A LoRa Wireless Mesh Network for Wide-Area Animal Tracking

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***Abstract*—The continuous evolution in technology and innovation empowers mankind to strive for more and move ahead towards living an easier and more convenient life with better safety measures and assisting systems. However, parallel to the aforementioned patterns are some contrastingly petrifying and frightening patterns. Mankind's greed for resources and inefficiency in using the same has led to the destruction of various lifeforms and their natural habitats. Animal tracking is key to conservation and protection of the beings itself as well as their habitats. It is mankind's responsibility to right what he has wronged. LoRa, a wireless technology, is capable of communicating over long distances while sipping efficiently on power. However, the vastness of the savannas and the deserts and the densities of the forests are out of bounds for existing conventional wireless communication technologies. Tracking via satellite would turn out to be expensive and infeasible in many scenarios. Tracking over the cellular network in such expansive remote regions would be quixotic and impractical. This work proposes a novel design of a mesh network formed by LoRa based animal collars or tags, for tracking location and monitoring other factors via sensors over very wide areas. Furthermore, the work proposes different models to choose from, based on the expanse of the area desired to be covered and it's geographical conditions.**

***Index Terms*—LoRa, Animal Tracking, Animal Tags, Animal Collars, Mesh Networks, Wide Area Tracking, Long Range Tracking**

I. INTRODUCTION

The establishment of human settlements and the destruction of wildlife habitats have caused erratic butterfly effects in nature. Amalgamating this with the fascinating movement of animals and their herds over climatic and mating seasons result in patterns that require highly demanding studies and analyses to comprehend. They underpin multiple interconnected biological phenomena [1]. Understanding the migration and territorial behaviour is essential for their conservation and protection from mankind as well as from other displaced or invasive fauna.

Conventional approaches to animal tracking use limited range GPS enabled trackers. These store the location coordinates received via GPS locally, and may wirelessly respond to transmitted beacon signals when the field biologists or animal trackers enter the limited range with their transceivers. There on, the devices may allow extraction of the devices' location history wirelessly. Other alternatives are fully satellite based trackers; they are expensive to operate, bulky and could be deemed unsuitable for medium to small animals (or birds). The operability of these devices and their battery life too, is sometimes a hefty limitation.

The Internet of Things (IoT) and Machine to Machine (M2M) communication technologies enable people to innovate and engineer solutions in various application fields that were unfathomable just a decade ago. Additionally, they allow us to design systems that require little to no human mediation. The application fields presently in focus are Home (or office/commercial/enterprise) Automation, Smart Cities and Autonomous Vehicles amongst others.

Long Range (LoRa) is a Low Power Wide Area Network (LPWAN) wireless communication technology that enables us to fabricate communication systems suitable for remote applications with extremely low power consumption and very wide coverage (LPWA - Low Power Wide Area).

II. LITERATURE SURVEY

There are a number of options available for long range communication. Cellular networks (2G/3G/4G etc) would be a sensible option for small and enclosed wildlife reserves or sanctuaries, however, with increase in size, set-up costs prohibitively increase.

Over open grasslands and plains, LoRa would function well, however, due to its selected frequency range, the signal deteriorates when obstructions are encountered. A normal LoRa network would require dense deployment of gateways. This is addressed in the proposed system and is discussed later. WiFi, Bluetooth and such short range communication technologies paired with conventional application protocols [2], would suffice for indoor home automation [3] and office automation [4] use cases, however, entirely different radio spectrum is to be considered for long range communication. Sigfox [5], LoRaWAN [6] via The Things Network [7] and Narrow Band IoT [8] are some examples. Amongst these, LoRaWAN (upper layer protocol) uses the LoRa physical layer, and is a set standard over the free-to-use frequency ranges allocated to LoRa. However, it is a star topology, supporting only a single hop. In indoor scenarios with obstacles such

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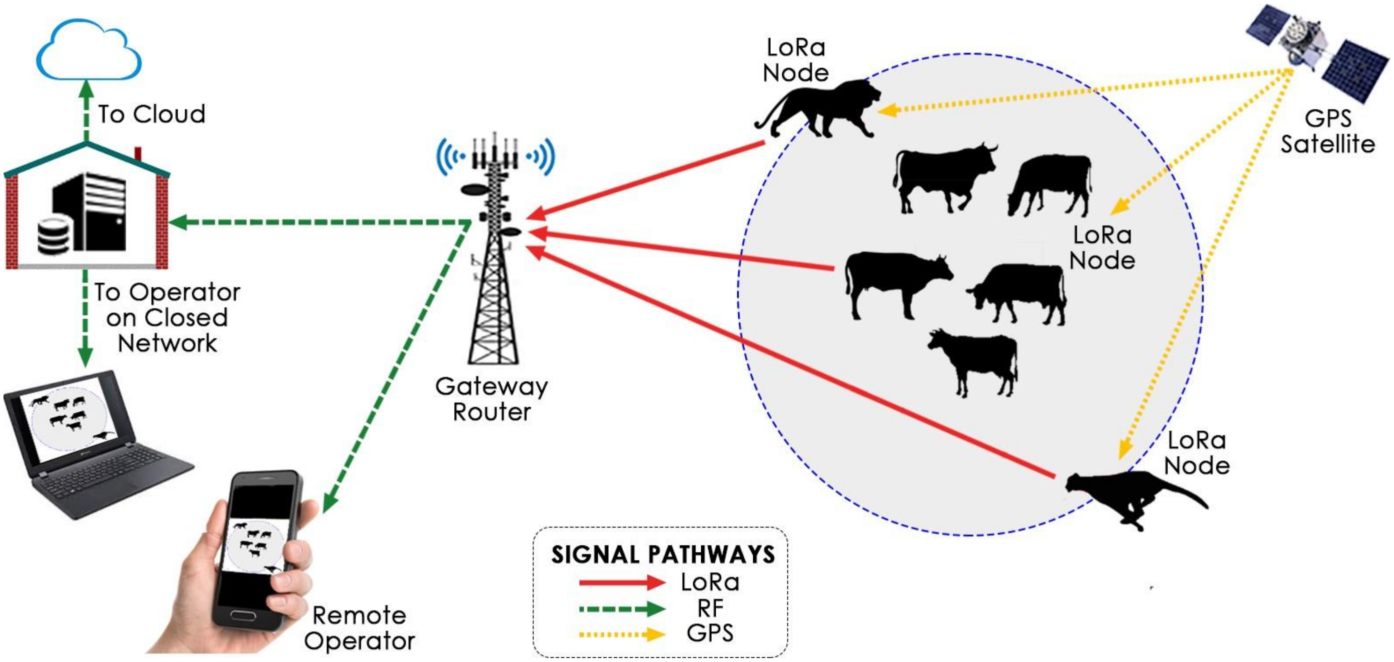

Fig. 1: Animal Tracking using LoRa devices

as walls and floors or in forests with rich flora and uneven terrain, this turns out to be a weakness. The interference and dampening of signals result in data loss and communication errors with low packet delivery ratio (PDR) [9]. Installation of multiple LoRaWAN gateways would be a possible but infeasible and uneconomical solution. A mesh network formed by the nodes, by the gateways or by both nodes as well as gateways is explored in this work in order to alleviate the aforementioned issues.

LoRa based antennas can be mounted onto basic cost-effective microcontrollers or microprocessors, allowing for the reinforcement of the sensor and GPS tags or collars. If an active communication link is maintained, the resolution of trajectories could be largely improved to such details, that analyzing and tracking relative locations between two animals to observe behaviour may be feasible with no eyes on the ground. These detailed facets of movement would give way to new discoveries in the field of ecology.

A. Salient Features of the Proposed Solution

- Easy setup
- Economical and cost-effective
- Flexible, with the ability to adapt to other applications
- Highly scalable
- Supports bi-directional communication, i.e, it allows devices to transmit as well as receive data
- Free to use frequencies
- Low power devices with battery life potentially up to tens of years
- Supports dynamic extension of range with ghost nodes

In this paper, a practically and economically feasible method of tracking animals is proposed. According to the geographical features, densities and other properties, alterations could be appropriated as per the bit-rate and latency requirements. Note that in this application, latency isn't of prime importance, hence the low bandwidth isn't much of a compromise.

III. PROPOSED SYSTEM

In this section, the design of an animal tracking system using LoRa wireless technology is presented. The main advantage of the mesh topology implementation is that the single-hop nature of the existing LoRaWAN network is being replaced by multiple hops between nodes as well as additional gateways.

The basic working of a conventional LoRa based animal tracking system (Star Topology) is depicted in Fig. 1. It consists of a LoRa gateway router and multiple LoRa nodes. Each LoRa node consists of a LoRa transceiver module mounted onto a microcontroller/microprocessor (MPMC) which would be planted into a ruggedized animal collar or tag. Sensors such as GPS sensor, temperature sensor, etc. can be embedded into the collar. The LoRa gateway also consists of a LoRa transceiver module mounted onto an MPMC. Along with the LoRa transceiver, the gateway has network connectivity in order to transfer the data received at the gateway to a local network server or to push the same onto the cloud. The LoRa gateway units would broadcast beacon signals in order to establish connections with the nodes. The nodes respond to these beacon signals by sending acknowledgement signals back to the gateway and thereby becoming a part of the LoRa network. The LoRa gateway is programmed to transmit beacon signals at regular time intervals. Each LoRa node is queried based on the availability of the node within the coverage area. If a LoRa node is to transmit data to a gateway router, it has to wait until all the other nodes present in the waitlist (within the coverage area) are done with their allotted time period or clock cycles, i.e. at a given instance, the gateway can communicate with only one node, hence the gateway will give a certain (static or dynamic) number of clock cycles to each connected node. If the data from a node is to be obtained at a lower latency, or higher bit rate, then priority sets can be assigned locally and/or centrally. The data signals transmitted to the gateway router would include the values obtained by the sensors mounted onto the MPMC as well as the routing table or a dynamic map. Each node will have its own unique address which will help the operator track each and every animal individually, allowing the management of profiles. To keep the data away from poachers, a closed network with a simple layer of encryption would be desirable.

The coverage area provided by a star configured LoRa network would be in the range of up to 22km in LOS links and around 2km in an urban region with buildings [10], similarly, the realistic range of LoRa in the presence of trees would largely vary [11].

Using the aforementioned LoRa network system would be impractical as the area to be covered increases. This brings the need of alternative solutions to solve the problem. Three models have been discussed below and the model to be chosen for implementation, depends on the geographic area under consideration, the migration and movement patterns of the regional fauna, their density, spread and the budget allocated.

- Model A: Mesh network using multiple LoRa gateways
- Model B: Mesh network using LoRa nodes
- Model C: Mesh network using LoRa nodes and multiple LoRa gateway routers

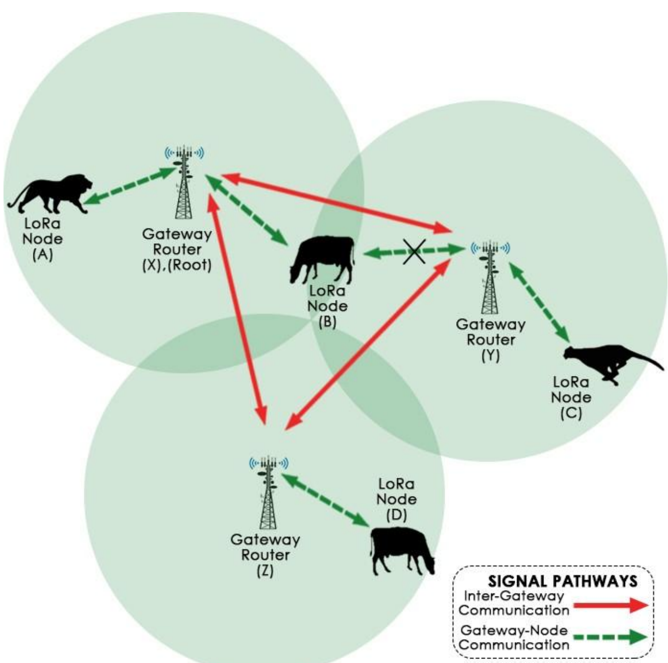

Fig. 2: Model A: Mesh network using multiple LoRa gateways

A. *Model A: Mesh network using multiple LoRa gateways*

A basic substitute would be to add multiple gateway units, however, a gateway is expected to be connected to the outside network and accessible by the users. Providing every gateway with such access would be impracticable. Countering this, a single (or a few) gateway may be made directly accessible by the user, while the rest of the gateways communicate with the user via that gateway (and via others). Model A is depicted in Fig. 2 where multiple LoRa gateway routers are set up to increase coverage area. The LoRa gateways are to be set at optimum geographical locations taking factors such as the topography, density of fauna, movement patterns et cetera into consideration. At least one of the gateways is to be considered as the 'Root' and the same gateway(s) will have an active network connectivity, hence would be directly accessible by the user via internet/cloud or a local setup. The other gateways would be used as mesh repeaters in order to increase the coverage area. The gateways may be mounted on erected poles to achieve LOS links if the terrain allows. In Fig. 2, LoRa Node 'C' is far from the coverage area of gateway router 'X', which is the root gateway with active network connectivity. But Node 'C' is located within the coverage area of gateway router 'Y', which acts as a repeater. This may be realized with custom upper layers, or with LoRaWAN [12]. Gateway router 'Y' will collect the data from Node 'C' and transmit it to the root gateway router 'X' and the data can further be uploaded to the server/cloud. The root gateway router periodically transmits routing information to all the gateways and nodes, so that the nodes and the gateways are aware of the path to the root node. Node 'B' is at the intersection of gateway routers 'X' and 'Y', hence can send to both the gateway routers, but will only send to the root gateway router. Dynamic prioritization may be executed for efficient flow of data. Cost-effective gateways can be designed with simple microprocessors, antennas designed as per the power requirements, and accompanying solar panel setups.

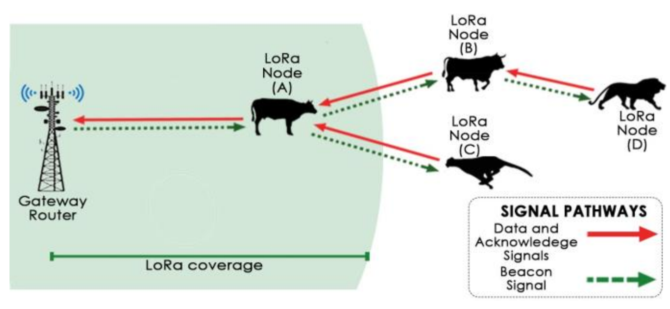

Fig. 3: Model B: Mesh network using LoRa nodes

B. *Model B: Mesh network using LoRa nodes*

If the fauna density and spread act as supporting factors or if the budget does not provide for installation of multiple gateways, an alternative would be to form a mesh network with the nodes themselves paired with a single gateway. Model B, as depicted in Fig. 3 is designed to comprise of a single gateway, but every LoRa node (client) acts as an intermediate gateway [13, 14]. If the animal goes beyond the coverage range of the LoRa gateway, the LoRa nodes will form a mesh network and there will be a direct node to node communication.

In Fig. 3, Node 'A' is within the LoRa gateway's coverage region and can directly establish a connection with the LoRa gateway. LoRa nodes 'B', 'C' and 'D' are outside of the region covered by the gateway. These nodes may communicate with the gateway router through the intermediate nodes. The data sent back to the gateway router from Node 'A' will act as a beacon signal for Node 'B' which is far away from the gateway router's coverage area, but can communicate with Node 'A', hence establishing a point to point link. Once the data is sent from Node 'A' to the gateway router, then Node 'A' will act as Node 'B's parent and allow it to transmit the signal to the gateway via Node 'A'. Similarly, Node 'B' will act as a parent for Node 'D'.

This could also be realized as a dynamic tree topology network, however, since the nodes are mobile, a flexible mesh network would be preferable. For example, Node 'C' may communicate with Node 'B', or with Node 'A' (assuming both are within its range). As mentioned previously, the gateway would send beacon signals to map the graphs, hence allowing dynamic formation of single links, or multiple links, whichever is optimum; accordingly, the system will identify the best path(s).

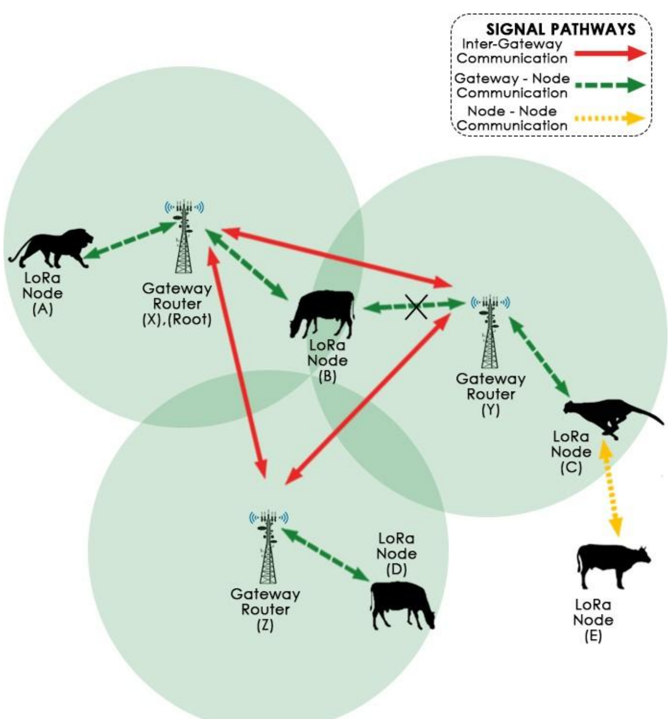

Fig. 4: Model C: Mesh network using LoRa nodes and multiple LoRa gateway routers

C. Model C: Mesh network using LoRa nodes and multiple LoRa gateway routers

In scenarios where the spread of fauna is unevenly distributed, a hybrid mesh network consisting of multiple gateways as well as the nodes would be superior and advantageous. Such a system would also provide with more flexibility in order to further optimize the connectivity as well as the cost-factors. Model C is a combination of Model A and Model B, and is depicted in Fig. 4. There are multiple gateways of which the root node (and maybe some others) has active network connectivity and the rest may be spread across strategically. The nodes are programmed to support node to node communication as discussed in Model B, and the gateways are programmed to support gateway to gateway communication as discussed in Model A. In Model C, the non-root gateway routers ('Y' and 'Z') act as mesh repeaters and periodically attain the route map from the root gateway. In Fig. 4, LoRa Node 'E' does not lie within the coverage of the gateway router 'Y'; Node 'C' forms a node to node connection with Node 'E'. The gateway router will now transmit the signal back to the root gateway router 'X'.

In a case where there are barren uninhabited regions or any regions that would cause discontinuity in the mesh network, ghost nodes may be set up. Ghost nodes would be devices mounted to stationary objects, that would act as mesh repeaters. In the case of Model B, ghost nodes would be client type nodes, while in Model C, ghost node could be gateways or client type nodes.

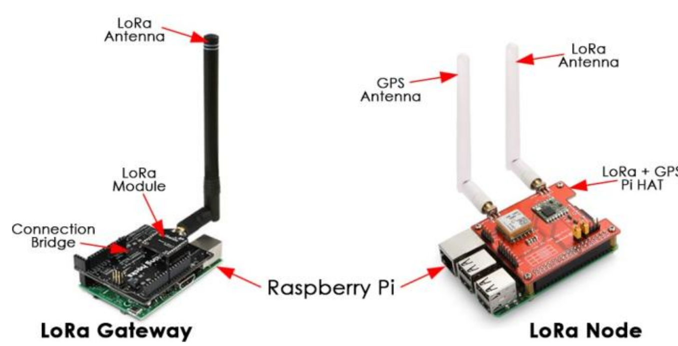

Fig. 5: Hardware Setup

Fig. 5 shows the hardware setup. The system was realized by using a set of Raspberry Pi boards. The LoRa gateway consisted of a LoRa SX1272 transceiver module mounted on a Raspberry Pi through a connection bridge. The LoRa module can transmit and receive at dual frequency bands of 863-870 MHz and 902-928 MHz. The LoRa node consisted of a LoRa GPS HAT (SX1278) module from Dragino. The SX1278 device could transmit at 3 different frequencies (433MHz/868MHz/915MHz). For nodes, unlike gateways, furthermore economical microcontrollers like the ESP line of products could also be used. However, for analysis of the network, microprocessors offer more features. The gateways were programmed to send continuous beacon signals to the nodes. The nodes respond to these beacon signals by sending acknowledgement signals back to the gateway along with the coordinates obtained from the GPS. A WiPS/WFPS [15] type of system could also be implemented.

Fig. 6 shows all the links that were successfully established. The routing tables will have all the available nodes in the vicinity to which the node may connect to, as per the model configuration. The table would be updated periodically with beacon signals. For transmission of data, the optimal route would be chosen. Further, a distributed ledger (blockchain) may also be considered for additional benefits.

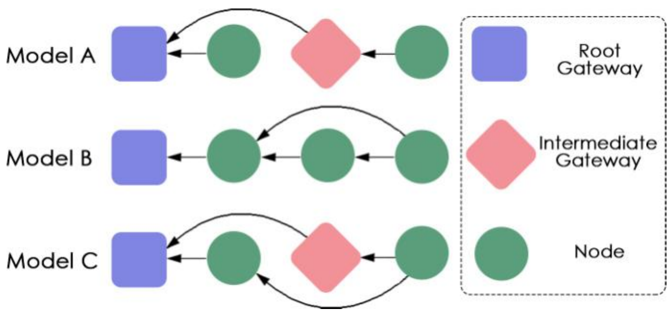

Fig. 6: Established Links

The implementation was just a basic proof of concept, transmitting data packets within a laboratory through established links. Empirical evaluation is necessary to determine the PDR for each model as it would vary with the region's geomorphology and other factors.

IV. CONCLUSION

The LoRa wireless technology plays a vital role in IoT/M2M applications. LoRa enabled devices do not require much power to function due to the narrow bandwidth at which they operate to transmit signals. The low-frequency spectrum (unlike WiFi, Bluetooth, etc) enables these devices to communicate through longer distances in comparison to the other conventional communication technologies. A flexible and dynamic mesh network topology enacted using LoRa physical layer would further increase the range with little technical bounds. Attributable to the long range and robust nature of the proposed system annexed with very long battery life, this technology could be implemented in various applications. This technology could be pivotal for animal tracking and wildlife conservation. It gives way to continuous monitoring with high-resolution trails which when laid over high-resolution terrain maps, would enable us to extract information unlike before, allowing us to elucidate and widen our understanding of our fellow earth-beings.

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