NATO Cooperative ESM Operations:
The Present and the Future

R. Thaens, F. Fiore, and M. Schmidt
NATO C3 Agency
P.O. Box 174
2501 CD The Hague, The Netherlands
E-mail: rene.thaens@nc3a.nato.int, franco.fiore@nc3a.nato.int, martin.schmidt@nc3a.nato.int

ABSTRACT

NATO and allied forces will be exposed to highly lethal but difficult to detect hostile air defence systems. Single ELINT collectors will not be able to geo-locate these threats anymore, but are able to share their detection data for triangulation purposes. During Trial Hammer 2005 a concept of operation for real-time triangulation was evaluated. Based on the results, NATO is currently scheduling another trial, Trial Spartan Hammer 2006, to refine cooperative ESM operations by using automated tools and data links. This paper describes the current developments of cooperative ESM operations in NATO.

1 INTRODUCTION

The modern battlefield shows the proliferation of so-called ‘integrated air defence systems’ (IADS) employing highly intelligent use of the radio frequency (RF) spectrum via elaborate low probability of intercept signals. These IADS can often relocate within ten to twenty minutes after the last transmission, rendering them extremely lethal due to their high mobility and low detectability. Countering the threat of such IADS requires allied forces to work together in locating and identifying these systems with a high accuracy within ‘single digit’ minutes. Currently, most of the stand-alone collecting platforms or ‘collectors’ often lack the means to geo-locate these IADS effectively. The only solution for the near future is to combine measurements from multiple platforms in order to calculate the emitter’s position. As the most lethal threats cannot always be timely identified by single platforms anymore, it is mandatory to employ a network centric / network-enabled approach via combining the efforts of many platforms, even if these platforms have had very little exposure to the threat emission.

1.1 THE MODERN THREAT

On 2 May 1999 an US Air Force F-16CJ, call sign Hammer 34, was shot down over Serbia by a Russian build SA-3 Goa missile while participating in Operation Enduring Freedom. Although the coalition forces held air supremacy in this part of Serbian air space, this could not prevent the loss of the F-16 to an anti-aircraft system dating from the 60’s. This example shows how such systems still pose a threat and will continue to do so to NATO platforms during operations.

Since the SA-3 entered service in 1961, many technological developments have led to the current generation of air defence systems. The philosophy behind air defence has shifted from stand-alone systems to a network-centric approach. Although these systems operate autonomously on a tactical level, they share a single air picture via communication links. All independent systems contribute to the maintenance of this air picture, which lowers
the overall activity level of the participating emitters. In addition, new technologies like tactical data links, advanced antenna technology, low probability of intercept (LPI) signals, etc, will reduce the RF footprint of these IADS even further. As such, the detectability of modern IADS has significantly decreased while the lethality has gone up.

Aside from the technical improvements of both IADS sensors and weapon packages, the newest generation of systems has the capability to relocate within very short time frames. This allows highly dynamic concepts of operations in which the air defence system receives the air picture, singles out a target, emits briefly to get an update on this target, engages and relocates, all within 15 to 20 minutes after deployment to a new position.

1.2 NEED FOR COOPERATION

Emissions from these air defence systems can be used to calculate the actual position of the emitter. Many approaches have been proposed to calculate the position of an emitter, but most of the calculations are based on the availability of multiple measurements of the angle-of-arrival (AoA) or the time-of-arrival (ToA) of the signal.

A measurement of the AoA is called Line-of-Bearing (LOB) from receiver to the target. Multiple LOBs originating from various receiver positions, can be combined into a position estimate through a process called triangulation. A similar approach can be taken for multilateration techniques using ToA or it’s derivates like time-difference-of-arrival (TDoA) or frequency-difference-of-arrival (FDoA).

In the absence of noise and measurement errors, the calculated target position will be a single point. In reality, the target position is usually expressed as an error ellipse around the most likely target position. The dimensions of the ellipse come from an error propagation applied to the original noise and measurement errors in the AoA [1]. The ellipse on the map around the most likely target position is a projection of the ellipse in AoA space onto the map.

Using more measurements from different receiver locations will reduce the size and orientation of the error ellipse. In case of a single receiver, this platform needs to move a certain distance while taking measurements in order to achieve a desired accuracy in the position estimate. Travelling this distance requires time, during which the emitter needs to stay active.

As described previously, modern IADS are characterised by short and difficult-to-detect-emissions, preventing receiving platforms to have ample exposure time to the emitter signal for accurate geo-location. The thus collected set of detections by a single receiver could prove insufficient to geo-locate the threat or to achieve accurate results in case geo-location is possible.

Combined datasets from multiple collectors on the same target could allow for geo-location or improve the accuracy of the coarse geo-location of a single collector. The multi-platform effort is captured under the term ‘cooperative geo-location (C-GLOC)’. When based on Radio Frequency (RF) signals only, NATO refers to C-GLOC as ‘cooperative Electronic Support Measures operations (CESMO). Without C-GLOC many modern hostile emitters cannot be found by single platform collectors, thereby limiting the overall success of NATO operations and endangering participating units. The proliferation of modern IADS forces NATO to reconsider its current policy and capabilities for C-GLOC to effectively deal with this treat, as demonstrated earlier by the loss of Hammer 34 in 1999.
1.3 THE SITUATION IN NATO

Many North Atlantic Treaty Organization (NATO) nations currently employ electronic intelligence (ELINT) or electronic support measures (ESM) platforms capable of detecting, identifying and geo-locating ground-based emitters. Generally, the data on hostile emitters is refined by the collecting nation prior to being shared with other NATO nations. In some cases the information is considered too sensitive to be disclosed directly to other nations, thereby delaying the exchange of relevant battlefield information between allies for reasons considered more important.

In 2003 NATO established the so-called ELINT/ESM Ad Hoc Working Group (EEAHWG), a task force focusing on improving the ELINT/ESM support to ‘Suppression of Enemy Air Defense’ (SEAD) missions. SEAD missions are the lethal answer to a geo-located enemy emitter, in which fighter aircraft like US F-16 CJ or German or Italian Tornado ECRs are actively engaging the emitter or air defence site (fig. 2). Before SEAD aircraft can be tasked, the ELINT/ESM platform needs to have achieved a specific accuracy in the geo-location of the target. With this minimum accuracy, SEAD aircraft can autonomously search and destroy the air defence site before the site is able to respond.

In the first one and a half year of its existence, the EEAHWG designed a procedure for C-GLOC in NATO, proposed a NATO standard for exchanging ELINT/ESM data and organised a successful life flying trial to put these results to the test. This trial was baptised ‘Trial Hammer 2005’, in honour of the crews involved the rescue of the ‘Hammer 34’ mission in 1999. Section 2 of this paper describes some of the results of Trial Hammer 2005, followed by section 3 on Trial Spartan Hammer 2006 (TSH06). TSH06 is the successor to TH05, in which the use of voice data communication for C-GLOC will be replaced by tactical data links. Section 4 will look a little further into the future and describe some of the aspects NATO will face when expanding the C-GLOC capability even further.

Figure 1 RAF Nimrod R.1, ELINT platform

Figure 2 F-16CJ SEAD aircraft
2. **TRIAL HAMMER 2005**

The first NATO wide trial on cooperative geo-location took place in April 2005 in the vicinity of Ramstein Air Base, Germany. During this trial, several ELINT/ESM platforms from various NATO nations have shared near-real time collector data in order to find the positions of a variety of emitters. These emitters adhered to a strict emission schedule to facilitate the data collection and data analysis of cooperative geo-location after the trial. In order to keep this paper unclassified, detailed quantitative results from TH05 have been omitted.

2.1 **SINGLE PLATFORM GLOC**

A theoretical analysis of single platform GLOC by NC3A has shown the following conclusions [2, 3];

- Geo-location of a stationary emitter with a single, moving sensor is possible, as is proven on a daily basis in NATO.
- Accuracy of geo-location depends mainly on sensor-emitter geometry, sensor accuracy, and number of LOBs on target.
- Given the accuracy of a sensor, more LOBs lead to reduced major and minor axis sizes, although the maximum achievable accuracy is bounded
- Larger angular displacement in the set of LOBs will result in more accurate position estimates.
- The sensor needs sufficient exposure time to the emitter signal in order to geo-locate this emitter accurately.

During NATO operations, multiple collectors will be present in the theatre, quite often collecting on the same set of target emitters. Under these conditions it is a natural step to share collector’s LOB sets in order to increase the overall detection and geo-location accuracy.

2.2 **COOPERATIVE GLOC**

ELINT/ESM collecting platforms are considered high value assets and will therefore not operate in close proximity to each other. As such, the use of multiple collectors already provides a benign geometry for large angular displacement. The earlier mentioned theoretical analysis showed for cooperative geolocation that:

- Sensor positioning (angle between both or more sensors versus the emitter) influences the size and shape of the error ellipse. Increasing this angle between sensors leads to smaller and more circular error ellipses, due to increased angular displacement in the overall LOB set.
- The decrease of the size of the error ellipse in two-sensor situation as function of the angular displacement is more visible in case of high-accuracy sensors.
- Even two non-precision sensors can provide operationally acceptable results when positioned carefully.
- Under certain geometrical conditions, the results of a high-precision sensor can be improved by including LOB’s from lesser-precision platforms.

Geo-location based on contributions from more than one platform requires a robust means to exchange detection and geo-location data between these platforms. Currently not many of the ELINT platforms are equipped with data links, although many nations have upgrade programs scheduled. During the initial C-GLOC trial TH05, emitter data was shared between the ELINT/ESM platforms via voice communications channels. TH05 analysis has shown that voice communications for numerical data is highly error-prone and has a low net data rate when compared to data.
link communication. As a consequence it was not possible to use the collected trial data to analyse the timeliness of the entire C-GLOC procedure. The following section will describe a specific case observed during TH05, which clearly shows the benefits of multi-platform geo-location.

2.3 C-GLOC: AN ILLUSTRATION

On Monday, 12 April 2005, multiple platforms reported a short emission of a target from the area south of the city of Pirmasens, Germany. Of these four participating platforms, only platform P2 was able to take more than one measurement of this target and reported two LOBs. The other platforms, P1, P3 and P4 only reported a single LOB each. In such a case, none of these platforms would be able to provide a useful estimate of this particular target’s position, as in today’s world no single LOB is sufficient for geo-location. As P2 had two LOBs, it could self-geolocate the target, but the resulting error ellipse would be approximately 11 km by 600 meters. This lack of accuracy prohibits direct weapons deployment like SEAD or denial of enemy air defence (DEAD) missions against the target. Table 1 shows the collectors’ positions including the angle of the LOB measurement.

<table>
<thead>
<tr>
<th>LOB</th>
<th>PF</th>
<th>Latitude</th>
<th>Longitude</th>
<th>LOB</th>
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<tr>
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<td>E007.55.04</td>
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<td>P4</td>
<td>N49.02.52</td>
<td>E008.35.10</td>
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</table>

Table 1: Reported LOBs on 12 April 2005

These five LOBs can be displayed on the map of the area around Pirmasens, Germany (Figure 3).

Further analysis produces the results in table 2. The set of data allows for varying the level of cooperation between the collectors, ranging from single platform geo-location (only P2 with LOBs 2 and 3) via combinations of two and three cooperating sensors, ending with full cooperation between all sensors.

<table>
<thead>
<tr>
<th>LOBs</th>
<th>Long</th>
<th>Lat</th>
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Table 2: Accuracies for various combinations of LOBs
The analysis of this actual situation has shown that:

- The single sensor ‘P2 only’ solution is a rough and unreliable estimate, not usable for weapons deployment.
- In some cases, triangulation by two collectors can provide better results than some of the ‘three collector’ triangulations.
- In the case of limited observations, care must be applied when combining LOBs from a composed set. The need to be careful shows mainly in the situation where the detection geometry plays an important role: the combination P4/P3 provides worse results than P4 with P1, mainly due to the smaller looking angles of P4/P1 versus P4/P3. Operational planners or analysts need to be aware of the factors influencing the quality of the geo-location in order to choose the proper combination of LOBs for the optimal position estimate.
- As this target emitted only briefly (< 1 minute), single platform geo-location would not allow for operational relevant targeting information.

Aside from the actual quantitative analysis of this particular case, it serves as a very useful example for the added value of cooperative geo-location. These results have been achieved by conveying detection data over noise voice communication channels and by calculating the geo-location of the target manually. In order to turn this methodology into an operationally useful feature, both the issues of automatic data dissemination and geo-location need to be addressed. Therefore, TH05 will be succeeded by a follow-on trial, which will focus on an automated toolset for the collection, dissemination, and geo-location of pop-up emitters.

3 TRIAL SPARTAN HAMMER 2006: THE NEXT STEP

Members of the NAFAG SIGINT ESM Working Group (SEWG) agree that a capabilities demonstration is the proper way to test the utility of its work and to gauge the efficiency of already existing NATO procedures and CONOPs. The major aim of this demonstration will be to trial the current joint, combined signals intelligence interoperability and emerging SIGINT/ESM sensor, geo-location and communication capabilities, available to NATO to facilitate SEAD and SOF missions. The results of the demonstration will provide not only NATO planners good feedback on doctrine and systems capabilities, but also to suggest to nations what future systems may be needed.

The new demonstration is called TRIAL SPARTAN HAMMER 06 and is a follow-on activity to the highly successful TRIAL HAMMER 05 conducted in April 05. Currently, TSH 06 is scheduled for November 2006 at the electronic combat range outside Andravida Airbase in Greece. The Hellenic positive response was based on the common understanding that they can meet significant NATO and national objectives by utilizing this national exercise to capitalize on the success of Trial Hammer and highlight Greek electronic warfare capabilities to broader communities.

Intelligence, Surveillance and Reconnaissance (ISR) aircraft cooperatively will collect SIGINT and/or ESM data to build a usable NATO Electronic Order of Battle (EOB). This EOB will be based on the creation of the theatre (trial) specific Emitter Data Base. The NATO EOB will be maintained at the SIGINT Electronic Warfare Operation Centre (SEWOC) or the EWCC (EW Coordination Cell), in order to support joint headquarters’ situational awareness and missions against emitting targets. NATO organizations and nations have agreed in principle to support this
test with air assets, naval, ground assets and personnel. A trial report will be prepared upon completion of TSH06 and disseminated among the participating nations and to NATO leadership.

The evaluation of the automated CESMO procedure with the use of data links is one of the objectives for TSH06.

3.1 ARCHITECTURE

At the moment the NATO C3 Agency is addressing both the issue of the use of tactical data links and the development of a trial-toolset for cooperative geo-location. Not many of the ELINT or ESM capable platforms have Link-16 available, which would be the default data link for exchanging CESMO messages. As the installation of Link-16 is a costly event, both in time and money, alternative options have been investigated. The most likely candidate data link to support TSH06 is an IP network over RF via the use of the Improved Data Modem (IDM) and a UHF radio set. Participating collectors will be equipped with a laptop including IDM, which needs to be connected to the platform’s UHF radio. On the longer term, the laptop/IDM CESMO functionality needs to be integrated together with the collector’s on-board system for fully automated geo-location.

The setup of the CESMO network in TSH06 is depicted in fig. 6.

All participants are connected to a modern IP based network that allows point-to-point and broadcast operations.

Upon first detection of a hostile emitter by a single collector (or participant as it is called in the CESMO network), the collector starts to communicate with other platforms using an provided application on a state of the art laptop. The Lead participant will relay this first measurement to other participants, thereby requesting measurement data to start geo-locating this threat. Participants that have data on this emitter will respond with their measurements containing either lines of bearing or geo-locations together with their measurements errors. Once sufficient accuracy in the geo-location of this emitter is achieved, the Lead participant broadcasts the findings to all participants as a conclusion of the CESMO activities for this particular target. This process is repeated for every newly identified emitter.

Other processes to reach cooperative geo-locating, situational awareness messages are also implemented.

The CESMO network is not the only way of exchanging data within TSH06. Other Data Links and message exchange mechanisms are available on some of the platforms and in the SEWOC. In this moment there is no automatic handover of CESMO Messages to other networks or vice versa.

3.2 USE OF DATA LINK

When properly configured, the IDM based IP network allows for exchanging both the management messages and the actual data messages needed for CESMO. Besides the obvious benefit of reducing the latency and error susceptibility of voice communications, the use of data links opens up the opportunity to fully automate the process of combined ESM operations. This also requires the political will of nations to give the complete
control of their sensors or at least of the sensor data to a Lead participant.

3.2.1 MESSAGE CONTROL

One of the questions to be answered in this trial is, whether further mechanisms are needed to insure the integrity of the communication. Crypto features are absolutely necessary because of the confidentiality of exchanged data and are already implemented. But as it is implemented now, there is only limited message collision detection or ARQ (Automatic Repeat-reQuest) capability and no way to detect that messages were not received.

3.2.2 MESSAGE SET GRANULARITY

As soon as multiple nations participate in a common effort, some sort of standardization of the interfaces is necessary. In terms of the Cooperative ESM Operations this means that the minimum set of messages that is necessary to ensure the operations has to be determined without asking for information that could not or would not be exchanged. In addition, some sort of growth potential for future technical advances is needed.

The following list comprises the minimum list of message content that should be possible to exchange:

1. **Situational Awareness (SA) messages**
   - Reporting position, status, and intent to Lead or all participants
2. **Alerting and Tasking messages**
   - Alerting that Signal of Interest (SOI) exists to Lead or all participants
   - Tasking all or specific participants with alert or routine operations
   - Acknowledgment of task and termination
3. **Reporting** Messages for intermediate or final results containing
   - Geo-location (DF, ToA/ TDoA/ FDoA information and geo-location results with errors)
   - Signal parameter for pulse or pulse groups
   - Identification/Fingerprinting of emitter

The message set used in TSH06 will satisfy these minimal needs, while not all

3.3 PRECISION

The precision in the measurements especially in time, frequency, and navigation on board of every participating system determines the overall accuracy of the geo-location and identification process.

The usage of the results determines the needed accuracy; mixed types of sensors will have obviously different accuracy, but that does not mean that the inaccurate result from a well-placed sensor is unimportant for the overall result.

The message set definition must anyway allow for reporting of results that are orders of magnitude more precise than what some sensors can produce.

3.4 MESSAGE LATENCY

In order to get a rapid reaction on pop-up sensors the time between first detection of a SOI and tuning of other sensors to this SOI must be as short as possible; certainly, it must be much better than one minute on the average. This requirement imposes some limitations on the types of links that could be used for this. As long as humans are involved, the budget time for data link transfer should be in the order of magnitude of 1 second. Multi purpose links where different communities of interest are sharing the same connection are disfavoured as well as links using round robin access.

The number of participants can influence the latency of messages because of message
collision and the multiple times needed to send a message to each one. The use of broadcast messages instead of point-to-point; and handling of addresses inside the message level instead of the connection level is a way to circumvent this problem.

3.5 SEMANTICS

The common understanding of the information items exchanged is one of the most disregarded but nevertheless fundamental issues of data exchange.

NATO has the NATO Emitter Database (NEDB), which could be used for the purpose of definition of signal parameters. The existing or initial Electronic Order of Battle (EOB) is a good reference for already known emitters. Navigational and timing issues are tricky in their and national efforts exist to standardize them. For now, most existing sensors are not equipped with systems supporting high accuracy cooperation beyond national limits.

3.6 TOOL REQUIREMENTS

As mentioned earlier, the data exchange is not enough to deal with the requirement of rapid geo-location. Tools must be integrated into the mission system of every platform to facilitate the communication with the sensors on one side and the other platforms on the other side. These tools should also implement the Human Machine Interface (HMI) that allows the operators to make the necessary decisions.

The tools will look different depending on the situation of the participant. In general it should be possible for one platform that can be Lead Participant to operate also as a common participant. Some platforms such as unmanned vehicles or fighter aircraft might not work as Lead participant, simply because of the lack of operator time.

Ground and maritime platforms can be normal participants or Lead Participants. Their restricted radio horizon however limits their possibilities. The use of a dedicated, non-sensor equipped air, ground, or maritime station as Lead Participant is also a possibility, but probably not so advantageous for reasons explained below. However, this might be the choice if this unit represents a NATO entity.

3.6.1 AUTOMATIC PROCESSING

Not all NATO Nations are willing to share their ESM information directly, but they are not giving up control over their sensors to another Nation or to a NATO entity;

Therefore, many participants will maintain some form of operator control on what is broadcasted by their own platform. The task of ‘Lead participant’ can probably not be fully automated over the next years, because many operational decisions still require human intelligence.

3.6.2 SITUATIONAL AWARENESS

Every operator and most certainly the Lead participant should have the overview over the Electronic Order of Battle and the disposition of the participants. This requires a suited map interface.

3.6.3 GEOLOCATION

The tools must have the ability to perform geo-location calculations with complete error analysis/propagation. This capability must go beyond what is normally implemented in a platform, because the other platform might have different types of location information and might have already aggregated them.

3.7 EW/ELINT IDENTIFICATION AND CONFIRMATION

The report messages from participants might already contain identifications. Based on on-board libraries and on additional sensor
information going beyond what is transmitted via the message set, the toolset should enable the decision on the identity of the emitter.

4 THE FUTURE

Based upon our analysis of the TSH06 results, the SEWG will decide on the following topics for further standardization:

- Necessity for changes in message set
- Do we need further CONOPS?
- Type of data links that are suitable for CESMO
- Need for further trials

Depending on the answers to these next questions, Nations will start the implementation of CESMO in platforms software. It will probably take some years before a complete NATO CESMO capability will exist. However limited capabilities will hopefully be demonstrated in the trial and afterwards be available soon.

BIBLIOGRAPHY

