Achieving energy efficiency in UAVs using Ant Colony Optimization

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Abstract – UAVs are used extensively in many applications such as surveillance, security, drones and weather forecasting etc. An operational UAV has a major bottleneck as it is operated by battery. As the battery of a UAV gets consumed the device stops working. A major chunk of UAV battery gets consumed in data transmission process in a network of UAVs. In this work, we propose a novel data routing algorithm using artificial intelligence algorithm any colony optimization that minimizes the transmission distance through which a UAV sends its data. This efficient routing protocol maps the behaviour of ants in ACO and finds the optimum route for UAV data transmission. Results of the proposed work are compared with genetic algorithm bases UAV data transmission and simple UAV data transmission. The proposed algorithm performs better than the past works.

Keywords – UAV, Data transmission, ACO, energy efficiency.

I. INTRODUCTION. In recent years, collaborative unmanned aerial vehicles (UAVs) are used in many civilian and military fields such as search and rescue missions, border surveillance, aerial mapping, agricultural imaging, and so on [1]. In this context, growing interest is being paid to the necessity of UAVs' autonomy in terms of navigation as well as in terms of energy, especially when acting in complex environments, both indoors and outdoors. Given a wide and open outdoor area, where the satellite signal is well received, the use of GPS is sufficient to ensure the autonomous safe navigation of the UAV. However, in many scenarios such as urban monitoring in bad weather conditions, the GPS signal could be totally absent (indoors) or insufficient due to different causes such as multipath fading and jamming. In such situations, alternative soft and/ or hardware solutions should be proposed in order to ensure reliable positioning for the UAVs [2]. In addition to the positioning autonomy of UAVs, the limited capabality of UAVs in terms of computing makes the preservation of energy an important challenge. The use of low-altitude and high-mobility unmanned aerial vehicles (UAVs) for assisting wireless communications has received significant research interests recently [1]. Compared to the traditional terrestrial communications that mostly rely on ground communication infrastructures such as base stations (BSs), UAV-assisted communications have lower cost and several other promising advantages. Firstly, due to the high mobility of UAVs, UAV-assisted communication systems are more swift and flexible for deployment, which makes them especially suitable for on-demand applications or unexpected events. Secondly, compared to the ground-to-ground links in terrestrial systems, the UAV-ground link is more likely to have line-of-sight (LoS) channels, and thus offers higher linkcapacity. Furthermore, UAV-assisted communications provide an additional design degree of freedom for performance improvement, via dynamically optimizing the UAV locations to best suit the communication requirement. As a result, UAV-assisted communications are expected to play an important role in future wireless systems, with various emerging applications such as cellular data offloading [2], [3], mobile BSs [4], [5], mobile relaying [6], information dissemination and data collection to/from infrastructure-less ground terminals Unmanned aerial vehicles (UAVs), or drones, have recently attracted a wide interest for various public, commercial, and industrial applications due to their versatility [1]. Their integration with wireless and mobile networks is expected to bring very high spectral efficiency and offer innovative solutions to solve many communication challenges, particularly for future 5G networks [2]. The rapid and dynamic deployment of UAVs and their reliable line-of-sight (LoS) communication links are the main advantages of UAV-based communications. As a result, this technology is expected provide broa dBand access to remote and inaccessible areas, e.g., areas affected by natural disasters. Also, UAVs will help in facing unexpected congestion situations by providing wireless access for limited time periods such as sports events. Moreover, UAVs can be used for the dispersion, relaying, and collection of data
to and from multiple other ground and flying devices, e.g., communicating with ground sensors and other UAVs However, UAV-based communication is also facing several challenges that should be addressed to ensure their effective
application [3]. One of these challenges is the limited energy availability [4]. In fact, the energy consumption of these battery-powered flying units is usually split into an energy consumed by the communication platform and the energy used for the drone hardware and mobility. Hence, it is important to efficiently manage the available energy for both components in order to save it and hence, extend the UAV operation time before draining its battery. For instance, multiple works in
the literature studied the optimal UAV placement that maximizes its performance [5]. Another challenge of deploying UAVs is the spectrum scarcity. Traditionally, UAVs operate at bands that are permanently exploited by other wireless technologies such as the IEEE S-Band, IEEE L Band and on Industrial, Scientific and Medical (ISM) band [6]. These bands are becoming more and more overcrowded which makes the UAVs suffer from interference caused by the users and vice versa. Hence, cognitive radio (CR) technology for UAV-based communications has been proposed as a potential solution to cope with spectrum congestion in UAV applications [7]–[9]. A structure of UAV routing is shown in figure 1.

II. SYSTEM MODEL AND UAV ENERGY EFFICIENCY

A. System Model As shown in Fig. 1 (a), we consider a wireless communication system where a UAV is employed to send information to a GT. In practice, wireless communication using only one single UAV is relevant in many scenarios. For example, for delay-tolerant applications such as data collection for periodic sensing, it could be sufficient to deploy only one UAV to communicate with the ground sensors sequentially so as to minimize the cost. As another example, the considered setup could correspond to the emergency service recovery scenario in cellular systems, where the GT corresponds to an isolated BS with the backhaul links destroyed after nature disaster. For the more general scenarios with multiple UAVs and/or multiple GTs, the design for energy efficiency optimization is more intricate, which will be left as future work. Our objective is to optimize the UAV's trajectory so as to maximize the energy efficiency in bits/Joule for a given finite time horizon $T > 0$, where the energy efficiency is defined as the aggregated information bits that are transmitted to the GT normalized by the UAV's total energy consumption over the duration T . Without loss of generality, we consider a three-dimensional (3D) Cartesian coordinate system such that the GT is located at the origin $(0, 0, 0)$.

B. UAV Energy Consumption Model and Energy Efficiency

The total energy consumption of the UAV includes two components. The first one is the communication-related energy, which is due to the radiation, signal processing, as well as other circuitry. The other component is the propulsion energy, which is required for ensuring that the UAV remains aloft as well as for supporting its mobility, if needed. Note that in practice, the communication-related energy is usually much smaller than the UAV's propulsion energy, e.g., a few watts [3] versus hundreds of watts [9], and thus is ignored in this paper. Furthermore, as shown in Appendix A, for fixed wing UAVs with level flight under normal operations, i.e no abrupt deceleration that requires the engine to abnormally produce a reverse thrust against the forward motion of the aircraft, the total propulsion energy required is a function of the trajectory

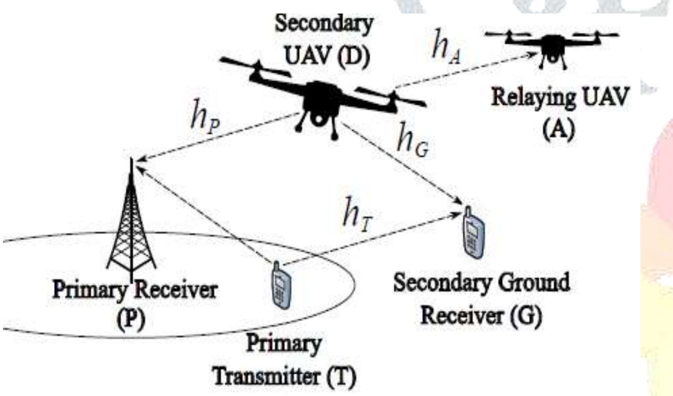

Figure 1 (a) – A structure of UAV routing [4]

II. SWARM INTELLIGENCE ROUTING PROTOCOLS.

Swarm intelligence is the study of insects on which routing protocols and algorithms are designed. Swarm intelligence routing protocols are based on the insect's behaviour. Swarm intelligence routing protocols are of three types: bee based, slime based and ACO (ant colony optimization) based. A. Bee Colony Based Routing Protocols Bee colony protocols based of foraging behaviour of honey bees, which is same as routing in sensor networks. Self organizing nature and dividing labour is the principle which is used by honey bees. 1) Bee Sensor: Routing protocol based on bee hive is developed with wired networks [5]. The principle is scout recruit system used with the help of bees. Foraging is used by on-demand route discovery AODV. Agents used for this are of three types: x Packers locate proper foragers for data packets at source node. x Scouts find paths with the new destination. x Foragers forward packets of data to sink node. B. Slime Based Routing Protocols Slime mold is term defined for heterotrophic organism like fungus. They can cluster themselves and pheromone are generated for self-organization Wireless sensor network is self organized sensor colony with is same as ant colonies and unicellular organisms. 1) Multi-sink Swarm-based Routing Protocol: WSN protocols are based on properties like environment adjustment, fault easiness and organizing themselves, which is same as social insect colonies. Protocol is based on cluster organize behaviour of slime mold organism, in which they cluster with the help of evaporation and pheromone generation, to organize themselves [6]. Multi-sink swarm based routing protocol use gradient concept for organizing the data traffic in direction of different sink nodes, it is inspired by slim mold organism. C. ACO Based Routing Protocols ACO ant colony optimization based routing protocols are based on foraging principle of ants, by which ant can build nest and perform complex tasks. 1) FP-Ant: Flooded Piggybacked Ant routing is used because flooding is dynamic, complex and extremely dispersed [3]. FP-Ant deliver novel ant to forward ant or to data ant, they also contain forward list. 2) T-Ant: It follow two-phase clustering process and involve setup to cluster and phases of stable state. Gathering and alteration approximation are the two methods used by TAnt. [5] Election ant is allotted for gathering. If node is to initialize then sink appoints multiple ants for messages control. After TTL time-to-live, network is invasion by ants. Ant apply prospect to choice any uninformed node, when it reaches the node. 3) Ant-Chain: Node life time, data integrity and energy efficiency are the main parameters over here. A specific chain is prepared in it, to broadcast data to all nodes in wireless sensor network [8]. Node can run independently after knowing chain kind data. For data collection, three chains are selected: x Bi-direction ant-chain is auto adaptive with little modification in topology. x Uni-direction ant-chain gather limited data. x Query chain collects data from node in focus. 4) QAAB: GPS is used to locate position of nodes to form a rational simulated grid, and here data is transferred by recognized locations [4]. To survive in region with self organization, nodes follow rules. Nodes are of different types: x Source Node also called Event node. x Sink Node also known as Destination node. x Queen Node provide interface with Internet. x Principal Node acts as monitor of group. x Member Node are the normal members. 5) ACLR: Ant-colony optimization-based location-aware routing protocol based on principle in which ant picks next hop neighbour node from selected set of neighbour nodes, to avoid loops during data transmission towards Sink. Route is made by determining pheromone quantity dropped by ant and evaporation of pheromone based on residual energy and location of node. 6) MADFT: It allocate ants to Source node, then one of the selected ant form a path by searching another ant close to last found path [9]. MADF is based on probabilistic routing technique to form least cost path by calculating pheromone amount and cost. 7) FF-Ant: Flooded Forward Ant routing is based on broadcasting technique, so ants are flooded to all the routes and explore all areas [6]. This technique is used where destination is not known or cost is not determined. 8) SC-Ant: Sensor-driven Cost-aware Ant routing is used to sense the best initial direction for ants, with the help of sensors, so that forward ant performance is maximized [5]. Each node retain probability distribution and the cost to reach destination from its neighbours. 9) AR and IAR: It is swarm intelligence based routing, it is established to increase the enactment by improving parameters like success rate, packet delivery ratio, energy consumption and time delay in wireless sensor networks. 10) EEABR: Energy-efficient ant-based routing is based on swarm intelligence in which every node contain data structure which store ant information and routing table stores value of time out, ant id, forward node and previous node [2]. When forward ant is received then node check routing table and find ant identification for loop. If found, then ant is removed; otherwise node store required data, restart timer and forward ant to following node [9]. When backward ant is acknowledged then node form routing table for next node to propel ant. If ant not reach node within assigned time, then timer delete record which find backward ant. 11) Ant Colony: This technique is dedicated to energy balance, network lifetime, battery life and end to end latency by selecting nodes with less hops and pheromone [8]. It aggregate the battery life, network lifetime and global energy consumption [10]. This technique outperform direct diffusion routing protocol. 12) E and D Ants: It is Energy X Delay model, which is used to reduce time delay and consumption of energy to send packets of data [10]. Real time data transmission, improved battery life and optimum network lifetime is achieved by E and D ants, which is seven times better than AntNet and Antchain algorithms [7]. 13) Ant-0, Ant-1 and Ant-2: Energy constraint is improved by stresses data aggregation and reducing number of message exchange between nodes in wireless sensor networks. Data aggregation tree of wireless sensor network is constructed, where multiple source nodes sense data and send to single destination node. Ants find all possible paths from source node to sink node, out of which little potential track is trailed. Search space is explored for data accretion, with support from swarm intelligence. Pheromone is gathered to build data aggregation tree [11].

III. Limitations of existing work.

- Existing drone surveillance algorithms focus only upon drone movement and the areas that it needs to cover in a predefined surveillance space.
- Not much study has been done on routing of data in an inter node drone to drone communication process.
- Routing is essential not only for inter node communication but also to transmit the aggregated data by a drone node to the base station.
- Also, not much emphasis has been laid in the past to efficiently use drone the resources of a drone using meta heuristic algorithms.
- There is a need of an algorithm using we which we can determine the optimum trajectory of the data flow in a UAV to achieve energy efficiency.

IV. Motivation and proposed Algorithm

UAVs are mobile while terminals are assumed stationary or quasi-stationary. A terminal is associated to no UAV if it detects no UAV with SIR value equal to or above 0.1. If there is at least one UAV with SIR value equal to or above 0.1, the terminal selects a UAV with the highest SIR value. The above-mentioned setting was originally stated in [6]. To decide whether to keep the current moving direction, a UAV in [6] must have the knowledge of the SIR values of all the terminals associated with it. In contrast, the proposed approach does not demand that knowledge from UAVs. Only after the deployment is the spectral efficiency measured. We do, however, require that each UAV know the distance from it to every terminal associated with it. We assume that the distance is calculated based on the location of the terminal. We assume that terminals inform the UAV they choose to associate via an uplink channel. During or after association, terminals then pass their geographic location information (.i.e., coordinates) to the UAV through uplink channel.

- A UAV aerial communication is mainly dependent on the node to node interaction process.
- Node to node interaction involves transmission of control as well as packet information from one UAV node to another.
- Most of the UAV energy gets dissipated in the routing of information in an inter node communication process.
- Since most of the UAV are equipped with consumable energy source, their battery must be utilized in an effective way.
- One possible solution the this problem is to use the shortest routing path from one node to another node in an inter node UAV communication process.
- We propose to use the artificial intelligence algorithm Ant colony optimization to search for the shortest routing path and then transmit the required information using this shortest routing path.
- ACO is an efficient AI technique used widely to find the shortest distance between any 2 points.
- ACO mimics the behaviour of ants and all the ants move in the straight line using the shortest path.
- The ant which is the first in the queue leaves a pheromone, which is sensed by the ants following it and causes it to move in the straight line following the first ant.
- In the same way all the ants present in queue leave its respective pheromone and causes all the ants to move in a straight line using the shortest possible path.
- In our scenario a UAV node represents a ant and the routing information from one UAV node to another UAV node is sent by shortest possible path using ACO.
- Since most of the UAV energy gets dissipated in data transmission or communication process, longer be the data transmission path and higher be the energy consumed by the UAV in transmission.
- Using the smallest path by ACO not only reduces the energy consumed in data communication but also extends the lifetime of working of a UAV.

V. Results.

We used 20 UAVs with initial locations set to the same as that of [6]. We considered two different terminal distributions, namely, uniform distribution and clustered distribution, and varied the area size and the number of terminals. The result of each configuration was averaged over 50 trials. Each trail consists of 10,000 iterations (as in [6]) and every UAV makes a single move in each iteration. The order in which UAVs move was random. The moving distance (step size) for UAV in one iteration was 0.1 km. Results of the proposed algorithm are obtained using the configuration of the hardware core-i5 processor with 4GB RAM.. Figure 2 shows the remaining energy of the UAV nodes when ACO based routing is compared with GA based routing and simple routing protocol. A sample UAV routing structure is shown in figure 1 (b).

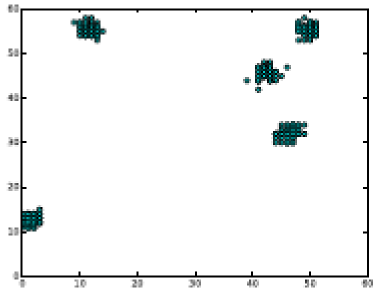

Figure 1 (b) – UAV terminal routing deployment.

A UAV node to node routing structure is shown in figure 1 (c).

Figure 1 (c) – Node to node UAV routing [5]

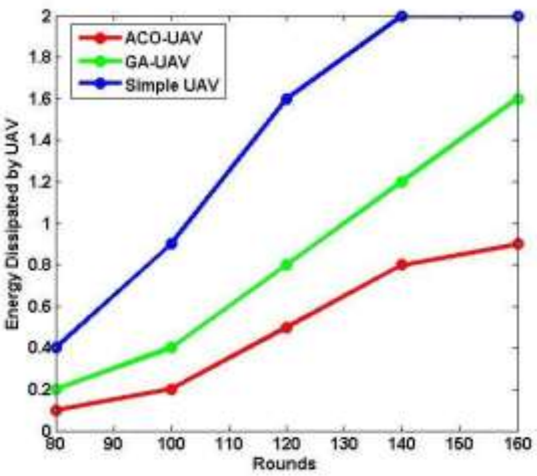

Figure 2 – Energy consumed by UAV node (Joules)

Figure 3 shows the lifetime of a UAV in terms of number of rounds. It can be seen that the proposed ACO based routing has the maximum lifetime as compared to other algorithms.

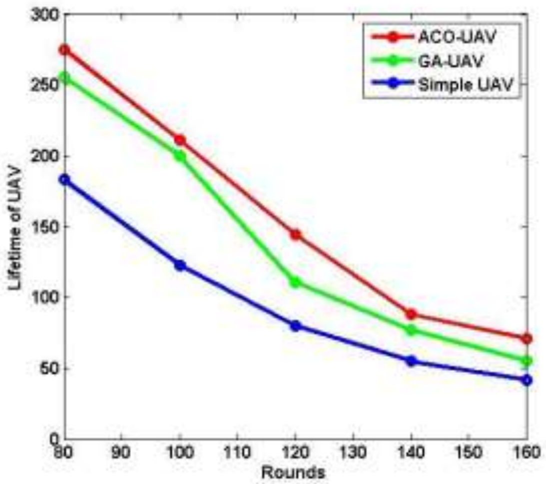

Figure 3 – Lifetime of UAV

Figure 4 shows the comparison in terms of number of packets sent to the base station. It is eveident from the figure that proposed work performs best in terms of packets sent as compared to the past algorithms.

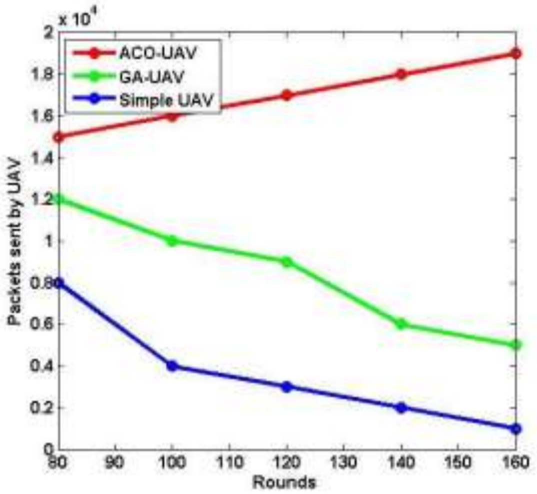

Figure 4 – Packets sent to the base station

Figure 5 shows comparison in terms of the remaining energy as rounds proceed.

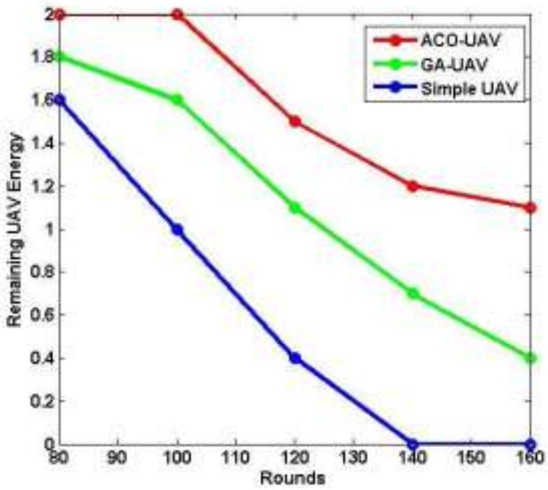

Figure 5 – Remaining energy of UAV nodes

It is evident from all the figures that the proposed work works best in all the cases which validates the performance of our work.

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