NATO Cooperative ESM Operations:

“Publish or perish”

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ABSTRACT

To counter the increasing threat of hostile pop-up emitters, it is important for NATO to be able to geo-locate these emitters accurately and timely. The limited detectability forces ELINT and ESM platforms to cooperate by exchanging detection data in real time. This paper discusses the current situation in NATO and introduces the concept of Cooperative ESM Operations. This concept has been designed and tested during two live flying trials and will be further refined in the near future.

1 INTRODUCTION

The modern battlefield shows the proliferation of so-called ‘integrated air defence systems’ (IADS) employing a 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 their last transmission, rendering them extremely lethal due to the combination of 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’ lack the means to geo-locate these highly mobile IADS autonomously.

The only solution for the near future is to combine measurements from multiple platforms looking at the same target to triangulate the emitter’s position. Triangulation requires real time exchange of target data between collectors, which was not an option in the past due to lack of technology like in-flight data links and a reluctance by nations to share data which has not been processed by the National Intelligence Centres first. Now data links have become available for many platforms and the Intelligence community has discovered the benefits of cooperative ELINT or ESM operations, the road is paved for further development.

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-built 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 sixties. This example shows how such systems still pose a threat and will continue to do so for 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 point to
point 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 detection capabilities and weapon packages, the newest generation of systems has the possibility 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 FINDING AN EMITTER

In case of a steady ground-based emitter, a moving collector can measure the angle of the received signal multiple times during its own movement. The easiest way is to plot the collector’s position on a map and draw lines in the direction of the emitter signal. When multiple lines are added, it becomes clear that these lines have the tendency to intersect at a certain location on the map. This location is the most likely position of the emitter, under the condition that the collector’s equipment is ideal and there are no disturbances of the emitted signal in the atmosphere. In reality, nothing is ideal and the transmitted signal is slightly changed when travelling from emitter to collector. This deviation from the perfect situation is called noise and can be seen on the map as a spread in intersections around a certain centre area. Fig. 1a shows the ideal world approach while fig. 1b depicts the expected real world situation:

Pen and paper plotting of emitters has been replaced by computers nowadays. There are many ways to calculate the emitter position, but most of the calculations are based on the angle-of-arrival (AoA) or the time-of-arrival (ToA) of the signal. A measurement of the AoA is called a Line-of-Bearing (LOB) from receiver to the target. Combining multiple LOBs in order to calculate the emitter’s position is referred to as ‘triangulation’. When using ToAs or differences in ToAs for finding a target, the general term ‘triangulation’ is replaced by ‘multilateration’. Multilateration on-board airborne platforms requires very high quality receivers, stable oscillators and high bandwidth data links connecting the participating platforms, which are currently not readily available. As such, this paper will only address triangulation, because most of the collecting platforms can determine the angle of arrival of a signal very accurately.
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 error ellipse describes the area which contains the actual emitter with a certain degree of confidence. With only a few measurements under noisy conditions, the error ellipse can have a size covering the entire continent of Europe. Once more LOBs are added to the calculation, the large initial error ellipse shrinks, narrowing down the area where the emitter can be. How the number and the quality of LOBs will influence the error ellipse, is addressed further in this paper.

Combined datasets from multiple collectors on the same target could allow for geo-location or improve the accuracy of the coarse geo-location by 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). Although the basic principle of C-GLOC stems from the early days of radio transmission research, it is a relatively new concept for NATO. Some nations and the NATO C3 Agency have explored ways to implement C-GLOC on a tactical level, which was evaluated during two trials. This paper presents some of the results as achieved by a specialised coalition of NATO ELINT or ESM capable platforms. Due to the classified nature of ELINT and ESM collection and data conditioning, C-GLOC will be treated only at a generic level in this paper.

1.3 THE SITUATION IN NATO

Many NATO nations currently employ electronic intelligence (ELINT) platforms or electronic support measures (ESM) equipped 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.

National ELINT/ESM platforms, like the Royal Air Force Nimrod R.1 in fig. 2, the US RC-135 Rivet Joint and Combat Sent, the Italian G-222, the French C-160G Gabrielle, the German BR-1150 Breguet Atlantic, the Norwegian DA-20’s and some others, are optimised to geo-locate hostile emitters based on the sensor suite on board of the individual platforms. Accurate geo-location of emitters requires sufficient exposure of the ELINT/ESM sensors to the emitters broadcasts, based on the general assumption that more measurements to the emitter will lead to higher accuracy in the estimate of the emitters position.
In 2003 NATO established the ELINT/ESM Ad Hoc Working Group (EEAHWG), a task force focusing on improving the ELINT/ESM support to ‘Suppression of Enemy Air Defence’ (SEAD) missions. SEAD missions are the lethal answer of choice to a geo-located enemy emitter, in which fighter aircraft like US F-16 CJ or German or Italian Tornado ECRs actively engage the hostile emitter or air defence site (fig. 3). Before SEAD aircraft can enter the area, 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 IADS before this site is able to respond and engage the SEAD aircraft effectively.

In the first two years of its existence, the EEAHWG designed a procedure for C-GLOC in NATO, proposed a NATO standard for exchanging ELINT/ESM data (STANAG 4633) and organised a successful life flying trial to put these results to the test. This NATO code name for this trial is ‘Trial Hammer 2005’ (TH05), in honour of the crews involved in the rescue of the ‘Hammer 34’ mission in 1999. Trial Hammer 2005 was followed by a similar but more extensive trial with code name ‘Trial Spartan Hammer 2006’ (TSH06), which, not surprisingly, took place in Greece in 2006 [3].

2 COOPERATIVE GEO-LOCATION

2.1 THE NEED FOR COOPERATIVE GEO-LOCATION

Hostile emitters will only radiate briefly to search the airspace for targets or to track an already detected target. As a consequence, ELINT or ESM systems on board of airborne platforms might detect these short emissions, without ample time to geo-locate the emitter. As a rule of thumb, ELINT or ESM platforms need to receive multiple emissions in a timespan of several minutes before a meaningful position can be calculated. IADS typically radiate in the order of tens of seconds, which means that many hostile emitters remain unfound for a single ELINT or ESM platform.

Tactical data links (TDLs) like Link-11(a/b), Link-16, Link-22, Improved Data Modem (IDM) and company proprietary TDLs like the German ODIN for the ECR Tornados have connected aircraft, ships and ground-based units. Through these data links, information generated on board of a single platform can be made available at every other participating platform in near-real time. As such, the individual ELINT aircraft hunting for a specific hostile emitter can be fed instantaneously with measurements from other platforms which happen to detect the same target during their mission(s). In a true Network Centric way, geo-locating emitters becomes a cooperative activity based upon the detection capability of the entire set of ELINT sensors in the area. This ‘system of systems’ approach creates a virtual set of many more LOBs then can ever be collected by a single platform during the time the emitter is active. In general, this set does allow for very accurate geo-location of hostile emitters to support SEAD or DEAD operations against these emitters.
2.2 TRIANGULATION

Triangulation requires a central function where the LOBs are collected and the position estimate is calculated. This central function could reside in a ground station or can be implemented on-board of one of the participating collectors. There are two different approaches towards an architecture for CESMO:

- **‘Broadcast to all’**. Every collector operates autonomously and broadcasts LOB reports over radio or data link when pre-defined ‘targets of interest’ are detected. All LOB data is made available to all collectors, who can geo-locate the target with on-board means. This ‘broadcast to all’ architecture does not require a single unit acting as CESMO Manager or CESMO Director. This situation is very effective in case of a limited number of hostile emitters to be geo-located. The advantage is that all participating platforms capable of receiving the broadcast messages are able to triangulate autonomously, which enhances their situational awareness. The main disadvantage is that an increase of target density could drive the communication channel capacity into saturation due the high number of LOB messages to be broadcasted almost simultaneously.

- **‘Directed CESMO’**. A denser hostile emitter scenario requires additional management of the individual collectors. To avoid wasting scarce resources like ELINT or ESM collectors on the battle field, the CESMO manager needs to task subgroups of collectors to hunt for specific emitters. The remaining collectors who did not have a tasking will maintain guard for pop-up emitters or can be tasked to scan for other known emitters. The rationale behind this sensor management is that a theoretical analysis by NC3A has shown that three collectors will provide a ‘reasonable accuracy within reasonable time’ and that adding a fourth collector will not improve accuracy or time to geo-locate substantially.

An LOB report usually consists of the collector’s call sign, position and time of measurement, the direction to the emitter and the accuracy of this direction report (e.g. plus or minus 2 degrees) and some parametrics on the detected signal to identify the particular emitter. Sometimes this basic message is amplified with additional operational data like the identity of the emitter (e.g. SA-8 but reported through brevity codes). Readers familiar with the ‘mudcall’ or ‘tacrep’ message formats will see the resemblance with LOB reports over a radio net.

The use of radio nets to convey verbal, numerical LOB reports has proven to be too limited for operational use. Conveying large strings of numerical data between two potentially non-native English speaking crew members on a noisy radio channel is prone to errors and delays due to required read-backs to confirm the reception of the message. On top of this error proneness, the use of voice over a radio channel is extremely slow when compared to data traffic over this same channel. As stated earlier, in case of a dense emitter environment, the radio channel capacity for voice messages does not allow timely transmission of all LOBs from all participants to the CESMO manager or to the other participants, thereby reducing the effectivity of CESMO strongly.

The use of tactical datalinks (TDL) can improve the overall success rate of exchanging emitter data between collecting platforms. Currently available TDLs, like Link-11, Link-16 or improved data modem (IDM) over Ultra-High Frequency (UHF) or Very High Frequency (VHF), contain dedicated electronic warfare (EW) words in the message libraries which can be used for supporting CESMO.

2.3 ACCURACY OF TRIANGULATION

Although a full analysis of the expected mathematical geo-location results is beyond the scope of this paper, it is worth while to mention the main contributors to the accuracy of CESMO. Some of these factors can be used by the CESMO manager to optimise the quality of geo-location, e.g. in the case where this manager assigns tasks to specific subsets of collectors. The choice of collectors belonging to this subset can make the difference between successful geo-location or no solution at all. The following aspects have operational relevance:
• Accuracy of the lines of bearing;
• Number of LOBs available for triangulation;
• Angular displacement (AD) of the emitter within the field of view of the collector. In a worst case scenario the collector hardly moves or is stationary. In this case the LOBs will be almost be identical and do not add to better triangulation accuracies. Higher accuracies require larger angular displacement. Small and large examples of ‘angular displacement’ and are shown in Figure 4.

![Diagram showing angular displacement and error ellipse](image-url)

The left hand side of fig. 4 shows an east to west moving collector taking three measurements at a target abeam the flight path. The three example LOBs are taken from closely space collector positions, resulting in an extended error ellipse with the major axis along the main direction of the LOBs. The right hand side of the same figure shows a similar setup but with three measurements spaced much wider. In this latter case the angular displacement of the target within the LOB set is much larger, which translates into a reduction in the size of the error ellipse [1, 2].

### 2.4 CESMO ‘CONCEPT OF OPERATIONS’

At this moment, NATO does not have a fully defined ‘concept of operations’ for CESMO. The SIGINT ESM Working Group under the NATO Air Forces Armaments Group (NAFAG) is preparing a Standardization Agreement (STANAG) 4658 which defines the message set to be used by tactical data links. The earlier mentioned trials TH05 and TSH06 have provided the opportunity for participating collectors to evaluate draft procedures during live flying exercises. As a result of this ‘trial and error’ design of CESMO procedures, a concept of ‘tip and tune’ has evolved:

- **Preparation of the battlefield.** The Joint Forces Command (JFC) or subordinate Command regularly publishes a list of targets of interest. This list is based on the most recent Electronic Order of Battle, intel reports on specific emitters in the area, planned blue forces operations etc. As CESMO is using scarce resources, it must only be applied to targets that cannot be geo-located otherwise. The list of targets of interest shall therefore be limited to highly mobile and lethal hostile emitters.

- **Emitter detection.** Collectors will start off with flying their regular ELINT mission or will use their ESM system to support ongoing operations. Once the ELINT or ESM system on board of a collector has detected a target which is on the ‘target of interest’ list, a tip message is sent to the CESMO manager. This CESMO
The CESMO manager can be any designated collector, but shall most likely be the collector with the highest situation awareness during the battle.

- **Collector planning.** The CESMO manager receives and analyses the tip message to determine the priority of this new potential task. If this new emitter is ‘CESMO worthy’, the CESMO manager will select a group of collectors which is going to be tasked to scan for this particular emitter. This selection is based on the ongoing CESMO taskings, the geometry of the collectors versus the estimated target position and the quality of the collectors receivers.

- **Collector tuning.** After having selected the group of collectors for the new target, the CESMO manager will send a tuning message to these units. A tune message is a tasking to every collector to scan for a defined target on a rough position estimate during a certain amount of time (e.g. the next 10 minutes).

- **Tune reporting.** When emissions of the emitter are observed, the receiving collector generates LOB messages and passes these message on to the CESMO manager. Depending on the architecture of the data link in use, all other platforms on this data link could be able to receive these LOBs as well an can start triangulating autonomously.

- **Triangulation.** After the tune message to some or all of the collectors, the CESMO manager awaits the arrival of LOBs. Any LOB received from a collector and pertaining to this particular target is automatically used to calculate the best position estimate given the data set. Once the required accuracy is achieved, the CESMO activity on this particular emitter should be ceased.

- **Termination.** When the target position is accurately calculated or extended search time did not result in an accurately geo-located emitter, the CESMO manager will send a termination message to release the tasked collectors.

The concept of ‘tip and tune’ has been applied in a similar form by the US between a high flying U2 reconnaissance aircraft managing several lower flying tactical unmanned aerial vehicles (UAVs). This situation resembles the ‘master – slave’ principle of CESMO enough to allow the use of slightly modified TDL messages. The next paragraph will detail the actual implementation of CESMO during two NATO exercises.

### 3 CESMO IMPLEMENTATION

The design and evaluation of a concept of operations for cooperative geo-location needs to take place with live flying assets but under controlled circumstances. Many nations have offered platforms for participation in two dedicated CESMO trials, but most of these platforms did not have a suitable data link available. As described earlier, ELINT collectors tend to operate autonomously, execute their long duration missions and need to reduce the collected data after the mission. ELINT platforms preferably do not communicate during their missions, primarily to avoid disturbing their own data collection on RF frequencies and secondarily due to the specific nature of the mission. To invite these platforms to start broadcasting their findings during the mission required a culture change to ensure a successful series of trials.

The CESMO concept of operations requires attention for two specific topics: installation of a data link on-board of all participating platforms and the design of a software application that generates CESMO messages, send and receive these messages over the data link and triangulates hostile emitters in near real time. Both topics will be addressed in more detail in the following sections.
3.1 A POOR MAN’S DATALINK: IDM

In general, Link-16 is perceived as the ‘data link of choice’ for modern combat platforms. Link-16 has an extensive library set of messages, which can be used to create LOB reports (J3.7 message) and to exchange specific emitter parametrics for identification purposes (J.14 message series). Unfortunately not all platforms have Link-16 at their disposal and due to the high integration costs it was not practical to implement Link-16 on all participating collectors.

An economic and ‘easy to implement’ alternative for Link-16 is the Improved Data Modem (IDM). Messages generated by a computer are translated into the proper signals to be broadcasted by HF, VHF or UHF radios already installed on all platforms. Cooperation with the manufacturer of these IDM’s, the US company Innovative Concepts (InnoCon) assured the availability of ample PC-IDM cards, which are PCMCIA versions of the IDM’s. These PCIDMs can be installed in a commercial-off-the-shelf laptop and are connected to the regular AN/ARC-164 UHF radio sets. Due to the classification of the data (NATO SECRET) it was necessary to encrypt the radio signals through a KY-58 crypto computer.

An IDM network is based on the Internet Protocol (IP), meaning that every participant has its own specific IP address. Messages can be sent to specific IP addresses or to entire groups of addressees. Message handling, acknowledgements, fault reporting etc. are compliant with IP standards. As such, an IDM network resembles a regular ‘internet in the sky’ although the data rate on the net is constrained by the UHF radio channel.

The airworthiness authorities of every nation have approved the installation of a laptop plus IDM on board of all ELINT collectors for the duration of the trials. Via this simple engineering approach, every platform could be included in a network of ELINT collectors sharing the same, dedicated data link.

3.2 A POOR MAN’S APPLICATION: CESMO TOOL

The IDM only provides the network layer but does not include any functionality to do CESMO. The NATO C3 Agency together with UK’s DSTL in Portsmouth have developed a simple application for CESMO, dubbed the ‘CESMO Tool’ lacking a more catchy name at that time. The CESMO Tool is based on a simple triangulation calculation core producing position estimates of emitters based on received LOBs. Besides this triangulation core, the CESMO tool handles all in- and output traffic to the PCIDM card and thus the network.

To integrate the laptop/IDM and CESMO Tool with the on-board ELINT or ESM systems required too much effort due to certification issues. As such, the ELINT or ESM operator would use the ‘swivel chair’ interface between the two systems by taking ESM or ELINT reports from his on-board systems and typing in the limited number of values in the CESMO tool on the laptop. After filling out the required fields in an LOB message window, the application itself would take care of sending out the message on the IDM net. Incoming messages are added to the stack of LOBs and are used for triangulation immediately. When sufficiently accurate results in geo-location were achieved, the CESMO tool user interface would report the position and the error ellipse dimensions to the operator immediately.

The CESMO tool was only designed for supporting both trials and is not meant to be released in its current form. After the evaluation results of both trials are available, the SIGINT ESM Working Group will determine the way ahead with future developments of this tool and the data link.

4 CESMO IN THE REAL WORLD

As mentioned, the first NATO wide trial TH05 on cooperative geo-location took place in April 2005 in the vicinity of Ramstein Air Base, Germany, and was followed by another one which took place in Nov 2006 in Greece. Although both trials were not limited to CESMO only, the evaluation of cooperative geo-location was one of the major events. TH05 was based on a concept of operations for CESMO without the data link. All communications between platforms
were based on voice communications over UHF, showing the severe limitations in data rate and quality of conveyed messages. Given the time critical aspect of CESMO, TH05 showed that voice communications were unsuitable and other, faster and more reliable means of communications needed to be identified. As addressed in previous sections, the use of IDM s over UHF was the only feasible option. Within a year after TH05 the participants were able to equip their platforms with IDM data links and to develop the CESMO tool for handling the traffic over the IDM network.

As TSH06 took place on Greece’s largest Electronic Warfare range, many collector versus emitter scenarios could be evaluated. Much of the data analysis is still ongoing but the preliminary results have shown the feasibility of CESMO with IDM. The trial has definitely proven the added value of real time exchange of ELINT and ESM data in order to find hostile emitters that otherwise would have escaped detection or geo-location. As such, CESMO is a force multiplier based on network centric principles that adds to not just air supremacy but also to ‘spectrum supremacy’ by denying hostile forces to deploy lethal and mobile air defence systems.

5 CESMO: AN EXAMPLE

Although most of the data pertaining to CESMO is classified, it is possible to show an anonymised example of how CESMO can geo-locate targets that cannot be found by stand-alone operating ELINT or ESM platforms. This example is only illustrative and does not pretend to be a proof of concept [4].

On one of the days during trial TH05, four platforms reported a brief emission of less than 30 seconds by target ‘XYZ’ from the area south of the city of Pirmasens, Germany. Of these platforms, only platform P2 was able to take more than one measurement on this target and therefore was able to report 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 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, covering a total area of 17.3 square kilometers. 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 and their LOBs.

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Table 1 Reported LOBs on emitter ‘XYZ’

Fig. 5 shows these five LOBs overlaid on the map of the area around Pirmasens, Germany. The small oval near the intersection of LOBs 2, 3 and 4 is the calculated error ellipse based on all five LOBs.
Although the actual LOB data set is very sparse, it does allow for some analysis of the benefits of cooperation between platforms. Fig. 6 shows the error ellipses for all possible subsets of LOBs, ranging from 2 to 5 out of 5. The main conclusion from these figures is that triangulation based on more LOBs usually reduces the size of the error ellipse until a certain accuracy is reached. Another important finding is that some combinations of 3 LOBs yield a more accurate geo-location than other combinations of 4 LOBs, due to a better angular displacement in the case of 3 LOBs.
From a qualitative perspective, this simple example clearly demonstrates the benefits of cooperative operations for detecting pop-up emitters:

- **Need for cooperation.** None of the sensors were able to achieve acceptable results when operating stand-alone
- **More is not always better.** Sometimes two emitters can provide better results than three others (based on quality of the individual ELINT systems, the geometry of collectors versus the emitter, atmospheric refraction, terrain effects etc)
- **Benefits of sensor management.** Some well-chosen subset of emitters can achieve acceptable results against a certain target, thereby freeing up time from the remaining emitters for other CESMO taskings.

6 CONCLUSIONS AND FUTURE WORK

Modern threats will employ emission control in order to be lethal but undetected. Stand alone operating ELINT or ESM platforms will not be able to detect these threats unless some form of real time cooperation between collectors is established. The current state of technology allows the design of a ‘concept of operations’ for effectively engaging these pop-up emitters. A rudimentary ‘concept’ has already proven its value during two trials, but needs to be further refined before turning into an operational capability.

BIBLIOGRAPHY


