KSII TRANSACTIONS ON INTERNET AND INFORMATION SYSTEMS VOL. 9, NO. 3, Mar. 2015

WSN Lifetime Analysis: Intelligent UAV and Arc Selection Algorithm for Energy Conservation in Isolated Wireless Sensor Networks

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Received August 11, 2014; revised November 17, 2014; accepted December 26, 2014;
published March 31, 2015

Abstract

Wireless Sensor Networks (WSNs) are widely used in geographically isolated applications like military border area monitoring, battle field surveillance, forest fire detection systems, etc. Uninterrupted power supply is not possible in isolated locations and hence sensor nodes live on their own battery power. Localization of sensor nodes in isolated locations is important to identify the location of event for further actions. Existing localization algorithms consume more energy at sensor nodes for computation and communication thereby reduce the lifetime of entire WSNs. Existing approaches also suffer with less localization coverage and localization accuracy. The objective of the proposed work is to increase the lifetime of WSNs while increasing the localization coverage and localization accuracy. A novel intelligent unmanned aerial vehicle anchor node (IUAN) is proposed to reduce the communication cost at sensor nodes during localization. Further, the localization computation cost is reduced at each sensor node by the proposed intelligent arc selection (IAS) algorithm. IUANs construct the location-distance messages (LDMs) for sensor nodes deployed in isolated locations and reach the Control Station (CS). Further, the CS aggregates the LDMs from different IUANs and computes the position of sensor nodes using IAS algorithm. The life time of WSN is analyzed in this paper to prove the efficiency of the proposed localization approach. The proposed localization approach considerably extends the lifetime of WSNs, localization coverage and localization accuracy in isolated environments.

Keywords: Isolated WSNs, IUAN, LDM construction, IAS algorithm, WSN lifetime.

http://dx.doi.org/10.3837/tiis.2015.03.004 **ISSN : 1976-7277**

1. Introduction

Wireless sensor networks are used in many geographically isolated applications like natural disaster management systems, military applications, forest fire detection systems, deep ocean navigations, industrial automations, elder people health care systems, smart home automation applications, etc. Akyildiz.etl [1] explain the applications of sensor networks, factors influencing the design of sensor networks, architecture of sensor network communications and the sensor network protocol stack in detail. Ramesh [2] explored the design, development and deployment of a wireless sensor network for landslide detection with the capability of providing real time data via the internet and issuing warnings ahead of time using the innovative warning system.

Yick.etl [3] explain the types of sensor networks, operating systems and platforms, WSN standards, data storage methods, network services required to co-ordinate the power management, task distribution, and resource usage, data compression, data aggregation, security mechanisms in WSNs. WSN is a collection of sensor nodes and energy lack of a single sensor node causes severe impacts. Sensor node’s battery energy is consumed in active mode, idle mode and sleep modes as explored by Perumal.etl [4]. The **Fig. 1** shows the various energy consuming modes of a sensor node.

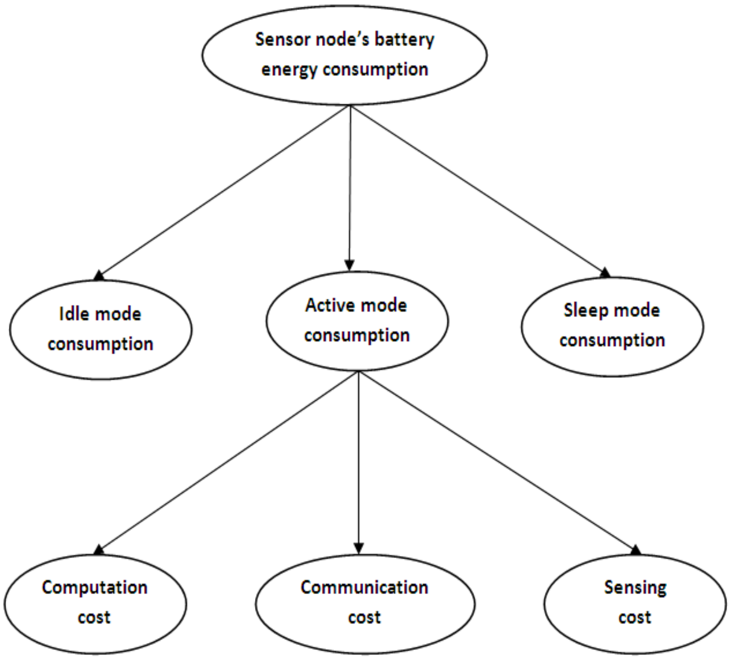

Fig. 1. Energy consuming modes of a sensor node

Anastasi.etl [5] discusses the mobility based energy conservation schemes using mobile sink based and mobile relay based approaches. Aguiar.etl [6] proposed an integer programming model for optimizing energy consumption. The importance of energy conservation in WSNs is explained by Heinzelman.etl [7]. The process of estimating the physical location of sensor nodes is localization and it is very important as the sensed data becomes meaningless without the location of the event. The detailed classification of the localization algorithms is explained by Han.etl [8]. Pal [9] explains about the centralized and distributed localization schemes in detail. Existing localization algorithms consume more energy by heavy computation and communication overheads thereby dry the sensor node's battery quickly. Ssu.etl [10] proposed a range free localization scheme using mobile anchor points equipped with the GPS that broadcasts its current location periodically to the sensor nodes, where sensor nodes compute their location using the data received from the mobile anchors. Ou & Ssu [11] proposed a range free localization scheme, that uses the location beacon messages transmitted by the flying anchor nodes. In this method, each sensor node is need to calculate their location with the help of the radio beacons received. Sheu.etl [12] proposed a localization scheme, which involves inter-sensor communication including sample selection phase, neighbour constraint exchange phase and refinement phase.

Xiao.etl in [13] proposed a localization scheme which involves anchor classification phase, distance estimation phase using different anchor distance estimator and location estimation phase. Ou [14] proposed a localization scheme with beacon scheduling, which forces each sensor node to execute the complex geometrical calculations to determine their locations. Mobile anchor node based position scheme is explained by Liao.etl [15] insists the inter-sensor communication, which causes unnecessary delay, data loss and high energy consumption. Johansson.etl [16] proposed a centralized spring based localization algorithm for large scale wireless sensor networks to reduce the computation cost at sensor nodes. This approach increases the communication overhead due to inter-sensor communication during localization. Bin.etl [17] proposed an improved weighted centroid localization algorithm to improve the location accuracy with minimum energy consumption. Arkin.etl [18] proposed an approach for the base station positioning to transmit the sensor data in an energy efficient way with low duty cycling and minimum end to end delay to maximize the sensor network lifetime. Carli.etl [19] proposed a new approach to tackle the routing and localization problems together for reducing the network signalling communication as maximum as possible which reduces power consumption in wireless sensor networks.

From the review of existing localization approaches, we observed that high communication and computation overhead at sensor nodes reduce the overall lifetime of WSNs. Any approach in WSNs must conserve the battery energy of the sensor nodes. We propose an IUAN approach with intelligent arc selection based localization algorithm to conserve energy in each sensor node to extend the life time of sensor networks deployed in geographically isolated location. The section 2 explains the IUAN assisted LDM construction approach. IAS algorithm for sensor node location computation is explained in section 3. Section 4 gives the simulation results and WSN lifetime analysis. Section 5 gives the conclusion.

2. Intelligent UAV Anchor Node (IUAN) Design and LDM Construction Approach

In the proposed work, unmanned aerial vehicles (UAVs) are used as IUANs by integrating the intelligence systems. The IUAN has its own energy to both fly and broadcast the beacon packets over the geographically isolated locations. Guerrero.etl [20] proposed an approach, where UAVs are used to carry self-positioning device and transmitter to localize the sensor nodes. Yadav.etl [21] explained about the localization method using global positioning system (GPS) enabled flying anchor nodes. Vincent.etl [22] employs the UAVs to distribute the energy burden across the WSNs. Our main idea is to construct the relevant location and distance data from the sensor nodes and compute their locations in the CS. In our approach, UAVs are utilized as flying anchor nodes and referred as intelligent UAV anchor nodes (IUANs). The novel design of the proposed IUAN is shown in the **Fig. 2**.

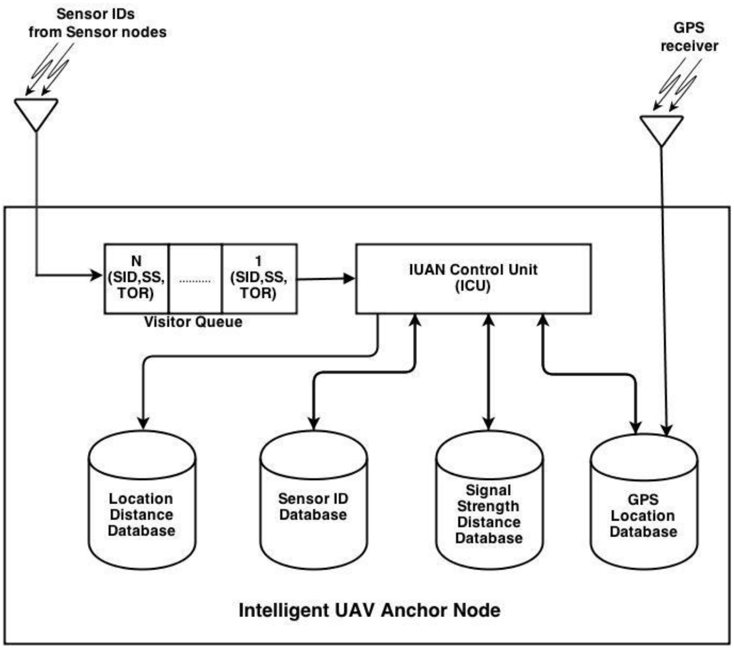

Fig. 2. Architecture of the proposed IUAN

A The IUAN contains IUAN Control Unit (ICU), sensor ID database (DB_{SID}), visitor queue (VQ), signal strength-distance database (DB_{SSD}), IUAN location database (DB_{ILOC}) and location-distance database (DB_{LD}). The ICU controls the overall operation of the IUAN like receiving sensor id message (SID) from sensor nodes, activating GPS receivers, communication with CS, guiding the IUAN in an optimistic trajectory. When an IUAN enters into the transmission range of a sensor node, the sensor node transmits its SID to that IUAN and the ICU executes the sequence of processes to construct the location-distance message (LD message). IUAN receives the SIDs from sensor nodes and stores the SIDs along with their signal strength (SS_{SID}) and corresponding time of reception TOR_{SID} in the VQ as shown in **Fig. 3.**

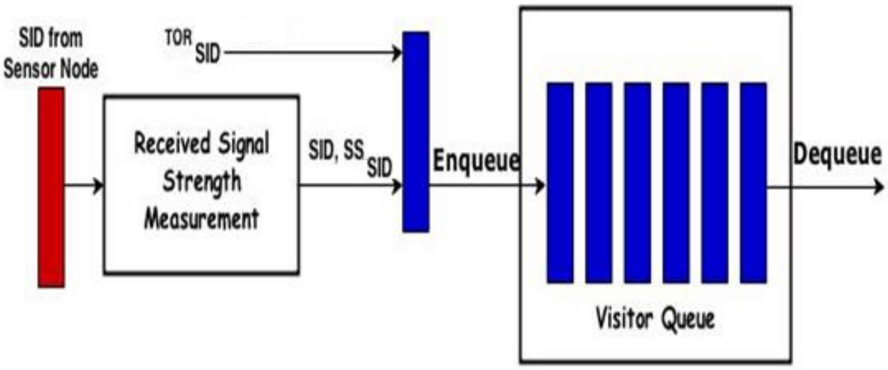

Fig. 3. Visitor Queue (VQ) Organization

TOR_{SID} is the time at which the IUAN receives the SID. Whenever, the IUAN receives the SID (at TOR_{SID}), it stores the SID, its own location (LOC_{IUAN}) along with TOR_{IUAN} to the DB_{ILOC} where $TOR_{IUAN} = TOR_{SID}$. The **Table 1** gives the structure of the DB_{ILOC}.

Table 1. Structure of the IUAN location database (DB_{ILOC})

Time of IUAN location reception TOR_{IUAN} (where $TOR_{IUAN} = TOR_{SID}$)	SID	Location of IUAN (LOC_{IUAN})
T_1	SID_1	(x_1, y_1)
T_2	SID_1	(x_2, y_2)
T_3	SID_1	(x_3, y_3)
T_n	SID_n	(x_n, y_n)

The proposed approach needs at least three Location-Distance Messages to compute the location of a sensor node. The IUAN moves continuously and collects the SIDs from sensor nodes deployed in the field. The **Table 1** shows three different locations $\{(x_1,y_1), (x_2,y_2), (x_3,y_3)\}$ of a single IUAN at three different time instants T_1, T_2 and T_3 within the transmission range of a sensor node (say SID_1). As the three different locations are observed within the transmission range of the same sensor node SID_1 at different time instants, the **Table 1** has different time instants T_1, T_2 and T_3 with different locations $\{(x_1,y_1), (x_2,y_2), (x_3,y_3)\}$ for same SID_1.

The IUAN authenticates the SIDs in the VQ using the DB_{SID} as DB_{SID} contains valid sensor id numbers. The invalid SIDs are ignored and LD messages are constructed for only the valid sensor nodes. In our approach, the DB_{SID} contains the identity of all valid sensor nodes deployed by the application user. Here SID_1 is a valid SID for the sensor node (say SN-1). Each SID is identified by the predefined secret code (equivalent to password). For example, SID_1 is interpreted as 1043. When an IUAN receives SID_1 message from SN-1, it immediately extracts the secret code (1043), determines the signal strength and stores these details in the visitor queue along with the time of reception (TOR_{SID}). Then the IUAN control unit compares the secret code with the DB_{SID}. As this secret code is matched with the database, then the IUAN understands that this SID_1 belongs to valid group. Otherwise this will be ignored and removed from the visitor queue. The secret codes other than stored in the DB_{SID} are considered as invalid SIDs.

The DB_{SSD} is used to withstand with radio irregularity. The signal strength at the locations around the transmission range of a sensor node varies with the distance and environmental effects. The path loss effect causes the radio signal to attenuate variously in different directions. The proposed work assumes the radio irregularity model (RIM) given by Zhou.etl [23]. The **Table 2** shows the structure of the DB_{SSD}, where the sample values of the signal strengths (SS) at the receiver at 3.048 m away from the mica2 mote are measured by the series of radio beacon transmissions in four directions. The signal strength around each sensor node is calculated based on the signal strength-distance relation using RSSI measurements with the knowledge of degree of irregularity (DOI). For a valid SID, an IUAN fetches the distance (D) between itself and the a sensor node using the corresponding SS_{SID}. In our approach, the computation cost for the signal strength and distance measurements are shifted from the sensor nodes to the powerful IUAN to conserve the energy at each sensor node. During the validation of SID and distance fetching process, the IUAN moves to different locations. Hence after fetching the distance, the IUAN fetches the corresponding location information (LOC_{IUAN}) at which it received the SID, using the TOR_{IUAN} and TOR_{SID}.

Table 2. RSSI value and distance of signal strength-distance database (DB_{SSD})

Signal Strength (SS) (dBm)	Distance (D) (m)	Direction
-63	3.048	East
-59	3.048	North
-58	3.048	West
-57	3.048	South

This mechanism ensures the construction of valid location and distance information. The IUAN constructs the LD message (LDM) and stores in the DB_{LD} database, where each LDM contains the location (L), distance (D) and the corresponding SID. The **Table 3** shows the list of symbols used in the LDM construction Algorithm 1 and corresponding flow diagram is shown in **Fig. 4**.

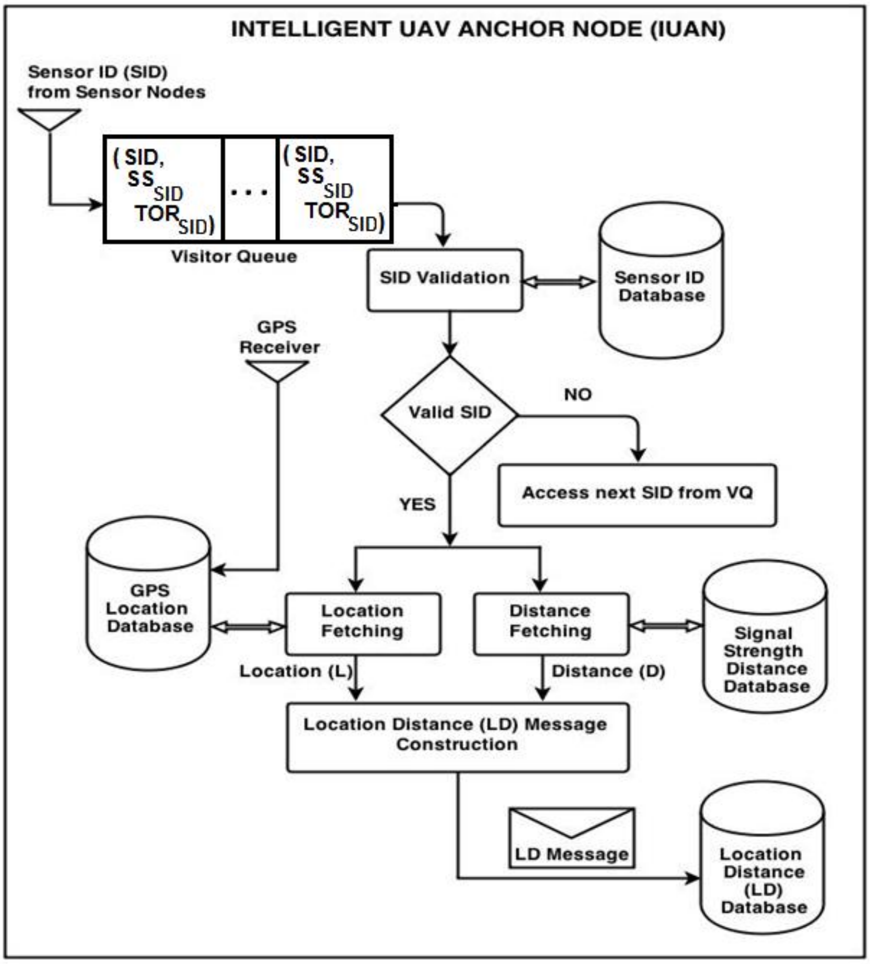

Fig. 4. Flow diagram of the LD message construction algorithm

Table 3. List of symbols used in LD message construction algorithm

SYMBOL	DEFINITION
IUAN	Intelligent UAV anchor node
$\Delta(f)$	Flight period of IUAN
SID	Sensor ID sent by the sensor node
TOR_{SID}	Time of SID reception
TOR_{IUAN}	Time at which the IUAN location is received from GPS
VQ	Visitor queue
DB_{SID}	Sensor ID database
DB_{SSD}	Signal strength-distance database
DB_{ILOC}	IUAN location database
DB_{LD}	Location-distance database
SS_{SID}	Signal strength of SID
D	Distance between sensor node and IUAN at TOR_{SID}
LOC_{IUAN}	Location of the IUAN when ir receives the SID
LDM	Location-distance message
ConstructLDMPacket (LOC_{IUAN}, D, SID)	Procedure to construct LDM with 'D', 'LOC_{IUAN}' and 'SID'

Algorithm 1: LDM Construction

Input: SID from Sensor Node

Output: LD Message (LDM)

```
Begin
  Interrupt Process 1: Whenever SIDi is received from sensor node
    measure $SS_{SIDi}$
    VQ $\leftarrow$ enqueue (SIDi, $SS_{SIDi}$, $TOR_{SIDi}$)
    $DB_{GLOC} \leftarrow$ insert($LOC_{IUAN}$, SIDi, $TOR_{IUAN}=TOR_{SIDi}$)
  end Interrupt Process 1
  while(VQ != NULL)
    if SIDi $\notin DB_{SID}$ then
      VQ $\leftarrow$ dequeue (SIDi, $SS_{SIDi}$, $TOR_{SIDi}$)
    else
      D $\leftarrow$ select D from $DB_{SSD}$ where $SS=SS_{SIDi}$
      L $\leftarrow$ select $LOC_{IUAN}$ from $DB_{ILOC}$ where $TOR_{IUAN} = TOR_{SIDi}$
      LDM.x $\leftarrow$ $LOC_{IUAN}$.x
      LDM.y $\leftarrow$ $LOC_{IUAN}$.y
      LDM.d $\leftarrow$ D
      LDM.id $\leftarrow$ SIDi
      LDM $\leftarrow$ ConstructLDMPacket (LDM.x, LDM.y, LDM.d, LDM.id)
      insert LDM into $DB_{LD}$
      VQ $\leftarrow$ dequeue (SIDi, $SS_{SIDi}$, $TOR_{SIDi}$)
      delete $LOC_{IUAN}$, SIDi, $TOR_{IUAN}$ from $DB_{ILOC}$ where $TOR_{IUAN}=TOR_{SIDi}$ and SID = $SID_i$
    end if
  end while
End
```

After constructing the LDM, the ICU removes the corresponding entries from the VQ and DB_{ILOC} to manage the storage efficiency. The CS aggregates DB_{LD} database of all IUANs and selects the sufficient LDMs to calculate the locations of the sensor nodes.

3. Intelligent Arc Selection (IAS) based Localization Algorithm

For the state-of-art, we propose a novel approach to completely remove the computation cost from individual sensor nodes during localization process with minimum communication overhead. Our approach computes the location of each sensor node in CS, where the computing and communication resources are not constraint. The proposed localization algorithm aggregates the LDM from different IUANs and computes the location of a sensor node with three relevant LD messages. Each LD message contains the LOC_{IUAN} and the distance between the LOC_{IUAN} and the corresponding sensor node's location (LOC_S). The proposed algorithm is an optimum version of the trilateration method. Our algorithm selects the boundary points and arc angles to construct the intelligent arc segments, where the intersection of these arcs gives the location of the sensor node. The algorithm starts with three LD message inputs, where these messages are constructed within the range of a sensor node as shown in the **Fig. 5**. The proposed algorithm has 6 phases.

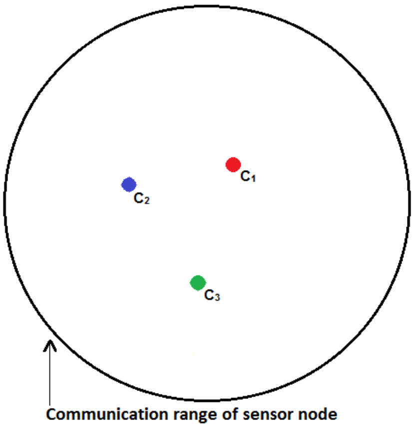

Fig. 5. Three LDMs constrcued within the range of a sensor node

In phase 1, the LD messages are processed to extract the $IUAN_{Centres}\{C_1,C_2,C_3\}$ and the corresponding $IUAN_{Distances}\{r_1,r_2,r_3\}$, where r_I is the distance between IUAN centre C_i and the sensor node. In phase 2, the boundary points (BPoints) around each $IUAN_{Centre}$ are calculated using the 2D translation as shown in the **Fig. 6**. All BPoints and $IUAN_{Centres}$ contain the associated 'x' and 'y' co-ordinate values and based on these both the $IUAN_{Centres}$ and BPoints are classified as the 'x' axis centre points (XCPoints), 'x' axis boundary points (XBPoints), 'y' axis centre points (YCPoints), 'y' axis boundary points (YBPoints). Each $IUAN_{Centre}$ has four associated bounday points. Eg: $\{P_1,P_2,P_3,P_4\}$is the set of boundary points around the IUAN centre (C_1). A complete circle around this centre can be constructed using these 4 boundary points and the corresponding distance/radius r_1. Similarly, three circles can be constructed around the three centres. The intersection of these three circles gives the location of the sensor as these locations and distances are constructed within the range of the sensor node. This method is referred as trilateration. Our approach optimizes the trilateration method by constructing the intelligent arcs using the intelligent boundary points, instead of considering the complete circles, which reduces the computation cost significantly in the localization process of the large volume of sensor nodes.

Phase 3 selects the intelligent boundary points on 'x' axis and 'y' axis, which contribute to the construction of the intelligent arcs and they are referred as IXBPoints and IYBPoints respectively. Among the 6 boundary points $\{P_2,P_4,Q_2,Q_4,R_2,R_4\}$ on 'x' axis, only 3 points contribute to the intelligent arcs. Similarly among the 6 boundary points $\{P_1,P_3,Q_1,Q_3,R_1,R_3\}$on 'y', only three points contribute to the intelligent arcs. The XCPoints and XBPoints are grouped as Points1 and Points2 respectively. The intelligent points IXBPoints are selected from Points2, where XCPoints lies between the range of first and last XCPoints in the Points2. This selection decision is taken based on the fact that, the boundary points lies out of this range are not contributing to the intelligent arcs. Similarly IYBPoints are selected. The **Fig. 7** shows the intelligent boundary points IXBPoints and IYBPoints selected in phase 3.

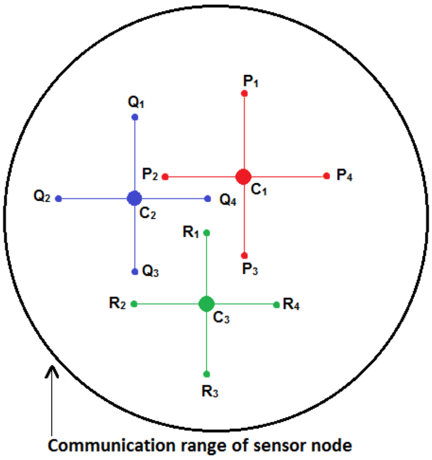

Fig. 6. Computation of boundary points

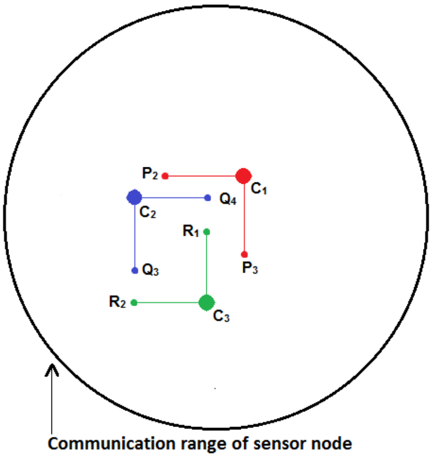

Fig. 7. Selection of intelligent boundary points

Definition of an arc: An arc can be constructed with a centre point C(x,y) and radius (r). The points on the arc is defined as the set of points P(h,k) using the parametric equations (1) and (2), $\forall\ \Theta, \Theta_1 \leq \Theta \leq \Theta_2$ where $0 \leq \Theta_1 \leq 2\pi$ and $\Theta_1 < \Theta_2 < (\Theta_1+2\pi)$. The point $P_1(x_1,y_1)$ with $\Theta = \Theta_1$ is called the start point of the arc, and the point $P_2(x_2,y_2)$ with $\Theta = \Theta_2$ is called the end point of the arc.

$$h = x + r\cos(\theta) \tag{1}$$

$$k = y + r\sin(\theta) \tag{2}$$

After selecting the intelligent boundary points, phase 4 identifies the starting and ending angles of each intelligent arc. The sensor node is positioned, where the three intelligent arcs intersect. So any two arbitrary arcs can be constructed, as the intersection of any two intelligent arcs gives the sensor node's location. Phase 5 constructs any two arbitrary intelligent arcs using the parametric Equations (1) and (2). Phase 6 compares the points on the arbitrarily selected (two) intelligent arcs and identifies the common point, i.e. the intersection of the two arcs. This common point is the location of the sensor node S (LOC_s.x, LOC_s.y) as shown in the **Fig. 8a** and **Fig. 8b**. The Algorithm 2 explains the mathematical logic behind the proposed intelligent arc selection based centralized localization algorithm.

Algorithm 2: Intelligent Arc Selection based Centralized Localization Algotithm

```
Input: $LDM_1$, $LDM_2$, $LDM_3$, where $LDM_1.id = LDM_2.id = LDM_3.id$
Output: Sensor Node's Location S ($LOC_S.x$, $LOC_S.y$)
Begin
    ($IUAN_{Centres}$, $IUAN_{Distances}$) $\leftarrow$ ExtractLDMessage ($LDM_1$, $LDM_2$, $LDM_3$)
    (XCPoints, XBPoints, YCPoints, YBPoints) $\leftarrow$ BPoints ($IUAN_{Centres}$, $IUAN_{Distances}$)
    IXBPoints $\leftarrow$ IXBPoints (XCPoints, XBPoints)
    IYBPoints $\leftarrow$ IYBPoints (YCPoints, YBPoints)
    St_End_Angles $\leftarrow$ Start_End_ArcAngles (IXBPoints, IYBPoints)
    ($A_1$, $A_2$) $\leftarrow$ Arc_Segments (XCPoints, YCPoints, St_End_Angles, $IUAN_{Distances}$)
    ($LOC_S.x$, $LOC_S.y$) $\leftarrow$ Sensor_Location ($A_1$, $A_2$)
End
```

Phase 1: Extracting Location Distance (LD) Messages

```
Procedure ExtractLDMessage
    $C(1).x \leftarrow LDM_1.x$
    $C(1).y \leftarrow LDM_1.y$
    $C(2).x \leftarrow LDM_2.x$
    $C(2).y \leftarrow LDM_2.y$
    $C(3).x \leftarrow LDM_3.x$
    $C(3).y \leftarrow LDM_3.y$
    $r_1 \leftarrow LDM_1.d$
    $r_2 \leftarrow LDM_2.d$
    $r_3 \leftarrow LDM_3.d$
    $IUAN_{Centres} \leftarrow \{C(1).x, C(1).y, C(2).x, C(2).y, C(3).x, C(3).y\}$
    $IUAN_{Distances} \leftarrow \{r_1, r_2, r_3\}$
    return ($IUAN_{Centres}$, $IUAN_{Distances}$)
End
```

Phase 2: Computation of Boundary Points

```
Procedure BPoints ($IUAN_{Centres}$, $IUAN_{Distances}$)
    $B(i).x \leftarrow C(j).x$;          where $B\ \forall\ P, Q, R$;  $i=1,3$;  $j=1,2,3$;
    $B(i).y \leftarrow C(j).y$;          where $B\ \forall\ P, Q, R$;  $i=2,4$;  $j=1,2,3$;
    $B(i).x \leftarrow C(j).x - r_k$;    where $B\ \forall\ P, Q, R$;  $i=2$;    $j=1,2,3$;  $k=1,2,3$;
    $B(i).x \leftarrow C(j).x + r_k$;    where $B\ \forall\ P, Q, R$;  $i=4$;    $j=1,2,3$;  $k=1,2,3$;
    $B(i).y \leftarrow C(j).y + r_k$;    where $B\ \forall\ P, Q, R$;  $i=1$;    $j=1,2,3$;  $k=1,2,3$;
    $B(i).y \leftarrow C(j).y - r_k$;    where $B\ \forall\ P, Q, R$;  $i=3$;    $j=1,2,3$;  $k=1,2,3$;
    XCPoints $\leftarrow \{C(1).x, C(2).x, C(3).x\}$
    YCPoints $\leftarrow \{C(1).y, C(2).y, C(3).y\}$
    XBPoints $\leftarrow \{P(2).x, P(4).x, Q(2).x, Q(4).x, R(2).x, R(4).x\}$
    YBPoints $\leftarrow \{P(1).y, P(3).y, Q(1).y, Q(3).y, R(1).y, R(3).y\}$
    return (XCPoints, XBPoints, YCPoints, YBPoints)
End
```

Phase 3: Selecting Intelligent Boundary Points on 'X' and 'Y' axis

```
Procedure IXBPoints (XCPoints, XBPoints)
    Points1 $\leftarrow \{C(1).x, C(2).x, C(3).x, P(2).x, P(4).x, Q(2).x, Q(4).x, R(2).x, R(4).x\}$
    Points2 $\leftarrow$ Sort (Points1), where $C(i).x < C(j).x < C(k).x$; $\forall\ i,j,k = 1,2,3$; $i \neq j \neq k$
    IXBPoints $\subset$ Points2, where $C(i).x <$ {IXBPoints} $< C(k).x$
    IXBPoints $\leftarrow \{P(m).x, Q(n).x, R(o).x\}$, wher m,n,o are either 2 or 4
    return (IXBPoints)
End
Procedure IYBPoints (YCPoints, YBPoints)
    Points1 $\leftarrow \{C(1).y, C(2).y, C(3).y, P(1).y, P(3).y, Q(1).y, Q(3).y, R(1).y, R(3).y\}$
    Points2 $\leftarrow$ Sort (Points1), where $C(i).y < C(j).y < C(k).y$; $\forall\ i,j,k = 1,2,3$; $i \neq j \neq k$
```

```
    IYBPoints $\subset$ Points2, where C(i).y < {IYBPoints} < C(k).y
    IYBPoints $\leftarrow$ {P(m).y , Q(n).y , R(o).y}, wher m,n,o are either 1 or 3
    return (IYBPoints)
End
```

Phase 4:

```
Procedure Start_End_ArcAngles (IXBPoints, IYBPoints)
    if P(m).y = P(1).y then $\Theta_1 \leftarrow \pi/2$
    else $\Theta_1 \leftarrow 3\pi/2$
    end if
    if P(m).x = P(4).x then $\Theta_2 \leftarrow 0\pi$
    else $\Theta_2 \leftarrow \pi$
    end if
    if Q(m).y = Q(1).y then $\Theta_3 \leftarrow \pi/2$
    else $\Theta_3 \leftarrow 3\pi/2$
    end if
    if Q(m).x = Q(4).x then $\Theta_4 \leftarrow 0\pi$
    else $\Theta_4 \leftarrow \pi$
    end if
    return ($\Theta_1, \Theta_2, \Theta_3, \Theta_4$)
End
```

Phase 5

```
Procedure Arc_Segments (XCPoints, YCPoints, St_End_Angles, $IUAN_{Distances}$)
    $A_1(i).x \leftarrow C(1).x + r_1.\cos(\Theta)$, where $\Theta_1 \leq \Theta_i \leq \Theta_2$ $\forall$ i=1,2,…n
    $A_1(i).y \leftarrow C(1).y + r_1.\sin(\Theta)$, where $\Theta_1 \leq \Theta_i \leq \Theta_2$ $\forall$ i=1,2,…n
    $A_2(j).x \leftarrow C(2).x + r_2.\cos(\Theta)$, where $\Theta_3 \leq \Theta_j \leq \Theta_4$ $\forall$ j=1,2,…n
    $A_2(j).y \leftarrow C(2).y + r_2.\sin(\Theta)$, where $\Theta_3 \leq \Theta_j \leq \Theta_4$ $\forall$ j=1,2,…n
    $A_1 \leftarrow \{(A_1(i).x, A_1(i).y)$ $\forall$ i=1,2,…n }: set of points on arc $A_1$
    $A_2 \leftarrow \{(A_2(j).x, A_2(j).y)$ $\forall$ j=1,2,…n }: set of points on arc $A_2$
    return ($A_1$, $A_2$)
End
```

Phase 6

```
Procedure Sensor_Location ($A_1$, $A_2$)
    Compare {($A_1(1).x$, $A_1(1).y$), ... ($A_1(n).x$, $A_1(n).y$)} and {{($A_2(1).x$, $A_2(1).y$), ... ($A_2(n).x$, $A_2(n).y$)}
    if (($A_1(i).x$, $A_1(i).y$) = ($A_2(j).x$, $A_2(j).y$)) then
        $LOC_s.x \leftarrow A_1(i).x$
        $LOC_s.y \leftarrow A_1(i).y$
    end if
    return S($LOC_S.x$, $LOC_S.y$)
End
```

The control station stores the location of sensor nodes in the sensor position database (DB_{SP}) along with the SID. This database is used to identify the location of event as each sensor node sends the sensed information along with their identification.

4. Simulation Results and Analysis

The performance of the proposed IUAN assisted LDM construction approach and existing localization approaches [10, 11, 16, 17] are evaluated by considering the parameters localization-communication cost and localization-coverage. The performance of the proposed localization approach and existing approaches are evaluated in a series of simulations using ns-2 simulator and compared. The **Table 4** shows the list of parameters used in the simulation.

Table 4. Simulation parameters

Parameters	**Value(s)**
IUAN velocity	5 m/s
IUAN heigth from ground	10 m to 30 m
Number of sensor nodes	300, 600, 900, 1200, 1500
Number of IUANs	30, 60, 90, 120, 150
Radio model	First order radio model
Radio communication range	30 m
Initial energy in each sensor node	0.001J
Energy dissipated by transmitter circuitry ($E_{Tx\text{-}elec}$)	50 nJ/bit
Energy dissipated by receiver circuitry ($E_{Rx\text{-}elec}$)	50 nJ/bit
Energy dissipated by transmitter amplifier (E_{amp})	100 pJ/bit/m^2
SID packet size	3 byte
Acknowledgement packet size	3 byte

4.1 Localization Communication Cost

An energy efficient localization algorithm shall not consume more communication cost at each sensor node to transmit and receive many beacons during localization period, since high communication cost reduces the lifetime of the sensor nodes and WSNs. The IUAN assisted LDM construction approach significantly reduces the localization-communication cost at each sensor node and its performance is compared with the existing localization approaches proposed by [10, 11, 16, 17]. The simulation assumes of first order radio model, where 60nJ of energy is consumed for transmitting one bit and 50nJ of energy is consumed for receiving one bit as explained by Heinzelman.etl [7]. Each SID and acknowledgement packet has the size of 3 byte. Using the equations (3.4) and (3.5), it is calculated that each sensor node consumes 480nJ of energy for transmitting 3 byte of message and 400nJ of energy for receiving 3 byte of message. The simulation is performed with the number of sensor nodes ranging from 300 to 1500 and the corresponding localization-communication cost is tabulated in **Table 5**.

Table 5. Localization communication cost (E_{comm})

	Energy consumption (10^3nJ)				
	300 Sensor Nodes	600 Sensor Nodes	900 Sensor Nodes	1200 Sensor Nodes	1500 Sensor Nodes
Proposed Approach	792	1584	2376	3168	3960
Scheme [17]	1584	3168	4752	6336	7920
Scheme [16]	1056	2112	3168	4224	5820
Scheme [11]	1848	3696	5544	7392	9240
Scheme [10]	3168	6336	9504	12672	15840

The values in the **Table 5** clearly show that the proposed localization approach consumes less communication cost than the existing localization approaches. The proposed approach conserves an average of $3393x10^3$nJ energy in localization communication cost than the existing approaches. This energy conservation is achieved by the proposed IUAN assisted LDM construction approach by reducing the communication overhead at each sensor node during localization. The pictorial representation of the localization-communication cost of proposed and existing localization approaches is shown in the **Fig. 9**.

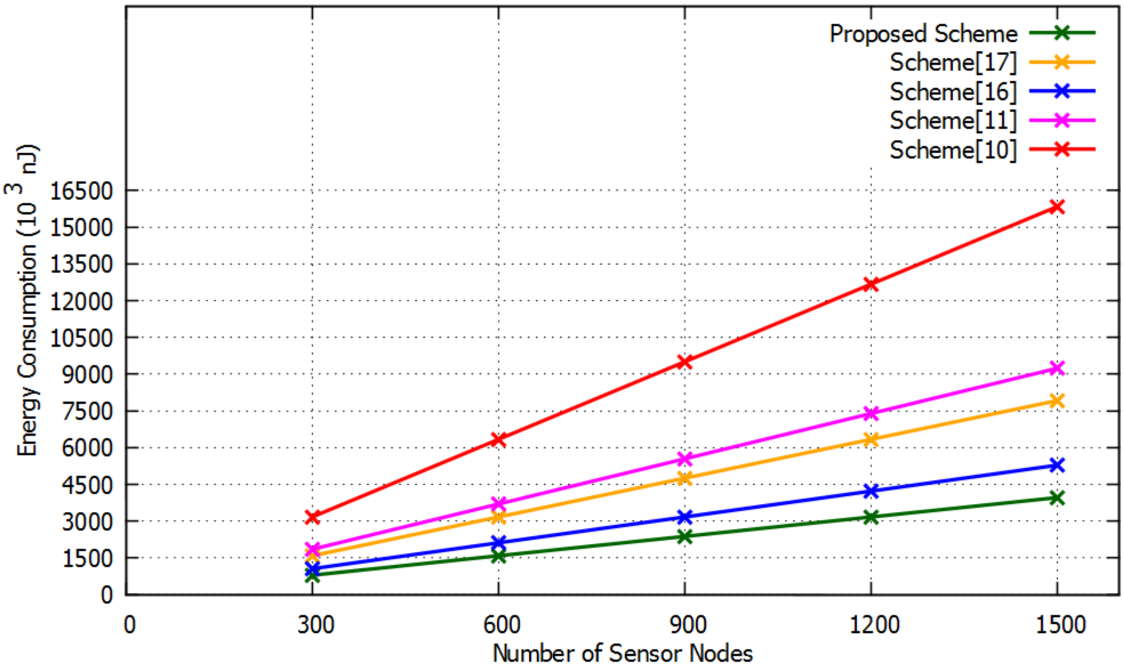

Fig. 9. Localization communication cost

4.2 Localization Coverage

The trajectory of the IUAN significantly influences the localization coverage while it constructs the location-distance messages for unknown sensor nodes. The IUAN aims to construct at least three location-distance messages for each sensor node to calculate their location. The proposed LDM construction approach gives better localization coverage. In existing localization schemes, sensor nodes are insisted to receive many beacon messages from single flying anchor node to compute their location which is not possible always.

In the proposed approach even if a single IUAN is not able to receive three SIDs and construct three LDMs for a sensor node, another IUAN may receive the balance SIDs and construct the LDMs for that sensor node. This flexibility increases the localization coverage even with the minimum level of anchor guiding mechanisms, where the existing localization approaches need highly complex anchor guiding mechanisms to guide the flying anchor nodes in the efficient trajectory to localize maximum number of sensor nodes.

The localization coverage performance of the proposed LDM approach is compared with the localization algorithms proposed by [10, 11, 16, 17]. The simulation is performed in ns-2 simulator by assuming the snake like walk model and random walk model. The **Fig. 10** shows the scenario where three different IUANs receive SIDs from a single sensor node and construct LDMs using the proposed LDM approach.

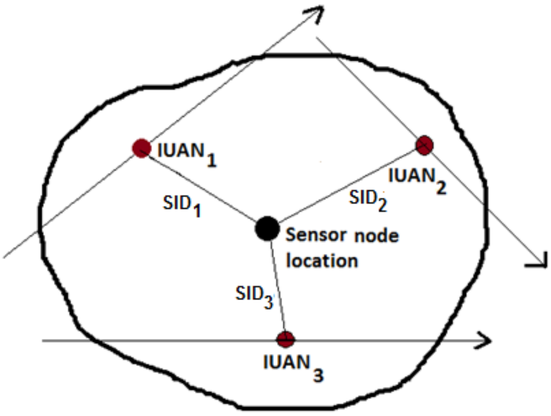

Fig. 10. Three different IUANs constructing LDMs for a single sensor node

The proposed approach prevents the IUANs from receiving more than three SIDs from a single sensor node thereby conserves the localization-communication cost at each sensor node. The simulation is performed to observe the localization-coverage in the snake like walk model and random walk model, where 30, 60, 90, 120, 150 IUANS are used to interact with the sensor nodes ranging from 300, 600, 900, 1200 and 1500 respectively. The localization coverage results of the proposed and existing localization approaches in snake like walk model and random walk model are given in **Table 6** and **Table 7** respectively.

Table 6. Localization coverage in snake like walk model

	Percentage of localization coverage for sensor nodes				
	300	600	900	1200	1500
Proposed Approach	73.3	74.2	75.3	75.9	76.1
Scheme [17]	62.66	63.66	64.55	65.08	66.06
Scheme [16]	63.16	64.68	64.99	65.75	66.68
Scheme [11]	60.33	61.83	62.44	63.33	64.67
Scheme [10]	57.33	58.5	58.67	59.83	61.93

Table 7. Localization coverage in random walk model

	Percentage of localization coverage for sensor nodes				
	300	600	900	1200	1500
Proposed Approach	69.33	69.55	70	70.56	70.99
Scheme [17]	59	59.5	60	61	61.5
Scheme [16]	60.1	61.12	61.45	62.3	62.64
Scheme [11]	58	58.5	59	59.58	60.52
Scheme [10]	55	55.5	56	56.23	57.56

The simulation values in **Table 6** and **Table7** show that the proposed localization approach gives an average of 12.15%, 10.86% extra coverage than the existing approaches respectively.

4.3 Localization Computation Cost

The existing localization algorithms [10, 11, 17] insist each sensor node to execute computations to find their location, which consumes huge energy from sensor node battery. The centralized localization algorithm proposed by [16] calculates the location of the sensor nodes in anchor nodes. The proposed IAS based localization algorithm removes the localization-computation cost at individual sensor node. The proposed IAS based localization approach also reduces the energy consumption in the control station by minimizing the localization-computation cost. The proposed approach significantly conserves energy thereby increases the life time of the WSNs. The simulation assumes 2.25 nJ energy consumption for single multiplication operation. The **Table 8** shows the localization-computation cost of the proposed localization approach and existing localization approaches

Table 8. Localization computation cost (E_{comp})

	Energy consumption (10^3nJ)				
	300 Sensor Nodes	600 Sensor Nodes	900 Sensor Nodes	1200 Sensor Nodes	1500 Sensor Nodes
Proposed Approach	135	270	405	540	675
Scheme [17]	202.5	405	607.5	810	1012.5
Scheme [16]	175.5	351	526.5	702	877.5
Scheme [11]	337.5	675	1012.5	1350	1687.5
Scheme [10]	405	810	1215	1620	2025

The tactice of selecting the intelligent arcs in the proposed IAS approach reduces the localization-computation cost and conserves energy than the exixting localization approaches. The pictorial representation of the localization-computaion cost of the proposed and existing localization approaches is shown in the **Fig. 11**. This clearly demosntrates that the proposed energy efficient localization approach consumes less localization-compuation cost than the existing localization approaches.

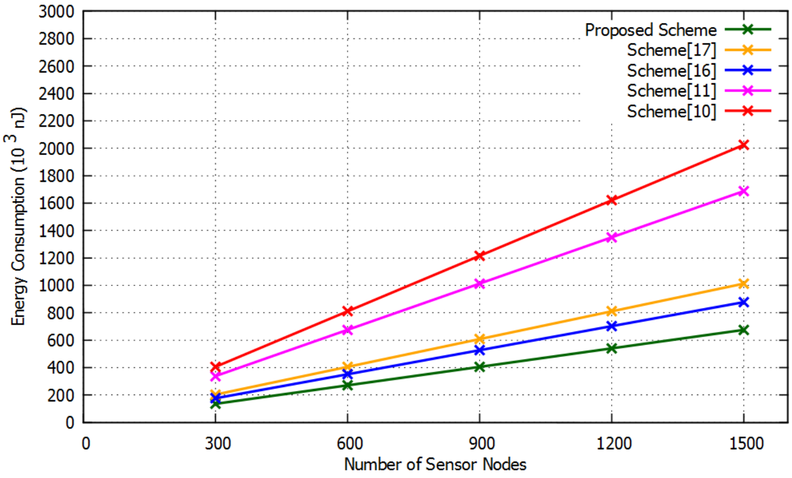

Fig. 11. Localization computation cost

4.4 Localization Accuracy

Location error is the measure of the distance between the estimated location and the actual location of the sensor node. The radio propagation patterns are not isotropic. Radio irregularity is caused primarily by the non-isotropic properties of the propagation media and the heterogeneity of the components. The irregular radio propagation patterns potentially interfere with the localization mechanisms thereby reduce the localization accuracy. The RIM model proposed by Zhou et al (2005) has been used in the proposed localization approach to estimate a realistic radio propagation pattern in a two dimensional plane and improve the localization accuracy.

The performance of the proposed localization scheme is evaluated and compared with the localization schemes proposed by [10, 11, 16, 17]. The simulation of the localization accuracy is performed with 900 sensor nodes for radio ranges of 10 m, 15 m, 20 m, 25 m and 30 m. The **Table 9** shows the average localization error obtained by both the proposed and existing localization approaches. The **Fig. 12**. shows the pictorial representation of average localization error with various transmission ranges for proposed and existing localization approaches.

Table 9. Average localization error (m) for 900 sensor nodes with various transmission ranges

	Transmission range (m)				
	10	15	20	25	30
Proposed Approach	2.04	2.95	4.3	5.8	7.15
Scheme [17]	2.32	3.31	4.9	6.24	7.91
Scheme [16]	2.23	3.13	4.5	5.99	7.52
Scheme [11]	2.63	3.86	5.42	6.9	8.35
Scheme [10]	3.01	4.45	6.3	7.95	9.85

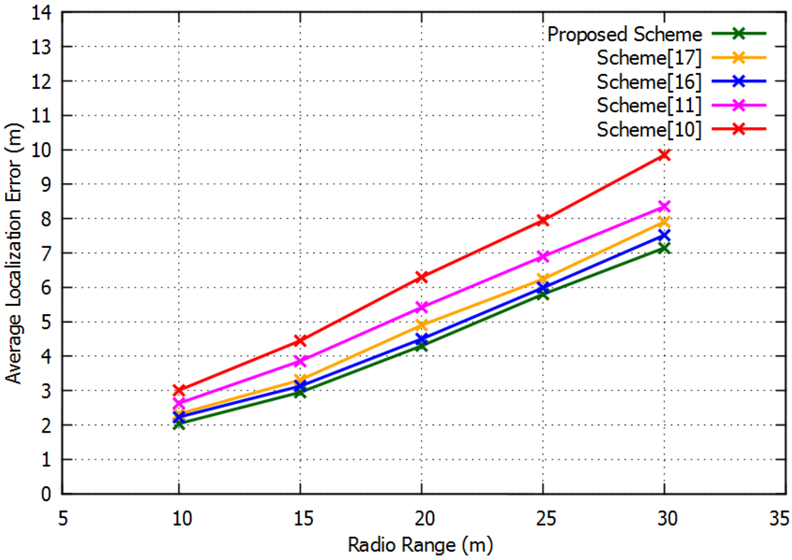

Fig. 12. Average localization error versus radio range

From the graph shown in **Fig. 12**, it is observed that the proposed localization approach outperforms the existing localization approaches in terms of accuracy. The simulation results show that the proposed approach gives an average of 0.89 m accuracy than the existing approaches.

4.5 Analysis of WSNs Lifetime

One of the fundamental design challenges in designing a wireless sensor network is to maximize the network lifetime. Each sensor node of the network is equipped with a limited power battery. Once the sensor nodes are deployed, it is often infeasible or undesirable to recharge sensor nodes or replace their batteries with manual intervention. These physical constraints make energy as a crucial consideration to design a long life time sensor network.

The WSN lifetime is analyzed with the proposed and existing localization approaches and compared. In the proposed approach, IUANs are utilized to collect SIDs from sensor nodes and to construct LDMs. Each IUAN has own power to fly and communicate with sensor nodes. Whenever an IUAN need energy, it can recharge its battery backup in control station as explained by Perumal.etl [24]. Hence energy is not a scarce resource for IUAN and energy consumption of IUAN does not affect the WSNs lifetime. Hence the analysis is performed only for the wireless sensor network and the energy requirements of control station and IUANs are ignored. Each sensor node has 0.001J of initial energy. Each sensor node consumes 200x10^3nJ of average energy per day for usual tasks like sensing, executing security algorithms, routing process, etc. Both the proposed localization approach and [16] calculate the sensor node location at control station and anchor node respectively. Hence their localization-computation cost is not consumed at the sensor nodes. For the localization approaches [10], [11] and [17], the localization-computation cost is consumed at sensor nodes. The **Table 10** shows the total energy consumption.

Table 10. Total energy consumption

	Total energy consumption (10^3nJ) (Localization Communication Cost + Localization Computation Cost)				
	300 Sensor Nodes	600 Sensor Nodes	900 Sensor Nodes	1200 Sensor Nodes	1500 Sensor Nodes
Proposed Approach	60792	121584	182376	243168	303960
Scheme [17]	61786.5	123573	185359.5	247146	308932.5
Scheme [16]	61056	122112	183168	244224	305820
Scheme [11]	62185.5	124371	186556.5	248742	310927.5
Scheme [10]	63573	127146	190719	254292	317865

From **Table 10**, it is observed that the proposed localization approach consumes less computation cost than the existing approaches. The proposed approach conserves an average of 435.38x10^3nJ energy in computation cost than the existing approaches. The lifetime of the WSNs depends on the sensor node's remaining energy, which is the energy left over with sensor nodes after localization process. The **Fig. 13** shows the lifetime of 1500 sensor nodes for the remaining energy.

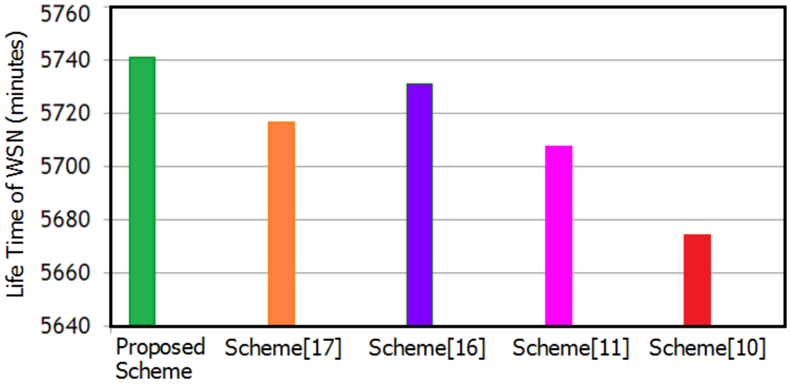

Fig. 13. Life time of the WSN with 1500 sensor nodes for the remaining energy

The **Fig. 13** clearly shows that both the proposed localization approach and [16] provides longer lifetime for the WSN than [10, 11, 17]. This performance is achieved as these two approaches calculate the location of sensor nodes in control station and anchor node. Further, the proposed energy efficient localization approach gives extra lifetime than [16] due to the IUAN assisted LDM construction approach and IAS based location computation.

5. Conclusion

A novel IUAN assisted localization approach is proposed to conserve the energy at each sensor node in geographically isolated applications. The proposed localization approach uses RIM model to withstand the radio irregularity nature for better location accuracy. The proposed IUAN assisted LDM construction approach conserves an average of $3393x10^3$ nJ energy in localization-communication cost than the existing localization approaches. The LDM construction approach also increases the localization-coverage. In snake like walk model, the proposed LDM construction approach gives an average of 12.15 % extra localization coverage than existing localization approaches. In random walk model, the proposed LDM construction approach gives an average of 10.86 % extra localization coverage than existing localization approaches.

The proposed intelligent arc selection approach removes the localization-computation overhead at each sensor node thereby the energy is conserved significantly at sensor nodes. The proposed energy efficient IAS localization approach conserves an average of $435.38x10^3$ nJ energy in localization-computation cost than the existing localization approaches. The proposed localization approach also increases the localization accuracy. For 900 sensor nodes with transmission ranges of 10 m, 15 m, 20 m, 25 m and 30 m, the proposed localization scheme gives an average of 0.89 m accuracy than the existing localization schemes. The analysis of WSN lifetime clearly shows that the IUAN assisted LDM construction and IAS based location computation of the proposed energy efficient localization approach significantly conserves energy at sensor nodes. The proposed approach prolongs the WSN lifetime by an average of 34 minutes than the existing localization approaches.

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