13th ICCRTS: C2 for Complex Endeavors

"Efficient Information Publishing in Service-Oriented C2IS based on Subject Managers"

Topic: T8 - C2 Architecture

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Efficient Information Publishing in Service-Oriented C2IS based on Subject Managers

Abstract

In this paper we introduce the concept of subject managers. In a service-oriented C2 Information System (C2IS), subject managers handle all the information providers of a specific subject, ranging from data in raw form (e.g., weather or intelligence) to evaluated form (e.g., politics or economics). An important class of information is georeferenced information. In this special case the concept of subject managers coincides with that of region services. In order to handle the potential information overload, a user of the C2IS can thus locate the appropriate information providers within the overall Global Information Grid (GIG) that are relevant for his current mission and can efficiently subscribe to them.

In case of potential network fragmentation in tactical networks, the subject managers can also serve as local data caches, enabling continuation of the work in such situations. By combining multiple subjects a DAG-like hierarchy of subject managers can be defined. Automatic information forwarding within this DAG allows a user or service to directly select the appropriate sub-subject manager in order to determine all corresponding information providers regarding this (combined) sub-topic.

Subject managers thus support the information management in service-oriented C2IS and are a step towards the realization of the NCW paradigm.

Keywords: Command and Control Information System, C2IS, Service-Oriented C2IS, Information Filtering, Information Publishing, Publish-Subscribe System, Subject Managers

Introduction

The paradigm of network-centric warfare (NCW) (Alberts 2007; Alberts & Hayes 2003; Kruse, Adkins & Holloman 2005; Wilson 2004; Villa 2004) is a powerful, new concept of warfare for the 21st century, employing the opportunities of modern IT systems to the battlespace. Its aim is to improve military effectiveness by achieving information superiority (Alberts & Hayes 2003). This improves mission effectiveness and helps dominating the battlespace, because it allows deploying military power more rapidly and effectively. (Kruse, Adkins & Holloman 2005) describe, for instance, as an example the time gained from using NCW capabilities in air-strike missions in Operation Enduring Freedom (OEF). The enhanced situational awareness thus allowed the staff officers "to do more tactical and strategic thinking".

Similarly holds in crises management for disaster relief (Arnold et al. 2004; Denning 2006a; Jungert, Hallberg & Hundstad 2006). Here, agility (Alberts 2007) of the forces and the ability to adapt to changing conditions is as important as in military operations.

In both cases the user has to make proper decisions and react quickly, i.e. in real-time, according to the current situation. For managing the operations – be they military or disaster scenarios – command and control information systems (C2IS) are used.

The number of elements – be they users, military forces or other spatial objects(like bridges or streets) – is too large to be directly observable. The C2IS thus has to provide appropriate mechanisms to filter the available information to the mission-specific parts that are relevant to the corresponding users (Denning 2006b; Hayes-Roth 2006; Nitsche 2006).

Areas of interest are a filtering concept which provides information about other elements and users located within a certain (geographic) area or elements having an effect on that area. To improve the efficiency for generating an operational picture and to easily handle dynamic changes of object positions we introduced the concept of a region service. Such a service handles a certain geographical region of the world containing a list of all elements that are located within this region.

In this paper we extend from geo-spatial elements to general information that represents other subjects in raw form (e.g., weather or intelligence) or in evaluated form (e.g., politics or economics). Similarly to region services, subject managers now contain references to all information providers of a specific subject. By combining multiple subjects a hierarchy of subject managers can be defined; allowing a user or service to determine all corresponding information providers. A C2IS can thus locate the appropriate information providers and efficiently publish/subscribe throughout the GIG.

Challenges of the NCW Global Information Grid

The global information Grid (GIG) (Blais et al. 2005; U.S. Government Accountability Office 2004) forms the technical basis for realizing the power of the network-centric warfare concept. It is based on the global connection of all military systems, ranging from sensors (e.g., reconnaissance systems) over the command and control systems to actors (effect systems).

However, using the GIG as an underlying basis for NCW operations imposes some challenges. These include, among others,

- Handling the potential information overload,
- Finding the relevant information and its providers,
- Communication and device restrictions.

Handling the Information Overload

In principle, every system or person may be able to communicate with everybody else in the network. In the information grid, all available information can thus be shared among the different users, provided that the required security criteria are satisfied. As a result,

potentially all the available data about own and enemy forces as well as other information becomes available in the GIG in a shared manner.

To handle the problem of information overload we have to restrict the (visualized) data in an operational picture to only that information that is relevant for the user (Denning 2006b; Hayes-Roth 2006; Nitsche 2006). Since the number of objects, users and other information is too large to be directly observable – it may reach millions in network-centric operations – the command and control information system has to provide mechanisms to filter the available information to the mission-specific parts that are relevant to the corresponding military commander or that are selected by the C2IS user as in the User Defined Operational Picture approach (Mulgund & Landsman 2007).

Finding the Relevant Information

We thus have to restrict information access to only mission-relevant information. Such a reduced view of the available information showing only the mission relevant data with the war-fighter needs is not only necessary from an information security point of view, but also a prerequisite for gaining the proper situational awareness and thus for taking proper actions.

However, the user or its C2IS services have to find the information for the specific user and his current mission. This includes locating the corresponding information providers, read the data from them (if the information is not delivered in a push-based manner, cf., e.g., (Hayes-Roth 2006)), process the data and, finally, visualize them (Spielmann 2006).

In this paper we merely concentrate on the first aspect, i.e., how services can efficiently inform other services or the user about the available information. Other aspects like the visualization of the data for the COP are discussed elsewhere (Jansen et al. 2007; Spielmann 2006).

The problem of finding the relevant information becomes especially critical, if information from multiple domains has to be taken into account. Since an important part of current and future missions are joint and probably multi-national, information from different organizations has to be considered in order to achieve a shared operational picture. The required standardization efforts as, e.g., done in the Multinational Interoperability Program (MIP), are out of the scope of this paper. We only assume some (minimal) standardized data formats and semantics. However, even in this case we still have to find those information providers within the GIG holding the information relevant for the current user and his mission.

This mission-relevant information obviously varies depending on the mission and the user, so the user should be able to define his own information pool. He can do so by establishing (and terminating) subscription relations with appropriate filtering rules to other service instances (Jansen & Nitsche 2008), provided these information publisher are known to the user, respectively his COP service instance.

Communication and Device Restrictions

Since the units on the tactical level are in general mobile, they cannot rely on fiber line communication but have to use satellite or radio communication. Here the available bandwidth is orders of magnitudes smaller the one that is available in higher-level command posts or head quarters, where Gigabit Ethernet (or at least 100 MBPS) are common. Software-defined radio (SDR) devices used for tactical radio communication only offer a bandwidth in the magnitude of kilobits per second. E.g., most radio waveforms defined for the Joint Tactical Radio System (JTRS) do not support data rates of more than 16 KBPS. Even the Wideband Networking Waveform (WNW) is expected to achieve at most 5 MBPS network throughput (JTRS 2006). Satellite connections can offer some more bandwidth, but the long distances impose higher latencies.

Moreover, the limited bandwidth has to be shared among the different units so delays and waiting for a free communication channel may occur (cf. Wilson 2004, page 23). Thus we have to limit the amount of communication to higher priority messages and cannot have access to all information we might wish of.

In addition to that, network connections may not be available at all temporarily due to non-cooperative environments. Reasons for that can be shielding effects, e.g. in urban operations, or radio interference by enemy forces. We may even require radio silence in order to hide the own location.

The bandwidth limitations and the (temporary) unavailability of network connections have a negative effect on the availability of services and information. This may potentially lead to network fragmentation. We therefore cannot rely on a C2IS architecture where all information is stored on a central server in the network, since its availability, i.e. its accessibility by the soldier in the field, cannot be guaranteed at all times.

Instead, we have to keep some services and data locally on our mobile devices (see (Käthner & Spielmann 2004) for an example implementation) or at least in the same network fragment. This leads to a distributed approach: Services are partitioned into multiple service instances that may reside anywhere in the network holding their own local data (Jansen et al. 2007). An example is a distributed database service. Here each service instance holds parts of the overall database. To allow local operations, some data elements may be replicated between the different instances. Similar holds for distributed COP service instances.

Note that on the tactical level not only the communication to the device of user is restricted but in general also the device itself. On mobile devices, processing power as well storage and energy capacity are normally limited, so we cannot process everything locally on the device of such “disadvantaged users”. Instead, we always have to trade-off the restrictions of the communication bandwidth against that of the local device in order to decide where a certain service should be located in the network (Jansen et al. 2007).

Geospatial Information Filtering in C2IS

Areas of Interest

Areas of interest (AOI) are one of the concepts that can be used to filter the available information in a C2IS according to the user's requirements. In our previous work (Nitsche 2007a; Nitsche 2007b) we have concentrated on the geo-spatial aspect of AOI, i.e. the location management (Hightower & Borriello 2001; Chew, Yeo & Kuan 2007). Since most of the elements like units etc. in a C2IS have a spatial reference, geographic areas like the surrounding of a user's position and his area of operation can be used to restrict the amount of information. Here a user only wants to get informed about those elements and users that either are within that specific area or that may have an effect on that area, e.g., due to the range of their weapons or movements (McEneaney & Singh 2007; Scott et al. 2007).

Region Services

Approaches in multi-cast communication schemes (Carzaniga, Rosenblum & Wolf 2001; Carzaniga, Rutherford & Wolf 2004; Sebé & Domingo-Ferrer 2007) lead us to the concept of region services which were introduced to efficiently manage such areas. A region service defines a certain geographical region of the world and contains a list of all elements that are located within this region (or that might have an effect on it, cf. (Nitsche 2007a)). Each of the spatial elements can than be added to one of the region service instances, depending on the location of the corresponding object (cf. Figure 1).

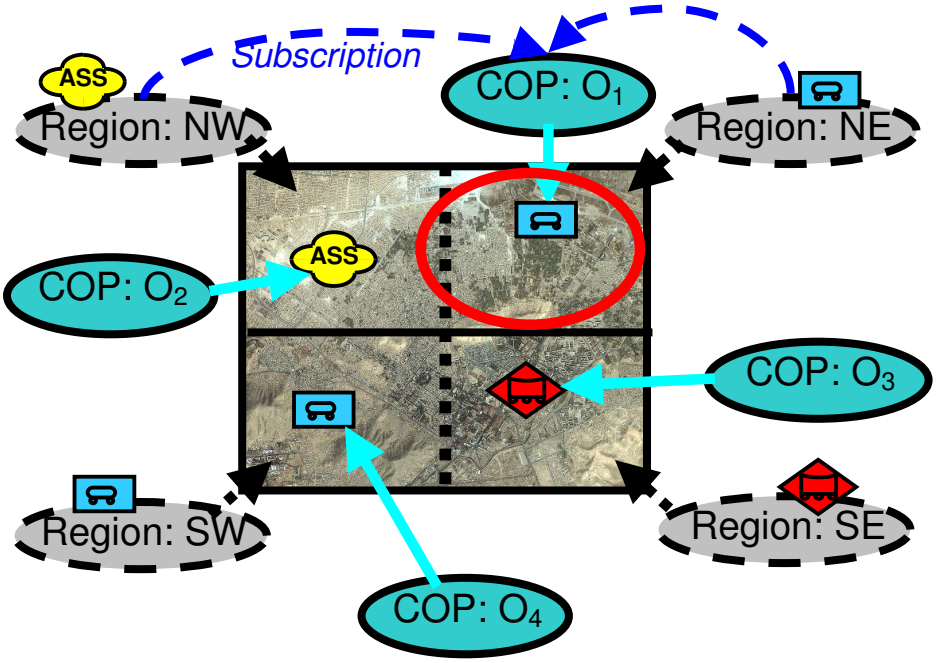

Figure 1. Region services containing information about the elements within their area

To detect the elements within the area of interest for a user, we now only have to request the elements from those region service instances that overlap with the user's AOI. These regions will only contain a small amount of neighboring elements, where neighborhood is

defined geographically or based on the effect on other elements. We therefore normally do not have to check all elements within the C2IS but only the relevant ones.

This approach is especially suited to manage the AOI on the tactical level, i.e. for lower level echelons. On the strategic level, however, the AOI can become too large to include all elements within that area into the visualized operational picture. If, in its extreme case, the AOI is the whole globe, the AOI alone does not offer enough information filtering. Instead, it has to be combined with the aggregation of information of subordinate units into their superior ones. This means that, as a default setting, only (aggregated) elements representing a certain echelon (or higher echelons) are shown in the users view of the COP. In this way the amount of information is restricted to manageable parts.[1] Such aggregated unit information according to the military hierarchy can be handled by a hierarchy of regions (see below).

Dynamic Movements

The concept of region services not only improves the efficiency for generating a COP but can also easily handle dynamic changes of element positions. As long as an element resides within its current region, the element list of the region service does not change and thus another user can fully ignore any changes within this region, as long as the region itself is outside his current AOI. Only if an element crosses the boundaries of a region, it might change the AOI those users that monitor the corresponding region.

This can be seen in Figure 2. In this example a unit (O_3) moves from the south-eastern region to the north-eastern region. This requires the corresponding COP-service instance (*COP:* O_3) to register at the new region service instance (*Region: NE*) and un-register at the old one (Figure 2– (a)). If a user (like O_1) is interested in a certain geographic area he can subscribe to the corresponding region services (*Region: NW* and *Region: NE* in the example). In this case he (or more precisely his COP-service instance (*COP:* O_1)) will be informed automatically via an update-message, that a new element (O_3) has entered this area (or might have an effect on it), see Figure 2– (b). If this new element is of interest to the user he can subscribe to the corresponding COP-service instance. As a result, the current data of the selected element are read, and future changes like position updates are forwarded automatically[2] according to the publish-subscribe-approach (Figure 2– (c)).

[1] Note that, according to the NCW approach (and because even local events on the tactical level of operations may have strategic or even political consequences), the C2IS user should still be able to "zoom" into details of specific units on lower level echelons on request, provided the security criteria are satisfied.

[2] To adopt to restricted communication bandwidth, such update messages have to be handled with lower priority than other messages like, e.g., warnings about ambushes.

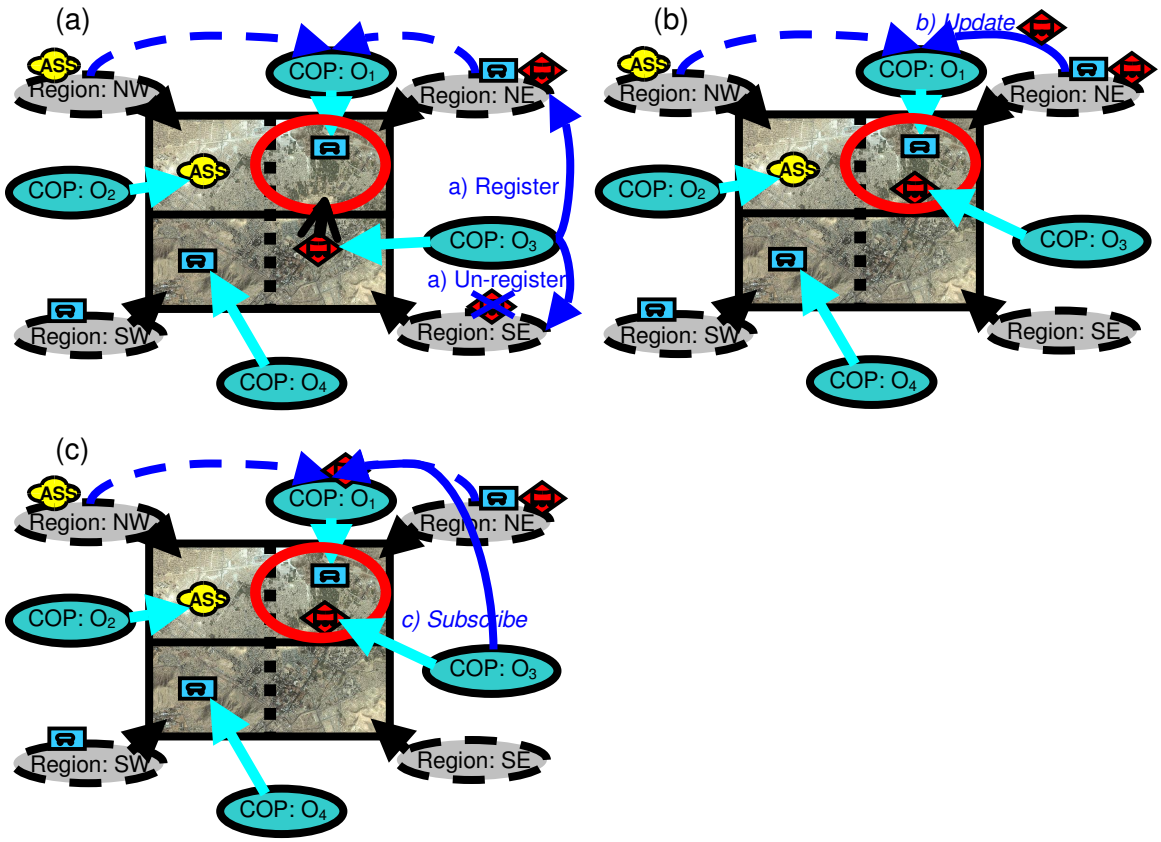

Figure 2. Dynamic movements of elements with crossing of regional boundaries: (a) O_3 crosses boundary from *SE* to *NE* and registers at corresponding region service instance; (b) updated list of elements within region is sent to interested user; (c) user subscribes to new element within AOI

Hierarchy of Region Services

The above described concept of regions (and the associated region service instances managing the geo-referenced elements within a C2IS) can easily be extended to a hierarchy of regions (and region service instances). Starting from a root region denoting the whole operational area, we can (recursively) split the area into sub-regions. These splitting can be done statically in advance or dynamically at runtime.

The commander can thus adapt the location management scheme to the expected distribution of forces in the field according to the plans and orders by using a hierarchy of regular regions with higher density at the battlefields. This reflects the fact that the elements are in general not distributed regularly around the world but in-homogenously in the operational area. In the military domain the elements are usually concentrated on the battlefield(s), while in disaster scenarios the distribution of users also follows certain patterns (cf., e.g., (Mitschke & Peter 2001) for an example). This implies that the number of elements located within each regular region may vary significantly, so sub-regions are used to cope with this inhomogeneity and distribute the load among the region service instances (cf. Figure 3).

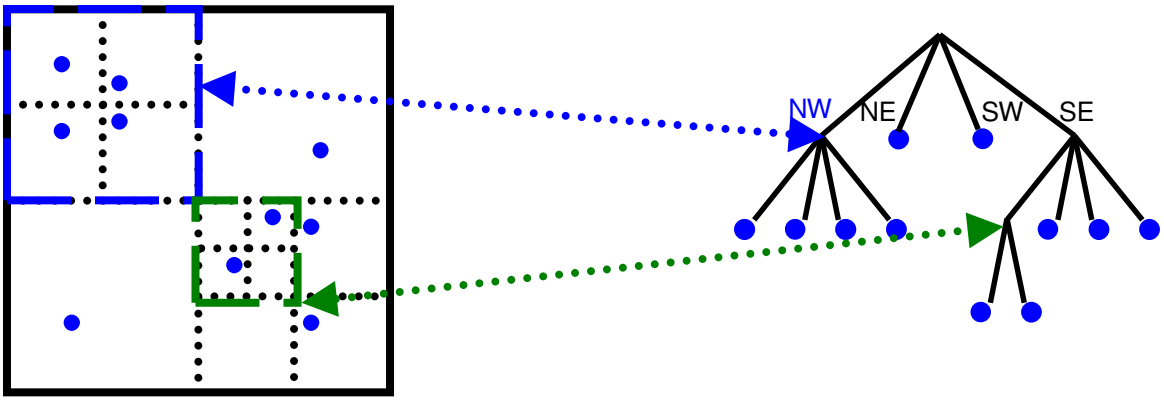

Figure 3. Hierarchy of regions, corresponding to the areas of operations and hence the distribution of elements on the battlefield

Such a region scheme according that reflects the area of operations can be statically derived in advance and broadcasted to all the COP-service instances. If the number of regions becomes too large, we can at least distribute to each COP-service instance the partial information about those regions where the corresponding element is supposed to operate according to its mission orders.

This pre-defined static region scheme can than further be refined at run-time according to the actual distribution of elements (units, etc.) on the battlefield, if the density becomes larger than expected in advance.

Subject Managers

Subject Managers as a Generalization of Region Services

This approach based on geo-spatial elements can be extended to more general information. Thus we also represents other subjects like weather data, intelligence data in raw form (such as ELINT data) or in evaluated form (such as politics, demography or economics), or others. In the same way as a region service instance contains references to all georeferenced elements of a certain area, we can introduce one (or more) subject manager for each of such subjects. These subject managers contain references to all information providers of the specific subject. The region service can than merely be seen as a special case that handles geospatial data.

Note that the region service instances as well as the more general subject manager instances do not need to hold all the actual data themselves. Instead of that they only contain references to those service instances that actually hold the data. As shown in Figure 1 for the region services, the subject manager instances can be seen as a kind of directory of information providers, i.e. service instances that contain information regarding a specific subject. The subject managers can thus be used to find those service instances within the C2IS that contain the required information for a specific user. By establishing subscription-relations to these information providers a consuming service can then gather the corresponding information, as shown in Figure 4.

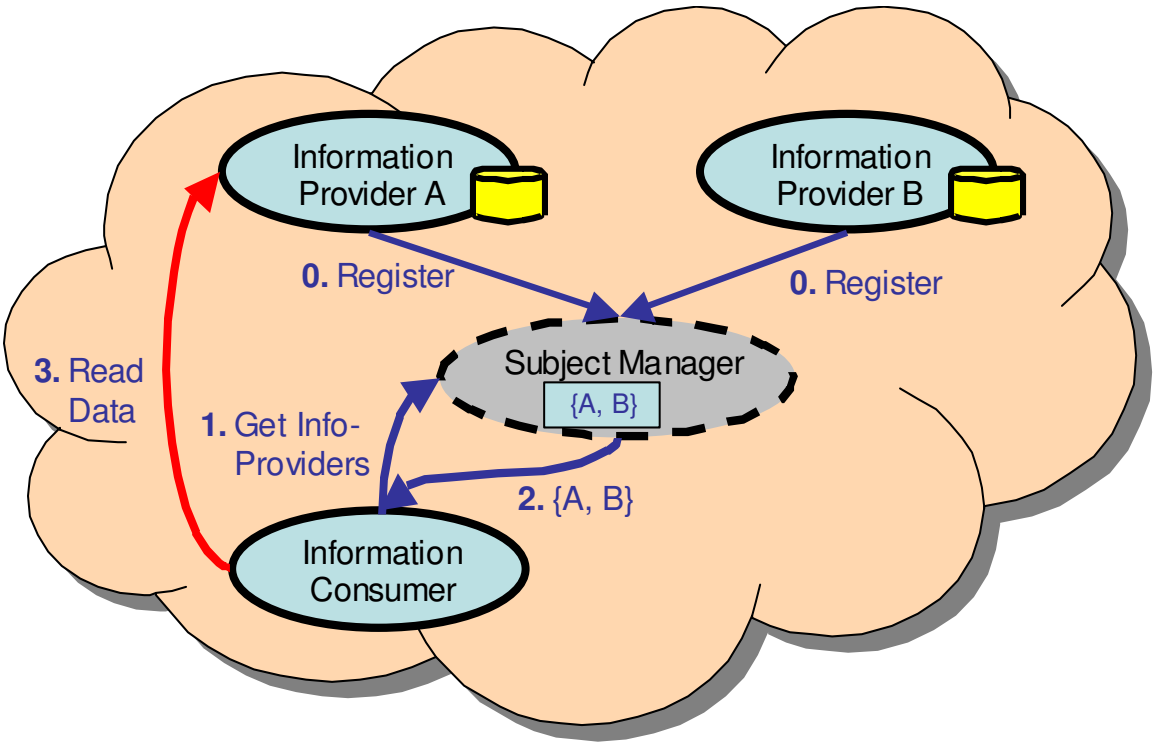

Figure 4. Information publishing using subject managers

Information Caching in Subject Managers

The subject managers are not restricted to simple information directories to other service instance. Instead, they can also be used to cache parts of the actual data itself. This means that some of the data (like the positions of certain elements) can also be stored within the subject manager. He can do so by directly subscribing to that service instance holding the information (cf. Figure 5).

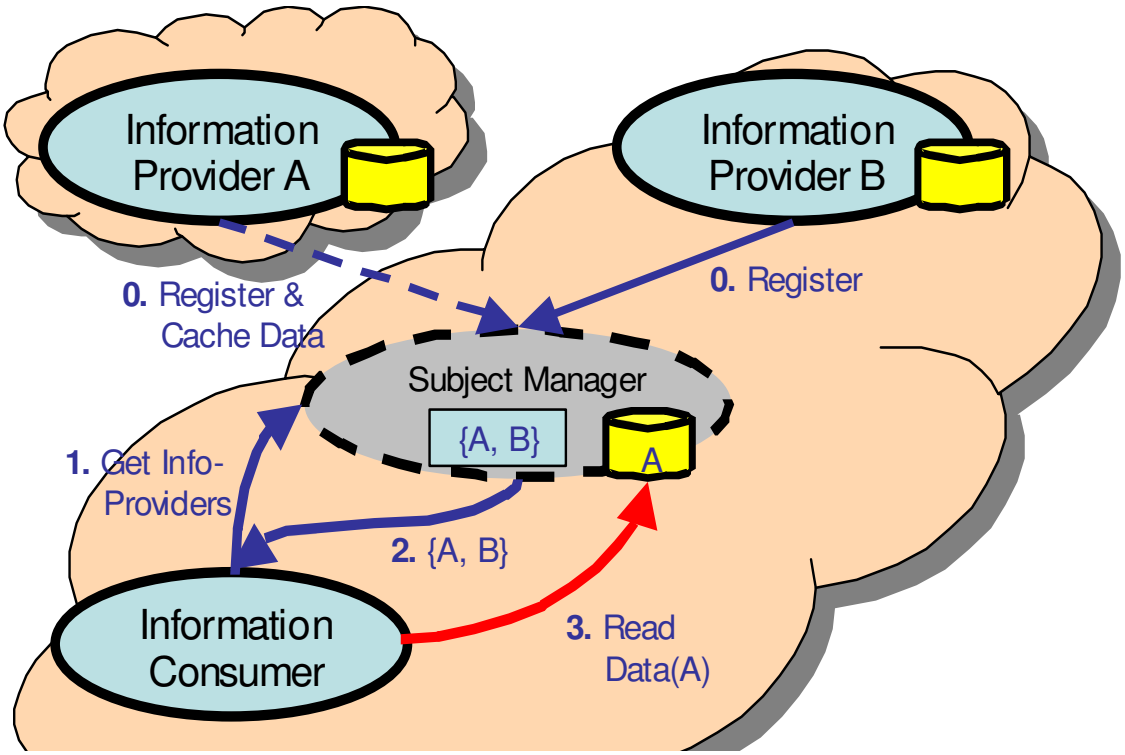

Figure 5. Information retrieving via cached data in subject managers in case of network fragmentation (In this example information provider A is outside the current network fragment of the information consumer, so he reads the cached data of A from the subject manager.)

This is useful for the tactical level where network fragmentation can occur and thus the availability of services and access to all nodes in the network cannot be guarantied. In this case where temporarily the actual information provider cannot be reached, we can retrieve the information from a subject manager instance if it is contained in its cache. Note that the cached information like the position of a unit may be out-dated, but we regard this as a much better approach than having no information at all. (If a service distinguishes between data that is read directly from the original information provider and potentially out-dated data that is read from a subject manager, the further processing and visualization steps may take this into account and may "warn" (or better inform) the user about the potentially incorrect data.)

Hierarchy of Subject Managers

Note that the different subject managers do not necessarily have to be different service instances. In fact, they can even be mapped to a single service (with a collection of subject-specific interfaces). The concept thus allows as a special case even a central database on a central server (cf. Figure 6).

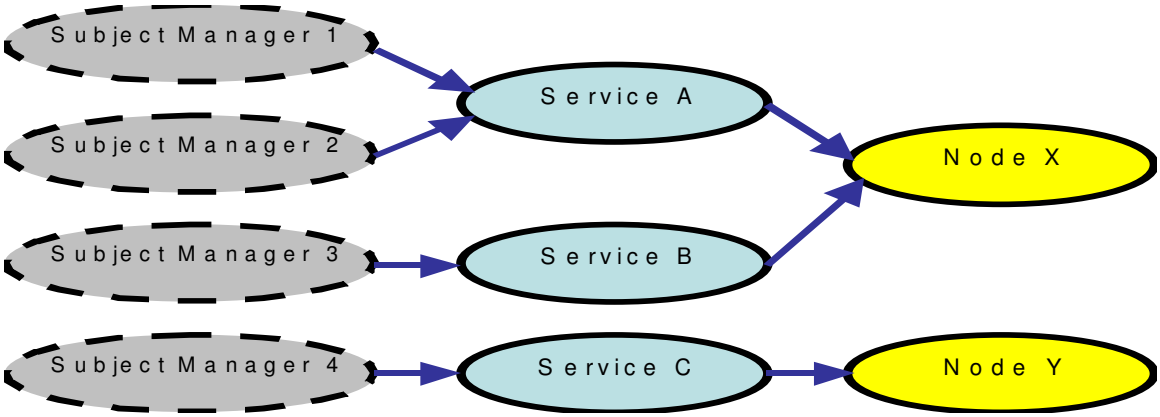

Figure 6. Mapping of (virtual) subject managers onto services and network nodes

However, in order to distribute the load within the network and to allow subject managers to be located near the information consumers to allow caching in case of network fragmentation (see above), this is normally not the best solution. In the general case, each subject will be managed by a different service instance located potentially on different network nodes.

By combining multiple subjects we can define a (partial) hierarchy of these subject managers that allows a certain user or service to directly determine all information providers of a specific (sub-)subject. An example may be weather data of a specific time or certain intelligence information about a specific area.

The combined subjects lead to a hierarchy of subjects, where combinations of subjects can be seen as specific sub-subjects. Technically, this leads to a DAG (directed a-cyclic graph), i.e. a kind of tree where each node may have multiple children but also multiple parent nodes (Figure 7). This is the case since a subject may be a sub-subject of different other subjects due to the different combinations.

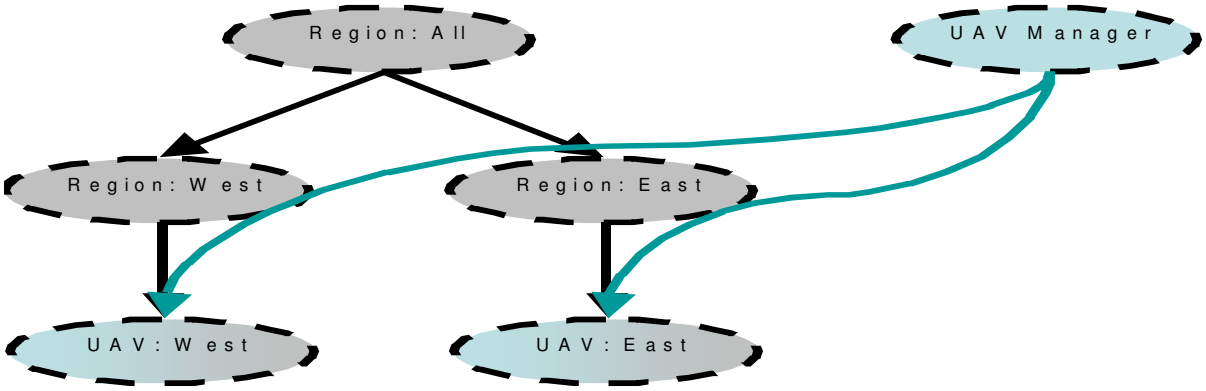

Figure 7. Example for a DAG representing combined (hierarchical) subject managers

Such combined subjects can especially be used to combine the hierarchy of regions with other information subjects. If some data not only belongs to a certain information subject

but also has some spatial reference, it may be published at the combined sub-subject manager that is responsible for the specific subject of a certain area. E.g., weather data, reconnaissance data (like SIGINT gained from satellites or UAVs, ELINT or others) usually have some associated spatial reference like, e.g., the position of an UAV or the area covered by its image. The service instance handling the combined sub-manager, e.g., UAV data of a specific area, can then be allocated in or near that specific area. In case of network fragmentation the specific information thus can still be made available in the corresponding area (cf. also the discussion above about information caching).

A service that publishes some information that belongs to a specific combined sub-subject may publish, i.e. register, the information either directly at the sub-subject manager itself or at one of the more general subject managers. E.g., UAV data of a specific position can either be registered at the UAV manager (with geo-reference, cf. Figure 8-(a)), be registered at the corresponding region service for the position (as UAV data, cf. Figure 8-(b)) or directly at the UAV manager for the specific area (cf. Figure 8-(c)).

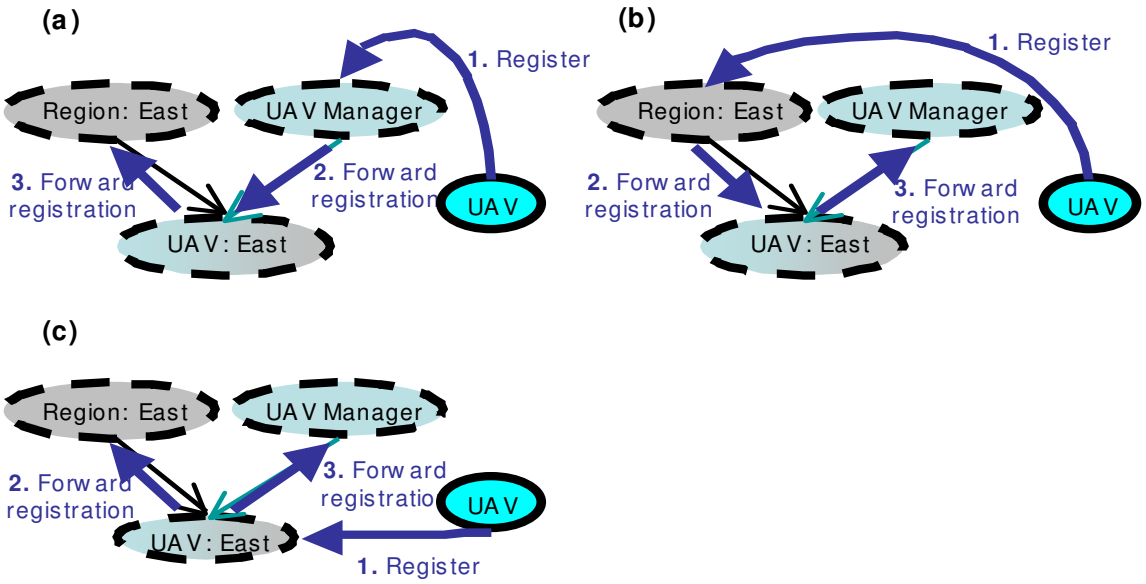

Figure 8. Information publishing via hierarchical subject managers with automatic forwarding of published information to other responsible subject managers: (a) Registration of UAV data at *UAV Manager* and forwarding of geospatial data to sub-subject managers *UAV:East* and *Region:East*; (b) Registration of geospatial data at region manager (*Region:East*) and forwarding of UAV data to UAV subject manager (*UAV Manager*) via *UAV:East*; (c) Registration at sub-subject manager *(UAV:East*) and forwarding to superior subject managers (*Region:East* and *UAV Manager*)

The subject managers will then forward the information to other subject managers involved. If, for example, we register the UAV data of a specific position at the UAV manager, then the UAV manager will automatically inform the corresponding UAV region manager, who in turn will inform the corresponding region service instance. A consuming service, i.e. a user who wants to retrieve some information, can thus subscribe to any of the three subject managers to get the desired information.

In a service-oriented C2IS (Jansen et al. 2007; Spielmann 2006; Käthner & Spielmann 2004) this can thus be used to efficiently publish the information provided by each service, locate the appropriate information providers for each user's operational picture and subscribe from them within the GIG.

Summary

In the Global Information Grid (GIG), potentially all the available cross-domain data becomes available in a shared manner. To handle the problem of information overload a C2 Information System (C2IS) has to filter the data to only that parts which are relevant for the user.

In this paper we introduced the concept of subject managers. In a service-oriented C2IS, subject managers handle all the information providers of a specific subject, i.e. they contain references to all the service instances of those elements or users holding (partial) information regarding the corresponding subject. In order to handle the potential information overload, a user of the C2IS can thus locate the appropriate information providers within the overall GIG that are relevant for his current mission and can efficiently subscribe to them. In case of potential network fragmentation in tactical networks, the subject managers can also serve as local data caches, enabling continuation of the work in such situations.

A DAG-like hierarchy of subject managers can be defined by combining multiple subjects. Automatic forwarding of published information within the DAG allows users to directly select the appropriate sub-subject manager in order to retrieve information regarding this (combined) sub-topic.

The information handled by the subject managers ranges from subjects with data in raw form (e.g., weather or intelligence) to evaluated form (e.g., politics or economics). An important class of information in a C2IS is georeferenced information, i.e. data about objects with a spatial reference. This includes military units, geo-basis data (like streets or bridges), but also data belonging to other information categories like, e.g. UAV data or intelligence reports about a certain area, handled by corresponding sub-subject managers. For this special case of spatial information the concept of subject managers coincides with that of region services, handling a certain geographical region of the world by containing a list of all elements that are located within this region or having an effect on the area. This improves the efficiency for generating an operational picture and can easily cope with dynamic changes.

Subject managers thus support the information management in service-oriented C2IS and are a step towards the realization of the NCW paradigm.

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