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TOUR TIME MINIMIZATION FOR MULTIPLE UAV IN DEADLINE BASED WSN APPLICATIONS

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ABSTRACT

Today, with scientific and technological advances in the field of robotics, artificial intelligence, control and computers, land, air and sea vehicles, they have been considered. Unmanned Aerial Vehicles (UAVs) have also significantly improved and are very useful for many important applications in the business, urban and military environment. One of the important uses of UAVs in Wireless Sensor Networks (WSNs) is that these devices may not be able to communicate in large areas due to their energy constraints. In this case, a UAV can play mobile collectors for WSN networks.

In this paper, we survey the work done towards all of practical applications of UAVs as mobile collectors for wireless sensor networks. We first examine the proposed UAV applications and compared their weaknesses with each other. We also examine the technical challenges we have about the applications of UAVs in the Wireless Sensor Network in detail.

Then, in this paper, we provide an energy efficient data gathering with a deadline for wireless sensor networks using the UAV and a series of virtual grid points, named virtual grid energy efficient deadline based data gathering (VGEEDDG), to determine the optimal virtual grid points, optimal sojourn time for deploying multiple UAVs with the minimum time required in a predetermined deadline time to collect buffer data from cluster heads. In fact, in many applications, especially in practical applications, the deadline is limited to the critical level of application, and as a result, this deadline time for collecting data is not enough, and single UAV cannot collect data from cluster head with minimal energy. In this situation, this paper presents seven strategies for solving the problem of inadequate deadline time is provided by multiple UAVs for deadline based WSN applications. The results obtained in the simulation section show that the proposed framework is able to provide efficient data collection with satisfactory energy constraints and a deadline when dependent on the critical level of the application.

Keywords: *Data Collection, Wireless Sensor Networks, Unmanned Aerial Vehicles, Mixed Integer Linear Programming Deadline, Virtual Grid Points.*

1) INTRODUCTION

In the near future, millions of UAVs, also known as the Drone, are expected to quickly operate in different parts of our daily lives and provide massive services [1]. Indeed, drones can play a key role in deadline based WSN applications, which consist of limited-size devices such as battles, forest monitoring, and animal tracking in a protected area [2]. Because of their energy constraints, these devices can not normally be transmitted over long distances. In such WSN scenarios, drones can dynamically move towards WSN devices, collect WSN data and transfer it to other devices that are outside the communication boundaries of transmitting WSN devices. (See fig. 1)

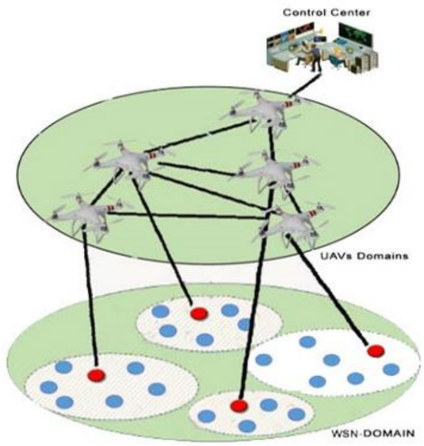

Figure 1: Connection between UAVs and WSN devices

The main applications of communications supported by the UAV can be divided into three categories [3]:

Coverage everywhere with the UAV, in which UAVs are used to provide integrated telecommunication coverage in the targeted area to assist existing ground telecommunication infrastructures. In this case, UAVs act as pseudosystems above the target area as base stations (BS) [4]. The UAV-based wireless communications have their unique ability to connect quickly, reliably and cost-effectively to areas covered by poorly-grounded networks [5].

Another promising relay application is the UAV-enabled UAV to provide reliable wireless connectivity between two or more remote users or user groups in the enemy's environment, such as between the front lines and the command center is sent for emergency response or military operations [6-7].

UAV systems can also be used to collect data/ disseminate data using UAVs. This is especially appealing for periodic measurements or wireless sensory networks (WSNs) in which UAVs can fly through sensors for communications, greatly reducing the operational capacity of the sensors, thereby increasing the lifespan of the network [8-9].

Data collection with UAVs not only has the flexibility of a mobile data set suitable for a large-scale WSN, but also has the following advantages [10]:

Aerial data collection using the UAV can be automatically guided as a mobile data collector. There is no mobility constraint on land transport and can be used in specially monitored areas that humans cannot access.

Compared with collecting ground data sets, aerial data collection can be controlled using an air vehicle that has faster movement. This can increase the speed of search and visit nodes, and shorten the lifecycle of data when WSN has a large-scale sensor network.

Compared to collecting air-to-surface data, air data sets often have fewer obstacles and a larger wireless signal coverage that can reduce communication delays and increase bandwidth.

Animal tracking, pollution monitoring, health monitoring, forest monitoring and battlefield monitoring in a protected area are examples of deadline based WSN applications. For example, in the forest monitoring, sensor nodes are used to detect fire and smoke in the forest. A drone in the monitored area regularly collects data from all sensor nodes in certain designated points, called virtual grid points, and this data collection should be done on a deadline time. See Figure 1. Another deadline based WSN applications is a deadline-based monitoring of the city to assess the risks and respond to appropriate actions by having a team of drones who benefit from the benefits of a smart city for public safety and parking spaces [28].

The deadline of the WSN data collection is determined according to the type of application. For example, in many applications, the WSN is based on the deadline, the data collection time is adjusted in accordance with the priority level and the critical level of the previously collected data; In this case, the remote user can request different deadline time for In this case, the remote user can request different time limits for network-level data collection. In network-level data collection..

The main problem of this study is to provide optimal deployment and trajectory, minimize the time required for data collection and the optimal number of UAVs to collect data from the network level in a predetermined deadline, which should be efficient in terms of energy consumption of UAVs and WSNs. In fact, the problem posed is a VRP problem. In addition to the problem of UAV routing, the data collection has been added at a specific deadline time and the VRPTW problem is raised. We divide our area into virtual grids based on the assumed sensitivity range and determine the optimal virtual points used by the UAV. To this end, providing the optimal route and movement of UAVs with the minimum time to collect the data needed to cover the area is also added, which in turn adds to the complexity of the problem, its modeling and solution. We cite this problem as an problem of energy-efficient data gathering using multiple UAVs and a series of virtual grid points in a predetermined deadline, named VGEEDDG problem.

The contributions of this paper can be defined as follows:

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1. By identifying the main challenges of the UAV in the WSN network, we carry out an accurate investigation of the wireless communications using the UAV, which constitute the main features of this paper.
2. We provide a framework for energy-efficient data collection using the number of UAVs in the wireless sensor network, taking into consideration a number of virtual point points, and taking into account the deadline time and energy constraints of sensor nodes and UAVs. We refer to this problem as (VGEEDDG).
3. We provide a seven strategies for solving the problem of inadequate deadline time and compare them together.

The rest of the article is as follows: In the second section, the related work of UAV activities in wireless sensor networks will be examined. The third section describes the system model and assumptions. In Section 4, the definition of the problem and the formulation are presented. In Section 5, the overall operation of the proposed framework is presented. In Section VI, the simulation and evaluation of the proposed framework will be discussed, and in the final section we will look at the results and future work.

2) RELATED WORKS:

In spite of several advantages and practical applications of UAVs as mobile collectors for wireless sensor networks, many technical challenges such as optimal route, optimal deployment, data routing, air-to-ground modeling, user participation, optimal flight time and efficient use of energy for UAVs and WSNs. We will first classify the relevant articles in this area according to the previous challenges, and then we will examine each of these categories and describe the weaknesses of each category.

One of the important challenges in UAV-based communication is optimal route. Feng et al [11] proposed a multi-objective optimization model of UAV route planning for monitoring roads. This model aims to minimize distance traveled by UAVs and number of UAVs used. Moreover, they suggested an evolutionary algorithm to resolve multi-objective UAV route planning problem based on Pareto optimality. Therefore, a UAV multi-object route-planning model was made in this article and then an evolutionary algorithm was proposed to resolve multi-object rout planning problem for UAVs.

Zheng et al [12] studied point-to-point relationship between UAV and a ground user to optimize UAV route. They proposed a new algorithm, which considers both operational power of communications and UAV energy use. Moreover, they suggested an efficient plan to maximize UAV energy efficiency with general limitations on route like initial/final places and velocities, and minimum/maximum velocity and acceleration. Consequently, suggested plans achieve higher energy efficiency for UAV communications. This article considers single UAVs.

In terms of UAV deployment, Ertan Yakici [13] studied small drones positioning and routing at tactical level with a certain purpose. He formulated this problem as a linear program to maximize total collected score from desired points visited by UAV flights/routes. He also creates an ant colony optimization (ACO) method, which is special for designed combined problem. This article only considers predetermined points. In addition, deadline is not used.

Ladosz et al [14] suggested a method for finding desired position of UAVs as a communicational relay node to improve network connection and communicational performance of a team of nodes/ground vehicles. Particle swarm optimization method was used to find desired position of UAV, which uses three different criteria of communicational performance. This article did not consider deadline in its analyses.

Routing is the only problem that remains active in all types of network. For multi-UAV networks, stronger routing protocols that are more resistant to error are needed which can provide least delay during route selection, efficient reconfigurations of route, quick retrieval, improved control on delays and jitters, and better preparation for service quality given to end users. Yu et al [15] suggested ACO-based Polymorphism-aware Routing Algorithm (APRA) to resolve problems. This article combines ACO algorithm with dynamic resource routing algorithm. Pheromone level in routes is what obtained in routing detection process, is selected as a standard for choosing selected route, and is calculated by assessing route distance, route compression, and route sustainability. Results of simulation show that APRA algorithm outperforms traditional algorithms in terms of data package delivery rate, end to end delay and routing discharge, and is reliable in battlefield.

Rosati et al [16] compare performance of P-OLSR and OLSR in FANET by small fixed wings UAVs. Such networks that are characterized with high degree of mobility are a challenge for routing protocol. Routing protocols designed for MANETs have been failed in tracking network topology evolution. They resolved this problem by extending OLSR, which is called P-OLSR. P-OLSR has used

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GPS information advantage to predict how quality of wireless links evolves. Networks simulation and field experiments confirm their expectations. With P-OLSR, routing continues after changes in topology; however, this is not true for OLSR.

Another important challenge in UAV-based communications is manner of collecting efficient data. Wang et al [10] designed a fundamental framework for collecting aerial data, which includes following elements: networks positioning, nodes positioning, searching end points, planning quick route for UAV, and collecting data from network. They realized key challenges in each element and recommended efficient solutions. This includes suggesting a Fast Path Planning with Rules (FPPWR) algorithm based on grid division to increase efficiency of route planning while guarantying a relatively short route length. This article did not consider multiple UAVs, deadline limitation and optimal number of UAVs in its analyses.

Ho et al [17] collected data by selecting communicational topology of sensor network and using UAVs. Usual wireless sensor networks, Low Energy Adaptive Clustering Hierarchy (LEACH), are used to select cluster heads in order to save energy. Saving energy is difficult for positioning in big scale. Particle Swarm optimization (PSO) has been suggested as the optimization method to find optimal topology for decreasing energy use, Bit Error Rate (BER) and UAV travel time. PSO was compared with LEACH by simulation and results show that PSO outperforms LEACH and BER in terms of energy use; however, their UAV travel time is similar. Results also show that performance gap between them increases by number of nodes of cluster head. In this article, data collection has not been done with several UAVs and deadline has not been considered.

Another important challenge in UAV-based communications is saving energy in UAVs and WSN. Zorbas et al [18] studied drones' energy efficiency in target tracking scenarios by setting number of active drones where UAVs equipped with camera can recognize and intercept mobile events that occur on the ground. They proposed a mathematical formula of minimizing UAVs total energy use problem when covering all events is required. Regarding particle swarm optimization problem, an optimal solution cannot be obtained even for small samples. In comparison, they proposed Localized Altitude Scheduler (LAS), which is a local solution for above problem, which is in order to save energy with regard to UAVs ability in flying in low altitudes. In this article, authors assumed that place of targets are predetermined and they did not consider network randomness.

Li et al [19] suggested an efficient energy repay plan that can extend life cycle of shared UAVs in human-friendly environments. NP-Hard optimization problem has been formulated for guarantying package success rate and energy use balance. A practical sub-optimal solution has been made by separating energy balance and compatibility rate, because these two parts are executed periodically. Results of simulation show that their sub-optimal method can decrease calculation complexity by different values with trivial decrease in efficiency and life cycle of network in comparison to optimal solution. Their sub-optimal method can also save energy up to 50%, increase network efficiency up to 15%, and network life cycle by 33% in comparison to available algorithms. This article did not consider several UAVs, optimal positioning of UAV, deadline limitation, and no. of optimal UAVs in its analyses.

In some articles, authors conducted air channel to ground modeling for UAV-based communications. Jeong et al [20] studied a UAV-based mobile cloud computation system where mobile UAV with computation capabilities was provided to compute offloading opportunities for mobile users (MUs) with limited local processing capabilities. This system aims to minimize total itinerant energy use while meeting quality requirements of offloaded mobile programs service. Offloading is activated by using uplink and downlink between mobile devices and UAV. This bit aligning shared optimization problem has formulated UAV energy together with under delay small cloud route and budget articles for uplink and downlink and for calculation in UAV. This problem has been solved by Successive Convex Approximation (SCA) strategies. The advantage of this method is significant save in energy which can be increased by suggested shared optimization for bit aligning and small cloud route in comparison to local mobile execution and trivial optimization approaches which only design bit aligning or small cloud route. This work is limited to one UAV and deadline and number of optimal UAVs have not been considered in its analyses.

Another important challenge in UAV-based communications is the association between UAV and WSN. Han et al [9] studied how to use UAV in order to improve connection to MANET network. They defined four types of network connection: universal message, worst case, network connection, and k connection. They formulated problems related to positioning and movement for drone and designed adaptive algorithms for proposing a simple solution and good performance. They presented a theoretical

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analysis for a simple sample of a two-node UAV and showed that increasing UAV improves universal message by 240%. For general network settings, a UAV can improve universal message connection and worst-case connection by 109% and 60%, respectively. They showed that network connection and k connection are improved by adding a type of drone to network. In this article, data collection was not done with several UAVs and deadline was not considered.

Mozaffari et al [21] proposed a new framework for cell association among cell networks in UAVs. Specifically, optimal cell partitions and basic ground stations are determined to minimize mean network delay in any desired spatial distribution of ground users. In this regard, powerful mathematical tools were used in transfer theory, which have proved existence of solution for optimal cell connection problem and have determined solution environment for this problem. Simulated and analyzed results of suggested cell association method not only improve mean network delay significantly, but also provides lower network delay in comparison to a SNR-based connection.

Flight time of UAVs is a challenge in designing for UAV-based communication systems. Mozaffari et al [22] studied effective use of drone's flight time as basic stations of flight that can provide wireless services to ground users. Specifically, a new framework for optimizing performance of drone-based wireless systems in terms of mean number of bit (data service) transferred to users and hovering time has been suggested. This model has been examined based on two practical scenarios. First scenario is based on maximum possible hovering time of drone where mean information service for users is maximized under a fair resource aligning schema by finding optimal cell segments related to drone. In second scenario, least mean hovering time of drone required for providing services for ground users has been differentiated with regard to load requirements of ground users.

Henchey et al [23] suggested a flight time approximation model, which can produce a big set of estimated flight times from possible combination of stations in a real time scenario. He formulated problems related to positioning and movement for drone and designed adaptive algorithms for presenting a simple solution and good performance. He showed that increasing UAVs improves universal message connection by 240%. Moreover, network connection and k connection are improved by adding a type of drone to network. In this article, data collection was not done with several UAVs and deadline was not considered.

Table 1 lists the previous articles for the UAV-based WSN network based on deadline time parameters, optimal deployment, UAV optimal number, multiple UAVs, mobile nodes, and minimize the time needed to collect data from the cluster heads. The table clearly shows that the existing approaches do not address the following issues:

- Deadline time has not been reviewed.
- Does not investigate the optimal deployment of UAVs.
- Do not check the optimal number of UAVs.
- Do not consider a multiple UAVs.
- Do not consider moving nodes
- Do not consider the minimum UAV tour time.

Table 1: Comparison of reviewed works

Reference	Journal/Year	Single/ Multiple UAV	Fixed/ Mobile nodes	Optimal No. of UAV	Optimal positioning of UAV	Predetermined points	Downlink / Uplink	Deadline
Feng et al 11]	Springer, Journal of Central South University, 2014	Multiple	Fixed	✓	×	✓	Uplink	×
Zeng et al [12]	IEEE Transactions on Wireless Communications, 2016.	Single	Fixed	×	×	×	Downlink	×
Yakichi [13]	Elsevier, Computers & Industrial Engineering, 2016.	Multiple	Fixed	×	×	✓	Uplink	×
Ladosz et al [14]	ICUAS (International Conference on Unmanned Aircraft Systems). IEEE, 2016	Single	Fixed	×	✓	×	Downlink Uplink	×
Wang et al [10]	International Journal of Distributed Sensor Networks,2015	Single	Fixed	×	×	✓	Uplink	×

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Zorbass et. al [18]	Procedia Computer Science 2013	Single	Fixed	×	✓	✓	Uplink	×
Li et al [19]	IEEE Transactions on Mobile Computing, 2015	Single	Fixed	×	×	✓	Uplink	×
Jeong et al [20]	IEEE Transactions on Vehicular Technology, 2017.	Single	Fixed	×	×	✓	Downlink Uplink	×
Hen et al [9]	IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, 2009	Single	Mobile	×	✓	✓	Downlink	×
Mozaffari et al [22]	IEEE Communications Letters, 2017.	Multiple	Mobile	×	✓	×	Downlink	×
Henchey [23]	John Wiley & Sons, Ltd,2016	Single	Fixed	×	×	×	Downlink Uplink	×

3) SYSTEM MODEL AND ASSUMPTIONS:

3-1 Basic Assumptions:

To provide a method for optimizing the collection of data in WSN/ UAV networks, the assumptions and limitations are as follows:

A) Assumptions and Limitations of the WSN Network:

- ❖ **Distribution of WSN Nodes in the Network**: We assume that the sensors are randomly used in a two-dimensional area and that the distribution of the WSN nodes in the network is uniform.
- ❖ **Division of Nodes**: For WSN nodes, two roles are assumed: CH (cluster head) and CM (cluster member). CHs and CMs are randomly assigned to the network. We assume that the clustering scheme is optimal in this paper.
- ❖ **Ground to Air Communications**: Each device typically has a LoS view toward a specific UAV with a given probability. This LoS probability depends on the environment, device location and UAV, and the elevation angle between the sensor node and the UAV.
- ❖ **Transfer Rates for WSN Nodes**: Each WSN node has the ability to set its transfer rate and the transmission radius.
- ❖ **Node Locations**: All wireless sensor nodes are aware of their location based on the Global Positioning System (GPS) and their locations are known for UAVs, and are used to find the optimal route for UAVs. .
- ❖ **Node Energy**: The nodes of the initial energy sensor are e_0 and each node is aware of the remaining energy. In fact, it focuses on the energy consumption of cluster nodes because collecting cluster data, processing and sending to UAVs has the most energy consumption than other cluster members.

B) UAV Assumptions and Limitations:

- ❖ **The UAV Mobility Model**: The random mobility model is assumed as the UAV mobility model, in which the UAV can move around the WSN network and stop at specific locations when needed to retrieve data from the sensor nodes to collect data.
- ❖ **UAV Type**: A rotary wing UAV is used instead of a fixed wing because the rotary wing is more flexible than other types of UAVs, and it can be flown in any direction, horizontally and vertically, as well as in a fixed position.
- ❖ **UAV Capacity**: Maximum distance that any UAV can travel is predetermined and traveled distance should not exceed it.
- ❖ **UAV Energy**: Each UAV has the maximum energy that can be predefined and the energy consumed should not be greater than that.
- ❖ **UAV Buffer**: Each type of UAV has its own buffer size. The cluster head collected data should not exceed the UAV buffer size.
- ❖ **The Ability to Move at Variable Speeds**: Each UAV has the ability to move at variable speeds.
- ❖ **Ability to Move at Variable Flight Altitudes**: Each UAV has the ability to move in variable heights.

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- **Absence of obstacle to UAV movement**: no obstacle to UAV movement.
- **Absence of UAV Collisions**: Each UAV is considered to be capable of moving without collision.

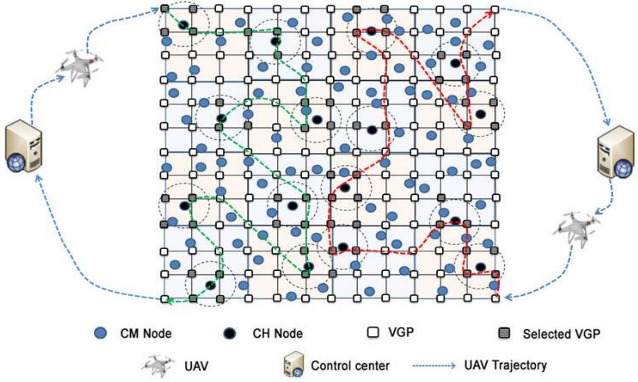
3.2 System Model:

In this section, the proposed network model is presented in detail. Figure 1 shows the network model of the proposed scheme. The network is intended to include a number of fixed wireless sensor nodes and a number of UAVs. Sensors are randomly used in a two-dimensional area and deployed using a uniform distribution around the control center (CC), using UAVs to collect data from clusters and transmit data to the control center. To be N and K are defined as the total number of sensors and UAVs.

For the Objective of determining the optimal path of an UAV, area A is divided into virtual grids. All grids are the same size. The number of virtual grid points depends on the size of the monitored area and node density, which ensures that there is no need to send more than one UAV to a CH for data collection.

The area is sensitive to clusters and each cluster has a cluster head (CH) that is responsible for identifying and aggregating data from other cluster members of the cluster (CM), and then the area is divided into virtual grid points and the virtual grid points responsible for data collection from cluster heads and UAV will only visit these virtual grid points to collect data. In addition, we assume that UAVs have limited buffer sizes and that data generated from network nodes should be continuously sent to the control center during the deadline time.

Thus, each UAV needs to complete its tour in the deadline time τ. The sensors consume a limited battery and energy for each operation. Therefore, network nodes can only work for a deadline time. In order to save energy and prolong network lifetimes, UAVs need to be controlled optimally, by optimizing the virtual grid points; UAVs dynamically collect sensor data from cluster head with minimal energy consumption. A solution to the problem of scheduling multiple UAV paths is shown in Figure 1, in which the 13 × 13 grid points are VGP (square points), 100 sensors nodes (circular points), 2 UAVs and 2 control centers (CC1 and CC2). The objective function of this solution is to select the optimal virtual grid points for a multi-UAV



trajectory with respect to the deadline time and energy constraints. Figure 2 shows the network model.

Each cluster head is only visited by a UAV. Each UAV starts its tour from the control center. The tour speed is v. The path of each UAV consists of a series of virtual grid points. When the UAV arrives at a virtual grid point, they say that VGP_i will spend a certain time t_i collecting data from the cluster heads. After t_i, the UAV leaves VGP_i and moves to the next cluster. When the UAV visits all clusters, the collected data is transferred to the control center.

Figure 2: Network model.

3-3 Energy Model:

The energy model is the same as reported in [24]. We estimate the energy used to send the data from the i to j sensor and the energy used for the sensor i to receive data from the sensor j at a fixed rate f, as follows:

$$\boldsymbol{e_{ij}^{tx} = c_{ij}.f} \qquad (1)$$

$$\boldsymbol{c_{ij} = \theta_1 + \theta_2 d_{ij}^{\delta}} \qquad (1.2)$$

$$\boldsymbol{e_{ij}^{rx} = \rho.\sum_{k\in N}^{i\neq k} f} \qquad (1.3)$$

where :

$\boldsymbol{e_{ij}^{tx}}$: The energy used to send data from i to j at a constant rate f.

$\boldsymbol{e_{ij}^{rx}}$: Energy consumption for sensor i to receive data from sensor j at constant rate f.

$\boldsymbol{c_{ij}}$: The energy required to transfer a data unit from the i to j sensor.

f: Data transfer rate (bits per second).

$\boldsymbol{\theta_1}$: Constant value for the power consumption of the transmitter circuit.

$\boldsymbol{\theta_2}$: Fixed value for the power consumption of the power amplifier.

$\boldsymbol{d_{ij}}$: Euclidian distance between the sensor node i and j and the UAV.

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δ: The path loss factor is in the range 2 <δ> 4. So that if the distance d_{ij} is greater than the threshold of distance d_0, then multi-path model is used and δ = 2, otherwise the free space model (δ = 4) is used. We consider multi-path modeling in this paper.

ρ: Constant terms in power model.

4) DEFININTION OF THE PROBLEM AND FORMULATION

Given the system model presented in the previous section, we define the problem in this section as follow:

4.1 Definition of the problem

The objective of this article is to find optimal routes for UAVs in order to minimize the total energy consumption of several UAVs and CHs, taking into account the deadline time and energy constraints by using a series of virtual grid points. The problem of finding optimal routes can be defined as follows.

Definition 1: Energy efficient data gathering using multiple UAVs, taking into account some virtual grid points and taking into account the deadline time and energy constraints of sensor nodes and UAVs., named VGEEDDG: The main idea of the VGEEDDG problem is to find optimal routes for multiple UAVs by specifying optimal virtual points for collecting data from sensor nodes, without violating the energy constraint of sensor nodes and UAVs, while the data collected by sensor nodes must be continuously delivered to the control center in a deadline time.

Definition 2: The problem of selecting the optimal grid points (OVGP) for a UAV from a set of candidate virtual grid points in a data collection path will be examined. Virtual grid points should be set for the UAV to minimize the energy required to collect data from the sensor nodes and to minimize the energy needed for UAV movement and also for receiving data from cluster head. This optimal route for the UAV consists of a series of virtual grid points. At any given point, the UAV stops for a specific time and collects data from cluster heads. By selecting an optimal virtual grid points, the UAV moves optimally with minimum energy consumption in the network, and each cluster head must have at least the energy when sending data to the UAV. The energy consumption of each UAV and cluster head should be minimized, while guaranteeing a deadline time. And the number of UAV must be optimally selected, and the time needed to move the UAVs should be minimal, without violating the deadline time and energy constraints of the sensor nodes and the UAVs. It is important to determine the optimal virtual grid points for the UAV trajectory and the stop of the UAV at any virtual grid point, in order to increase the efficiency of the UAV-based data collection framework.

Definition 3: The problem of determining the optimal sojourn time (OSTP) for an UAV at any point in the virtual grid in a data collection path will be examined. The UAV stops at any point in the virtual grid should be determined based on the buffered data in the cluster head. The total UAV sojourn time at the selected virtual grid points must be less than or equal to the deadline time.

Theory 1: Problem (VGEEDDG) is NP-hard.

Proof: The VGEEDDG problem is a more general problem than the VRPTW because the data collected by the UAVs from a sensor node should be delivered to the base station at a deadline time. Since VRPTW is NP-hard, VEEDDG is also NP-hard.

Theorem 2: The problem of determining optimal virtual points (OVGP) is NP-hard.

Proof: The problem of Uncapacitated Facility Location (UFL) is a known problem of NP-hard [29]. In UFL there is a set of clients C and a set of F facilities provide a product or service and the goal is to determine a subset of the minimum cost of these facilities to open, according to the sum of the distance $dist_{ij}$From each request for the closest facility and the cost of opening f_i for each facility $j \in F$.

In the OVGP, the set of W consists of N nodes that transmit data, and a set of G consisting of a n candidate virtual point grids that the UAV can stop at this virtual grid point for a certain time t and collect data from cluster heads. For each sensor node $i \in W$ and any point of the virtual grid $j \in G$, C_{ij}, the energy required to send data from i to j in the low energy path.

The OVGP issue is equivalent to the UFL problem, since the parameters W, G, C_{ij}, and t in the previous problem can be converted to the $parameters\ C, F, dist_{ij}$ and t in the OVGP problem (and vice versa).

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4-2 Problem Modeling:

In this section, we present a mixed integer linear programming model (MILP) for VGEEDDG. The definitions for the symbols used in the MILP formula are given in Table 2.

Table 2: Symbols

Symbol	Definition
$U = \{1,..,K\}$	A series of UAVs. (K: maximum number of UAVs available)
$N = \{0,1,\dots,n,n+1\}$	The network nodes set to contain nodes 1 through n as virtual grid points and virtual nodes 0 and n + 1 as nodes start and end the tour of all UAVs.
$G = \{1,\dots,n\}$	Virtual grid points set
$W = \{1\dots,n\}$	A set of WSN nodes that contain nodes 1 through n as clusters heads.
d_{ij}	The distance between two points i, j
$\bar{d}_{i,j}$	Distance between two virtual grid i, j
$d_{max} = \tau v$	Maximum distance traveled by each UAV
v	UAV speed
v_{max}	UAV maximum speed
ρ_i	The amount of data that collects in the cluster heads
f	Data transmission rate (in bits)
$t_i = \frac{\rho_i}{f}$	The time it takes to stop the UAV at the virtual grid points
t_{max}	The maximum sojourn time of UAV in virtual grid point t_i (constant value)
t_{min}	The minimum sojourn time of UAV in virtual grid point t_i (constant value)
$t_{ij} = \frac{d_{i,j}}{v}$	UAV movement time is between two nodes.
τ	Deadline for data collection
t_s	Time to create a cluster
t_c	The required time to collect data from the sensor nodes to the cluster node
T_{round_k}	Round time
T_{all}	Total simulation time
τ_{max}	Maximum deadline
τ_{min}	Minimum Deadline
τ_{mid}	Average deadline
φ_k	UAV buffer size
h_{max}	The maximum height of UAV
h_{min}	The minimum height of UAV
$c_{i,j}$	The energy required to transmit a unit of data from *i* to *j*
θ_1, θ_2	Constant coefficients in transmission power modeling
E_{rx}^{uav}	UAV energy consumption to receive data
E_{tx}^{uav}	UAV energy consumption to transmit data
E_{mo}^{uav}	UAV energy consumption for moving between two nodes
E_{max}^{uav}	Maximum energy consumed by each UAV
$\mathrm{T_k}$	Maximum time of $\mathrm{UAV_k}$ movement.
$\mathrm{y_i}$	Free integer variables to check the presence of a round in the path
κ	Number of UAVs required (UAV number determined by model)
$\mathrm{E^t_{UAV_k}}$	Energy consumed by a UAV
$\mathrm{E^t_{ch_i}}$	Energy consumed by a cluster head $\mathrm{ch_i}$

In the following paragraphs, the formula for energy-efficient data gathering based virtual grids using multiple-UAVs (VGEEDDGs) is presented, taking into account the deadlines and energy constraints of sensor nodes and UAVs as described above.

. In order to determine the network graph to perform an energy-efficient data collection problem, we define the network graph as follows:

$$\mathrm{G = (N, E)}$$

$$\mathrm{N = \{0,1,2,\dots\dots,n,n+1\}}$$

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Where $E(i,j)$ represents the Euclidean distance between the nodes. N sets are considered as network nodes that contain nodes 1 through n as virtual grid points and virtual nodes 0 and n + 1 as nodes that represent starting the ending of the routes of all UAVs. In addition, U is considered as a set of UAVs $U = \{1,..,K\}$, each with constant velocity v and buffer size φ_k , and the collected data ρ_i by the UAV should not exceed the volume buffer is a UAV. d_{ij} shows the Euclidean distance from node i to j.

We define $X_{i,j}^k$ the binary decision variable that represents the specific UAV movement between two distinct nodes:

$$x_{i,j}^k = \begin{cases} 1, \text{if } UAV_k \text{travel between } i, j \\ 0, \quad \text{else} \end{cases}$$

In addition, the binary decision variables associated with the virtual grid VG are also considered. These variables are explained in Table 3.

Table 3: VG Binary Decision Variables

Definition	variable
$B_{i,j} = \begin{cases} 1, if\ wsn_i\ is\ covered\ by\ uav_j \\ 0, \quad else \end{cases}$	The variable representing the node wsn_i is covered by uav_j.
$G_{i,j} = \begin{cases} 1, if\ grid_i\ is\ covered\ by\ uav_j \\ 0, \quad else \end{cases}$	The variable $grid_i$ node is covered by uav_j.
$A_{i,j} = \begin{cases} 1, if\ wsn_i\ must\ send\ its\ data\ to\ grid_j \\ 0, \quad else \end{cases}$	The variable representing the node wsn_i can send its data to $grid_i$.
$\overline{H}_{i,j} = \begin{cases} 1, \quad if\ g_i \in H \\ 0, \quad else \end{cases}$	The variable represents the set of virtual grid points covered by the radius (R) of the cluster head H.

Sensor nodes are randomly located in the target area A. A is divided into small networks, sensor nodes are divided into two groups: CM and CH. Respectively. A set of virtual grid points covered by the radius (R) of the cluster head CH_j, represented by H, and H are described as follows:

$$H = \{g_j \backslash d(ch_i, g_j) < R; i \in W, j \in G\} \quad (1)$$

The network operation cycle can be divided into several rounds. In one run, cluster sensor nodes are first divided (cluster creation time (t_c)), each cluster head collects its cluster member data at time (t_d), then the UAV moves towards one or the multiple virtual grid point (t_{ij}) has passed a specific time at each of these virtual grid points (t_i) to receive buffer data from its cluster head. According to the previous assumptions, the time T_{round_k} can be calculated as follows:

$$T_{round_k} = t_c + t_d + \sum_{i\epsilon N\backslash\{n+1\}} \sum_{j\epsilon N\backslash\{0\}} X_{i,j}^k.(t_{i,j} + t_i), \forall k \in \tau \quad (2)$$

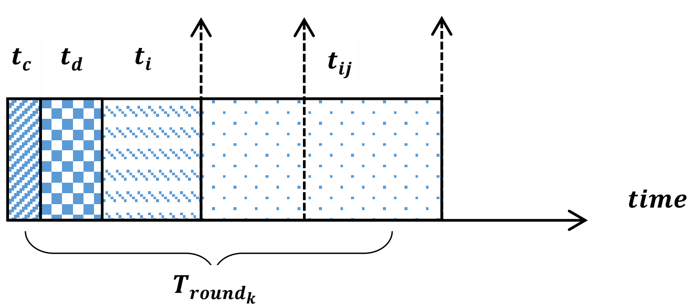

Figure 4: Time of a run (T_{round}) and its component.

The total time for simulation as T_{all} can be expressed in terms of the formula:

$$T_{all} = \sum_{k=0}^{K} T_{round_k}$$

The deadline time of the data collection (τ) is determined in accordance with the type of network application because network design is based on a specific application. τ_{min} and τ_{max}, shown in Figure 4, represent the minimum and maximum time that can be assigned to the deadline. The maximum and minimum deadline time will be checked as follows:

The maximum deadline time τ_{max} depends on the buffer data given from the cluster heads (ρ_i) and their constant transmission rate (f). This can be calculated as follows:

$$t_i = \frac{\rho_i}{f}, \forall i \in W \quad (3)$$

$$\tau_{max} = \sum_{i \in G} t_i \quad (4)$$

You can also consider the minimum deadline τ_{min} for the network, which is computed as follows:

$$\tau_{min} = max\{t_i\}, \forall i \in W \quad (5)$$

It is also possible to consider the average deadline interval τ_{mid} for the network, which is calculated as follows:

$$\tau_{mid} = (\tau_{max} - \tau_{min})/2 \quad (6)$$

τ_{min} and τ_{max} represent the upper and lower limit of the deadline interval τ. The time of data collection is adjusted according to the priority level and the level

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of criticality of the previously collected data; in this case, the remote user interface can request different deadline time for collecting data in the network level, depending on the type of application.

In each turn, the total energy consumption of UAVs $E^{t}_{UAV_k}$ can be calculated as follows:

$$E^{t}_{UAV_k} = E^{uav}_{mo} \sum_{k \epsilon U} \sum_{i \epsilon N\{n+1\}} \sum_{j \epsilon N\{0\}} X^{k}_{i,j} . d_{i,j} + \tau f E^{uav}_{rx} \sum_{k \epsilon U} \sum_{i \epsilon N\{n+1\}} \sum_{j \epsilon N\{0\}} X^{k}_{i,j} \quad (7)$$

The first part of the equation above indicates the energy consumption to move it from one virtual grid point to another. The second part is the energy required to receive the data collected from cluster headss and the energy needed to send data to the control center.

The objective function of the VGEEDDG problem can be expressed as the MILP problem:

$$\boldsymbol{Min \ \ f_1 = \left(\sum_{k \epsilon U} E^{t}_{UAV_k} + \sum_{i \in W} E^{t}_{ch_i}\right)}$$

$$\boldsymbol{Min \ \ f_2 = \sum_{k \epsilon U} T_k}$$

$$\boldsymbol{Min \ \ f_3 = \kappa} \quad (8)$$

In the optimization formula (8), our goal is to minimize the energy consumption of cluster heads in sending and collecting data and energy of UAVs in receiving data (Part 1 of Formula 8), the minimum time required to collect data from the network level The minimum number of UAVs needed to collect data from the network level (Part 1 and 2).

VGEEDDG has many constraints that can be used to handle the categories (virtual grid, Arrival UAV at Virtual Grids and Nodes, Sub-tour Elimination Constraint, UAV buffer, UAV Maximum Flight Distance, cluster head energy, UAV energy, Minimum Travel Time of UAV and also the minimum number of UAVs). Constraints include:

- **Virtual Grid Constraints**:

$$\sum_{k \in U} B_{i,k} = 1 \qquad \forall\, i \in W \qquad (8.1)$$

$$\sum_{i \in G} G_{i,k} = 1 \ , \quad \forall\, k \in U \qquad (8.2)$$

$$\sum_{k \in U} G_{i,k} \le 1 \ , \quad \forall\, i \in G \qquad (8.3)$$

$$B_{i,k} \le \ G_{j,k} \quad , \forall i \in W, \forall j \in G, \forall k \in U \qquad (8.4)$$

$$A_{i,j} \le \ G_{j,k} \quad , \forall i \in W, \forall j \in G, \forall k \in U \qquad (8.5)$$

$$G_{i,k}.\, t_{max} \le t_i \ge G_{i,k}.\, t_{min} \quad , \forall i \in G \ , \forall k \in U \qquad (8.6)$$

The constraint (8.1) means that each WSN must be covered by a UAV. Constraint (8.2) means that each UAV must cover a grid. This constraint (8.3) means that each grid must be covered by a UAV at most. The constraint (8.4) means that if wsn_i can be connected to UAV_k, the UAV will be located in the $grid_j$. Constraint (8.5) means that if wsn_i can send its data to $grid_j$, this grid is covered by the UAV_k. This constraint (8.6) means that if the UAV is stopped in the grid, the random value for t_i is selected in the interval τ_{min} and τ_{max}.

- **Arrival UAV at V. Grids and Nodes Constraints:**

$$\sum_{k \in U} \sum_{j \in N\setminus\{0\}} X^{k}_{i,j} = 1, \quad \forall i \in G \ (8.7)$$

$$\sum_{k \in U} \sum_{i \in N\setminus\{n+1\}} X^{k}_{j,i} = 1, \quad \forall j \in G \ \ (8.8)$$

$$\sum_{i \in N\setminus\{n+1\}} X^{k}_{i,p} - \sum_{j \in N\setminus\{0\}} X^{k}_{p,j} = 0, \forall p \in G, \forall k \in U \qquad (8.9)$$

$$\sum_{k \in U} \sum_{j \in N\setminus\{0\}} X^{k}_{0,j} = \kappa \qquad (8.10)$$

$$\sum_{k \in U} \sum_{j \in N\setminus\{n+1\}} X^{k}_{j,n+1} = \kappa \qquad (8.11)$$

$$\sum_{k \in U} \sum_{i \in N\setminus\{n+1\}} X^{k}_{i,0} = 0 \qquad (8.12)$$

$$\sum_{k \in U} \sum_{j \in N\setminus\{0\}} X^{k}_{n+1,j} = 0 \qquad (8.13)$$

$$X^{k}_{i,i} = 0, \forall i \in N, \forall k \in U \qquad (8.14)$$

Each middle virtual grid point should be connected to only one output node (Constraint 8.7). Each middle virtual grid point should only be connected to an input node (constraint 8.8). In each virtual grid point, the input flow is equal to the output flow (constraint 8.9). The number of nodes in the node is 0 equal to κ (Constraint 8.10). The number of inputs of the node n + 1 is equal to κ (Constraint (8.11)). The number of inputs of node 0 is 0 (Constraint 8.12). The number of outputs of the n + 1 node is 0 (Constraint 8.13). The absence of a loop in the node (Constraint 8.14).

- **Sub-tour Elimination Constraint:**

$$y_i - y_j + N.\sum_{k \epsilon U} x^{k}_{i,j} \le N - 1, \forall i, j \in N\setminus\{0, n+1\}, i \ne j \qquad (8.15)$$

Absence of the Sub-tour of the path (Constraint (8.15))

- **UAVs Buffer Constraint:**

$\sum_{i\in W} \rho_i \sum_{j\in N\setminus\{0\}} X_{i,j}^k \leq \varphi_k\ , \ \ \forall k \in U$ (8.16)

The data collected by the UAV should not be greater than the UAV buffer size (Constraint 8.16).

- **UAV Maximum Flight Distance Constraint:**

$\sum_{i\epsilon N\{n+1\}} \sum_{j\epsilon N\{0\}} X_{i,j}^k . d_{i,j} \ \leq \tau v\ , \quad \forall\ k \in U$ (8.17)

Maximum distance that any UAV can travel is predetermined and traveled distance should not exceed it. (Constraint 8.17).

- **Energy of Cluster Head Constraints:**

$t_c p_j - \sum_{i\in G} t_i\, f G_{ik}\, \overline{H}_{i,j} = 0, \forall j \in W\ , \forall k \in U$ (8.18)

$\sum_{i\in W} A_{i,j} \tau\, f\left(\theta_1 + \theta_2 \bar{d}_{i,j}^2\right) = E_{ch_i}^t, \forall j \in G$ (8.19)

$f e_{ij}^{tx} \sum_{i\epsilon W} \sum_{j\epsilon W} X_{i,j}^k . \left(t_{i,j} + t_i\right) + f e_{ij}^{rx} \sum_{i\epsilon W} \sum_{j\epsilon W} X_{i,j}^k . \left(t_{i,j} + t_i\right) \leq e_0$ (8.20)

The constraint (8.18) means that the energy consumption of the cluster head i is specified for transmitting data of the cluster members to the specific UAV. Constraint (8.19) states that all data stored in the cluster head is sent to the UAV at the virtual grid point. Constraint (8.20) ensures that the energy consumption of each CH, including the receipt of data, cannot exceed its initial energy e_0.

- **Energy of UAV Constraint:**

$$E_{UAV_k}^t = E_{mo}^{uav} \sum_{k\epsilon U} \sum_{i\epsilon N\setminus\{n+1\}} \sum_{j\epsilon N\setminus\{0\}} X_{i,j}^k . d_{i,j} \quad (8.21)$$
$$+ \tau f (E_{rx}^{uav} + E_{tx}^{uav}) \sum_{k\epsilon U} \sum_{i\epsilon N\setminus\{n+1\}} \sum_{j\epsilon N\setminus\{0\}} X_{i,j}^k$$
$$E_{UAV_k}^t \leq E_{max}^{uav}, \forall\ k \in U \quad (8.22)$$

The energy consumed by UAV_k for its movement energy, energy consumption to receive data from cluster nodes and energy consumption for sending. The energy consumed by a UAV should not exceed the maximum energy consumed (Constraints 8.21 and 8.22).

- **Minimum Travel Time of UAV Constraints:**

$\sum_{i\epsilon N\setminus\{n+1\}} \sum_{j\epsilon N\setminus\{0\}} X_{i,j}^k . \left(t_{i,j} + t_i\right) \leq T_k\ , \forall k \in U$ (8.23)

$T_k \leq \tau$ (8.24)

Each UAV stops at the virtual grid point to process data and spends time t_i . The UAVs movement time is between two virtual grid points, in other words, the time spent on each route should not be much more than the maximum UAV traveled time (Constraint 8.23). The UAV maximum traveled time (T_k) should not be more than the deadline time (τ) (Constraint 8.24).

- **Minimum No. of UAVs Constraints:**

$\sum_{k\in U} \sum_{j\epsilon N\setminus\{0\}} X_{0,j}^k = \kappa$ (8.25)

$\kappa \leq K$ (8.26)

The minimum number of active UAVs (κ) must be less than the maximum number of available UAVs (K) (Constraints 8.25 and 8.26).

- **Non Negative and Binary Decision:**

$N = \{0,1 \ldots, n, n+1\}$ (8.27)

$W = \{1 \ldots, n\}$

$G = \{1 \ldots, n\}$

$U = \{1, \ldots, k\}$

$B_{i,j} = \{0,1\}, \quad \forall i \in W, j \in U$

$G_{i,j} = \{0,1\}, \quad \forall i \in G, j \in U$

$x_{i,j}^k = \{0,1\}, \quad \forall i, j \in N, k \in U$

$\overline{H}_{i,j} = \{0,1\}, \quad \forall j \in W\ , \forall k \in U$

$t_i, \tau_{min}, \tau_{max} \geq 0$

$0 \leq v \leq v_{max}$

$h_{min} \leq h \leq h_{max}$

The constraint (8.27) is necessary because B, G and X are binary decision variables and the variables τ, v, h, and t_i are non-negative.

5) MINIMIZE THE TOUR TIME OF MULTIPLE UAV:

In this section, we detail the strategies for minimizing travel time of multiple UAVs for deadline based WSN applications. The pseudo-code VGEEDDG in algorithm 1 is presented in Fig. 8.

Theory 3: The N set is defined as network nodes that contain nodes 1 through n, which considered as virtual grid points and virtual nodes 0 and n + 1 as start and end of the route of all UAVs. K represents the number of UAVs used in collecting data, τ is a

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threshold representing a deadline time, T_k is the maximum time that a UAV needs to end the tour in a T_{round} run, ρ_i the data value which is collected in the cluster head, f is the fixed transfer rate (bits per second) of the UAV, $d_{i,j}$ shows the euclidean distance of the node i to node j and v is the speed of the UAV. This is the only energy efficient data gathering using multiple UAVs in deadline based WSN applications if and only if the travel time between the nodes (t_{ij}) and the sojourn time (t_i) of each UAV in the virtual grid points should not be greater than the maximum travelled time T_k (Equation 9) as well as the maximum UAVs travelled time (T_k) for the end of a tour must not exceed the given deadline time τ. (Equation 10).

$$\sum_{i\epsilon N\{n+1\}}\sum_{j\epsilon N\{0\}}X_{i,j}^{k}.\left(\frac{d_{i,j}}{v}+\frac{\rho_i}{f}\right)\leq T_k\ ,\forall k (9)$$

$$T_k \leq \tau \quad (10)$$

Proof: To collect data with minimum energy using an UAV in deadline based WSN applications, all buffered data in the cluster head must be sent to the UAV in a deadline time. T_k is the maximum time for a UAV to complete a tour in a T_{round} run not to be greater than the given deadline time interval τ. T_k can be calculated as follows:

$$T_k = \sum_{i\epsilon N\{n+1\}}\sum_{j\epsilon N\{0\}}X_{i,j}^{k}.\left(t_{i,j}+t_i\right) \quad (11)$$

T_k is the UAV travelled time, which includes the travel time between the nodes (t_{ij}) of the sojourn time (t_i) of each UAV in the virtual grid points. The sojourn time (t_i) depends on the buffer data given in the cluster head (p_i) and the constant transmission rate (f). This can be calculated as follows:

$$t_i = \frac{\rho_i}{f}, \forall i \in W \quad (12)$$

It is also possible to calculate the travel time between the nodes (t_{ij}) with respect to $d_{i,j}$ the euclidean distance from node i to node j and velocity v of UAV:

$$t_{ij} = \frac{d_{i,j}}{v}, \forall i,j \in N \quad (13)$$

By putting Equations (12) and (13) in (11), the UAV travelled time can be rewritten as follows:

$$T_k = \sum_{i\epsilon N\{n+1\}}\sum_{j\epsilon N\{0\}}X_{i,j}^{k}.\left(\frac{d_{i,j}}{v}+\frac{\rho_i}{f}\right) \quad (14)$$

Therefore, most of the time when a UAV needs to complete a tour in a T_{round} run, it should not be greater than the given deadline time τ given as follows:

$$T_k = \sum_{i\epsilon N\{n+1\}}\sum_{j\epsilon N\{0\}}X_{i,j}^{k}.\left(\frac{d_{i,j}}{v}+\frac{\rho_i}{f}\right) \leq \tau\ ,\forall k \in U$$

If a timed τ is sufficient, a steady-speed UAV can collect all buffered data from clusters individually, and cluster heads transfer their collected data with minimum energy to UAV, because a UAV is placed in the closest transmission range of each CH. In fact, in many applications, especially in practical applications, the deadline time depends on the critical level, and as a result, this deadline time for data collection is not enough, and a UAV cannot collect data from clusters with a minimum total energy. In this situation, there are seven strategies for solving this problem:

1. **Change the speed of a UAV.**

In this strategy, we use a single UAV to collect buffered data in clusters from virtual grid points with UAV variable velocity. This is the first solution to the problem when using a UAV with the ability to change its speed throughout the cluster heads' path to collect data. The question is, when should UAV increase or decrease its speed, and how it can determine the optimum speed for the UAV. To answer this question, we offer two modes:

1) If the deadline is at most $\tau_{\max}$, a fixed-speed UAV can collect all buffered data in cluster headers individually. And as a result, the UAV does not change its speed and does not need to increase its speed.
2) Otherwise, the deadline is at least $\tau_{\min}$, the speed of the UAV increases so that a UAV can stay between several cluster heads and collect their data at the same time. However, the UAV speed v should be less than or equal to the predetermined maximum speed $v_{\max}$.

As a result, the UAV speed v should be changed according to the deadline time and distance of the UAV. And v will be calculated based on theory 3 and will be calculated as follows:

$$v = \frac{\sum_{i\epsilon N\{n+1\}}\sum_{j\epsilon N\{0\}}X_{i,j}^{k}.d_{i,j}}{T_k f-\sum_{i\epsilon N\{n+1\}}\sum_{j\epsilon N\{0\}}X_{i,j}^{k}.t_i} \quad (15)$$

2. **Change the transmission range of cluster heads.**

This strategy can be done by adjusting and changing the transmission range of CH to transfer data, and each node has the ability to set its transmission range. The problem is whether all clusters need to increase their transmission range? There are two ways to increase the transmission range (radius of transmission) of the cluster heads:

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1) **The transmission range of all cluster heads increases evenly.**

Increasing the transmission range depends on the deadline time. So we have two modes:

- If the deadline time is at most $\tau_{\max}$, the UAV will have enough time to collect data from cluster heads. Therefore, when the UAV is placed in the closest transmission range of each CH, CH uses its minimum energy to transfer its buffered data to the UAV. As a result, cluster heads do not change their transmission range and do not require an increase in their transmission radius.
- If the time period is at least $\tau_{\min}$, all cluster heads must increase their transmission radius so that a UAV can stay between several clusters and collect their data simultaneously. But cluster heads use up their energy. So in this case, cluster heads increase their transmission range according to the deadline time.

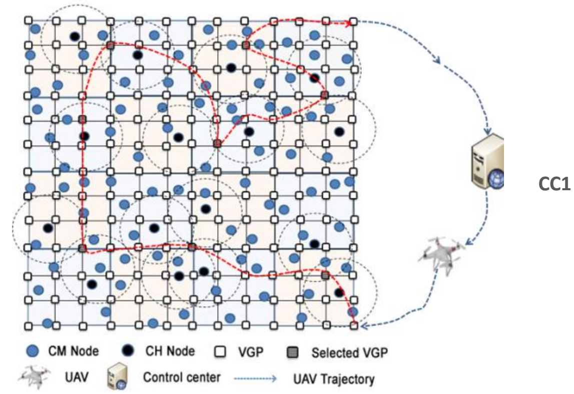
2) **The transmission range of some cluster heads increases.**

Increasing the transmission range of each cluster depends on the length of the trajectory travelled by the UAV. Some cluster heads can change their transmission range to reduce the total length of the route taken by the UAV. So we have two modes:

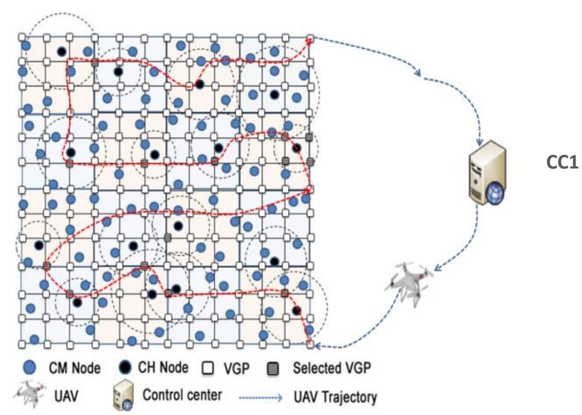
- The path taken by the UAV is less than or equal to the maximum distance it can move that is already specified($\sum_{i\epsilon N\{n+1\}}\sum_{j\epsilon N\{0\}} X_{i,j}^{k}.d_{i,j} \leq d_{max}$) In this case, we can use multiple UAVs or change the speed or height of the UAV to collect data in deadline time. Therefore, cluster heads do not change their transmission range and do not require an increase in their transmission radius.
- The path traversed by the UAV is greater than the maximum distance that can be moved that is already specified ($\sum_{i\epsilon N\{n+1\}}\sum_{j\epsilon N\{0\}} X_{i,j}^{k}.d_{i,j} > d_{max}$) In this case, some cluster heads must change their transmission range so that the total path traveled by the UAV is less than or equal to the maximum distance d_{max} that can be moved and collect cluster head data. Figure 5 shows a network model for increasing all cluster heads or some cluster heads. As shown in Fig. 5.

3. **Change the height of an UAV to collect data simultaneously from several CHs.**

If deadline time is the maximum value, the UAV can collect their data at the closest distance from each CH. For this reason, UAVs can lower their altitude, because when the altitude is lower, the distance is shorter, and as a result, the cluster sends its data to the UAV at its lowest energy. But when the deadline time is the minimum, the UAV must increase its height simultaneously to collect data from several cluster heads, as a result of which the cluster head energy is consumed more quickly, which reduces the lifespan of the network because the cluster heads they have to send their data to the UAV for a long time (As shown in Fig. 6). The UAV is not allowed to fly over h_{max}. In addition, the UAV can not fly below altitude h_{min}.



(A)



(B)

Figure 5: Network model for strategy 2: A-Increasing the transmission range of all cluster heads B-Increasing the transmission range of transmission of some cluster heads.

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4. Change the elevation angle of an UAV

The probability of LoS depends on the elevation angle between the cluster head and the UAV [26]. So :

- If the deadline time τ is sufficient, the UAV will have enough time to collect cluster data individually. Therefore, the UAV does not need to increase its elevation angle, and CH uses its minimum energy to transfer its buffered data to the UAV.
- If the deadline time τ is not enough, the UAV should increase its elevation angle so that it can stay between several clusters and collect data at the same time. In this case, the cluster heads use the maximum energy, since cluster heads should send their data to the UAV for a long time. As shown in Fig. 6.

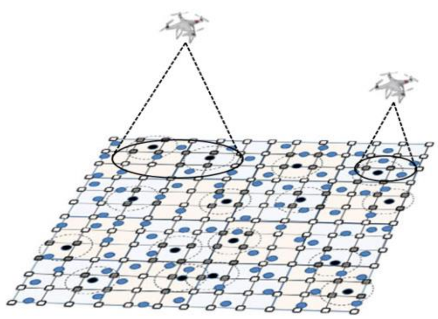

Figure 6: Network model for increasing UAV altitude

5. Use more than one UAV to collect data from cluster heads

Unfortunately, for some practical applications, any data collection tour may take a long time that a UAV may not be enough to visit the entire range of cluster heads before buffering overflow. So in this way, a number of steady-speed UAVs can take all the buffer data from several CHs to reduce energy. Hence, the main problem is how to determine the optimal number of UAVs needed to collect all buffered data from cluster heads in order to reduce the energy of cluster heads without violating the deadline time. Figure 7 shows that the four control centers (CC1, CC2, CC3 and CC4) and four UAVs to collect data from the CHs located in a given area. As shown in Figure 7, the entire network can be sub-divided into sub-networks. In each subset, the UAV is responsible for collecting data from local nodes under the network. The following model provides the minimum number of required UAVs for collecting data from the network level indicating that the minimum number of active UAVs (κ) should be less than the maximum number of available UAVs (K).

$$\boldsymbol{minimum} \ \sum_{k\epsilon U} \boldsymbol{\kappa} \qquad (16)$$

$$\sum_{k\in U} \sum_{j\epsilon N\setminus\{0\}} X_{0,j}^{k} = \kappa$$

$$\kappa \le K$$

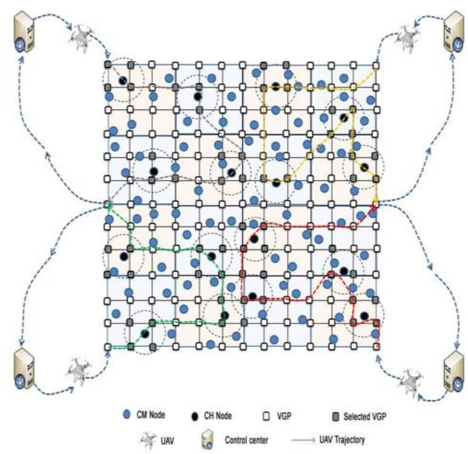

Figure 7: Network model to increase the number of UAVs

6. Determine Optimal Sojourn Time:

The UAV's sojourn time at any virtual grid point should be specified based on the predetermined deadline time. In addition, when the sojourn time of the UAV at any point in the virtual grid point increases, additional time increases due to an increase in the UAV sojourn time. As a result, the total UAV traveled time to gather data from cluster heads will increase. Therefore, the total UAV sojourn time at the selected virtual grid points should be less than or equal to the deadline time.

$$\sum_{i\epsilon G} G_{ik}.t_i \le \tau, \forall k \in U \ (17)$$

$$G_{i,k}.t_{max} \le t_i \ge G_{i,k}.t_{min}, \forall i \in G, \forall k \in U$$
(18)

t_i is the time required to stop the UAV at the virtual grid point, and the binary parameter G_{ik} if equal to one, the $grid_i$ is covered by UAV_j. Therefore, UAV_j in $grid_i$ will remain between t_{min} and t_{max} for a time t_i. Otherwise, the UAV_j will not remain in the virtual grid point $grid_i$. It is obvious that the UAV's sojourn time at any point in the virtual grids should be optimal and without violating the deadline time.

7. Find the optimal collection of virtual grid points

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Each virtual grid point represents a place where the UAV stops and collects data from cluster heads. Clearly, with the increase in the number of virtual grid points, the UAV's time to collect all buffered data from cluster heads increases. This time depends on the time the UAV moves between the virtual grid point and sojourn time when it stays at any virtual point in the virtual grid for transmission. Therefore, we must find the minimum number and location of the virtual grid points for the UAV to collect all buffered data from the cluster heads in order to reduce the energy of the cluster heads and also the energy of the UAV in terms of deadline time constraints. Therefore, the total traveled time of the $\mathrm{UAV_k}$ can be written as:

$$T_k = \sum_{i\epsilon G}\sum_{j\epsilon G} X_{i,j}^{k}.\left(t_{i,j} + t_i\right), \forall k \in U$$

$t_{i,j}$ is the time of movement of the UAV, t_i is the time it takes to stop the UAV at the point of the virtual grid and G is the set of virtual grid points. It is obvious that the entire time of movement depends on the distance between the virtual grid points and the place and the number of virtual grid points. In this study we use the weighting scheme in [26] as follows:

Definition 5:

Suppose that N is the total number of cluster heads, G is the total number of virtual grid points, N_{CH} is the total number of cluster heads belonging to the virtual grid point, ℓ_k the total length of the routing of the shortest path from the current grid point VGP_k to all points in the grid virtual $G-1$ ،($d(VGP_k, CC)$ the distance between the current virtual grid point VGP_k and the control center CC , τ are the deadline for delivery from the cluster head. The virtual grid point VGP_k is optimal if and only if:

$$W(VGP_k) = max\left(\alpha\frac{1}{\ell_k} + \beta\frac{N_{CH}}{N} + \gamma\frac{1}{d(VGP_k,CC)} + \lambda\tau_{ni}\right), k = 1, \dots, N \quad (19)$$

The coefficients α, β, γ and λ with importance / weight assigned to the total length of the shortest route routing, the total number of cluster heads belonging to the virtual grid point VGP_k , the distance between the current virtual grid point VGP_k and the CC control center and the deadline is delivered from the cluster head, so that $\alpha + \beta + \gamma + \lambda = 1$ and $\alpha > 0, \beta > 0, \gamma > 0, \lambda > 0$.

Algorithm 1: Virtual Grid Energy Efficient Deadline based Data gathering (***VGEEDDG***).

1. **While** alive nodes
2. Receive time deadline τ from practical application
3. Start the rounds($\mathrm{Round_i} = 0$)
4. Virtual Grid Formation
5. Clusters formation and clusters head selection during time t_c
6. Data gathering from CMs by CHs during time t_d
7. Setting $T_k = 0$
8. **While** $T_k \leq \tau$ do
9. According to the τ, choose the solution:
   - ❖ **Solution 1**: The no. of UAV is set to 1 and velocity v of UAV will be changed
     - **If** $\tau = \tau_{max}$ then the velocity v of UAV will not be changed
     - **If** $\tau = \tau_{min}$ then the velocity v of UAV will be increased with condition $v \leq v_{max}$
   - ❖ **Solution 2**: The transmission range of CHs will be increased according to τ and d_{max} :
     - **If** $\tau = \tau_{max}$ then the transmission range of all CHs will not be changed
     - **If** $\tau = \tau_{min}$ then the transmission range of all CHs will be increased
     - **If** $\sum_{i\epsilon N\{n+1\}}\sum_{j\epsilon N\{0\}} X_{i,j}^{k}.d_{i,j} \leq d_{max}$ then the transmission range of CHs will not be changed
     - **If** $\sum_{i\epsilon N\{n+1\}}\sum_{j\epsilon N\{0\}} X_{i,j}^{k}.d_{i,j} > d_{max}$ then the transmission range of some CHs will be increased
   - ❖ **Solution 3**: The velocity of UAVs is set to constant and the optimal no. of UAVs will be determined by equation(15)
   - ❖ **Solution 4**: The height of UAV will be changed according to τ:
     - **If** $\tau = \tau_{max}$ then the height of UAV will not be changed
     - **If** $\tau = \tau_{min}$ then the height of UAV will be increased
   - ❖ **Solution 5**: The elevation angle of UAV will be changed according to τ:
     - **If** $\tau = \tau_{max}$ then the elevation angle of UAV will not be changed

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- **If** $\tau = \tau_{min}$ then the elevation angle of UAV will be increased

10. Finding the optimal virtual grid points according to OVGP algorithm (1)
11. Finding the optimal sojourn time according to to OST algorithm (2)
12. Data gathering from all CHs by single UAV or multiple UAV
13. $T_k = T_k + \sum_{i\epsilon G}\sum_{j\epsilon G} X^k_{i,j}.(t_{i,j} + t_i), \forall k \in U$
14. **End While**
15. Increasing the no. of rounds ($Round_i = Round_i + 1$)
16. **End While**

Figure 8: VGEEDDG Pseudo Code

Algorithm 2: Optimal Virtual Grid Points (**OVGP**).

1. **Input**: Deadline time τ ,Current location of UAV, allocated cluster heads and virtual grid point list G
2. **Output**: Optimal virtual grid points to gather the data from CHs
3. **While** G is not empty do
4. Compute weighted sum W for all grid point in list G according to equation (19)
5. Select the virtual grid point VGP with maximum weight
6. Add virtual grid points of G with the maximum weight to optimal virtual grid points list VGL
7. Remove the current virtual grid points of G with the maximum weight from G
8. **End while**
9. $T_k = 0$
10. **While** $T_k \leq \tau$ do
11. Select the VGP with maximuin weight from optimal virtual grid points list VGL
12. Remove the current virtual grid points with the maximuin weight from VGL
13. Compute T_k for the virtual grid point VGP
14. $T_k = T_k + \sum_{i\epsilon G}\sum_{j\epsilon G} X^k_{i,j}.(t_{i,j} + t_i)$
15. **End while**
16. **If** the buffered data from all CHs are gathered, terminate the algorithm.

Else, Increase the speed, number or height of UAV or increase the transmission range of CHs. And return to Step 3.

Figure 9: OVGP Pseudo Code

Algorithm 3: Optimal Sojourn Time(**OST**).

1. **Input**: Deadline time τ ,Current location of UAV, allocated cluster heads and virtual grid point list
2. **Output**: Optimal Sojourn Time
3. $t_i = 0$
4. **While** $\sum_{i\in G} t_i \leq \tau$ do
5. **If** virtual grid point g_i is selected by UAV_k then
6. Select Sojourn Time t_i between t_{min} and t_{max}
7. Send the buffered data in CHs to the UAV located at point g_i during the sojourn time t_i.
8. **Else** $t_i = 0$

End While

Figure 10: OST pseudo code

6) SIMULATION AND PERFORMANCE EVALUATION:

In the first part of this section, simulation settings are explained; then, in the next section, we evaluate the effectiveness of the VGEEDDG framework strategies by comparing them.

We use four metrics to evaluate the performance of our proposed framework. The first metric of the death of the first sensor node as a sensor network lifetime. The second metric of average energy consumption as the average energy consumed by all UAVs to end the tour. The third metric is the maximum traveled distance, which is defined as the average length of the tour used by all UAVs to end one round. The last metric is the total traveled time defined as the average maximum travel time for UAVs to end a round.

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6.1 Simulation settings

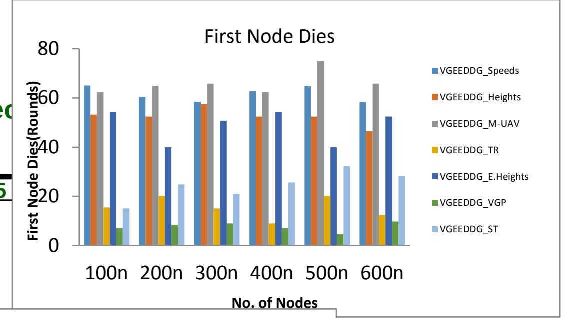
In this simulation, the size of the 600x600 square meter network is assumed to be 139 × 13 = 169 virtual grid with a distance of 10 meters between the grid points. Evaluation Using MATLAB software as a implementation platform, the PuLP library has been implemented to perform the MILP optimization function on a system with a core processor unit Core i5-2410M 2.30 GHz and 4 gigabytes of main memory. The other simulation parameters are summarized in Table 4.

Table 4: Simulation Parameters

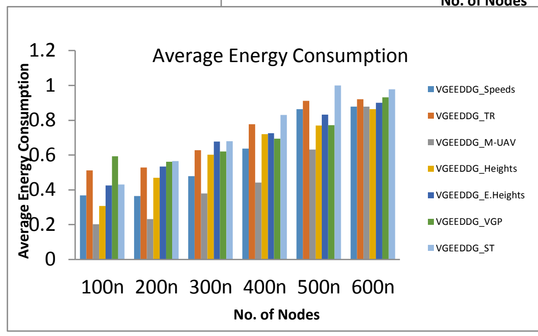
Parameter	Value
Area size	600 × 600 m^2
No. of grids	(4×4) (6×6) (8×8) (10×10) **(13×13)**
No. of sensors	**100** 200 300 400
No. of UAV	**2** 3 4 5
Speeds of UAV	10 **20** 30 40 m/s
Heights of UAV	50 60 **70** 80 m
Deadline Times τ	60 **80** 100 120 s
Sojourn Times t_i	**30** 45 60 75s
Transmission range	20 **40** 60 80 m
UAV Elevation Angles	30 **45** 60 75 deg
Transmission bit rate f	200 kbps
Initial energy E_0	0.1 J
Packet size	2000 bit
d_{max}	30 km
v_{max}	40 m/s
t_{max}	0.0001
t_{min}	1000
h_{max}	90 m
h_{min}	10 m
θ_1, θ_2	10 nJ/b/m^2, 30 pJ/b/m^4
E_{max}^{uav}	70 KJ

6.2. Evaluation of the proposed framework strategies compared to each other

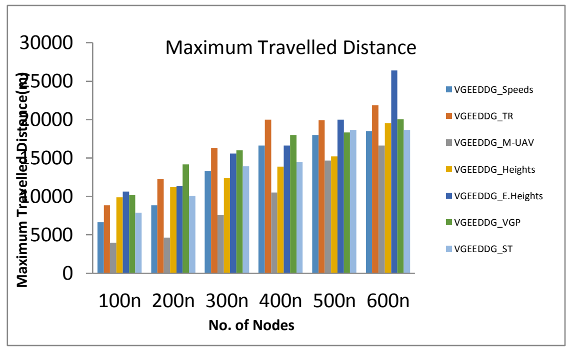
In this part of the simulation, we will compare the proposed strategies for the lifetime of the network, the maximum travelled time of the tour and the maximum distance of the UAV. For this comparison, we consider seven strategies related to the proposed framework. We define the minimum deadline strategies as VGEEDG_Speeds, VGEEDDG_T.Ranges, VGEEDDG_M.UAVs, VGEEDDG_Heights, VGEEDDG_E.Heights, VGEEDDG_S.T, and VGEEDDG_VGP, and compare them with each other.



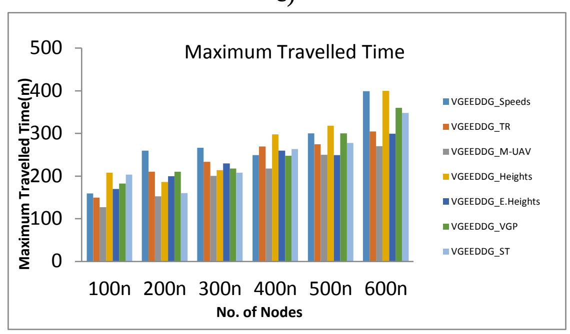
a)



b)



c)



d)

Figure 11: a) Comparison of the First Node Die b) Comparison of Energy Consumption c) Comparison of the Maximum Travel Time d) Comparison of Maximum Travelled Distance for tour time minimization strategies.

The results shown in Figure 11.a show that both proposed strategies (VGEEDG_M.UAVs and VGEEDG_Speeds) have better network lifetime performance than other strategies. The proposed strategy network lifecycle can be easily ordered from best to worst: VGEEDDG_M.UAVs, VGEEDDG_Speeds, VGEEDDG_ST, VGEEDDG_E.Hieghts, VGEEDG_Hieghts,

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VGEEDDG_TR and VGEEDDG_VGP). Figure 11.b shows the average energy consumption between these seven strategies. Clearly, with increasing number of nodes, the average energy consumption of each strategy increases. As shown in Figure 11.b, the proposed VGEEDDG_M.UAVs and VGEEDDG_Speeds designs have lower energy consumption than other strategies. In Figure 11.c, it can be seen that for each strategy, the maximum traveled distance increases with increasing number of nodes. VGEEDDG_M.UAVs and VGEEDDG_Speeds strategies are better than the other proposed strategies. As shown in Figure 11.d, the VGEEDG_M.UAV and VGEEDG_Speeds strategies show the maximum traveled time less than other strategies. In addition, as shown in Fig. 11.d, when the number of sensors increases, maximum traveled time increases.

7) COCLUSIONS:

In this paper, a framework is proposed to solve the problem of increasing the efficiency of data collection. We cite this problem as problem of energy-efficient data gathering using multiple UAVs in deadline based WSN applications by taking into account some of the virtual grid points, this problem named VGEEDDG. We first formulate the VGEEDDG problem into a MILP model, then, if the deadline time τ is not enough to collect data from cluster heads, a UAV cannot collect data from the cluster heads with minimal energy. In this situation, we provide seven strategies for solving the problem of insufficient deadline time.

Simulation is used to compare the performance of strategies (which is used to solve the deadline problem) in different scenarios. The results show that the proposed framework is able to provide efficient data collection with satisfactory energy constraints and a deadline.

Four interesting directions are referred to as future work. Providing an optimal clustering plan and cluster head selection algorithm is the first direction. Secondly, a distributed algorithm is proposed to achieve the optimal route planning of an UAV based on virtual grid points. The third direction could expand the proposed framework to support the mobile wireless sensor network. The last direction is to extend the proposed framework to support real-time applications.

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