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## DYNAMIC AIR AND SPACE CONTROL MODEL FOR ADVANCED AUTOMATED CENTRELIZED COMMAND AND CONTROL

Autonomy, Networks and Networking, Architectures, Technologies, and Tools

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**Abstract**

Airspace control plan (ACP) and airspace control order (ACO) have been used to prevent chaos in the battlefield, to identify friend or foe forces, and to decrease or totally prevent friendly fire cases. On the other hand, prepared air tasking order (ATO) has been used to engage friendly forces to different targets in order to prevent possible chaos and source waste. Complexity of modern and future warfare and increasing user demands require dynamic air and space control mechanism. In this study a conceptual dynamic air and space control model is described. Furthermore, "Novel Data Distribution Model for Tactical Units in Military Operations" and "TOADO: Target Optimization for Air Defence Operations" were presented as parts of dynamic aerospace control system. Conventional aerospace procedures require planning of missile engagement zone (MEZ), fighter engagement zone (FEZ) and similar controlled areas well ahead of execution. Model we present allows operation planners and commanders to change, recreate and cancel such zones and as well as to help calculate safe routes for friendly forces. Commanders also use data distribution model to inform all tactical units about air control, mission orders, and movements of enemies. An algorithm for automated aerospace control is also developed.

**Introduction**

Military planners take their time when they plan an air strike against enemy. What would they do when an unexpected air to ground attack happens? There is no time for defence planning. Commanders in national or NATO Combined Air Operations Centre (CAOC) have time just to give orders to tactical units in order to protect the country. There is no time for planning and giving right orders is a matter of existence. The purpose of TOADO algorithm is to prepare and implement an automatic target optimization algorithm for air defence operations in order to help military planners, especially CAOC personnel, to react in the best way in an unexpected air attack. The TOADO algorithm that we developed and presented here was designed to reach the highest number of target hits while calculating the least use of source inputs. Source inputs were described as time of reaction to each target, the turn around time for each resource, and cost of resources. Weapon-target assignment problem was solved aiming maximization of damage on target in (Ni, M., Yu, Z., Ma, F. and Wu, X. 2011). The value of this study is to provide an optimal solution of the problem by maximizing the damage on attacking enemies while minimizing the total cost of response time, turn around time, and financial expenditures of the operation. Java application of the optimization algorithm was developed and tested according to generic scenarios. Time needed to calculate the solution of each given problem and to print ATO was less than two seconds. Analyzing results of the tests proved that performance of optimization algorithm perfectly satisfies the expectations of senior military defence planners.

Future forces needed to be well aware about tactical situation in operational area. Future warfare will use machine observations and network centric ability to complete kill chain with or without human interaction (Langley 2004). That expresses the urgent need for automated situational awareness. Every single tactical unit in the battlefield needs information about friendly forces and enemies. Since situational awareness is crucial, and since each tactical unit has very limited ability to discover environment in the battlefield, delivering necessary data about friends' and enemies' tactical positioning and movements is essential. Tactical situation data and task orders are sent through radio links. Number of units that communicate through links and amount of data needed to be transferred is exploding. Data needs rise extremely fast nowadays and load on communication channels is an upcoming problem to be solved not only by extending IT infrastructure but also by using it more effectively. Using data channels more effectively requires determination of the minimum data needed by each unit.

Warfare is challenging in every meaning. Management of uncertainty in battlefield, taking risk of human life, taking decisions about the magnitude of effort to spend and many other factors make warfare challenging a lot. Military operations should be aimed to accomplish a given task (Alberts, Garstka, and Stein 2000). Almost all military operational plannings are related to making optimal decisions. Any aimed target should be totally destroyed by using minimum amount of weapons. No more or no less than needed. Many operations should be done right on time. Not earlier and not later.

Operational demands require focusing on data transfer model that optimizes data delivering to each single tactical unit and decreasing total data traffic through network. Situational awareness of data optimization for each unit is based on tactical maneuvering ability of the unit and on possibility of approaching enemy attacks. In this article two challenges were investigated. First one is moving area of interest for each unit. This first one comes from principle that every unit needs to have information that will be used. Not any unusable information needs to be delivered. None of the tactical units need information about all enemies in the battlefield. This will be discussed further. Second challenge is that despite of limits related to area of interest; some enemies positioned far away from the unit itself might have potential risk to destroy that unit. Another work was done to search for possible killers and add them to deliverable data package.

Data package to be delivered consists of positioning and vector information about friendly forces and enemies within area of interest, positioning and vector information about threats out of the range, information about declared military zone and task orders. First two types of information are mandatory for every update. Last two should be sent only when newly established or in case of any changes.

Synchronizing events in the battlefield, achieving superior speed of command and increasing survivability are some of the benefits expected from network centric warfare (The Implementation of Network-Centric Warfare 2005). Attempt to implement Network-Centric Warfare is a technology driven transformation (Schmidtchen 2005). Despite all of its challenges such that transformation is necessary for future forces to keep competitiveness. Many efforts were spent to make NCW applicable for armed forces. Method explained here was developed to aid efforts on making network centric warfare possible and to assist central command and control. Complete radio connectivity, stable information channels, whole and complete sensor - decision maker - executer cycle and environment protected from electronic attack were prior assumptions for this study.

Once that data delivery is established and target optimization is ready to use against attackers on the air, the automated airspace control model is required. Since battle on the air causes a very fast changing battlefield environment, demand for simultaneous command and control requires a dynamic model to control air and space.

The airspace control authority (ACA) is responsible for planning, coordinating, and developing airspace control procedures by developing airspace control policies and procedures for all airspace users according to Joint Publication 3-52 Joint Airspace Control 2010. Location and procedures associated with active procedural airspace coordinating measures (ACMs) (HIDACZ, JEZ, FEZ, MEZ, MRR, CA, corridors, ROZs, and other appropriate procedures) needed to be placed in airspace control plan (ACP). This requirement indicates that particular zones in the battlefield needed to be placed and geographically located well before executing operations.

The ATO preparation for joint air operations takes a specific execution timeframe, normally 24 hours as stated in Joint Publication 3-30 Command and Control for Joint Air Operations 2010. Time needed to plan and develop ACMs, and time needed to prepare ATO might not meet present day operational needs. TOADO algorithm and data distribution model that discussed in this study are two essential tools to effectively execute dynamic planning simultaneously during air operation. There are many other tools prepared to aid operation planners. Since technological advances offer such that opportunities, further discuss on changing the way of using air control authority is essential. Before that, tools mentioned here needed to be presented.

**TOADO: Target Optimization for Air Defence Operations**

First of all, data used here needed to be explained. According to scenario there are SAM systems, scramble jet fighters on the ground in 5 minutes readiness, and fighter jet planes in the air on combat air patrol (CAP) role. Those are sources that CAOC is able to use. In other hands enemy aircrafts are attacking by flight packages. Basically they are jet fighters, UCAS' or cruise missiles. Most of the information about enemy aircrafts was given by radar operators.  An info label for each echo on radar screen was fulfilled by a radar operator. Info in such that label includes lat, lon, altitude, speed vector, id of the aircraft, type of that air vehicle. Physical information was provided by radar automatically.

Current position in terms of lat, lon and altitude, speed vector and proposed vector were provided by radar computer. Operator defines it as enemy or friend, label it with a unique id number and type number that presents air vehicle as plane or missile. After that, label control was handed over to operations officer in CAOC. That officer adds a firepower number to the label that indicates how much fire power needed to be used in order to destroy that air target.  Finally information label of enemy aircraft is ready to be used by algorithm. Figure 1 presents an example of an aircraft labeled by radar operator on the radar screen. After handing over to operations officer firepower number, 5 for example, will be added to that label.

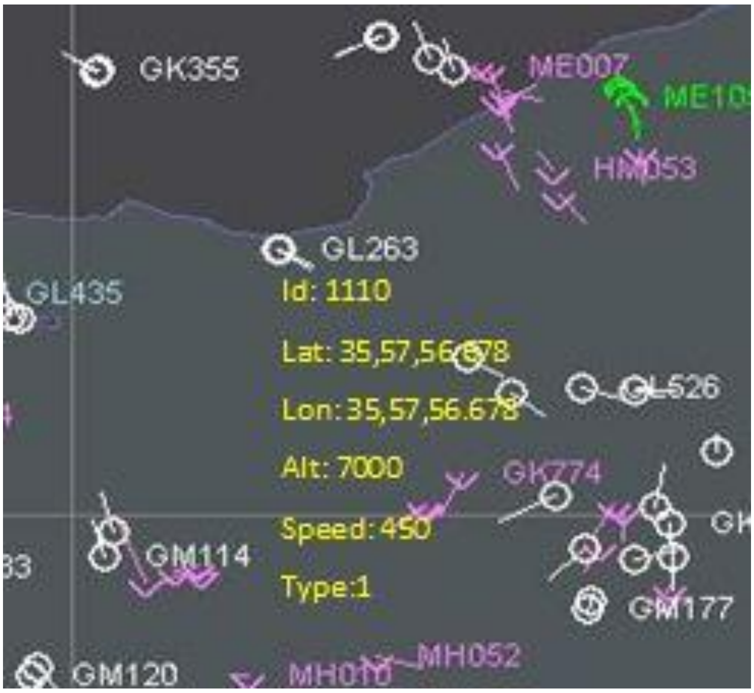


Fig. 1: Air vehicle labeled by radar operator.

Firepower number 5 means basically that any weapon that has firepower at rate 5 or higher will be able to destroy that target. Calculations about which weapon can kill which target are very complicated and are not be discussed in this study. Algorithm uses similar information about sources that will be used to kill enemy aircrafts. Jet fighters in 5 minutes readiness on the ground, jet fighters in CAP areas and SAM missiles are sources. Information for each one source consists of position in terms of lat, lon and altitude, speed vector, id number, type number and firepower which indicated how many enemies to be killed by that source. Magnitude of speed vector is average speed on duty. Vector was originated from position of SAM system, position of end of the runway from where scramble jets will take off or centre of CAP area. Vector ends up in some interception point where in the future time target and hunter will reach each other in the air. Figure 2 presents geometry about interception.

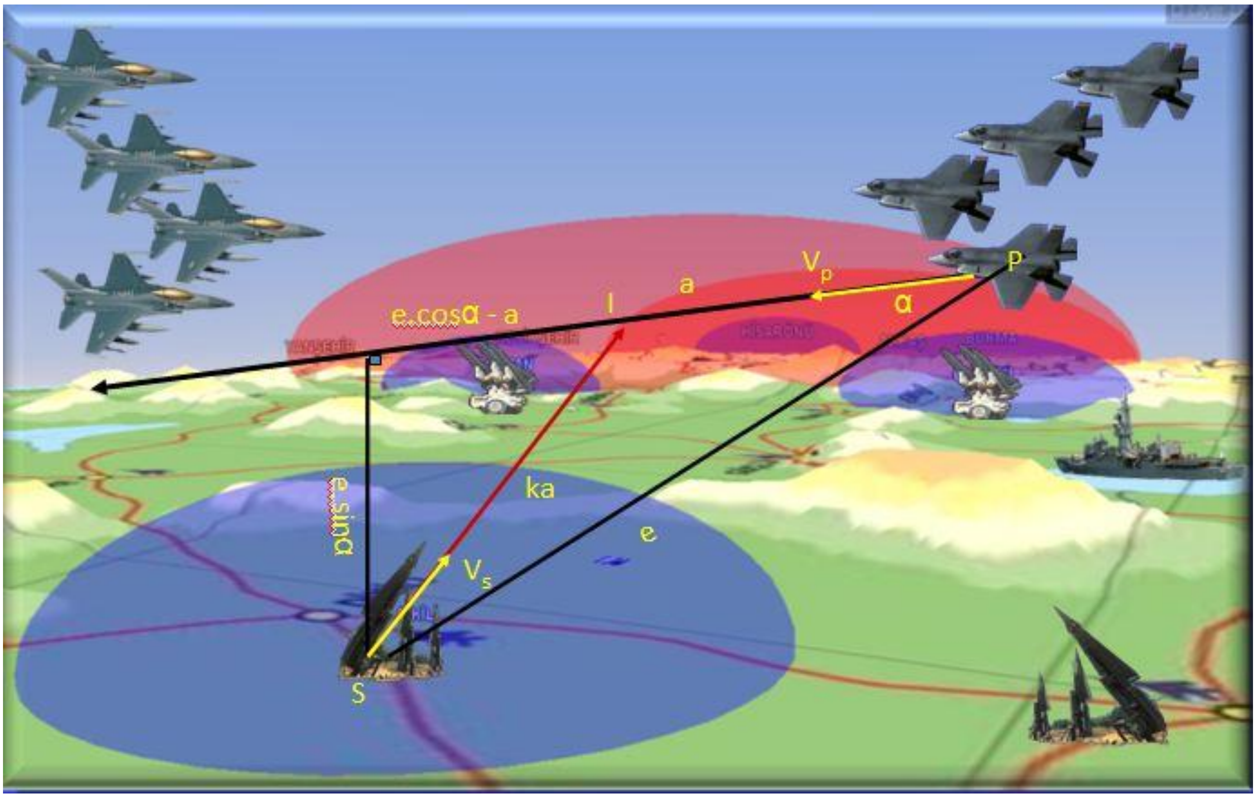


Fig. 2: Hunter SAM missile catches up attacking jet fighter in I, point of intercept.

Here in Figure 2, position of hunter SAM missile is known, position of attacking enemy aircraft is known also. Distance in between them was calculated and presented as “e” in the figure. Speed vector of enemy is known and presented as $V_p$. Speed vector of SAM missile is known and presented as $V_s$. Point of intercept “I” is not known and is object to be found out of calculation. Since time needed to be on the same I point should be the same for two flying objects, and since magnitudes of speed vectors are known distances to point I could be calculated as presented in (1).

$$\frac{|Vs|}{|Vp|} = \frac{|SI|}{|IP|} = k, \qquad (1)$$

Since |IP|=a then |SI|= ka according to (1). Here angle α is not known and needed to be calculated.

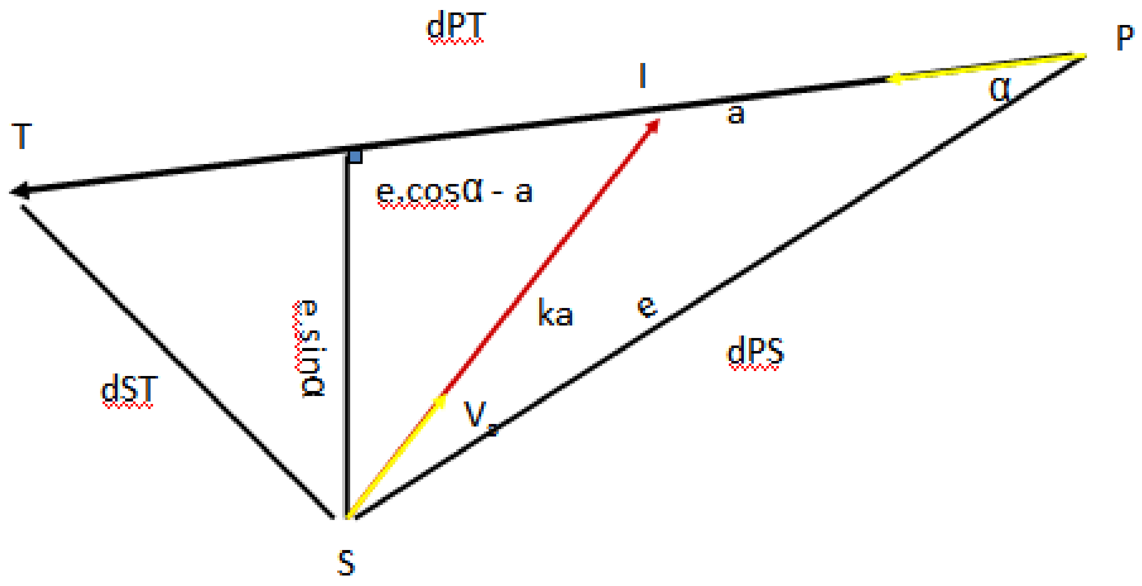


Fig. 3: Geometry for calculation of angle α and I, point of intercept.

An iteration algorithm identifies a target point T where enemy aircraft or package aims. Many moving target indicator (MTI) algorithms used in modern radars can do this. Geometry as shown in Figure 3 presents current position of enemy as P, position of source for defence as S and aimed target as T.

The distance between enemy and target was represented by dPT, distance between defence source and enemy was represented by dPS, and distance between source and target was represented by dST. Since mathematical calculations were done in three dimensional Cartesian coordinate system coordinates of location points should be presented in Cartesian coordinate system. Representations of location points are:

$\begin{bmatrix} x_p \\ y_p \\ z_p \end{bmatrix}$ for point P, $\begin{bmatrix} x_s \\ y_s \\ z_s \end{bmatrix}$ for point S, and $\begin{bmatrix} x_t \\ y_t \\ z_t \end{bmatrix}$ for point T. Since location information

was given as lat, lon and altitude it needed to be converted to Cartesian coordinate system. Calculation to convert from World Geodetic System 1984 to Cartesian coordinate system was shown below.

$$
\begin{aligned}
brad &= \varphi_1 + \phi_2/60 + \varphi_3/3600 \\
b\deg &= brad * \pi/180 \\
\lambda rad &= \lambda_1 + \lambda_2/60 + \lambda_3/3600 \\
\lambda\deg &= \lambda rad * \pi/180 \\
a &= 6378137 \\
\mathrm{f} &= 1/298.257223563 \\
\mathrm{ex2} &= (2-\mathrm{f}) * \mathrm{f} / (1-\mathrm{f})^2 \\
\mathrm{c} &= \mathrm{a} * \sqrt{(1+\mathrm{ex2})} \\
\mathrm{N} &= \mathrm{c} / \sqrt{(1+\mathrm{ex2} * \cos^2(\mathrm{b}))} \\
\mathrm{X} &= (\mathrm{N}+\mathrm{h}) * \cos(\mathrm{b}) * \cos(\lambda\mathrm{deg}) \\
\mathrm{Y} &= (\mathrm{N}+\mathrm{h}) * \cos(\mathrm{b}) * \sin(\lambda\mathrm{deg}) \\
\mathrm{Z} &= ((1-\mathrm{f})^2 * \mathrm{N} + \mathrm{h}) * \sin(\mathrm{b})
\end{aligned}
\tag{2}
$$

Once coordinates were transformed into Cartesian coordinate system, then distances between points were calculated.

$$dPT = \sqrt{(z_t - z_p)^2 + (y_t - y_p)^2 + (x_t - x_p)^2} \tag{3}$$

$$dPS = \sqrt{(z_s - z_p)^2 + (y_s - y_p)^2 + (x_s - x_p)^2} \tag{4}$$

$$dTS = \sqrt{(z_t - z_s)^2 + (y_t - y_s)^2 + (x_t - x_s)^2} \tag{5}$$

Then $\cos(\alpha) = \dfrac{dPS^2 + dPT^2 + dTS^2}{2 * dPS * dPT}$ (6)

Finally $\alpha = \arccos(\cos(\alpha))$ (7)

Distance between unknown point of intercept I and enemy was presented as a, distance between source and point I was shown as k*a according to (1), distance between enemy and source was calculated as dPS also shown as e in Figure 3. There was drawn a perpendicular triangle where one edge was e*sin(α), other edge was (e*cos(α) - a) end hypotenuse was k*a as seen in Figure 3.

Relationship of hypotenuse and other edges in a perpendicular triangle was used to find distance a.

$$(e*\cos(\alpha)-a)^2+(e*\sin(\alpha))^2=k^2*a^2 \tag{8}$$

$$(1-k^2)*a^2-(2*e*\cos(\alpha))*a+(e*\sin(\alpha))^2 \tag{9}$$

$A=(1-k^2)$, $B=-2*e*\cos(\alpha)$, and $C=(e*\sin(\alpha))^2$.

$$\Delta=B^2-4*A*C \tag{10}$$

Positive solution of the system gives a, the distance between enemy and the pint of intercept I. Since k is known according to (1), from now on the distance between defence source and point of intercept is known. Since the speed vector of enemy is known and distance to point of intercept is also known it is easy to iterate position of enemy to position of point I. Distance and speed information also provides time needed to present on point I. Speed vector of defence source was adjusted to be at the same time on point I with the enemy.

After all these calculations time needed to present on point I for the source of defence was saved on the memory. The same all calculations for each enemy were repeated changing sources of defence. All series of calculations were repeated for all possible missiles, jets on CAP duty or scramble fighters that were in 5 minutes readiness. Times for being in point I for all those defenders were saved in the memory. Numeric results of series of times were normalized for simplicity reasons. Turn around times for each one of defenders were also stored in memory. Turn around time here was used to describe time needed to be ready to fight and fire again. It is well known in aviation for aircrafts. The same term here was used for missiles too. Term was used to describe time needed to get additional guided munitions for surface to air missiles. Shortly numeric values of series of turn around times were stored and normalized. Finally, expenditures for each shoot in a standard rate of value were saved and normalized as well. These three variables described here were actually three types of cost.

Revenue needed to be explained here. There was firepower number for each enemy. That firepower number was used to represent how much firepower, how many missiles or how much powerful weapon, needed to fully destroy that enemy. Enemy here could be a single jet fighter, a formation of a couple of fighters, a guided missile or even an unmanned combat air system (UCAS). Number here may differ even for a single aircraft, depending of ability to survive. Fire power number of defender represents ability of destruction. Each single shoot to enemy means that number of fire power of enemy was decreased as much as the number of power of defender. Probability of successful shoot was calculated well before and was applied to number of fire of defender. So, we do not need to deal with probability of hit in this calculation here. Decrease of fire power of enemy is revenue of the shoot.

Net revenue of the shoot was calculated by subtracting total cost of normalized cost variables. This calculation was done for single defender against the enemy. As enemy stays constant calculations were repeated for all possible defenders. Different net revenues were saved and after end of calculating net revenues of all defenders, net revenues were sorted and the biggest one was selected. This selection means that the selected defender is the most suitable defence source to be used against that enemy.

This was just one cycle of calculations done for the first enemy on the list. The used weapon was dropped from defence sources list then another cycle of calculations was done for the second enemy on the list of the enemies. This was done until all enemies were hit at least once. Then it begins again from the first one on the list. There are two break outs in the algorithm. One was checking if all enemies were destroyed. The other was checking if all defence sources were spent out. If one of those situations occurs the algorithm breaks up and writes resulting weapon to target allocation.

Prioritization of enemies is important due to possibility of lack of enough fire power needed to destroy all of them. Three optional methods were recommended here in this study. First option is to prioritize friendly targets. The speed vector of enemy aims a possible target or a set of possible targets. It is recommended to prioritize the friendly targets on a list. At time when enemies appear on the radar screen, they could be matched to targets they aimed, and they could be put in prioritization order according to targets they aimed. Second option is to prioritize the enemies according to speed they entering in or approaching to friendly territories. Last option is simply to put them in order according to appearance time on the radar screen. List prepared by one of these methods is subject to change any time by operator due to operational needs.

## Novel Data Distribution Model for Tactical Units in Military Operations

### *A. Area of Interest*

Data to be delivered to each tactical unit depends on effective operational radius of the unit that defines the physical area of interest, the speed vector of the unit that defines the movement of area of interest, the speed vector and positioning of the enemies and of course the current positioning of the unit itself. Area of interest is described as physical area where the tactical unit has ability to affect the enemy within a mission time period. Mission time could be flight time period for an air vehicle or one day cruise for a naval warship or a run time with a full tank of fuel for a tank or armored ground vehicle. Data that is essential for each tactical unit consists of information about friend or enemy tactical units within area of interest of each tactical unit.

Description of area of interest was done due to need to limit data delivery to each tactical unit. Refresh time period of data delivery is related to reliability of delivered data. Refresh time depends on data sources. Data retrieved from radars or similar sources depends on the time cycle that radar antenna needs to scan sky once. It is similar for airborne radars or other sensors. If a time cycle of radar for a full turn scan is about a few seconds that means information in tactical units’ hands might be a few seconds older than actual situation.

Movement of the tactical unit causes movement of area of interest. That means data delivered according to area of interest should be updated since change of area of interest. It is recommended to synchronize update requests to cycle of the available data sources. Delivering data every few seconds to keep it updated could be criticized. Keeping forces networked and providing opportunities to operate with increased speed, increased synchronization and achieving multi object tasks simultaneously is a big advantage for armed forces.

Area of interest could be considered as an invisible bubble around tactical unit in the battlefield as shown in Figure 4. As long as unit is moving the bubble is moving with it. Friendly or foe forces that exist in that bubble might change in time due to movement of bubble itself or movement of forces themselves.

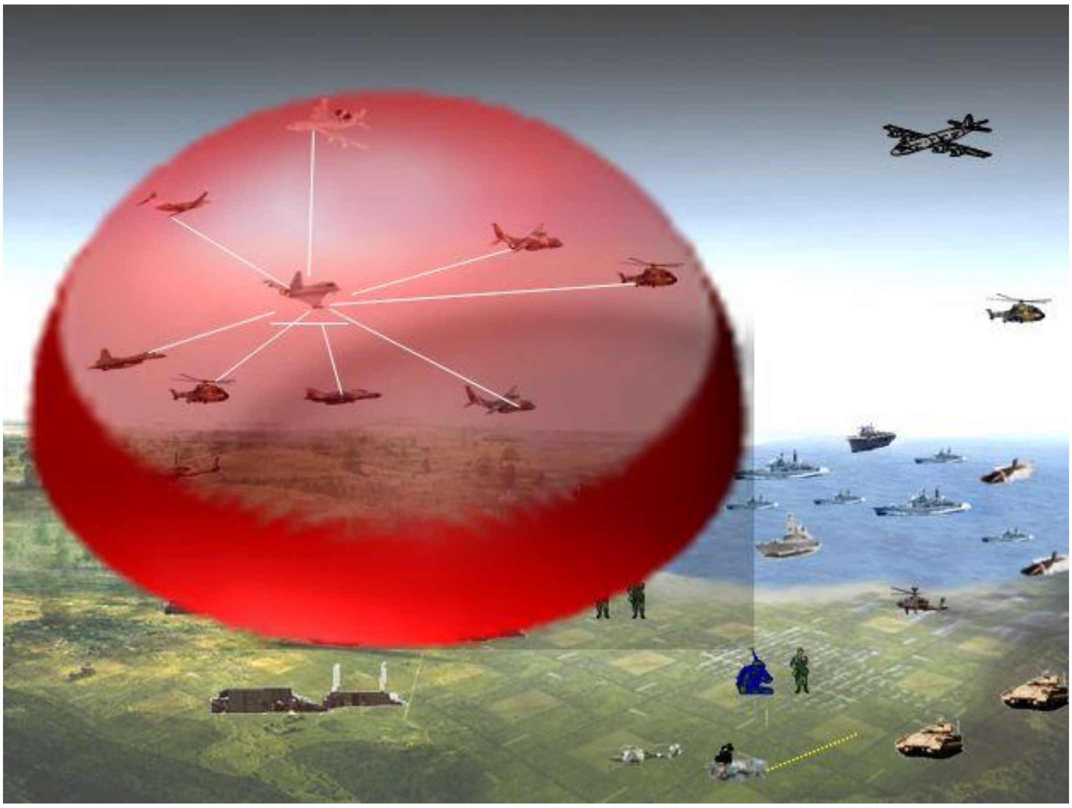

Fig. 4: Area of interest is shown for a jet fighter.

Main computer in command and control center has the information related to friendly forces stored in the data base repository. Computer also receives data about moving friendly vehicles and enemies as well. List algorithm calculates the distance between a tactical unit and other units and compares it with radius of area of interest or the radius of the bubble. This calculation was done for each friendly tactical unit and list of interested objects was prepared for each unit. This first basic list contains information about friend and enemy units which are in the bubble of the tactical unit. The list contains the data needed to be delivered to that tactical unit in a cycle of data acquisition.

### *B. Potential Threats*

Limitation of delivered data was done to limit total data flow in the communication channels. Another reason was to limit access to data. Everyone needs to take exactly as much as needed. Data transfer operations will be discussed further. Area of conflict was divided into 3 dimensional grids to make it clearly understandable for commanders. Upper level grids were reserved for satellites, mid level grids for airborne vehicles and the rest for the surface units. Horizontally division was made in addition to vertical separation to clearly represent military zones. Figure 5 shows a complicated battle area that consists of ground, airborne and space friend and enemy units and three potential threats that aimed one unit, which is a jet fighter in this example, as a target. Data transactions were shown as light beams in the figure and arrows were used to connect potential threads and their target.

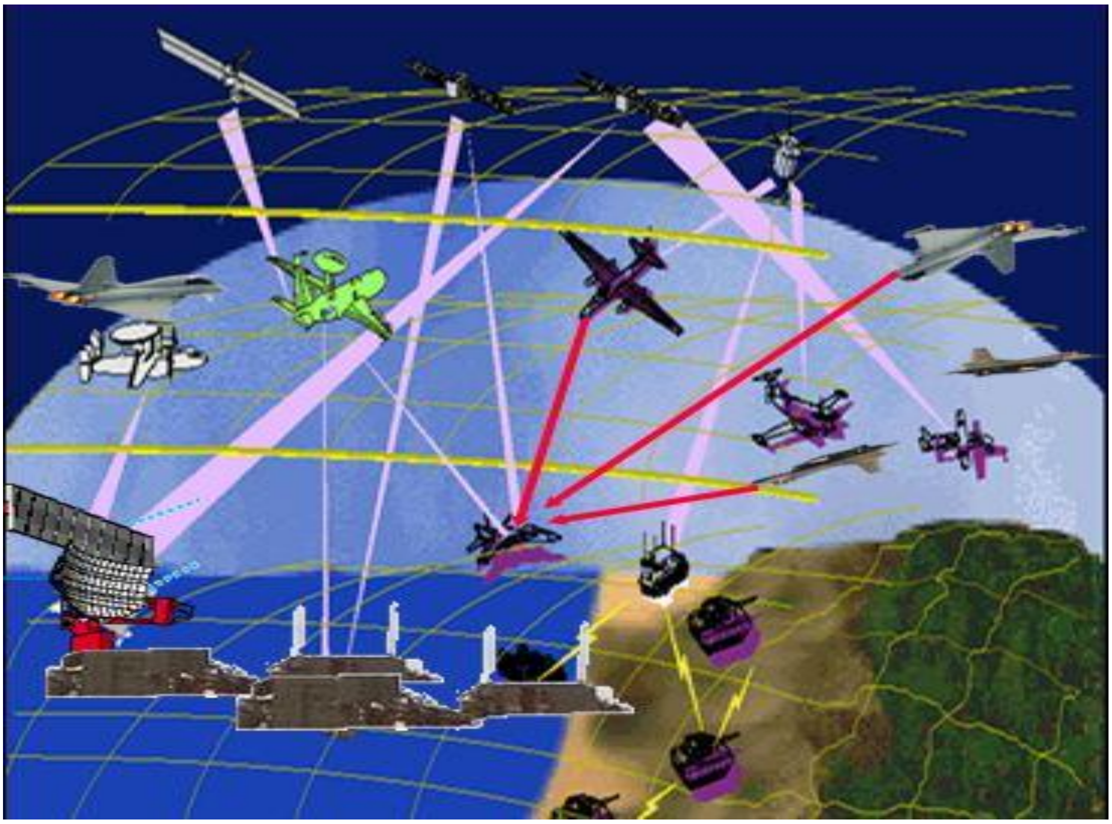

Fig. 5: Potential threats aiming a jet fighter.

### *C. Data Distribution*

Data acquainted from variety of sensors was collected in a computer located at headquarters of operation. All positioning calculations and risk determinations were done in that central computer. Data packages were prepared unique for each one of the tactical units. Delivery needed to be done after that preparation. Transferring data packages to units spread out in wide area, as it is in battlefield nowadays, is not quite practical to be done from nod to nod as recommended in (Yang, Q., Lim, A., Li, S., J. Fang, and Agrawal, P. 2009). Since the need to protect the information itself and information system from unauthorized use, misuse destruction or modification as explained in (Saha, S., Bhattacharyya, D., Kim, T. and Bandyopadhyay, S. K. 2010.), data flow is not from mod to nod but from centre to main carriers and from main carriers to local users. Vice versa is true for feedback or response messages. Example flow was presented in Figure 6.

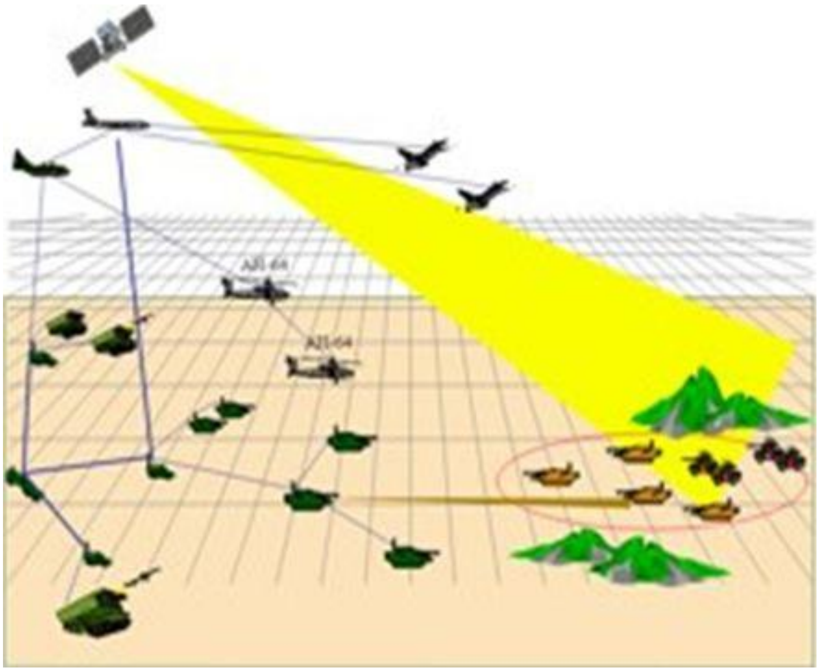

Fig. 6: The middle point of crossing lines.

Small communication unit sends signals to airborne command and control unit above, that unit sends data packages to jet fighters that are in the front left grid sector according to the airborne unit, in the other hand it sends data packages to another plane which is on its right grid sector, that plane sends data packages to helicopters. Communication unit sends data packages to one ground unit right in front of itself and another package to ground unit on grit grid sector. These ground units resend data packages to last users. Satellite sends the information to a group of armored ground vehicles, one of them sends feedback information to ground unit which is in front sector of communication unit. Al these connections are not random. Armored ground vehicles have no ability to send signals to satellite, so they send feedback data to closest possible nod. Line of sight vision, distance and technical abilities may vary from unit to unit. The network constructed here is very elastic and changeable over time. Although it is that elastic we can not say that it is or should be cloud based as stated in (Feng, T., Bi, J., Hu, H. and Cao, H. 2011). Data distribution was done level by level. Original data source, which is communication unit in this example, generates data packages unique for every single last user. After that the source first level receivers or nods, second level nods and last users. Then user addresses were added to data packages. It as some similarities to internet protocols but is not exactly the same. All data packages were sent to first level nods. Sector division is useful for data delivery here. Users that are in the same sector with first level nods will receive their packages at that moment. Rest of the data packages will be sent to next level nods. This will continue until last users. It is similar to blood delivery in human body. We can call this method as delivery trough levels.

## Dynamic Air and Space Control Model

Any air control model must establish unity of command and effort reducing risk and maximization of effectiveness of air defence. Planning and locating ACMs before execution of mission might not meet present operational needs. First of all the importance of unity of air control needed to be stated strongly. All weapons available for air defence should be assigned to targets by central air control authority. Control of area air defence weapons should be handed over to central air control authority.

Each one flying tactical unit like jet fighter, UAS or UCAS, cruise missile or SAM needed to have zone of safety to prevent crashes on the air. It will decrease effectiveness if deconfliction distances for civil aviation would use in military operations. It is not common for civilian aircrafts to fly in formation, but is applicable and safe for jet fighters. Vertical separation limit of 1000 feet could be used as spherical separation from other flying objects. Air vehicles aiming same group of targets might be in risk of collision due to crossing routes. Rule to apply here should force the slower one to temporarily change heading at least to end up in parallel flight condition.

Another challenge is to establish and apply ACMs like HIDACZ, JEZ, FEZ, MEZ, MRR, CA, and ROZs temporarily just before use and to inform all air space users about the latest changes. Since data distribution model was explained above, there is no need to repeat here. Users needed to have latest changes will be informed according to data distribution model. Establishing a MEZ for example or any kill box requires placing a centre of that space and radius if it is spherical or boundaries if it will be a different shape. Kill boxes or other temporarily established air zones needed to have the smallest volume in the air possible for that mission. First off all the centre of the kill box was calculated as point of intercept in TOADO method. The point of intercept I, calculated there, should be used as center of kill box or other air zones.

Maneuvering abilities of foe and friends that will fight in that air zone dictates the boundaries of the air zone. Since it is not possible or even effective to establish single kill boxes for each jet fighter in a formation or if density of foe aircrafts in the air is too much one big FEZ could be established. If MEZ was established and it was restricted for friend jets, it should be opened for entering right after end of the mission of the missile. If enemy was killed, the kill box established there should be canceled and all related units needed to be informed using data distribution model. If shoots towards foe aircraft in a kill box are not successful and if is still approaching to sensitive targets, in that case location of kill box should be refreshed according to current position and speed vector of the enemy, then TOADO algorithm should run again to allocate new friendly defenders against tat enemy. It is obvious that this process would be endless if defence sources and foe attackers were endless. Centralized control of all air defence sources including ones belong to different force components and new technological developments will make dynamic air control in operations possible.

## Conclusion

Conceptual dynamic air and space control model was described. "Novel Data Distribution Model for Tactical Units in Military Operations" and "TOADO: Target Optimization for Air Defence Operations" were presented as parts of dynamic aerospace control system. Centralized control over all air defence sources including ones belong to different force components and use of technological advances stated as two important factors that were essential for dynamic air and space control. Model presented here in this study, allow operation planners and commanders to change recreate and cancel ACMs and to command air defence forces simultaneously. Commanders also use data distribution model to inform all tactical units about air control and mission orders and as well as movements of enemies.

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