Agriculture Internet of Things: AG-IOT

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***Abstract*— The Internet of Things (IoT) for agriculture is a rapidly emerging technology where seamless connected sensors device make it possible to monitor and control crop parameters to get quality and quantity of food. This research proposes a new dynamic clustering and data gathering scheme for harnessing the IoT in agriculture. In this paper, an Unmanned Aerial Vehicle (UAV) is used to locate and assist ground IoT devices to form themselves in cluster formation then establishes a reliable uplink communication backbone for data transmission. Use of multi-frequency, multi power transmission, and mobile sink make it possible to reduce power utilization of IoT devices as much as possible. The proposed scheme is evaluated by using simulation models and practical experiments. It is found working outclass as compare to all existing systems.**

Keywords*— IoT; Smart agriculture; Dynamic routing; WSN; Clustering

I. Introduction

In this era, Smart Agriculture (SA)[1]–[4] is not only a technology to ease the human life but it has rather become a necessity or even a compulsion to cope with rapidly increasing food demand of the world population, which is multiplying itself every second. With the passage of time, the agriculture sector is facing more problems and greater challenges such as falling land fertility and dwindling water reservoirs. Some of the wildlife is losing their habitat and thus being pushed to the verge of extinction. Furthermore, arable lands are being replaced by urban population and industrial units at an alarming rate. Environmental pollution, excessive use of pesticides and contaminated water are some additional factors, which are further compounding the problems in agriculture.

Smart agriculture in the Kingdom of Saudi Arabia (KSA) is considered as a case study in this research. The agriculture sector in KSA faces even greater challenges because of scarcity of water, very extreme climatic conditions characterized by high temperatures, dry air, dust / sand storms, vast expanse of desert and lack of communication infrastructure in very remote geographical locations. The only plausible solution to overcome the above-mentioned challenges lies in making an effective use of the most modern tools and technologies in classical agriculture such as: Unmanned Aerial Vehicles (UAVs) and Internet of Things (IoT) to ensure optimum usage of the available resources in achieving better quality and higher yield of crops. In this study, UAV based Routing Protocol (URP) is proposed for Agriculture-IoT we name it (AG-IoT). The life cycle of proposed AG-IoT is consists of six steps (Figure-1). Wide range of heterogynous IoT devices are used to monitor different parameters related to crop, soil and environment. UAVs are utilized to build cheap, handy and instant communication infrastructure for AG-IoT devices that is considered as reliable backbone uplink.

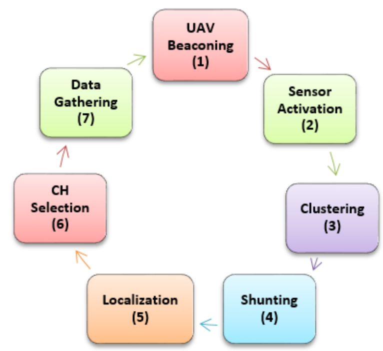

Figure 1: Life Cycle of the proposed system

The process starts when UAV send beacon message to activate ground sensors. The entire activated sensors make a cluster on UAV call. Once cluster is formed, all the nodes that are capable to communicate with UAV starts replying a narrow band signal and begin contesting to be selected as Cluster head (CH). Shunting is the next step to keep the contestants in a reasonable range (more than one and less then UAV antenna capacity). UAV has limited functionality to locate sensor nodes that is mostly *(M-1)* where, *M* is the number of antenna elements mounted over UAV. Shunting is introduced to limit number of replying sensors between 1 and *M*. UAV locates and evaluate all the candidate cluster heads and select one of them as CH then establish a link with it to collect data.

A. Localization

In proposed AG-IoT, many sensor nodes are installed in crop field to monitor crop, soil and environmental parameters. An UAV is used to harvest data from ground sensors. UAV should know the exact number and location of sensor nodes, not only to collect data but also to assist them in cluster formation and CH selection. Many schemes are proposed for localization like [5], [6] but in all proposed schemes multiple antennas are used to measure Angle of Arrival (AOA) for incoming signal to estimate location of field sensor. However, the drawbacks of mounting such multiple antennas on UAV outweigh the benefits. The challenge is that adding multiple antennas and receivers on an UAV, increases its weight which ultimately decreases its payload capacity, flight time, speed and agility. Design and development of light weight energy efficient antenna that can be installed on small sized UAV was a challenging task. We have already proposed such an antenna in research paper [7]. In this paper, we are considering that the used UAV is equipped with light weight energy efficient localization antenna and always has up to date list of connected nodes and their locations in the 3D plane.

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B. Dynamic Clustering

Clustering is an important aspect to increase network lifetime and reliability. Many clustering techniques are proposed and they can be classified into 4 broad categories: Static sink static nodes (classical LEACH, HEED [5], [6]), mobile sink static nodes (Rendez-vous base routing [7]–[10]), static sink mobile nodes (cellular Network [11]), and mobile sink mobile nodes (ad-hoc routing [12]). This paper focuses on mobile sink static nodes clustering fashion as all agriculture sensors are assumed to be static and we are considering a mobile UAV to collect data from crop field. For static sensor nodes, researchers are proposing predefined clusters and cluster head schemes to collect data. This type of clustering is not feasible in our case as large number of sensor nodes may become unavailable due to weather conditions or harsh environment (covered by sand, water or plant follicles). Situation becomes more critical if CH is included and whole network becomes un-functional. In addition, path of UAV is dynamic and sensor nodes are unaware of it; in this case, it rarely happens that predefined CH resides in the path of UAV and has good link to it. Network defined and Rendez-vous base clustering is also proposed in the literature, where all the nodes send periodic updates to maintain up-to-date CH or Rendez-Vous Point (RVP) from where UAV can collect data. In this situation, the main drawback becomes the overhead of all nodes to update CH continuously which results in battery drainage and reduces network life time. Besides, UAV should have to search and track network assigned CH/ Rendez-vous that will affect the throughput of the system and deflect the UAV form its path. As per our best of knowledge, none of previously published clustering schemes considers the UAV path as a clustering criterion.

In this paper, we developed a dynamic clustering scheme. All the field sensor nodes initially considered indistinguishable (no potential CH), UAV sends a beacon message to activate all nodes reside in its vicinity, made a cluster by considering path of UAV and type of required data. The next step is to choose one node as the CH, merge whole cluster data on this point, locate and connect it with UAV at reasonable height and distance.

C. Bayesian classifier for CH Selection

Each node will participate in CH selection process depending upon its probability $P_i = P(s_i = CH|a_{ij})$ that is calculated by using Bayesian classifier.

There are N sensor nodes $S = (s_1, s_2 \ldots s_N)$ and each sensor node s_i have z attributes (independent variables) represented by a vector $A = (a_{i1}, a_{i2} \ldots a_{iz})$. 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_i is calculated as;

$$P_i = P(s_i = CH|A_i) = \frac{P_{i1} \times P_{i2} \ldots \ldots P_{iz}}{P_{i1} \times P_{i2} \ldots \ldots P_{iz} + \left(\frac{P(s_i = CH)}{1 - P(s_i = CH)}\right)^{l-1} (1 - P_{i1}) \times (1 - P_{i2}) \ldots \ldots (1 - P_{iz})} \quad (1)$$

If considering "not biased" condition, where all nodes in the network have the same probability to become cluster head then equation (1) can be written as:

$$P(s_i = CH|a_{ij}) = \frac{P(a_{ij}|s_i = CH)}{P(a_{ij}|s_i = CH) + P(a_{ij}|s_i = CM)} \quad (2)$$

And equation (2) can be written as:

$$P_i = P(s_i = CH|A_i) = \frac{P_{i1} \times P_{i2} \ldots \ldots P_{in}}{P_{i1}.P_{i2} \ldots \ldots P_{in} + [(1 - P_{i1}) \times (1 - P_{i2}), \cdots, (1 - P_{iz})]} \quad (3)$$

As equation (3) may cause floating point underflow problem, converting the equation in log domain.

$$\frac{1}{P_i} - 1 = \frac{(1 - P_{i1}) \times (1 - P_{i2}) \ldots \ldots (1 - P_{iz})}{P_{i1} \times P_{i2} \ldots \ldots P_{iz}}$$

$$\ln\left(\frac{1}{P_i} - 1\right) = \sum_{j=1}^{n} \ln(1 - P_{ij}) - \ln P_{ij}$$

Let $\mu = \sum_{j=1}^{n} \ln(1 - P_{ij}) - \ln P_{ij}$

$$\left(\frac{1}{P_i} - 1\right) = e^{\mu}$$

$$P_i = \frac{1}{e^{\mu} + 1} \quad (4)$$

The node having the highest value of P_i will be selected as CH.

II. PROPOSED SYSTEM

Existing clustering and data gathering schemes do not fulfill all the requirements of our case study (agriculture in KSA). Here, we are proposing a dynamic clustering and data gathering scheme that is developed to satisfy not only the under-consideration scenario but all other like problems as well e.g. ware field, security and severance, wild life monitoring etc.

We are presenting here a dynamic clustering that consists of two components, sensor nodes and UAVs. The assumption about each component is as:

A. UAV

In the developed system, UAV plays a vital role and performs major tasks of localization, communication and data gathering. Whole the system is trigged by UAV beacon. Considering the importance of UAV in our system, we build a special customized quadcopter S500, assumptions and specifications of developed UAV are:

- Quad copter with hovering functionality,
- Minimum flight height = 20 meter,
- Maximum flight height = 500 meter,
- Maximum speed = 7 m/s.

UAV sends beacon message to activate sensor node, the parameters set in the beacon are as:

- **Sensor type:** Type of sensor nodes or combination that needed to be activated in response of this beacon.
- **Height:** Current data collection height of UAV (note: it is not the flying height). The sensor nodes that are capable to communicate at least this distance will be considered as candidate for a CH.
- **Threshold:** This threshold will be used to limit the number of sensor nodes that will contest for CH.
- **Trailer:** A trailer contains Error Detection Code (EDC) or any other information.

Type 6 byte	Height 2 byte	Threshold 1byte	Others 2 bytes
Header		Payload	Trailer

B. Sensor Nodes

Field sensors installed to monitor a specific parameter about crop, soil or environment has the following properties.

- Location unaware, cheap in cost and left un-attendant.
- Support multiple frequencies, at least 2 frequencies 433 MHz and 2.1 GHz for localization and data transmission.
- By default, 433 MHz is switch on to hear from UAV, afterward it will be used for localization and synchronization. While 2.1 GHz transmitter / receiver will be activated on demand for communication only.
- Can hear UAV if in range, but all might not be able to connect with because of their internal parameters.
- Maximum communication range = 500 m.
- processing + memory enable.

All sensor nodes considered to have a unique ID of format as given below:

- **Type:** We are considering 3 basic types: crop, soil and environment. However, we are allocating 1 byte for further and future extensions.
- **Subtype:** Leaf, stem, root and all combinations.
- **Purpose:** Temperature, humidity, thickness, flow and all possible combinations.
- **Unique id:** Unique number of each sensor node.

The field sensor nodes will have 6 bytes of unique id. UAV will select any particular type or any combination with the help of this id (called prefix). Sensor nodes will also use it to send beacon acknowledgement/reply.

Circle No	Type	Sub Type	Purpose	Unique No	Total size
1byte	1byte	1byte	1byte	2 byte	6 byte
Prefix					

In our proposed system, initially all sensor nodes are considered as indistinguishable (no special CH). A sensor node has to keep 5 parameter values about its health. All activated sensor nodes will calculate a probability value to become a CH based on these health indicators.

1. **Energy:** How much remaining energy
2. **Consumption rate:** The consumption rate of energy to perform its job.
3. **Renewable energy:** Renewable energy is available or not
4. **Antenna size:** Antenna size to estimate its communication range
5. **Data size:** How much data it has to transmit

The sensor node reply to UAV will be consists of 9 Bytes containing prefix (node id) in packet header, probability value in payload and trailer. The trailer 1 byte is allocated for CRC (Cyclic Redundancy Check) and future use. A sensor node activated in response of UAV beacon, will send a reply as:

ID 6 byte	Probability 2 byte	Trailer 1 byte
Header	Payload	Trailer

The UAV and sensor nodes having mentioned above specificities and functionality will complete data gathering proposed in three layers, the top layer consists of UAVs taking care of all UAVs related tasks. Middle layer composed of CHs acts like connection between low power small size sensors and UAV. The lower most layer is sensing layer consists of many heterogenous sensors engaged in assessment of crop, soil and environment.

C. Three layer Protocol

The Proposed system is developed in three layers;
Layer-1 UAV: UAVs are the main part and top layer,
Llayer-2 CH: One node per cluster will be selected as CH and, they will form a 2nd middle layer,
Layer-3 CM: Composed of ground sensor nodes.
Each layer contained three phases as shown in Figure 2.

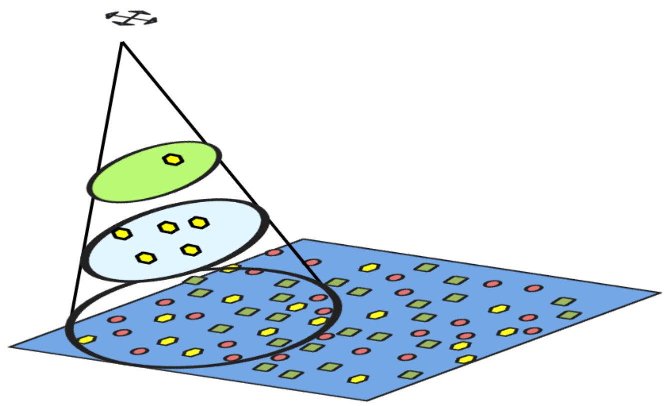

Figure 2: Three Layer Architecture

The main part of this system is UAV, that acts like a data mole; its working cycle is combination of three phases:
Discovery: UAV performs five main tasks in this phase beaconing, estimation of number of connected nodes, shunting, localization and CH nomination as explained in figure 3.

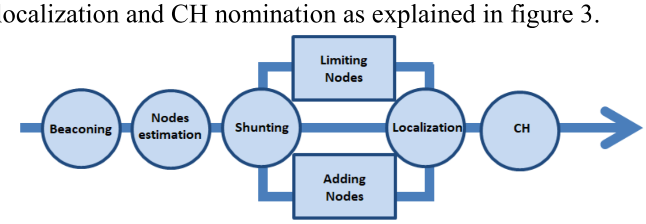

Figure 3: UAV discovery phase

Let us suppose that UAV is flying at a height D_1 and initiates data gathering process by sending a beacon $B(T_{ys}, D_2, Th)$ containing type T_{ys} of nodes required to activate for data collection, distance D_2 at which it will collect data and Th is, the threshold to limit the activated node who will contest for CH. Initially $Th = 0$ mean all nodes can participate in CH selection process. Suppose that there are n sensor nodes $S = \{s_1, s_2, \dots, s_n\}$ installed in a crop field. Assume O nodes become activated in response of UAV beacon such that $1 \le O \le n$ and $SS = \{SS \subseteq S \middle| SS \in T_{ys}\} = \{ss_1, ss_2, \dots, ss_O\}$. SS is the set of nodes that will make cluster in response of this beacon. If each active node SS_i has $\mathscr{b}_i$ bit data to transmit then $T\mathscr{b}$ represents the total size of cluster data, that is expected to be transmitted by CH to UAV:

$$T\mathcal{b} = T\mathcal{b}(SS) = \sum_{i=0}^{O} \mathcal{b}_i \quad (5)$$

The energy required to transmit $T\mathcal{b}$ to UAV for distance D_2 is;

$$TE_{Tx} = (E_{elec} \times T\mathcal{b}) + \left(E_{amp} \times T\mathcal{b} \times (D_2)^2\right) \quad (6)$$

While UAV is in the discovery phase, activated ground sensors SS will be in setup phase to make a cluster. Every member of SS will calculate a Bayesian probability P_i considering all its parameters (energy, consumption, antenna size, data size, etc). Detail discussion on Bayesian probability is given in section 3.6.4. Based on E_i, the energy of the node SS_i, and P_i, the probability to be selected as CH, a further subset called Candidate Cluster Heads $CCH = \{cch_1, cch_2, \ldots, cch_q\}$, where $1 \leq q \leq O$, is formed such that

$CCH = \{CCH \subseteq SS \mid \forall E_{i_{current}}\ T\mathcal{b}\ \&\ P_i > Th\}$. As described earlier, $Th = 0$ means any activated node having enough energy can be a member of CCH.

All CCH nodes start sending beacon replies to UAV in the form of narrow band signals. At this point, UAV estimates the number of CCH $|CCH| = q$. If UAV estimates that $q = 0$ or $q \geq m$, where m is the number of antenna elements on board, then shunting process is started to keep the candidate cluster heads in a reasonable range; Otherwise, UAV will locate all CCH nodes by using a special virtual phase array antenna developed for said purpose and detail model is given in [8]. Based on CCH location and P_i values, UAV nominates a final CH and broadcast a message to all nodes of set SS to let them informed about the CH nomination.

Shunting is the important process of discovery phase to handle the situation when:

$q = 0$ or $q \geq m$

If $q = 0$ or $CCH = \emptyset$ it means no CCH member has the capability to send aggregated data to UAV in this case, shunting decreases D_2 in steps up to a minimum height depending upon safe flight constraint.

If $q \geq m$ means there are many good CCH nodes and UAV cannot locate all at once, in this case, shunting can take 3 steps.

1. Increase antenna capacity from m to $2m$,
2. Increase D_2 in steps up to the limit of F_2,
3. Increase Th.

Once cluster head is selected, the next phase of UAV is navigation.

Navigation: Once CH is selected UAV enters in next phase called navigation. In similar way, CH and CM switch their phases from setup to aggregation and communication respectively. In this phase, all active nodes will switch on their frequencies from F_1 to F_2 (433 MHz to 2.4 GHz). Only CH will operate on both frequencies. CH will use F_2 to collect data from CMs and F_1 for UAV navigation. While UAV approaches CH and attains an agreed height D_2; All CM nodes must transmit their data to CH which will aggregate it and get ready to make a link with UAV. As soon as UAV approaches D_2 and starts handshaking, CH will switch off its F_2 module and navigation phase becomes over. Navigation process is elaborated in a diagram Figure 4.

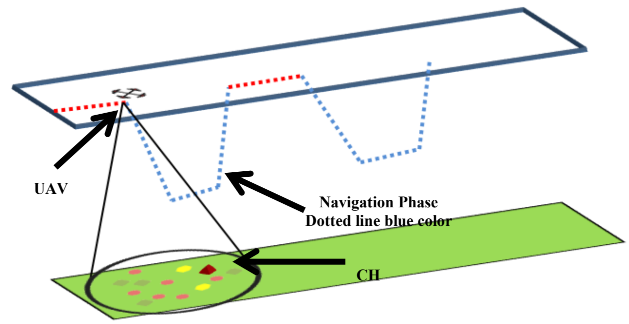

Figure 4: Navigation phase

Communication: In the last phase, only the top two layers (UAV and CH) of our developed system will participate. CH will transmit the whole data to UAV at frequency F_2; Once transmission is done, CH will go to sleep for a specific time T, while all CMs had already been shifted to sleep.

III. SIMULATION

We conducted a Matlab simulation to evaluate the performance of developed system. Results are compared with existing three schemes LEACH, HEED and network assisted. The simulation input parameters are as under:

We took 1 Km^2 area to disperse 100 nodes randomly. Initially, UAV is set to fly at 400 m high and covering 10 m radius on ground. Snapshot of simulation test bed is shown in Figure 5. Sensor nodes are represented by 100 green color dots, UAV is represented with yellow color dot and red color circle is its range. In the figure, S shape lines pattern shows the path of UAV in the form of 10 waypoints.

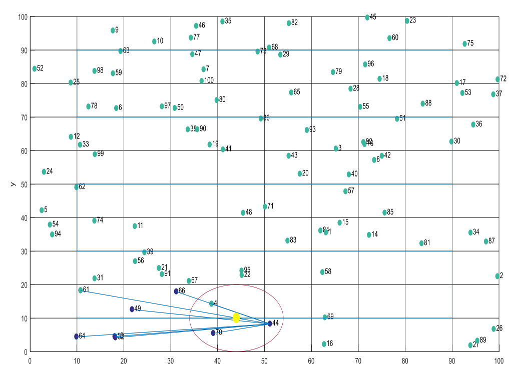

Figure 5: Matlab simulation 2D view

Matlab simulation was made in 3-D plane. To explain the working of developed system and cluster formation, some 3-D views of the system are shown in Figure 6, 7 and 8 from different angles.

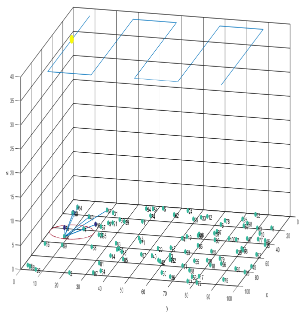

Figure 6: Matlab simulation 3D view-1

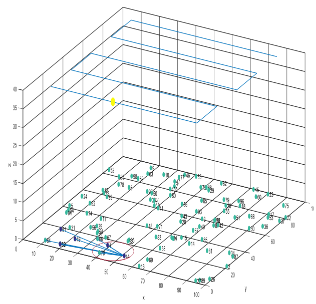

Figure 7: Matlab 3D simulation view-2

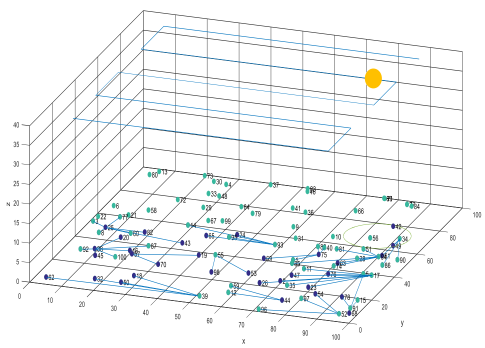

Figure 8: Matlab simulation 3D view-3

UAV is represented by a yellow dot and straight lines on the same level are representing its path. On the ground level, blue dots with numbering shows the installed sensor nodes and star line connected lines are the clusters. Each cluster is shown by blue connected lines. Different simulation models are executed with varying parameters and some results are presented here.

The Figure 9 shows the comparison of dead nodes VS UAV rounds in different routing schemes. Two variations of proposed system are tested, fixed and constant UAV height and adopted height, our proposed system is working better in both cases because of no periodic updates, no flooding of information, better CH selection, duel frequency use, etc. Curve 1 shows the performance of proposed system with adaptive height. UAV and CH negotiate a suitable height for data collection. As long-range communication is the main source of energy depletion, adjusting data collection height results a good impact of overall system life time.

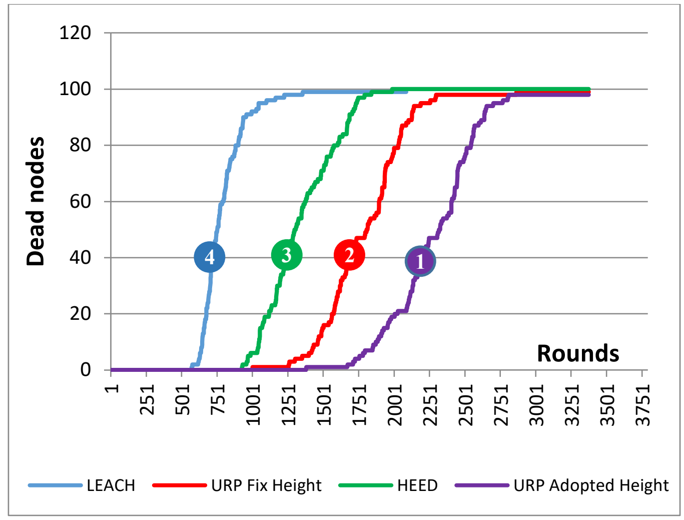

Figure 9: Number of dead nodes in proposed system VS HEED and LEACH

IV. Proof of Concept

We used Arduino microcontroller to build a proof of concept devices composed of three main components UAV, ground sensor nodes and UAV sink node. Sensor nodes and UAV sink node are shown in Figure 10 and 11.

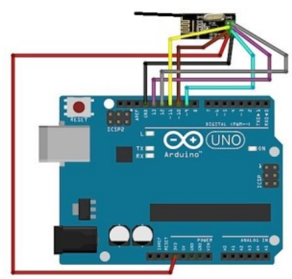

Figure 10: UAV Sink unit

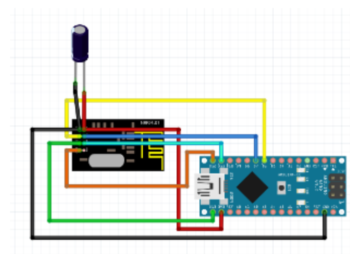

Figure 11: Ground sensor nodes

Both the devices are build using NRF24L01 transceiver. NRF24L01 is low power consumption transceiver operate at 2.4 GHz frequency and capable to transmit data at the rate up to 2 Mbps. Initially, we have loaded all sensor nodes with 20 Kb of data and 5 nodes are deployed to install in the field. When UAV came in contact, one of them is elected as CH dynamically and it collected all the data from neighbor nodes and finally transmit 100Kb data to UAV.

We chose Arduino mini to build a small size of node. Figure 12 is the activity graph of ground sensor node that acted as cluster member. It is observed that it took about 5.4 seconds to complete the cluster formation and data delivery. X-axis represents the CM sequence of activities, Y-axis shows time in seconds and curve represents the relationship of time and activities. The parameters of this node were set as it doesn't have good specification and its CH probability is 0 so it decided immediately to set its status to CM.

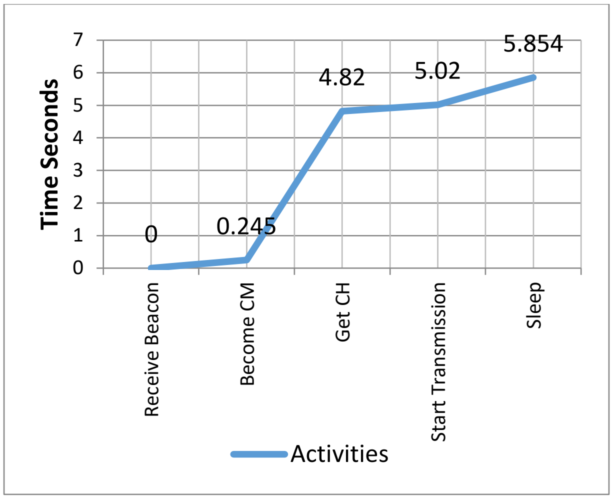

Figure 12: Cluster member activities VS time

Cluster head selection took about 4.5 second and finally data transmission took less than a second to complete its process. Figure 13 is the graph of CH working. It is analyzed that it took about 10 seconds to complete its working cycle. It is observed that this node becomes CH in 5 seconds, during this period, it becomes activated, contacts neighboring nodes and share information with UAV. As this node has been selected as a CH it has to collect data from all other members and transmit aggregated data to UAV. Whole this procedure is conducted in 5 seconds.

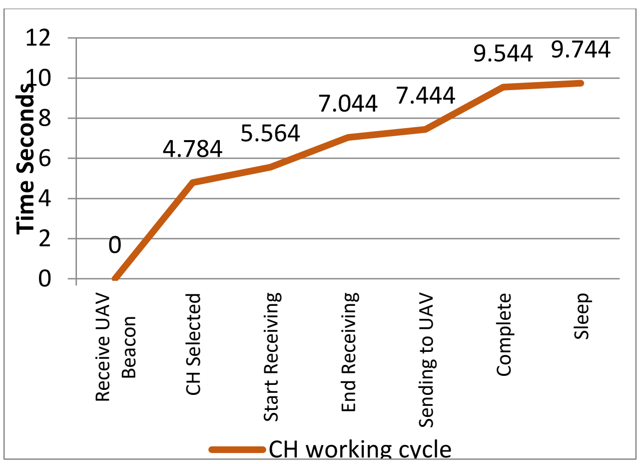

Figure 13: Cluster head activities VS time

Life cycle of an UAV is shown in Figure 14. It sends beacon message in first 5 seconds, then switches to discovery phase to search and select a suitable CH. It will navigate to approach CH and takes data at some reasonable height. It takes about 10 seconds to complete the process.

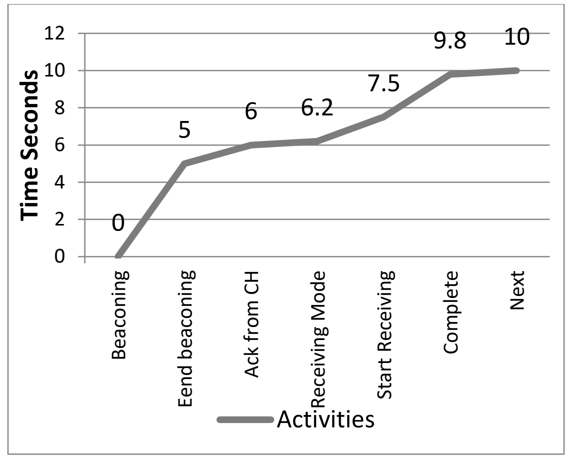

Figure 14: UAV activities VS time

V. Conclusion

In this paper, we proposed UAV assisted dynamic clustering and routing technique URP to harness IoT in agriculture, we name it AG-IoT. In this proposed URP, heterogeneous IoT devices are installed in farm field and they form themselves in clusters format according to the instructions of UAV. The best node among all is then elected as CH. The process of node localization, clustering, and CH formation is conducted dynamically at runtime. Minimum inter-cluster communication and use of multiple frequencies make it possible to preserve node energy as maximum as possible. Simulation and practical experiment shows that proposed clustering and routing technique is working best among all others.

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