AC/DC: Autonomic Computing to Maintain Drone Fleet Continuity

Fiachra Merwick, Roy Sterritt
Ulster University
Belfast, Northern Ireland
email: fiachra.merwick@gmail.com
| r.sterritt@ulster.ac.uk

***Abstract*— This paper aims to review the current state of the art of autonomic computing as it relates to the management of a fleet of drones being used for surveillance. Drones, for the purposes of this paper, refer to unmanned aerial vehicles that incorporate sensors for autonomous detection and surveillance. As economies of scale and improvements in the technology continue to materialize, fleets of drones become a viable commercial option to perform surveillance. In order to ensure self-management of these complete systems, an architecture is proposed to ensure the self-Configuring, Healing, Optimizing and Protection (self-CHOP) properties of the system are realized. The theoretical implementation of this autonomic computing solution is then discussed with respect to both its advantages and ethical implications.**

Keywords—Autonomic Computing; UAV; swarm; self-management.

I. Introduction

Autonomic Computing is a term originally derived and proposed by IBM in 2001, which describes the area of self-governing systems [1]. It has been compared with some biological functions of the human body which are essentially self-managed, not requiring conscious thought, such as the nervous system which self regulates the body [2]. As the predicted increase in complexity of computer systems would far outweigh the number of operators required to maintain them at that time, it was imperative to develop a discipline of computing whereby the systems would manage themselves to a certain degree, often occurring in the background unbeknownst to both the user and the operator [3]. This initial concept gave rise to the idea of the CHOP properties, which defines self-managing systems as being self–configuring, self-healing, self-optimising and self-protecting [4]. The self in this instance refers to the information system [5].

Recent improvements in drone technology, or more specifically Unmanned Aerial Vehicles (UAVs), which incorporate autonomous flight capabilities, have led to the ability to deploy UAVs in commercial settings for surveillance purposes [6]. There are still many hurdles to overcome with respect to the technology, however, incorporating a fleet of UAVs will become increasingly commercially viable as the technology scales and the scope of work/area of surveillance increases [7].

One distinction that is important to make is the difference between the terms autonomous and autonomic. Although IBM initially described Autonomic computing as self-governing [1], a more recent distinction between autonomy and autonomicity is that autonomy is self-governing and autonomicity is self-managing. Self-governing relates to the “delegation of responsibility to the system to meet the defined goals of the system (automation of responsibility including some decision making for the success of tasks), whereas autonomicity is system self-management (automation of responsibility including some decision making for the successful operation of the system)” [8].

Surveillance systems using UAV technology have the advantage of being adaptive with respect to automation for both flight controls, altering coverage and improving flight efficiency, as well as the object or risk detection models used to power the sensing portion of the system. This is particularly important where surveillance is used as a deterrent to criminal activity or threats, as individuals that pose the threat may adapt to the safeguards put in place, thus there is more scope to keep up with any potential changes in the behaviour of those that pose the threat.

The main objectives of this paper are to:

- Identify the current state of the art in UAV surveillance technology.
- Outline requirements of an autonomic system as it relates to a surveillance system comprising of multiple UAV’s.
- Propose an autonomic solution to ensure appropriate self-management as fleets of UAV’s begin to scale.
- Consider both the suitability and ethical implications of this proposal.

The format of the remainder of this paper is organised in the following manner: Section 2 details previous work carried out relating to the development and use of autonomic computing, focussing on its use in multi agent systems. Section 3 introduces an architecture that could be implemented to ensure self-management of the system. Section 4 discusses the results and provides a conclusion to the study.

II. Related Work

A. *Autonomic Computing*

A self-managing or autonomic system is summarised in [9] by four general properties, which include both objectives and attributes. The objectives of the system are to be self-configuring, self-healing, self-optimising and self-protecting. The attributes help to define the implementation of the system in order to achieve the objectives and can be categorised as self-aware, self-situated, self-monitoring and self-adjusting [10]. This is represented as a quality tree presented in Figure 1 and accurately captures the elements of autonomic computing [10].

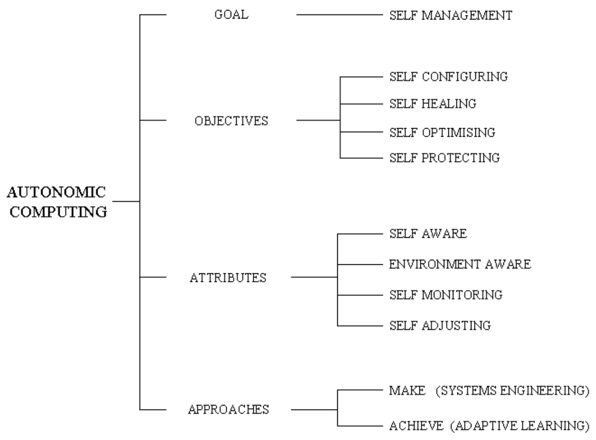

Figure 1. Autonomic Computing Tree [10].

a) Self-Configuring

This can be described as the system's ability to "automatically install, configure or integrate new software components" [10] or more simply, the ability to "readjust itself automatically" [9].

b) Self-Healing

This is the ability of the system to recover from a fault, including identifying the fault and repairing it where possible.

c) Self-Optimisation

This is the system's ability to improve its performance against its ideal performance, which is known by the system, by measuring its current performance and implementing policies that attempt to improve it.

d) Self-Protecting

The system will have awareness of potential threats and will defend itself from these threats, whether they be accidental or malicious in nature.

The autonomic element, shown in Figure 2, is a control loop that manages the self-monitoring of a system, which was coined as MAPE by IBM. This refers to the functions of Monitoring, Analyzing, Planning and Executing [11]. The autonomic managers also communicate with each other using a reflex signal, which ensures the robustness of the system.

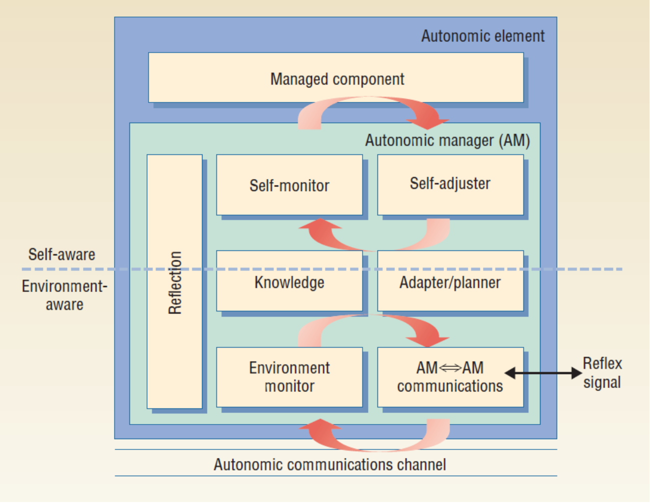

Figure 2. Control loops in an autonomic element [11].

B. Heartbeat Monitoring

The reflex signal, introduced in the previous paragraph, is a crucial element in the design of autonomic systems and heartbeat monitoring can enable achieving this. It is noted in [4] that there is a facility designed within Grid computing to detect and report on whether processes are still alive. The idea behind heartbeat monitoring is that a process or agent within a system continuously broadcasts a signal to indicate its health.

The important aspect of heartbeat monitoring is that it reduces the amount of data sent by an agent or process, by just transmitting a simple signal. It is only in the absence of receiving this signal that the reflex signal then performs more complex tasks and more detailed information can be sent [11].

Ultimately, this can then be used to ensure the self-CHOP objectives can be met by the system.

C. UAVs

The concept of a large fleet of UAV's operating autonomously and self-managing using autonomic computing methods with a surveillance objective as topic for investigation was inspired by research carried out for NASA on the use of swarms for future missions, where a swarm describes a "large number of simple entities that have local interactions (including interactions with the environment)" [12].

The limitations in the use of induvial UAVs are highlighted in [13], noting the limited battery life and field of view and suggests a swarm of UAVs working in collaboration with each other as a sustainable solution. It is quite evident from recent studies that the main stakeholders when it comes to swarm technology for surveillance are world militaries [14], [15], [16]. This raises some ethical concerns with respect to the development and improvement of the technology.

In a review of communication architectures for swarms of UAV's by [17], autonomic computing, as per the goals, objectives and attributes outlined in Figure 1, is not referred to specifically, and is not encompassed by the architectures; however, many aspects of autonomic computing are considered.

A more robust autonomic computing approach to communication between multiple agents is taken by [18], where computer vision is the primary method of communication using optical character recognition.

The following section attempts to improve on the swarm communication architecture by implementing an autonomic computing approach, inspired by [18], with due consideration to each aspect of the system goals.

III. AC/DC Architecture

A comprehensive review of UAV swarm communication architectures is provided in [17]. The "Single-Group Swarm Ad hoc Network" architecture is used as the baseline architecture in this proposal and will be enhanced using lessons learned from [18]. A schematic of the infrastructure is shown in Figure 3, where U-T-U stands for UAV-to-UAV communication and U-T-I stands for UAV to base infrastructure communication.

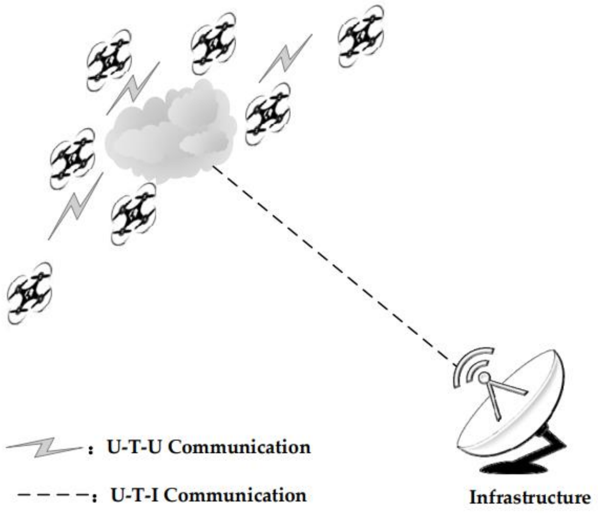

Figure 3. Single-Group Swarm Ad hoc Network architecture [17].

In a "single-group swarm Ad hoc network", there is no dependence on the base station infrastructure providing communication to all UAVs, therefore eliminating a single point of failure in the system. At any given instant, the closest UAV to the base station infrastructure, known as the "gateway UAV" sends and receives information at high power, with only low power transmission being required to transmit and receive information between the remaining UAVs.

Although "UAVs in the swarm can share situation information in real time to optimize collaborative control and improve efficiency" [17], loss of the gateway UAV may constitute a single point of failure if the loss is not managed appropriately, and this is where an autonomic solution fits in perfectly to maintain the continuous deployment of the swarm without human intervention. This is due to the fact that the gateway UAV contains additional transceivers to allow it to communicate at high power to the base station infrastructure.

An enhancement is proposed for this infrastructure by including heartbeat monitoring, similar to that described in [11] [18]. Autonomic elements, as per Figure 2, will be incorporated in each individual UAV of the swarm, as well as the base station infrastructure.

The concept is that each UAV in the swarm will be emitting an "*I am alive*" signal. This will be received by both surrounding UAVs using the U-T-U communication and by the base station infrastructure using the U-T-I communication, for the UAV sending the high-power transmission. If this signal is not received at any instance, then an algorithm, as specified in Figure 4, will be executed.

```
Swarm autonomously performing surveillance of environment
if "I am Alive" signal not received then
    Determine last known GPS position
    Closest UAV to the GPS position self identifies
    Closest UAV moves to within imaging range of the gps position
    Closest UAV runs computer vision algorithm for detection of obstacles and UAVs
        If unexpected objects found by computer vision then
            Relay signal to reconfigure the route planner for the swarm
        Elsif threat is identified by computer vision then
            Relay signal to reconfigure the route planner for the swarm
            Report threat findings to base station operator
            Endif
        If lost UAV found by computer vision then
            Send communication of updated GPS location and video for recovery team
        Endif
    If signal received by base station then
        Dispatch new Gateway UAV to replace lost UAV
        Establish new connection between the gateway UAV and the swarm and base station
    Else
        Dispatch generic UAV to replace the lost UAV
    Endif
Endif
```

Figure 4. Proposed algorithm for reflex signal, inspired by [18].

The successful implementation of this algorithm will rely on the swarm of UAVs and the base station operating as autonomic managers and it aims to:

1) *Dispatch a new UAV:* This will ensure self-healing of the system is achieved, specifically addressing the issue of gateway UAV loss and re-establishing the connection between the swarm and the base station infrastructure.

2) *Send the closest UAV by GPS position:* This is carrreid out to monitor the location of the lost UAV and identify any obstacles or threats and the location of the lost UAV. This ensures the system achieves the self-protection objective, if threats or new obstacls do exist.

3) *If applicable, update the routing plan for the swarm:* Based on the findings from point 2, this aspect will help achieve the self-configuration and self-optimisation of the autonomic system by ensuring repetition of the UAV loss will not occur due to spacial or external threats.

4) *If applicable, send information on lost UAV:* Also, based on the findings from point 2, this aspect will help achieve self-healing to a degree, although the underlying motivation for the execution of this procedure is for an operator to use this data for physical retrieval and inspection of the site of the loss.

IV. CONCLUSION & FUTURE WORK

The proposed autonomic solution is an enhancement to the current state of the art of UAV swarm communication technology, as informed by the reviewed literature. The main advantage of incorporating an autonomous computing element to the swarm architecture is ensuring self-configuration and self-healing of the system, particularly in the case where the gateway UAV is lost.

The heartbeat reflex signal methodology is a good fit for the autonomic elements of this architecture, as it is imperative for UAVs to consume as little power as possible and a simple signal achieves that requirement. The result of the implementation, which achieves the self-CHOP objectives, will be UAV swarms operating without operator intervention, for the most part, though it is noted that the physical nature of robotic swarms will always require some physical involvement.

Although this enhancement will improve upon swarm route optimisation and threat avoidance, a real ethical concern is raised, as military usage of these swarms is inevitable. It is difficult to state, prior to implementation, if this could be used purely defensively, or offensively also. However, it is clear from both the research carried out and the reasons behind implementation of the autonomic elements of the system, such as healing due to loss of UAVs and optimisation after identification of threats to the system, that military use is the use case that would ultimately benefit the most.

Autonomic computing and its implementation in systems is not as widely known or publicised as autonomous implementations, however it is clear from the research carried out for this paper and the potential implication of the implementation of the proposal in this paper, that without autonomic computing, the autonomous algorithms may be rendered useless.

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