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C2 SYSTEM ENGINEERING FOR THE ADVERSITIES OF THE AMAZON ENVIRONMENT

Topic 7: Architectures, Technologies, and Tools

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C2 SYSTEM ENGINEERING FOR THE ADVERSITIES OF THE AMAZON ENVIRONMENT

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Abstract

This article presents a proposal for structuring a command and control system to cope with the adversities of Amazon environment, especially the poor communications infrastructure toward large distances involved. Initially it is described theAmazon environment for the area characterization, followed by a contextualization of the C2 approaches under the C2 tools developed by the Brazilian Army, as well as the experiences gained from the use of these tools in the military environment and cooperative environment with civil segment. In a second part, we discuss the systems engineering process for development of the proposed system, with studies employing Tethered Aerostat technology as communications support, alternative to satellite, HFandVHF communications, integrated to fixed and mobile wireless sensors network.

Keywords: *Capacity Building, systems integration, CORTEX, SOA, Tethered Aerostats, wireless sensors network, UAVs, Agility, C2 Approach, Shared Awareness.*

I – INTRODUCTION

"*Arduous is the mission to develop and to defend the amazon. However, much more difficult it was for our ancestors to conquer it and to keep it*"[1].

This statement reveals in short some ideas and concepts that guide our work: to conquer and to keep as mission parameters such as "where we came from", and to develop and to defend, as mission parameters such as "where are we going", all coped to the fact that all tasks were, and still are, hard to be done.

Distances associated with all types of transportation difficulties explain most of the past and the current scenario. The difference resides solely on the technologies we have available today. How can we put them together in an efficient way is the challenge.

The answer starts with some guidelines stated by the Brazilian government, such one that states to develop the ability to monitor and control the Brazilian air space, the territory and the jurisdictional waters which will happen from the adoption of land, sea, air and space monitoring technologies that shall be fully and unconditionally mastered domestically.[1]

Others two guidelines that are tied together are the development of the capacity to promptly respond to any threat or aggression supported by the capacity to monitor/control, named strategic mobility, and the presence enhancement of Army, Navy and Air Force units in the border areas.

The guideline to develop logistic capacity, in order to strengthen mobility, moreover in the Amazon region, highlights the importance to have transport and command and control structures capable of operating under a wide variety of circumstances, including the exceptional conditions imposed by an armed conflict.

[1]General Rodrigo Octávio

Finally, for these paper objectives, the guideline to structure the strategic potential in terms of capacities points the importance to organize the Armed Forces in terms of capacities, and not specific enemies. Presently, Brazil does not have any enemies. In order not to have them in the future, it is necessary to keep peace and be prepared for war.

The remainder of this text is organized as follows. Section II presents a short description of the Amazon environment, highlighting some difficulties Brazilian government faces there. Section III describes some C2 concepts that guide the systems engineering process and position the current C2 development, covered by sections IV and V, respectively. Section 6 presents some simulation results regarding the employment of tethered aerostat and wireless sensor networks (WSN) as a viable and efficient solution for the monitor/control capacity required by the Brazilian Government. Section 7 ends the paper.

II – THE AMAZON ENVIRONMENT

Figure 1 - Amazon region

The Amazon environment covers approximately seven million square kilometers and this region includes territory belonging to nine nations. The majority is contained within Brazil (60%), followed by Peru (13%), Colombia (10%), and with minor amounts in Venezuela, Ecuador, Bolivia, Guyana, Suriname and French Guiana.

The region has great potential with estimates of mineral wealth alone valued at thirty trillion dollars. Often referred to as the "lungs of the earth", the Amazon represents over half of the planet's remaining rainforests, and it comprises the largest and most species-rich tract of tropical rainforest in the world. The Amazon River is 6,275 kilometers long and is navigable for most its length and it flows from northern Peru, through the Brazilian Amazon, to the Atlantic Ocean. The Amazon is a region of great geostrategic importance, especially to Brazil.

Amazon is more than just a large area in the country. It symbolizes Brazil's strong nationalism. Further, Brazil sees the Amazon, with its vast natural resources, as essential to their nation's future survival and is instinctively suspicious of international interests in the region. Brazilian Government is aware of regional problems and that the inadequate political, economic and social control of the region creates vulnerability. These concerns help to explain some actions to develop the Brazilian Amazon in order to maintain control of the region that includes border incursions; combating illegal mining and deforestation; and avoiding general ecological degradation. [2]

III – C2 CONCEPTS

III.a - Collaborative Environment

In order to better understand the role collaboration in the formulation of an efficient command and control model, it is important to define the Collaborative Environment (CE) in the command and control sense. The CE is directly related to the freedom of information exchange among the people that are trying to solve a problem, following the concepts presented by ALBERTS [3]. In military operations a quick and precise information sharing atmosphere is needed, in order to exchange and to coordinate the actions among several entities and agencies.

The amount of misunderstanding and false information generated in a crisis command and

control requires a constant communication link to check and to improve knowledge in each good tale achieved. The CE is important to help developing shared situational awareness (SA).

Regarding on technology aspects of CE, a web portal is a good tool to make it possible to share tips of information in a quick way. C2 software using web-services and Service Oriented Architecture (SOA) can even increase the interoperability, enabling users to share information and to generate knowledge collaboratively.

The web-services and SOA Command and Control approaches can build a virtual collaborative environment that facilitates the sharing documents, reports, images related to a problem supporting the generation of new knowledge through interaction and collaborative work.

III.b - C2 Approaches

In order to handle the adversities that the Amazon environment presents, it is necessary to identify which C2 approach is suitable to handle any hypothetical situation.

Accordingly to SAS-065 (StudiesAnalysis and Simulation) NATO Network Enabled Capability C2 Maturity Model (N2C2M2), C2 approaches can be classified in accordance to the: 1) allocation of decision rights; 2) patterns of interaction; and, 3) distribution of information. These three parameters define the so called C2 Approach Space and such way to organize and classify helps to clarify the C2 functions characteristics needed to face the operations complexities and, moreover, to drive the actions and projects in order to get the suitable agility to deal with them.

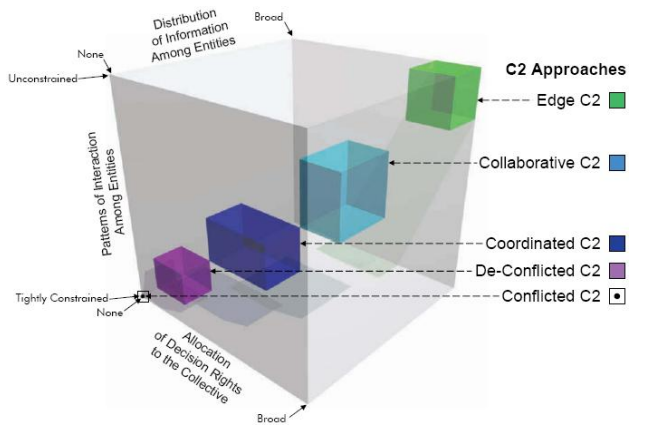

Figure 2- C2 Approaches and the C2 Approach Space

SAS-065 studies classified the C2 approaches into five types, which are:

- **Conflicted C2**: in this approach, there will be assigned distinct areas to perform the mission to each team and the only C2 that exists is that exercised by the individual contributors over their own forces or organizations. There is no distribution of information between or among the entities, all of the decision rights remain within each of the entities, and there are no interactions (in a C2 sense) between or among the entities.
- **De-Conflicted C2:** this seeks the avoidance of adverse cross-impacts between and among the participants by partitioning the problem space. In order to de-conflict their intents, plans, or actions, organizations need to be able to recognize potential conflicts and attempt to resolve them by partitioning across geography, function, echelon, and/or time. This involves limited information sharing and limited interactions. Instead, participating entities agree not to act in a manner that violates any agreed upon constraint. A De-Conflicted approach to C2 allows partners with different levels of C2-related capability to work together, coexistingin the same operational space. The nature of the constraints imposed will vary, but may include the creation of boundaries (exclusive areas assigned to a given entity)

along time, geography, space, function, and/or echelon lines;

- **Coordinated C2:** It aims to increase overall effectiveness by (1) seeking mutual support for intent, (2) developing relationships and linkages between and among entity plans and actions to reinforce or enhance effects, (3) some initial pooling of non-organic resources, and (4) increased sharing in the Information Domain to improve the quality of information;
- **Collaborative C2:** This approach aims to develop significant synergies by (1) negotiating and establishing collective intent and a shared plan, (2) establishing or reconfiguring roles, (3) coupling actions, (4) rich sharing of each other resources, and (5) increasing interactions in the Social Domain to increase shared awareness. It involves the collaborative development of a ***single shared plan***. The intents of the entities/elements are subordinate to common intent;
- **Edge C2:** The objective of Edge C2 is to enable the collective to selfsynchronise, which requires that a rich, shared understanding exists across the contributing elements. This, in turn, requires a robustly networked collection of entities with widespread and easy access to information, extensive sharing of information, rich and continuous interactions, and the broadest possible distribution of decision rights. Self-synchronisation includes self-organization. Thus, entities or collections of entities can look and behave as if they are employing other approaches to C2.

III.c - Agility

Agility is the capability to successfully effect, cope with and/or exploit changes in circumstances. [4]

It is the synergistic combination of versatility, resilience, responsiveness, flexibility, innovation, and adaptation, as described in [3] and [5]. Each of these attributes of agility contributes to the ability of an entity (a person, an organization, a coalition, an approach to command and control, a system, or a process) to be effective in the face of a dynamic situation, unexpected circumstances, or sustaining damage.

In order to be recognized as agile, an organization must be able to exhibit the property to change from one C2 approach to another and that can happen only if the six attributes are present within the organization. The more approaches it shows, the more agile it is. But such property does not come randomly. Only applying methodical and disciplined way can lead to this wished ability.

Summarizing, Agility involves:

1) recognizing the significance of a change in circumstances;
2) understanding the most appropriate Approach for circumstance and;
3) being able to transition to this approach.

In section V we will present some systems and developments examples ongoing within Brazilian Army that fulfill those concepts.

IV – SYSTEMS ENGINEERING

IV.a - Traditional SE

To build a system, a very well exercised approach is to decompose the “monolithic” system into “small” parts. This is not so easy. Most of the time, decomposing the complex system is also a matter of negotiation and agreement.

On complex systems, a good practice to adopt is to decompose the system into different layers - sub-system, assemblies, unit or whatever you can call it.

A top-level system requirement just covers system-level issues to reduce document sizes and apply intelligence at the right level.

Usually, sub-system engineers receive a package of requirements about the architectural element they are to design. They may need to define additional local requirements for that component. Additionally, business implications must be considered to increase engineering efficiency.

In a similar fashion (on a complex project) the process may be repeated, i.e. the sub-system will require an architecture, and will pass requirements down a layer.

Each transfer downwards bundles a 'contract' of requirements concerning the product, including interoperability requirements.

It will also include development requirements such as the management plan, need date, estimated resources, plus risk attached to that component.

Modeling supports the design activity. It assists the engineer in understanding enough of the system to decompose the requirements at a particular level into the next level down. The requirements themselves are a complete snapshot of what is required at increasing levels of detail. Modeling is where most the creative work takes place, resulting in a design document containing the diagrams of the model and textual explanations, rationale and context.

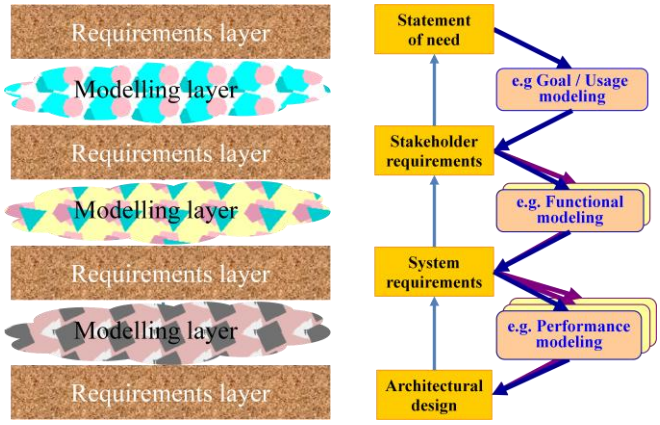

Figure 3 - Traditional SE Modeling

The requirements management activities can be considered to be generic since textual requirements are handled in a similar way regardless of the application domain. Modeling is potentially a domain-specific activity because different modeling techniques can be applied to represent different aspects of a system. This is particularly true of the detailed design layers.

The Role of Models

Models can be used to complement requirements management at each of the different layers and are useful in a number of ways:

Architecture modeling adds formality to the design process that lies between each layer of requirement

The architecture model promotes an active understanding of the details in large requirements documents

The design rationale gathered around the architecture model becomes the rationale for traceability between layers of requirements

The structure of the architecture model can be used to give structure to the requirements document

The architecture model is the basis for: costing, interoperability analysis, partitioning to different development teams, scheduling (WBS), analysis of alternatives, early validation, and risk management.

The design and modeling activity provides a unique opportunity to add value to the traceability of requirements. Embedded in the model are all kinds of explicit and implicit rationale explaining why the new layer of requirements is necessary and sufficient to satisfy the requirements of the last layer. Rather than tracing directly back to the requirements in the layer above, tracing can now pass through the design document, using the model and the supporting rationale to explain it. Using this approach, impact analysis can be

carried out in a uniform fashion through the models as well as the requirements. If a particular requirement or design changes, then those requirements and models impacted can be identified up and down the layers.

The design document can also express rationale associated with the decomposition of non-functional requirements that are not represented in the model. In this way, there is a single point of reference – the design document – for all aspects of the system at a particular level. Making use of design rationale in this way is akin to an approach that has become known as "rich traceability", in which the design justification and/or satisfaction argument for each requirement is captured.

The separation of design from the requirements documents (and the maintenance of tracing between them) also makes it possible to reuse designs, and to establish a library of designs that can form the basis for product family management.

IV - Systems Modeling Techniques

A very wide range of very domain-specific modeling techniques may be used to aid systems design:

- Aerodynamic models using wind tunnels;
- Safety, reliability and maintainability models;
- Weight distribution models;
- Network performance models using queuing theory.

Although many models are necessarily domain-specific, every system has aspects which can be modeled using a basic approach such as DoDAF.

A basic architecture model that proves that the architecture provides the desired capabilities (structure and behavior) should be done prior to committing resources to more detailed modeling and simulation.

There are two major activities in the Basic systems engineering process:

1) Analysis of the input requirements and the creation of a model;
2) Achievement of the output requirements from the model.

These steps are applied recursively through the layers.

The first of these uses requirements as input, and creates a design description (DoDAF Architecture). The second takes the design description (DoDAF Architecture), and creates a new layer of requirements.

IV.b – DoDAF

Although technologies like Pacificador and C2 Cmb (described in section V) and Aerostat and Wireless Sensors Network (described in section VI) are capability key enablers for C2, they solely cannot provide the desired effect in a crisis situation. They must be put together in such manner that the information user can employ it to accomplish the mission, and moreover, can identify when the mission space has changed so he can adapt itself to the new situation, even applying another C2 approach.

One powerful tool that helps to ensemble all technologies in an agile fashion tied to organizations and process is the Department of Defense Architecture Framework (DoDAF). The framework is compound by views and working products, which depends on the version. DoDAF 1.5 defines 4 views and 26 products while DoDAF 2.0 defines 8 viewpoints and 41 products.

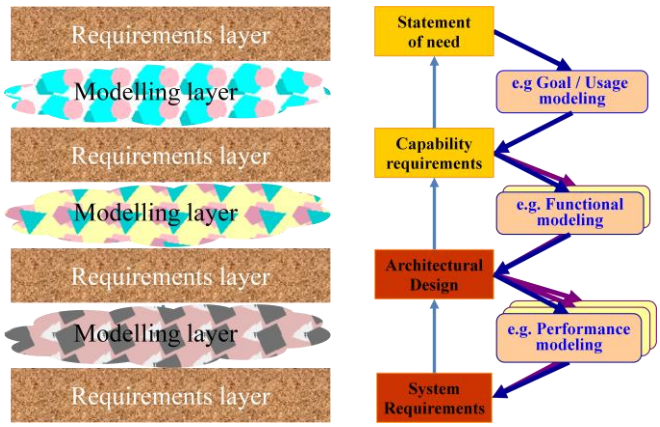

Figure 4 - SE Modeling with DoDAF

IV.c – Service Oriented Architecture

Service Oriented Architecture (SOA) is a paradigm for organizing and utilizing distributed *capabilities* that may be under the control of different ownership domains. The fundamental parts of a SOA paradigm that guide the infrastructure solution are: [6]

1) *Visibility*, which refers to the capacity for those with needs and those with capabilities be able to see each other that can be translated to the *service description*, which needs to be in form where its syntax and semantic be accessible and understandable;

2) *Interaction*, which is the activity of using a capability. It proceeds through a series of information exchanges and invoked actions, mediated by exchange of messages. The service registration in a publisher server and its look up capability are the main tasks of an interaction proceeding, followed by the capability to send messages between service consumer and service provider;

3) *Effect*, which is the result of an interaction. This effect may be the return of information or the change in the state of entities (known or unknown) that are involved in the interaction.

These fundamentals have been exercised in some projects within the Ministry of Defense and mainly in the C2Cmb, whose software infrastructure has evolved to this concept, named CORTEX, and been proved to be a suitable solution for agile development and interoperability, as explained in [7].

V – C2 SOLUTIONS

V.a - Duality

Brazilian Government seeks to strengthen the bonds between the development of the Science and Technology and of the production.

It aims to take advantage of the potential of the technologies employed in the country and transform them into final goods, stimulating the national industry.

In accordance to this, projects to be supported has to be selected and assessed according to the following described strategic actions, and to the characteristics that consider the public demand potential, the possibility of common use by the service branches, the dual use - military and civilian - of the technologies, the technological by-products of civilian use, the nationalization rate, the exporting potential, the presence of critical raw materials that depend on imports, and the international embargo potential.

Based upon these END´s guidance, Brazilian Army started two huge projects that fulfill the duality concept not only under technological usefulness aspects but also other than war operations, which are the SISFRON and the PROTEGER projects following described.

V.b - SISFRON

The Integrated Border Monitoring System (SISFRON, in Portuguese) is a system of sensing, decision support and integrated operational support activities whose purpose is to strengthen the presence and capacity of state action in the border region, under the aegis of the trinomial monitoring/control, mobility and presence, emphasizing the thickening of the units of the

Armed Forces at the border and directing training industry for the conquest of national independence in critical technologies for the defense.

Figure 5 - Border extension and the Amazon area

The border extension includes three distinct environments: rainforest, swamp and dry borders. For each environment, the monitoring and C2 solutions have to be the appropriate one. By specifically referring to this paper, UAV and aerostat are part of the monitoring and sensing solution that is planned to be employed at the Amazon border environment, due to the telecommunication infrastructure limitations.

The SISFRON was modeled using DoDAF 1.5 to explore the integrated architectural concept to allow the sought agility in the border.

V.c - PROTEGER

The Brazilian MoD is conducting a Revolution in Military Affairs under way of the so-called National Defense Strategy (END – *Estratégia Nacional de Defesa*, in Portuguese), released in 2008, that is under implementation in Brazilian Army throughout several strategic projects. The project PROTEGER[2] is one of these projects that aims to promote a real transformation, not only in the military equipment, but also in the way of troops thinking and deployment, making the Effect Based Operations and the Inter-agency Command and Control environment to become reality in the Army Staff Planning procedures.

PROTEGER will seek to build a permanent Interagency Command and Control infrastructure including computers, satellite links, data fusion tools and several IT tools to make it possible to establish a real Common Operational Picture in critical situations where the Brazilian Army needs to be deployed. The Project will try to identify, manage, articulate and integrate all the agencies involved in critical infrastructure points in the Brazilian territory, including power plants, nuclear facilities, oil and gas refineries, IT data centers and so on. For this reason the strategic points that will be protect is called Ground Strategic Structures, that will be monitored using aerostat, long range infrared cameras, ground surveillance radars and other technologies assets.

A real information grid will be assembled with this project, the first step towards the agility needed to face distinct threats within distinct environments, linking tactical and operational procedures in an effective way.

PROTEGER is under development guided by DoDAF 2.0.

V.d – SISTED[3]

The Brazilian Military Command and Control System (SISMC[2] – *Sistema Militar de Comando e Controle*, in Portuguese) covers all levels of command, from the highest strategic Supreme Command Armed Forces to the lowest tactical

[2]Portuguese acronym for PROTECTION OF GROUND STRATEGIC STRUCTURE.

[3]Portuguese acronym for Tactical Data Link System.

levels of each Force. Since each Armed Force has its own C^2 system, according to their operating environments, weapon systems, platforms and other specifics, the Ministry of Defense promotes interoperability between these systems, and supports the Joint Operational Command and Peacekeeping Forces, contained in Defense Military Structure, when activated.

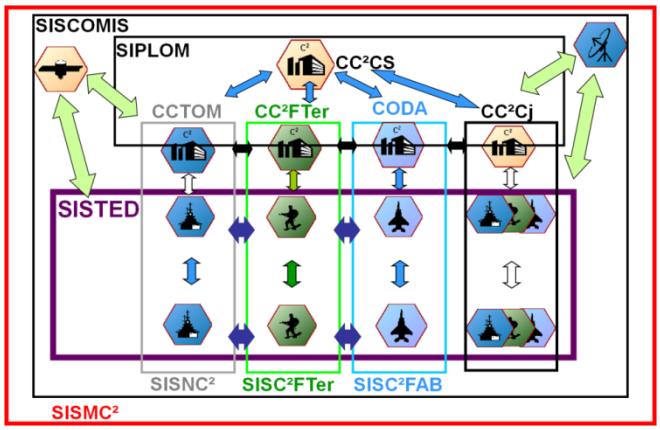

Figure 6 - Brazilian Military C2 System

The SISTED is a Joint Tactical Data Link System and its objective is stated by the MoD as following:

"*To exchange tactical messages among Services, in a standardized and parameterized way throughout the processing, in order to ensure that the actions in interservice tactical scenarios are conducted with efficiency, effectiveness, safety and without mutual interference.*"

Besides the objective, the systemic solution must take into account the following premises:

- Services have autonomy to conceive, develop, operate and maintain their own tactical C^2 systems;
- Services have different organizational cultures;
- Services have different technological generations;
- Services have different methodologies for systems engineering.

The adopted methodology to develop this system is based upon the initial assumption that all legacy systems eventually will become obsolete and a new system would be prepared to replace it. The new system must keep at least the functional requirements performed by the retired one. If new capabilities are provided by the new system, these shall be available for the entire system, including those subordinated sub-systems. This methodology deals with the creation of new System of Systems (SoS), using a System of Systems Engineering approach, aiming the replacement of the obsolete legacy systems in long term.

It employs guidance of ISO/IEC 15288 - Systems Engineering - System Life Cycle Processes, INCOSE Systems Engineering Handbook v3 and DoDAF 1.5 as modeling architectural framework.

V.e - C2 in Combat

The C2Cmb software was developed under directive that its distribution must be free of any licensing costs. The result is that it is based on open source free database and GIS software integrated into a user interface that can run on either Windows or Linux platforms.

It has been completely developed by Army personal and is configured to operate on a distributed basis (i.e. no centralized servers being employed), even over HF networks.

It was originally conceived to be used only for conventional military operations in tactical level, but the variety of missions and tasks performed by Brazilian Army forced a change of this perspective. C2Cmb software should be able to deal with different sorts of missions, each of them requiring specific features and resources. The C2Cmb should be able to fulfill both issues, in

order to match the Brazilian Army everyday challenges.

Since the new perspective represents a change from rigid hierarchical communication structures to edge ones, the C2Cmb project also had to face the need for improve data exchange and replication mechanisms. It leads the developers to find more suitable solutions to deal with different configurations of data flows, depending on the nature of the mission.

This new approach has lead C2Cmb to a new level, revealing new unseen capabilities, although intended to be obtained.

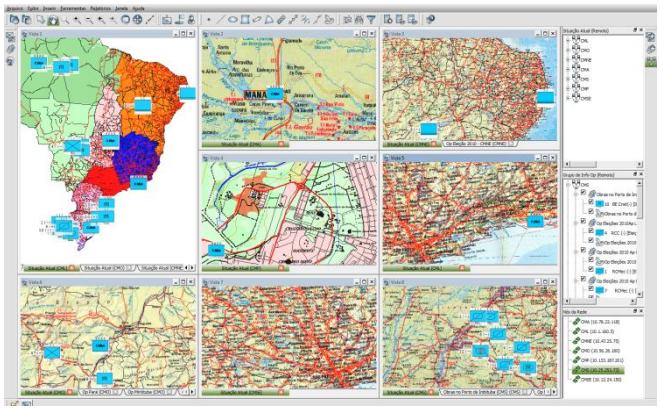

Figure 7 - C²Cmb Software Screen Capture

One of these new capabilities was the "god´s view" added to the Army Command of Ground Operations (COTER, in Portuguese) that allowed it to follow simultaneous operations conducted in whole country.

Other useful capability was the quick development of new software component that allowed an unseen interoperability with the Brazilian Air Force, specifically with A29 aircraft, under the SISTED Close Air Support capability.

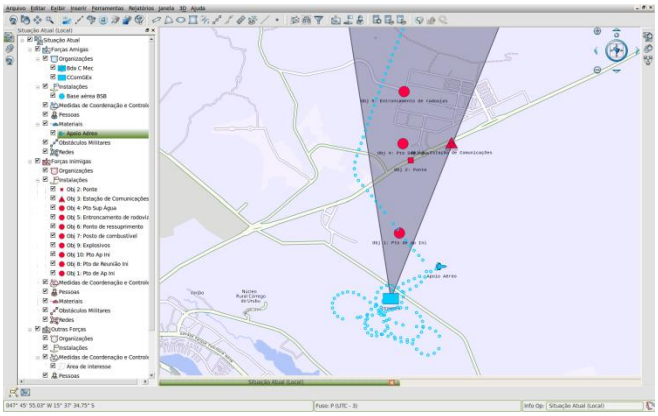

Figure 8 - Flight Test Screen Capture

VI – INFRASTRUCTURE

In order to allow the information flow to C2 Centers, some studies and researches are ongoing to provide suitable sensing and communication infrastructure solutions under restrictive environment like the Amazon that will technically support the necessary C2 agility to face the threats. Two such studies are presented following.

VI.a – Communications

As mentioned in Section 2, among the difficulties faced by the Brazilian Army, the poor communications infrastructure toward large distances involved is a factor that hinders the ability to monitor and control the Brazilian territory. One way to reduce the shortage communication infrastructure is integrating available technologies such as satellite, HF and VHF using aerostats with EO/IR cameras as payloads as well as radio equipments and radars as source of data for C2 systems developed by the Brazilian Army.

The proposed solution is based on simulations performed on Radio Mobile [8], considering aerostats placed in platoons in the Amazon border. It was considered the operating altitude of 3000 meters and payload capacity of 3200 kg. These parameters refer to TCOM 74M used in the JLENS program, which could carry some radio equipments capable of providing an extensive

coverage area as providing accurate and rapid decisions.

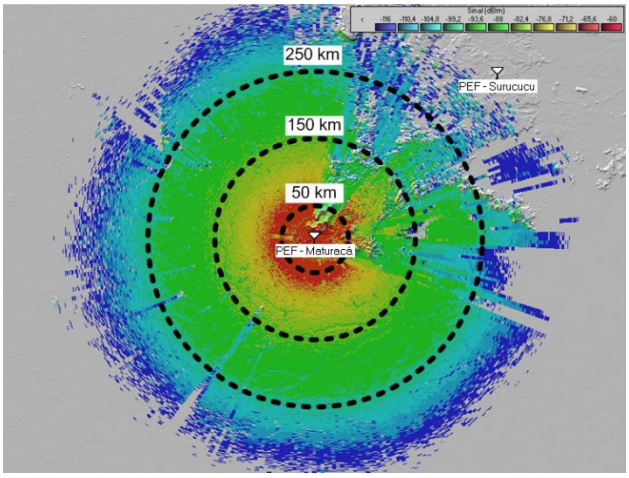

Figure 9 - Maturacá coverage area.

Adopting the parameters of radio equipments currently in use by Brazilian Army (VHF range, 10W transmitter,omnidirectional antenna), the result of the Maturacá platoon simulation (Figure 9) shows the capacity to achieve larger distances, providing VHF communications to any patrol inside the jungle, solving an old problem that Brazilian Army faces in the border. Using this technology is possible to increase the capacity to promptly respond to any threat or non authorized incursion in this region. It can be noted that the signal coverage from Maturacá is short in Surucucu area, where there is another platoon at a distance of 370 km (Figure 10).

Figure 10 - Distance between Maturacá and Surucucu platoons.

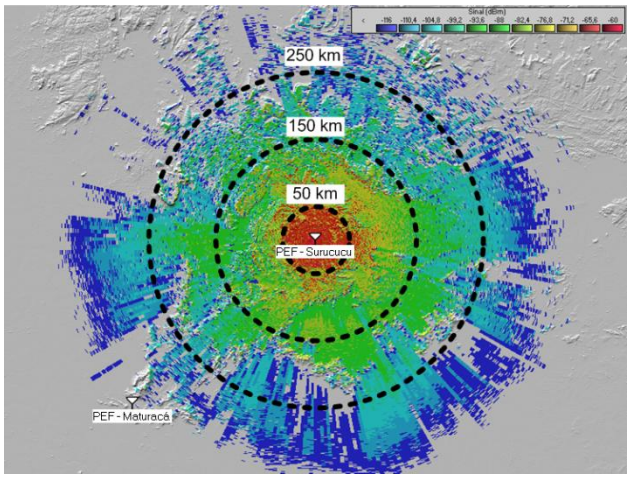

Figure 11 - Surucucu coverage area.

Adopting the same parameters in Surucucu platoon, the result of coverage area is quite different because some irregularities in its relief strongly attenuate the signal (Figure 11).

Although the coverage areas of these platoons overlap, there are some communication gaps. A possible alternativeto solve this issue is the use of UAVs and Aerostats Network solution that will be exploited in the next section,where aerostats provide backbone links to the C2 system back-end network.

VI.b – Wireless Sensors Network

A survey on sensor networks presented by Akyildiz et al [9] describes recent advancement in wireless communications and electronics that have enabled the development of low-cost sensor networks. These sensor networks can be used for various application areas and for each one, there are different technical issues that must be resolved.

A Wireless Sensor Network (WSN) is composed of a large number node, which consist of sensing, data processing, and communicating components, which aredensely deployed either inside the phenomenon. In WSN, protocols and

algorithms must possess self-organizing capabilities and have cooperative effort.

The sensor nodes are scattered in a field and each sensor has the capabilities to collect data and route back to the sink by a multihop infrastructure less architecture. The design of the WSN is influenced by many factors that serve as a guideline to develop protocols or algorithms for a specific application. Some of these factors are:

- **Fault tolerance**: the ability to sustain functionalities without any interruption due sensor node failures;
- **Scalability:**the number of sensor nodes deployed may be on the order of hundreds or thousands;
- **Production costs**: the cost of a single node is very important to justify the overall cost of the network;
- **Hardware constraints:** a sensing unit, a processing unit, a transceiver unit, a power unit, and an additional application-dependent components must to fit into matchbox-sized module;
- **Topology:**deploying a high number of nodes densely requires careful handling of topology maintenance;
- **Environment:**sensor nodes usually work unattended in remote area where they were deployed;
- **Power consumption**: power conservation and power management are the most important factor in design of WSN.

WSN have many possible applications in the military and defense domain. They represent an important source of data for C2 systems, providing situation awareness (SA) and thus supporting informed decisions. Despite this promise utility of WSN, in the vast operational scenario offered by the amazon environment, it is impractical (useless and high cost) to deploy a WSN that completely covers large extensions such as the amazon part of the Brazilian borderline. Nevertheless, several spots of areas like this are of great interest that stays under permanent surveillance of a WSN. A zoom out view of this scenario represents then a WSN that has several groups of nodes covering a given area, which are disconnected from the other groups. In other words, there is a sparse WSN composed of “islands” of nodes. The problem in this scenario is how to collect the data from these isolated groups of nodes. A possible solution for this problem is to have one or more mobile sink nodes collecting data from the isolated nodes periodically or sporadically. This way, the nodes would be waiting for a mobile sink for data collection, as presented in [10]. The solution for the presented problem can be also related to the concept of Delay Tolerant Networks (DTN) [11], where such kind of controlled nodes’ connection and disconnection is addressed. This DTN-based solution is relatively simple to be implemented and is able to retrieve data from the sparse sensor nodes. However, from the application point of view, a defense system, it does offer the responsiveness needed in this domain. The delay involved in the sink movement to acquire data from the isolated groups of sensor nodes can be inacceptable. In order to be really useful, such WSN needs a solution that provides fully connectivity of the sensor nodes towards a base station that drives the data to the C2 system.

Observing these needs, the proposed solution in relation to this aspect described herein consists of a heterogeneous network, in which the WSN of sparse sensors is part of a larger network composed also of Unmanned Aerial Vehicles (UAVs) and Aerostats. The idea is to have few Aerostats units spread over the region of interest providing backbone links connected to the C2 system back-end network. In order to the sparse WSN be able to communicate with the Aerostats to deliver their data to the C2 system, a relay network of UAVs provides persistent connectivity towards the Aerostats. Figure 12 presents the overall system solution.

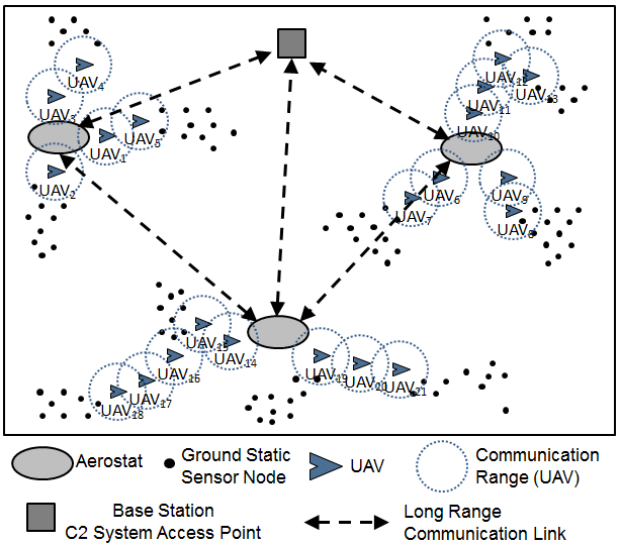

Figure 12 - Wireless Sensors, UAVs and Aerostats Network solution.

This hierarchical approach provides an efficient way to explore the possibilities offered by the WSN being deployed in selected areas, enabling them to communicate with the back-end system through the communication link capillarity provided the UAVs towards the Aerostats which by their turn have long range communication links to the C2 system access point.

In order to the UAVs maintain the relay network to provide communication link between the islands of nodes and the Aerostats, the proposed solution is adjust their movement so that the end-to-end connection is permanently maintained.

The UAVs fly according to a given movement pattern, such as a random movement for instance. In the case of a random movement, they keep flying randomly until they recognize that the last link that keeps their connectivity with the rest of the UAV-network (or with the Aerostat or the island of sensor nodes in the case of the UAVs that are in the extremities of this network) is about to break. This measurement is done based on a link estimation metric assessed by the received signal strength intensity (RSSI) of periodically exchanged beacon messages. When this situation happens, they change their movement and try to fly in the direction that keeps the network connectivity, i.e. in the direction of the last received beacon with RSSI above a given predefined threshold. Considering the UAVs along the relay network, this means that they try to keep close enough so that the communication link from the sensor nodes towards the Aerostats is maintained.

Experiments and Results

The proposed UAV-relay network solution to connect sparse WSN to Aerostats was tested via simulations using GrubiX ad hoc network simulator, an extension of the ShoX project [12]. The performed simulations aimed to assess how effective the UAV-relay network is to maintain the connectivity between at least two far apart static ends, one representing the Aerostat and the other(s)one(s) or more islands of isolated sensor nodes. The UAVs are represented in the simulation tool as nodes of a network, so from now on the term “node” will be used interchangeably with the term “UAV”, representing the same mobile entity.

The selected metrics to assess the proposed strategy were: 1) Number of disconnected nodes over time; 2) Connection rate; 3) Average distance among nodes; and 4) Average number of neighbors. By measuring the number of disconnected nodes over time and the rate of network disconnection it is possible to directly evaluate how good the proposal is to address its main goal, i.e. keeping the connectivity. The target is to minimize the duration of network disconnections, or the number of nodes that are disconnected. The last two metrics provide an insight about how the nodes are distributed and how their movement is influenced by the proposed solution. Good results would present distances among the nodes not too large so that their connectivity could be broken. This means that by using the proposed solution the nodes can move apart from each other, but not too much. However, the nodes should not keep too small distances among them, which would imply in high

concentration of nodes, which is not desirable either. The same reasoning is valid for the fourth metric, in which a very small number of neighbors, or none, would represent that the nodes would be very sparse and then very prone to become disconnected. However, a too large number of neighbors would mean that the nodes would be too concentrated, which is also undesirable, as mentioned above.

The simulation setup used in the performed experiments is described in the following. The UAVs are randomly distributed over the area in the beginning of the simulations. Once the simulation is started, the nodes search for neighbors to communicate and make the network connected. As soon as they get connected, or directly from the beginning if they are placed in an initial position that provides such connection, they start acting as previously explained to maintain the network connection.

Eight UAVs fly in an area of 10 Km X 10 Km, and they have a communication range of 3Km. The duration of each simulation run was 60 minutes (simulation time). It is assumed that the UAVs fly at the same height, and their communication range is represented by a circle around their current position, as the used communication mechanism is an omnidirectional model available in the library of the simulator. The choice of the setup parameters were based on the characteristics of the scenario targeted by this study, which considers Mini or Micro UAVs [13]. These UAVs have an operational range at maximum of 10 Km and fly at altitudes around 250 meters. They usually have communication ranges that are compatible with those provided by technologies such as IEEE 802.15.4 (extended range version). Assuming such communication technology and flying altitude, the used communication range is fairly realistic considering negligible obstructions in the Fresnel zone [14].

Figure 13 presents an example of the evolution of the proposed solution. This is a result obtained for the first evaluated metric for one of the simulation runs. It is possible to observe that in the beginning, there was a number of disconnected nodes (6 in the worst case), if compared with the total number of UAVs in the simulations (8 in total). However, the number of disconnected nodes drops quickly with time and achieves zero disconnected nodes from 5 minutes of the simulation start and remains zero until the end of the simulation. Notice that Figure 13 presents what happens in one simulation run, but for all ninety nine other runs, the behavior is almost the same. There is a small difference among the simulation runs in relation to the time in which the number of disconnected nodes becomes equal to zero, which varies from 2 to 5 minutes of the simulation time. However, from the moment in which the number of disconnected nodes reaches zero, in all simulation runs it maintains zero for the rest of the simulation time.

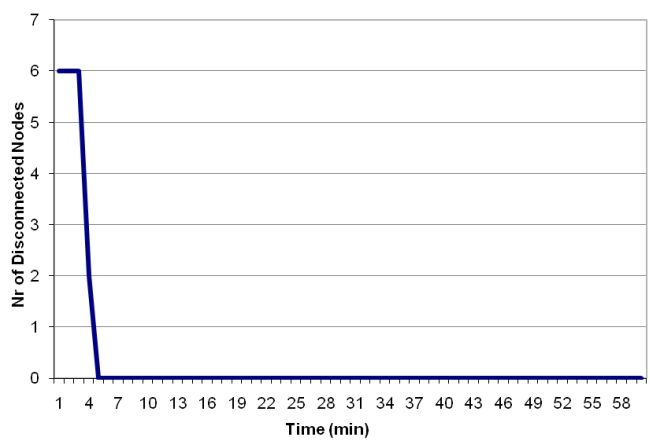

Figure 13 - Number of disconnected nodes over time.

The results for the second metric for all simulation runs are presented in Figure 14. The plot presented in this figure brings a comparison between the normalized results for the set of runs using the proposed approach and a set of runs also using the random movement pattern, but without the proposed system behavior. The results clearly show how useful the proposed solution is to keep the connectivity, as a significant number of runs show 100% connectivity, while the remaining ones are very close to this. On the other hand, the results achieved by the pure random movement

are really poor and result in very low connection rates.

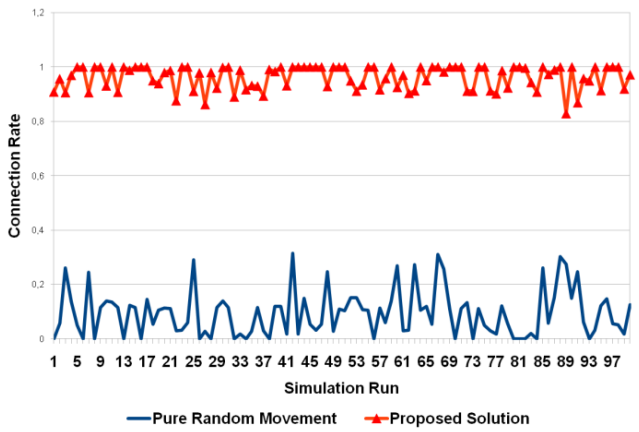

Figure 14 - Connection rate.

The third set of results presents the average distance among the UAVs in each simulation run. These data are shown in Figure 15. The results of the proposed solution are also compared with those obtained by simulation runs using pure random movement. As it is possible to observe, the results achieved with the proposed solution provides movements that allow a dispersion of nodes which, in almost all the cases, is smaller than the one achieved by the pure random movement. This result shows that the solution allows the UAVs to fly as farther as they can before loosing the connectivity. This is a good result, because it contributes with the freedom that the UAVs need to cover the area according to their movement pattern, while keeping the connectivity. This also means that the proposed solution does not heavily affect the UAVs' movement pattern.

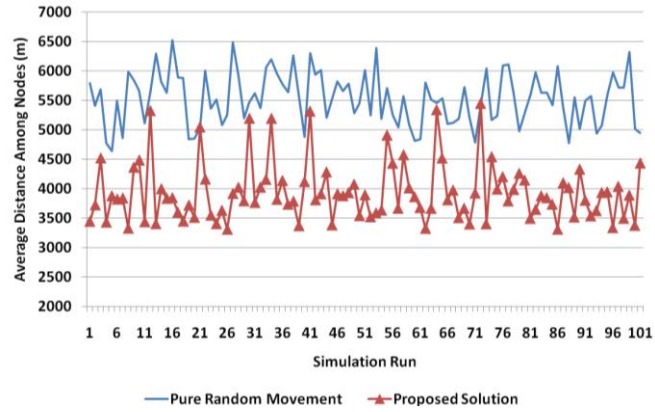

Figure 15 - Average distance among the nodes – nodes' dispersion.

A result for the average number of neighbors for each node for one of the simulation runs is presented in Figure 16. By the presented numbers, it is possible to observe that each node has in average around 2 or 3 neighbors. This means that, in average, they present a good distribution, i.e. they are not too sparse neither too concentrated. Taking the general case, i.e. a node in the middle of the network, ideally such UAV has one neighbor that provides its connection to the network towards the Aerostat and another neighbor that uses this UAV to provide such a connection, i.e. a UAV towards the direction of one (or more) island(s) of sensor nodes. This assumption would result in at least 2 neighbors for the general case. As the simulations are using a random movement pattern, it is reasonable to expect that the network topology becomes diversely branched during the simulation executions, providing opportunities to the nodes to have more neighbors. However, there is no occurrence of nodes with a large number of neighbors (much larger than the general case). A large number of neighbors would indicate the undesirable concentration of nodes in a given region. It is also possible to observe that the nodes have not too few neighbors, i.e. one or none, which is not a good result because if it were so, they would be isolated. The data in Figure 16 are an example of one simulation run, but the results for the other runs are very similar to this one. This example confirms the previous result presented in

Figure 15 that describes the node distribution compared with a distribution of the nodes moving randomly.

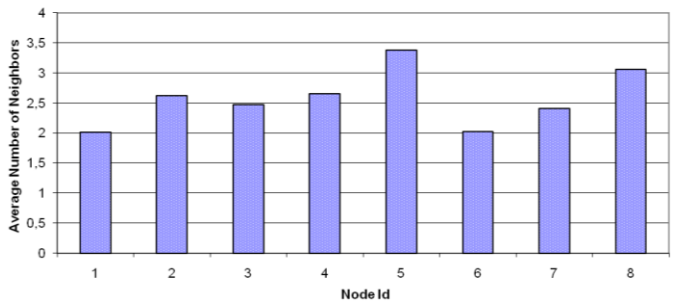

Figure 16 - Average number of neighbors for each node.

VII – CONCLUSION

We have presented in this paper a short overview of C2 systems engineering approach to allow the improvement of situational awareness in Amazon region.

This approach involves DoDAF as the architectural modeling framework to organize the systems under development, allowing interoperability with legacy systems and products, in order to provide the needed agility to face the diverse threats that the Brazilian Army can face in Amazon.

As communication is a severe issue within that region, and to provide sensors and radio communications based on satellite solution would be cost prohibitive due to the large area, it was investigated the joint utilization of wireless sensor networks and aerostats. The results obtained point to a very interesting and cost effective solution that can improve dramatically the SA in Amazon region.

VIII – REFERENCES

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18th ICCRTS
"C² in Underdeveloped, Degraded and Denied Operational Environments "

Paper 114

C² SYSTEM ENGINEERING FOR THE ADVERSITIES OF THE AMAZON ENVIRONMENT

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OBJECTIVE

- To present a proposal for structuring a command and control system to cope with the adversities of the Amazon environment, under the poor communications infrastructure

OUTLINE

1. Introduction
2. Area Characterization
3. C^2 Approaches
4. Systems Engineering
5. C^2 Solutions
6. Infrastructure
7. Conclusion

Introduction

C^2 SYSTEM ENGINEERING FOR THE ADVERSITIES OF THE AMAZON ENVIRONMENT

INTRODUCTION

"Arduous is the mission to develop and to defend the amazon. However, much more difficult it was for our ancestors to conquer it and to keep it"

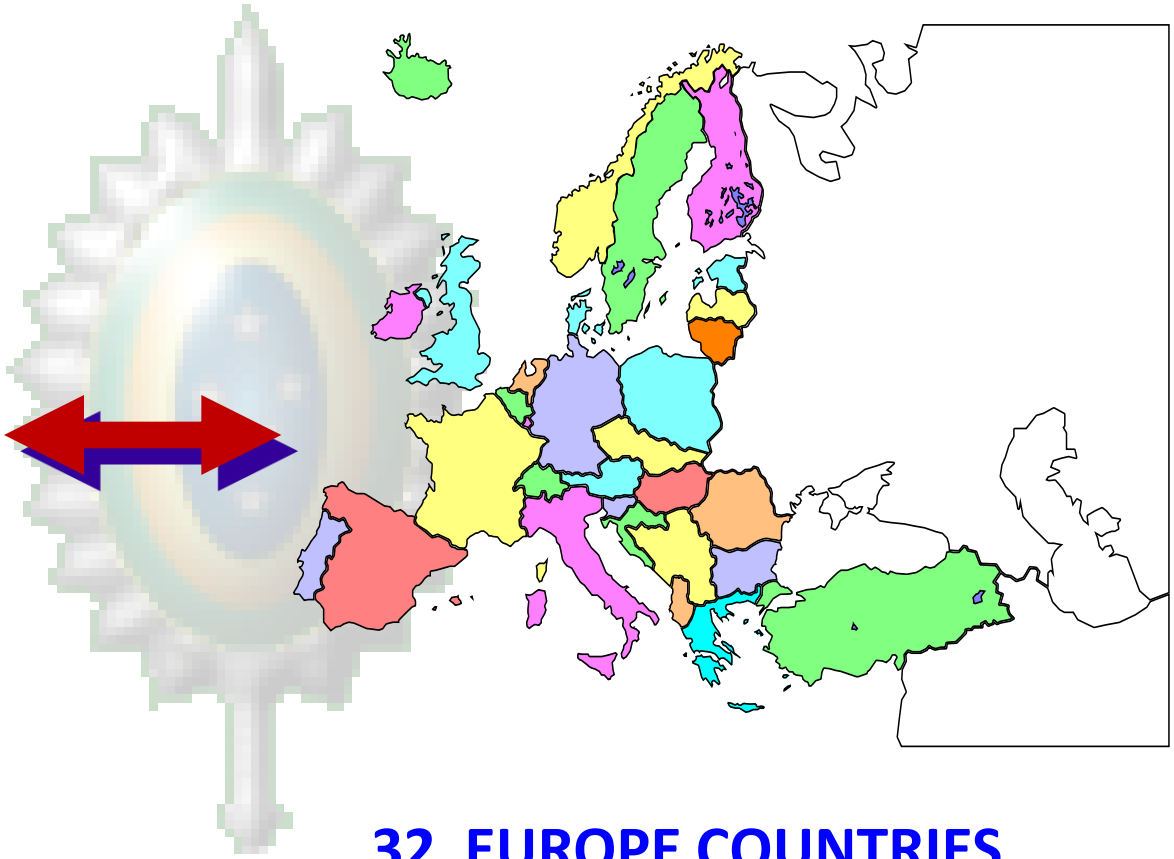
General Rodrigo Octávio

Area Characterization

C^2 SYSTEM ENGINEERING FOR THE ADVERSITIES OF THE AMAZON ENVIRONMENT

AREA CHARACTERIZATION

- Amazon Size



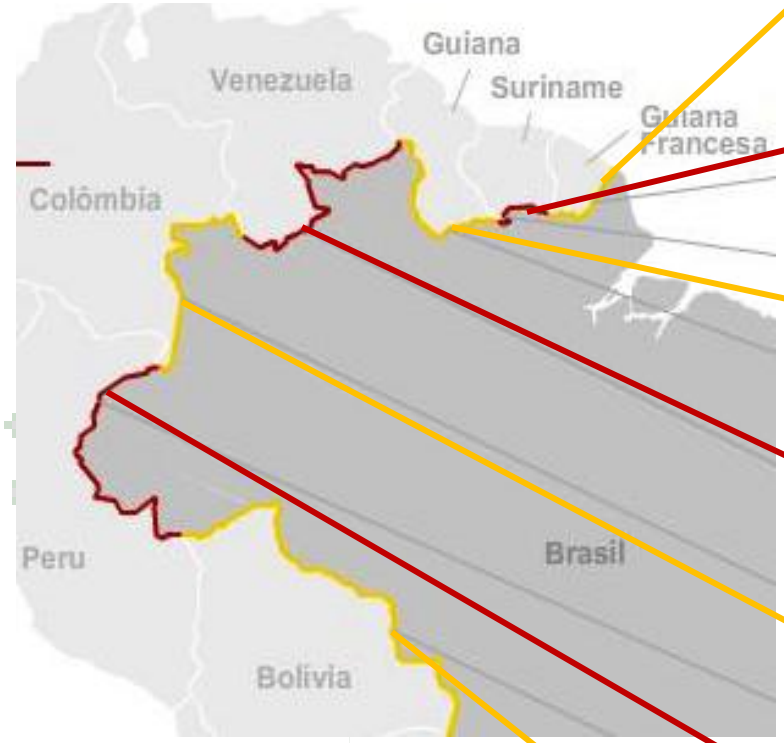
32 EUROPE COUNTRIES

Area: 5.200.000 km²

AREA CHARACTERIZATION

- Amazon Border Extension

MEXICO-USA BORDER: 2,500 Km

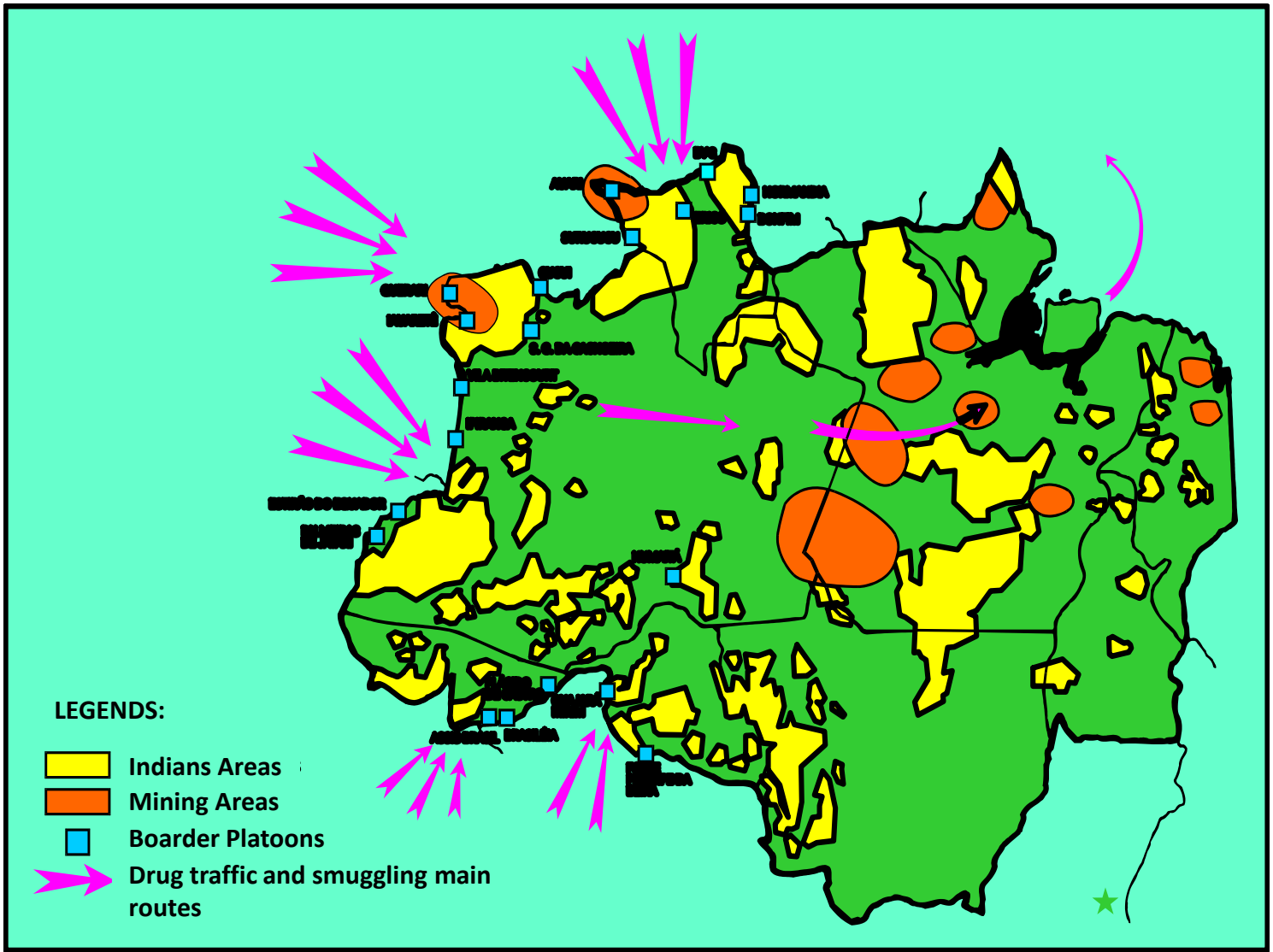


13,191.1 km

- French Guyana 730,4 km
- Suriname 593 km
- Guyana 1606 km
- Venezuela 2199 km
- Colombia 1644,2 km
- Peru 2995,3 km
- Bolivia 3423,2 km

AREA CHARACTERIZATION

- Some Amazon Issues



AREA CHARACTERIZATION

- Some boarder crimes

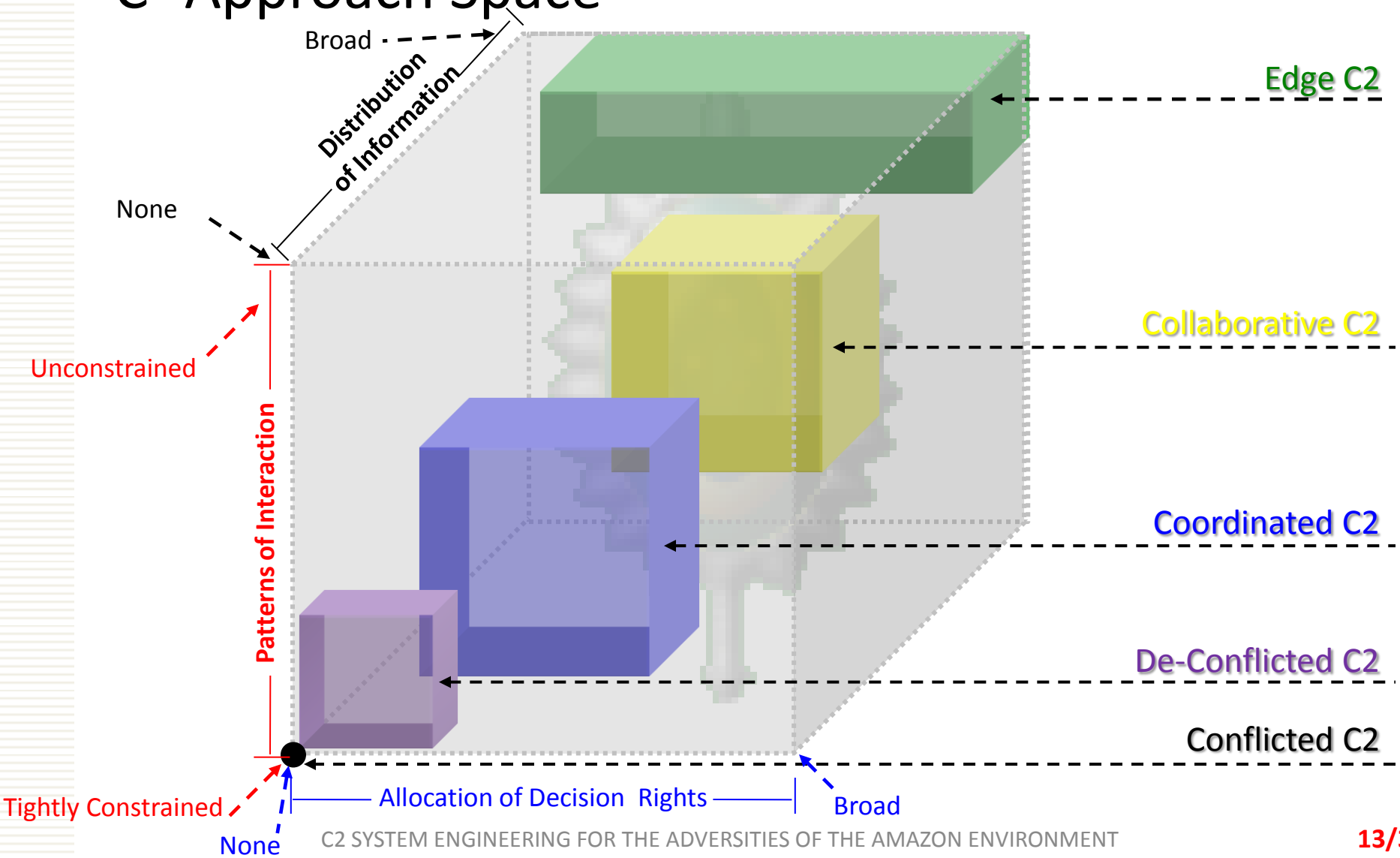
Crimes	State					
	MT	RO	AC	AM	PA	AP
Smuggling	X	X		X		X
Drug traffic		X	X	X	X	X
Trafficking in persons			X			X
Trafficking in weapons and ammunition	X	X	X	X		X
Cargo and vehicles theft	X	X		X	X	X
Child sexual exploitation		X	X	X		X
Refuge for criminals	X	X	X	X		
Tax evasion						X
Environmental crimes	X	X	X	X	X	X
Gunmen			X	X	X	
Sex tourism						X

C^2 Approaches

C^2 SYSTEM ENGINEERING FOR THE ADVERSITIES OF THE AMAZON ENVIRONMENT

C² APPROACHES

- C² Approach Space



Systems Engineering

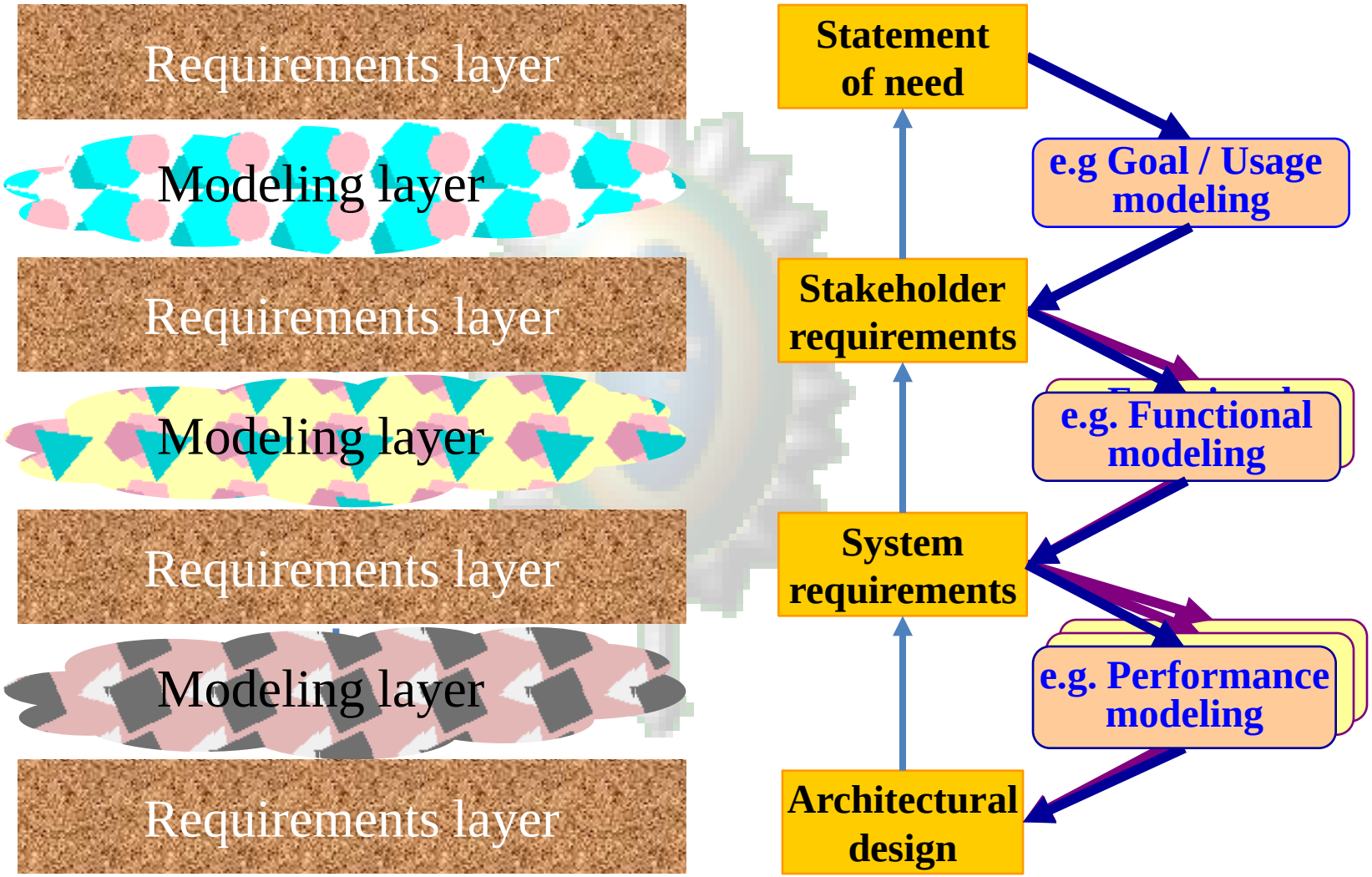
C^2 SYSTEM ENGINEERING FOR THE ADVERSITIES OF THE AMAZON ENVIRONMENT

SYSTEMS ENGINEERING

- It is a mix of:
  - Human resources
  - Project and business management
  - Rational decomposition
  - Studies of transactions
  - Requirements traceability
  - Integration, testing, verification and validation
  - Operation and decommissioning of systems at the end of the life cycle.

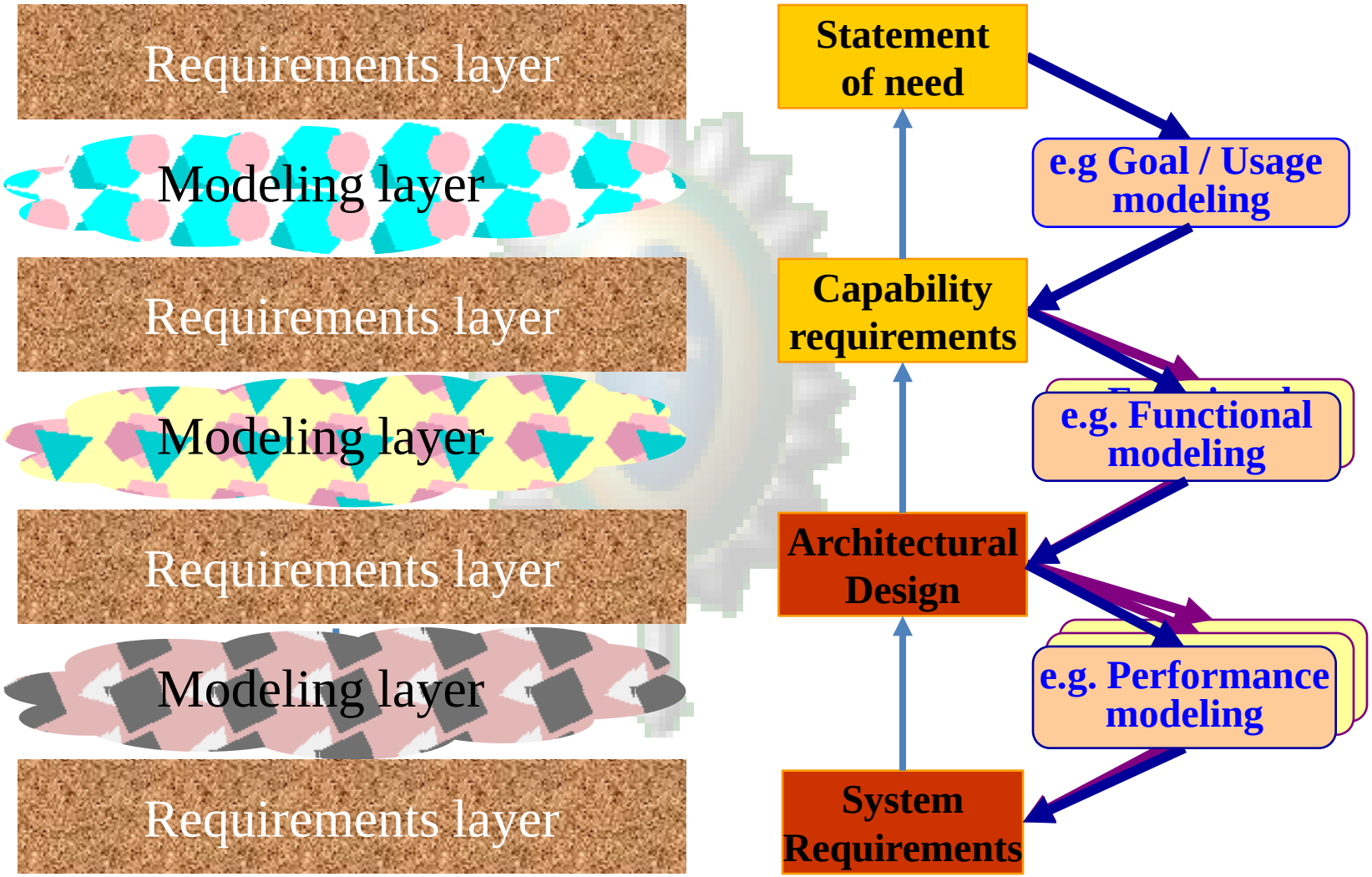
SYSTEMS ENGINEERING

- Traditional SE



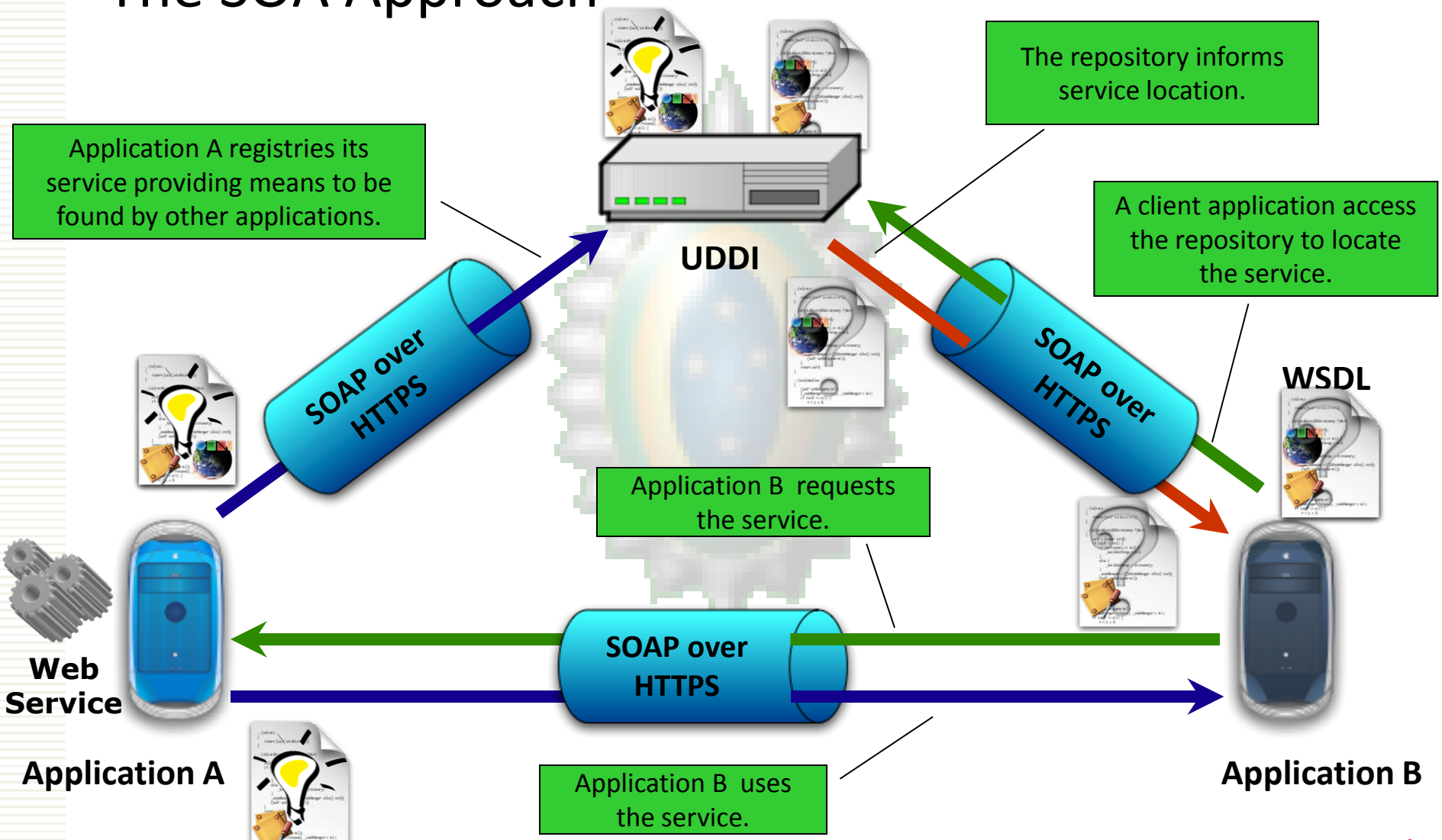
SYSTEMS ENGINEERING

- DoDAF Perspectives



SYSTEMS ENGINEERING

- The SOA Approach

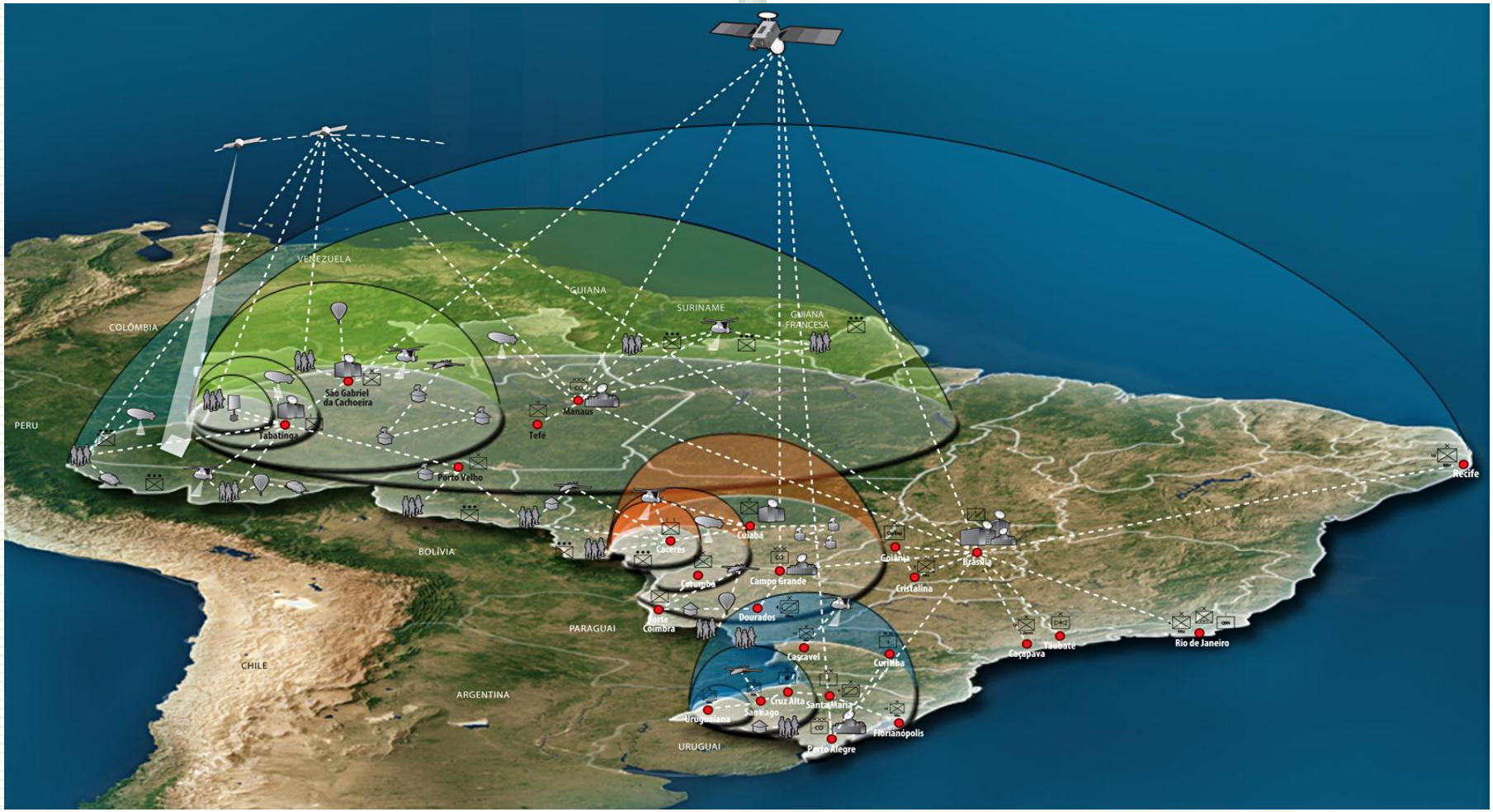


C^2 Solutions

C^2 SYSTEM ENGINEERING FOR THE ADVERSITIES OF THE AMAZON ENVIRONMENT

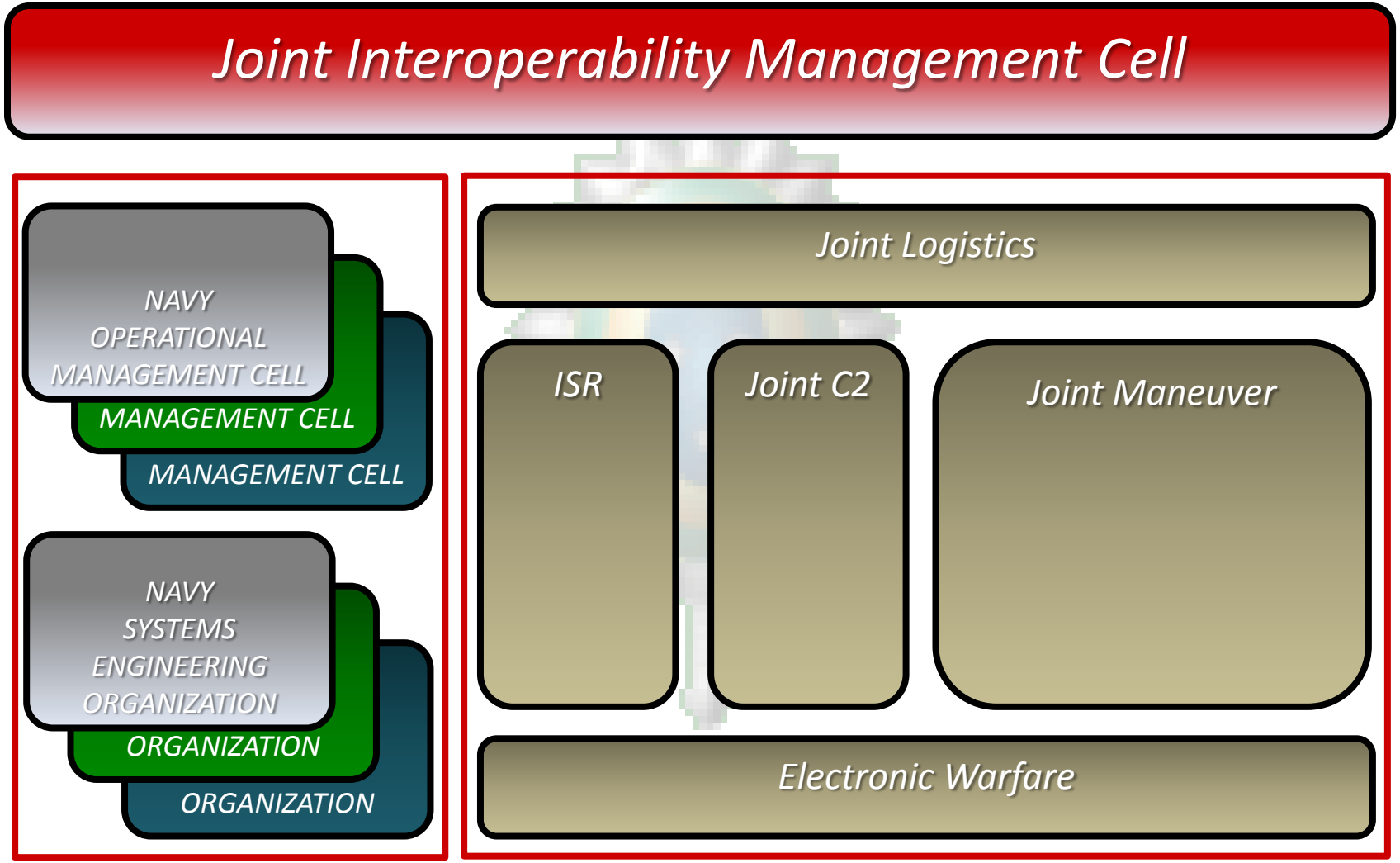
C² SOLUTIONS

- Integrated Border Monitoring System



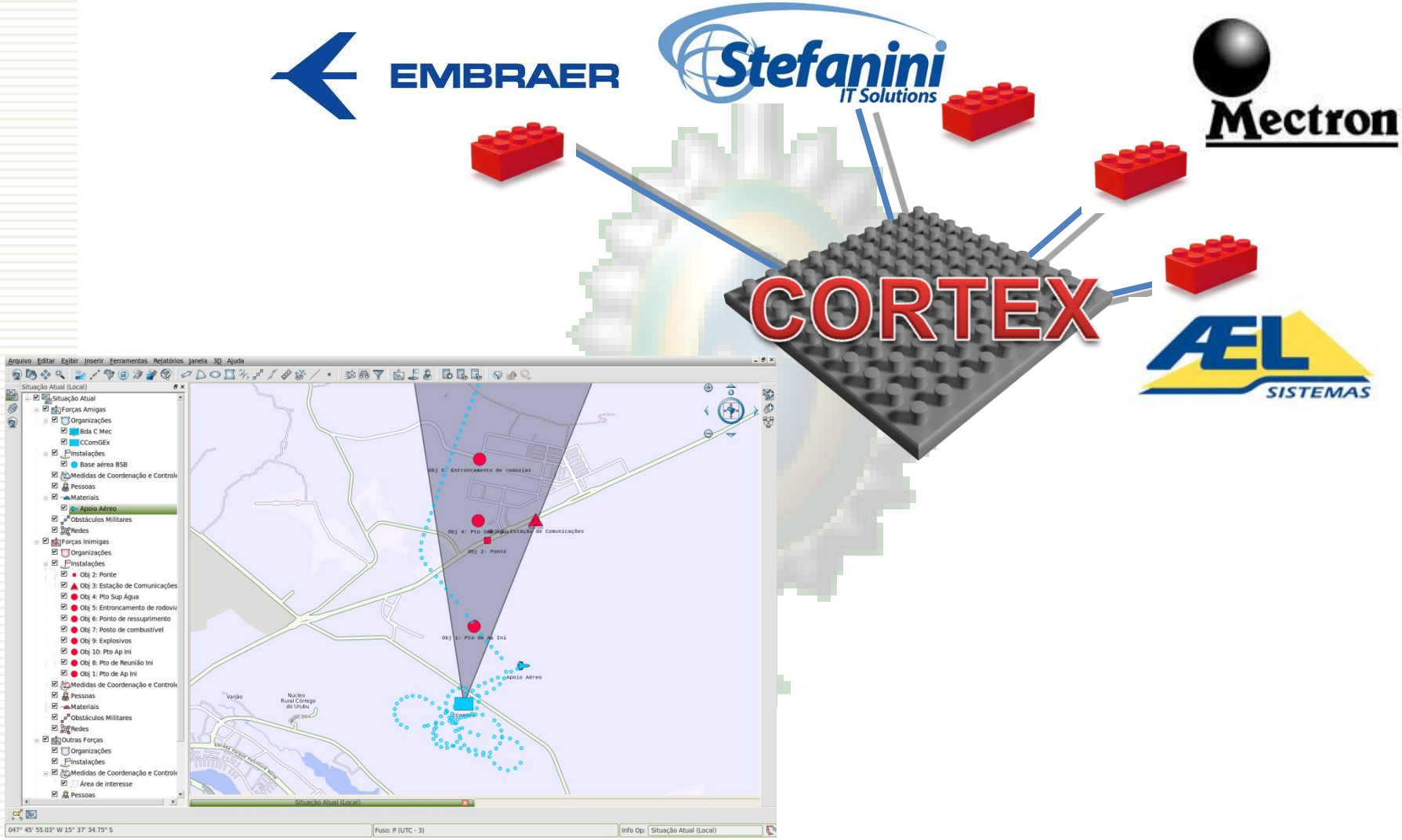
C² SOLUTIONS

- SISTED (Architectural Design)



C² SOLUTIONS

- C² in Combat (C²Cmb)



C² SOLUTIONS

- SW Set Family

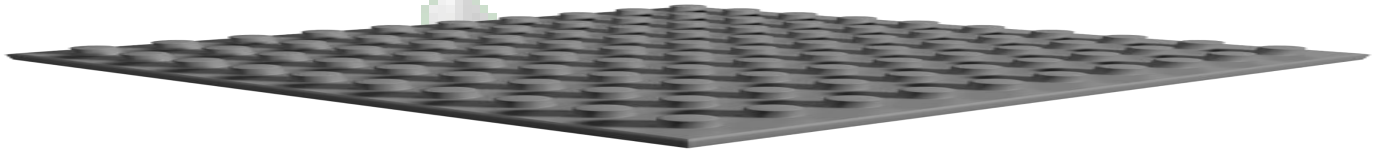
COp

GCB

PC

Amv

Mv

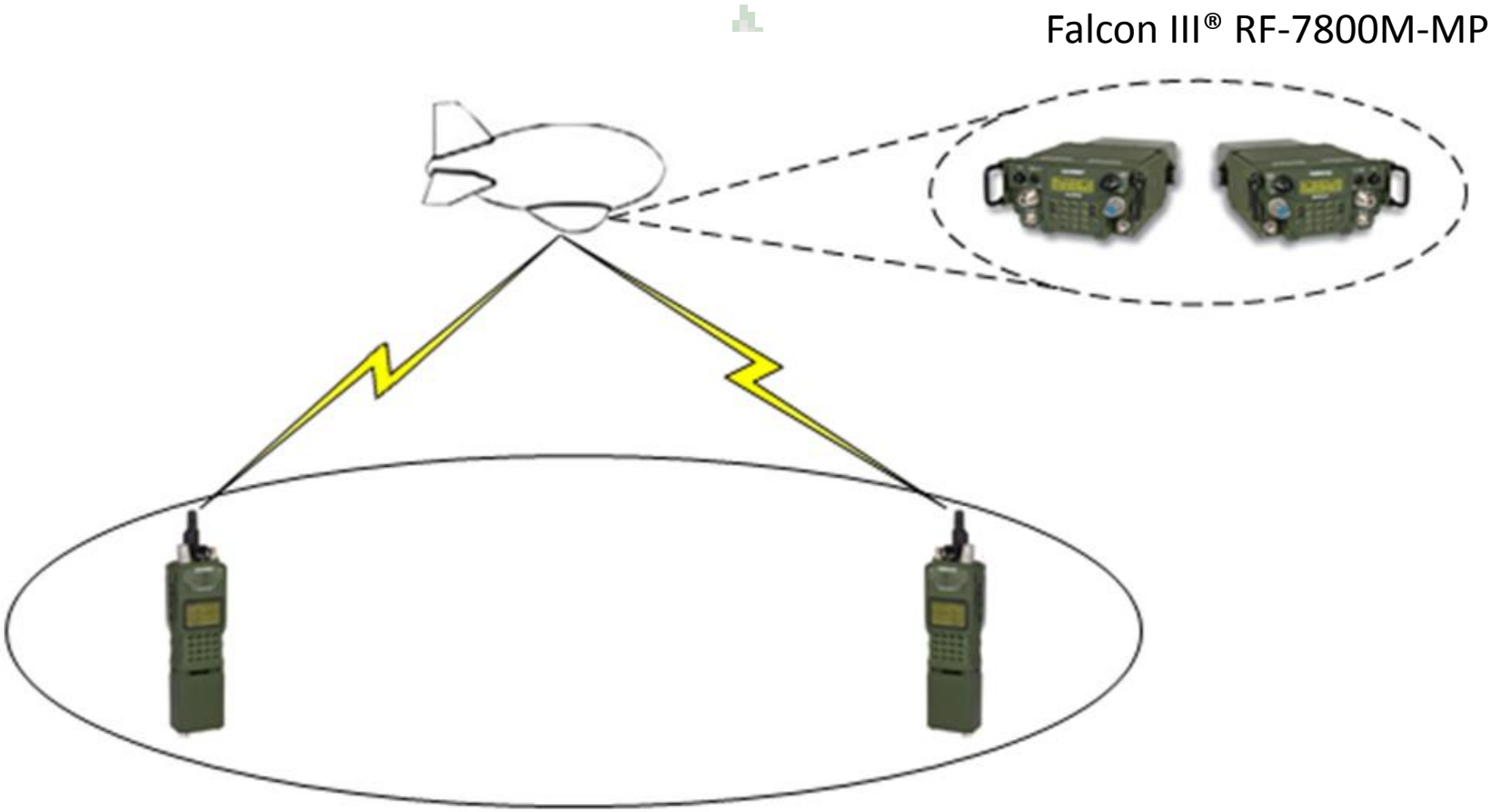


Infrastructure

C^2 SYSTEM ENGINEERING FOR THE ADVERSITIES OF THE AMAZON ENVIRONMENT

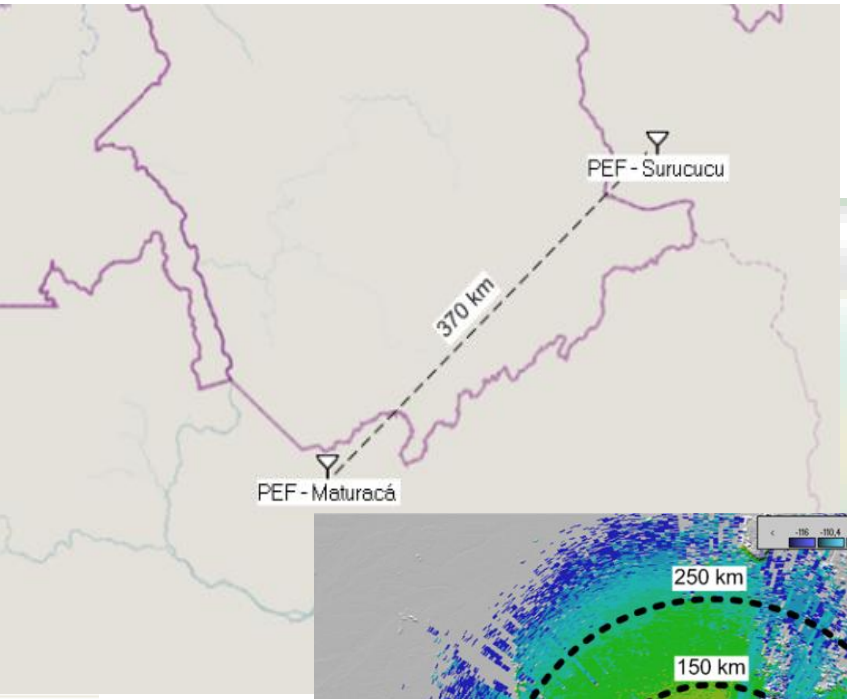
INFRASTRUCTURE

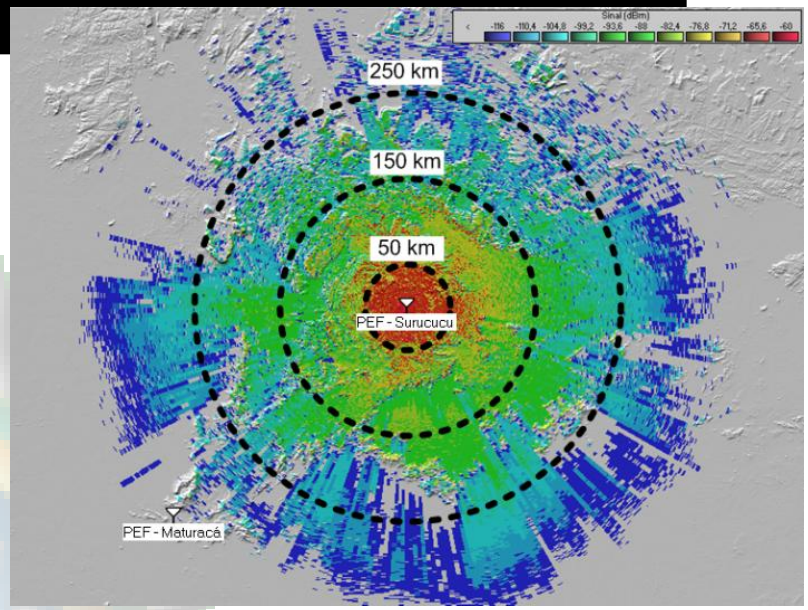
- Thetered Aerostat

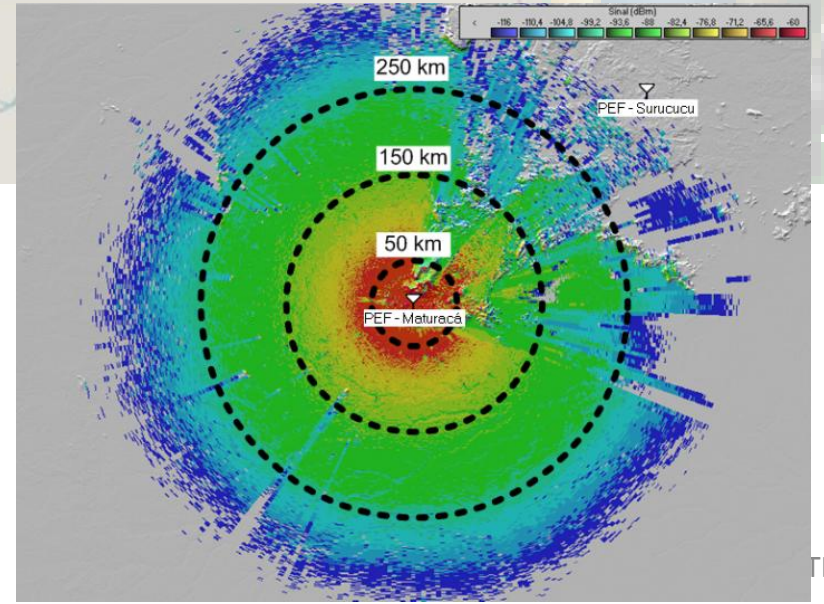


INFRASTRUCTURE

- Thetered Aerostat

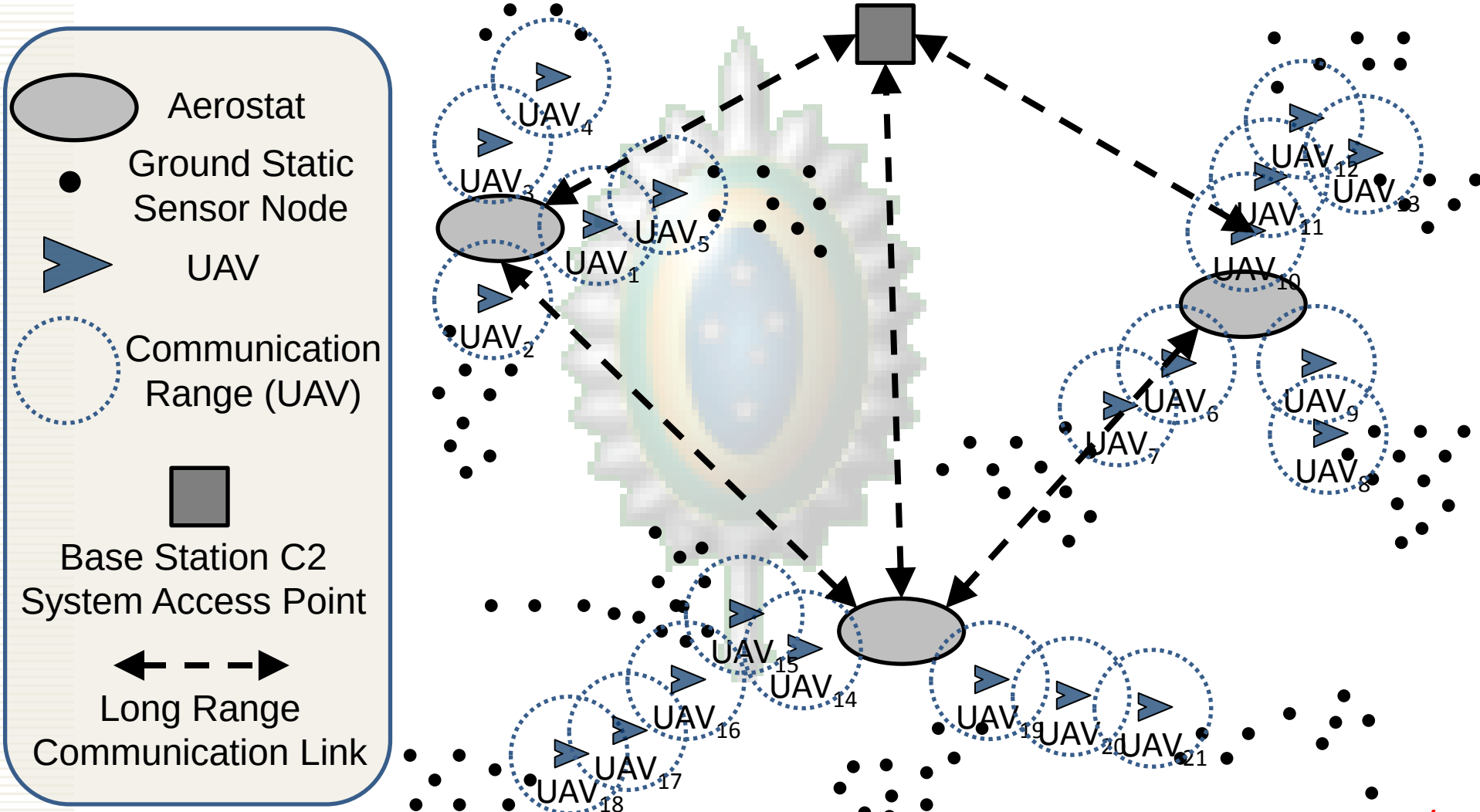






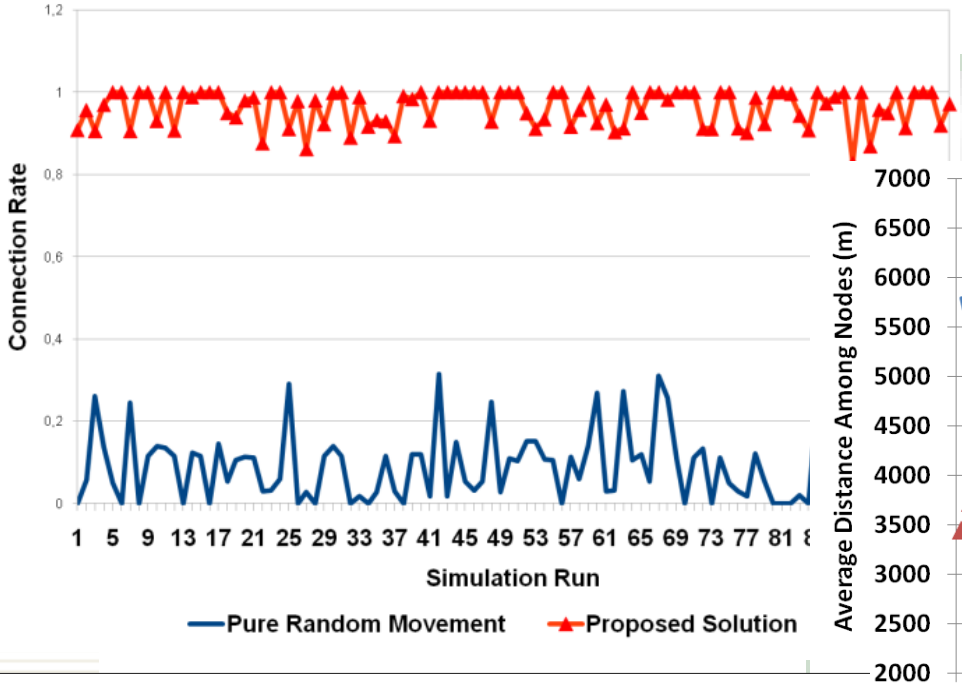
INFRASTRUCTURE

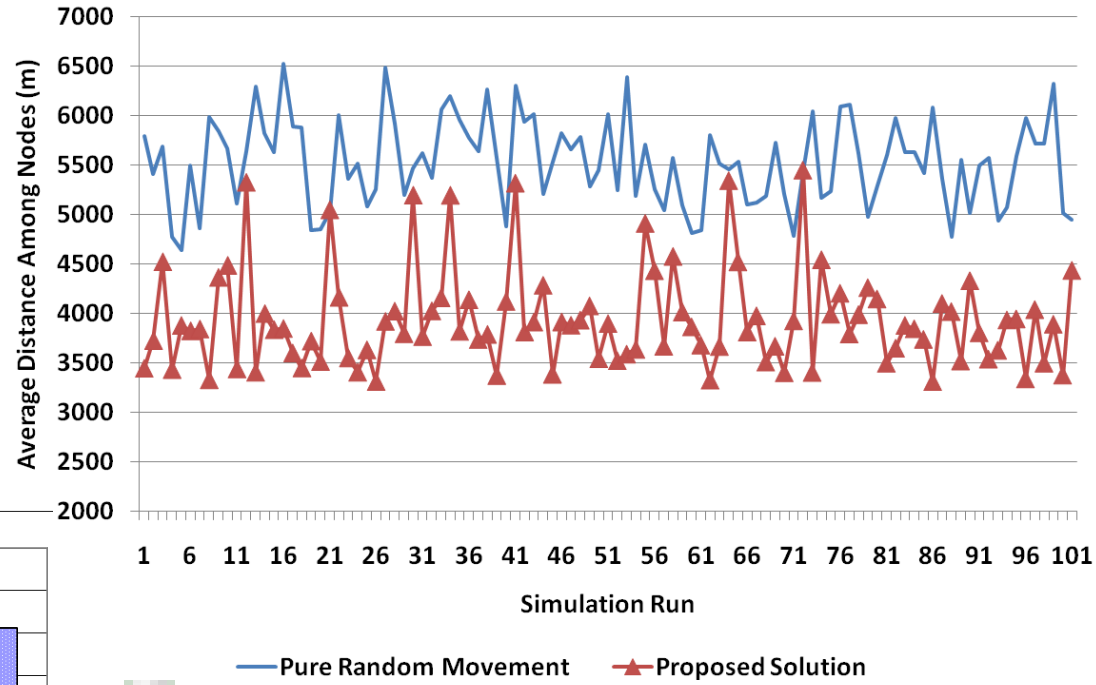
- Wireless Sensors Network

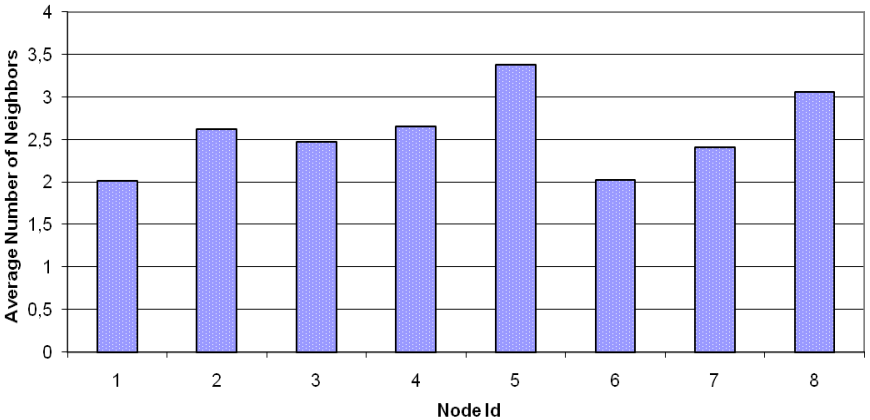


INFRASTRUCTURE

- Wireless Sensors Network







Conclusion

C^2 SYSTEM ENGINEERING FOR THE ADVERSITIES OF THE AMAZON ENVIRONMENT

CONCLUSION

- As communication is a severe issue within the amazon region, and to provide sensors and radio communications based on satellite solution would be cost prohibitive due to the large area, the joint utilization of wireless sensor networks and aerostats was investigated.
- The results obtained point to a very interesting and cost effective solution that can improve dramatically the SA in Amazon region.

CONCLUSION

"Technology is not the issue. It's how we put it together."

Gen. Koen Gisbers, Deputy Commander, NATO Allied Command Transformation.

ORDEM E
BRASIL