaneous demand (e.g., priority of fires of the Field Artillery component of a Brigade Combat Team as expressed in the operations order). Additionally, it also constitutes the criterion for the preemption of battlespace resource usage, aiming at the exploitation of high payoff opportunities in detriment of lower payoff ones.

- *Packet Loss Ratio.* This parameter specifies the probability of packet loss. Its battlespace counterpart is the probability of failure to exploit arising opportunities.

- *Maximum Transfer Unit.* This parameter establishes the maximum size of packets generated by a traffic source. The greater the packet size, the greater the number of channels required for transmission within the *Delay Bound*. Its battlespace counterpart is the expected maximum challenge presented by any arising opportunity.

- *Instant Data Rate* (of a Channel). This parameter represents the data rate offered by a communications channel. This may vary over time, depending on physical factors (e.g., fading or path loss in radio communications). The greater this parameter is, the lesser the number of channels required to transmit the packet within the *Delay Bound*. Its battlespace counterpart is the amount of remaining capability in a battlespace resource (e.g., unit strength, available ammo, etc.).

We are now ready to understand the parallel between network and battlespace resource management, which is summarized in Table 1.

Table 1. Equivalencies/similarities between network and battlespace resource management.

Network	Battlespace
Successful data transmission	Successful mission accomplishment
Packet	Opportunity
User sessions	Decision entities
Channels	Battlespace resources that are not decision entities
QoS Policy	Battlespace resource management doctrine
Mean Rate	Average amount of resources/capability required by the decision entity at any time instant taking into account the expected probability, challenge and window of opportunities
Peak Rate	Maximum amount of resources/capability required by the decision entity at any time instant taking into account the expected probability, challenge and window of opportunities
Delay Bound	Window of opportunity
Packet/Session priority	Opportunity/Mission priority
Maximum Burst Duration	Maximum interval within which the maximum amount of resources/capability can be allocated

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[9] E. Olaussen, A. Karlsen, "A Policy-Based and Precedence Framework for Military IP Networks". Proceedings of the AFCEA/IEEE Military Communications Conference 2004 (MILCOM'2004), Monterey, CA, Oct.-Nov. 2004.

Packet Loss Ratio	Probability of missing an opportunity arising in the battlespace due to lack of available resources/capability
Maximum Transfer Unit	Expected maximum opportunity challenge, and by extension the respective resource requirement for successful seizure
Instant Data Rate	Amount of capability remaining in a battlespace resource

QoS parameters like those defined above constitute the input to the admission control (i.e. network resource allocation) and packet scheduling algorithms found in the networking context[10]. All these algorithms try to maximize the utilization of network resources while taking into account factors like priority and fairness. However, while network resource management has usually to deal only with bandwidth (sometimes power consumption as well), battlespace resource management has to deal with a much greater diversity of mission tasks, resources, faced opportunities and contingencies. In fact, some battlespace resources (e.g., satellites, JSTARS, etc.) are scarce or even unique in a theatre of operations, requiring special care in terms of allocation and tasking. Unlike in network resource management, the issue is not only about the amount of resources allocated by specific decision entities, but also which specific resources are allocated, for what purpose, for how long and at what cost. Anyway, network resource management algorithms can still provide useful hints on the way the WBRM Engine can be instructed to autonomously arbitrate and manage resource allocation and usage.

The allocation of resources starts with a request from a decision entity to a WBRM Service Web Site. The quantity and quality of requested resources may be the result of an a priori analysis of the battlespace status by the requesting decision entity. Otherwise, it may be the result of WBRM MTOF decision support taking into account the counterparts of the *Delay Bound* (window of opportunity), packet size or *Maximum Transfer Unit* (estimated challenge presented by the opportunity), *Packet Loss Ratio* (probability of failure to exploit the opportunity), *Instant Data Rate* (estimate of capability that remains in each available resource), as well as information related with battlespace status, allocation and tasking overheads and resource availability, which is constrained by the doctrine rules.

In either case, the allocation of a resource establishes a bi-univocal relationship between the allocated resource and the allocating decision entity. A request for the allocation of a battlespace resource must be validated by the WBRM Service Web Site, which accesses the WBRM Status DB and performs "admission control" verifying the following sets of doctrine rules (please refer to the description of the WBRM Doctrine Profile DB presented above):

1. **Rules that constrain in a quantitative way the allocation of a specific resource by decision entities.** This kind of rules should be related with *Priority*, echelon, resource status, and the absolute or relative accumulated usage of the resource by each decision entity. The following are simple examples of this kind of rules, where *d* represents the requesting decision entity and *r* represents the requested resource doctrine profile:

    a) $priority(d) \geq p$, where *p* is a priority threshold.

    b) $echelon(d) > Brigade$.

    c) $status(r) = reserve$, where the function $status(r)$ indicates the allocation and commitment status of *r*.

    d) $capability\_loss(r,d) < 30\%$, where the function $capability\_loss(r,d)$ indicates *r*'s overall capability expended under the control of *d*.

    e) $time\_share(r,d) > 1.2 \times average\_time\_share(r)$, this is a fairness enforcing rule where the function $time\_share(r,d)$ indicates the total time in which r was under the control of *d*, and the function $average\_time\_share(r)$ indicates the average time in which *r* was under the control of any requesting decision entity.

[10] For a general introduction to networking issues: S. Keshav, '*An Engineering Approach to Computer Networking*'. Addison-Wesley, USA, 1998.

2. **Rules that constrain in a qualitative way the allocation of a specific resource by decision entities.** This kind of rules imposes limitations on the form the resource can be tasked by decision entities, e.g. maneuvering tasks, call for fire tasks, etc.

3. **Rules that constrain the quantity and quality of resources that a specific decision entity can allocate.** This kind of rules should deal with the battlespace counterparts of *Mean Rate* and *Peak Rate*, i.e. they control the amount of resources that the requesting decision entity can allocate over time. The following are simple examples of this kind of rules, where d represents the requesting decision entity and r_i represents the resources that compose the requested mission package:

   a) $\left[capability(d) + \sum_i capability(r_i) \right] < max\_capability(d)$, where the function

   $capability(\text{r})$ returns a normalized estimate of the capability remaining in a resource r, and $max\_capability(d)$ indicates the maximum capability that d is allowed to have under its control at any time instant.

   b) $token\_bucket\_time\_remaining(capability(d) + \sum_i capability(r_i)) \geq MTAT$, where the

   function token_bucket_time_remaining(c) indicates the time interval within which the overall capability c (current plus requested) of d can remain under its control, and *MTAT* is the estimated mission task accomplishment time.

4. **Rules that constrain in a qualitative way the allocation of resources in general by a specific decision entity.** This kind of rules imposes limitations on the forms in which the resources can be tasked by the decision entity, e.g. maneuvering tasks, call for fire tasks, etc.

5. **ROE that can override the rules of types 1, 2, 3 and 4 depending on the mission or operational situation.** This facilitates WBRM configuration and maintenance, allowing rules of types 1, 2, 3 and 4 to be defined in a more general and static way, while ROE can tailor WBRM doctrine to conform to specific missions.

When there is no contention and the resources are waiting in reserve, rule satisfaction is the only criterion for allocation. On the other hand, contention for the resources may lead to one of two situations:

1. The windows of opportunity associated with contending requests are compatible and the risk of capability loss over time is low enough. In this case, the requests may be multiplexed in time, sharing the resources and thus optimizing resource utilization.

2. The windows of opportunity associated with the contending requests are incompatible or the risk of capability loss over time is high enough to make time multiplexing nonsense. In this case, resources may be reallocated through priority-based preemption.

After a resource is allocated and the WBRM Engine is updated accordingly, control must be exerted to place limits over the usage of the resources. The supervision agents must ensure in real-time that the applying doctrine rules (e.g., rule 1.c ceases to apply after allocation, as the resource will surely change its tasking/commitment status) continue to be satisfied, triggering appropriate alarms and actions upon detection of rule violation. Supervision agents for owned resources shall typically supervise rules of type 1, 2 and 5 while supervision agents of owning decision entities shall typically supervise rules of type 3, 4 and 5. As a decision entity is usually tightly coupled with a resource, most supervision agents will have to supervise all types of rules.

When contending requests feature compatible windows of opportunity that allow them to be multiplexed in time, sharing some or all resources, the involved supervision agents may queue and serve the requests according to a priority aware Earliest Deadline First[11] based policy, triggering the required alarms or actions whenever the shared capability decreases and ceases to satisfy the demand.

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[11]Also designated Earliest Due Date. It consists of scheduling actions in ascending order of their deadlines.

WBRM and the Network Enabled Capability

As any other new concept, network centric operations are inspiring the academic and research communities, but are looked in a cautious way by the military, those that will have the responsibility to conduct them. A C2 framework for Dynamic Battlespace Resource Management based on networking concepts like WBRM will contribute to test those concepts and will promote its phased and gradual development aiming to improve force effectiveness.

Despite the revealed advantages of NCW tenets the military have to face the challenge of sustaining operations in a dynamic battlefield if the technological backbone fails. This thought introduced some cautions in the adoption of these concepts and have taken some countries like the United Kingdom to adopt the concept of Network Enabled Capability (NEC) instead of network centric force.

In fact, this approach can be considered an interim concept were the network centricity of the force can be limited to the exact extent that the current situation demands.

A decision can be seen as the selection of a Course of Action (CoA) in response to a situation. The commander (decision maker), based upon the necessary mission analysis can organize the available assets in mission capability packages that can be tailored to face a possible enemy CoA or operational outcome. This is like having different mission "spaces" that the force may have to face each of which is characterised by a different arrangement of forces and means.

Since the decision maker bases his decisions on perception of the situation, the information about the operational environment assumes a central role in the adoption of a specific course of action. The links between information nodes and decision nodes are also very important because an "Information Element Space" is associated with each CoA.

As time goes by, the commander's perception (estimate) of the overall situation will change and the degree of uncertainty may increase. Only the timely access to the right information will clarify his situation assessment and will help him to adopt the right course of action.

The quality of a network will be a function of information accessibility, network redundancy and the degree of existing information overload. Since redundancy will increase the overall information accessibility, information flow can be seen both as a cost and a benefit. According to Gardener, Moffat and Pernin (2004)[12] a network access cost[13] and an information overload cost[14] can be used as metrics to define an optimal network plecticity (the adequate information flow). This means that is also possible to define the desirable degree of force network centricity for each mission space or mission package. As shown in Figure 4 it is possible to optimize the degree of network centricity of a military force, based upon a quantitative assessment of information flows. For each mission "space" an optimal network centricity will enhance the quality of decision-making processes and will improve decision entities interactions with WBRM, which can therefore be used as a tool to evaluate and optimize the degree of network centricity.

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[12] T. Gardener, J. Moffat, and C. Pernin. "Modelling a Network of Decision Makers". Proceedings of the 9th ICCRTS, September 2004.

[13] The Network Access Cost can be defined as the "connectivity score based on the distance a piece of information must travel from source to decision maker" (Gardener et al., 2004).

[14] The Information Overload Cost is a "measure of the process time required to distinguish between needed and unneeded information" (Gardener et al., 2004).

Minimal information flow   Adequate information flow   Excessive information flow

Sub-optimal Network Centricity   Optimal Network Centricity   Sub-optimal Network Centricity
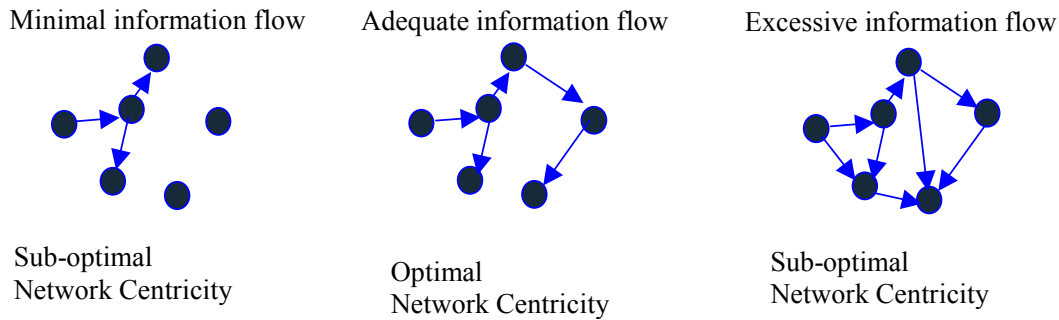
Figure 4. Network centricity as a function of a quantitative assessment of information flows.

Overall, in order to build a NEC the military should be aware that a Force that will adopt an adequate level of network centricity will very likely be more effective that a full network centric force. From a WBRM perspective, this can be also mapped to the degree of flexibility allowed for decision entity interaction with the WBRM and the managed resources. In the proposed architecture this flexibility can be limited by the rules defined in the WBRM AA Service and (in a finer grain) in the WBRM Doctrine DB. At one extreme, WBRM can enforce rigid battlespace resource assignments and even limit the degree of system re-configuration, defining static configurations that closely map the stove-piped hierarchies of the Industrial Age. At the other extreme, WBRM can bestow a fully flexible and dynamic battlespace resource assignment to an exceedingly self-synchronized network centric force. In the middle, WBRM can provide different levels of flexibility to the NEC that must be tested and evaluated in a mission-by-mission basis.

Conclusions and Future Work

This paper has presented a C2 framework for dynamic battlespace resource management, which is designated Web-based Battlespace Resource Management (WBRM). As the name implies, WBRM is based on Web technology, using a *post and smart pull* approach that borrows from e-Commerce concepts and practice its potential for operational use. WBRM allows resource allocation adjustments to be performed by resource consumer decision entities transparently to other decision entities, without significant collaboration overhead, as far as these adjustments remain within the bounds that are well defined by doctrine rules for resource management. The paper has tried to specify a tentative architecture model for the WBRM service, defining the main components that should constitute the WBRM Core, as well as the latter's interface with user decision entities. A proposal is made for resource management supervision by dedicated software agents that incorporate the WBRM doctrine rules and whose hierarchy mirrors the hierarchy of the warfighting enterprise task organization. The paper also proposes a network based approach for resource allocation and usage control, demonstrating that battlespace resource management follows principles that are similar to those found in network resource management.

Although WBRM brings many advantages, it also brings difficult challenges. Decision entities and the respective commanders cannot be allowed to fall in the selfish temptation to look at their partial mission objectives as unconditionally high priority in detriment of the overall command intent, allocating at all times the maximum amount of resources that can be at their disposal. Although this behavior can be controlled at the expense of less flexible resource management rules (and this may be required as long as doctrine and training are not well established), this is not a desirable solution. On the contrary, the main virtue of WBRM resides on the potential flexibility to exploit battlespace awareness to free resources where they are not needed, allocating them where they are decisive. This can only be leveraged by appropriate doctrine and extensive training. Consequently, doctrine must not only address the definition of the resource management rules encoded in the system, but also address the way decision entities and their commanders should make use of the system aiming at true collaboration.

Overall, this paper has only paved the way for further work, presenting the fundamental concepts for the specification and development of a WBRM system and required applications, establishing the necessary basis to test WBRM in both NCW and NEC options, with or without a full force network centricity. This process will be incremental, involving the definition of doctrine based on both current procedures and innovation backed up by extensive analysis and simulation studies. The latter shall be complemented with other forms of experimentation, namely the development and evaluation of tools that incorporate relevant subsets of WBRM concepts. Evaluation criteria and measures of merit will have to reflect the need to

achieve an operational optimal resources distribution according with the dynamics of a discontinuous and fast changing battlespace.

REFERENCES

A. Grilo, *'Quality of Service in IP-based WLANs'*. PhD thesis, Instituto Superior Técnico, Technical University of Lisbon, June 2004.

D. S. Alberts et al, '*Command Arrangements for Peace Operations*'. National Defense University Press, Washington DC, USA, 1995.

D. S. Alberts et al, '*Power to the Edge*'. CCRP, DoD, Washington DC, USA, 2003.

D. Potts, '*The Big Issue: Command and Combat in the Information Age*'. CCRP, DoD, Washington DC, USA, 2004 (reprint). The ISTAR C2 Model is proposed in chapter 11.

E. Olaussen, A. Karlsen, "A Policy-Based and Precedence Framework for Military IP Networks". Proceedings of the AFCEA/IEEE Military Communications Conference 2004 (MILCOM'2004), Monterey, CA, Oct.-Nov. 2004

S. Keshav, '*An Engineering Approach to Computer Networking*'. Addison-Wesley, USA, 1998.

T. Gardener, J. Moffat, and C. Pernin. "Modelling a Network of Decision Makers". Proceedings of the 9th ICCRTS, September 2004

U.S. DoD, '*Department of Defense Dictionary of Military and Associated Terms*'. JOINT PUB 1-02, U.S. DoD, 23 March 1994 (as amended through 7 December 1998).

A C2 Framework for Dynamic Battlespace Resource Management Based on Networking Concepts and a 'Post and Smart Pull' Approach

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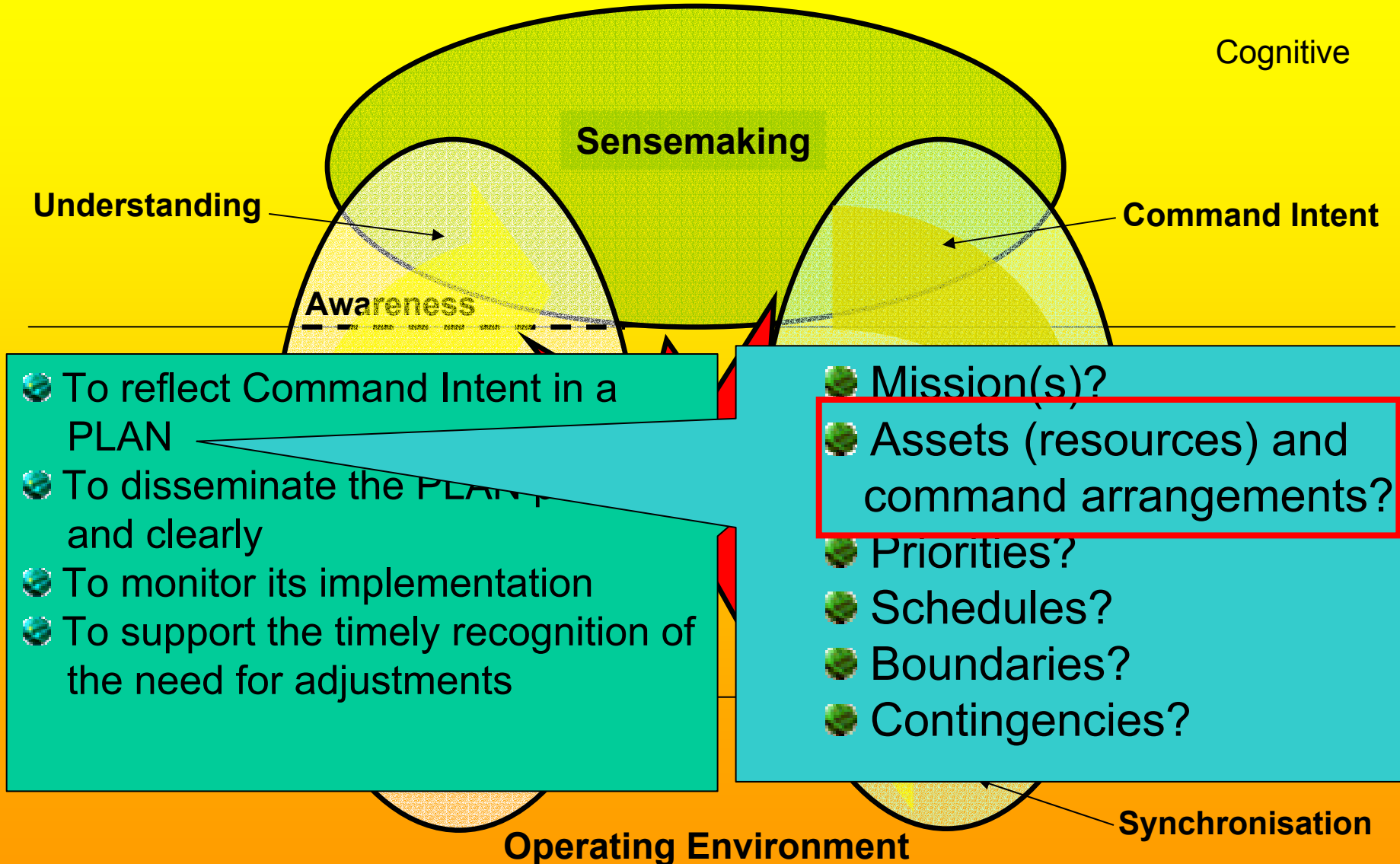[2]IST, Portugal
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1

Summary

- Introduction
- Motivation
- Web-based Battlespace Resource Management (WBRM)
- WBRM vs Networking Resource Management
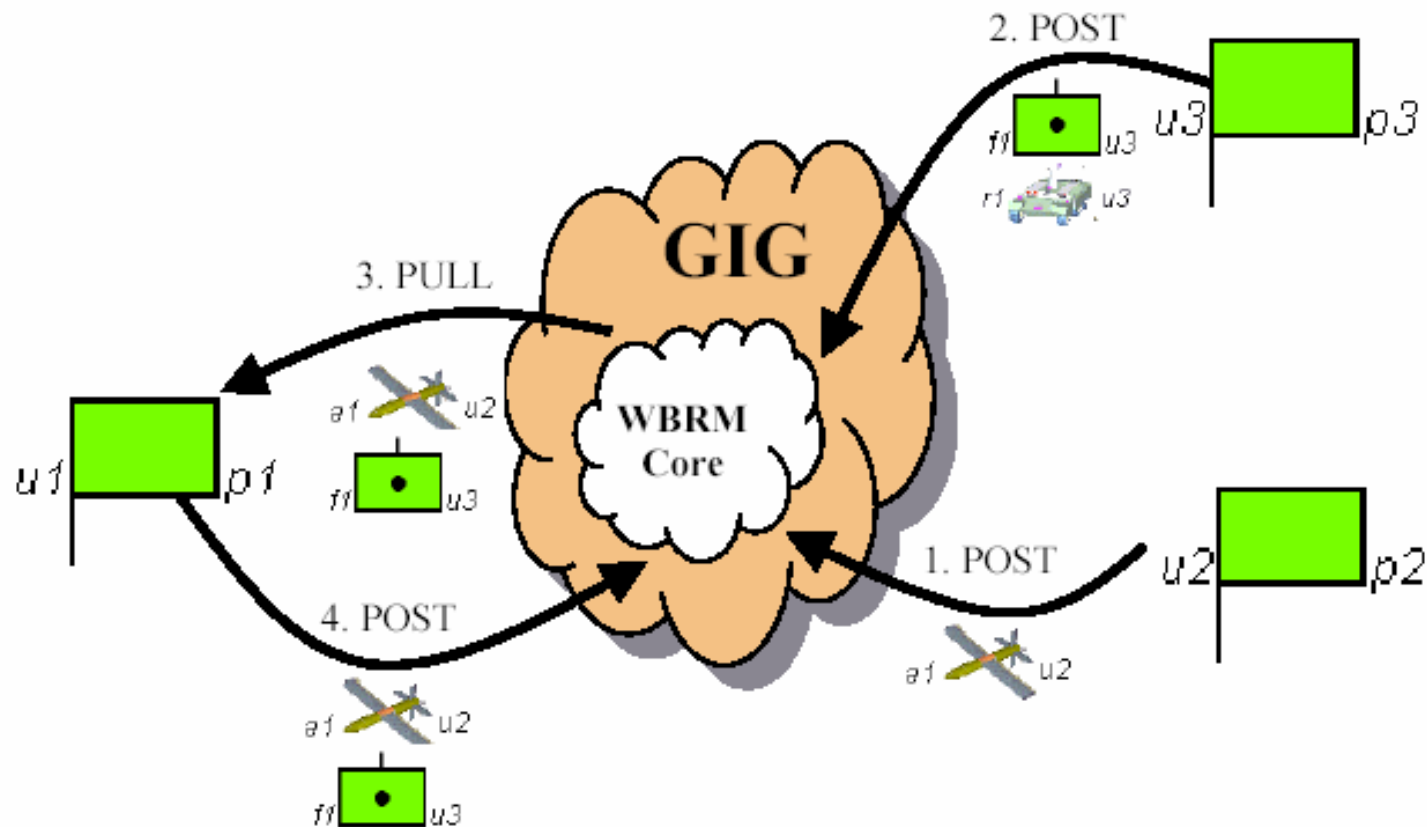- Conclusions
- Future Work

Introduction

Cognitive

Sensemaking

Understanding

Command Intent

Awareness

- To reflect Command Intent in a PLAN
- To disseminate the PLAN and clearly
- To monitor its implementation
- To support the timely recognition of the need for adjustments

- Mission(s)?
- Assets (resources) and command arrangements?
- Priorities?
- Schedules?
- Boundaries?
- Contingencies?

Operating Environment

Synchronisation

(CCRP, Dr. David Alberts)
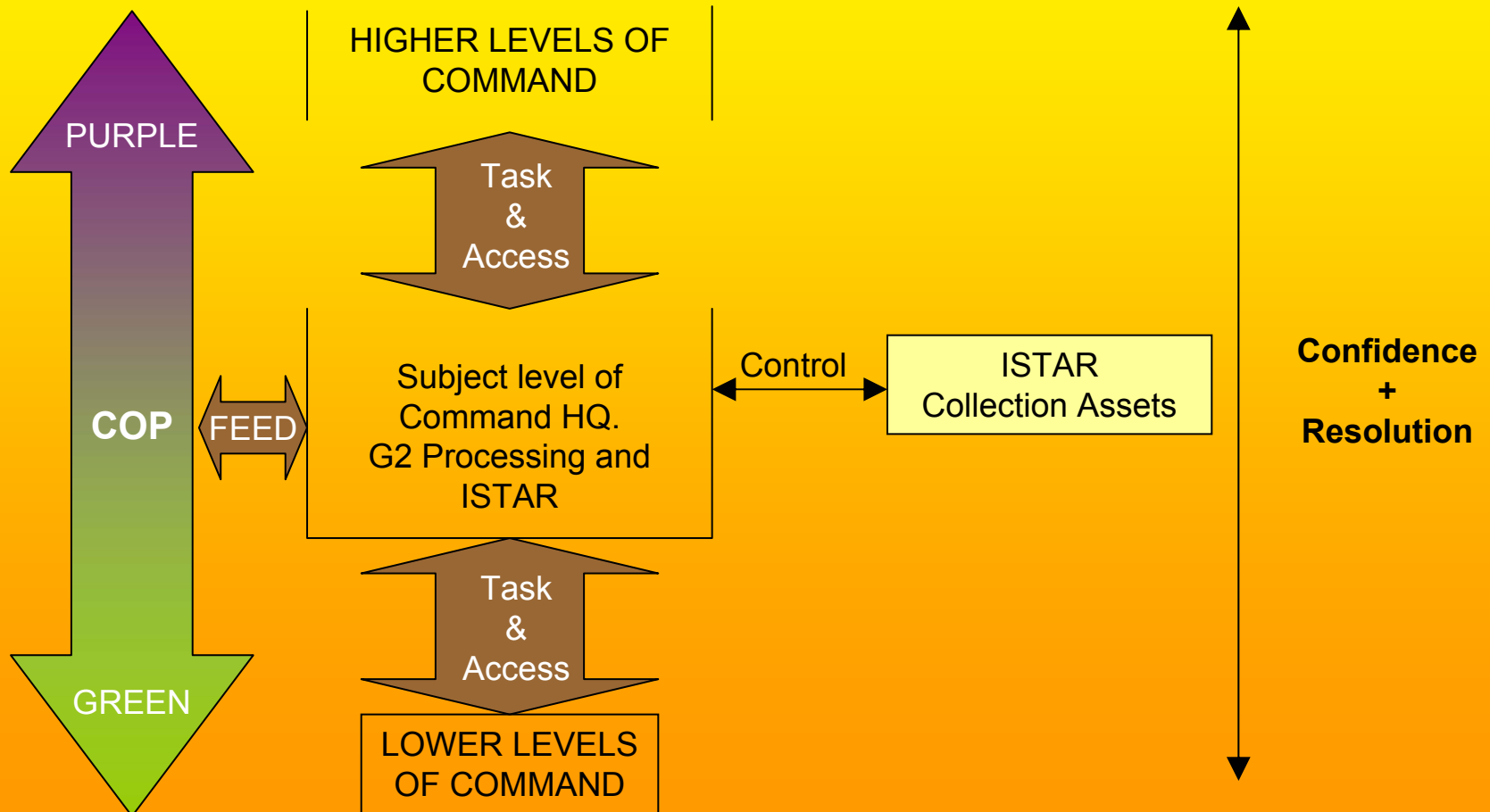
3

Motivation

- Collaborative planning is time- and attention-consuming:
    - Re-planning and re-allocation of resources pays a price in terms of time and focus
    - Contingency planning can increase plan resilience and reduce the need for re-planning under manageable complexity and uncertainty
    - Overprovisioning of resources reduces the need for re-planning, but is resource inefficient
    - Overprovisioning may be avoided through the support of dynamic adjustment of resource assignments to missions

Web-Based Battlespace Resource Management (WBRM)

C4ISR trends urging WBRM (1)

- ISTAR C2 Model proposed by Graham Le Fevre (in D. Potts, *The Big Issue*).

PURPLE

COP

GREEN

FEED

HIGHER LEVELS OF COMMAND

Task & Access

Subject level of Command HQ. G2 Processing and ISTAR

Control

ISTAR Collection Assets

Task & Access

LOWER LEVELS OF COMMAND

Confidence + Resolution

6

C4ISR trends urging WBRM (2)

- NCO with UAVs: USJFCOM exercise Extended Awareness 1 (see SIGNAL Magazine, April 2005).

WBRM Similarities with the e-Commerce paradigm

- Physical domain resources have only one instantiation (difficult replication)

- Physical domain resources are subject to expenditure/degradation over time

- Physical domain resources are subject to physical domain constraints and overheads

WBRM Requirements

- Transparency
  - *Post and smart pull* approach
- Flexibility
  - Support of different command arrangements
- Hierarchy mapping
  - Constraints on command arrangements based on echelon relationships
- Mission Package consistency
  - Support of atomic Mission Package *pull* transactions

Proposed WBRM Architecture

Resource Entity Record:

- Resource identifier
- Reference to the resource's supervision agent running in the WBRM Engine.
- Resource description.
- Resource's doctrine profile.
- Identifier of the decision entity that is its owner by default.
- Allocation and commitment status, including the identifier of the decision entity or entities to which it is currently allocated.
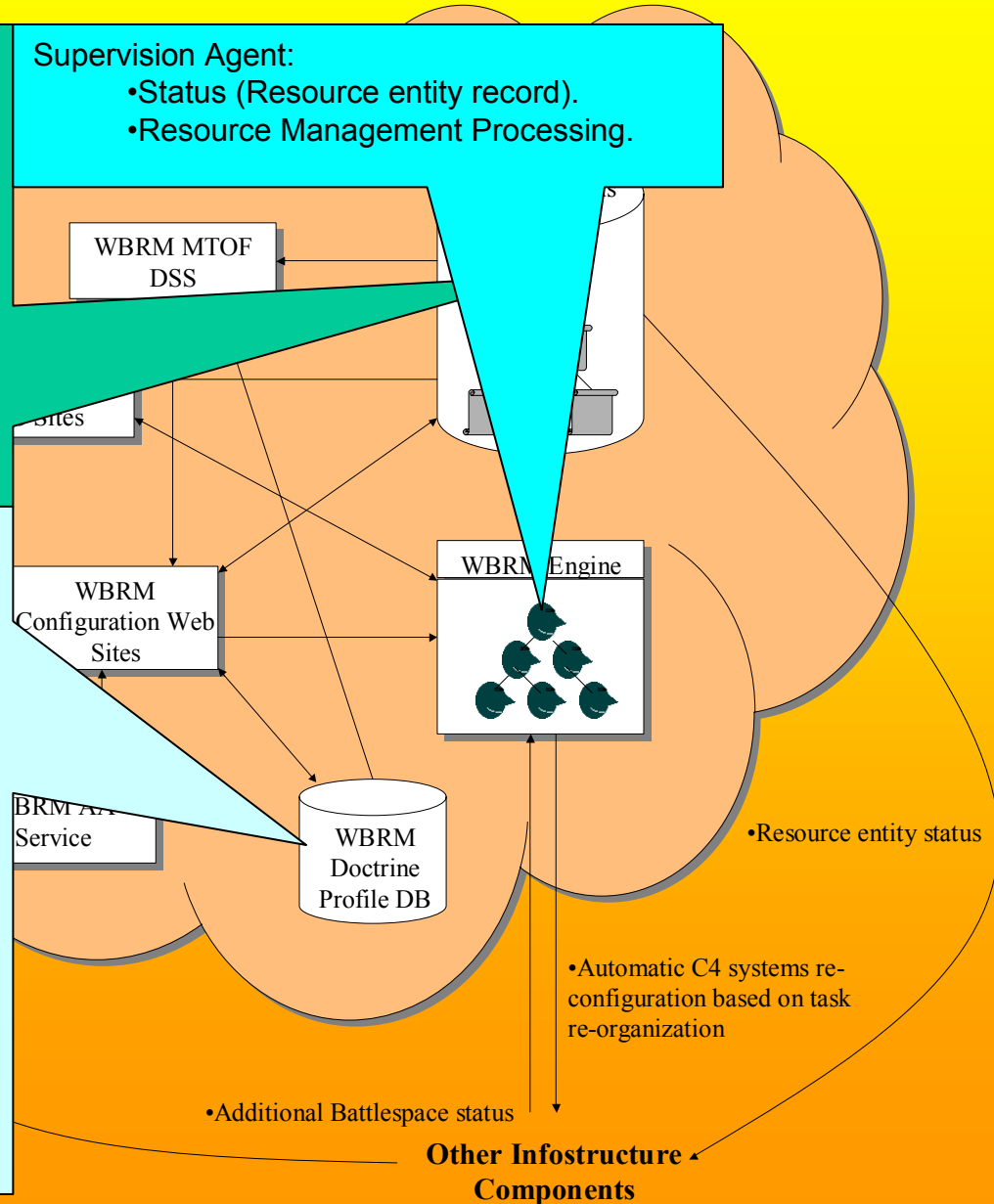- Decision entity's currently assigned priority.

Doctrine Profile:

3. Rules that constrain the quantity and quality of resources that a specific decision entity can allocate.

4. Rules that constrain in a qualitative way the allocation of resources by a specific decision entity.

1. Rules that constrain in a qualitative way the allocation of a specific resource by decision entities.

2. Rules that constrain in a quantitative way the allocation of a specific resource by decision entities.
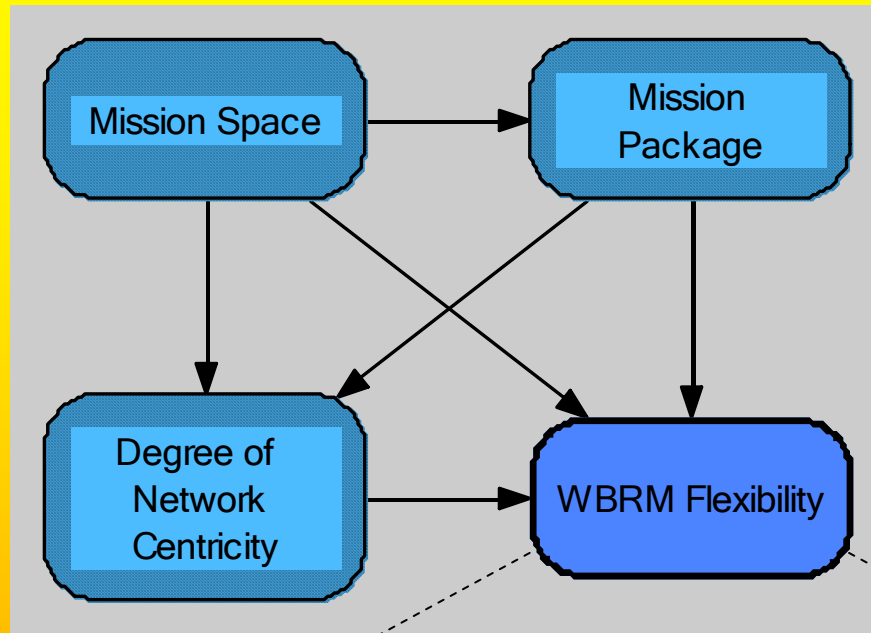
5. ROE

Supervision Agent:
- Status (Resource entity record).
- Resource Management Processing.

WBRM MTOF DSS

Sites

WBRM Configuration Web Sites

WBRM Engine

BRM A/ Service

WBRM Doctrine Profile DB

- Resource entity status

- Automatic C4 systems re-configuration based on task re-organization

- Additional Battlespace status

Other Infostructure Components
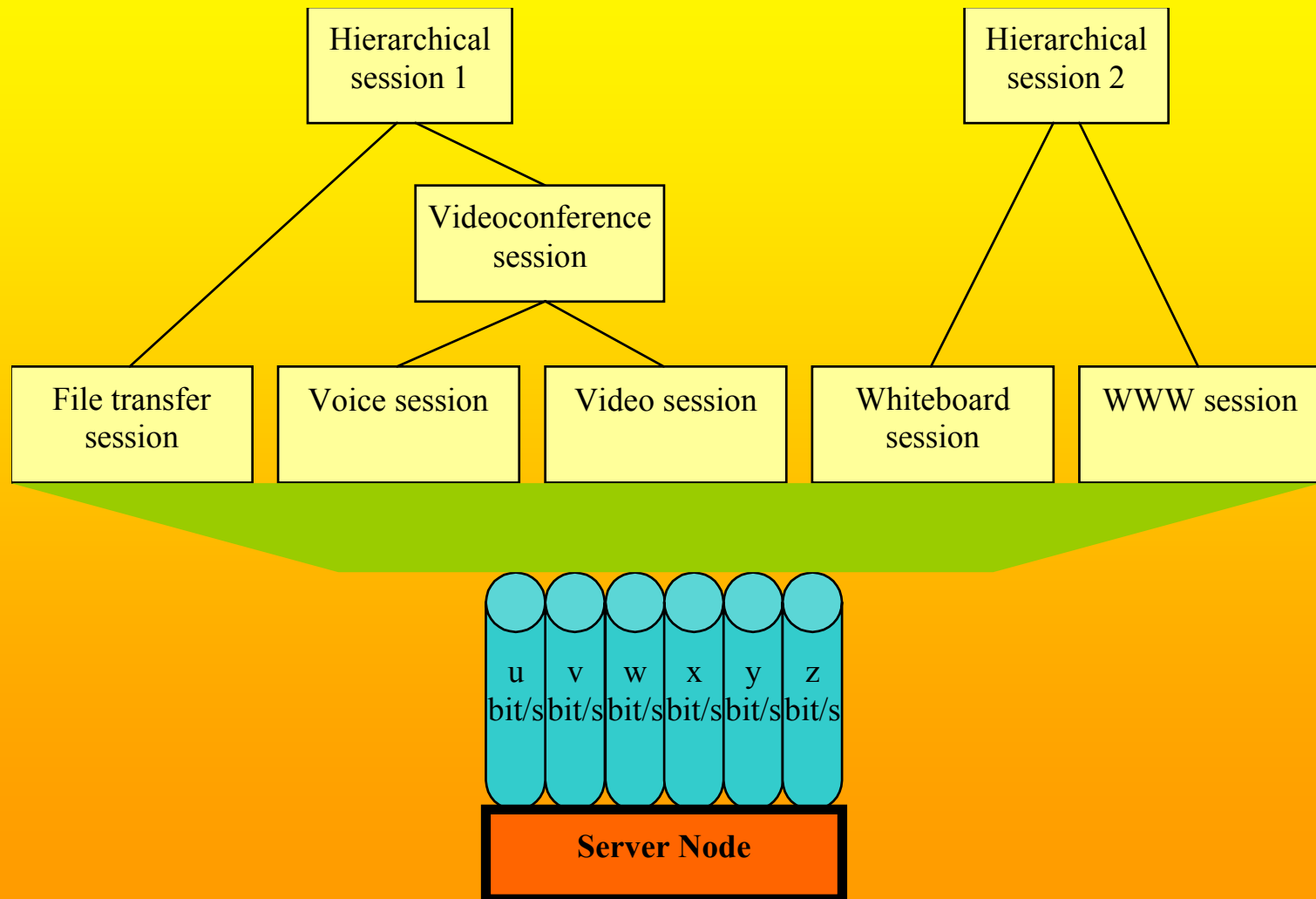
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WBRM and Network Centricity

Summary

- Introduction
- Motivation
- Web-based Battlespace Resource Management (WBRM)
- WBRM vs Networking Resource Management
- Conclusions
- Future Work

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Network Resource Management

Static vs Dynamic Allocation

- Static Resource Allocation
  - + Simple
  - + No management overhead
  - − Not adaptable to burstness/non-linearity
    - − Unable to deal with sudden bursts
    - − Waste of resources at times of inactivity
- Dynamic Resource Allocation
  - − More complex
  - − Increased management overhead
  - + Adaptive to activity changes

Network RM vs Battlespace RM (1)

Network	Battlespace
Successful data transmission	Successful mission accomplishment
Packet	Opportunity
User sessions	Decision entities
Channels	Battlespace resources that are not decision entities
QoS Policy	Battlespace resource management doctrine
Mean Rate	Average amount of resources/capability required by the decision entity at any time instant taking into account the expected probability, challenge and window of opportunities
Peak Rate	Maximum amount of resources/capability required by the decision entity at any time instant taking into account the expected probability, challenge and window of opportunities
Delay Bound	Window of opportunity

Network RM vs Battlespace RM (2)

Network	Battlespace
Packet/Session priority	Opportunity/Mission priority
Maximum Burst Duration	Maximum interval within which the maximum amount of resources/capability can be allocated
Packet Loss Ratio	Probability of missing an opportunity arising in the battlespace due to lack of available resources/capability
Maximum Transfer Unit	Expected maximum opportunity challenge, and by extension the respective resource requirement for successful seizure
Instant Data Rate	Amount of capability remaining in a battlespace resource

Network RM vs Battlespace RM (3)

- Battlespace Resource Management must deal with greater complexity:
    - Greater diversity of mission tasks, resource types, opportunities and contingencies.
    - Higher cost of error.
    - The challenge and window of an opportunity as well as the required amount of resources/capability is more difficult to guess than packet size.
    - Which specific resources? For what purpose? For how long? At what cost?

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Conclusions

- Web-based Battlespace Resource Management framework uses a *post and smart pull* approach.

- Dynamic Battlespace Resource Management is urged by current C4ISR trends to promote agility and efficiency through self-synchronization.

- An agent based reference model for the WBRM architecture is proposed.

- Supervision Agent processing may be inspired by network admission control and scheduling.

- Degree of WBRM flexibility should match the degree of network centricity.

Future Work

- Definition of a basic WBRM rule set.
- Definition of Supervision Agent algorithms.
- Agent-based simulation of WBRM:
  - In which conditions is WBRM feasible?
  - In which conditions is WBRM advantageous?
  - What is the desirable degree of WBRM flexibility?
- Refinement of the WBRM architecture.
- Development of basic demonstration applications for tactical level WBRM.

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