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# ACTIVE / PASSIVE MOBILITY DRIVEN ROUTING DESIGN AND IMPLEMENTATION FOR ANIMAL MONITORING SENSOR NETWORK

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## ABSTRACT

Animal Habitat monitoring can be better carried out remotely without active human interruption. The designed sys- tem should provide data that facilitates proactive measures to prevent the spreading of health hazards among animals, detect intruding poachers and track the locomotive behavior of animals in their habitat. In this work, reliable and resilient cost effective routing solutions are implemented addressing Passive and Active Mobility requirements through embedded plat- forms such as Raspberry PI and Arduino. For addressing passive mobility requirement, an alternate to Zigbee mesh routing protocol (Modified AODV) namely a Greedy Based Geographic Forwarding with Delay Tolerant approach is implemented. Nodes tagged on to animals are equipped with GPS and IEEE 802.15.4 wireless transceiver to transmit the location information along with sensed parameters either via single hopor maximum forwarding progress neighbor (animal) towards sink in multi-hop manner. The payload is buffered until a forwarding neighbor (neighboring animal) or sink is detected in transmission range to handle void issues in deployed monitoring area. Sink is assumed to be stationary and this solution is designed to address application requirement that demands to track the locomotive behavior of animals via passive mobility. It isachievedthrough802.15.4MACaddressbasedtagging.However, for Active Mobility requirement, a routing solution is implemented where nodes are equipped with camera and driven through stepper motor(s). These spatially distributed nodes are made to move across the field to capture the detected animal images and transmit through Wi-Fi network to the gateway directly or through Optimized Link State Routing Approach (OLSR). These active mobile nodes run High Speed Multimedia Stack in Raspberry PI and transmit the compressed images by applying Discrete Cosine Transform (DCT) to reduce the band width and communication cost in addition to resolving congestion in a dense deployment.

**Keywords:** AODV, geographic forwarding, greedy, delay tolerant, mobile wireless sensor network, multimedia, multi-hop, OLSR, routing.

## INTRODUCTION

Reduced Manual Intervention, Remote Monitoring and Control are the key goals for a smarter world. Numerous applications of Wireless Sensor Networks (WSN) such as Animal Habitat Monitoring, Environmental Monitoring, Health Care, Precision Agriculture, Industrial Control and Automation etc. demands the need of tiny battery powered embedded sensor (s) nodes. These nodes need to collaboratively work and function together autonomously via complete network protocol stack implementation and IEEE 802.xx compliant transceiver [1]. The radio transceiver are interfaced to these sensor nodes to communicate and transfer the intelligent information to the data collection center named sink (destination node). The node (computing unit) is interfaced with one or several sensors depending on the application requirement. Raw sensed data captured about the physical world phenomena are processed (and fused if necessary) to one or several payloads of information. Depending on the QoS (Quality of Service) demands of the application such as reduced latency, higher through put, reliable delivery, lower signaling over head to prolong battery life etc. information needs to be delivered to the sink to achieve the required QoS. The delivery of information is done via wireless communication by direct transmission or through multi-hop communication [2-3] to reach the sink due to limited transmission and coverage zone by sensor nodes. The control and corrective action has to be performed by a sink based on the criticality / necessity of the information conveyed [4].

Due to proliferation of Internet of Thing (IoT), several fields of WSN has emerged and gained significant importance to meet enormous applications requirements. This paper focus on subject fields such as Wireless Multimedia Sensor Network, Mobile Wireless Sensor Networks and Delay Tolerant Mobile Sensor Networks to achieve reliable data delivery for customized Animal Habitat Monitoring Application requirements.

Wireless Multimedia Sensor Network caters to numerous applications involving surveillance of the monitoring area (video/images transmission), detection and tracking of captured object/events. This network category demands high band width due to multimedia transmission [5]. Efficient Data Compression Algorithms becomes necessity for optimized usage of band width in a constrained device and environment. Due to dynamic and rapid topology changes, static sensor networks is replaced/superseded by mobile wireless sensor networks. Mobility introduces a new dimension to cater needs to demanding applications and imposes new challenges and

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design issues in WSN as depicted in Figure-1 for Animal Habitat Monitoring and Tracking application.

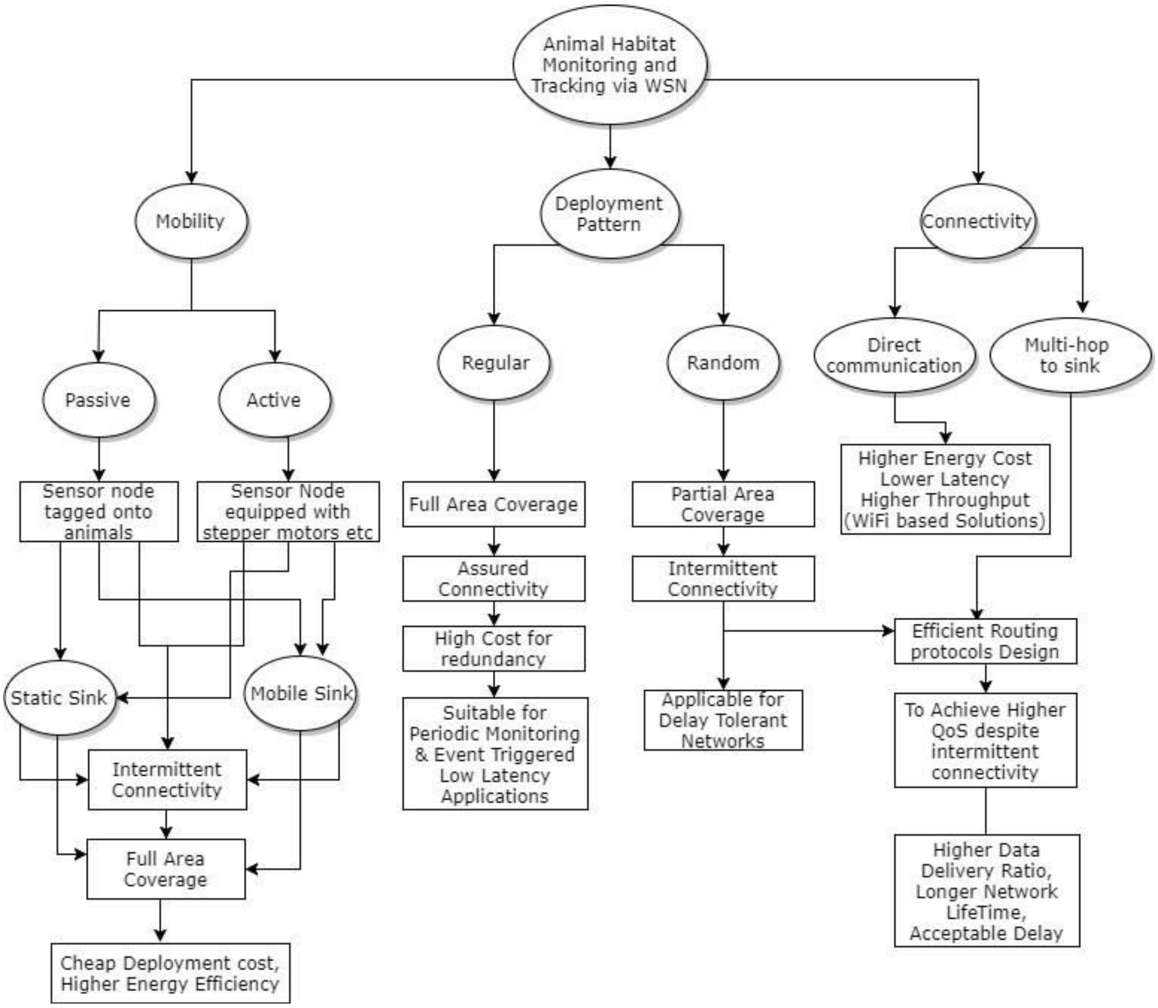


**Figure-1.** Design issues and challenges for WASN.

Different entities in sensor networks can possess mobility namely

- Mobility due to sensor nodes
- Mobility due to sink
- Mobility imposed by monitoring object or the event

An example of mobility due to sensor node is in the area of WSN based Animal Sensor Network (WASN). WASN includes wild life animals / vertebrates habitat monitoring [6] and tracking where sensor nodes are tagged on collars or body of animals that needs to be monitored, localized and tracked as shown in Figure-2. Mobility due to sink can ease the data collection process and potentially can reduce the deployment and energy cost of sensor network [8]. Active Mobility is the form of mobility in WSN where the nodes can autonomously move, take decision regarding the direction of movement, pause time, trajectory and destination.

**Figure-2.** Sensor nodes tag on a cow ears [7]

Passive Mobility is the form where nodes are not capable of autonomous movement but rely on the external movement such as human, vehicle, animal motion etc. This work exploits these two forms of mobility design and tested implementation of routing solutions.

## LITERATURE REVIEW

Recently several research work [9-10] is carried out in Delay Tolerant Mobile Sensor Network (DTMSN) where network connectivity is intermittent or lacking and data needs to be transferred/gathered in mobile environment. Store, Carry and Forward, Buffering limitations, Delay Tolerability, Node Mobility, Frequent Partitions leading to intermittent connectivity, limited battery; limited bandwidth and data rate etc. are the several design issues in DTMSN. Numerous works on Delay Tolerant Networks (DTN) and DTMSN deal with efficient data gathering mechanism.

The survey on Wireless Multimedia Sensor Networks (WMSNs) [5] provides a general idea of what kind of hard- ware, software, protocols, and architecture sa reused in WM- SNs. Soro and Heinzelman's survey on Visual Sensor Net- works [11] suggests that Zigbee is unsuitable for usage as a communication protocol in a multimedia network. The comparative study on DCT and DWT [12-13] affirms that the Discrete Cosine Transform (DCT) is a faster algorithm in terms of execution time when compared to the Discrete Wavelet Transform (DWT).

Scott Kidder's GitHub repository (HSMM-Pi) [14] provides the source for installation and configuration of HSMM-Pi, a package that can be used to create a mesh network for a wireless multimedia network that is used for test bed implementation of this work exploiting active mobility.

Periodic beaconing in the form of Hello messages used in assessing if links to neighboring nodes are valid consumes more energy. This is routing behavior of Proactive routing protocols. On the other hand, Reactive routing protocols finds route when needed. Large scale sensor networks are susceptible to link failures due to long transmission range and deployment of a large number of sensor nodes. With this in mind together with the ad-hoc nature of deployment of senso rnodes in sensor networks, Reactive routing protocols (on-demand routing protocols) are suitable communication protocols for these networks as it allows the network to quickly adapt to dynamic link states. Sensor nodes are allowed to respond timely to frequent changes in network topology and to breakages in link connectivity. This is made possible by the use of destination sequence numbers that ensure free loops in the network at all times. This category of routing are also energy efficient for most of the applications of wireless sensor networks. However, Ad-hoc On-demand Distance Vector (AODV) and Dynamic Source Routing (DSR) which belongs to the category of reactive routing protocols still floods the network by broadcasting control packets (Hello, Route Reply, Route Request and Route Error messages) to form an end-end route. With the broadcast of control packets, more power is consumed in the network.

Numerous works are proposed in literature to restrict the flooding by means of Location information [15-17]. In the modified AODV adopted by Zigbee, they used link quality as the metric and but fails to justify the control overhead and energy consumption in the network [16].

Geographical based beacon less routing protocols [18-19] which are almost stateless can be a better option. Greedy Perimeter Stateless Routing (GPSR) was the first approach adopted in Geographic routing [18]. The GPSR serves as the bases for all Geographic based approaches. In Geographic based routing, maximum distance forwarding neighbor are chosen, which makes the chosen neighbors to be heavily loaded as compared to other neighbors in a static deployment applications. Also in Geographic based protocols, link quality is not addressed as routing metric which causes information or packet loss. This routing approach also faces a problem when there exist no eligible forwarding nodes; hence, the approach switches to perimeter/face routing as proposed in literature [18]. The Authors [20] has made efforts in surveying of deployment strategies for connectivity and coverage in sensor networks. In a similar work, Authors [21] covered extensively the issues in sensor network based animal habitat monitoring.

The remainder of the paper is organized as follows. Section 3 gives design algorithms adopted in the design and implementation of Active/Passive mobility driven routing for application of animal monitoring. Section 4 presents the hardware implementation design, results followed by inferences made based on results. Finally, some conclusions are given in Section 5.

## MATERIALS AND METHODS

### Algorithmic design: Greedy Based Geographic Forwarding Solution with delay tolerant approach (Passive Mobility)

This passive mobility driven routing solution comprises several algorithmic modules that include location management, energy management, routing (forwarding) management and neighbor table management.

The function of the location management module is to get the GPS data (extract Latitude and Longitude from NMEA frame) and to calculate the distance between two nodes (cur- rent node and sink). Each node is assumed to be aware of sink's deployed location).

The routing management module has the following functionalities:

a) Send beacons to all the immediate neighbors at fixed regular intervals.

b) Form a neighbor table by extracting information from the received beacons.

c) Monitor the sensor and whenever a trigger is detected, generate a Transmit Request Frame.

d) Forward the Transmit Request Frames (either generated at the current node or received from the previous node) to the coordinator directly or by finding the maxi- mum progress neighbor using Store, Carry and Forward mechanism

Figure-3 shows the various modules depending on the functionality performed.

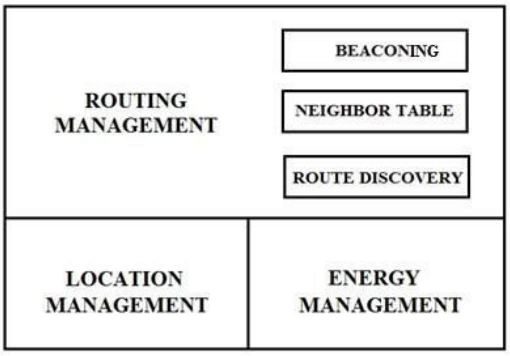


**Figure-3.** Processing modules for passive mobility routing solution.

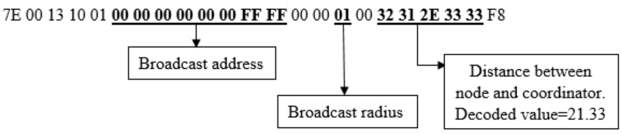


**Figure-4.** Transmit request frame format.

AsamplebeaconframeisgiveninFigure4adheringtot he API fame format IEEE 802.15.4 specification [22].

There are two possible operations in neighbor management:

If a beacon is received from anode whose MAC addressal- ready exists in the neighbor table, then the distance and time fields for that particular node in the neighbor table are up- dated. If a beacon is received from a node whose MAC address does not exist in the neighbor table, then a new entry is added to the neighbor table.

If a beacon is not received from a particular neighbor for a certain period of time (say nTi, where Ti is the time interval after which beacons a resent), the new assume that the particular node is no longer an immediate neighbor, and thus it is removed from the neighbortable.

The routing management module incorporates the Route Discovery process. Whenever a sensor node senses some data, it forms a transmit request frame to be sent to the coordinator. However, if the coordinator is not in the range of the sensor node, the transmission takes place in multi-hop fashion. Multi-hop transmission requires route-discovery i.e. to figure out the best possible route to the coordinator. Greedy forwarding tries to bring the message closer to the destination in each step using only local information. Thus, each node forwards the message to the neighbor. The most suitable neighbor can be the one who minimizes the distance to the destination in each step (Greedy). If no progressing neighbor, it switches to store, carry and forward mode till a forwarding progress neighbor comes in as an entry into neighbor table.

Energy Management Module constitutes the additional circuitry that can be used with the system to reduce the energy consumption by performing the following actions:

a) Using a switching circuitry to switch the GPS Module ON/OFF as per requirement.
b) Using sleep mode in ZigBee Compliant IEEE 802.15.4 radio transceiver

**Compressed image transmission based optimized link state routing approach (Active mobility)**

The design flow of proposed Active mobility driven routing solution is depicted in Figure-5.

Query Dissemination: The queries disseminated from the user end (from base station) are User Data grams. In each node, there is a python socket program which constantly listens, to identify queries addressed to that node. When anode receives one of the above mentioned control queries, it performs the required action. The control area is used to send queries in the form of user data grams.

The control queries that could be disseminated are

- To control nodemobility
- To change the periodicity of image capture
- To request a snapshot image

The movement of each node can be controlled through the user interface. The user can select which node to control and that particular node will provide a live video feed of what it sees. The user can then instruct the node to move forward, backward, left, right, rotate clockwise, or rotate anticlockwise. Figure-6 shows the system architecture.

All the nodes form a mesh network when powered up. One of the nodes is designated as coordinator. The coordinator is physically positioned between the local server and the rest of the network. All control and data packets transferred between the local server and the network pass through the coordinator.

**Discrete cosine transform**

In Discrete Cosine Transform (DCT), finite sequences of data points are expressed, which are in terms of sum of Co- sine functions. The functions oscillate at different frequencies. DCT-II Form is a transform which is exactly equivalent to a Discrete Fourier Transform (DFT) of 4N real inputs for which the inputs are even symmetry where the even-indexed elements are zero

$$X(k) = \sum_{n=0}^{N-1} x_n \left[cos \frac{\pi}{N}\left(n+\frac{1}{2}\right)k\right] \quad (1)$$

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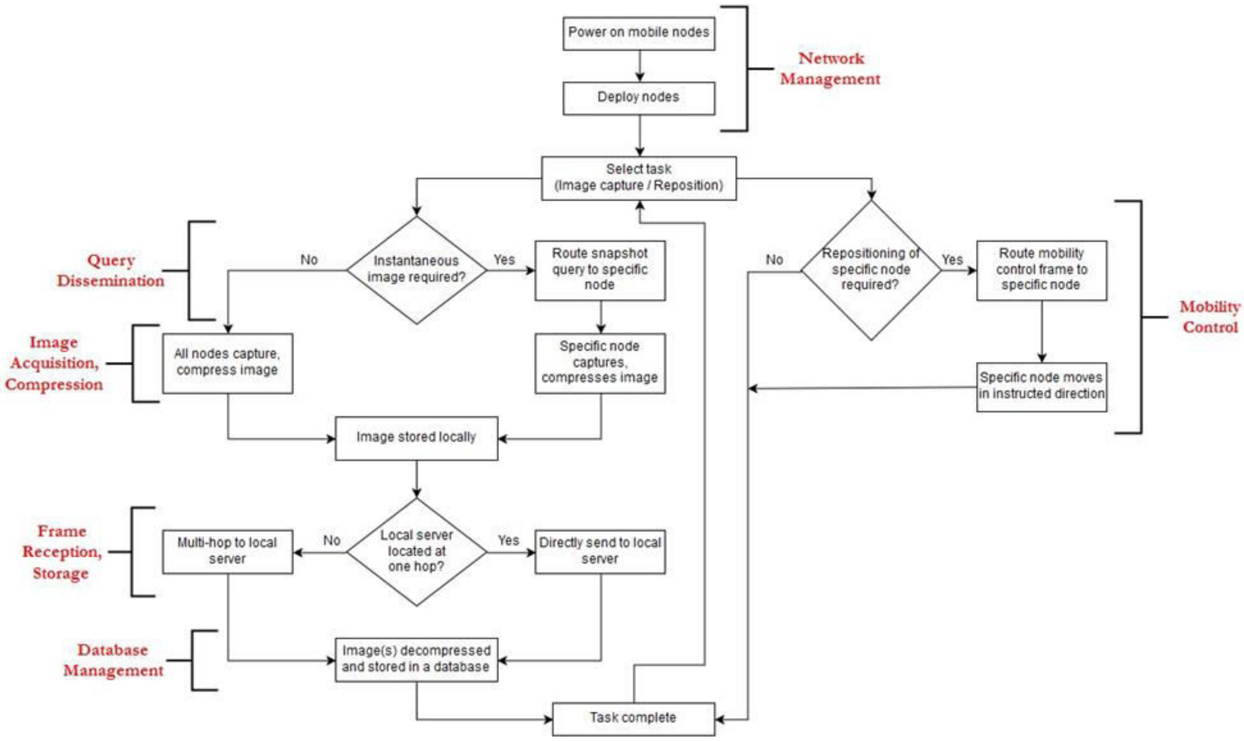


**Figure-5.** Design flow.

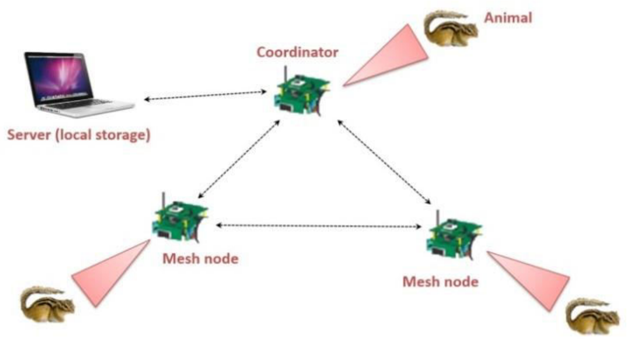


**Figure-6.** System architecture

### Optimized link state routing

If the distance between two nodes increases, the quality of the link between them also decreases. As link quality decreases, data transmission starts becoming unreliable. In such a case, data is transmitted in multiple hops from source to destination. Multi-hop routing is automatically taken care of by the OLSR daemon running on all the nodes. If the link quality to the destination is less than 60%, the daemon routes packets through intermediate nodes to the destination, for a more reliable transmission.

## RESULTS AND DISCUSSIONS

**Hardware implementation:** Greedy Based Geographic Forwarding Solution with delay tolerant approach (Passive Mobility) Figure-7 shows the circuit schematic of the sensor node.

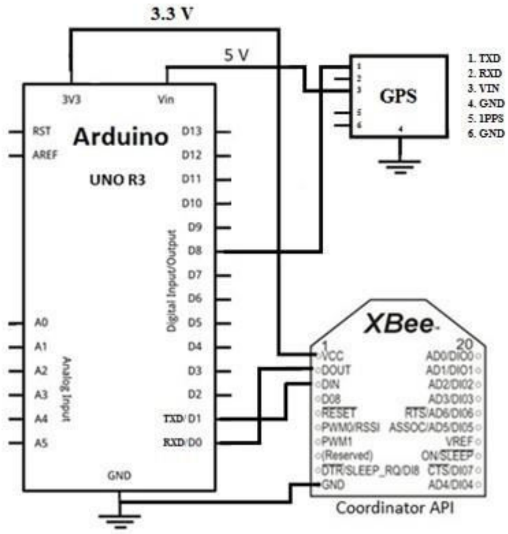


**Figure-7.** Circuit schematic of sensor node (Passive mobility).

Figure-8 shows the interfacing gof Xbee radio and GPS module.

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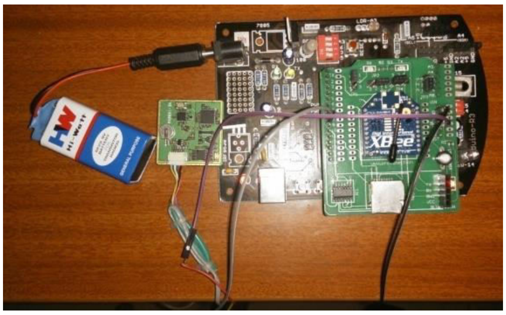


**Figure-8.** GPS Interfaced circuitry.

An optimal transmission power level selection is made based on the density of sensor nodes and nature of environment. Figure-9 and Figure-10 illustrates the possible cases for multi-hop forwarding either due to obstacles or void due to partial connectivity.

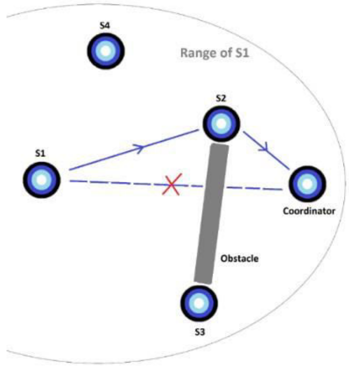



**Figure-9.** Case I - coordinator lies within the range of S1 but obstacle in between prohibits LOS.

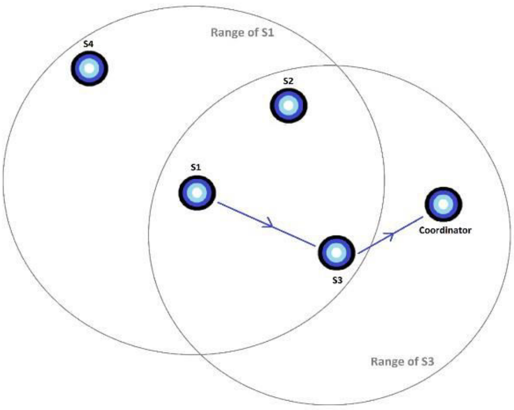



**Figure-10.** Case II - Multi Hop when coordinator is not in range, either S1, S2 orS3 comes in contact via passive mobility.

Passive mobility speed and transmission power level parameters could be key parameters to ensure connectivity.

Figure-11, Figure-12, Figure-13 shows the frame forwarding implementation by intermediate node, timestamp details of received frames at sink and received frame payload.

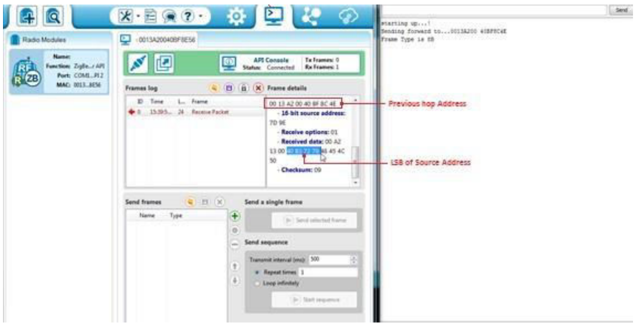


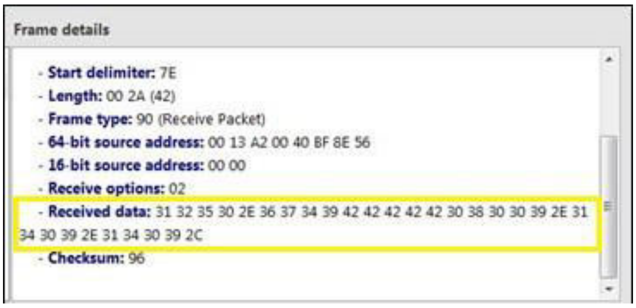

**Figure-11.** Frame forwarding in multi hop.

This routing solution takes advantage of location information of nodes for their operation. Sending a frame to a particular neighbor is much more energy efficient than flooding it to all the neighbors.

Frames log

| | ID | Time | Length | Frame |
|---|---|---|---|---|
| | 0 | 19:26:44.995 | 42 | Receive Packet |
| | 1 | 19:26:56.007 | 42 | Receive Packet |
| | 2 | 19:27:06.997 | 42 | Receive Packet |
| | 3 | 19:27:18.002 | 42 | Receive Packet |
| | 4 | 19:27:28.997 | 42 | Receive Packet |
| | 5 | 19:27:40.004 | 42 | Receive Packet |

**Figure-12.** Received frames log.



Frame details

- **Start delimiter:** 7E
- **Length:** 00 2A (42)
- **Frame type:** 90 (Receive Packet)
- **64-bit source address:** 00 13 A2 00 40 BF 8E 56
- **16-bit source address:** 00 00
- **Receive options:** 02
- **Received data:** 31 32 35 30 2E 36 37 34 39 42 42 42 42 42 30 38 30 30 39 2E 31 34 30 39 2E 31 34 30 39 2C
- **Checksum:** 96

**Figure-13.** Received frames log.

Energy management module is responsible for energy conservation by either switching off the GPS modules when not in use or putting the Zigbee radios to sleep when not in use. Since all the sensor nodes are homogeneous, the work can easily be scaled up and all nodes can sleep. No single point of failure is associated with relying on coordinator in order to maintain time synchronization (un-slotted CSMA/CA).

**Compressed image transmission based optimized link state routing approach (Active mobility)**

**Compression of test images**

Figure-14 shows the designed node. Figure-15 representstheoriginalimageofaduck.Figure-16 represents the image obtained by compression. Figure-17 represents the decompressed image.

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**Figure-14.** Designed node.

$$CompressionRatio = \frac{OriginalImageSize}{CompressedImageSize} \quad (2)$$

$$CompressionRatio = \frac{4.70}{1.75} = 2.69$$

**Figure-15.** Original image (4.7 MB).

**Figure-16.** Compressed image (1.75 MB).

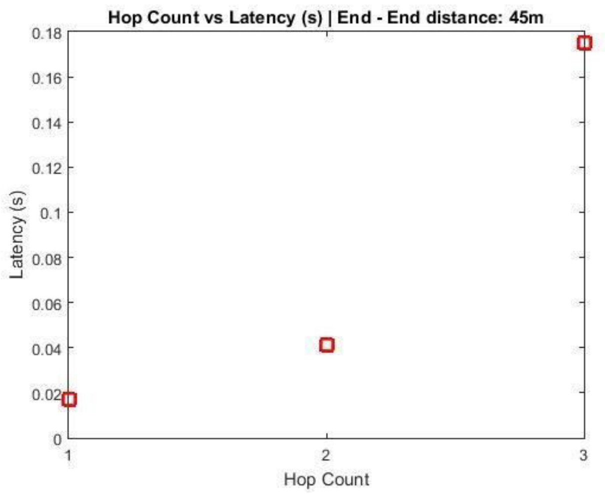


**Figure-17.** Decompressed image (4.11 MB).

**Image compression inference**

Imagecompressionratioofabout2.5obtainedusing DCT, hence data rate requirements reduced by nearly half DCT is faster and less computationally intensive than DWT, but DWT provides a slightly better compression ratio. A reduction in processing time is far superior to a small increase in compression ratio, and hence DCT is more suitable for our application than DWT.

**Figure-18.** Circuit schematic of raspberry PI node.

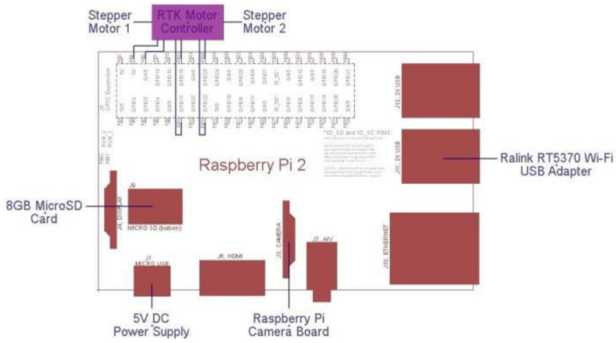


**Figure-19.** HSMM-PI Link quality status page (OLSR).

**Active mobility**

The motors used are geared motors running at 100 RPM. The diameter of the wheels is 7cm, and the distance covered per rotation is equal to its circumference. Hence, the node can cover 22cm in one rotation. Since the motors spin at100 RPM, the maximum speed of the node is 36.67cm/s.

**Multi-hop test inferences**

a) Greater the number of hops, greater is the latency. (Figure-20, Figure-21).

b) As distance of the end node increases from the server, the latency for each hop increases. (Figure-20, Figure-21)

c) Routing switches from single hop to multi-hop when the link quality between two nodes is less than 60% (Link Quality status is shown in Figure-19).

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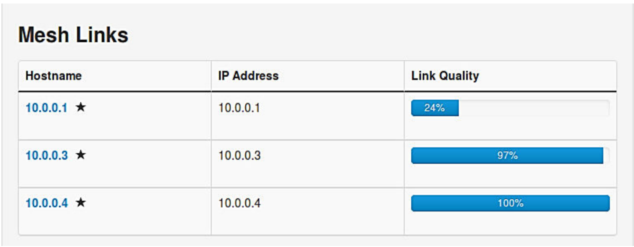
Mesh Links

| Hostname | IP Address | Link Quality |
|---|---|---|
| 10.0.0.1 ★ | 10.0.0.1 | 24% |
| 10.0.0.3 ★ | 10.0.0.3 | 97% |
| 10.0.0.4 ★ | 10.0.0.4 | 100% |

**Figure-20.** Hop count vs latency for end-to-end distance of45 m.

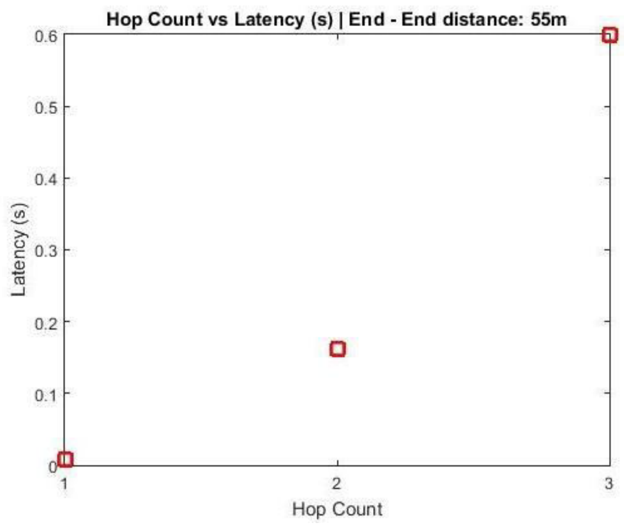


**Figure-21.** Hop count vs. latency for end-to-end distance of55 m.

**Mobility test inference**

The maximum speed of anode is 36.67cm/s. Itiseasierto control a node moving at lower speeds, and 36 cm/s is more than sufficient for our application.

**Deployment cost inferences**

The analysis of deployment cost versus optimum number of nodes over the deployment area is carried out in this section. Let the maximum one hop range (with acceptable PSR (Packet Success Rate) & Average RSSI > Receiver Sensitivity) with optimal transmission power level $P_{opt}$ be $d\,meters$. Considering a square field of side $\sqrt{2} * d\,meters$, where diagonal of $d\,meters$represents the maximum transmission range= a minimum of 2 nodes is required to cover this deployment area.

| Minimum of 2 nodes for a deployment area of $\frac{d^2}{2}m^2$ |
|---|

Every $2 * d\,meters$transmission coverage and deployment Area of $2\sqrt{2} * Z\,meters$ =minimum 3 nodesrequired.

Let us assume per node cost = X units

| Area of $\frac{d^2}{2}m^2$ coverage costs = 2X units |
|---|

Based on Wi-Fi Range Test inference, the maximum range for one hop for optimal power level is 60 m. Consider a square field of side 42 m, its diagonal will be 60 m, and the area will require 2 nodes. A square field of 85m will have a diagonal of 120 m and will require 3 nodes, as shown in Figure-22. An analysis of cost for various areas of deployment revealed that the cost per unit areade creases as the deployment area increases, as shown by the graph in Figure-23. Per node built is estimated to cost INR7000.

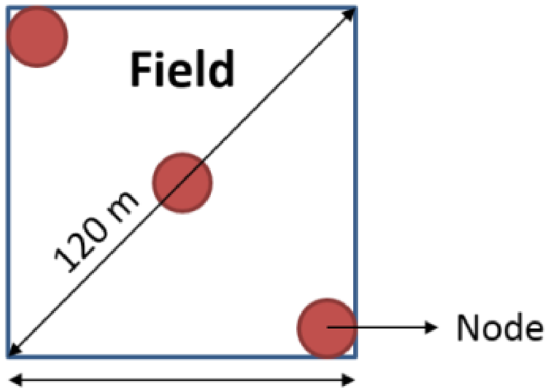


**Figure-22.** Sample area deployment.

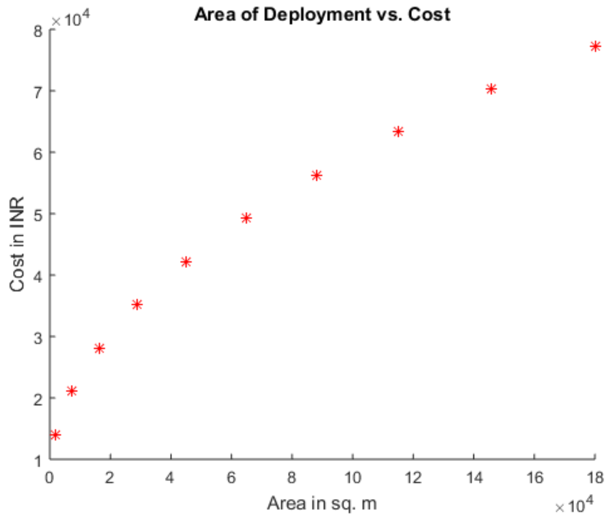


**Figure-23.** Area of deployment vs. total cost.

**CONCLUSIONS**

Based on the Application requirements for Animal Habitat Monitoring, either Passive mobility driven or Active Mobility driven multi-hop routing solutions could be implemented. To meet the QoS demands for high throughput multimedia based applications, Active mobility driven multi-hop routing solution is implemented in this work. The designed system can be used to monitor any kind of habit at and find its application in several non-emergency fields ranging from agriculture to traffic, or even exploration of new territory. However, parameters like mobility on the terrain, node placement, and delay must be taken into consideration in such cases. To meet the QoS demands for delay tolerant, low throughput applications, passive mobility driven routing solution is implemented. Location Based delay tolerant protocols provide promising solutions for wireless sensor based mesh networks. These protocols take advantage of the location information of nodes for their operation. This help store strict the process of flooding to a particular direction from where the information is to be sent. These save activating other nodes which will never come in the route.

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