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OPTIMIZING UNMANNED AERIAL VEHICLE ASSISTED DATA COLLECTION IN CLUSTER BASED WIRELESS SENSOR NETWORK

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Abstract. *Wireless Sensor Networks have proven to be of significant importance when it comes to monitoring and statistical data collection. WSN can be easily deployed in remote and inaccessible areas, where human intervention is not easily possible. Also, the WSN networks are useful in military and surveillance operations. The depleting energy as a result of broadcast and multihopping transmissions is an issue. Moreover, the clustering algorithms help elevate the multihopping problem to a level but result in transmission bottleneck as every node is trying to communicate with its cluster head. In this article an efficient data dissemination approach is presented which employs Unmanned Aerial Vehicles as relays, thus reducing the multi-hop characteristics. Additionally, a multilevel clustering algorithm is introduced which facilitates the transmission towards sub-cluster heads in order to avoid transmission choking of the designated cluster head. The UAV banks required to facilitate data transmissions are calculated by using Ant Colony Optimization algorithm.*

Keywords: Wireless Sensor Network, Clustering, Data dissemination, Mobility, Path optimization, Performance

1. **Introduction.** A sensor node is a miniature mechanical device capable of receiving and transmitting data generally in the form of electrical or radio signals. The spatial or geographical distribution of these sensor nodes along with gateways and routing nodes which are capable of transmitting data towards and from base station and inter node data transmission respectively is called a Wireless Sensor Network (WSN). WSN networks use both standard and proprietary bands of communication and are in direct contact of a Base station or Terrestrial Network. With technological advancements the WSN has proved useful in wide and varying application scenarios as well as in such geographical locations where human interaction or intervention is far from possible. The deployment of WSN can range from terrestrial WSN where nodes are spatially distributed over a wide geographical area to underground WSN where nodes are deployed underground and sink nodes present on the surface are responsible for data gathering and dissemination.

WSN nodes are generally scattered through hostile environments where frequent human intervention is not possible making restructuring nearly impossible and with regard to the frequent energy depletion as a result of communication, data processing and operation in unstructured conditions. The frequently changing topology makes the design of an efficient routing scheme based on the geography very complex. The over utilized communication also results in sensor holes and jamming holes. Scalability and fault tolerance is an inherent issue with the deployment of WSN. The WSN when laid in harsh environments cannot participate in the process of self organization. Limited storage and processing capacity is also an issue. Sensor nodes are generally application specific and deployed once without the opportunity of reconfiguration [1, 2, 3, 4]. Generally the network topology is

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either flat or hierarchical. In flat architecture each sensor node is responsible for sensing data and passing it on to the designated sink. The hierarchical layout being more complex involves clustering.

With flexible movement and ease of application UAVs have found application in varying fields of research and applications [5, 6]. In general UAVs are deployed in collaboration with the ground nodes. The collaboration between ground networks and UAVs has provided significant gains in the fields of search, acquisition and tracking. The prominent rise of UAV networking is due to its military applications. Also one characteristic of UAVs, acting as sinks for ground nodes deployed in inaccessible locations has a significant impact. Another important field of UAV application is autonomous networking where UAVs facilitate guidance, supervision, coverage enhancement and relaying [7]. Nature-based algorithms have been proposed in literature which help perform cooperative rendezvous and efficient task allocation [8]. Cooperative ground to air surveillance systems are presented in [9, 10]. The UAVs acting as relays for WSN are presented in [7, 11, 12, 13]. Selection of UAV banks and the area that a UAV will sweep while in collaboration with the ground based node must be carefully chosen. UAV flight path must cover every node in the deployed area and also allow consistent data traffic from all nodes. In a random node deployment there will be regions with higher node density producing large data traffic and regions of less node density producing low data traffic. UAV flight planning should essentially take account of the dynamic nature of WSN. UAV flight path optimization not only reduces distance and time but also gives equal opportunities to the ground nodes to relay their data to the UAV. The hierarchical clustering layout reserves a designated node as the Cluster Head (CH), which in turn is responsible for data aggregation from all the constituent nodes of its cluster and forwarding it to the base station. Clustering elevates the energy consumption problem to a level as less energy is required to transfer a burst of aggregated data as compared to the bit by bit transfer of unstructured and unsorted data. A consequence of clustering technique is that the cluster head is also a sensor node which is subject to energy depletion and dying. Furthermore, CH selection becomes a tedious process as a wrong metric can lead to steep decline of overall performance. A mechanism for cluster formation, cluster head selection, cluster maintenance and initializations is required as result of frequently dying nodes and depleting energy [14, 15, 16, 17].

In order to facilitate data dissemination and overcome the challenges of data transfer in unknown geography. We present multi-level clustering algorithm and an ACO based route finding and maintenance algorithm. The algorithm starts by the formation of conceptual topology and further dives down towards breaking the topology into multiple sub-clusters. The algorithm puts in application the density of the clustered areas in order to find efficient route. Based on existing issues and above underlined shortcoming, our method provides the following contributions.

1) A clustering algorithm which works in two steps to perform multilevel clustering (Formation of conceptual topology) which helps elevate long multi-hopping paths.

2) An ACO based route finding and updating algorithm, which utilizes the ACO pheromone trails in order to find shortest path between successive UAV banks from one dense cluster to another.

The rest of the paper is organized as follows. Section 2 presents system model and proposed approach. Section 3 evaluates the performance and finally, Section 4 concludes the paper.

2. **System Model and Proposed Approach.** The proposed framework does clustering in order to achieve a conceptual topology. The topology is virtual in nature and the model tries to limit the clusters geographically according to the connection strength. The initial phase consists of clustering of the overall network. The nodes are spread geographically and in order to preserve the geographical properties and also form tightly coupled

clusters a function of Round Trip Time (RTT) and distance between the nodes is developed in order to perform the partitioning. RTT ensures the quality and connectivity of the link whereas a function of distance gives the link strength and also enforces a tight bound on spatial arrangement. Equation (1) describes the function considered for network partitioning.

$$S_m = RTT_s \times \frac{1}{d_{W_i \to n_i}} \tag{1}$$

where S_m is the selection metric, RTT_s is the round trip time and $d_{W_i \to n_i}$ is the distance between node and randomly chosen cluster head. The Mean Selection Metric, i.e., $Mean_{S_m}$ is defined by

$$Mean_{S_m} = \frac{\sum_i \left(RTT_s \times \frac{1}{d_{W_i \to n_i}} \right)}{\sum_i n_i} \tag{2}$$

where $\sum_i n_i$ is the number of nodes in a particular cluster.

For cluster stabilization we replace the randomly chosen cluster heads with $Mean_{S_m}$, such that the node with minimum difference becomes the new cluster head. Equation (3) defines the process of cluster head adjustment.

$$\min(|Mean_{S_m} - S_m|) \tag{3}$$

Generally, the clusters grow oversize and thus hinder the performance gains achieved using the clustering architecture. In order to achieve scalability alongside facilitating a consistent and efficient mode of data transmission further re-clustering of the initially formed clusters is performed. These sub-clusters within the clusters are called *s*-clusters. Equations (4), (5), (6) outline the sub-cluster head adjustment procedure.

$$X_c = d\left(n_{k_{jx_i}}, n_{k_{jx}}\right) \tag{4}$$

$$Y_c = d\left(n_{k_{jx_i}}, n_{k_{jy}}\right) \tag{5}$$

$$Z_c = RTT_s\left(n_{k_{jx_i}}\right) \tag{6}$$

where X_c, Y_c and Z_c are distance between the node and sub-cluster head, distance from the node to the sub-cluster head of adjacent sub-cluster and round trip time of a node from its sub-cluster head respectively. The selection metric for sub-clusters SM_1 can be defined as Equation (7)

$$SM_1 = \min\left(\frac{1}{X_c} \cap Y_c \cap Z_c\right) \tag{7}$$

$$MRTT_c = \frac{\sum_i RTTn_{j_i}}{\sum_i n_{j_i}} \tag{8}$$

where $MRTT_c$ is the mean RTTs of a cluster and $RTTn_{j_i}$ is the RTT of nodes in a cluster. The approach requires updating whenever

$$V_c = |MRTT_c - Z_{MRTT_c}| \leq \sqrt{\frac{1}{n_{j_i} - 1} \sum_i \left(RTTn_{j_i} - MRTT_c\right)^2} \tag{9}$$

where Z_{MRTT_c} is the maximum allowed deviation from the average round trip time.

Mean round trip time M_{RTT_s} is given by the equation

$$M_{RTT_s} = \frac{\sum_i RTT_s}{\sum_i n_i} \tag{10}$$

Round trip time is taken as the metric of link condition. The increase in RTT is directly proportional to the falling link condition and overall impact on the system performance.

The algorithm reinitializes the topology formation in case the performance falls below the experimental threshold.

$$V_c = |M_{RTT_s} - Z_{MRTT_c}| \leq \sqrt{\frac{1}{\sum_i n_i - 1} \sum_i \left(RTT_{s_i} - M_{RTT_s}\right)^2} \tag{11}$$

where Z_{MRTT_c} is the experimental threshold.

With the conceptual topology being stabilized and all the cluster and sub cluster heads selected, Ant Colony Optimization (ACO) is used for route establishment between the clusters in order to facilitate UAV movements. The cluster chosen randomly by the UAV as its next bank is given by P_k which is effectively a measure of total probability selection for a particular cluster.

$$P_k(src, dst) = \begin{cases} \dfrac{(\tau(A))(\eta(A))^{\beta}}{\sum_{u \in J_k(src)} (\tau(A))(\eta(A))^{\beta}}, & dst \in J_k(src); \\ 0, & \text{otherwise} \end{cases} \tag{12}$$

where $A = (src, dst)$, τ is the pheromone concentration, η is $(src, dst)^{-1}$, src and dst are source and destination nodes respectively, $J_k(src)$ is the set of cluster heads where k is the source head. $\beta > 0$ is the weight of heuristic function. The transition or movement from one cluster to another is marked by Equation (13)

$$s = \begin{cases} \operatorname{argmax}_{u \in J_k(src)} (\tau(src, u))(\eta(dst, u))^{\beta}, & q < q_0; \\ S, & \text{otherwise} \end{cases} \tag{13}$$

where $0 \leq q \leq 1$, determines the choice based on τ and η, and q and S are a random number. s is the destination cluster. The pheromone trail is updated according to Equation (14)

$$\tau(src, dst) \Leftarrow (1 - \alpha)(\tau(src, dst)) + \sum_{k=1}^{m} \delta J_k(src, dst) \tag{14}$$

where m is the number of UAVs, $(1 - \alpha)$ is the pheromone decay rate, and $(\tau(src, dst))$ is the current pheromone level. $\delta J_k(src, dst)$ is defined by Equation (15)

$$\delta J_k(src, dst) = \begin{cases} \dfrac{1}{L_k}, & (src, dst) \in \text{path traversed by the } k^{\text{th}} \text{ UAV}; \\ 0, & \text{otherwise} \end{cases} \tag{15}$$

where L_k is the tour performed by the k^{th} UAV. Equations (16) underlines the values of $\eta(src, dst)$.

$$\eta(src, dst) = \frac{1}{D(src, dst)} \times CS(dst) \tag{16}$$

where D is the distance, and CS is the cluster size. Algorithm 1 gives the virtual topology formation and route estimation algorithm.

3. **Performance Evaluation.**

The proposed technique was simulated and tested on network simulator NS3. Simulation consists of WSN motes, and UAV is used as a relay to base station. Simulations composed of 100 WSN motes place randomly over an area of 1 km^2. Table 1 lists out the details of simulation.

Figure 1 gives the average flight distance that a UAV has to cover to service all sensor nodes and Figure 2 gives the corresponding flight time for a UAV. UAV path optimization reduces the distance and flight time required by the UAV for a round of data collection. Figure 3 gives the remaining energy of each sensor node. For one round of data collection the energy requirement of the proposed algorithm is 5 percent. While in a random flight plan, energy required is about 8 percent of the total available to node. Figure 4 gives the average delay at a sensor node. Average delay for the proposed method is 0.020 seconds and that of the random flight plan is 0.156 seconds. Figure 5 gives the jitter at each node.

Algorithm 1 Virtual topology formation and maintenance algorithm

```
 1: Input: Population Size: $|W|$
 2: Input: Number of Clusters: $|n|$
Cluster Assignment
 3: while $W_i ! = NULL$ do
 4:     if $\min\left(RTT_s \times \frac{1}{d_{W_i \to n_i}}\right)$ then
 5:         Add $W_i$ to cluster $n_i$
 6:     else
 7:         Proceed to next cluster
        End If
    End While
Cluster Stabilization
 8: $Mean_{S_m} = \frac{\sum_i \left(RTT_s \times \frac{1}{d_{W_i \to n_i}}\right)}{\sum_i n_i}$
 9: Repeat 3-8 with $Mean_{S_m}$ as cluster head.
10: Repeat 3-8 till no new assignment occurs.
Cluster Partitioning (Sub-Cluster)
11: Input: Number of Sub-Clusters: $|n_k|$
12: Input: Randomly Chosen Semi-Cluster Heads
13: Assign Node $n_{j_i}$ to cluster $n_{k_j}$ according to 3-8.
14: Repeat 3-8 till no new assignment occurs.
Sub-Cluster Head Adjustment
15: while $(n_k \times n) ! = NULL$ do
16:     if Neighbour Semi-Cluster $(n_{k_{jx}}, n_{k_{jy}})$ = True And No boundary sub-cluster head set then
17:         Make $n_{k_{jx_i}}$ new semi-cluster head
18:         $SM_1 = \min\left(\frac{1}{X_c} \cap Y_c \cap Z_c\right)$
19:     else
20:         Proceed to next node
        End If
    End While
Topology Maintenance
21: if $V_c \leq \sqrt{\frac{1}{\sum_i n_i - 1} \sum_i \left(RTT_{s_i} - M_{RTT_s}\right)^2} \to V_c = |M_{RTT_s} - Z_{MRTT_c}|$ then
22:     Re-initiate Algorithm 1
23: else
24:     Proceed Normal operation
    End If
Route Establishment
25: while Best Path changes do
26:     for $UAV_k$ do
27:         Start from random cluster
28:         while UAV traversal not complete do
29:             $\frac{(\tau(src, dst))(\eta(src, dst))^\beta}{\sum_{u \in J_k(src)} (\tau(src, dst))(\eta(src, dst))^\beta}$, $dst \in J_k(src)$, $0 \to$ otherwise
30:             $\mathrm{argmax}_{u \in J_k(src)} (\tau(src, u))(\eta(dst, u))^\beta$, $q < q_0$, $S \to$ otherwise
            End While
        End For
Pheromone Update
31:     for (Every Cluster Link) do
32:         $\tau(src, dst) \Leftarrow (1 - \alpha)(\tau(src, dst)) + \sum_{k=1}^{m} \delta J_k(src, dst)$
        End For
33:     if Best Path then
34:         Update Route
35:     else
36:         Continue (25-33)
        End If
    End While
37: exit and start transmission
```

Table 1. Simulation parameters

Simulation Parametwers	Values
WSN Nodes and Mobility	100 and Stationary Positions
UAV & UAV Altitude	1 & 80-100 m
Simulation Area	1000 m × 1000 m
WSN-WSN Communication	IEEE 802.11, (DSSS) Rate 1 Mbps
WSN UAV Communication	Low Power Wide Area Network (LPWAN)
Propagation Loss Model	Friis Propagation Loss Model
Packet Size, Data Rate, Packet burst	512 bytes, 10-11 Kbps Variable Bitrate, 10 s

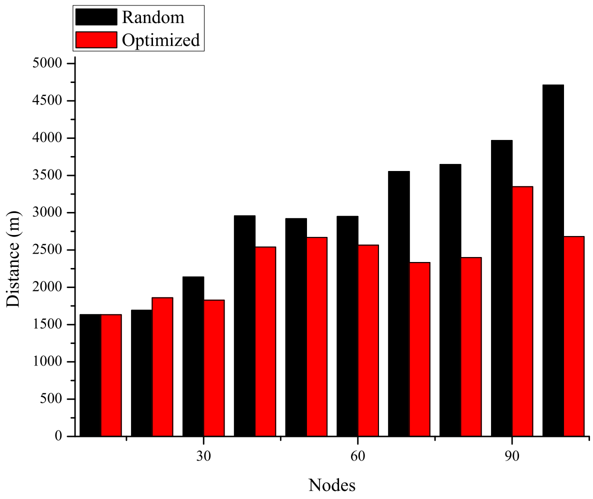

Figure 1. Flight distance

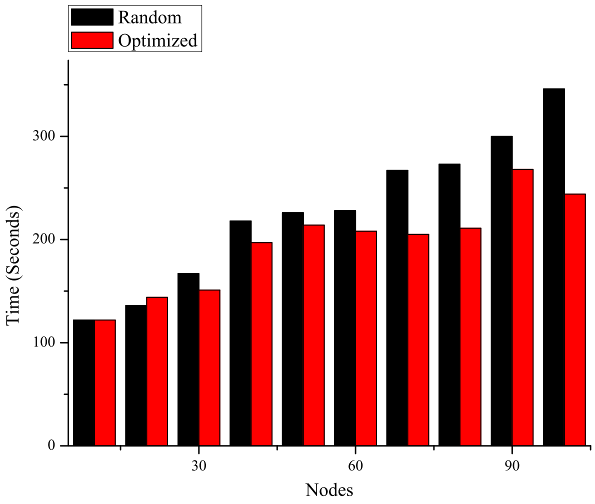

Figure 2. Flight time

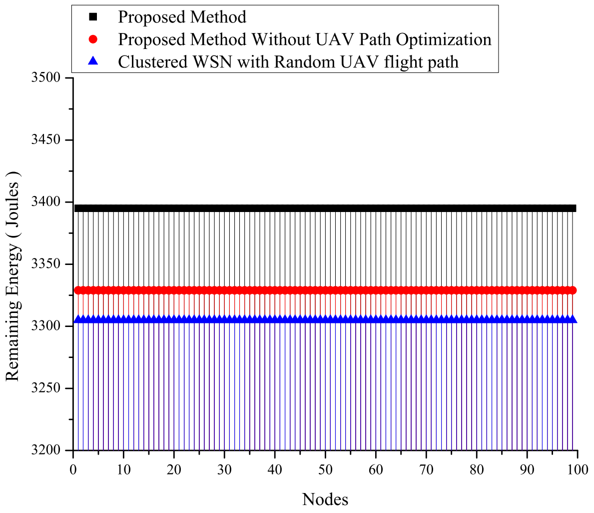

Figure 3. Remaining energy

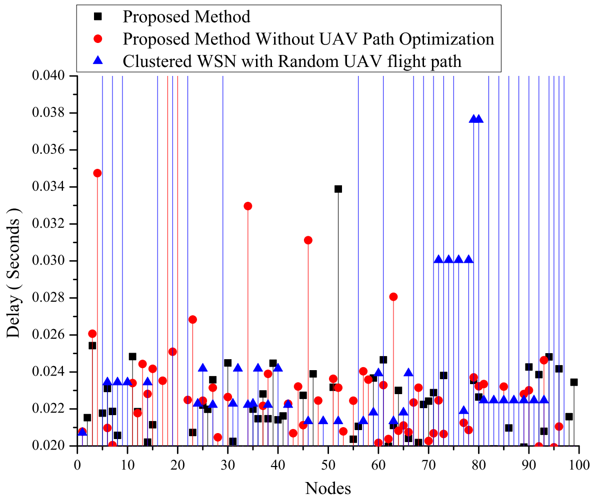

Figure 4. Delay

Figure 6 gives the throughput at each node. Figure 7 and Figure 8 give the amount of data transferred from each node. Proposed method has a very low packet drop rate and higher packet delivery rates. Table 2 lists out the simulation statistics of the simulated technique for one complete round of data collection. The UAV flight optimization together with clustering significantly reduce the average delay and jitter for packet delivery from ground node to UAV. Reduced delays help in higher and consistent packet delivery rate. As the delays in end to end packet delivery are short, higher throughput is achieved. UAV path optimization is also responsible for lower packet loss.

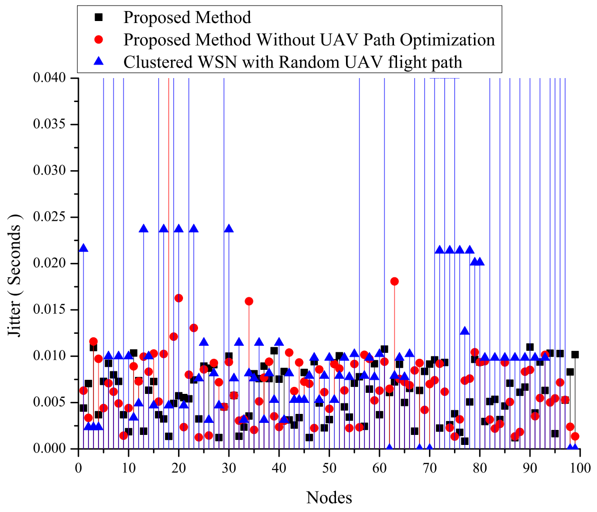

Figure 5. Jitter

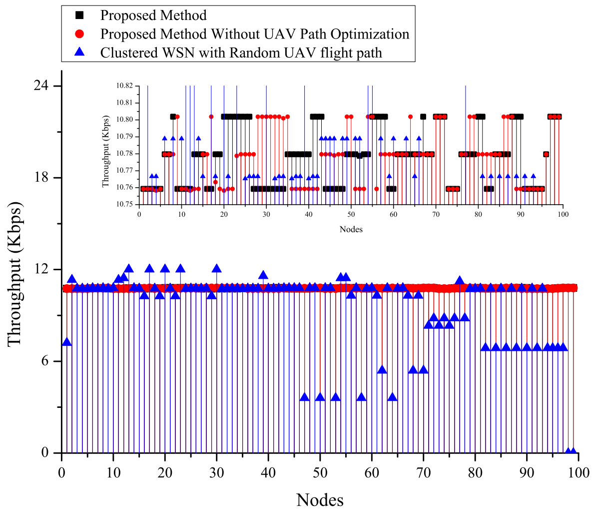

Figure 6. Throughput

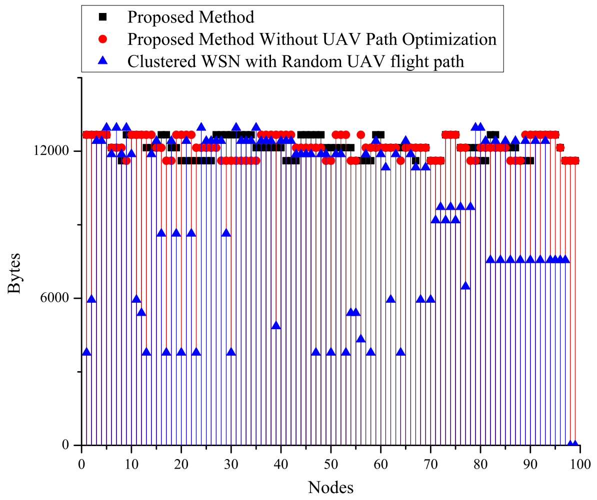

Figure 7. Bytes transferred

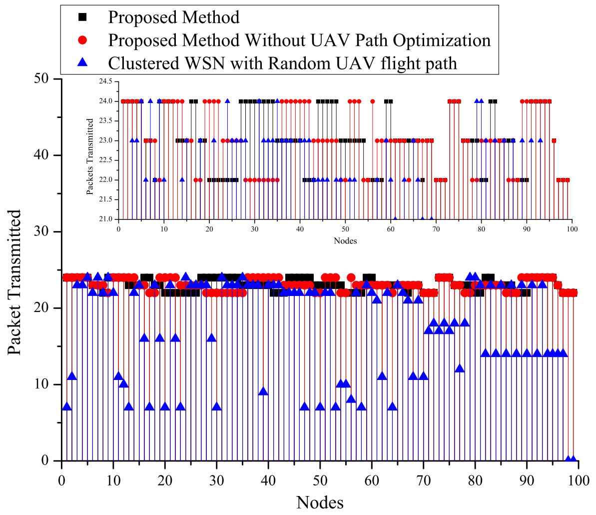

Figure 8. Packets transferred

Table 2. Simulation performance

Statistics	Proposed method	Proposed method without optimization	Clustered WSN with random UAV path
Average throughput	10.77	10.77	9.51
Average jitter	0.006	0.007	0.087
Average delay	0.020	0.022	0.156
Average bytes transferred	12192	12186	9523
Average packets delivered	23.09	23.08	17.63
Average packet lost	0%	0.06%	6.06%
Energy dissipated	5%	7%	8%

4. **Conclusions.** In this article an optimized technique for sensor data acquisition was presented. The multi-level clustering algorithm presented uses the quality of link and round trip time to form clusters. It improves the packet transmission and minimizes the delay. UAV assisted WSN relies on UAV path selection. The proposed method performs UAV path optimization by using ant colony optimization on the basis of distance and cluster size. The method presented increases the number of bytes transferred per node

while keeping delay short. This results in higher data transfer, less packet drops and consistent throughput for all WSN nodes. UAV flight path optimization delivers better response time, flight coordination and coverage. It helps significantly reduce the UAV flight time, lower the time required to complete a round of data collection, and thus reduce the energy dissipation of the WSN nodes. In future a mac layer protocol is to be designed for further increasing data transmission and reducing end to end delay between the ground nodes and UAVs.

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