UAV Routing Protocol for Crop Health Management

Muhammad Ammad-udin[1,2], Ali Mansour[1], Denis Le Jeune[1], el. Hadi M. Aggoune[2], Muhammad Ayaz[2]
[1]Lab STICC, ENSTA Bretagne, Brest, France
[2]Sensor Network and Cellular Systems (SNCS) Research Center, University of Tabuk, Tabuk 71491, KSA
mashfaq@ut.edu.sa, mansour@ieee.org, denisle_jeune@ensta-bretagne.fr,
aggoune.sncs@ut.edu.sa, ayazsharif@hotmail.com

Abstract —**Wireless sensor networks are now a credible means for crop data collection. The installation of a fixed communication structure to relay the monitored data from the cluster head to its final destination can either be impractical because of land topology or prohibitive due to high initial cost. A plausible solution is to use Unmanned Aerial Vehicles (UAV) as an alternative means for both data collection and limited supervisory control of sensors status. In this paper, we consider the case of disjoint farming parcels each including clusters of sensors, organized in a predetermined way according to farming objectives. This research focuses to drive an optimal solution for UAV search and data gathering from all sensors installed in a crop field. Furthermore, the sensor routing protocol will take into account a tradeoff between energy management and data dissemination overhead. The proposed system is evaluated by using a simulated model and it should find out a class among all under consideration.**

Keywords- Smart farming; Routing protocol; Precision agriculture; Data gathering; Wireless sensor network, UAV

I. INTRODUCTION

The total area of the Kingdom of Saudi Arabia (KSA) is 2,149,690 km^2. While, only 1.6% of it is urban area, and about 80% (1,736,250 km2) is desert of which only 1.6% is agriculture land [1]. The biggest hurdles for cultivation are the shortage of water, the spread of land, and adverse weather and atmospheric conditions. To cope with the scarcity of water, there is a need to equip the agricultural sector with modern tools and implement scientific approaches suggested by the fast-developing precision agriculture and smart agriculture relying on Wireless Sensor Networks (WSNs) to achieve sustainability. More recently, with the advent of Unmanned Aerial Vehicles (UAVs) and the accompanying progress in research and development in ad-hoc and vehicular communication, WSNs are positioned to gain further functionality. Some of the nodes can become dynamic (carried by UAVs) facilitating both data collection and wireless communication in areas that are not equipped with fixed communication infrastructures. Sensors are normally planted in strategic locations forming disjoint network and sub-networks in individual parcels. The data can be collected from the individual networks using UAVs that have the ability to loiter and hover at certain collection points. The objective is to collect and store vital data relative to the environment, soil, and crop and allowing farmers to make timely decisions or decision is taken by automatic Supervisory Control and Data Acquisition (SCADA) system. In this proposed system, all the field sensor nodes are taken static while, a mobile sink (UAV) is used to harvest the field data. The system is supposed to be dynamic enough to adopt network changes like nature of data, type of sensors, number of alive sensor node, field area of interest, and path of UAV in every mission, as well as robust in the sense that can sustain even in severe weather and geographical conditions.

Many routing and data gathering schemes are developed and proposed for wireless sensor networks, we classify existing schemes into four categories: 1) static sink routing, 2) mobile sink direct contact data collection and 3) rendezvous based data collection 4) Hash Table based routing.

Static sink routing protocols like LEACH [2], HEED [3], Linked cluster [4], Adaptive clustering [5], random competition based clustering [6], and node hierarchical control clustering [7] are not suitable in our scenario because of their fix communication infrastructure and no compatibility with mobile sink (UAVs), therefore we are not discussing them.

Other related three types of protocol are described below and comparison is given in TABLE 1.

A. Mobile Sink Direct Contact Data Collection

In this category of protocols, data is collected from the sensor network by using mobile sinks. But sink has to collect data by visiting each sensor node in the network one by one, therefore is not considered efficient, due of very low latency and small coverage area.

B. Rendezvous based Data Collection

In this type of data collection, sensor nodes are grouped in clusters and the mobile sink has to visit each cluster at predefined rendezvous (appointment points) which acts as CH and delivers the data to the mobile sink.

C. Hash Table

Data is hashed according to the geographical locations and collected by static or mobile sink [8].

D. Distinction of our Proposed System

In our proposed system, fixed (static) sensor nodes are deployed in a crop field and a mobile sink (UAV) is used to collect data. All the sensor nodes are heterogeneous in nature and deployed to monitor different parameters. Sensor nodes are unaware of their location, the location of UAV and its path. The first distinction of this research is that only specific data from selective sensors is collected from the field in order to investigate as per need basis. While, second distinction is the path of UAV, which is fixed but adaptive as well means combination of both. Fix in the sense that it needs to follow a predefined path to scan a particular area (suspected area or area of interest) and at the same time UAV can deviate from its path up to certain extent as per location of cluster and cluster head. Clusters are made dynamically with respect to the UAV path. Another difference is the selection of the cluster head, which will be the most suitable node among all others in term of residual energy, location and other parameters. According to the best of our knowledge none of above mentioned categories of protocol has developed such a system having all these characteristics.

By using mobile data collector (UAV), the life of network can be extended significantly as it helps to save the sensor node energy, however the low latency problem exists due to slow movement of UAV. Specifications of UAV, sensor nodes and underlying technologies that can be used for agriculture are investigated to overcome this latency in proposed system.

II. Architecture of the Proposed System

The proposed system is composed of two components: 1) UAVs and 2) sensor nodes, no predefined special cluster head nodes are installed. Specifications of each component is as

TABLE 1. MOBILE SINK DATA COLLECTION

Existing protocols	Path control able	Clustering	Dynamic Clustering	Heterogynous sensor	Dynamic Data	CH mobility	GPS Aware Node	Problems
Direct contact data collection								
[9]							Y	
[10]							Y	No clustering support and fixed mobile sink path
[11]							Y	
[12]							Y	
Rendezvous based data collection								
[13]		Y	Y				Y	Sensor node are equipped with GPS sensor
[14]	Y	Y	Y			Y	Y	Deployment of mobile CH is overhead and not feasible and practical
[15]		Y	Y					At least 2 rounds are required to get data and Sink Path is fix
[16]	Y	Y	Y					All nods are pre located and cluster is made on RSSI value
[17]	Y	Y	Y					Extra energy is required to maintain network topology. Path of UAV is totally decided by sensor nodes and their topology.
[18]	N	Y					Y	Each sensor is location aware and always need a connected graph to make cluster
[8]	Y	Y					Y	Sink is static. Data must be replicated on hashed and home node
[19]	Y	Y	Y			Y	Y	Nodes are mobile and event detection is done by virtual infrastructure
[20]	Y	Y	Y			Y	Y	Nodes are location aware. Keep on tracking the UAV location.

A. UAV

In this research a Dragan flayer X8 [21] equipped with an open source autopilot is used. This UAV can be programmed and rebuild easily.

B. Agriculture Sensors

We can divide agriculture sensors into three main categories according to their data rates and power consumption.

1. Small sized data and low power consumption sensors

Small in size and less costly sensors, that can have only few bytes of data to transmit. There are verities of such type of sensors to monitor different attributes related to environment, soil, and crop like air temperature, humidity, direction, speed, soil temperature and humidity, leaf thickness, leaf color (chlorophyll), trunk thickness, trunk flux flow, and fruit size[22].

2. Medium sized data and medium power consumption sensors

These sensors are bit complicated required more processing, energy and have more data to transfer to the sink node (UAV). Examples are sound and still picture camera [23] based sensors that may have up-to hundreds of KB data.

3. Large sized data and high power consumption sensors

It is well-known that crops are negatively affected by intruders (human or animals) and by insufficient control of the production process. Video-surveillance may be solution to detect and identify intruders as well as to better take care of the production process. These types of sensors support large commutation with high power consumption and are used when bulk of data need to be transfer to the sink node (UAV) like video streaming camera [24].

III. Proposed System

Main points of our proposed system are as:

1. All sensor nodes are heterogeneous and may differ in size, processing power, memory size and available energy and consumption.
2. Field data from heterogeneous sensors is harvested by UAV.
3. Path of UAV is given in advance before mission started and cannot change during mission, however it can be deviated up to a certain extent so that UAV can visit a sensor node closely to collect data more efficiently, and resume the fix path afterward.
4. A mission will be composed of an area of interest that can scan within UAV flight time (dynamic path).
5. Only selective types of sensors will be activated by UAV (required information is dynamic).
6. Sensor nodes are unaware of UAV path, targeted area, and information that need to be collected. All this information is only known by the UAV.
7. Nodes will organize themselves in groups according to the UAV motion and required data (dynamic clustering).
8. Suitable node among all will be selected as a cluster head (dynamic cluster head selection).

In this study we are proposing multi-layer and multi-phase routing protocol. Proposed UAV based routing protocol will be completed in three phases and each phase will be composed of three layers named UAV layer, CH layer and member layer as shown in Figure 1. The tasks in each phase will be processed in distributed and parallel way at each layer.

Phase 1:- Consists of three sub-phases one at each layer		
Localization at UAV layer	**Cluster formation at CH layer**	**Node setup at member layer**
UAV will start routing protocol by sending beacon message to only selected sensors	Selective sensors that are Directly Connected (DC) will activate on getting UAV beacon	
UAV will locate all the sensor nodes in its vicinity		
	DC node will send beacon to activate other nodes (indirect connection with UAV(IDC)	Indirectly Connected Nodes (IDC) nodes will start synchronization with DC nodes

UAV will send necessary information to the DC nodes that is required for clustering process.	All the DC nodes will choose a CH CH will ACK the UAV, to let it know that it is ready to transmit	
Phase 2:- Consists of three sub-phases		
UAV navigation	**Data aggregation**	**Communication**
UAV will locate the CH UAV will start navigation to the CH node	CH will aggregate the overall data CH will ACK the UAV to let it know that it is ready for communication	Non CH (member) nodes will transmit their data to the CH nodes IDC turn into sleep mode
Phase 3:- UAV and CH communication phase		
UAV navigation	**Data aggregation**	**Communication**
UAV start receiving data	CH will start transmission with UAV	

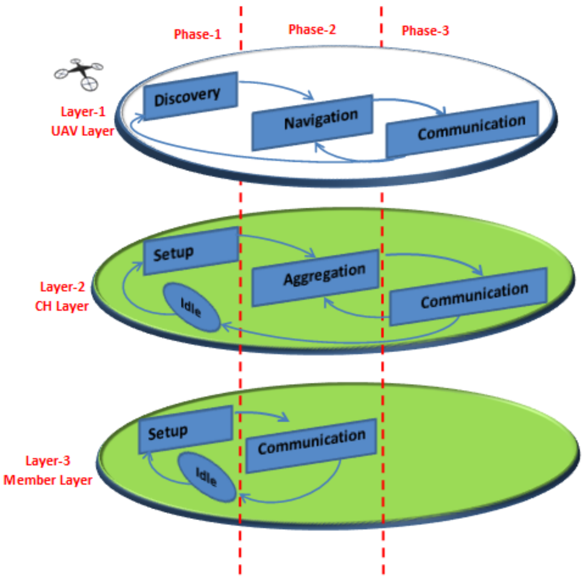

Figure 1: Multi-layers and Multi-phases proposed system architecture

A. Time Synchronization

In the proposed system, data delivery between cluster head and member nodes are conducted by using TDMA scheme to preserve their energy as maximum as possible. TDMA is also used for coordinated sensor wakeup to preserve maximum energy, rather than activated all the time. To use TDMA scheme, all sensor nodes need to be well synchronized so that each one knows about its time slot to send data to prevent collision. Time synchronization in wireless sensor nodes is not as simple as in wired network because of unreliable sensor nodes, random wakeup time, and unavailability of centralize clock, timing server and GPS module.

In the proposed system, Lightweight Time Synchronization mechanism (LTS) is used [25]. CH node will act as reference clock and will synchronize the clocks of all sensor nodes that are directly connected with it and it can also extend to multi-hope scenario. Local time in every sensor node is equipped with a hardware clock that may consist of an oscillator generating pulses at a fixed nominal frequency. A counter register $H_i(t)$ denotes real physical times of node i is incremented after a fixed number of pulses t and node-local software clock is usually derived by:

$$L_i(t) = \theta_i H_i(t) + \varphi_i \quad (1)$$

Where θ_i is the (drift) rate and the φ_i is phase shift.

CH node acts as an external synchronization source and all member nodes in cluster synchronize their time clock with it. Nodes $I = 1, \ldots, n$ are accurate at time t within bound δ when

$$|L_i(t) - t| < \delta \text{ for all } i, j \quad (2)$$

B. UAV Path

UAV path should be given in advance before mission started. The path will be selected by considering UAV flight time specification. The time required to complete the mission should not be more than 80% of the total flight time because 20% deviation margin is set in the proposed scheme to allow the UAV to go closer to the CH to get the data and resume its path.

C. Bayesian Classifier

Each node participats in CH selection process depending upon its probability $P(s_i = CH / A_i)$ that is calculated by using a Bayesian classifier.

There are m sensor nodes $S= (s_1, s_2, \ldots, s_m)$ and each sensor node have n independent attributes represented by a vector $A= (a_1, a_2, \ldots, a_n)$. A sensor node s_i can be in one of two states Cluster Head (CH) or Cluster Member (CM) representing by $State= (CH, CM)$. $P(s_i = CH \mid a_{ij})$ shows probability of sensor node s_i to be a cluster head knowing attribute a_{ij}.

$$P(s_i = CH|a_{ij}) = \frac{P(s_i = CH)\ P(a_{ij}|s_i = CH)}{P(s_i = CH)\ P(a_{ij}|s_i = CH) + P(s_i = CM)\ P(a_{ij}|s_i = CM)} \quad (3)$$

By considering "not biased" condition, all nodes in the network have the same probability to become a cluster head then:

$$P(s_i = CH|a_{ij}) = \frac{P(a_{ij}|s_i = CH)}{P(a_{ij}|s_i = CH).+P(a_{ij}|s_i = CM)} \quad (4)$$

Equation (4) is the probability of a node s_i to be cluster head by knowing only one parameter j. considering that the parameters related to the node are independent then accumulative probability of node s_i can be calculated as:

$$P_i = \frac{P_{i1}.P_{i2} \ldots\ldots P_{in}}{P_{i1}.P_{i2} \ldots\ldots P_{in} + (1 - P_{i1}).(1 - P_{i2}) \ldots\ldots (1 - P_{in})} \quad (5)$$

D. Cluster Head Selection

In the proposed system, four parameters are required to declare a node as CH, details are given bellow.

UAV Probability P_u: - All the sensor nodes directly connected with UAV will get a priority value P_u from UAV. This P_u value describes how good that sensor node location is, to be a CH with respect to the UAV path. The node with a higher P_u value is more apparent to be a CH.

As UAV is equipped with phase array antenna system and can monitor the position of each DC nodes; it will calculate cost of each node depending upon distance and slope of that node from its way point.

$$\text{Cost of Node } i = C_i = |\text{Distance} * \text{Slop}| \quad (6)$$

It will assign a maximum P_u value to the node that is more close to the way point and gradually decrease the value as per proportion of their distances.

$$P_{ui} = |\, Ci/\max(C_1, C_2, - ,- C_n)| \quad (7)$$

All these P_u values will be transmitted to the DC nodes by using broadcast message.

Available Energy P_a: - It is the percentage of remaining energy of each node

Energy Consumption Rate P_r:- Energy consumption rate is an important parameter needed to deal with heterogeneous sensor nodes. For example if there are two nodes, where one of them having larger energy source and higher consumption rate like image processing, video processing while, other node having small energy but less power consumption. If neglecting consumption rate and considering energy level as the only parameter for CH selection then the node having higher energy will be selected as CH always as a result it makes it un-functional very soon.

Renewable Energy P_n: - This parameter is required to give priority to the node having renewable energy source attached with it, over other.

E. Energy Utilization

Dissipated energy during the transmission (ETx) is

$$E_{Tx}(k, d) = k \times E_{elec} + k \times E_{amp} \times d^2 - - - (8)$$

Where k is the number of the bits of packets, E_{elec} is the energy dissipated in electronic circuits, E_{amp} is the energy dissipated for transmission in power amplifier and d is the transmission distance [26]. Nodes closest to the UAV path and destination will be selected as cluster head (CH) to reduce significantly the energy consumption.

F. Algorithm for cluster head selection

```
Input all sensors nodes S_i where i E [1, n]
Input list of attributes for all the sensor nodes A_ij where j E [1, m] such that m=total
attributes
Output Header Node H_x [P_x , i_x ]
Output list of connection C_i [(S_i), (S_i , S_j), - - - - -, (S_i , S_j, --) ]
For each node S_i do
   P_i = Equation (5)                    // Probability of each node
   Status = Head
   H_i [ ] = [P_i , i ]                  // Initially self  Pi and Self i store as CH
   C_i [ ]= 0                            // Link with CH
    M_i = Available Energy
    Broadcast message CCH (M_i, P_i, i )
End
If Receive message CCH (M_j , P_j , j) by node S_j
     If (M_i < M_j)   P_i  = P_i × M_i / M_j      // Calculate new probability for node i
    Else  P_j  = P_j × M_j / M_i               // Calculate new probability for node j
    End
    If (P_j  <  P_i)
        Status = Member       //Change the status on node as member
         H_j[] =[P_i, i]        // Accept node i as head and store its id and probability
        Update routing table C_j [ link ]    // route to the head is stored
        Append message CCH ( P_i , i ) + j // node will append its id and forward message
        Forward Message
    End
End
```

Proposed cluster head selection algorithm found best due to its strength as it use single broadcast for each sensor node, as a result everyone in the network will get to know about the node ID and route to the sensor node that is selected as CH. The overall working of the proposed system is shown in Figure 2.

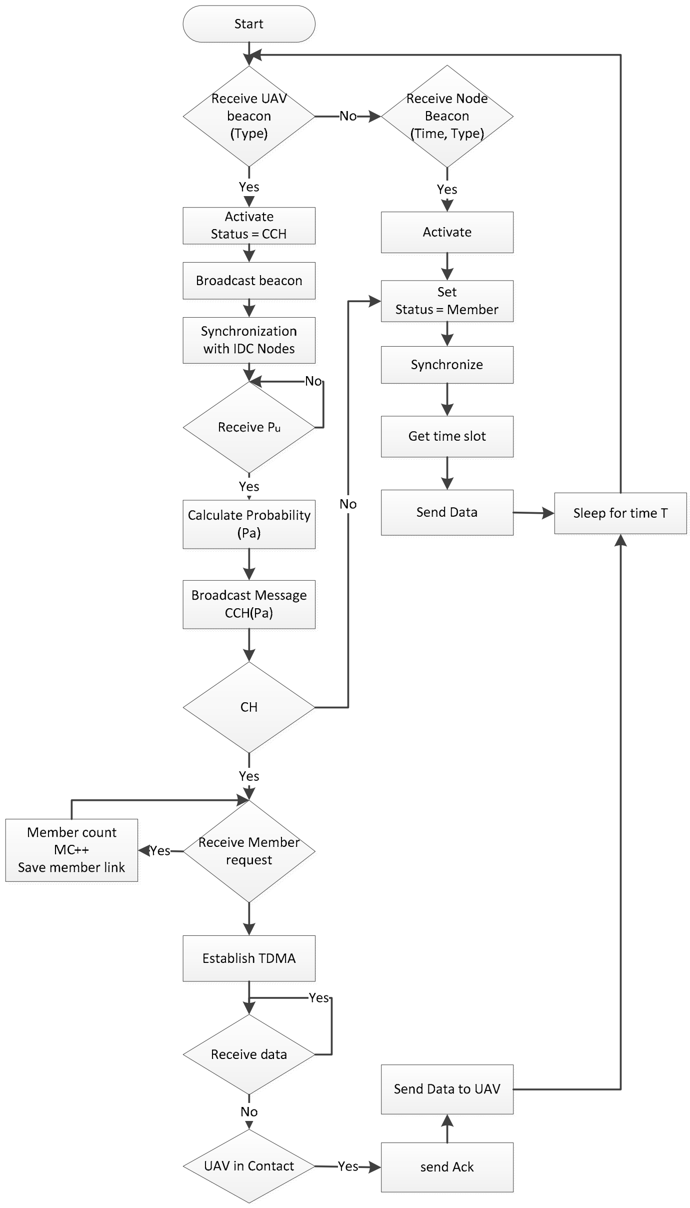

Figure 2:-Flow chart of the proposed system

IV. SIMULATION

Simulation is conducted in OMNet++, and the proposed system is evaluated with varying different parameters and scenarios results are presented. Proposed system (Figure 4) is evaluated and compare its performance with existing network assisted data collection scheme (NADC)[17] (Figure 5) and direct communication (Figure 3) .

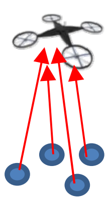

Figure 3:- Direct Communication

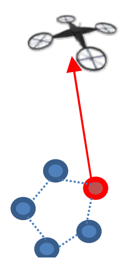

Figure 4:- Proposed URP

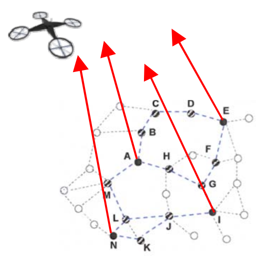

Figure 5:- NADC [17]

A. Simulation Input Parameters

Input parameters		
Area	= 2000 x 2000	# meters
Number of sensors	= 100	
UAV rounds	= 1- 100	
Beacon period in setup phase	=1.5 2.5 4.5 second	
Radio Delay	= 10ms	
Total Energy of each node	= 1	# 1000 mJ
Energy required per byte transfer ETx	= 0.000005	# 50 nJ
Energy required per byte receive ERx	= 0.000001	# 10 nJ
Transmit amplifier Energy Eamp	=0.0000008	#800 pJ/byte/m2
Beacon/ACk size	= 1	# Byte
Data size	= 150	# bytes
UAV height	= 400	# meters
Wi-Fi throughput	= 15000000	# 15 MB/s

a. Simulation results

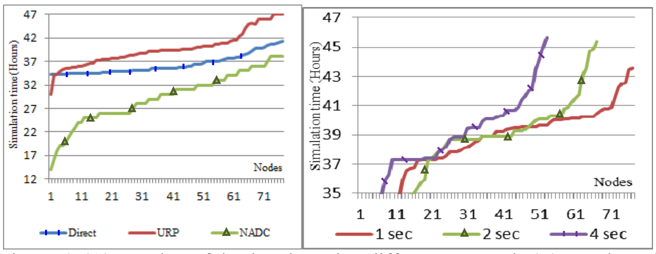

Figure 6: (A) Number of dead nodes using different protocols (B) Number of dead nodes with varying beacon sending period

Three routing and data collection schemes are analyzed in Figure 6(A). Direct communication means every node is sending its data to the UAV directly, no clustering is farmed. NADC is Network Assisted Data Collection scheme and URP is our proposed UAV based Routing Protocol. It is shown that our proposed system is working out class as compare to the NADC. In Figure 6 graph-B, number of dead nodes is observed with increasing simulation time and beacon sending period and all other parameters are kept constant. By increasing the beacon sending period, larger sized clusters are made, CH nods have to aggregate more data and transmit more data to the UAV and CH node energy is drained more rapidly. It is found that 1 second beacon period is found most economical.

If beacon sending period is very small more clusters will be made in each round, and more nodes will be selected as CH and overall energy consumption will be high.

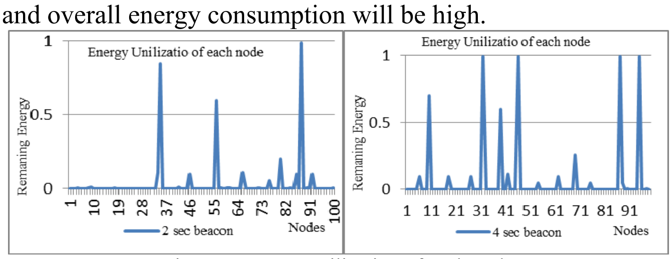

Figure 7: Energy utilization of each node

Energy utilization of each node is observed in Figure 8 and it is found that by decreasing bacon period, number of clusters per round will be increase.

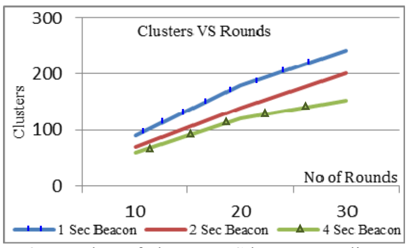

Figure 8: Number of clusters VS beacon sending period

V. Conclusion

In this paper, we proposed an UAV Routing Protocol (URP) for crop monitoring where heterogeneous sensor nodes are installed in the large crop field and only selective data from selected sensors is harvested by UAV. The distinction of this study is that all alive and active sensor nodes are arranging themselves in clusters dynamically. Appropriate node in term of energy and connectivity with UAV is selected as cluster head (CH). The CH node will aggregate the data from all neighboring nodes and transmit it to the UAV. The proposed system is evaluated by using simulated model and it is found that this system efficiently optimizes the energy utilization for sensor nodes as well as UAV.

ACKNOWLEDGMENT:

Authors gratefully acknowledge the support of SNCS research center at University of Tabuk under the grant from the Ministry of Higher Education, Saudi Arabia

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