Architecture for Networked Sensor Integration as an Enabler for Future Multi-Sensor Multi-Platform Operation

Christoph Fischer, Ulrich Martin, Bernd Mohring, Felix Rueting,
Matthias Wegner, Reiner Zimmermann
Hensoldt Sensors GmbH
Woerthstr. 85, 89077 Ulm
GERMANY

{christoph.fischer, ulrich.martin, bernd.mohring,
felix.rueting, matthias.wegner, reiner.zimmermann}@hensoldt.net

ABSTRACT

Future military scenarios require fast decision making and a high operational speed in a congested and very dynamic environment. A network centric approach is a key enabler to satisfy those requirements, where individual platforms in a system of systems contribute to the overall operation. Networking, together with an adequate level of autonomy to operate, enables the whole system to take decisions as closely as possible to the final actor (being a sensor or effector in our case). This increases the operational speed substantially in addition to synchronising each individual OODA (Observe Orient Decide Act) loop on different decision layers. To enable decisions at the edge, data must be aggregated and interpreted as early as possible to provide the best situational picture, which is a prerequisite for making informed decisions. These two aspects result in resilience against loss of connectivity on higher levels and enable the individual or smaller tactical groups to still pursue their mission, even if the connectivity to higher command and control is temporarily limited. As such, they are also the answer to new attack vectors, ranging from brute force attacks on the physical links to more sophisticated attacks on higher OSI layers within the communication system. Architecture principles answering the problems mentioned above with focus on airborne applications have been formulated. For these architecture principles, first exemplary applications on multi-platform sensing use-cases will be discussed. In the long term, the proposed architecture principles may be transferred from the airborne domain to other domains and finally be applied to multi-domain scenarios.

1.0 INTRODUCTION

Successful future military operations require information superiority in highly dynamic and contested environments. Taking the right decisions in those operations requires that the decision-making instance has access to an adequate relevant operational picture and is aware of its operational goals. To fulfil these two requirements, all available resources have to be used very efficiently. In a system of systems with a dynamic network of available information sources (e.g. sensors or sources external to the system) in a challenging communication environment, as expected for future missions, this implies that, whenever possible information rather than raw data shall be transmitted and decisions shall be taken as close as possible to the executive instance to avoid communication overhead and unnecessary latency between decision and action. From an implementation point of view this results in a distributed architecture with decision making (resource management) and information generation capabilities (data fusion) on several levels. A network of sensors not only provides new, crucial capabilities due to the cooperation and collaboration of the involved sensors, but also enables new sensing capabilities like multi-static radar with a small number of illuminators and a high number of passive receivers that can have full situational awareness without emitting radar waveforms.

In this paper, we give a short overview of the emerging multi-platform sensor technologies that will contribute to the network. After this overview, the architecture principles to connect these sensors amongst each other and with the superior command is presented together with the key technologies that are required to implement such architectures. The paper closes with a short summary and an outlook.

2.0 MULTI-PLATFORM SENSOR OPERATIONS

2.1 General Aspects

For the evolution of multi-platform sensing, there are two general options: The first option is to deploy multiple sensors of the same kind on multiple platforms and basically use the resulting output data for data fusion. Joint resource management improves the performance [1] due to reduction of redundancy but does not have to be realised to deploy such a system. In the following, we refer to this kind of system as a **coordinated sensor system**. The requirements resulting from this kind of coordination are time synchronisation in the order of milliseconds, geometric synchronisation in the same range as the required target localisation requirements, resource management on task level and data links between the platforms need typical performance (link capacity to transfer plot data with latencies in the order of 10ms).

The other option is to combine multiple sensor frontends together with a joint signal processing to form a new sensor. A bistatic radar may be used as an example for this type. This enables a number of features that are not possible by high level data fusion. Obviously, the hardware requirements for such a deep integration are much higher especially with respect to coordination and synchronisation. This type of system will be referred to as **multi-platform sensor** as it cannot be divided into single platform sensors without losing its functionality. The requirements resulting from this kind of sensor integration are time synchronisation in the order of sub-microseconds, geometric synchronisation in the same range as the required target localisation requirements, resource management on job level and data links between the platforms need high performance (link capacity to transfer jobs, plot data with latencies in the order of milliseconds).

Typically, the systems mentioned above will not exist strictly separated from single sensor systems. In a real environment, the individual sensor frontends will operate as single platform sensors, coordinated sensor systems and multi-platform sensors depending on the situation and mission requirements. This results in requirements not only on the multi-sensor level, but also on the sensor level itself, because the sensor resource management has to consider the multi-platform tasks and jobs in between its single platform tasks and jobs. This all has to be done without introducing delays due to synchronisation gaps that would reduce the overall performance of the sensor. Another aspect is the synchronisation of flight paths that must be coordinated between the multiple platforms in a way that all tasks of the platform can be accomplished with the required quality. Additionally, for active sensors, the multi-platform resource management also has to consider mutual interference. As data links will be RF-based for the foreseeable future, these contribute to the interference scenario as well and consequently will need to be coordinated together with the RF-sensors occupying the same RF-spectrum.

With all these general challenges, the problem space spans over many dimensions and therefore a highly sophisticated management of these new multi-platform sensor systems is required. This demands new approaches for sensor and multi-sensor resource management beyond the currently established rule-based or quality-of-service based approaches.

The following sections will give a short overview of coordinated and multi-platform sensor systems.

2.2 Radar Aspects

Depending on the operational requirements and the available synchronization between the involved platforms, different operational modes of a multi-platform radar system exist. *Non-coherent operation* of a multi-platform radar system is achieved by the coordinated usage of several monostatic radars located on different platforms.

However, *coherent operation* requires a higher degree of synchronization between the systems located on different platforms. Coherent operations can be implemented in a bistatic setup, in which the transmitter and receiver are located on different platforms. Also, the monostatic measurements of different monostatic systems can be processed coherently to obtain additional information (see [2] for an example). The following sections give a brief overview of potential applications of non-coherent and coherent multi-platform radar systems and also outline the challenges to be tackled for their implementations.

2.2.1 Expected Operational Benefits

Non-coherent radar processing from monostatic radars: For a non-coherent processing of multi-platform, monostatic radar systems, each system operates independently as monostatic system, but their operations are coordinated in order to maximize their efficiency. Different schemes might be used to maximize the overall efficiency. An **optimization of search regimes** can be applied to minimize the revisit time. The complete area of interest might be split and assigned to the individual systems such that the average burst length required to reach a required probability of detection is minimized. This would then in turn reduce the revisit time compared to an individual operation of the involved systems. A different optimization strategy of the search might be that spatially distributed systems look to the same part of the area of interest at the same time. This can be exploited to a faster characterization due to measurement of the same target from different angles and potentially within different frequency regimes. Although the detection range might be increased by using detection schemes as *m* out of *n* and hence by increasing the probability of false alarm of the individual systems.

Non-coherent operation of monostatic radar systems can also be used to **increase the robustness** of the combined system. Increased robustness is reached by coordination of the emission to degenerate the effectiveness of adverse ESM and/or jamming systems. Additionally, in case of a failure of one of the systems, the remaining ones can take over the task and ensure that the mission tasks are fulfilled.

Coherent processing: In case of bi-/multi-static radar operation, i.e. the transmitter and receiver of one radar system are on spatially separated platforms, additional operational benefits can be exploited. **Protection of high value platforms** can be implemented by using the platforms to be protected as receiver. Operating as receiver this allows those platforms to perform radar measurements while remaining invisible for adverse ESM systems. Spatially distributed receivers also enable the use of just one transmission to obtain more information compared to the monostatic case and hence allow to **reduce the total amount of RF emissions**. The additional information might be observation of one target from different aspects angles. Alternatively, the different receivers might also operate in different modes and to obtain complementary information. For example, one receiver can operate as moving target indicator, while a second receiver can use the same transmit pulses to operate in an imaging mode. For A/G modes the additional geometrical degrees of freedom also allow to implement **clutter tuning**. To this end, the flight path of the transmitter and receiver can be chosen such that the echo of the ground clutter is at a deliberately chosen position within the range doppler map. A bistatic setup also allows **more flexibility in the flight path planning**. In a monostatic setup, SAR operation is effectively only possible in a side-looking geometry. Hence, a SAR image of an area of interest (AOI) cannot be taken while approaching this area directly. In a bistatic setup the flight paths of the transmitter and receiver can be chosen such that the receiver is approaching directly the AOI. Bistatic radar operations also have the potential to enable the **detection of stealth targets**. Stealth platforms are designed to minimize their monostatic RCS. Typically, their bistatic RCS for sufficiently large bistatic angles is significantly larger than the monostatic RCS. [3] Coherent processing of the data of different monostatic systems enables to obtain additional information. For example, an **increased resolution** can be achieved if the measurement of data of several monostatic systems operating at different frequencies is combined to obtain data with an effective bandwidth larger than those of the individual systems.

2.2.2 Challenges

Non-coherent radar processing from monostatic radars: As for the non-coherent processing the involved radar systems are operating as monostatic systems, on system level no changes are required compared to the operation as individual system. The challenges to overcome are the combined management of the sensors. A resource management of the system of radar systems is required to enable their effective usage. The resource management has to be implemented as multilayer resource management with layers for the collective management and lower levels for the individual sensors.

Coherent operation: Similarly, to the non-coherent case also for the coherent operation a multilayer resource management is required. This resource management has to allow to take decisions on the different layers and shall enable an effective usage of the all systems both as monostatic and as bi-/multistatic systems. For bi-/ multistatic radar systems the achievable performance also depends critically on the flight paths of the involved systems. Hence, a close cooperation between flight path planning and sensor management must be implemented in order to enable an efficient usage of the sensors. Coherent operation also requires synchronization of the involved platforms in space and time. The specific conditions depend of course on the actual mode, but typically challenging synchronization requirements must be fulfilled. Hence, dedicated synchronization methods must be implemented, and those methods have to work reliable even in very challenging environments. If also an absolute phase synchronization is required, as for example in the above-described increased resolution mode, the synchronization becomes even more challenging.

2.3 EW Aspects

The objective of Electronic Warfare is the control of the electromagnetic spectrum. In order to achieve this goal, multi-platform EW operations are expected to be very beneficial, especially in the case of networked operations of the adversary. The following two sections describe the expected operational benefits and the challenges for multi-platform “Electronic Support Measures” and multi-platform “Electronic Counter Measures”, respectively.

2.3.1 Multi-Platform Electronic Support Measures

The goal of Electronic Support Measures (ESM) is to successively receive electromagnetic radiation, to identify signals of military interest and to gather intelligence about them. The development of concepts for multi-platform ESM systems depends on the objective one wants to accomplish. By using multi-platform ESM, different objectives are possible.

By using more than one platform, the reconnaissance area of an ESM system can be expanded. However, in this case the sensor of a single platform still acts independent and the coordination between the different platforms is limited to the assignment of a certain reconnaissance area and operational mode of each sensor. The individual platforms collect data, which is exchanged to obtain a situational awareness of the combined reconnaissance area of the platforms. Therefore, this approach resembles a coordinated sensor system, which is for example realized by “Cooperative Electronic Support Measure Operations” (CESMO). CESMO is a digital protocol which is defined in NATO Standardization Agreement (STANAG) 4658 to support Electronic Warfare. By sharing CESMO information all systems on a network get a consistent view of threats and friendly forces. This results in a better common operating picture.

If the same sensor is present in the same reconnaissance area, an improvement of data quality is accomplished by using specialized sensors. This is possible by overcoming the physical limitations of a single sensor. An example for such a system could be direction finding which relies usually on a large antenna base, i.e. a larger antenna base enables an improved direction finding capability. By employing sensors on distributed platforms, the size of the antenna base is then defined by the distance of the platforms. This can lead to a higher precision of direction-finding measurements. Techniques, which can be employed to realize direction finding by passive emitter tracking (PET) are based on TDOA/FDOA (Time/Frequency Difference of Arrival) measurements. However, to realize such measurements in a multi-platform environment, several requirements need to be fulfilled as outlined in Sec. 2.1.

2.3.2 Multi-Platform Electronic Counter Measures

Depending on the role of a certain platform, different tasks regarding Electronic Counter Measures (ECM) have to be performed by it. E.g. a platform outside the missile engagement zone can perform a stand-off jamming task for other friendly platforms. In contrast, stand-in jamming task is performed by platforms which are deep inside the enemy territory to protect other friendly platforms. As such a task is very risky for manned aircraft, this task is usually assigned to UAVs (Unmanned Aerial vehicles). Other possible tasks are (Modified) Escort Jamming and Self-Protection Jamming.

For all these tasks, different types of jamming are possible: The aim of Noise Jamming is to saturate the radar receivers of the adversary and to blind them to deny the radar operation of the enemy. Cover Jamming is used to mask the skin echo of the own or other friendly platforms with appropriate jamming pulses to prevent the detection of the protected platforms. The aim of Deception Jamming is to generate a number of credible false targets for the radar of the adversary. This is usually done by employing a DRFM (Digital Radio Frequency Memory) to create jamming pulses, which are as similar as possible to a real target. In this way, the radar receiver and processing resources are occupied and also the operator is kept busy to handle this situation.

By using multiple platforms for Electronic Counter Measures, this enables several new opportunities. As already discussed for sensors, we can also distinguish for ECM the case of just a coordinated system and a cooperative multi-platform system. In the case of a coordinated system, jammers on several platforms coordinate their activities towards common targets. Therefore, a higher-level threat management is necessary to coordinate the task, which jammer engages on a certain target. If there is just one target, the assignment of certain jamming techniques to each platform enables a higher jamming efficiency in comparison to independent platforms, which might result in a combination of jamming techniques that mutually cancel each other. However, for the reason of interoperability, it might even be necessary in the case of several targets to assign certain jamming techniques to each platform.

A cooperative multi-platform ECM system can apply cooperative (or distributed) techniques. In this case, jammers on several platforms are able to apply collaborative jamming techniques. An illustrative example would be a Cross-Eye Jamming like technique, where platforms have to exchange received signals of a target and transmit these signals in an appropriate way. To realize such kind of system is very challenging and in addition, several requirements regarding data links, synchronization… as outlined in Sec. 2.1 need to be fulfilled.

If one wants to apply a cover pulse jamming technique or a deception technique and if the adversary employs a networked system, it is very important to apply ECM techniques that are consistent for all systems in the network. Otherwise, it is quite easy for the adversary to identify targets as a jamming technique might be functional for just one system in the network. An example would be e.g. the failure of a deception technique as false targets are only visible for one system. Using a cooperative multi-platform ECM system, the implementation of jamming techniques consistent for all systems in a network is possible.

In summary, multi-platform ESM and ECM are important concepts for a future system. Although the requirements to implement multi-platform techniques are quite high, one can expect a significant advantage in EW and is therefore well-prepared to control the electromagnetic spectrum. In contrast to individual platforms, a better performance is expected by applying multi-platform ESM and ECM techniques.

2.4 EO/IR Aspects

Passive Targeting and Geo Location

The increased complexity of targeting scenarios and identification before targeting, improved efforts in countermeasure principles as well as improved short air defence capabilities create the need of stealthies in inbound track, target selection and attacking. Passive optical systems offer a target identification in medium and short distance but are limited due to atmospheric constraints. The main drawback of single passive sensors is the missing range information to the target and therefore a reduced precision to fulfil any Geo Location task. Limited platform sizes and SWaP (size, weight and power) as well as the aerodynamic shaping of airborne platforms constrains the installation of stereoscopic view systems with suitable base length for accurate ranging. Therefore, algorithmic solutions by comparing the measured target image size within the expected size deliver a rough range estimation but the accuracy for targeting and Geo Location in such a way is not mature enough.

The usage of platform distributed EO/IR sensors mitigate this drawback and allows precise ranging and Geo Location of an object. The scenario is illustrated in Figure 1 by an example of two fighter jets and one remote carrier observing and tracking a ground tank.

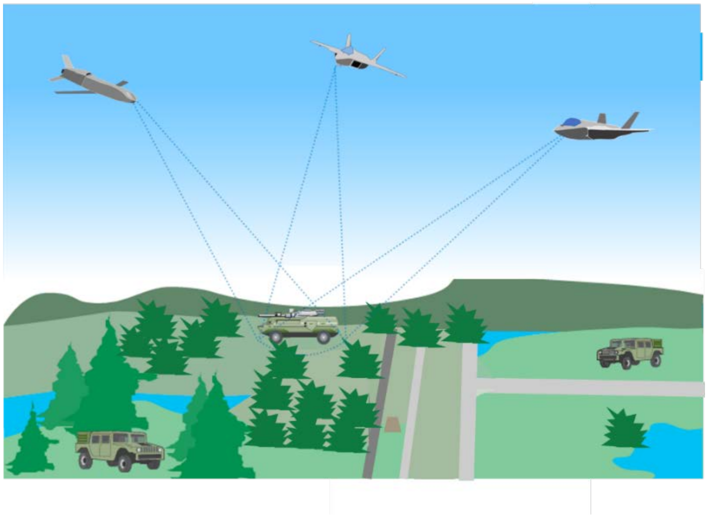

Figure 1: EO/IR Triangulation example realized by two fighter jets and one remote carrier

Each platform observes the object on ground and transfers its own position, its attitude as well as the observing angles of the target to the others. Using real-time triangulation algorithm technologies, the range as well as the Geo-Position of the target can be determined by this distributed sensor information. Therefore, a high position and attitude accuracy of each involved EO/IR platform as well a very precise time synchronization of the data is necessary to achieve an accurate measurement. The configuration shown in Figure 1 is similar to a coincidence rangefinder with large and variable optical bases of the detecting sensors. This offers the potential for a very high accuracy without emitting any kind of radiation to the target.
Such kind of configuration can also be constructed by different types of EO/IR sensors with individual characteristics as shown in Figure 2. For example, high altitude platforms (HAP) can be used for covering a large area on ground and are able to detect and analyse moving targets by an optical Wide Area Moving Indication (WAMI) sensor. A lower flying Remote Carrier (RC) will perform the target identification before the man in the loop-based fighter jet initiates the attacking. Depending on the complexity of the scenario the number of platforms and sensors can be adapted to the needs.

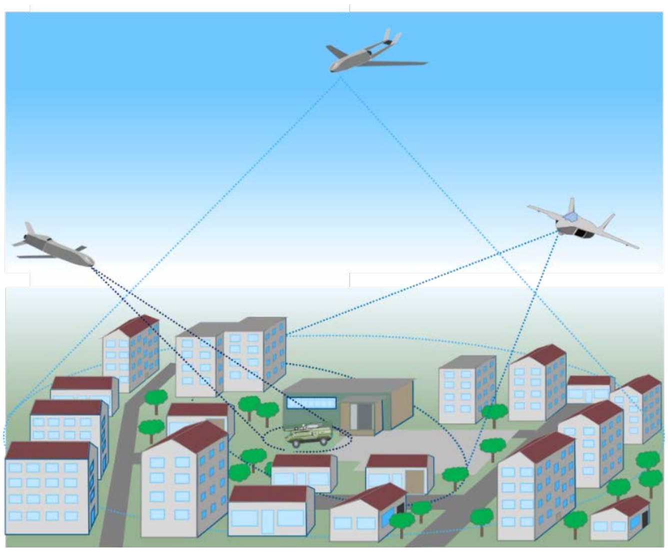

Figure 2: Homogenous distributed EO/IR scenario with different types of EO/IR sensors

Operational benefits

The large variants of effector types in short range air defence systems (SHORAD) increases the danger during identification and attack phase of the air strike, therefore stealthiness and passive operation will become more and more important in future air strike scenarios. One of the potential solutions to overcome this could be passive identification and targeting. The needed short or medium operational ranges of EO/IR systems offer high potential for a passive target identification to avoid the drawback of an active optical or RADAR range finder to determine a suitable target position. This active signal could be recognized by the target and the nearby SHORAD can be concentrated to the direction of the source.

The usage of distributed EO/IR sensors offer the possibility to perform a high accurate determination of target position without emitting signals in the direction of the target. Consequently, the target is not able to recognize the targeting procedure. Even if the involved platforms are recognized, it is not clear for the adversary which platform is operating and the SHORAD has to spread its effectors to all reachable platforms.

EO/IR sensors are limited by atmospheric effects, clouds, fog, dust and sun and always need a line-of-sight direction to the object of interest. So, the platform position determines the possibility and quality to investigate an object by EO/IR sensors. By the usage of distributed sensors located at different positions in the scenery allows a selection of the best positioned sensor achieving the highest data maturity to fulfil the task.

The usage of different EO/IR sensors, adapted to specific needs, offers additional information of the scenario, the target behaviour and hypothesis about the target position to a dedicated time. In the example of Figure 2 the WAMI offers a complete situational awareness within the covered region. This allows to follow objects of interest with hazard potential in the scenario as well as it maps tracks and analyses the target speed, direction and behaviour. With this additional information, the best position for identification and tracking by the RC can be chosen and the fighter jet can plan the most successful trajectory and schedule for the attack.

Challenges

The required accuracy for the range measurement or Geo-Position determination needs a time synchronization between the involved sensors. The position of the platforms, their attitude as well as the direction of detection must provide an accuracy level high enough to fulfil the needed precision for the targeting.

In case of ranging and tracking a fast-moving object (e.g. ATA targets), data acquisition- and detection processing-time as well as communication latencies must be low enough to achieve the necessary update rate and accuracy of the results.

The image data collected by each sensor will lead to high-speed low data rate communication links between the platforms. Transmission of a real time image or video communication within disturbed air strike areas seems to be not realistic, and the communication will be limited only to essential information exchange. So, the detection processing and coordination to attitude data has to be done at each platform to reduce the amount of exchanged data.

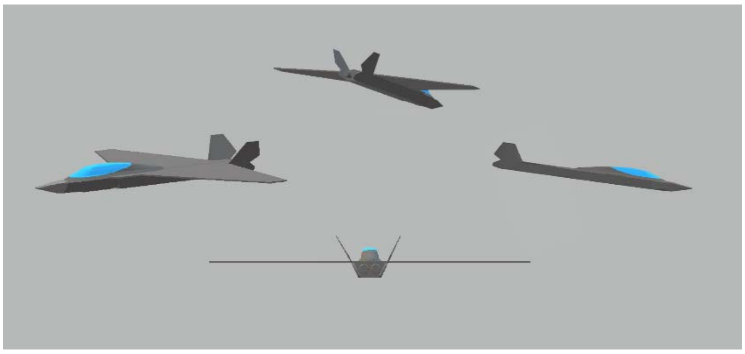

Figure 3: Example of different aspect view examples of a simple 3D A/C model

The different position of the platforms and the generated different aspect angle to the target object will generate divergent images and outline pictures of the target (see Figure 3). So, an aspect angle independent object detection algorithm as well as accurate 3D information of the potential objects of interest build the major challenge for this technology. Even if an object is partly covered or camouflaged. In the use case of different EO/IR sensor types, the specific optical aspects and characteristics have to be considered as well.

3.0 NETWORKED MULTI-PLATFORM ARCHITECTURE

3.1 Motivation and Central Challenges

The technical capabilities of new sensor technologies discussed in the previous chapters offer new operational possibilities and mission opportunities. But to enable those possibilities and opportunities and to unleash the full potential of future multi-sensor multi-platform operations new architecture solutions for networked sensor integration are required. Future airborne systems like the 6th generation of fighter aircrafts will face a new paradigm on future battlefields. Upcoming enemy systems will rely on networked and collaborative operation capabilities trying to establish superiority and dominance of the electromagnetic spectrum (EMS). Therefore, a new architecture approach for the sensors & non-kinetic effector suite will be required to grant own success in future air combat operations. That means, sensors cannot remain isolated elements that just collect measurement data. They should act in a coordinated and reactive way based on service requests from the Combat Management System (CMS) transforming measurement data via refined/improved information into reliable and consistent knowledge.

The sensor architecture principles proposed in this article will take these challenges and requirements for the future sensors & non-kinetic effector suite into account. In concrete terms: Our architecture approach propagates the smart distribution of capabilities and the consequent sub-delegation of responsibilities within a network centric, collaborative group of operational entities. A task allocation within the group is based on the associated task priority, e.g. the use of a Radar to scan an area of interest or to track a specific target. Thereby, the downstream flow of messages is to control the task while the related upstream flow of messages consists of the aggregation of requested information and status updates to establish a consistent feedback loop and control cycle. This means: The underlying general concept of the proposed network centric architecture is the principle of subsidiarity with its well-known key characteristics: (a) the level of decision-making authority is always as low as possible and as high as necessary, (b) the flexible formation building of autonomous groups and (c) an efficient self-organization. The principle of subsidiarity consequently states that higher level of decision-making authority should only (but always) intervene in a regulatory way if the possibilities of a smaller group or lower hierarchical level alone are not sufficient to solve a certain task. The Oxford English Dictionary defines subsidiarity as: “The principle that a central authority should only control those tasks which cannot be performed at a more local level”. The subsidiarity principle is in general an important concept for federal states such as Germany, Austria, Switzerland, or the United States.

3.2 Architecture Description

Future warfare will not see units fighting units but networks fighting networks. The application of the principle of subsidiarity implies that the intrinsic character of a suitable network centric architecture approach is its decentralization. Within this context decentralization means: Hold electro-magnetic spectrum operations (EMSO) up & running in contested EMS environment, fight the enemy without lowering own EMSO capabilities, enable & maintain scalability of EMSO, ensure reliable stability of EMSO and allow full-spectrum dominance. But why subsidiarity and its decentralization matter in the context of a system architecture and why should the associated network centric approach work better than a hierarchical centralistic approach? To explain the “Why” to all sceptics let us try an analogy about the benefits of a decentralized network centric system architecture: The football match.

A football match is a fairly complex ball game with time critical dynamics. Surprisingly, once kicked off, it works without a centralized management for all issues taking place during the match. The organization of a running match is decentralized and network centric: the coach (in his coaching zone) just gives general guidelines, and the payers must be able to network to each other in order to adapt the “service request” from the coach with respect to the game dynamics. They will win the match because the individual players don’t ask: “What next?” – but instead they anticipate the particular situation and establish forward-looking actions based on guidelines of the coach.

This real-life example of a system architecture which follows the principles of subsidiarity brings just another very important aspect in to play: Service requests as a control structure. Future 6th generation fighters will be systems of systems, built on individual systems that are themselves highly complex and with long running lifecycles. To master the overall complexity and maintain consistency of the overarching architecture during design, development, operational use, and upgrade cycles, the underlaying architecture principles should promote low-coupling, ease of integration, interoperability, and reuse, while accommodating integration of legacy systems that may persist for decades after the new fighter aircraft system entry into service. This can be achieved by the principle of Service-oriented Architecture (SoA). For designing defence means, services are the cornerstone of interoperability and capability development supported by the NATO Architecture Framework (NAF) and others architecture methods. Service-oriented Architecture (SoA) is centred on the services provided by system components. These services wrap-up specific functionalities that can be accessed locally or remotely by service consumers and updated independently within a decentralised network. In a SoA approach, a service has the following key properties: (a) it logically represents a set of activities that has specified outcomes, (b) it is self-contained and defined independently from its uses by consumers, (c) it may be composed of other underlying services, (d) for its implementation, it is a black box for its consumers, meaning it encapsulates its own structure and internal logic, that consumer do not have to be aware of. Services are defined by what they provide to their consumers (outcome, interface with income, service contract), not by how they realize their intended outcome.

With (a) the principle of subsidiarity and its decentralised network-centric approach and (b) the principles of a service-oriented architecture the remaining third cornerstone of the proposed architecture principles incorporate three important architecture design drivers. The purpose of the architectural design drivers is to establish a set of properties which shall drive the architectural system design and provide guidance for decision making during the actual systems engineering activity of architecture creation.

Flexibility: The architecture should support modifications (e.g. internal sensor modifications, new sensors addition, service modifications, etc.). Innovations in equipment should be integrated quickly and easily by using well defined interfaces.

Scalability: Is the property of the architecture to cope with a large number of sensors and functions and the ability to compensate for a greater data load by using distributed resources to return the most beneficial information according to the related service request.

Resilience: The architecture should be adaptable to unexpected events, failures, or communications issues (e.g. jamming, etc) by re-scheduling tasks, resources and services if necessary.

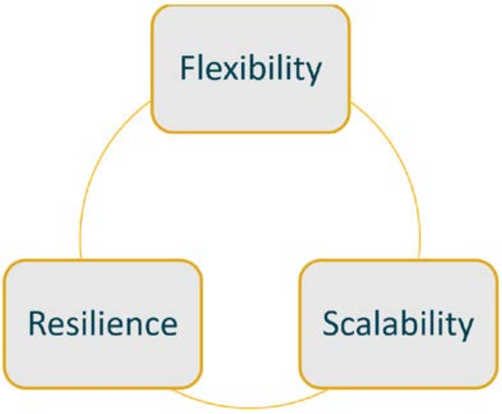

Figure 4: Architecture design drivers

The proposed architecture principles do allow small or big scale system compositions of assets. Therefore, there are no limitations on platform types or the number of sensors. To achieve this the proposed architecture has a consequently decentralized decision finding process on the lowest possible level, which is based on an advanced de-conflicting mechanism. To support this and to enable a maximum of flexibility and resilience the data flow and information usage in the distributed sensor network is not prescribed by distinct connections. Instead, all entities are connected by a network and can exchange data and information in any structure. This allows a flexible restructuring of the network in reaction to external conditions, or internal events and status.

3.3 Application Example

A brief example will be used to explain how paradigm change from direct command to directive control might look. In order to enable individual elements to continuously align themselves with the mission objectives, significantly more information must be distributed at the beginning of the mission and the selection and equipping of air assets must be improved in terms of flexibility. For this example, we use a platform with a radar and another platform with an IR system. Mission tasking will be done with so-called service requests that contain in this example only an area in which air targets are to be searched. The threat classification is considered low and there is no EMCON limitation. The expected air targets of interest are roughly known as well as the own armament and the environmental conditions. The air targets are to be attacked upon clearance. In this example the service request is distributed to all platforms with the same mission priority.

From these operational directives the first technical requirements can be derived. From the own armament the necessary probability of detection and the necessary track accuracy can be derived. For a release of the weapons a certain quality and depth of the classification of the target is necessary. This first derivation gets the same mission priority as the service request. To keep the example simple, we focus on the Surveillance function, which further breaks down the task for the sensor system. Therefore, we have the tasks for the sensing with the priority from the mission objective:

1. scan the area/volume ➔ acceptance condition: probability of detection.

2. guide targets ➔ acceptance condition: tracking probability, kinematic accuracy.

3. classify targets ➔ acceptance condition: classification depth and quality (e.g. platform specific type with a certain confidence).

Task 1 is an area related task, while 2 and 3 are target related tasks which are created and evaluated per target. Initially, task 1 is fulfilled by both sensor systems and reported by the sensor manager. This status information leads to a local gradation of the priority of task 1 in the resource manager of the surveillance function. The recognition of a target leads to the first competitive situation, which is evaluated and solved in the sensor manager as he is the only one who can estimate the costs for a technical task. The profit for the mission goal is defined as the combination of mission priority and estimated technical quality. The cost of a technical task is the exclusive duration of the action. The ratio of gain to cost is used to find the best overall result. It should be noted that the sensor manager is able to combine technical tasks that can be executed simultaneously, this is also called Tetris planning. For the radar, the emerging target means immediate further scanning. The rationale behind is the additional gain for task 2 is offset by a low cost and task 1 can continue to be fully completed. Failure to achieve the kinematic accuracy as well as the classification result leads to a local increase in priority for task 2 and 3 for this objective. A similar situation applies to the IR system. The evaluation at the network level with the fusion of the measurements from the radar and the IR system finds the kinematic accuracy to be sufficient in terms of the target but not the classification result. This leads to a local devaluation of task 2 and an upgrade of task 3 for this target triggered by the network level resource manager. The IR system needs a different angle to improve its result for task 3 and sends a corresponding request to the mission planning which includes the task priority and the possible relative position changes. The radar is faced with the decision to schedule a very expensive HRR (High Range Resolution) acquisition to improve the result for its task 3 in return for which it would not continue to perform task 1 anymore.

The example has been extremely simplified and shortened and is only intended to illustrate the abstract process. In a real mission planning, there are many service requests that are handed over to the platforms with different priorities.

With this method, consistent attention is paid to making decisions as close as possible to the sensor. This requires more information to be exchanged in advance, and planning prior to deployment is more complex. The big advantage is stability and responsiveness to external influences. We do not have to rely on a connection to a higher authority that distributes commands at very short intervals. A break of such a connection only leads to a non-optimal adjustment of priorities. Thus, the individual components of a system remain highly reactive and can adapt to changing influences in the sense of the mission. Environmental influences become directly visible during the measurement and can be directly taken into account to compensate model assumptions. Complex synchronization and feedback mechanisms are significantly reduced by the various control loops.

3.4 Key Technologies

In order to implement the presented architecture principles, different technologies are required. The following list summarizes the most prominent ones into four domains:

Technology Domain 1: Enabling Technologies: Robust communications for data and information exchange between platforms and reliable, robust and precise PNT (positioning, navigation, timing), including synchronisation between platforms form the basis of all technologies and techniques mentioned above.

Technology Domain 2: Robust Single Sensor Technologies: Sensor Resource Management must be flexible enough to perform single sensor tasks together with the capability to incorporate multi-sensor tasks in its timeline.

Technology Domain 3: Robust Distributed Decision Making, Resource Management and Data and Information Fusion: Distributed decision making and resource management without hierarchy and single points of failure and integration of the different sources in a distributed manner without introducing data incest [4].

Technology Domain 4: Robust Distributed Data and Information Processing: Having the required data and processing power on the right platform without moving large quantities of data.

4.0 CONCLUSION AND OUTLOOK

In this paper different multi-platform sensor technologies have been summarised that are currently finding their way from academia to actual product implementations in future military airborne systems. These technologies will contribute with new capabilities to the sensing environment like enhanced capabilities to detect low observable platforms together with the capability to see without being seen in a multi-spectral way by considering active RF sensors like electronic warfare and radar and electro optical sensors. It has been shown that the sensors form the foundation of a new network centric, de-centralized architecture approach to exchange information and control multi-platform operations following the principles of subsidiarity. However, new technologies are required to implement this architecture in a fully dynamic airborne environment. With a stable implementation, it is conceivable that the proposed architecture will not only be applied to the challenging airborne environment but enhanced to contain a multi-domain sensor network integrating all available sensors into one network.

REFERENCES

[1] Nadjiasngar, Roaldje & Charlish, Alexander. (2015). A Performance Model for Target Tracking with a Radar Network. 10.1109/RadarConf.2015.7411887.

[2] K. M. Cuomo, J. E. Pion and J. T. Mayhan, "Ultrawide-band coherent processing," in *IEEE Transactions on Antennas and Propagation*, vol. 47, no. 6, pp. 1094-1107, June 1999, doi: 10.1109/8.777137.

[3] M. Cherniakov: “Bistatic Radar: Principles and Practice”, 2007, Wiley

[4] McLaughlin, S. & Krishnamurthy, V. & Challa, S.. (2003). Managing data incest in a distributed sensor network. 5. V - 269. 10.1109/ICASSP.2003.1199920.