AGENT BASED SIMULATION OF COOPERATIVE SURVEILLANCE

By

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Military College of Signals, National University of Sciences and Technology,
Islamabad, Pakistan, in partial fulfillment of the requirements for the degree of MS in
Computer Science (Software) Engineering

May 2019

ABSTRACT

Unmanned Aerial Vehicles (UAVs) are nowadays used in many areas such as Agriculture, Defense, Civil Security, Border Surveillance, Air Traffic Control, Healthcare etc. Usage of Unmanned Aerial Vehicles has been increased dramatically over the past decades due to its low cost, small size, autonomous structure, and high mobility [8]. UAVs play a vital role in performing dull and risky tasks without endangering a human pilot. UAVs can enter the area where onboard pilot vehicle cannot enter. Unmanned Aerial Vehicles (UAVs) are highly used in intelligence, surveillance and reconnaissance in both civil and military territory [2].
The study focuses on performance factors of UAVs in wide area surveillance environment in which multiple UAVs are given surveillance task. Task in security patrol is to detect the location of intruder in real time to capture the intruder and avoid escape. In forest fire monitoring to adequately point out the newly started forest fire location, to rapidly perform effective strategy to overcome the damage. The system presented here establishes performance parameter to efficiently provide wide area surveillance with multiple cooperative UAVs. This thesis focuses on the overall system performance of cooperative unmanned aerial vehicles that performs surveillance in a given area. The thesis main theme is to lay down performance parameter that is required for UAVs surveillance tasks.
Three different algorithms are simulated in Net logo to study the performance of overall system. The behaviors are simulated in Net-logo with different data to check the efficiency of the overall system. The simulation results are compared to indicate performance parameters. This thesis provides answer to this research question. What are the performance parameters/indicators of the overall system in multiple cooperative UAVs are performing surveillance task in the given area?

DEDICATION

The thesis is devoted to

MY FAMILY, TEACHERS & FRIENDS

for their love, all out encouragement and support

ACKNOWLEDGMENTS

I am thankful to ALLAH who has blessed me with strength & the passion to pursue the subject thesis and I am obliged to Him for His benevolence and mercy . Without his consent I could not have indulged myself in this demanding work.

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ACRONYMS

Unmanned Aerial Vehicles	UAVs
Region of interest	ROI
Intelligence Surveillance Reconassiance	ISR
Field of View	FOV
k-winners-take-all	k-WTA
Cooperative Localization	CL
Global navigation satellite system	GNSS
Analysis of variance	ANOVA

Chapter 1

INTRODUCTION

Agent based modeling is a method of modeling systems comprising of individual, cooperative agents. The agents are autonomous in this type of system; the agents assess the situation in the given environment and take their own decision to accomplish a task. The agents perform individually with their own capabilities. In multi-agent simulating environment the agents cooperate with other agents for exchange of information, sharing resources and getting help from one another to consummate the required task. Agents can have different type of deportments in the system. Usage of Unmanned Aerial Vehicles has been increased dramatically over the past decades due to its low cost, small size, autonomous structure, and high mobility [8]. Unmanned Aerial Vehicles (UAVs) are highly used in intelligence, surveillance and reconnaissance in both civil and military territory [7]. Properly equipped UAVs have the ability to provide information about the region of surveillance without jeopardize the human pilot which makes them highly desirable for ISR [7] [5] [6]. Wide-area surveillance cousld be effectively performed by cooperative multiple UAVs. UAVs are advantageous than a human-piloted vehicle in the sense of low cost and can fly through highly risk and endanger area. When multiple-UAVs are assigned a task, the task will be completed more quickly than that when single UAV is working on similar task. Multiple UAVs keep advantageous of single UAV, increasing the performance and reliability of the undertaken mission.

Area surveillance is not only used in military operations but also in civil domains as forest fire monitoring, border patrol, aerial mapping, farming, agriculture and private security. There exists some challenges for Unmanned Aerial Vehicles as compared to ground base vehicles, For example a ground vehicle can be stopped and locate its path, but UAVs cannot be stopped, they will be in continue motion or else they will fall to ground. So UAVs need real time path planning algorithm. Another challenge is that aerial vehicle cannot take a 90 degree turn around the edges while ground vehicles can turn at 90 degrees.

Small and light weight UAVs can go to narrow places where full size vehicles cannot enter.

The purpose of this research is to simulate a dynamic system in which multiple agents cooperatively work together to accomplish a task, to study the efficiency and performance of the whole system in which multiple agents (UAVs) do surveillance and cooperate with each other using the available resources efficiently. The research focuses on a detailed system level study in order to establish performance parameters. Initially we have a given number of UAVs that will operate in a given environment.

1.1 Unmanned Aerial Vehicles

Unmanned Aerial Vehicles (UAVs) play a key role in today ISR missions (Intelligence, Surveillance and Reconnaissance). UAVs perform tasks intelligently and dynamically without any risk. UAVs have capability to move in 3d space and this ability makes them suitable for aerial surveillance. UAVs are efficiently used in many areas, for example, Border surveillance; Aerial mapping etc. Coordination and cooperation among multiple Unmanned Aerial Vehicles are the key factor in surveillance of a given area. Non cooperative UAVs surveillance will result in redundant coverage of the surveillance environment and hence the resources cannot be efficiently utilized. [8] There is numerous numbers of UAVs worldwide with unique capabilities. UAVs applications are extending more than military purposes. Nowadays Unmanned Aerial vehicles are used in both Civil and military domains. There are various sizes of UAVs available depending on their application in a given domain. UAVs are divided into four different groups as shown in below Fig1.1. UAVs vary in feature i:e speed, endurance and battery life or fuel capability. There are small and large UAVs. Large UAVs have more features than small UAVs and are used in large area surveillance mission over land or water.

UAVs are fixed wings and quad rotors. Fixed wings UAV cannot take 90 degree turn while quad rotor can take 90 degree turn. SUAVs (Small Unmanned Aerial Vehicles) are inexpensive and less dangerous. Due to these characteristics SUVs are used in both military and civil domain. The flight time and wings span of small UAVs are given in table 1.1.

1.2 Motivation and Objective

The motivation of this thesis is to simulate a dynamic system in which multiple agents cooperatively work together to provide better task completion and study the efficiency and performance of the whole system, in which multiple agents(UAVs) do surveillance and co-

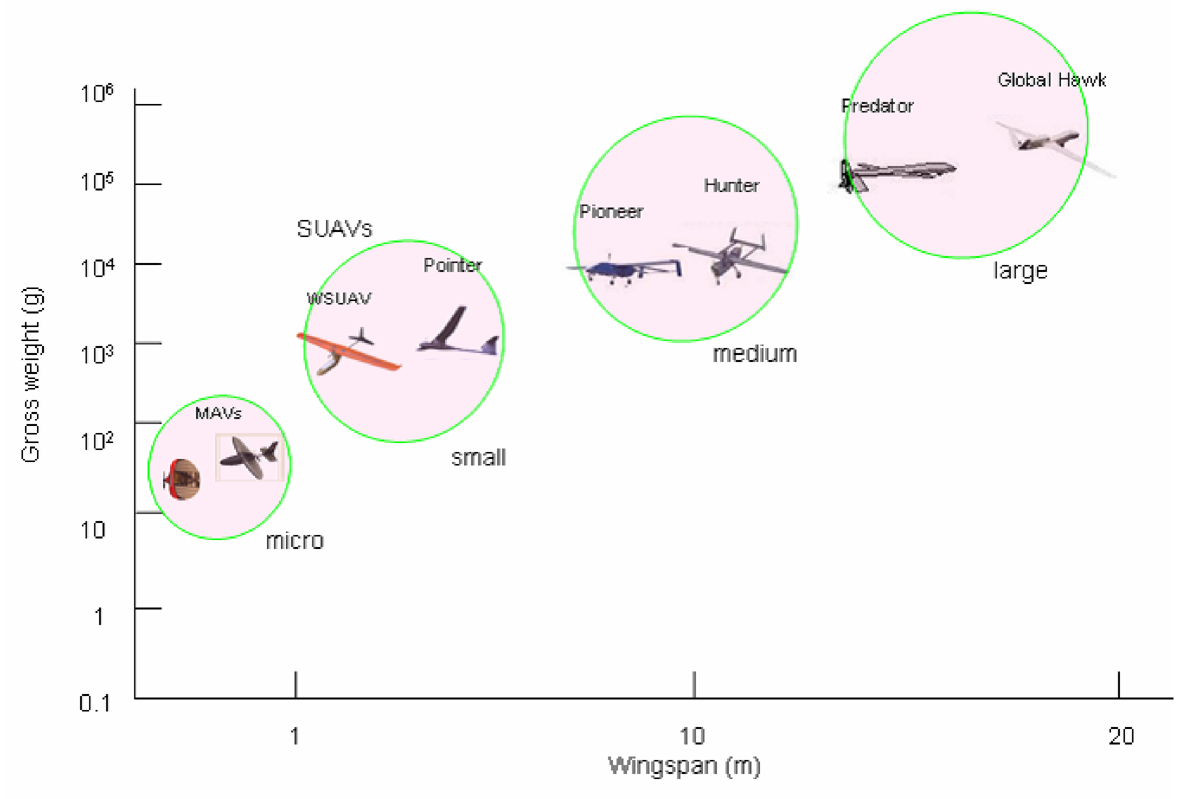

Figure 1.1: UAVs categorized based on size and weight [17]

Table 1.1: Small Unmanned Aerial Vehicles [17]

Name	Manufacturer	Wingspan(m)	Endurance(hr)
Pointer	AeroVironment	2.7	2 %
Raven	AeroVironment	1.28	1.5 %
Dragon eye	AeroVironment	1.14	1 %
Casper-200	Top vision	2	1 %
Skylark	El bit	2.7	1 %

operate with each other using the available resources efficiently. Wide area surveillance missions are key area in today's research. Examples include securing border, locating and tracking of fire etc.

The UAV's in an area cooperate and share data with each other to perform surveillance in the specified environment. The Agents perceive the environment through available sensor on board of each UAV (e.g., Camera). The intruders in the area of surveillance may be another UAV or person or vehicle and so on. These types of missions are very critical with respect to time and have large geographic area.

Nowadays multiple autonomous UAVs are used with increasing applications in both commercial and civil domains by the research community. Wide-area surveillance could be effectively performed by cooperative multiple UAVs. UAVs are advantageous than a human-piloted vehicle in the sense of low cost and can fly through highly risk and endangered area. When multiple-UAVs are assigned a task, the task will be completed more quickly than that when single UAV is working on similar task. Multiple UAVs keep advantageous of single UAV, increasing the performance and reliability of the undertaken mission. Sensors and Cameras on board of each UAV, is used for getting information about the surveillance environment. UAVs assess the environment current situation using sensors and cameras. cDrones [16] and SINUS [16] are examples of aerial surveillance systems.

Small and light weight UAVs can go to narrow places where full size vehicles cannot enter. The purpose of this research is to simulate a dynamic system in which multiple agents co-operatively work together to accomplish a task, to study the efficiency and performance of the whole system in which multiple agents (UAVs) do surveillance and cooperate with each other using the available resources efficiently. The research focuses on a detailed system level study in order to establish performance parameters. Initially we have a given number of UAVs that will operate in a given environment.The surveillance area is to be allocated to the available number of UAVs. The UAVs will capture intruder agents in that area. Multiple parameters are assigned to each agent in each strategy i-e initial placement, surveillance area, sensor capability, fuel capacity and communication constraints. When an intruder agent came in field of view of surveillance agent, the surveillance agent chases the intruder agent. If an agent goes for refueling, it communicates with other agents to cover its area too until it comes back from refueling.

Multiple UAVs and collection of sensor forming a cooperative network provides better performance in border surveillance. This network provides better coverage for border area, therefore effectively expanding the area coverage of surveillance [18]. The goal of this research is to evaluate the overall system performance. The system having multiple agents assigned for surveillance is simulated and analyzed. Given an environment for surveillance with a limited number of agents and dynamic targets recurrences. The study and evaluates the overall system to provide best efficient results with the available resources. The agents should perform surveillance in the area with dynamic target detection and tracking.

In cooperative search each UAV do surveillance in its own provided area and capture any intruder coming in his limitations. The Objective of this thesis is, to develop an algorithm that in a given environment has multiple UAVs and intruders are entering dynamically. The area is divided among the available number of watch agents. The full coverage cooperative and non cooperative simulation results are compared with random placed and linear placed agents algorithm.

1.3 Contribution

The Thesis presents the simulation results of multiple UAVs surveillance strategies where UAVs operate in a given environment to provide surveillance capability. Three different strategies are simulated and their results are compared. The development and simulation of these strategies are carried out in Net Logo. The important and key contributions of this thesis are the following.

- We performed an exhaustive study on the current approaches of UAVs surveillance and illustrated each one pros and cons. Different researcher proposed surveillance strategies for UAVs, [23] proposed an algorithm having more variants, allow agents perform as many tasks as possible (Allocation loop), avoid assigning tasks that are not suitable for the agents (Sorting and Allocation loop), efficient work load balance (Limit allocation loop). The simulation is static, requires prior knowledge of the environment.

- We have proposed simulation of different strategies i:e Linear strategy, Random strategy, Local cooperative strategy, Global cooperative strategy and Sight strategy. The results are evaluated by comparing with each of the above strategies. The sight strategy results are compared with [20].

- Simulation analyses of different strategies are presented to show to performance and resources efficiencies of each strategy.

- Analysis of the simulation is performed using statistical methods ANOVA up to confidence level of 0.01.

1.4 Thesis Outline

- Chapter 1: Chapter 1 focuses on introduction and background study.
- Chapter 2 focuses on background study and related work. The work done so for in this area is presented in this chapter. In this chapter we presented the work done on target localization, target acquisition.
- Chapter 3: In Chapter 3, UAVs surveillance missions are explained. This chapter focuses on mission type and mission details. The simulation design is explained in later part of this chapter.
- Chapter 4: Chapter 4 introduces different strategies i:e linear, random, local coverage, global coverage and sight strategy. The strategies details are presented with simulation data.
- Chapter 5: Chapter 5 presents results and findings of each strategy.
- Chapter 6: In this chapter the conclusion and future direction are presented.

Chapter 2

BACKGROUND AND RELATED WORK

2.1 Multiple UAVs Surveillance

Unmanned Aerial Vehicles play an important role in both civil and military domain. Unmanned Aerial Vehicles (UAVs) are used for ISR missions. In military domain precise and timely information is very crucial for resource utilization and effective planning. UAVs are aircrafts having no pilot on board. Controlling these types of aircrafts, two methodologies are used, one is the aircraft is controlled from the ground station and the second one is the aircraft has well defined algorithm on board of each aircraft. Having these easy manipulation and low cost, UAVs has multiple applications in entertainment, science and technology and military domain [9] [10]. UAVs aerial surveillance provides a better way to study the environment. It may be threat detection, photography, surveillance etc.

Multiple UAVs surveillance system consists of multiple UAVs equipped with sensors, camera and network connectivity mechanism. The UAVs collecting information from the surveillance domain and send it to online server for action or take appropriate actions autonomously. These UAVs have limited sensing and communication capabilities what makes it a little harder for them to get the full view of the desired area and targets in that area.

The environment in which UAVs operate may be static or dynamic. Static environment have unchanged surroundings throughout the entire mission. Dynamic environment the targets are moving around and entering continuously.

Each UAV in multiple cooperative surveillance system needs the following main capabilities, sensing the environment, processing of information, communication with other UAVs and online server, and mobility. UAVs sense the environment and process the information about the targets and environment. The processing depends on the resources available on board of UAV.

Target in the given area are observed by the UAV with the help of sensors on board. The target is said to be observed, if it is in the field of view of the UAV. So the target observation depends on sensor attached on board of UAV and the sensor's FOV (field of view). UAVs communicate with each other by passing information about the target they have under observation, the area they are covering, and fuel they have etc. UAV search for a target in its area and gets the target geo location once it is observed. When the target is observed the UAV can take the appropriate action to achieve the mission objective i:e tracking target, destroying target etc.Past research work is done on static environment and static targets. No work is done on dynamic occurrence of targets in the surveillance environment [6] [7].

One common scenario of ISR mission for UAV is that the UAV provide surveillance in a given area of interest. The target location in area of interest is unknown. So with the help of sensors and on board cameras, can detect and localize the target and will send the information to another location to take appropriate actions on that target. If the area of interest is large, so it will take time for the single UAV to survey the area and localize the target, multiple cooperative UAVs will perform this task efficiently. Multiple cooperative UAVs will do surveillance in the given area of interest and will provide timely and accurate information of the target localization depending upon the reliability and effectiveness of sensors and cameras etc. In [1], Diana et al proposed an object tracking algorithm from UAV. In [23], Janaina et al proposed an algorithm for solving task allocation problem in multi Unmanned Aerial Vehicle System. The proposed algorithm has three variants as following, Allow agents perform as many tasks possible(Allocation loop), Avoid assigning tasks that are not suitable for the agents(Sorting and Allocation loop), Efficient work load balance(Limit allocation loop). The proposed algorithm has better task allocation but need prior knowledge of the environment. In [4],Caillouet et all proposes a full coverage algorithm for covering multiple static targets by minimizing cost and altitude of UAVs. Garcia et all in [10],introduced behavioral model of multiple agents with different behaviors to get better performance. Complete area coverage of a known area using multiple robots are proposed in [15]. In [2] Gustavo et all proposes a methodology for the coverage of ground area in minimum time using multiple UAVs. Dimitrios et all [29] proposes a solution for finding the best location of drones to survey static targets with minimum cost.

Compared to single drone or UAV, multiple cooperative UAVs can accomplish a task efficiently and effectively. In general multiple cooperative UAVs take the advantages of a single

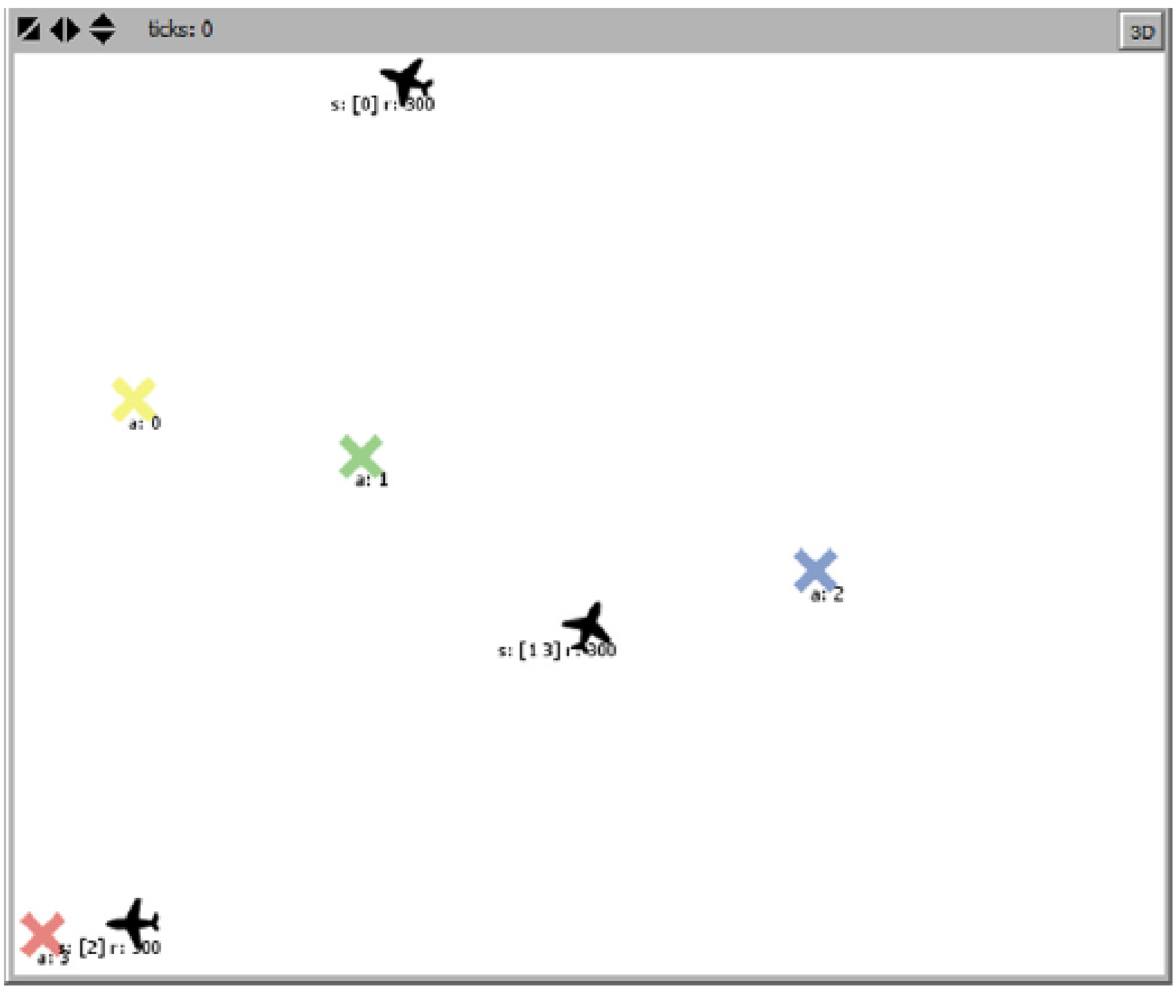

Figure 2.1: Simulation in Netlogo [23]

UAV and provide better performance and reliability than that of single UAV [12].

Gu, Jingjing et al [9], proposed a method for recognition of multiple moving targets. The algorithm works on localization and tracking of both air and ground targets. The algorithm proposes the localization and tracking of a target with high accuracy but there is no occurrence of dynamic targets inclusion.

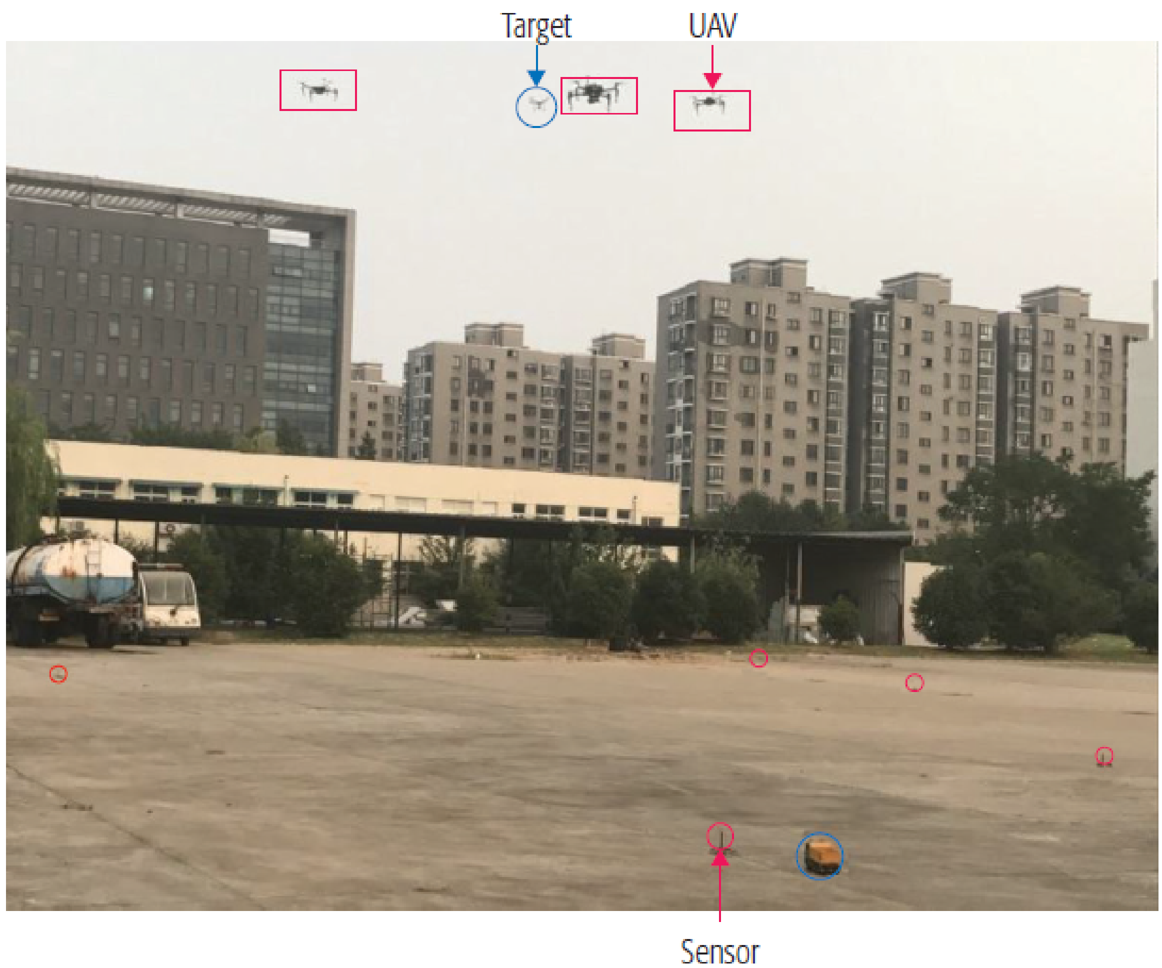

Figure 2.2: Localization and tracking targets [9]

Intelligence Surveillance and Reconnaissance mission flow is given in fig 2.3. The effectiveness of the mission is affected greatly by sensors model and camera resolution. Sensors have multiple parameters and specific parameters required for a mission will be different. For Area coverage problem two essentials parameters required are resolution and field of view.

Pan,Yen, et al [20] proposes an algorithm for monitoring moving targets using multiple unmanned aerial vehicles. The algorithm is named as MUTF means Most Uncovered Target

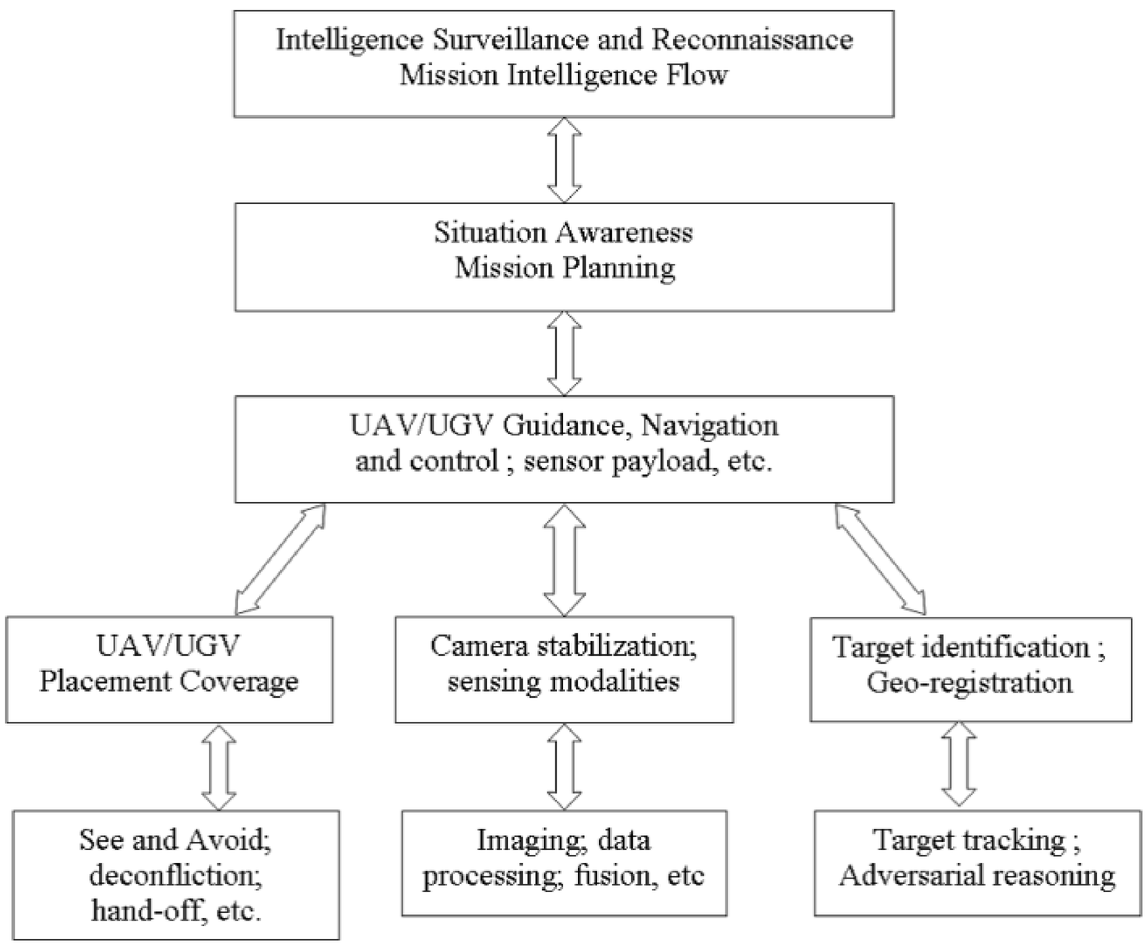

Figure 2.3: A hierarchical control structure for mission intelligence flow [27]

First. The algorithm tracks target when the target is in field of view of the UAV. In this algorithm the number of covered targets is maximized as compared to the previous method but have limitation that is, cannot detect target even closer to UAV but not in the field of UAV and works in static environment.

In Liu et al [18], proposed algorithm to generate paths to collect enough information about

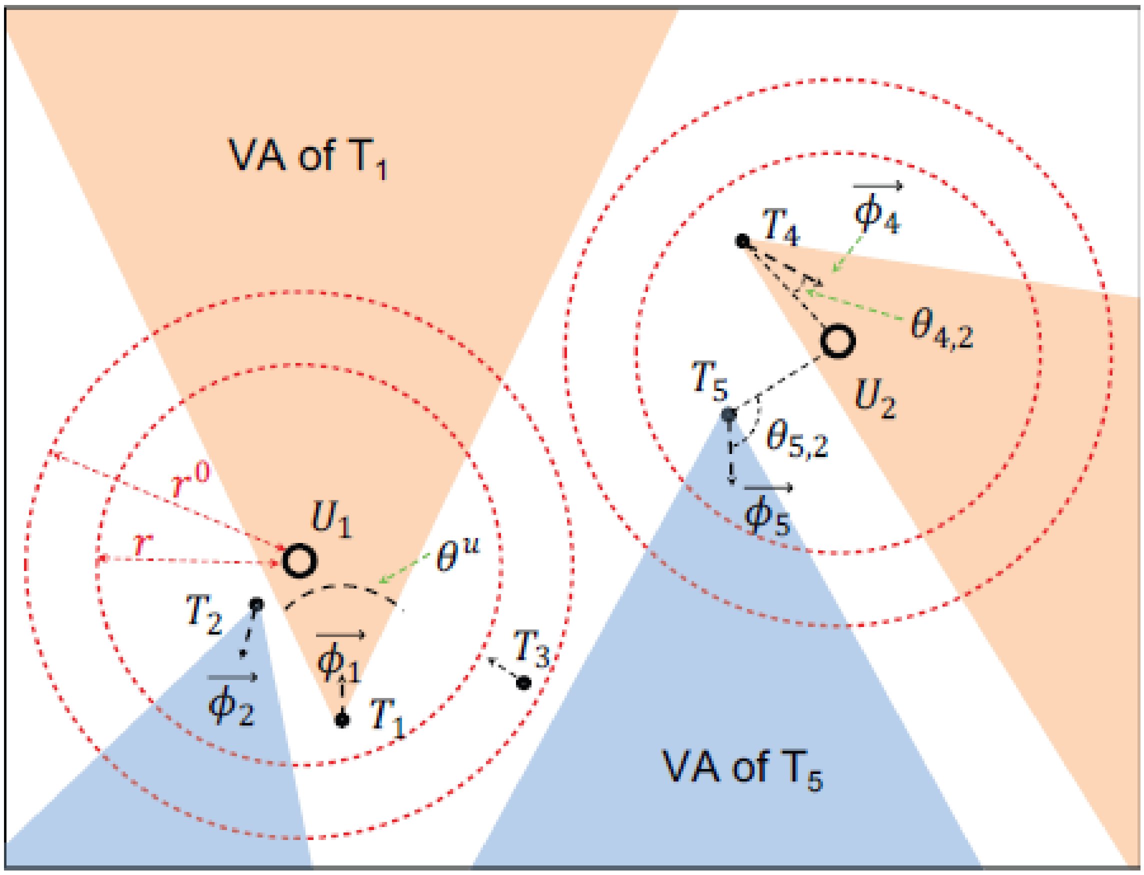

Figure 2.4: Tracking of targets in the FOV of UAV [20]

the environment and find more targets. Algorithm is to, control UAVs to revisit areas that have high probability of targets or not visited for longer period. This algorithm cannot detect moving targets.

2.2 UAV localization and acquisition

UAV localization is finding the location of intruders in the surveillance area. Acquisition is finding the intruders in the specific area of interest. Different researchers provide methods for target localization and acquisition [18] [23] [9] [20]. Multiple UAVs cooperatively perform surveillance task in the desired environment. Each UAV has the sensing processing and communication capabilities. The UAV search for the target and observe it. Once the target is observed, it processes the information as specified for a particular mission to achieve the desired goal. The UAV send information of the target to the ground station to perform actions. The UAV may track the target until the ground station action is arrived. In [8] Fu, Xiaowei, et al proposes multi UAV cooperative localization algorithm. UAVs search in the surveillance area and locate the targets with the help of available sensors on board of each UAV.

Chapter 3

UAVs SURVEILLANCE MISSION

3.1 Mission Types

Agent based modeling is a method of modeling systems that comprises of individual, cooperative agents [19]. Different agents perform automated surveillance having different behavior. Multiple agents cooperate with each other performing their task. The agents perform task on their own according to the situation occurs inside the agent environment. Cooperative surveillance helps in monitoring activity in center region. Multiple agents perform surveillance in their specific locations given in the desired surveillance area. A detailed system level study is carried out in order to establish performance parameters.

Unmanned Aerial Vehicles are used in military and civilian missions. Different missions can be accomplished by the use of multiple cooperative UAVs deployed in a given area. These missions may have different criteria, different severity level, and different resource requirement. Missions may include patrolling border, securing a private function etc.

Today UAVs are contributing very much to National and Military needs. Cooperative UAVs are used for monitoring roads, railway stations, to survey agricultural production, forest fire monitoring and prevention, flood monitoring, etc. For military purposes, border surveillance, coastal surveillance, Observing and securing large events.

UAVs have the advantage of no pilot on board so can perform dull and dirty missions without endangering human life. UAV involved in a mission performs autonomously. It means that UAV perform surveillance in the given area and whenever it finds a target, it performs the appropriate action, either sending information to the ground unit or takes action on its own behalf. UAVs use different resources when in a mission and it directly affects the mission success. The UAVs sensors, cameras capability, flying time etc. improves mission success.

Unmanned Aerial Vehicles has different capabilities; they vary in size, flying capability, system on board, sensors etc. UAVs are used in different missions without human hazards i:e railway system and infrastructure , agriculture production surveillance, border area surveillance, fire monitoring, aerial photography, aerial mapping and surveillance etc.

Different missions or applications which UAV performs are depicted in the following figure 3.1.

The realization of autonomous behaviors of team level is becoming feasible as the technology is evolving. However, this adds to the stochastic behavior of overall system. In this research we are using different strategies that provide surveillance performance of muti-agents in a given area. The low level work that is UAV movement, target localization, target finding, target tracking is not the focus of this research. This research focuses on overall system performance. We have a given area for surveillance and number of unmanned aerial vehicles that will operate in this area. The area of interest is allocated efficiently among the number of UAVs. So we simulate that mission to get the system level performance.

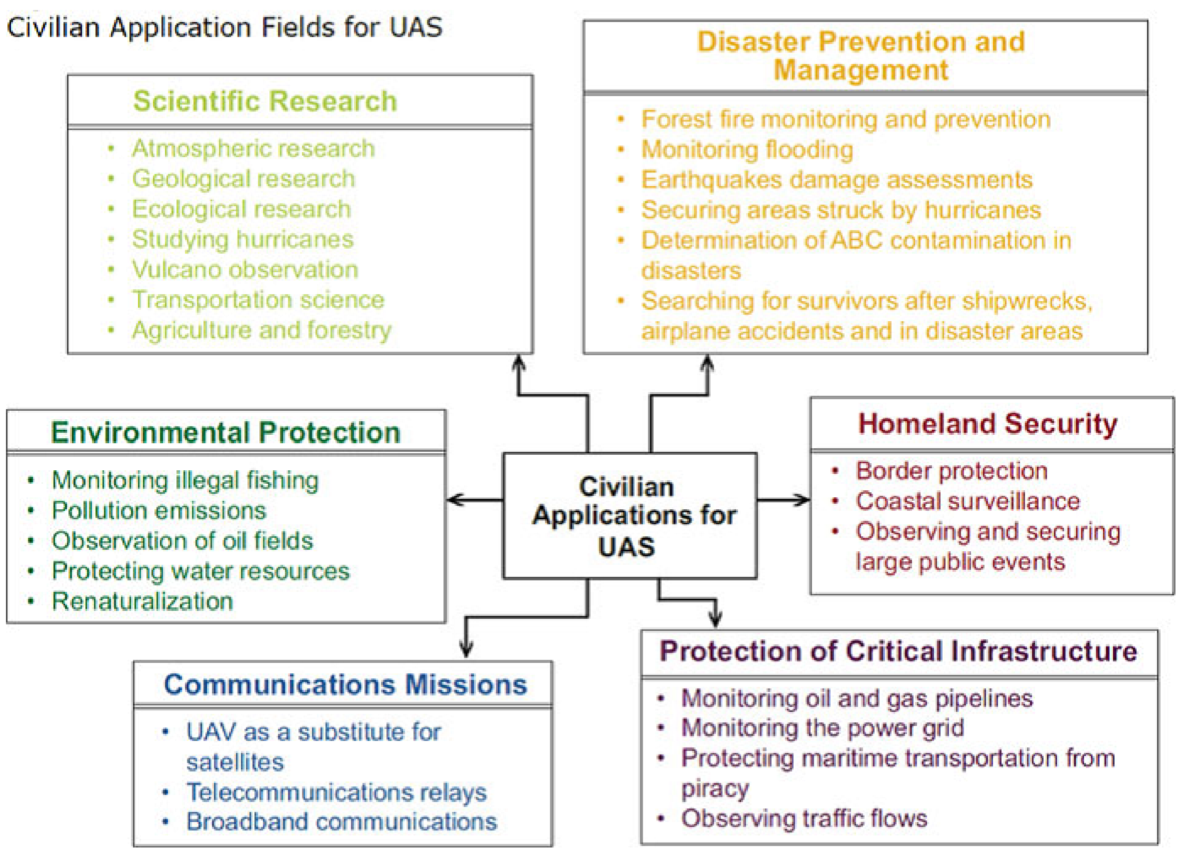

Figure 3.1: Civilian applications for UAS [25]

3.2 Mission Details

Surveillance missions include different performance factors such as environment, number of agents (UAVs) that are available for surveillance, intruder occurrences, UAVs cooperation and communication, fuel capacity, allocating area to an agent for surveillance,UAVs localization, UAV tracking, path finding.There are many research work done on these low level area as in [24] [26]. Each agent is given its own area for surveillance. The agent will do surveillance in the given area and will utilize its resources to efficiently perform the tasks.

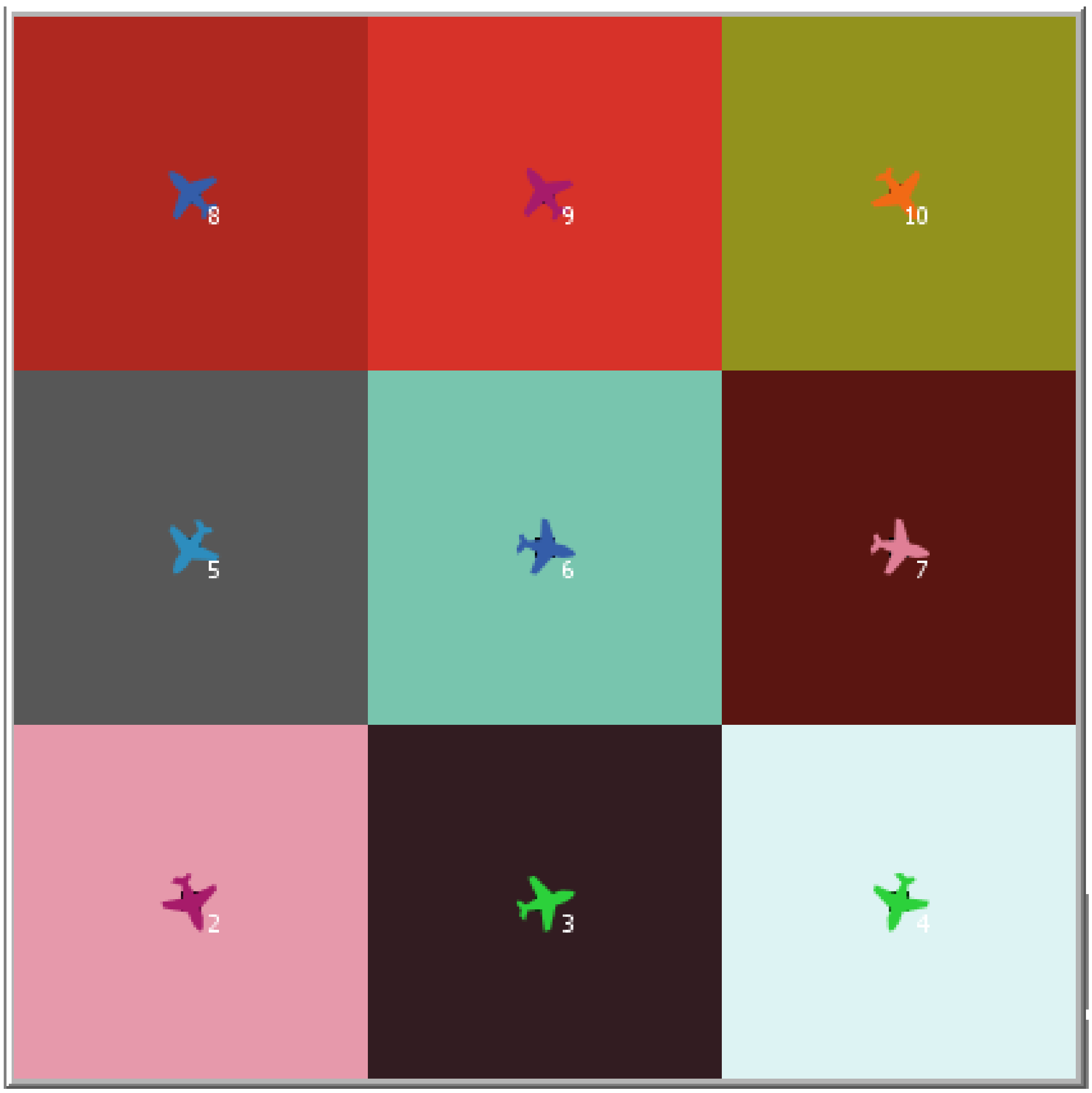

Figure 3.2: Mission Simulation in Net Logo

Proposed Model

In the fig 3.2, we have, Let W is the number of watch agents. So $W = \{w_1, w_2, w_3, ..., w_k\}$ And E is the area available for surveillance. So area of surveillance is divided among the available number of agents. $E = \{e_1 + e_2 + e_3 + ... + e_l\}$. Each agent is assigned its own area in which it will do surveillance, e_i assigned to w_j where $i = 1, 2, ..., l$ and $j = 1, 2, 3, ..., k$. The mission area is modeled as grid workspace where the coordinates are 0 to X_{max} , 0 to Y_{max}. Each agent x, and y axis coordinates are $X_{min}, X_{max}, Y_{min}, Y_{max}$. Total area given for surveillance in term of cells is:

$$E_{total} = (X_{max} - X_{min} + 1) \times (Y_{max} - Y_{min} + 1) \tag{3.1}$$

Each watch agents area of surveillance is:

$$A_s^{w_i} = (X_{max}^{w_i} - X_{min}^{w_i} + 1) \times (Y_{max}^{w_i} - Y_{min}^{w_i} + 1) \tag{3.2}$$

where $X_{min}^{w_i}$,$X_{max}^{w_i}$,$Y_{min}^{w_i}$ and $Y_{max}^{w_i}$ are corresponding coordinates in which the watch agent w_i will perform surveillance. The watch agent w_i will perform surveillance in the corresponding cells that lie inside its area of surveillance $A_s^{w_i}$.The watch agents capture intruder agent in their field of view.

$$FOV_{w_i} = r\theta \tag{3.3}$$

where r is the radius and θ is the angle. Intruders are appearing at random locations at random time intervals, so the positions of intruder agent $u_i = (x_{random}, y_{random})$. The intruder agent u_i is captured and chased by watch agent w_i when the distance d_{wu} between w_i and u_i is less than r_{w_i}.

$$d_{wu} = \sqrt{(x_w - x_u)^2 + (y_w - y_u)^2} \leq r_{w_i} \tag{3.4}$$

where (x_w, y_w) and (x_u, y_u) are the coordinates at which watch agent and intruder agent are located respectively.

Threats are entering in the area at random positions at random time interval. Let $T = t_1, t_2, ..., t_n$ be the number of threats that enter the surveillance area. The intruder agent t_i position is given by

$$T_n(x, y) = (X, Y) \tag{3.5}$$

where $X \sim U([u_{min}, u_{max}])$ and $Y \sim U([u_{min}, u_{max}])$, are random numbers between u_{min} and u_{max}. The intruder agents t_i randomly moving in the area.

3.2.1 Random Strategy

Random strategy as the name suggests, the watch agents are place at random x_{random}, y_{random} positions. The agents perform surveillance in the whole provided environment irrespective of their own area. Intruder agents occur randomly at random positions. Watch agent capture and chase intruders coming under FOV of watch agent as shown in 3.3 with radius r = 5 and angle $\theta = 360$. Watch agents survey the area randomly in whole area given in Equation 3.1. So the next x_w, y_w coordinates of watch agent are as follow

$$x_{i+1}^{w_j} = x_i^{w_j} + \theta \tag{3.6}$$

$$y_{i+1}^{w_j} = y_i^{w_j} + \theta \tag{3.7}$$

where $\theta \sim U([-\alpha, \alpha])$ is a random angle between $-\alpha$ and α.

---

1 Random Strategy

Given Area E, Watch agents W
Watch agents are placed at random position x_{random}, y_{random}
Intruders enter at random intervals at random positions
Watch agents W survey the area E
while Resources Available **do**
  Do surveillance
  if Intruder found **then**
    Chase intruder
  else
    Survey the area to find intruder
  end if
end while

3.2.2 Linear Strategy

In this strategy the total area of surveillance E as given in Equation 3.1 is divided horizontally in two sections E_1 and E_2. The watch agents W_n are divided into two groups G_1 and G_2. Agents in G_1 are placed in area E_1 and agents in G_2 are placed in area E_2. Each sectioned area is divided by the number of agents in the respective group. So dividing the area horizontally we get

$$E_{sub} = (X_{max} - X_{min} + 1) \times \left(\frac{Y_{max} - Y_{min} + 1}{2}\right) \tag{3.8}$$

Dividing Watch agents in two groups

$$G_1 = round(\frac{W_n}{2}) \tag{3.9}$$

and

$$G_2 = W_n - G_1 \tag{3.10}$$

So each agent gets an area of surveillance as

$$A^{w_i}_{surveillance} = (\frac{X_{E_{sub}}}{G_j} \times Y_{E_{sub}}) \tag{3.11}$$

Each agent w_i will perform surveillance in its own area $A^{w_i}_{surveillance}$ and will capture and chase intruders that came inside its FOV as given in Equation 3.3.

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2 Linear Strategy

Given Area E, Watch agents W
Area is divided into two sections horizontally $E_{subsection}$
Watch agents are divided into two groups G_1 and G_2
Each agent is assigned area linearly as given in Equation 3.11
Intruders enter at random intervals at random positions
Watch agents w_i survey its own area $A^{w_i}_{surveillance}$
while Resources Available **do**
  Do surveillance
  if Intruder found **then**
    Chase intruder
  else
    Survey the area to find intruder
  end if
end while

3.2.3 Full Coverage Strategy

In this strategy the surveillance area is equally divided among the available number of watch agents. The agents perform surveillance in its own area with available resources. If the agent goes for refueling so it communicates with its neighbors and the neighbors passes the message to their neighbors to cover the area of the agent that gone for refueling. Let's $W = \{w_1, w_2, ...w_n\}$ be number of agents. $E = (X_{max} - X_{min} + 1) \times (Y_{max} - Y_{min} + 1)$ be the total area available for surveillance.So the agents W are placed in C columns and R rows. Calculate Columns C and Rows R

$$R_{total} = round(\sqrt{W}) \tag{3.12}$$

Number of Columns C in Row R_i is

$$C_{R_i} = ceiling\left(\frac{(W - \sum_{j=1}^{i} C_{R_{j-1}})}{(R_{total-i+1})}\right) \tag{3.13}$$

where W is the total number of agents available for surveillance, R_{total} is the total number of rows as given Equation [3.12], C_{R_i} is the number of columns in Row R_i. Each watch agent w_i performs surveillance in its own area given by X_{min}, X_{max}, Y_{min} and Y_{max}. Each watch agent X_{axis} size and Y_{axis} size are given by

$$X_{axis}^{w_i} = \frac{X_{max} + 1}{C_{R_i}} \tag{3.14}$$

$$Y_{axis}^{w_i} = \frac{Y_{max} + 1}{R_{total}} \tag{3.15}$$

At each column C_i, $X_{min}^{w_i}$ and $X_{max}^{w_i}$ of every watch agent w_i in that column have same values. $Y_{min}^{w_i}$ and $Y_{max}^{w_i}$ are same for all agents across the same row R_i.

$$X_{min}^{w_i} = \left\{ \begin{array}{cc} 0, & c = 1 \\ X_{max}^{w_{i-1}} + 1, & i > 1 \end{array} \right\} \tag{3.16}$$

where c is column index

$$X_{max}^{w_i} = X_{min}^{w_i} + X_{axis} \tag{3.17}$$

$$Y_{min}^{w_i} = \left\{ \begin{array}{cc} 0, & r = 1 \\ Y_{max}^{w_{i-1}} + 1, & i > 1 \end{array} \right\} \tag{3.18}$$

where r is row index

$$Y_{max}^{w_i} = Y_{min}^{w_i} + Y_{axis} \tag{3.19}$$

So each watch agent w_i is given its own area for surveillance.

$$A_{surveillance}^{w_i} = (X_{max}^{w_i} - X_{min}^{w_i}) \times (Y_{max}^{w_i} - Y_{min}^{w_i}) \tag{3.20}$$

When an agent goes for refueling it notifies its neighbors so the further passes the message to cover the area.

3 Full Coverage Strategy

Given Area E, Watch agents W
Area is divided into Rows and Columns
Watch agents are given its own area
Each agent do surveillance in the assigned area
Intruders enter at random intervals at random positions
Watch agents w_i survey its own area $A^{w_i}_{surveillance}$
while Resources Available **do**
  Do surveillance
  if Goes for refuel **then**
    Notify Neighbors
    Neighbors notify their neighbors to cover the area
  else
    if Intruder found **then**
      Chase intruder
    else
      Survey the area to find intruder
    end if
  end if
end while

3.2.4 Full Coverage Strategy Constraints

The full coverage strategy is applied with different constraints to analyze the effect of each constraint on the strategy. The constraints applied are local communication constraint, global communication constraint, refueling on/off and no communication constraint.

Global Communication Constraint

When an agent goes for refueling. It passes message to all agents to cover its area or to a central point where all agents can access the message. The communication is global, means that each agent can communicate with all other available agents.

Local Communication Constraint

When an agent goes for refueling, it must notify its neighbors whose in turn notify their neighbors, so every agent gets the message that an agent gone for refueling. They will cover the area of the refueling agent.

No communication

When an agent goes for refueling, it does not notify anyone. Its area remains free and no one is surveying its area.

No Refueling

All agents have enough fuel available to perform surveillance for the designated time interval. As each agent has fuel available, no one goes for refueling.

Sight Strategy

The surveillance agents captures intruder agents that came inside its field of view. In sight strategy surveillance agents has a limited field of view with an angle θ to capture intruder agent.

AGENT BASED MODELING FOR SYSTEM ANALYSIS

4.1 Simulation Details

Simulation of this research is carried out in Net Logo. This research is carried out to analyze the overall system performance. Low level details i: e UAV movement, target localization, target tracking etc. is not the scope of this research.

In fig 4.1 the total area for simulation is 51*51 patches, each patch in this simulation is 8.12

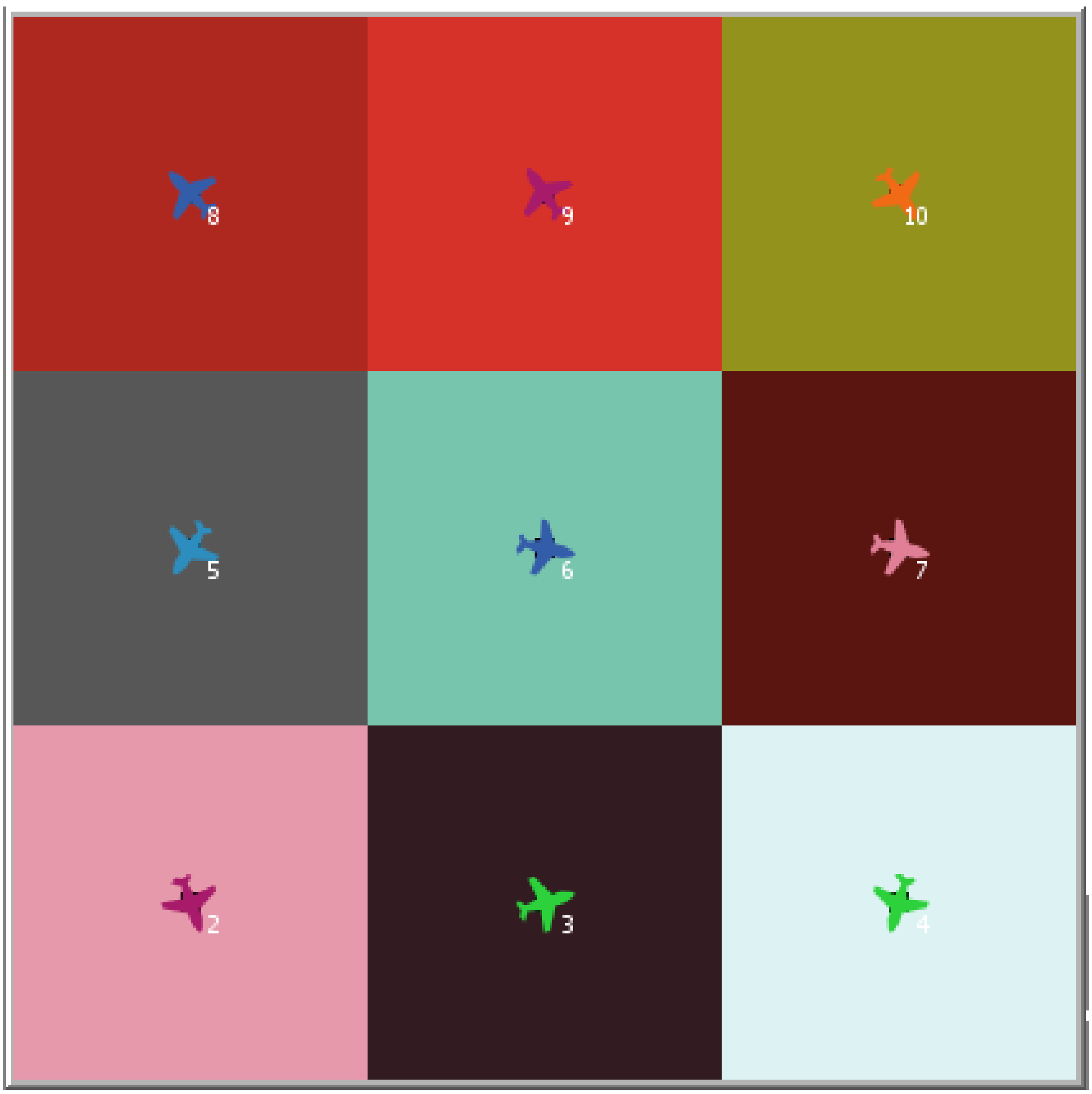

Figure 4.1: Simulation Screen

pixels. The area start from $X_{min} = 0$ and to $X_{max} = 50$ and $Y_{min} = 0$ and to $Y_{max} = 50$. The area is divided differently in different strategies, i:e in random, linear and full coverage the area is divided differently. Each watch agent is given its own specific area for surveillance and each agent survey its own area and does not enter other agent area. Background color of each agent surveillance area is different so that it can be easily identified. Each agent has given the capability to locate intruders in its field of view. Once the intruder's agent is in the sight of watch agent the intruder agent dies.

The intruder agents are created randomly and at random positions at runtime of the simulation. The algorithm is flexible and can adopt any size of the environment and any number of watch agents. For example if the area is changed to 100*100, the algorithm will adopt the changes and will perform the same i: e will divide the area among the agents. If the number of agents is changed, the algorithm will handle it. An agent when goes for fueling, the remaining agents are adjusted accordingly to cover the area. The speed and size of watch agents and intruder agents can be changed from interface. The agents are assigned an initial fuel and once that fuel consumes, they go for refueling.

Fig 4.2 shows the details of each component in the simulation interface. The red color

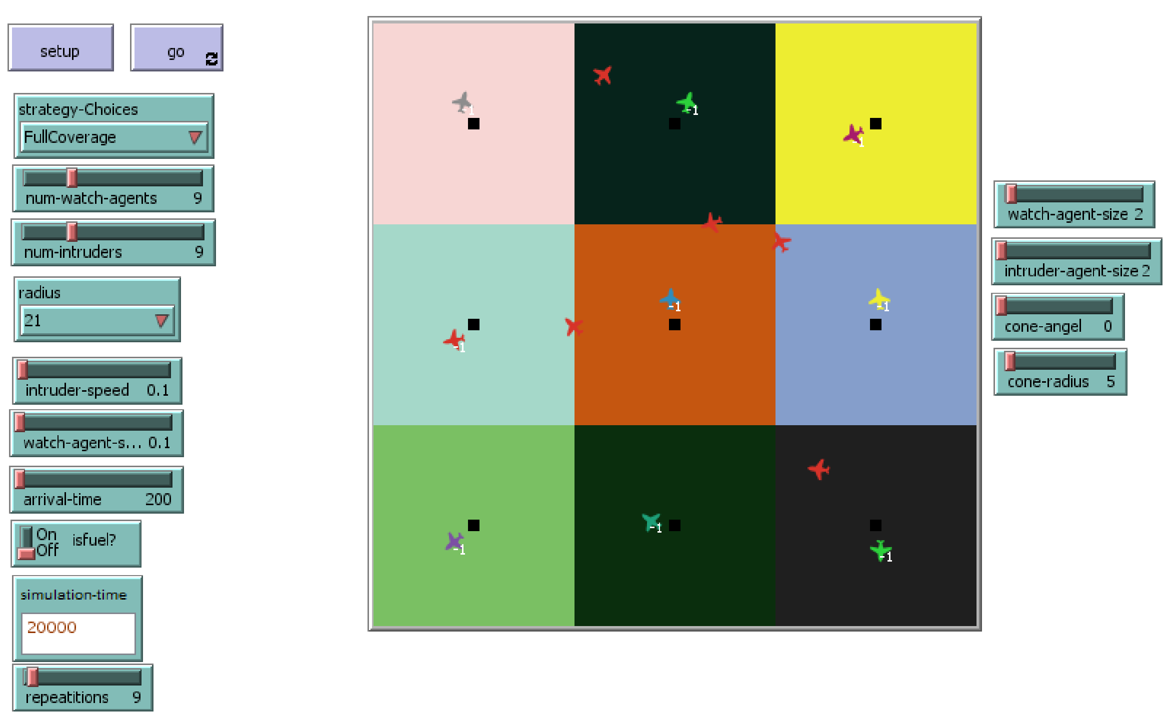

Figure 4.2: Simulation Screen Interface

airplanes are intruder agents. While other than red color are watch agents. Some variables used in above fig 4.2 are constant and will not change across different strategies. Some variable are dynamic and will change as the strategy changes. Static and dynamic variables are given in table 4.1

Table 4.1: Variables used

Factors	Random Strategy	Linear Strategy	Full Coverage Strategy
Watch agent speed	static	static	static
Intruders agent speed	static	static	static
Number of watch agents	6,9,12,16	6,9,12,16	6,9,12,16
Number of Intruder agents	random	random	random
Watch agents Placement	random	linear	center in assigned area
Intruder agents placement	random	random	random
Watch agent surveying area	random	linearly assigned	equally divided
Re-fueling	yes	yes	yes
Simulation time	20000 ticks	20000 ticks	20000 ticks
Communication	No	local/global	local/global
Detection Range	5 patches	5 patches	5 patches

4.2 Random Strategy Algorithm

Random strategy as the name suggests the watch agents are placed at random positions in the given area. The same simulation attributes are used for all the strategies for comparing the results.

Variables used in this strategy are given in table 4.1. Watch agent caught intruders agent when the intruders came in the range of 5 patches around the watch agents.

Fig 4.3 shows the watch agents placement in the simulation environment. The agents are placed at random position and move through the entire area. The agents caught intruder agent when it came in the dark area of watch agent. The white color agents are intruder agents. How the random strategy algorithm works? , is given below.

Let W = w1, w2,………., wm be the set of watch agents I = i1, i2, ….., in be the set of Intruder agents. E = minX, maxX, minY, maxY is the environment given for surveillance. F = f1, f2, ….., fm is the fuel of the corresponding watch agent. R is the radius of watch

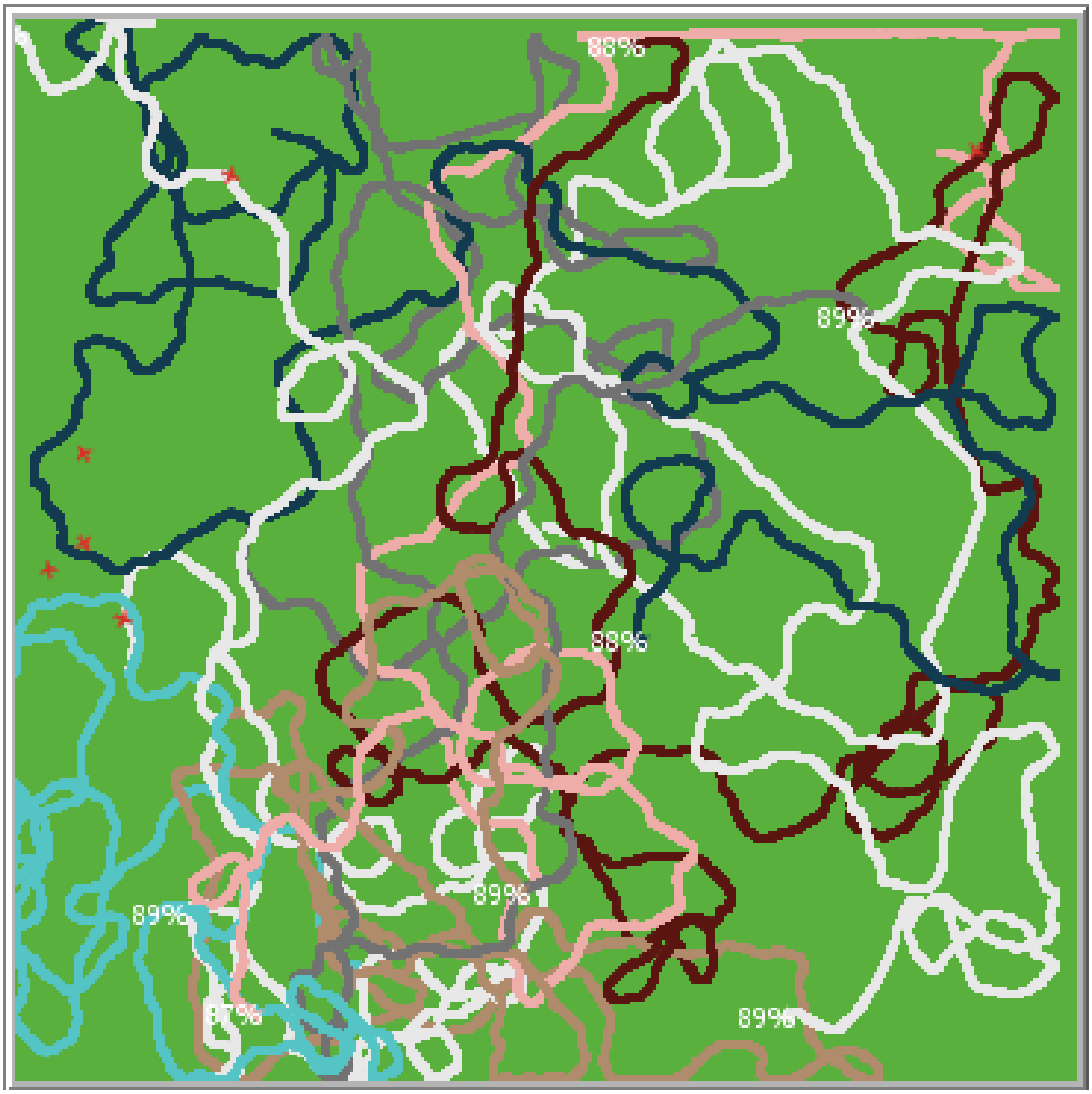

Figure 4.3: Random Strategy Watch agent's placement

agent, i:e the sensor capability to capture intruder agent.

A mission M is composed of the number of Intruder agent I =i1, i2, ….., im, the environment given for surveillance is E= minx, maxX, minY, maxY and the available number of watch agents are W= w1, w2,……, wm. The watch agents are randomly placed in the surveillance area and will search for the targets. The algorithm efficiency is the number of intruder agents captured.

Algorithm 4.2 Random Strategy

- watch agents are placed randomly and given initial fuel and radius r.
- watch agents do surveillance in the entire environment with no limitation.
- If fuel is available do surveillance
- Else
- Go for fuel

Intruder agents are randomly appearing at random position. Watch agents survey the area and captures the intruders agent that came inside the radius r of watch agent.

To keep simulation data normalized for the statistical analysis, all strategies are simulated with constant factors given in table 4.1

Set up 1: Watch agents surveying in this setup are six with attributes given in table 4.1

The graph 4.4 shows the simulation data of this setup. Total number of intruders entered, caught intruders and their average is given. Horizontal axis shows the number of simulations run while the vertical axis shows the intruder agents. The labels on graph line shows the intruder agents at each setup.

Set up 2: In this setup, 9 watch agents perform surveillance task. In graph 4.5 simulation results are given. The graph depicts the number of simulations carried out and intruder agents caught.

Set up 3: In the next setup the watch agents used for surveillance are 12. The agents perform surveillance randomly in the given area. Results are given in fig 4.6. The fig shows the number of simulations done with setup along with the total intruders entered, total intruders caught and average intruders caught. As the number of watch agents increases, results become better and better.

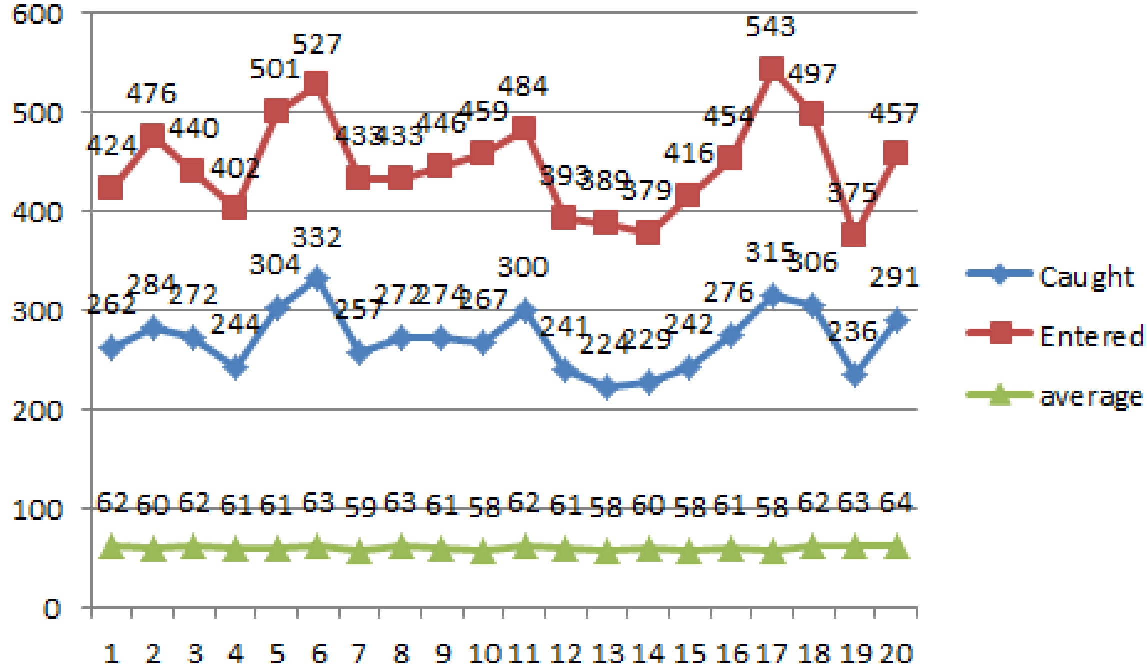

Figure 4.4: Random Strategy setup 1 results

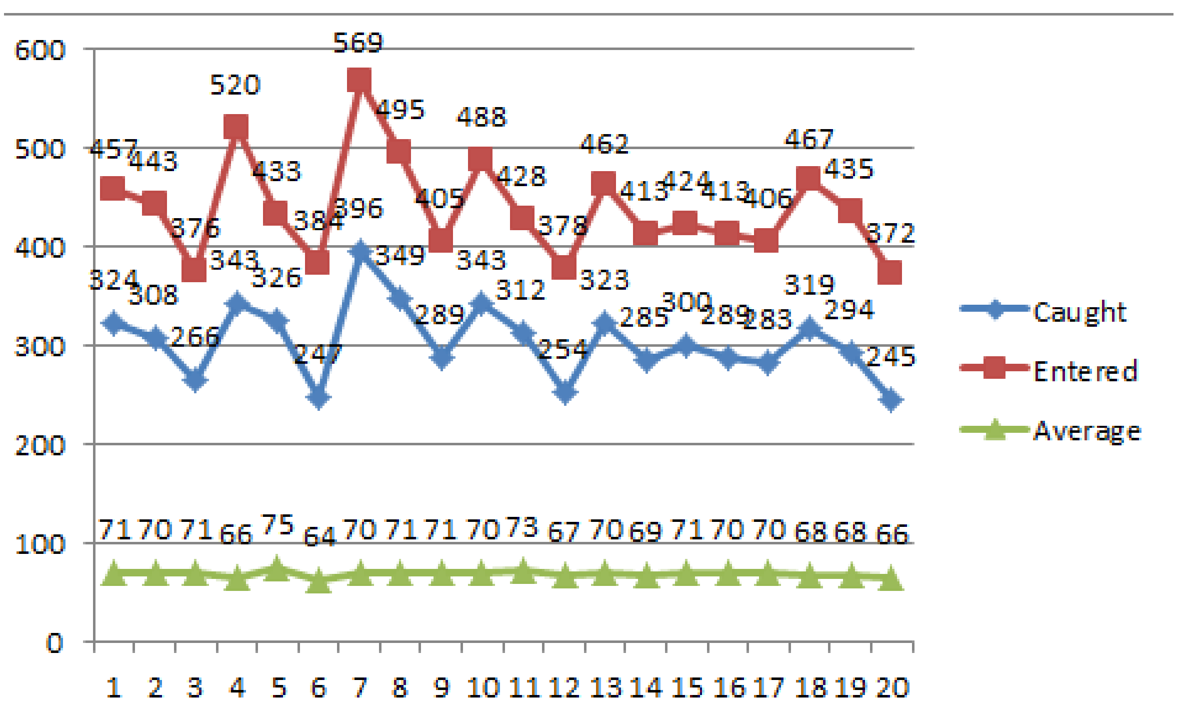

Figure 4.5: Random Strategy setup 2 results

Set up 4: In this setup 16 watch agents are used for surveillance. The results are shown in fig

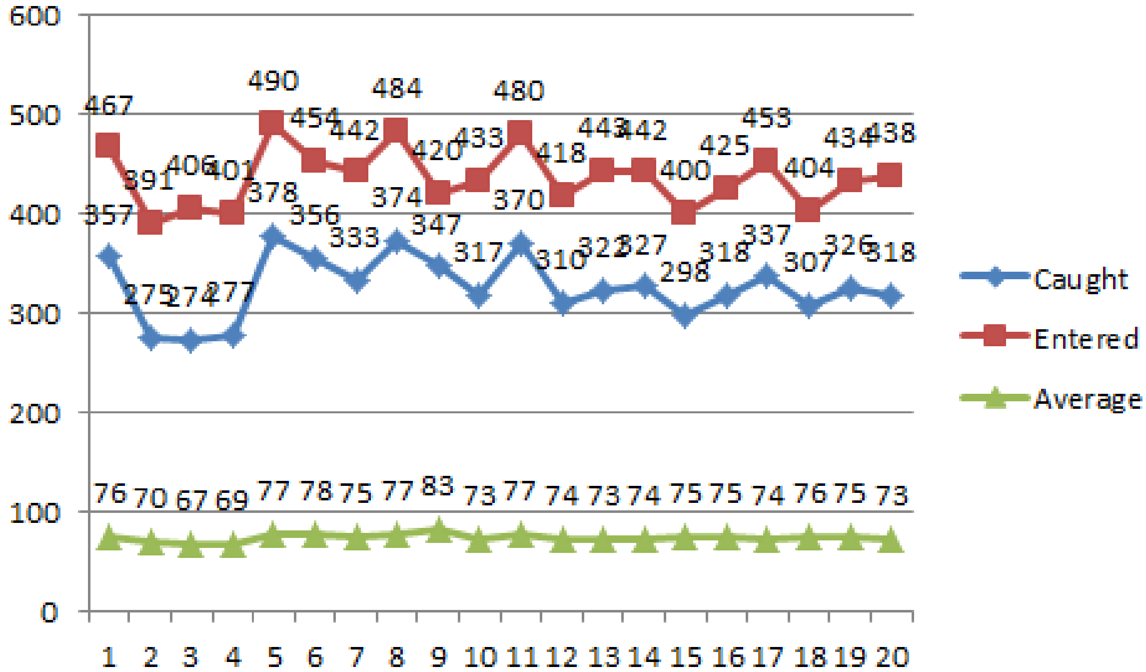

Figure 4.6: Random Strategy setup 3 results

4.7. The fig shows average number of intruders caught in each simulation. As watch agents in this setup are large in number as compared to other, its results are better than others.

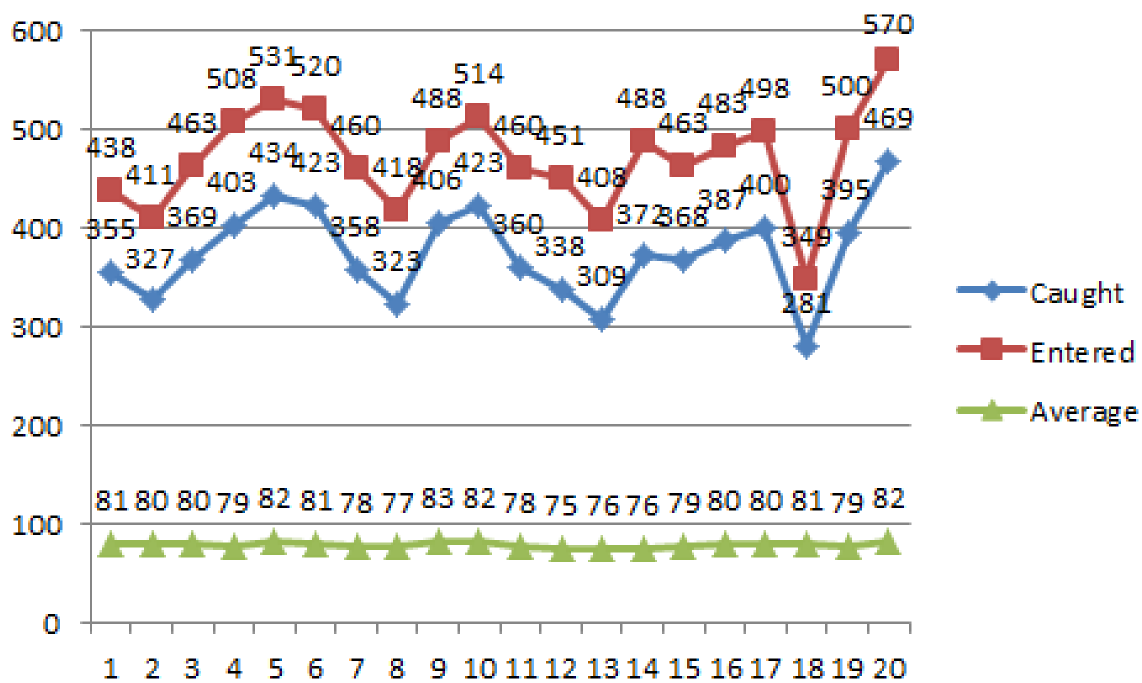

Figure 4.7: Random Strategy setup 4 results

So as the number of watch agents increases and the surveillance area remains the same the results of surveillance improves. The results comparison are given in table 4.2

Table 4.2: Combined result data of random strategy

Watch Agents	Average Intruders Caught	Number of Simulation	Simulation Time	Strategy
6	61%	20 simulations	20000 ticks	random
9	70%	20 simulations	20000 ticks	random
12	75%	20 simulations	20000 ticks	random
16	79%	20 simulations	20000 ticks	random

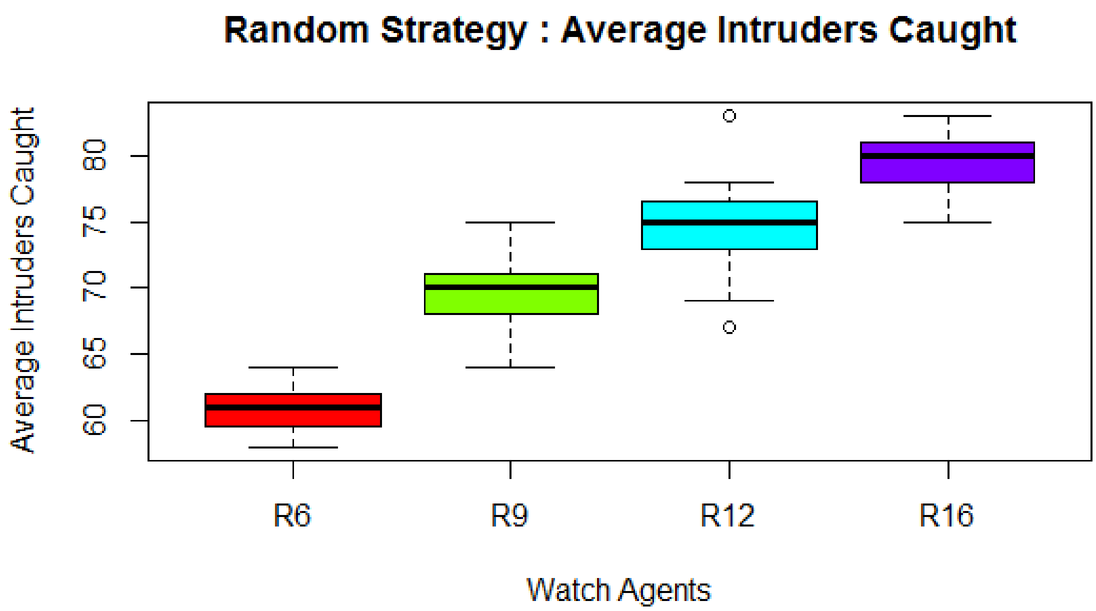

Figure 4.8: Random Strategy combined results

4.3 Linear Strategy Algorithm

In this strategy the area of surveillance or we can say the area of interest is divided in two sections horizontally. The watch agents are divided into two groups and place in each section. The area in each section is divided horizontally among the given number of watch agents. Below is the problem evaluation Let $W = \{w_1, w_2, \ldots\ldots\ldots, w_m\}$ be the set of watch agents $I = \{i_1, i_2, \ldots.., i_n\}$ be the set of Intruder agents. $E_{total} = \{minX, maxX, minY, maxY\}$ is the environment given for surveillance. $X_{w_i} = \{(X^{w_1}_{min_1}, X^{w_1}_{max_1}), (X^{w_2}_{min_2}, X^{w_2}_{max_2}), \ldots\ldots, (X^{w_m}_{min_m}, X^{w_m}_{max_m})\}$ is the set of minimum X coordinate and maximum X coordinate of the corresponding watch agents $Y_{w_i} = \left\{(Y^{w_1}_{min_1}, Y^{w_1}_{max_1}), (Y^{w_2}_{min_2}, Y^{w_2}_{max_2}), \ldots\ldots, (Y^{w_m}_{min_m}, Y^{w_m}_{max_m})\right\}$ is the set of minimum Y coordinate and maximum Y coordinate for surveillance area of the corresponding watch agents r is the radius of watch agent, i:e the sensor capability to capture intruder agent. The simulation environment of linear strategy algorithm in Net logo is given in fig 4.9

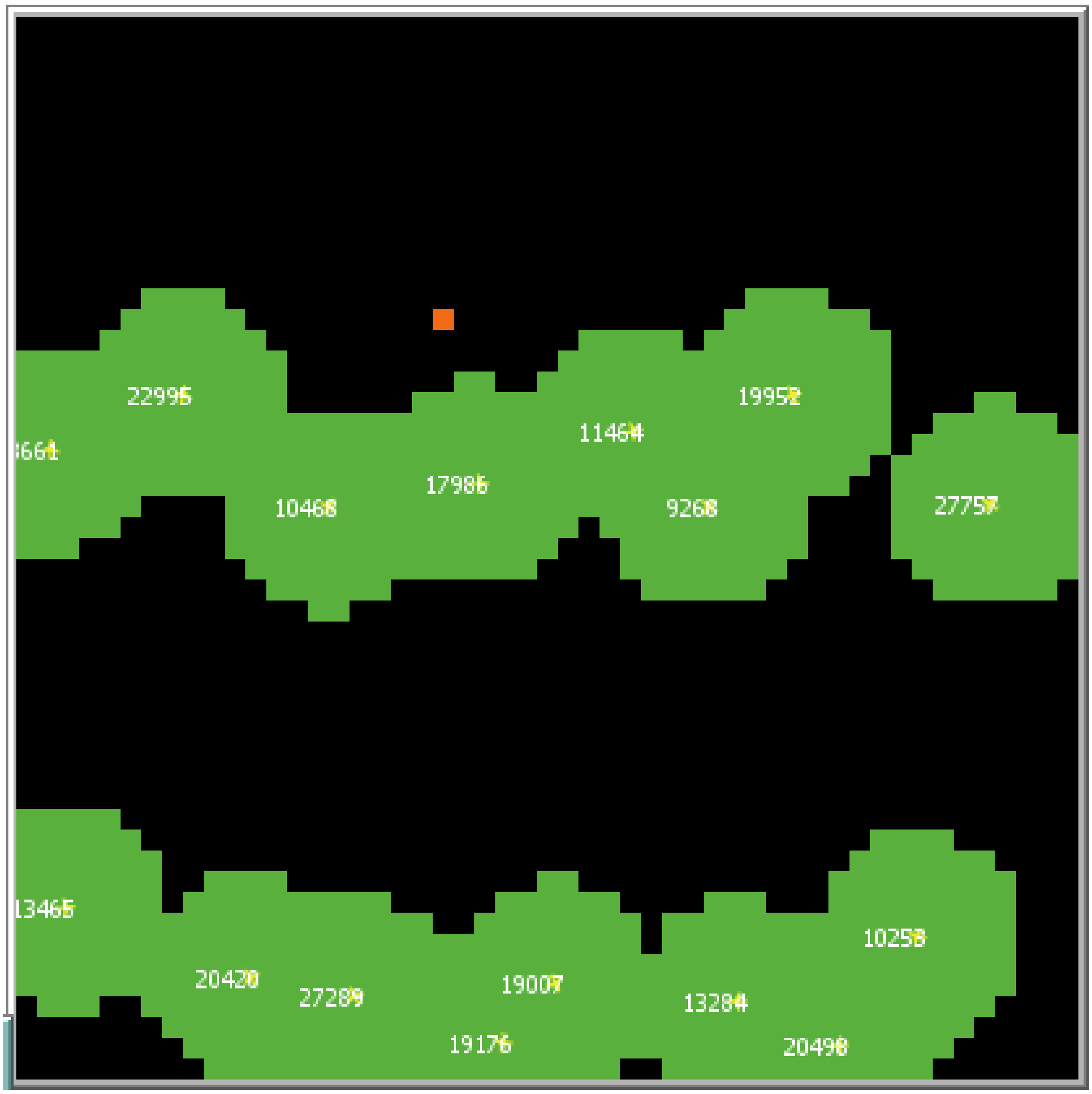

Figure 4.9: Linear Strategy Simulation in Net Logo

The watch agents are placed in two linear lines and survey the given area. The area is divided linearly so the horizontal area x-axis of each agent is less than the vertical area y-axis. Watch agents capture intruder agent that came inside the green area as shown in the fig 4.9. Simulations with four different setups are done for linear strategy.Results of each setup are given below.

Set up 1: In this setup 6 watch gents are used for surveillance. The agents perform surveillance in the area provided. Results are depicted in fig 4.10. The fig on horizontal axis shows total number of simulations run for this setup. Total intruders entered,caught and average intruders caught are given on vertical axis.

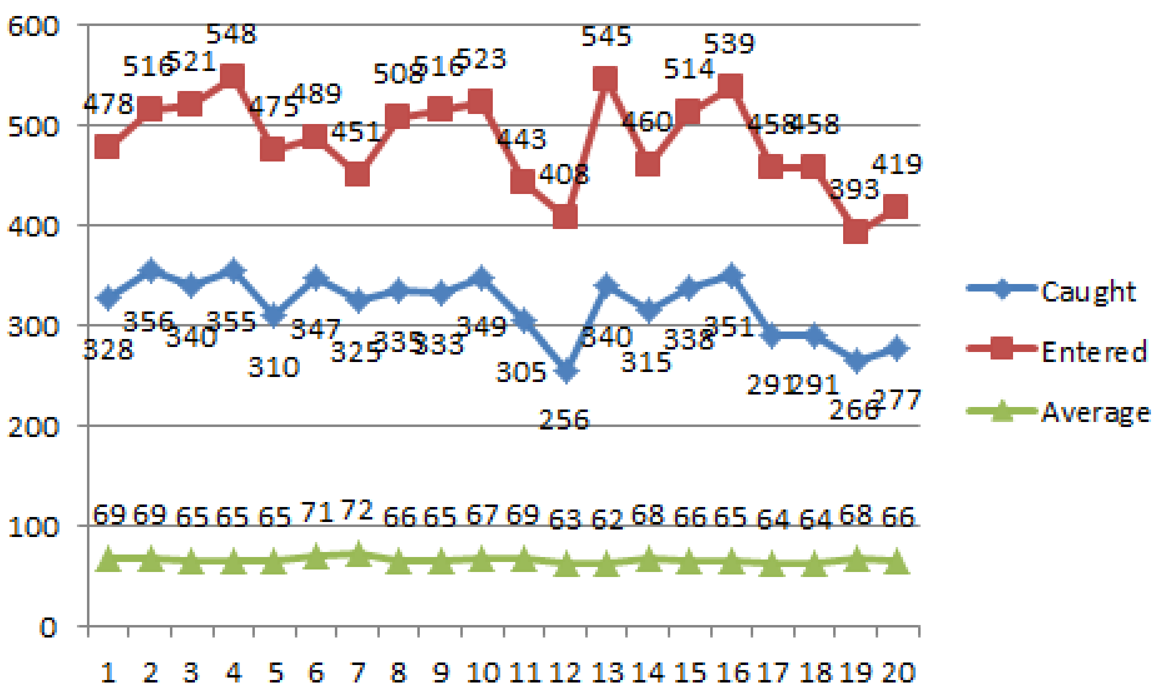

Figure 4.10: Linear Strategy setup 1 results

Set up 2: The Linear strategy simulation is carried out for this setup with 9 watch agents and with attributes as given in table 4.1. Results are depicted in fig 4.11, which shows the average number of intruders caught using this setup.

Set up 3: Watch agents used for surveillance in this setup are 12.Results are given in fig 4.12. The results in fig shows the intruders entered, intruders caught, average intruders caught and number of simulations.

Set up 4: Watch agents used for surveillance in this setup are 16.Results are given in fig 4.13. The results in fig shows total intruders entered, intruders caught, average intruders caught and number of simulations. As the number of agents increases, the surveillance efficiency

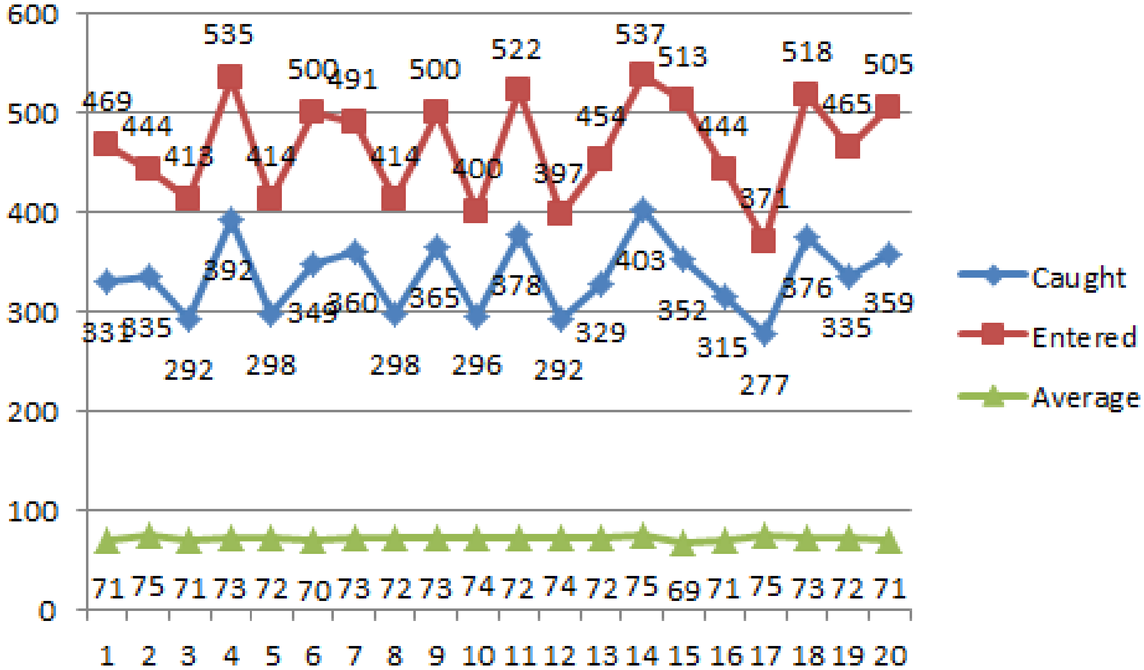

Figure 4.11: Linear strategy setup 2 results

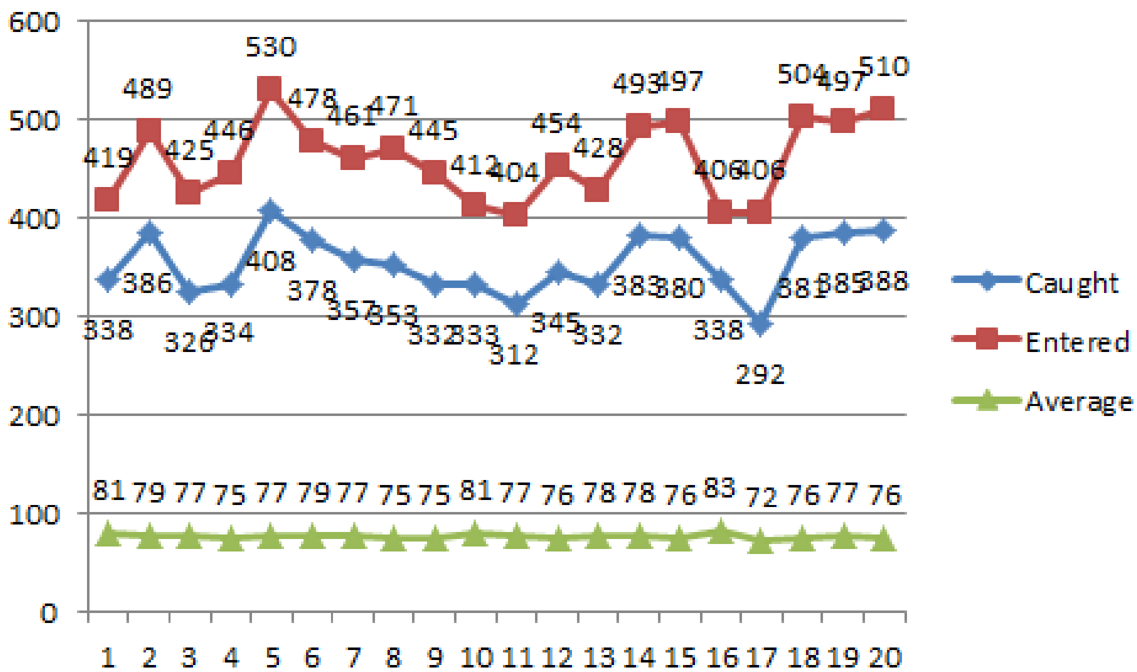

Figure 4.12: Linear strategy setup 3 results

becomes better and better.

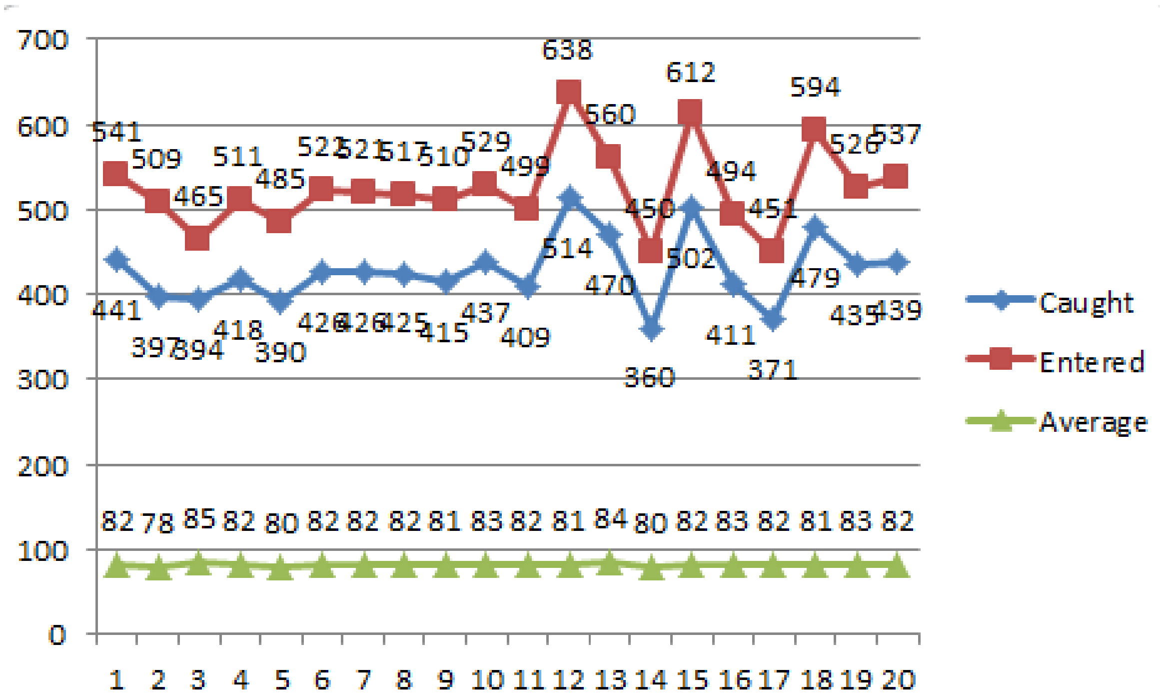

Figure 4.13: Linear strategy setup 4 results

The linear strategy results are better than random strategy because it avoid unnecessary arrival of multiple watch agents at the same location. The combined result of the linear strategy simulations is given in table 4.3

Table 4.3: Combined result data of linear strategy

Watch Agents	Average Intruders Caught	Number of Simulation	Simulation Time	Strategy
6	66%	20 simulations	20000 ticks	linear
9	72%	20 simulations	20000 ticks	linear
12	77%	20 simulations	20000 ticks	linear
16	82%	20 simulations	20000 ticks	linear

4.4 Local Communication Coverage Strategy

This strategy presents the full coverage of the surveillance area with the available number of UAVs. The area of interest is divided among the available number of UAVs. Each UAV gets its own area and survey that area. The communication among the UAVs are local, means that if an agent wants to deliver a message, it transfers the message to its neighbors and in this way all UAVs get the desired information through the available communication channel.

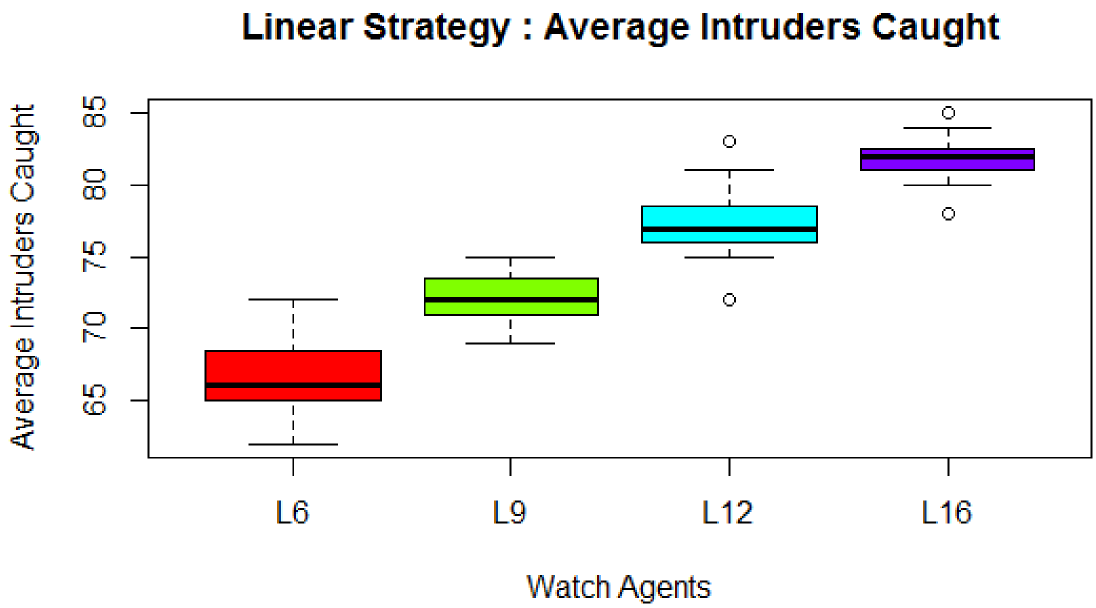

Figure 4.14: Linear strategy combined results

Simulation interface of this strategy is shown in fig 4.15. Each agent has its own resources such as fuel, sensor, communication channel, placement location, surveillance area, sensor range and distance from base station. Simulation for this strategy is carried out on the same data set used for other strategies. The results achieved from each set up are:

Set up 1: Watch agents available for this setup are 6. The agents are assigned area equally to perform surveillance. Communication among agents is local. Results graph is shown in fig 4.16. The graph shows the average intruders caught along with total entered.

Set up 2: The setup 2 is simulated with 9 agents and the results are shown in fig 4.17, which shows the average intruders caught in this setup.

Set up 3: Setup 3 simulation is carried out with 12 agents. The results are shown in fig 4.18, showing the average intruders caught, total intruders entered at each simulation and total caught at each simulation.

Set up 4: Watch agents used for surveillance in this setup are 16. Results are shown in the fig 4.19. The graph shows the average number of intruders caught at each simulation.

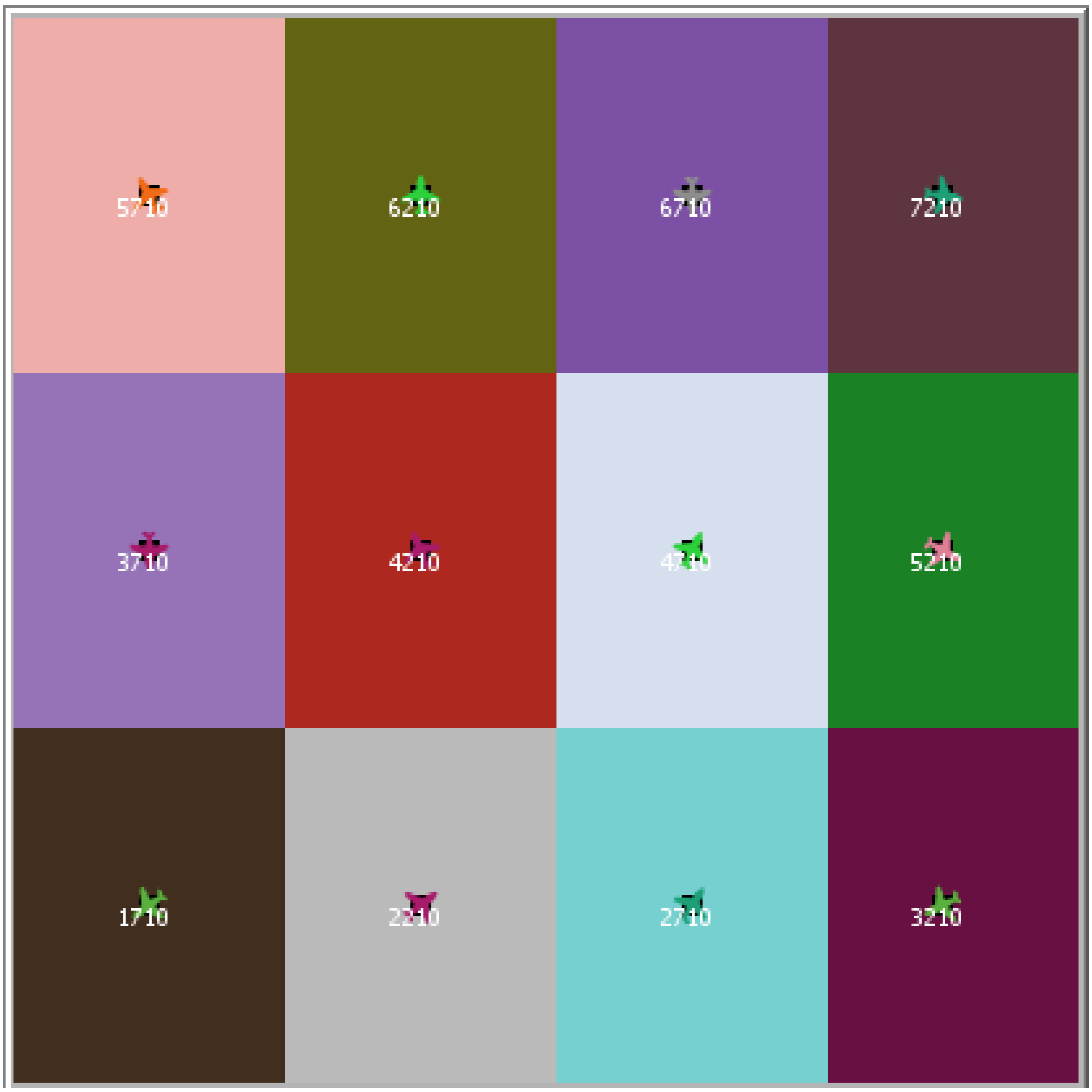

Figure 4.15: Local strategy simulation screen in Net logo

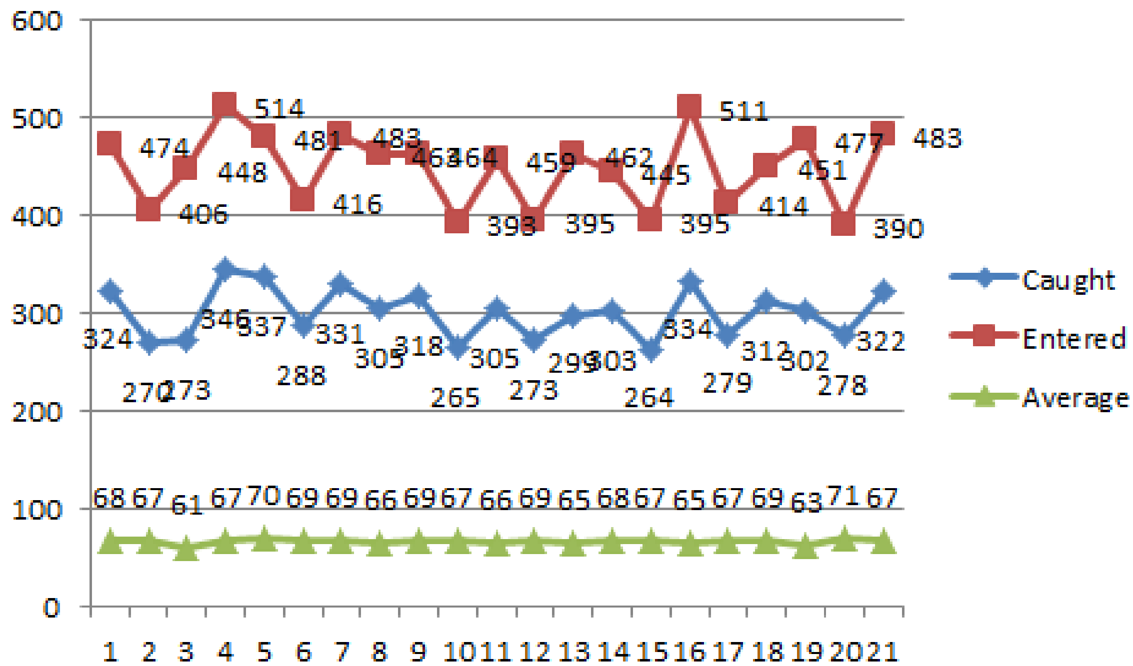

Figure 4.16: Local communication Strategy setup 1 results

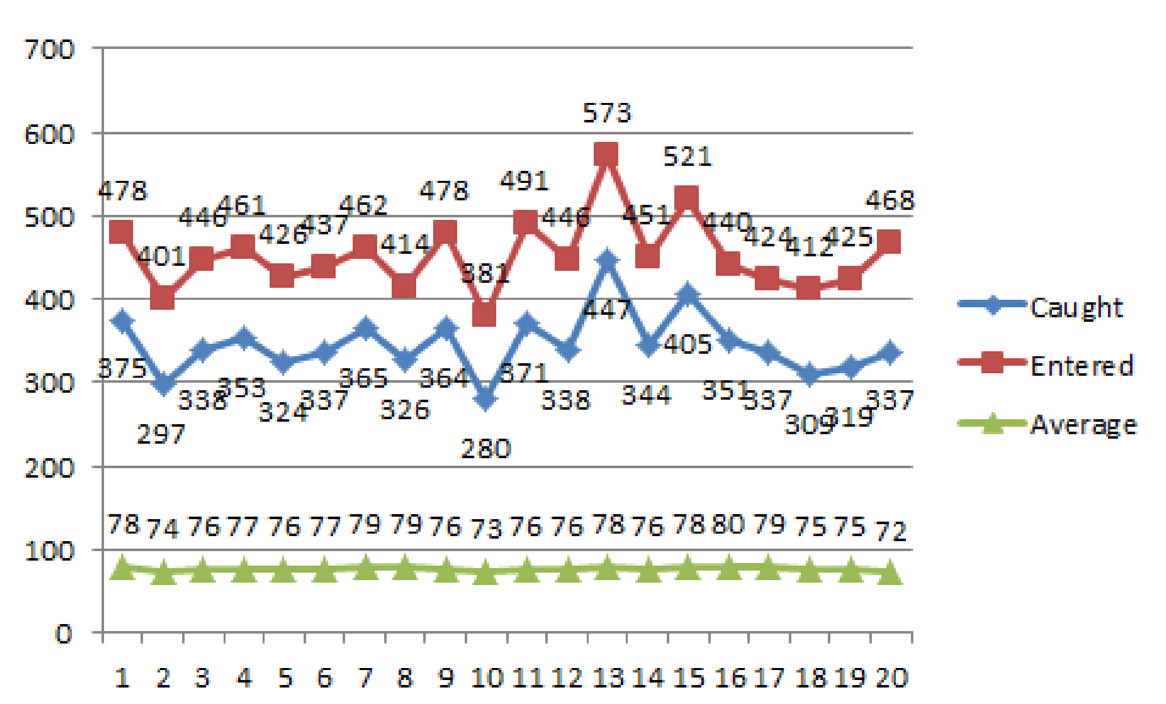

Figure 4.17: Local communication Strategy setup 2 results

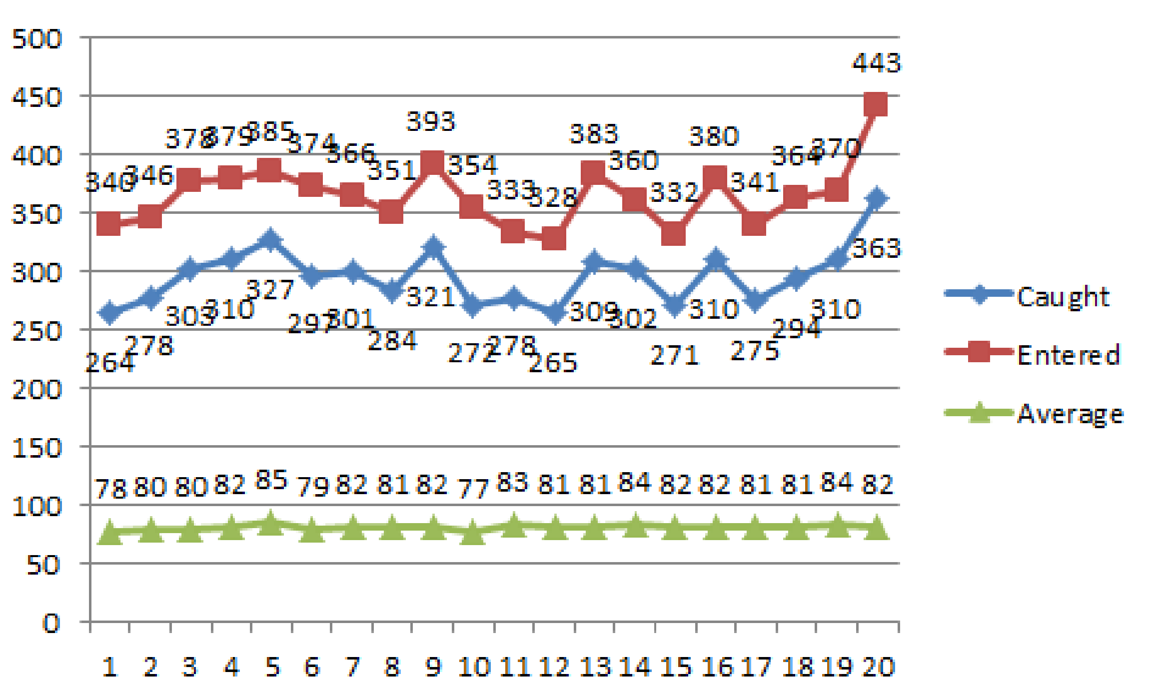

Figure 4.18: Local communication Strategy setup 3 results

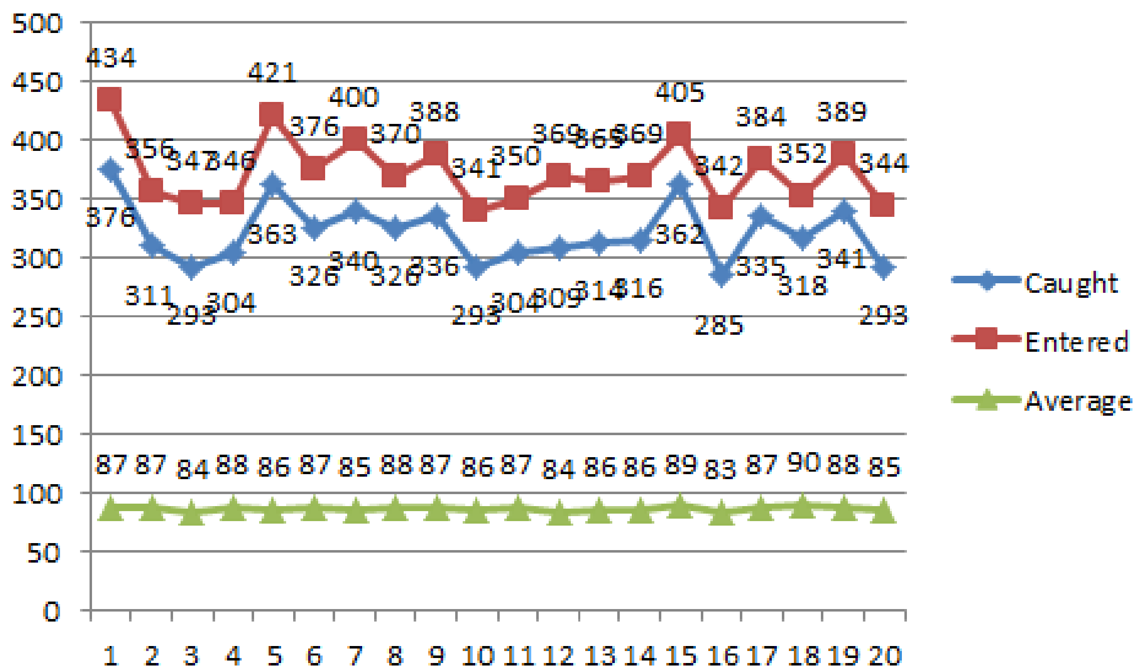

Figure 4.19: Local communication Strategy setup 4 results

The result of local communication strategy is better than the random and linear strategy results. The area is divided equally among the agents. The result of this strategy is given in table 4.4

Table 4.4: Combined result data of local communication strategy

Watch Agents	Average Intruders Caught	Number of Simulation	Simulation Time	Strategy
6	67	20 simulations	20000 ticks	local communication full coverage strategy
9	77	20 simulations	20000 ticks	local communication full coverage strategy
12	81	20 simulations	20000 ticks	local communication full coverage strategy
16	87	20 simulations	20000 ticks	local communication full coverage strategy

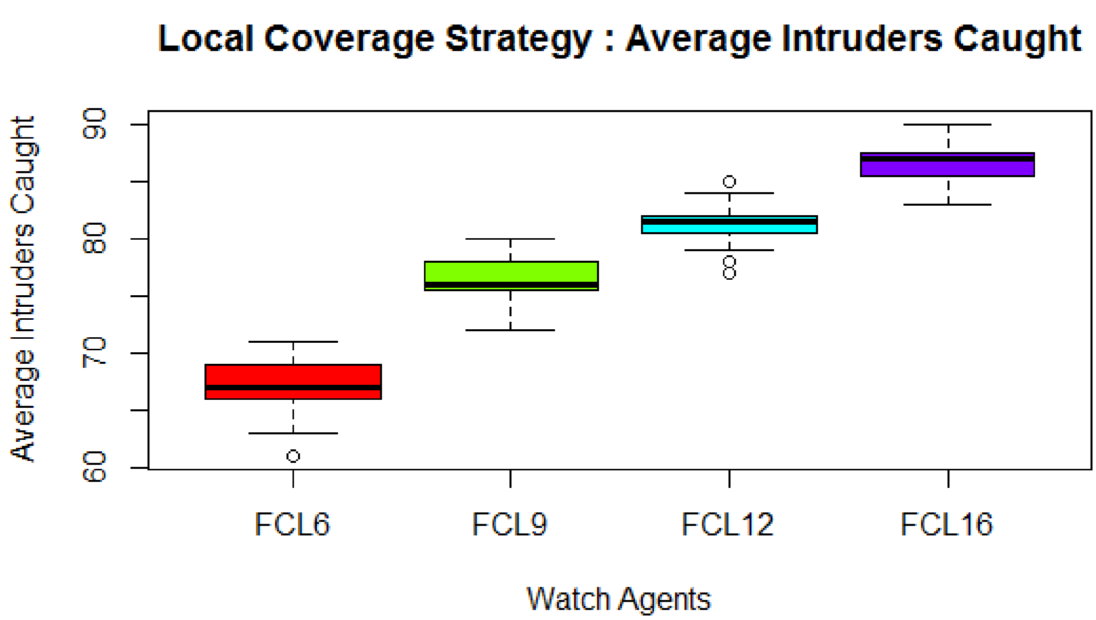

Figure 4.20: Local communication coverage strategy combined results

4.5 Global Communication Coverage Strategy

This strategy limits the communication burden or delay occurred in local communication coverage strategy. The surveillance area is divided among the available number of agents. The agents survey their own area with the available resources on board of each UAV. The agents communicate directly with each other without any limitation. For example Let W = w1, w2, ….. , wn is the set of available number of agents for surveillance. If wi , communicates with wi-1, wi-2 ... and so on. Wi will broadcast the message to all the available UAVs. Simulation results of global communication coverage strategy is as follows Set up 1: This setup for global communication strategy is simulated with six agents. Other factors used in this setup are given in table 4.1. The simulation results are given in fig 4.21. The result graph shows the total number of intruders entered at each simulation, total intruders caught and average intruders caught.

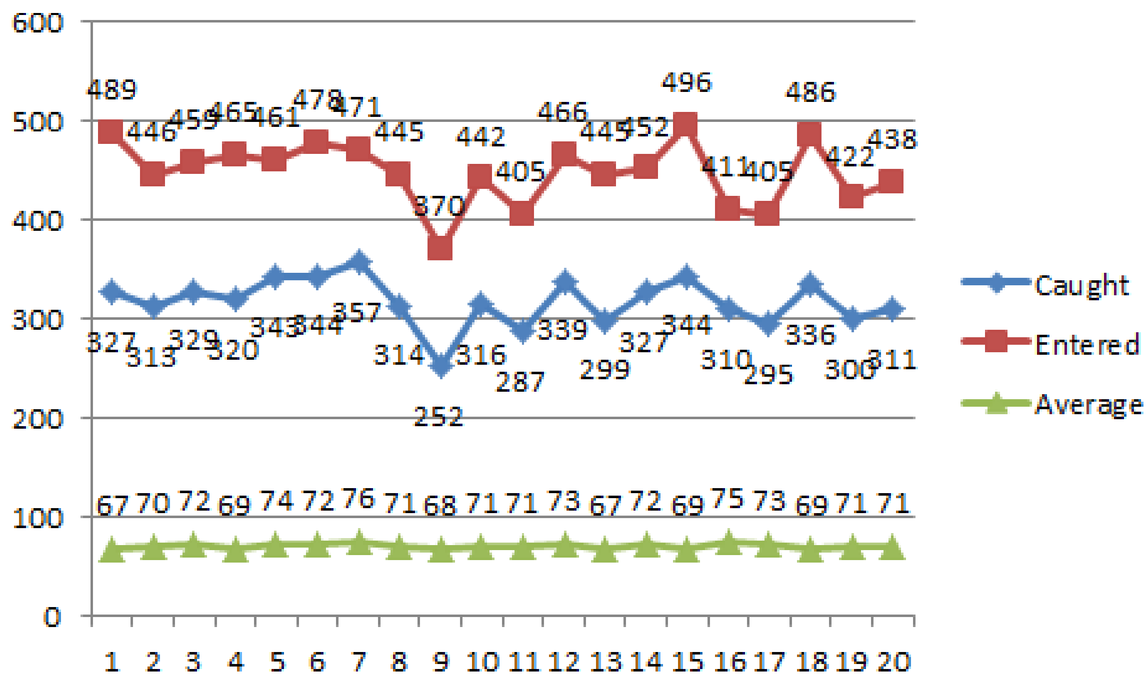

Figure 4.21: Global communication Strategy setup 1 results

Set up 2: The Global communication full coverage strategy simulation is carried out for this setup 20 times. Watch agents used for surveillance in this setup are 9. Result is shown in the fig 4.22. Total intruders entered, total caught and average intruders caught at each simulation are shown in the graph.

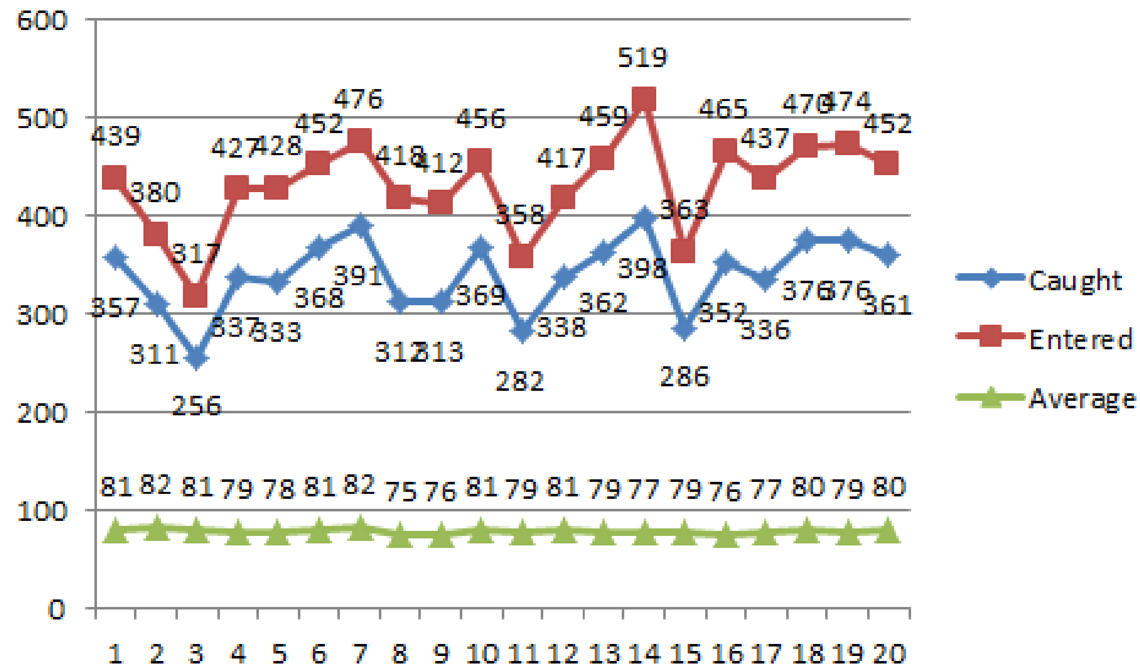

Figure 4.22: Global communication Strategy setup 2 results

Set up 3: This setup is simulated with 12 agents and the results are shown in fig 4.23. The result shows average intruders caught, total entered and total intruders caught.

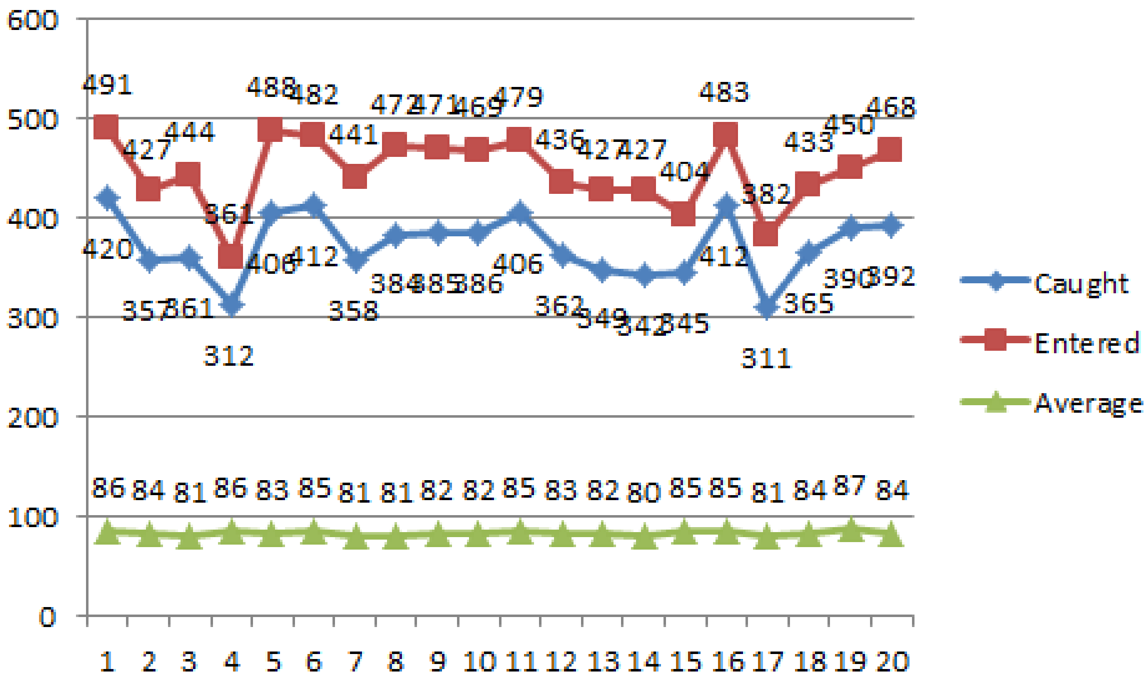

Figure 4.23: Global communication Strategy setup 3 results

Set up 4: Simulation is carried out in this setup with 16 agents. Fig 4.24 shows the results of this setup. The graph depicts the total intruders entered, total intruders caught and average intruders caught.

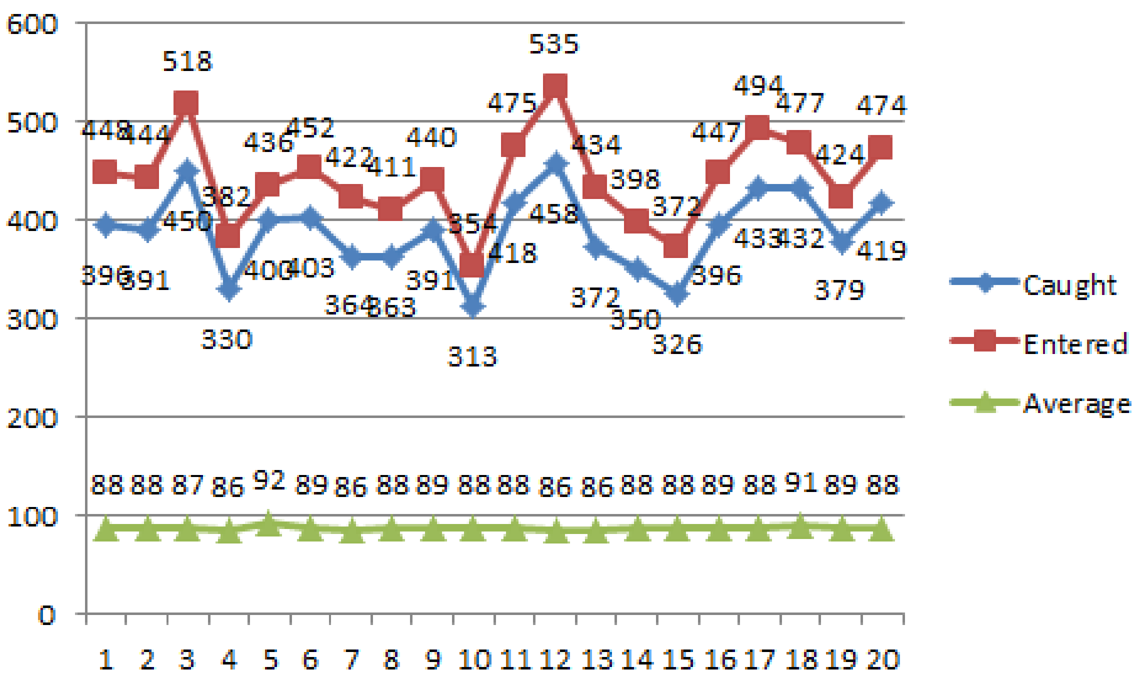

Figure 4.24: Global communication Strategy setup 4 results

The results of this strategy are better than all the three strategies, random, linear and local communication coverage strategies. The results of this strategy are compared in table 4.5

Table 4.5: Combined result data of global coverage strategy

Watch Agents	Average Intruders Caught	Number of Simulation	Simulation Time	Strategy
6	71	20 simulations	20000 ticks	global communication full coverage strategy
9	79	20 simulations	20000 ticks	global communication full coverage strategy
12	83	20 simulations	20000 ticks	global communication full coverage strategy
16	88	20 simulations	20000 ticks	global communication full coverage strategy

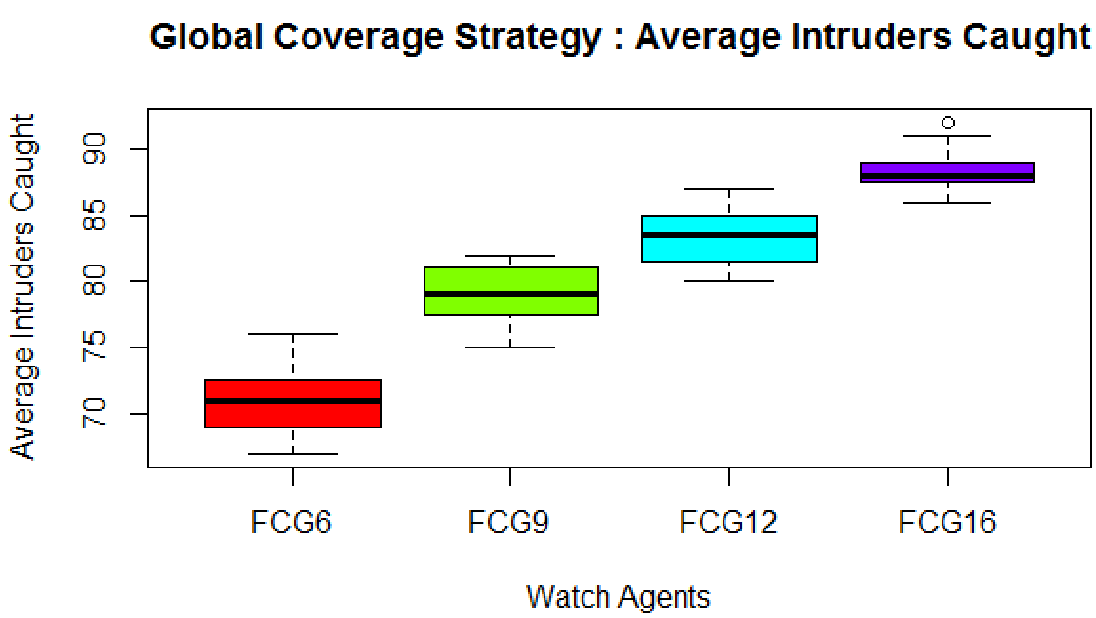

Figure 4.25: Global communication coverage strategy combined results

4.6 Sight Coverage Strategy

This strategy is the improvement of the work presented in [20]. The surveillance area is divided among the available number of agents. The agents survey their own area with the available resources on board of each UAV.The watch agents captures intruders agent in their own field of view which is 5 patches in this strategy simulations and with an angle of 45 degree. The agents communicate directly with each other without any limitation. For example Let W = w1, w2, ... , wn is the set of available number of agents for surveillance. If wi , communicates with wi-1, wi-2 ... and so on. Wi will broadcast the message to all the available UAVs. Simulation results of Sight coverage strategy is as follows

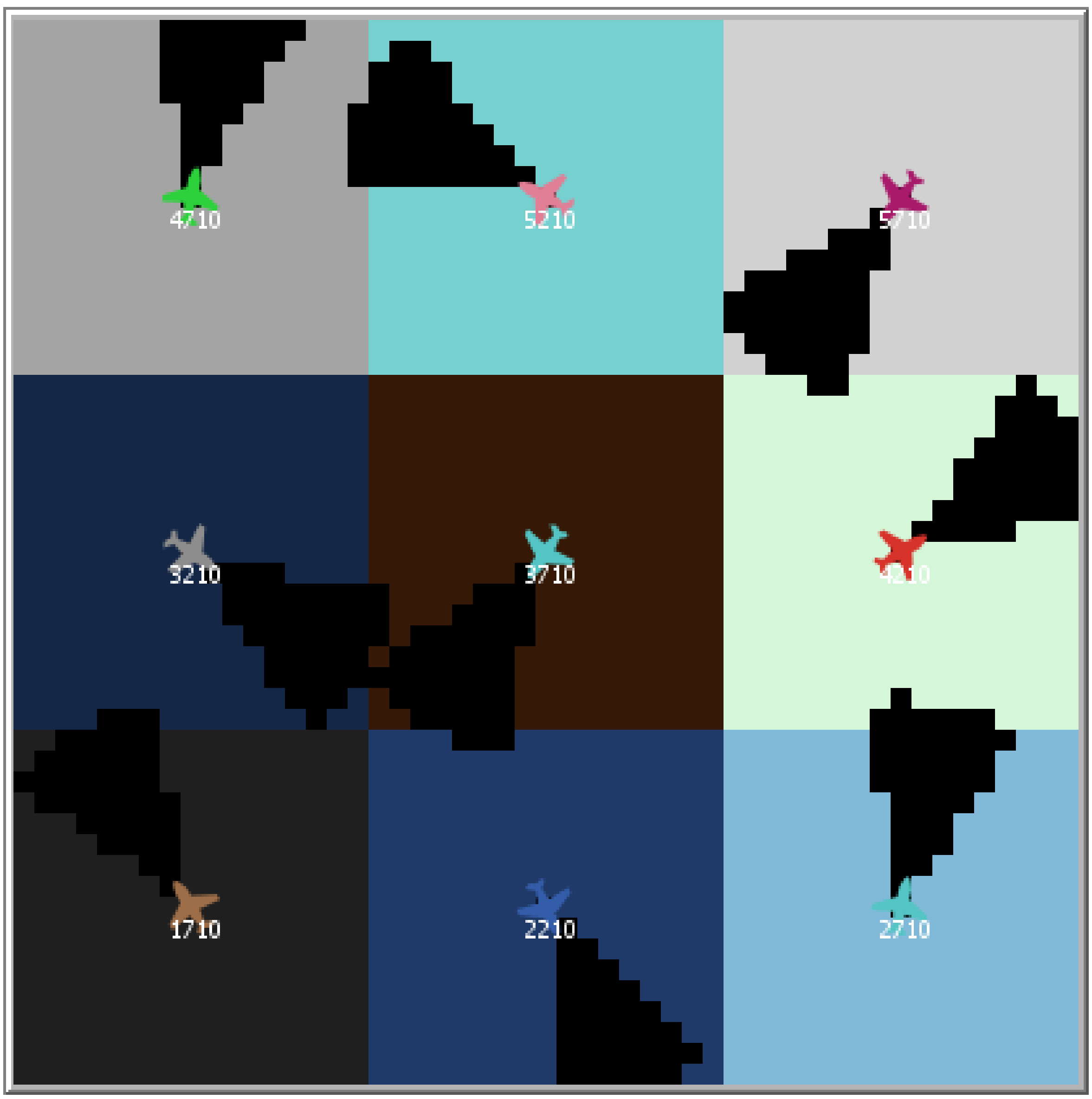

Figure 4.26: Sight Strategy NetLogo Interface

Set up 1: The Sight coverage strategy simulation is carried out for this setup 20 times, each simulation is run for 2000 ticks and the watch agents can capture intruder agent in the radius of 5 patches around itself with an angel of 45 degrees. When the intruder agent came in the field of view of the watch agent, it is captured by the watch agent. The simulation results are depicted below. The surveillance area in this setup used are 51*51 patches.Watch agents used for surveillance in this setup are 6.

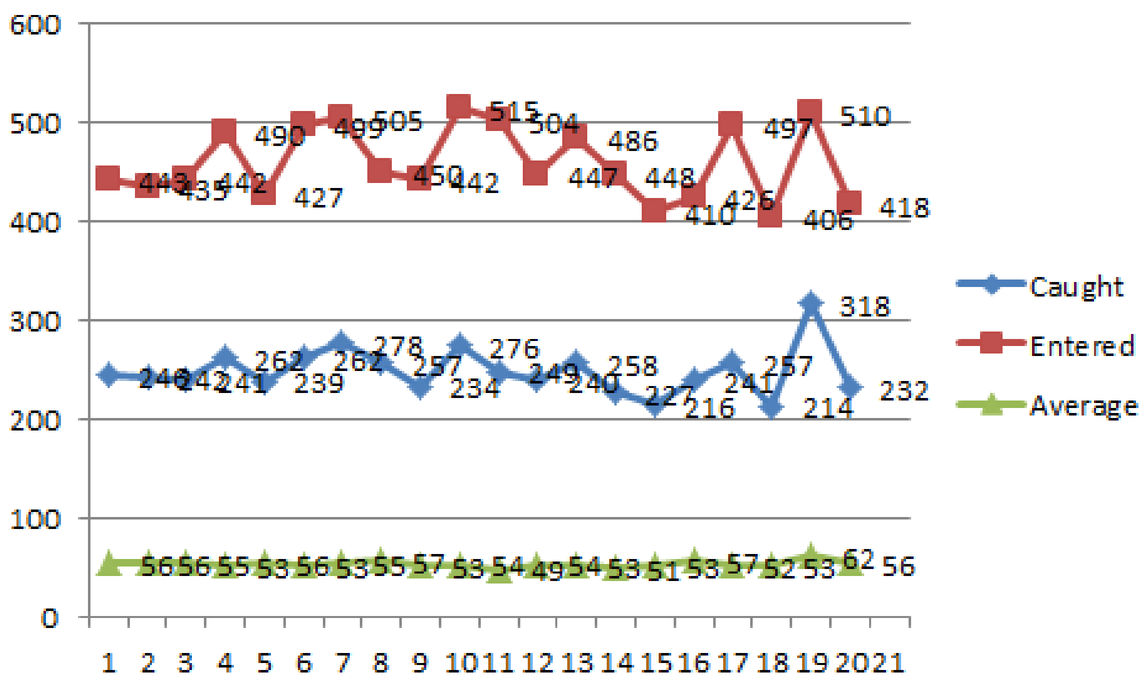

Figure 4.27: Sight Strategy setup 1 results

Set up 2: The Sight strategy simulation is carried out for this setup 20 times, each simulation is run for 2000 ticks and the watch agents can capture intruder agent in the radius of 5 patches around itself with an angel of 45 degrees. When the intruder agent came in the field of view of the watch agent, it is captured by the watch agent. The simulation results are depicted below. The surveillance area in this setup used are 51*51 patches.Watch agents used for surveillance in this setup are 9.

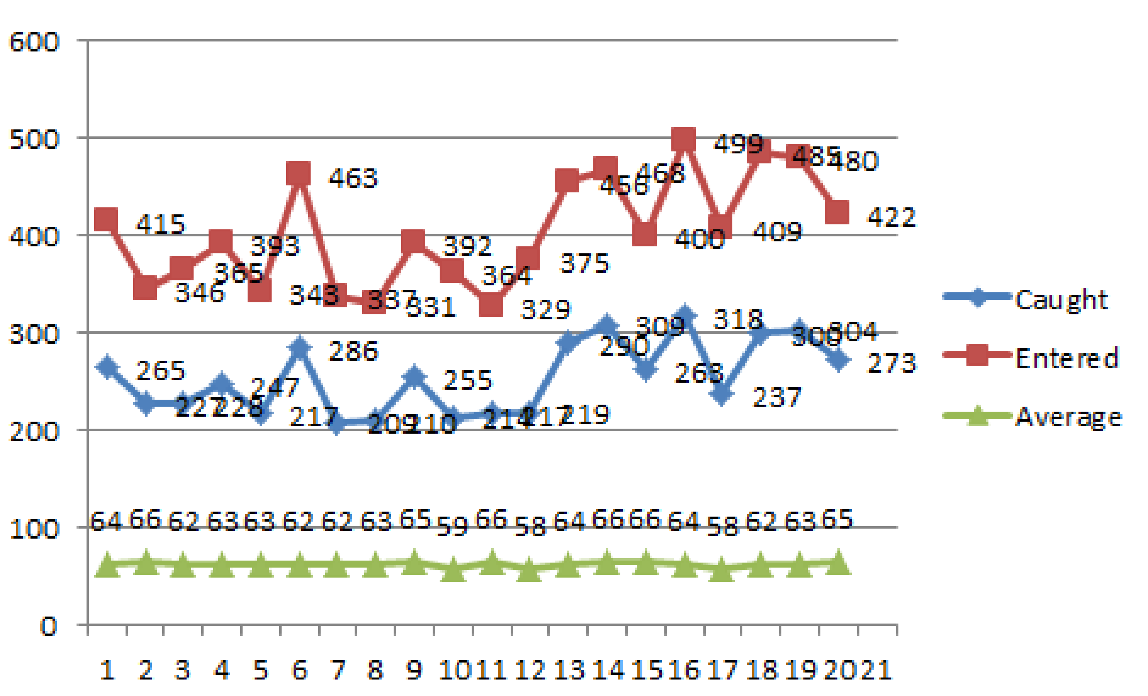

Figure 4.28: Sight Strategy setup 2 results

Set up 3: The Sight strategy simulation is carried out for this setup 20 times, each simulation is run for 2000 ticks and the watch agents can capture intruder agent in the radius of 5 patches around itself with an angel of 45 degrees. When the intruder agent came in the field of view of the watch agent, it is captured by the watch agent. The simulation results are depicted below. The surveillance area in this setup used are 51*51 patches.Watch agents used for surveillance in this setup are 12.

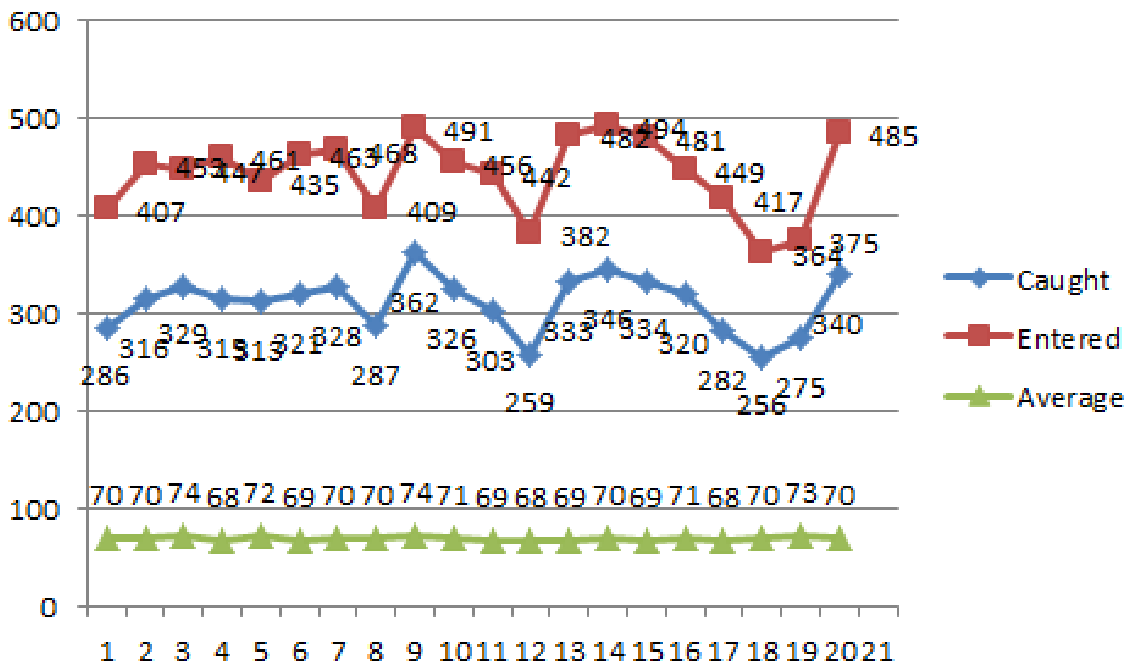

Figure 4.29: Sight Strategy setup 3 results

Set up 4: The Sight strategy simulation is carried out for this setup 20 times, each simulation is run for 2000 ticks and the watch agents can capture intruder agent in the radius of 5 patches around itself with an angel of 45 degrees. When the intruder agent came in the field of view of the watch agent, it is captured by the watch agent. The simulation results are depicted below. The surveillance area in this setup used are 51*51 patches.Watch agents used for surveillance in this setup are 16.

The combined result data of sight strategy is given in table 4.6

Table 4.6: Combined result data of sight strategy

Watch Agents	Average Intruders Caught	Number of Simulation	Simulation Time	Strategy
6	54	20 simulations	20000 ticks	sight
9	63	20 simulations	20000 ticks	sight
12	70	20 simulations	20000 ticks	sight
16	76	20 simulations	20000 ticks	sight

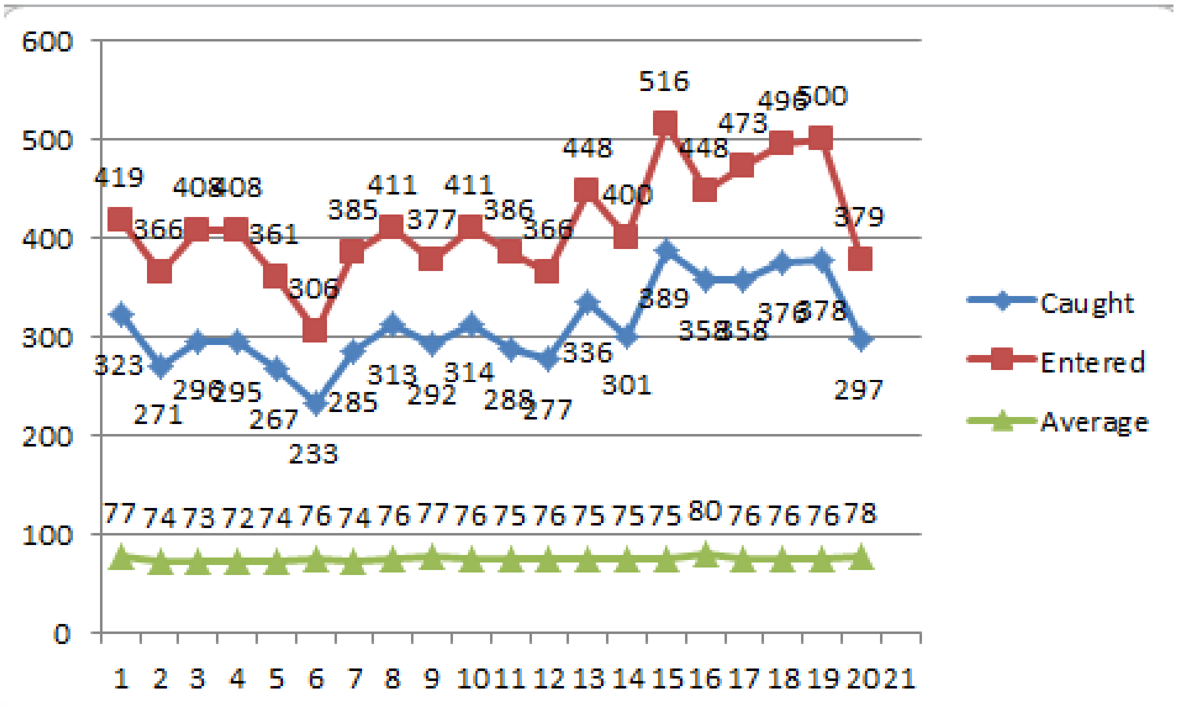

Figure 4.30: Sight Strategy setup 4 results

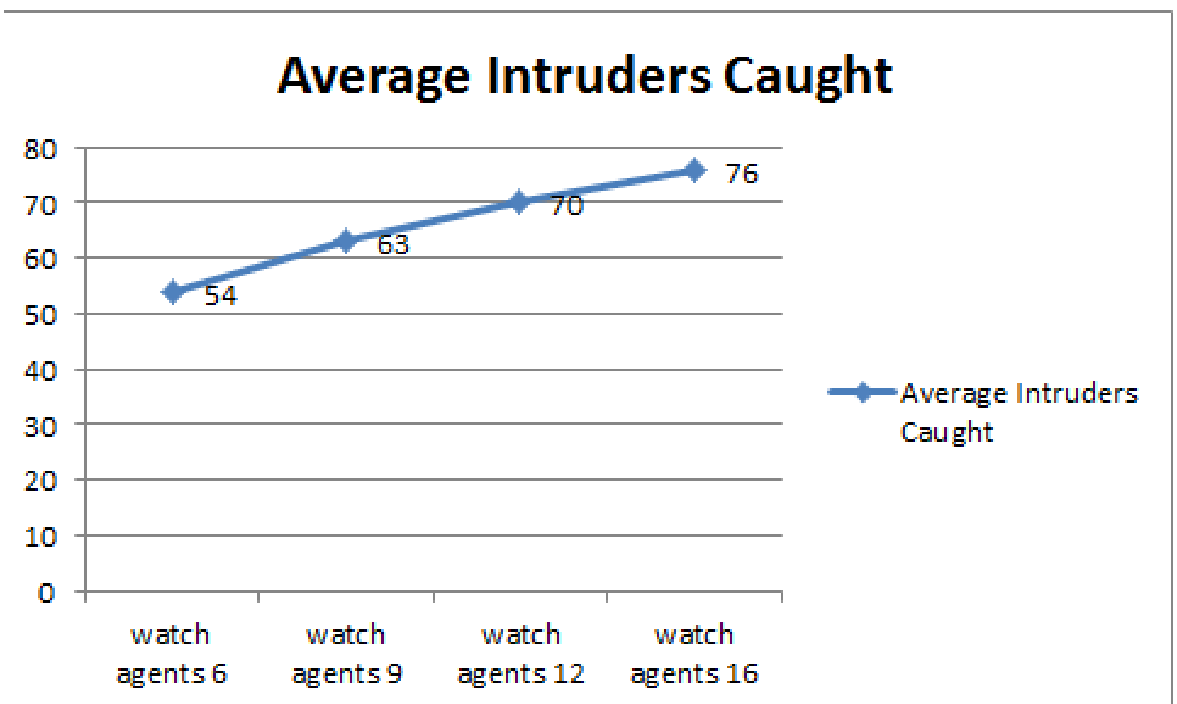

Figure 4.31: Sight strategy combined results

Chapter 5

RESULTS AND FINDINGS

5.1 Result Analysis

Simulation results of each strategy are analyzed in R studio with different data comparison. The results show a great impact on the surveillance of agents in a given environment. The results are analyzed for finding out the following.

- UAV team size effects on the surveillance performance.
- Different strategy effect on the surveillance performance.
- Re-fueling UAV effect on the surveillance performance.

5.1.1 Experiment:1

UAV team size effect on the surveillance performance

When the UAVs team size changes, it greatly effect on the surveillance performance of UAVs team. The data is collected for a team of 6,9,12,16 UAVs for different strategies i-e Linear, Random, Local Coverage and Global Coverage.

Random Strategy

In Random strategy UAVs are randomly placed in the surveillance area. UAVs perform surveillance autonomously in the whole environment. Simulation results are taken for a team of 6,9,12 and 16 UAVs. Results are given in fig 5.1 The results show that when team size increases, the performance gets better and better.

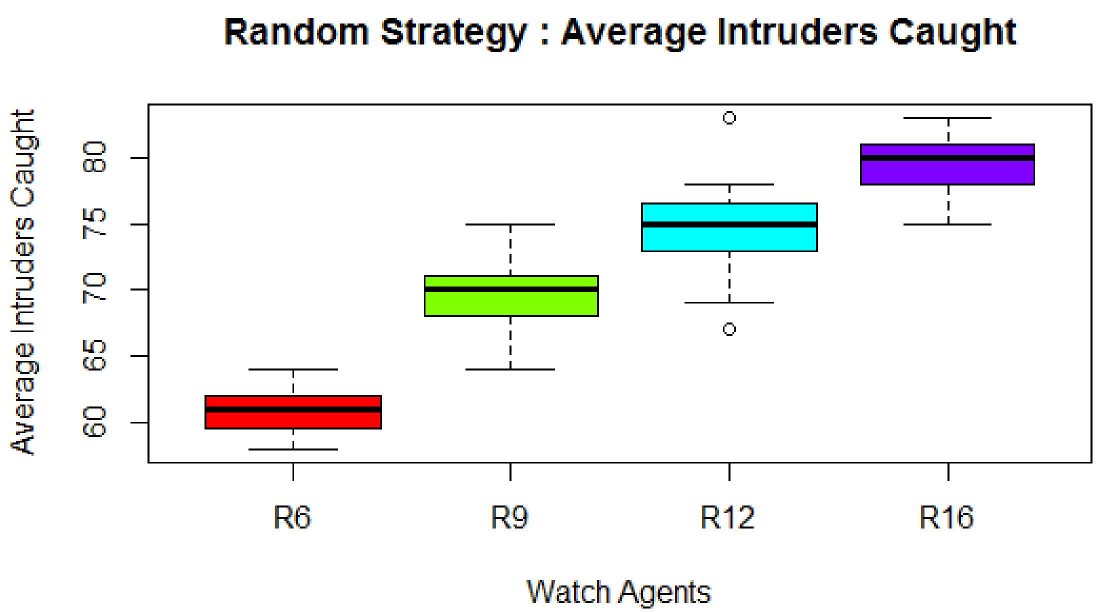

Figure 5.1: Random Strategy Average Intruders Caught

Linear Strategy

In Linear strategy UAVs are placed linearly in two rows and perform surveillance in its own area. Result is shown in figure 5.2

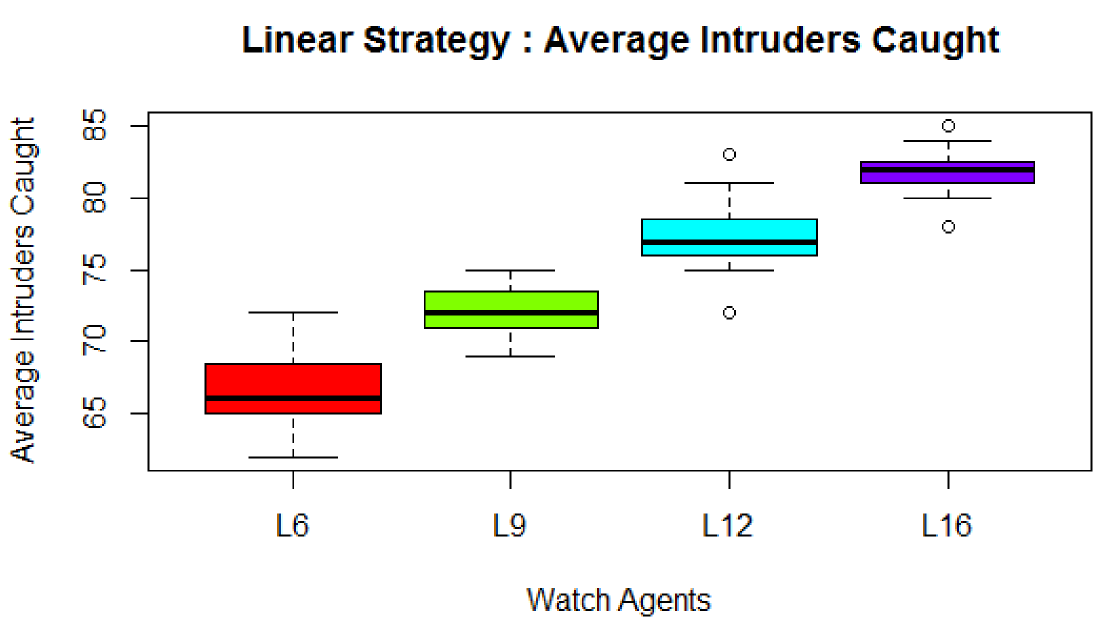

Figure 5.2: Linear Strategy Average Intruders Caught

Local Communication Coverage Strategy

In this strategy the surveillance area is divided in $C_n \times R_n$ matrix form where C_n are columns and R_n are rows. Watch agents are placed in center of its provided cell and perform surveillance in that cell. In this strategy communication among the agents is local i-e each agent communicate with its neighbor agent to convey message to all team members. Results are depicted in figure 5.3

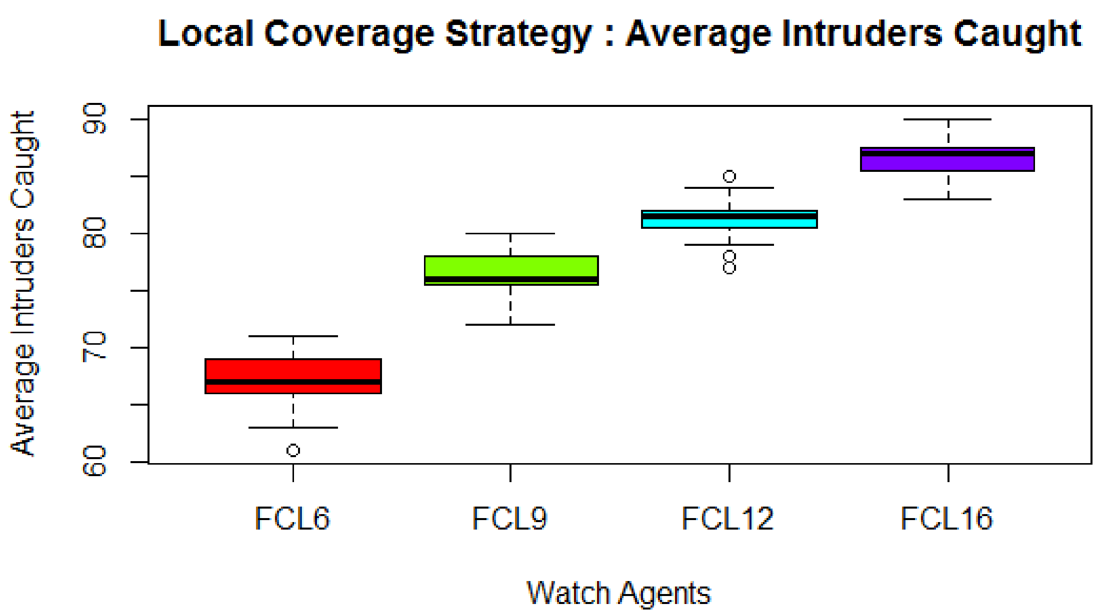

Figure 5.3: Local Communication Average Intruders Caught

Global Communication Coverage Strategy

In this strategy each agent gets area for surveillance as in Local coverage strategy. Communication among agents in this strategy is global i-e each agent communicate directly with all team members. Results are shown in figure 5.4

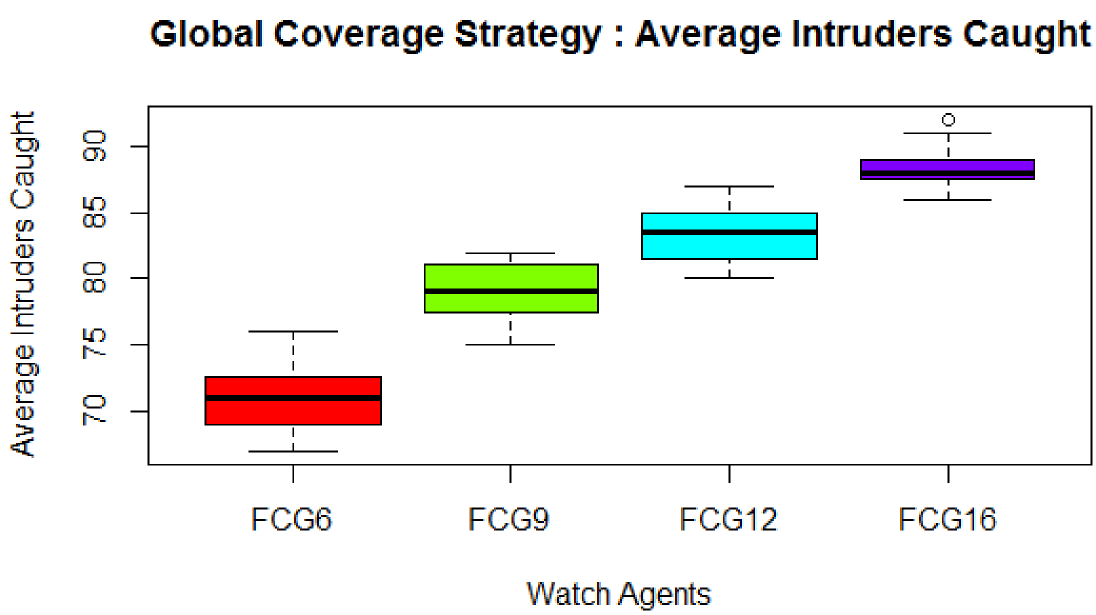

Figure 5.4: Global Communication Average Intruders Caught

Different strategy effect on the surveillance performance

Results analyzed of different strategies with same data set are different. UAVs initial placement and coverage area has great impact on the surveillance performance of UAVs team.

Data set 1:All Strategies

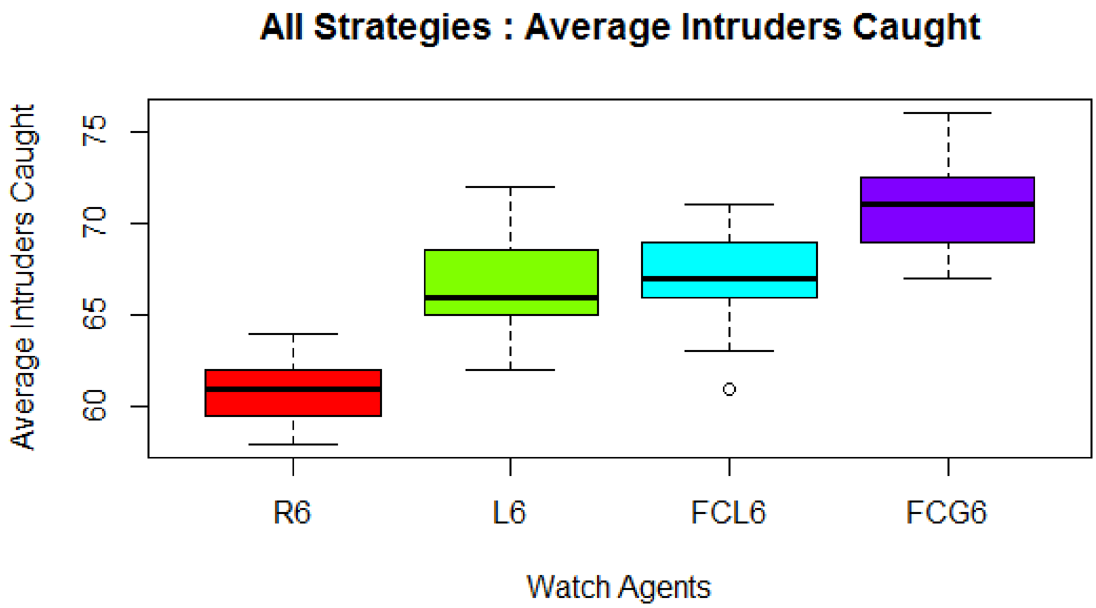

Figure 5.5: Team size 6 Average Intruders Caught

Data set 2:All Strategies

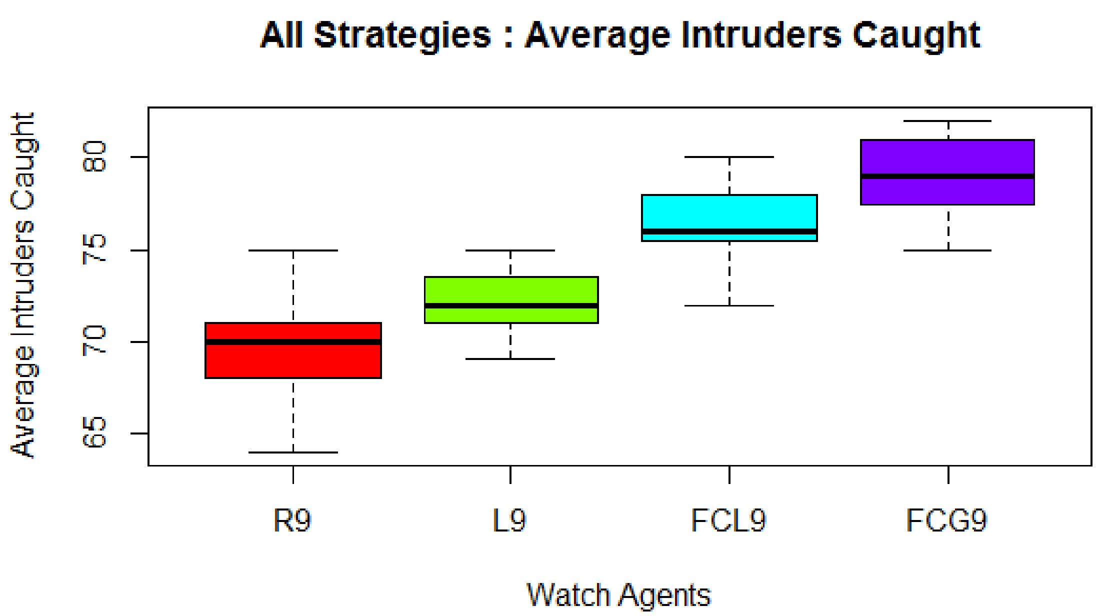

Figure 5.6: Team size 9 Average Intruders Caught

Data set 3:All Strategies

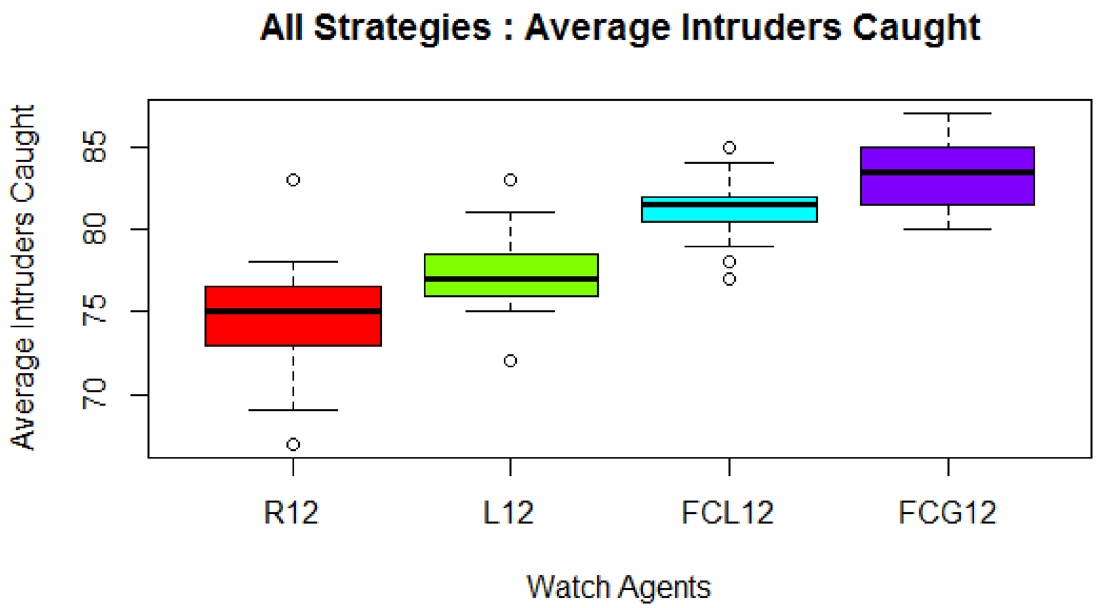

Figure 5.7: Team size 12 Average Intruders Caught

Data set 4:All Strategies

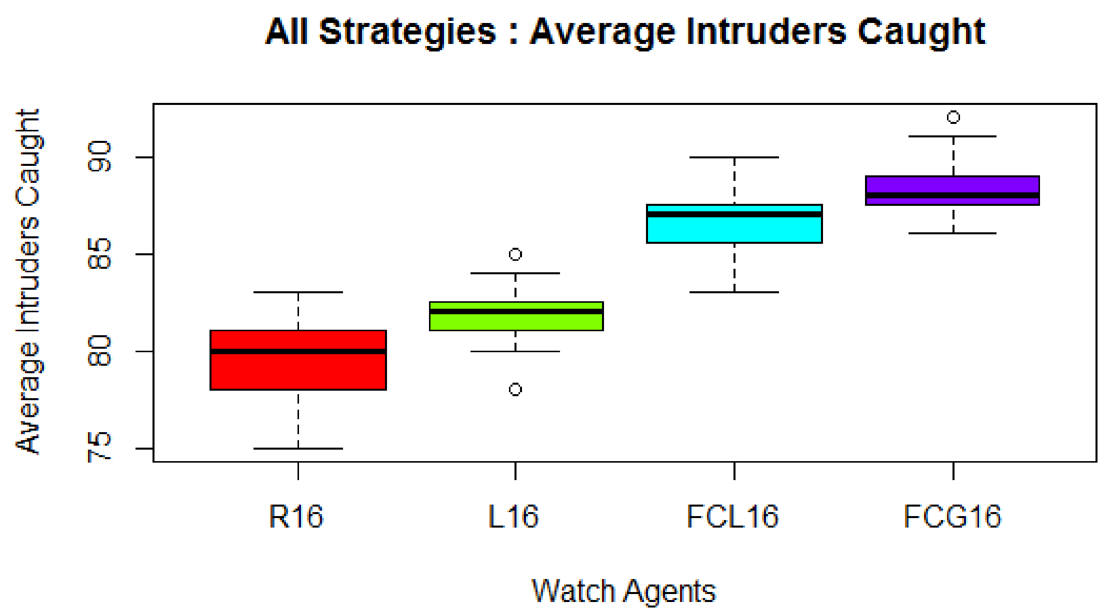

Figure 5.8: Team size 16 Average Intruders Caught

Simulations are carried out on four different team size. Results of team size performance is given in fig 5.9. Surveillance performance also increases as the team size increases. The

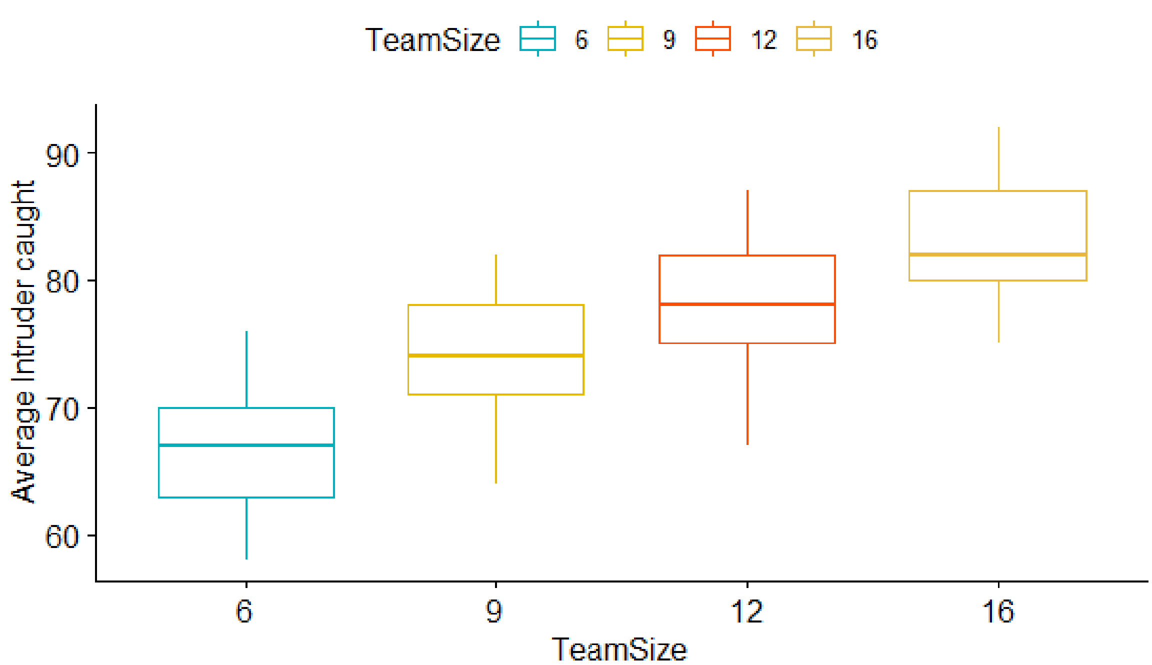

Figure 5.9: All Team Size Average Intruders Caught

mean and standard deviation values with respect to different team size in all strategies is

Table 5.1: Mean Values

Factors		Missions	Mean Value	Standard deviation
Team Size	6	120	66.5	4.47
	9	120	74.6	4.29
	12	120	78.7	4.45
	16	120	83.2	4.04

given in table 5.1. The F value and Pr value with respect to team size is given in table 5.2. Probability value (Pr) of team size is less than $Fvalue$, that depicts that team size greatly effects the surveillance performance.

Table 5.2: Results F value

Factors	Df	Sum sq	Mean sq	F value	Pr(>F)
Team Size	3	18156	6052	325	<2e-16

5.1.2 Experiment:2

This experiment results are analyzed to show the effect of surveillance performance of UAVs with re-fueling on and off along with the difference in strategies. Results of linear, random and full coverage strategies are compared. Results shows significant effect on surveillance by differing the strategies. The full coverage results are better as compared to random and linear strategies. From fig 5.10, it's shown that the performance of full coverage is clearly different from linear and random allocation strategies. Surveillance performance also increases as the team size increases. The mean and standard deviation values with respect to different strategies and refueling on/off are given in table 5.3

The effect of refueling on/off is low as shown in table 5.3 because in refueling on if an agent goes for refueling its area is divided among the available agents. So the efficiency is maintained.

Table 5.3: Mean Values

Factors		Missions	Mean Value	Standard deviation
Strategy	Full Coverage	160	80.4	6.64
	Linear	160	75.4	5.89
	Random	160	71.4	7.04
Refueling	On	240	75.9	7.44
	Off	240	75.6	7.59

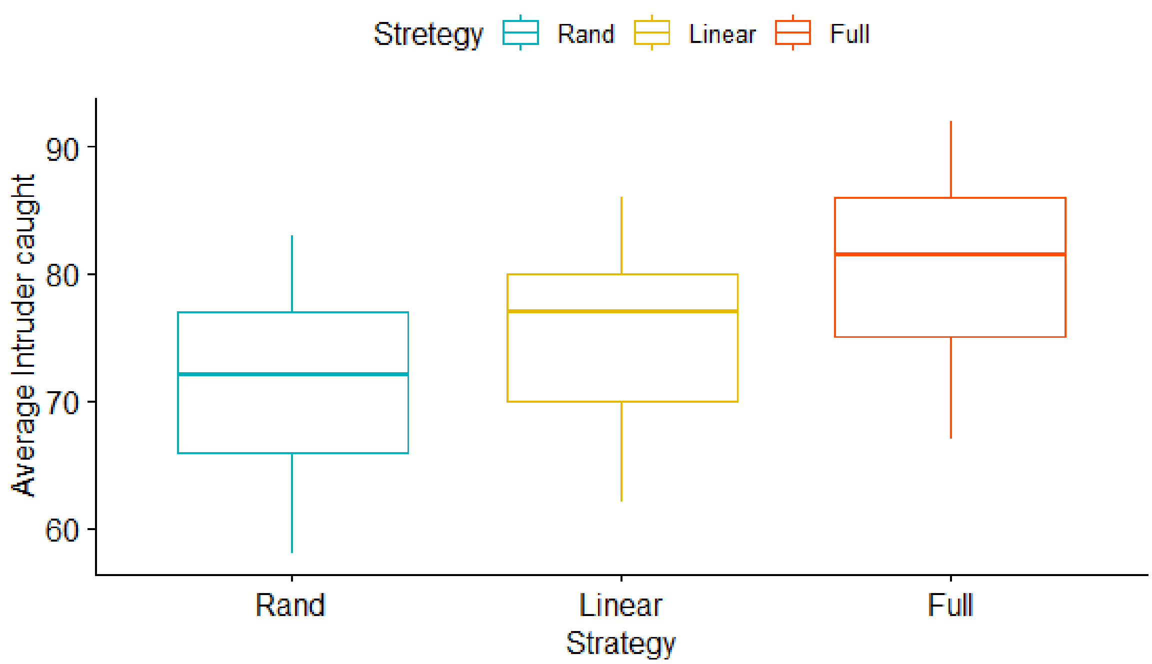

Figure 5.10: All Strategies Average Intruders Caught

The F value and Pr value with respect to strategy, team size and refueling is given in table 5.4. Probability value (Pr) of team size and strategy type is less than $Fvalue$, that depicts that team size and strategy type greatly effects the surveillance performance.

Table 5.4: Results F value

Factors	Df	Sum sq	Mean sq	F value	Pr(>F)
Refueling	1	8	8.27	0.146	0.702
Strategy	2	6627	3314	77.51	<2e-16

5.1.3 Experiment:3

In this experiment results of linear and full coverage strategy with local and global communication constraints are analyzed. The result shows very little difference in local and global communication constraints. The communication constraints can be better analyzed by adding real time communication. Results are depicted in fig 5.11. Mean and standard deviation of communication constraints on linear and full coverage strategy are given in table 5.5 The probability value Pr for communication is $Pr(> F) = 0.053$ and the F value is 3.773.

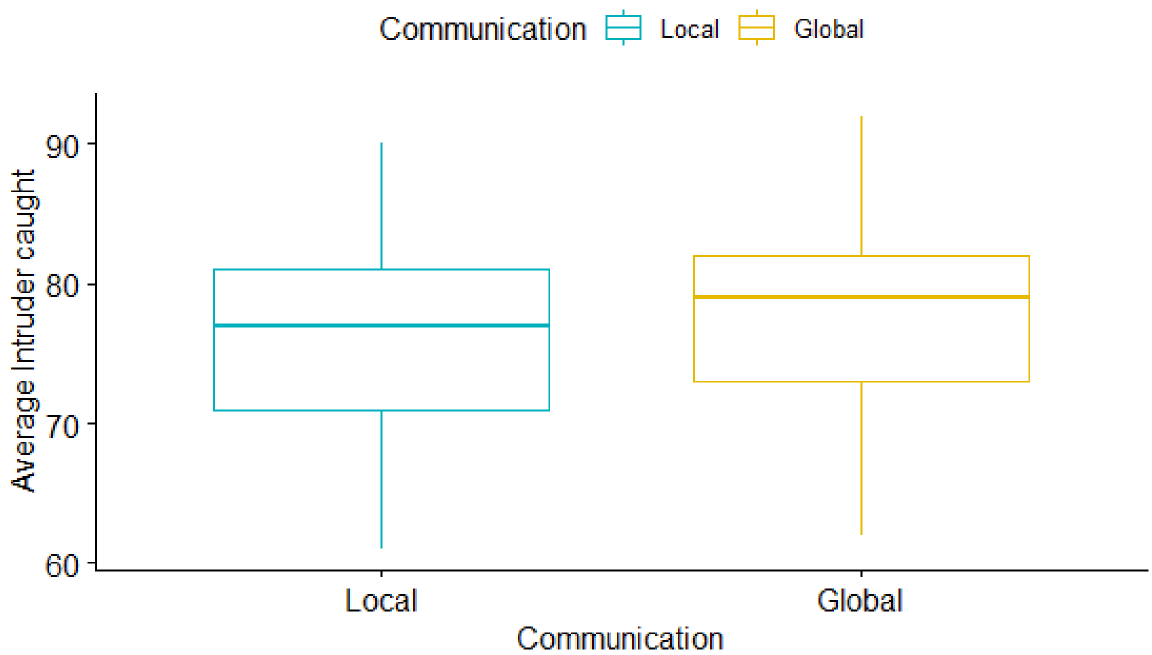

Figure 5.11: Communication local/global Average Intruders Caught

Table 5.5: Communication Constraints result

Constraints	Missions	Mean value	Standard deviation
Local	160	76.4	6.57
Global	160	77.8	6.67

5.1.4 Experiment:4

In experiment 4 the result data of linear and full coverage strategy with cooperation on and off is analyzed. Cooperation on means that the agents can cooperate with each other. When an agent goes for refueling it informs others to take care of its area too. In cooperation off, the agents do not communicate with each other. If an agent goes for refueling, its area is not covered by other agents. The results are depicted in fig 5.12. Cooperation on and off has great affect when the agents available are limited. As team size increases the effect decreases gradually. The mean value of cooperation on and off is given in table 5.6 P value

Table 5.6: Cooperation on/off

Cooperation	Missions	Mean value	Standard deviation
On	160	77.8	6.67
Off	160	76.2	6.88

for cooperation on and off is 0.0302 and $F = 4.742$.

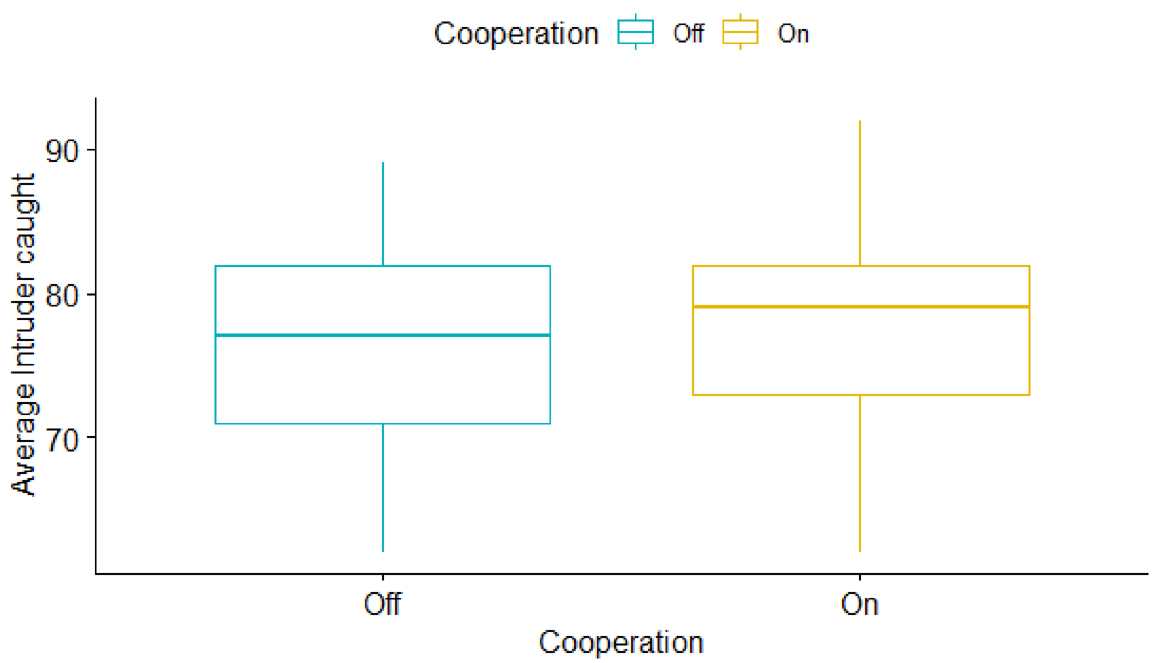

Figure 5.12: Cooperation On/Off Average Intruders Caught

Chapter 6

CONCLUSION AND FUTURE WORK

Different Strategies are proposed for surveillance of a given area. The strategies implemented different performance parameters such as flying time (fuel), Camera (sensors), Communication Channel, Initial Placement, Communication Mechanism. The Global communication full coverage algorithm provides best results. The results of global communication coverage algorithm are compared with linear and random placement algorithm. Different strategies for path planning and localization and tracking of target can be used such as minimum spanning tree. We present a system level view of the surveillance system and provide overall system level performance using multiple cooperative UAVs. The result shows that better initial placement and better allocation of area to multiple UAVs results in better performance. So the performance parameters that affect the performance of the whole system that includes multiple cooperative UAVs are the placement of UAVs, their flying time that is directly proportional to fuel, Sensor capability and Cooperation among the UAVs.
Future direction will be to further enhance this global communication full coverage algorithm by

- Using most unvisited area first algorithm for each UAV in its specific surveillance area. A UAV surveying in its area should equally survey the area, i: e to enhance that UAV visit all the area and no portion of the surveillance area is left unvisited.
- The UAV surveying in its area can improve the resource efficiency by not moving to the area where its field of view (FOV) captures area that is outside of its scope.
- As this algorithm is simulated, real time implementation of this algorithm will further improve this algorithm.
- Addition of mid and low level controls.
- Addition of obstacles e.g urban environment.

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