A Conceptual Framework of Starlings Swarm Intelligence Intrusion Prevention for Software Defined Networks

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1 Introduction

The idea of using the defense mechanism observed in some bird species such as starlings has not yet been exploited in the development of Intrusion Prevention Systems (IPS). Starlings are self-organized with a characteristic of collective response. Starlings as prey have a way of detecting single or multiple predatory attacks and responding to danger that may be visible to only a small fraction of individuals in the flock [1]. The ability of starlings to evade predators is associated with several factors, including murmuration, collective response and confusion effect. These factors are detailed as follows: (1) Murmuration: this is a phenomenon that hampers predation success [2]. It follows three simple rules, namely cohesion, alignment, and separation; other rules include predator avoidance and flee behaviour [3]. (2) Collective response: this is the way the whole group responds to its environment. For gregarious animals under strong predatory pressure collective response is vital and in fact it is the hallmark of self-organized order as opposed to centralized order [4]. (3) Confusion Effect: this is a phenomenon describing that decreasing predator attack success is associated with increasing prey group size in the eye of the predator. Benedict *et al* [5] used a computer game style experiment to investigate the confusion effect in three-dimensions, but the authors used human predators to track and capture a target starling. In this research we conducted a similar experiment in two-dimensions with both prey and predator simulated instead of (human) predator to further investigate the confusion effect and collective response.

2 Research Questions

- What are the essential features of starlings that reduce success rate of predators on them?
- Can these features be adapted to develop a framework for Software Defined Network Security?
- Can the starlings attack evasion feature inform an algorithm for intrusion prevention in Software Defined Networks?
- How best can this algorithm be implemented and evaluated?

3 Related Work

Bio-inspired approaches have proved effective as artificial alternatives in mitigating the deficiencies of conventional models in areas such as robotics, optimization problems, classification, computer security and prediction [7]. Inherent to their self-organisation and adaptive capabilities, bio-inspired approaches are generally suitable for robust platforms design.

Predator-prey systems (PPS) demonstrate complex relationships and interactions between entities in which one depends on the other for food and protection [8]. Current research on the predator-prey domain on one hand seeks to explore the importance of behavioural and interaction attributes between two entities and their implications. On the other hand, it focuses on functions of individual depending on attributes within them. The former concerns evolution; how biological systems change and adapt in time, for example the kinetochore system's ability to learn and memorise new information, typified in organic self-organisation and individual diversity [9]. In contrast, the latter relates to exploring the dynamics in entities within a biological system, including how they associate. Through extreme and diverse living environments, animals in nature have developed equally extreme and diverse defense mechanism through adaptation and collective response, to ensure their continued survival.

4 Computational Modeling

Simulation was carried out in 2D, by means of processing jar library [1], Version 3.2 with Java NetBeans Integrated Development Environment (IDE). Experiments were conducted with 100 starlings and one predator (peregrine falcon). Collective response was simulated following [6], and the confusion effect was simulated following [1]. Here, we encode certain information in each starling that enable it detect a predator and transmit that encoded information with neighbours within its euclidean distance. When these neighbours receive such information (i.e. location and velocity), they calculate the location of the bird under predator attack and re-compute their speed and change it from $murmuration\_speed\ to\ confuse\_speed$, and move in the direction and location of the birds with the distress call. By doing so the starlings become too many in the eye of the predator, thus, confusing the predator. The speed of the birds depicted their fitness which followed a log normal distribution Equations as in [10]. Each Starling could identify its friends (nearest neighbours) and the predator, and they can respond to attack situations. Once an individual starling detects a predator it flees and if in danger of attack, it alerts neighbours within its topological range, which triggers collective response and confusion effect. There are two prompters to the speed of the starlings: $confusion\_speed = starlingsMeanSpeed * (n+1)$, where $starlingsMeanSpeed$ represents average of

[1] https://processing.org/download/

the normalized speed of the starlings population and n represents a factor that increase the $starlingsMeanSpeed$ and $murmuration\_speed = starlingsMeanSpeed$. The $confusion\_speed$ is an incentive through which the starlings acquire a certain speed due to predator attack. Once the danger is eliminated or contained the starlings revert to $murmuration\_speed$.

5 Result Analysis

First question: What is the extent to which confusion effect reduces predator attack success rate?

Ten different experiments were carried out using different parameters in ten trials, each of which has twenty attacks ($Figure$ 1) and we tuned the parameters of starlings interaction and adaptation to an attack situation (confusion-effect) to optimal values. These are: global scale, neighbourhood radius, crowd radius, avoidance radius, cohesion radius, separation radius, predator radius, eat radius, catch radius, starlings speed, predator speed and we ran ten experiments, as shown in $Figure$ 1. Also, we set our starlings speed to follow a log-normal distribution with 2 standard deviation of their mean speed. The decision to use log normal distribution is based on the study by Eastwood *et al* [10], where the authors postulate the radar ring angle phenomenon, and proved that these rings were produced by the dispersal of starlings from their roost at sunrise and showed that the time interval between such departure waves varies in accordance with a log-normal distribution. The value on each bar is the average number of successful attack in each ten trials.

The error bars define variability in the experiments which we attribute to: physical fitness of the individual bird, daily form of the bird and current wind speed.

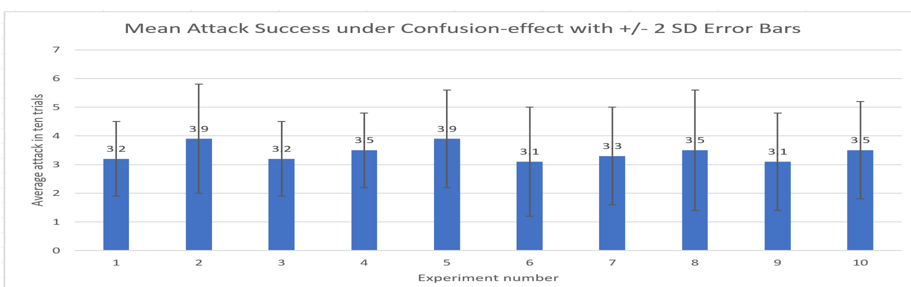


Fig. 1. 17% success of predator attack with confusion-effect.

From $Figure$ 1, we infer that there is a strong evidence that the results of our simulation is consistent because, the error bars of the ten experiments overlap and almost all the overlap includes the mean of the error bars, which is a strong evidence that the results of our experiment (i.e. success rate due to confusion effect) is consistent. Therefore, we compute predator attack success rate as:

$$S = \frac{m}{a} * 100\%, \tag{1}$$

where S denotes success in predator attack, m denotes the mean number of attacks from the average values of ten different trials, and a denotes the average number of attacks.

Based on the results, we identified that confusion effect reduced the success rate of predation by about 85% in starlings simulation with Standard Error of the Mean (SEM) = 0.297. In comparison, if a predator has 17% success rate in twenty attempts, a predator (i.e. peregrine falcon) will have a 0.85% success rate in a single attempt to capture a starling in a swarm, in a ratio of one to twenty.

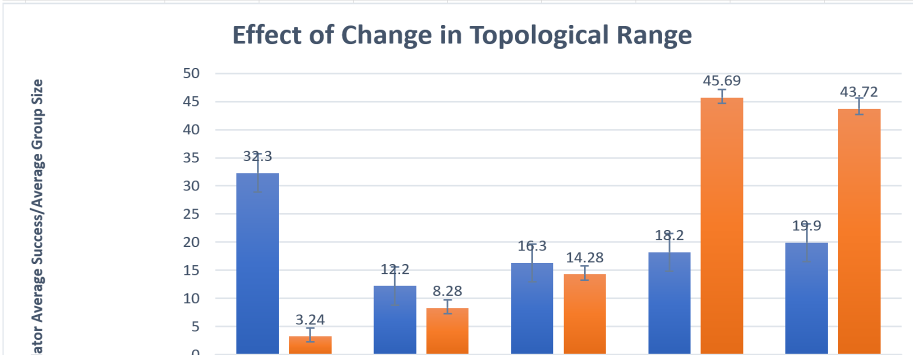
Second question: is there an optimal neighbourhood radius at which the confusion effect is more effective in reducing predator success rate and starlings conserve energy?

Five different experiments were carried out using different parameters in ten trials, each of which last for five minutes as shown in $Figure$ 2 using different radii to set the topological range of the swarm. We used connectivity (graph theory) to know the average group size within the starlings at each draw during the experiment, and this enabled us to find the number of successful predator attacks and the corresponding neighbourhood size. See $Figure$ 2 for more details.

The result shows the average predator success rate with corresponding neighbourhood size at each radius. The error bars on the average predator success shows the variability in the average success (SD) while those on the neighbourhood size shows the precision of the group size (SEM). Results in $Figure$ 2 shows that there is an optimal neighbourhood size through which starlings can effectively confuse the predator without dissipating much energy ($Figure$ 2). This size is observed to be between seven and fourteen, which is the number that starlings use in keeping update with the entire swarm. Therefore, we conclude that there is a positive correlation between the optimal neighbourhood size and the confusion effect and that this relationship contributes to reducing predation success rate.

6 Conclusion and Future Work

In conclusion, this research presents an in depth investigation of the starlings murmuration and defence mechanisms particularly the confusion effect through computer simulation. We have discovered novel underlying information such as



	100	200	300	400	500
success	32.3	12.2	16.3	18.2	19.9
average sub-group size	3.24	8.28	14.28	45.69	43.72

Fig. 2. Showing optimal topological range enough to effectively confuse a predator and conserve energy

the positive correlation between group size and neighbourhood radii, the rate at which confusion effect contribute to reduced predator success rate.

Further to this research, we will develop a meta-heuristic algorithm and set up an experiment using virtual environment to identify the network attacks that can best be mitigated using the algorithm to validate the performance of our intrusion prevention framework for Software Defined Networks.

Software-Defined Network (SDN) is a new and emerging area that promises to change the way networks are designed, build and operated. It is a paradigm shift from the traditional network architecture that is proprietary to a non proprietary, simple and programmable network architecture. [2]

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