

Real-time Livestock Tracking and Alerting Method for Proactive Warning System

Ahamed Aljuhani

Department of Information Technology
University of Tabuk
Tabuk 71491, Saudi Arabia
a.aljuhani@ut.edu.sa

Amer Aljaedi

Department of Information Technology
University of Tabuk
Tabuk 71491, Saudi Arabia
aaljaedi@ut.edu.sa

Abdullah D. Alanazi

Department of Biological Sciences
Shaqra University
Ad-Dawadimi 11911, Saudi Arabia
aalanazi@su.edu.sa

Abstract

The evolution of smart technologies and wireless sensor networks has made it possible to develop more effective and efficient solutions over traditional paradigms. These advances have had a tremendous impact on tracking moving objects in real time and improving decision-making and automation processes. Tracking livestock such as camels is crucial for avoiding traffic accidents and ensuring the safety of both people and animals. Although several techniques have been proposed for tracking moving objects, some limitations have been observed, such as adaptability, communication in wild areas, operational cost, and energy consumption. Therefore, this paper proposes a camel tracking device and an alert system to ensure safety for both humans and animals. The proposed livestock monitoring system can track camels in real time and dispatch alerts when they approach dangerous or prohibited areas determined by the proposed dynamic safety margin. Because camel sensing devices can experience low communication signal or completely disconnect from the communication network, we use LoRaWAN technology to extend network coverage and improve the reliability of connected devices. To conserve the power energy of the camel sensing devices, the proposed work uses a customized and weighted low energy adaptive clustering hierarchy protocol for the cluster head selection process. The proposed tracking device along with the proactive alerting system enable effective and efficient tracking of livestock in real-time.

Keywords

Proactive warning system, tracking moving objects, tracking device.

1. Introduction

The advancement of communication technologies and the Internet of Things (IoT) has transformed the capabilities of tracking systems, making it attainable and more cost-effective to track the locations and movements of roving objects. For example, tracking animals near highways to avoid any collisions or car accidents. In addition, the integration of location-based services and wearable sensing devices has further improved the ability to track and monitor objects in real time (Al Bassam et al., 2021). Such evolving technologies unleashed the opportunities for industries to optimize operations, improve safety, and boost overall efficiency (Nižetić et al., 2020).

Tracking wildlife animals in reserves or livestock that graze in vast wild areas, such as camels in the desert, is essential to avoid car accidents and ensure the safety of humans and animals. The incidence of animal collisions has grown, causing 200 deaths, 29,000 injuries and substantial property losses of 1.1 billion dollars per year in the United States (Mammeri et al., 2016). Traditional ways of tracking livestock are not effective in the vast wild areas, as they require human involvement to control animals and ensure safety. However, with advances in emerging technologies, there are now more effective techniques to track livestock without the need for constant human supervision. For example, using computer vision methods to track and detect the movements of livestock in real-time (Dorrazehi et al., 2020), (Sharma et al., 2017) or utilizing GPS tracking devices attached to the camels' collars (Al Balushi et al., 2019). Although many techniques have been proposed for tracking moving objects in general, some limitations have been observed, such as adaptability, increased cost, and energy consumption.

To overcome the aforementioned challenges, this paper proposes a tracking and alerting system to monitor livestock in wild areas, where network coverage is usually limited due to its wide diameters, lack of communication infrastructure, or rugged nature. As part of our proposed monitoring system, the livestock tracking device is designed to track moving objects in real time and alert authorities, if needed, using an elastic safety margin. As moving objects may experience low communication signals or become completely disconnected, the proposed technique of our monitoring system utilizes multi-hop LoRaWAN communication to improve network efficiency, coverage, and capacity in wild areas. To conserve massive amounts of energy, the proposed work uses Customized Weighted Low Energy Adaptive Clustering Hierarchy (CW-LEACH) protocol inspired from (Abdulsalam et al., 2010), (Cheng et al., 2022) for cluster head selection process. Because some sensing livestock nodes are unable to communicate directly with the leader node, which is the cluster head, we employ LoRaWAN multi-hop communication to ensure packet delivery to its intended destination.

This paper is organized as follows. Section 2 discusses previous works related to livestock tracking and alerting techniques. Section 3 presents the proposed system architecture for livestock tracking and proactive warning system. Section 4 concludes this research.

2. Literature Review

This section reviews previous studies on tracking moving objects, such as camels. Betke et al. (Betke et al., 2007) proposed a method to detect and monitor moving objects, specifically bats. The technology used has the potential to make further important contributions, for example, providing tools to analyze wildlife interaction and answer pressing questions about bird and bat mortality in places with high winds. The study focuses on identifying, monitoring, and analyzing a large group of bats by observing flying objects through a series of images over long periods of time. Sanchez et al. (Garcia-Sanchez et al., 2010) proposed a wireless sensor network-based method for tracking and monitoring wildlife passages. The proposed system identified moving objects via the connected video sensors. The system is deployed in various sites to validate the proposed method. One of the disadvantages of the system is that it is expensive and impractical, as it requires installing a large group of cameras at different points for monitoring. Sharma et al. (Sharma et al., 2017) proposed a method to detect animals and collision avoidance using computer vision techniques. The proposed method relied on the camera mounted in the vehicle to determine the distance between the animal and the camera mounted in the vehicle, and an alert was generated when the object was detected. The proposed system is considered expensive and not practical as it required installing cameras for each passing vehicles.

Dorrazehi et al. (Dorrazehi et al., 2020) proposed a system to monitor camels on the roads and send a warning messages to drivers when they approach. The system included night vision cameras installed on a number of vehicles to identify camels on the roads. When a camel is detected, the system sends a message containing the location to a central processing unit over the cellular network. The central unit broadcasts a map of the area including probability distribution profiles to drivers' mobile phones. Drivers therefore adjust their speed based on the probability of the

presence of camels in the area, adjusting appropriate speed to react on time when observing camels. The proposed system is expensive as it requires to install a camera on each passing cars to detect camels and send the data to the central processing unit to simulate the movement of camels. Also, the proposed system relies mainly on data sent from cameras installed on vehicles to detect the possible presence of camels near the roads. Panda et al. (Panda et al., 2022) suggested a system that uses Internet of Things (IoT) technology to help in detecting the intrusion of wild animals into agricultural areas. The proposed method used ultrasonic sensors installed in the corners of the field to detect the moving objects. The system first detects the intrusion, then captures the image of the intruder via a camera mounted on the electronic vehicle. An alert message is sent to the farmer via the IoT application. One drawback of the system is that it relies mainly on a camera mounted on an electronic car. In addition, the proposed system is limited only to protecting agricultural areas from wild animals attacking agricultural crops.

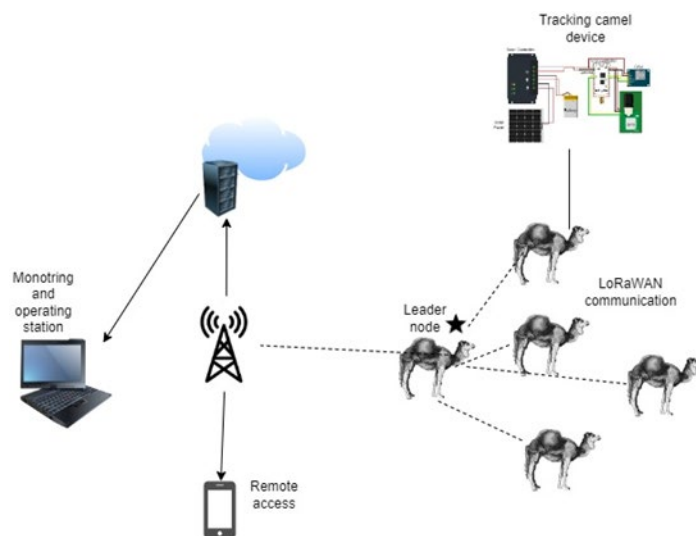


Figure 1. The system architecture for camel tracking

3. System Architecture for Camel Tracking

This section delves into the architecture of the proposed livestock tracking and alerting system. In addition, the livestock tracking device is illustrated in this section.

3.1 Livestock Tracking Device

The livestock tracking device aims to remotely track camels and expel them from dangerous areas, such as vehicle routes, as well as to alert drivers and save lives from the damage that could be caused by a camel collision. As shown in Figure 1, the system architecture for livestock tracking includes a tracking device attached to camel collars, LoRaWAN technology to create communication between camel sensing nodes, a server side powered by cloud computing, and a monitoring and operational station managed by end users.

The livestock tracking device contains a microcontroller unit that offers the Long Range Wide Area Network (LoRaWAN) module. LoRaWAN technology enables the tracking devices to communicate over long distance with less power consumption (Cotrim et al., 2023), (Islam et al., 2023) and offers a reliable and scalable means of tracking the location of camels in real-time. Therefore, the proposed approach applies the concept of mesh networks in which camel tracking devices are linked together to further extend the network communication range and longevity, especially in wild areas where cellular networks are not available. The tracking livestock device also contains a GPS unit to determine the longitude and latitude of moving objects in real-time such as camels. The device also features a solar panel, which uses solar energy and turns it into power that is meant to be stored and used to operate the device. The device battery stores electrical energy to operate the device when solar energy is insufficient to keep it running even in the absence of sunlight. The solar charging unit controls and flows electrical energy from the solar to the battery, enabling power to pass when it is needed and cutting it off when it is not, and also protecting the battery from

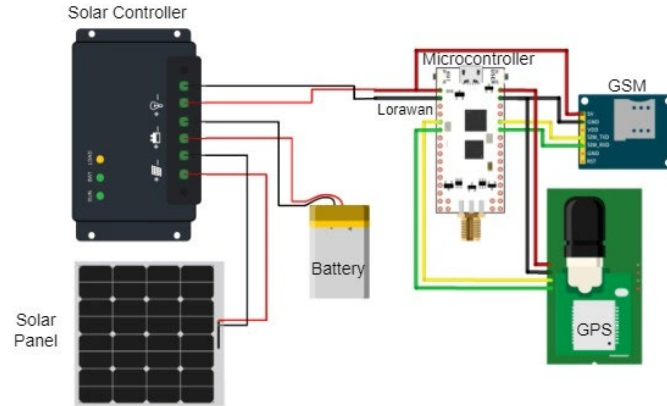


Figure 2. The components of tracking device

overcharging or discharging (Figure 2). The livestock tracking device also has a Global System for Mobile (GSM) module to provide communication between camels and a cellular network.

3.2 System Modes of Tracking Livestock Device

The tacking and alerting system contains three modes: *Normal* mode, *Suspicious* mode, and *Warning* mode. Initially, the system operates in *Normal* mode, which means that the camel moves inside the permitted zone. The *Suspicious* mode, on the other hand, shows that the camel is outside the safe zone and moving toward the potentially dangerous area. The system shifts to the *Warning* mode when the camel enters the prohibited zone.

3.3 Energy-Efficient Cluster for Camel Tracking Devices

The camel herd usually scattered out when they graze in wild, and they could move in different locations with attached tracking devices. However, as sensing devices collect, aggregate, and send data to the cellular network or other devices on a regular basis, the battery is rapidly depleted. Therefore, clustering techniques are required to conserve massive amounts of energy by splitting sensing devices into cluster groups led by a cluster heads (CH). When camel tracking devices are placed, sensing devices form clusters, with one (CH) for each cluster, which is responsible for aggregating data from other members of the same cluster (CM) and sending it to the base station (BS); for example, cellular tower (See Figure 3). The clustering protocol we adopted has three stages: *Initialization*, *Steady-state*, and *Transition-state* stages. During the initialization stage, the sensing camel devices are grouped into cluster led by a leader (CH) who is in charge of collecting data from all other device nodes. In the steady-state stage, data is transmitted from sensing camel nodes to the leader camel node (CH), which then forwards it to BS. The transition-state stage occurs when a sensing camel node cannot communicate directly with a leader (CH) due to long distance, thus it must be linked via an intermediary (relay) sensing camel node in order to reach connectivity to the leader node (CH) (Figure 4).

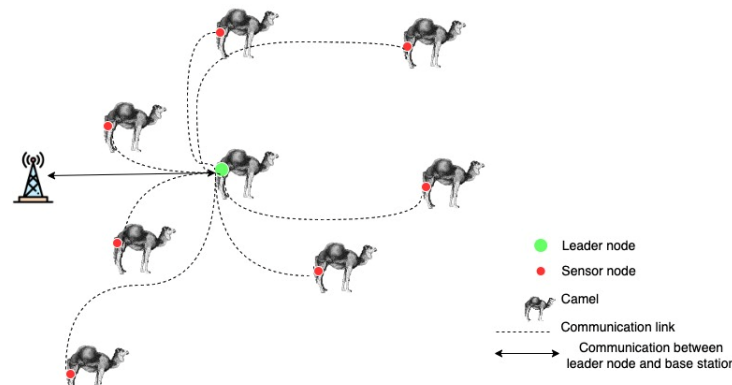


Figure 3. Cluster-based communication for camel tracking device

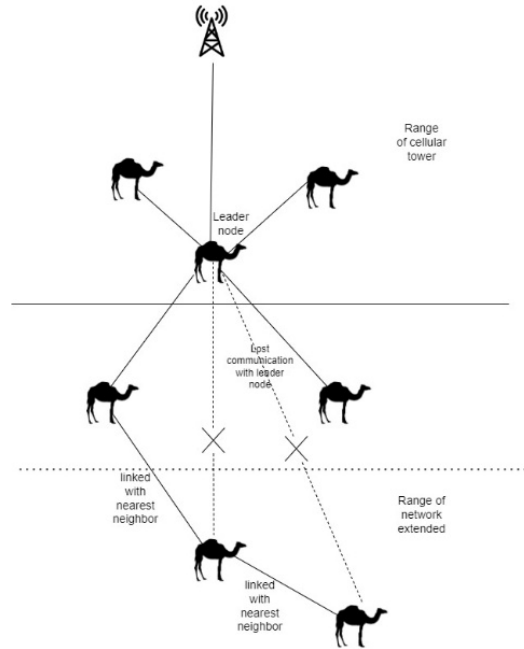


Figure 4. LoRaWAN multi-hop communication for expanding the network coverage

A. Initialization Stage

During this stage, the camel sensing nodes are deployed, and the leader node is chosen using our proposed CW-LEACH protocol, which is unlike the original LEACH protocol (Heinzelman et al., 2000) proposed by heinzelman et al, as our proposed CW-LEACH clustering protocol takes into consideration three factors, namely the remaining energy, neighboring density, and distance to BC. In this section, we first briefly discuss the limitation of the LEACH, and then present our proposed CW-LEACH protocol.

In the LEACH protocol, the $P\%$ of n sensor nodes are chosen randomly to be cluster heads based on the threshold calculation $T(n)$ as shown in equation (1) for current round:

$$T(n) = \begin{cases} \frac{p}{1 - p \times (r \bmod \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Where P is the desired percentage of the cluster heads in the network, r is the ongoing round, G is set of nodes that have not been CHs in the last $\frac{1}{p}$ rounds. Each node in the network chooses random value x , and if the randomly chosen $x < T(n)$, then the node becomes CH, else it becomes cluster member (CM). The G prevents the same node from becoming CH repeatedly, as chosen CH node will not be chosen again until all other nodes in the network became CH. Other nodes that are not CH in the current round have join to any cluster after all CHs are chosen. The CH nodes for the current round broadcast advertisement messages to all other nodes in the area, so the non-CH nodes joins the nearest CH based on the signal strengths from the broadcast messages they received from CHs. In this phase of LEACH, which is named *Set-up* phase, clusters are formed. Then, CH in the network creates a TDMA schedule and sent it to the cluster nodes in the *Steady* phase of LEACH. The member nodes in *Steady* phase send data at regular intervals (i.e., time slot) based on the TDMA schedule. The CH aggregates received data from the cluster nodes and send it to the BS.

The LEACH protocol aims to prolong the network lifespan by evenly spreading the workload among nodes through the rotation-based CH node selection process, which safes the energy of network nodes to some extent. However, it has some drawbacks as well:

- The CHs are selected randomly without taking their remaining energy in to account, as the randomization process alone do not grantee that the node with low remaining energy will not be selected as CH for the cluster.

- The cluster heads in LEACH are not uniformly distributed when they are chosen, as the random selection process of CHs do not consider the neighboring nodes and distance among nodes.
- It did not consider the distance between CH and BS, as CH is responsible for aggregating data collected from other nodes, and sending this aggregated data to BS regularly, the distance to BS can play critical for saving the energy power of CH.
- Some of the nodes can be located far, out of the CH range, and can not join the cluster directly, such case indeed occurs for moving nodes.

To overcome the limitations highlighted above of LEACH, we proposed customized weighted clustering protocol CW-LEACH, which gives each node in the network weight based on the factors: (1) the remaining energy of the node, (2) density of and distance to neighboring nodes, and (3) the distance to BS. Note that the nodes in our system are location aware as they equipped with GPS, and the they can exchange location data over broadcasting when forming clusters. The CH in our approach is chosen based on its calculated weight value in equation (2) and (3):

$$C(n_i) = \frac{1}{\sum_{n_i \neq n_b} d(n_i, n_b)} \quad (2)$$

$$W(n_i) = \begin{cases} E_{n_i} * C(n_i) & \text{if } n_m > m_{thresh} \wedge (B_s \geq 1 \vee n_c \geq 1) \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

Where $C(n_i)$ is closeness centrality, which measure how close n_i to other neighboring nodes, and it takes sum of the distance between n_i and its neighboring nodes including BS, and then inverse that sum. The percentage of the remaining energy power E_{n_i} of node n_i is used to calculate the weight $W(n_i)$ of n_i as shown in equation (3). Nodes in WC-LEACH can exchange location and energy power information as well in the *Initialization stage* of our proposed protocol, then each node can calculate its weight and the weights of its neighboring nodes, then the number P % of n nodes with highest weights are chosen to CHs in ongoing round, and the rest of the nodes will be cluster members. The B_s in equation (3) represents base stations, while n_m represents the number of neighboring nodes. It worth mentioning that moving node can be located in far zone with no reachability to BS, such node does not need to form or join cluster if there are no neighboring nodes or the number of neighbors is under m_{thresh} , especially when the BS is unreachable. The parameter of m_{thresh} can be controlled remotely via system server. However, our proposed protocol tackles the case of moving nodes when they are located in far zone where the BS is unreachable. In such case that node can connect to the cluster through one of cluster member node n_c , which can act as relay to transmit messages from far located node to CH.

The same principle applies to group of nodes located far from BS, and they cannot reach BS. In this case, they can together form cluster when the m_{thresh} is satisfied, and the CH₂ of that cluster can be connected to CH₁, which can reach BS, via member node n_c . This actually can lead us to spanning three clustering when there are multilevel of CH in the network. Nevertheless, the m_{thresh} parameter can still control such scenarios. On the other hand, allowing multilevel clustering can feature the extendibility of network coverage, especially in wild areas and when the animals of herd are distributed while grazing over an extensive area.

B. Steady-State Stage

After the completion of *Initialization stage* discussed above of the proposed CW-LEACH protocol, the second stage of our protocol starts, which is similar to the *Steady* phase in LEACH but without TDMA Scheduling. As our proposed

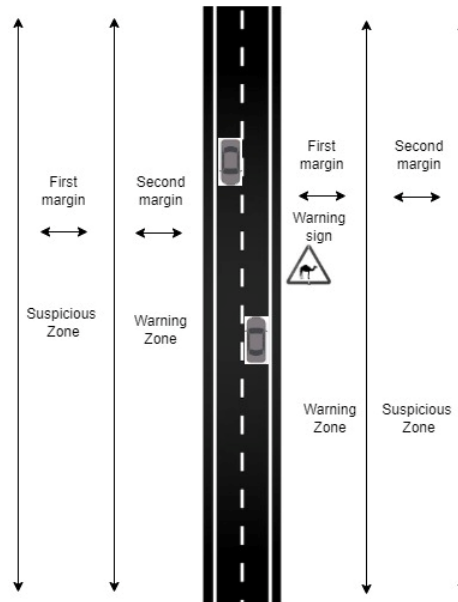


Figure 5. Flexible safety Margin design for early warning system

protocol operates on top of LoRaWAN protocol, it uses Aloha-based (unslotted) for uplink transmissions and class-based downlink scheduling.

C. Transition-State Stage

While camel sensor nodes are not stationary, they move across large areas, emphasizing the necessity to expand network coverage and ensure long-range communication over large distances. LoRaWAN transmission utilized to wirelessly connect camels over long distances, improving scalability, efficiency, and capacity of the network. In such a scenario, multi-hop LoRaWAN communication is required to facilitate communication and extend network coverage across camel sensing nodes over long distances (Centelles et al., 2021). As shown in Figure 5, some sensing camel nodes are not inside the range of network coverage to convey a message, so they need to deliver their messages over more than one hop. In this case, sensing camel nodes must send messages to intermediary nodes (relay nodes), until the data is successfully delivered to the destination BS via CH of the cluster. To address this issue, LoRaWAN multi-hop communication is essential to improve network efficiency and reliability while also ensuring packet delivery to other camel sensing nodes that are unable to communicate directly with the leader node (Cotrim et al., 2023), (Lalle et al., 2021).

3.4 Flexible Safety Margin Design for Early Warning System

When camels enter the first margin, whether from the right or left side of the road, the system mode is changed to *Suspicious* mode, which indicates that there is a risk of danger if the camel herds or one of their members keep moving toward dangerous or prohibited locations. The system sends notifications to stakeholders who have been advised of the camels' locations, allowing required measures to be taken as soon as possible to keep camels out of danger. Note that in the first margin, there is no need to alert drivers as the danger can be mitigated and removed before a camel reaches the second margin, which is considered to be close to highways. Therefore, the system reduces alerting notifications when there is no real threat. However, when the moving object enters the second margin on either side of the road, the system mode will switch to *Warning* mode, as the potential of danger increases in this mode, warning alerts are sent to drivers and stakeholders via *SMS* messages, with the option of activating road signs so that caution can be widely seen by drivers.

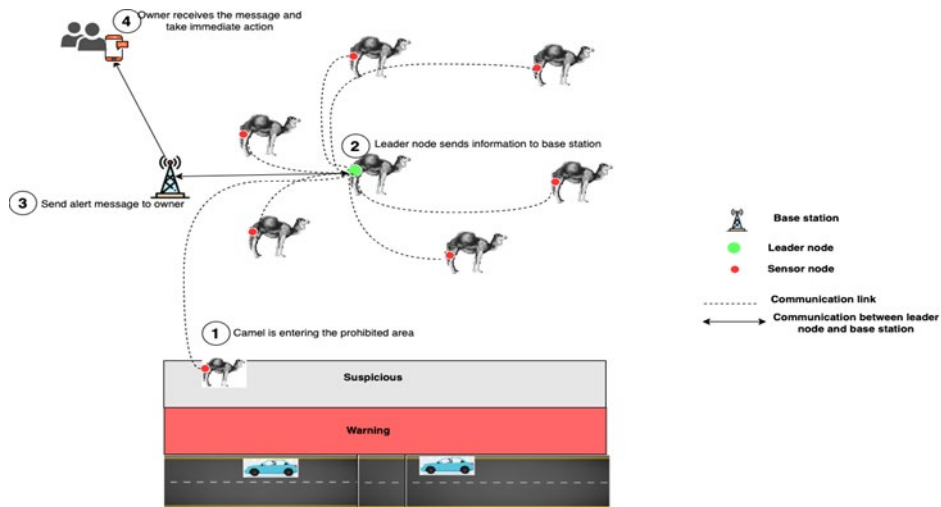


Figure 6. The workflow of suspicious mode

Figure 6 illustrates the workflow of the early warning system when moving objects (camels) enter the first margin (suspicious zone). As illustrated in Figure 6, the leader camel node will collect and send the animal location data to the tracking system via communication with the cellular tower. The tracking system will then send an alert message to the camel owner, indicating that one of his camels is in the prohibited area (Suspicious Zone), allowing the owner to directly track the object's location and take the necessary action to keep it safe and away from danger. The issue could get worse if the moving object (camel) continues to walk toward the danger location (See Figure 7), and enters

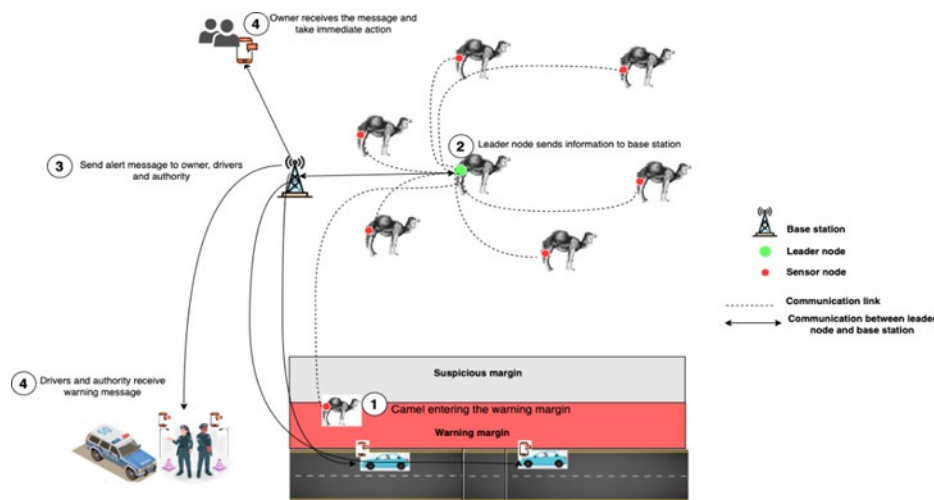


Figure 7. The workflow of warning mode

the second margin (Warning Zone). The leader node will gather and transmit data about the camel who enters the warning zone more frequently, allowing real-time tracking of the moving objects. In this situation, the tracking system delivers warning messages to the owner, and tracking system can be also linked to the proper government organizations to inform them about this incident. Moreover, in this case the nearest cellular tower to the incident location can send out emergency alerts via the Wireless Emergency Alerts (WEA) system. Thus, warnings will reach to all passers-by in this region to be informed about the incident.

4. Conclusion

The evolution of cutting-edge technologies has enabled industries to design and develop smart solutions in various domains. Precisely, tracking moving object is critical to ensure safety, efficiency, and reliability. This paper proposes camel tracking device and alerting method for early warning system. The proposed camel monitoring system can track camels in real-time and alert when they approach risky areas determined by the proposed dynamic safety margin. Because sensing camel devices may experience low communication signal or completely disconnected from the network, the proposed camel tracking device uses LoRaWAN technology to extend network coverage and improve reliability of connected devices. To conserve power energy of sensing camel devices, we proposed novel clustering protocol CW-LEACH that takes into account sensor location, remaining energy, and distance to base station for the cluster head selection process, which is crucial for the network lifespan and connectivity, as data from sensing camel nodes is aggregated and transmitted to the base station via the cluster head and subsequently to the system servers. The integration of a tracking device with an alerting mechanism in the proactive warning system facilitated effective real-time monitoring of camels and timely notification of authorities, thereby preventing incidents from escalating into critical situations.

References

- Al Bassam, N., Hussain, S. A., Al Qaraghuli, A., Khan, J., Sumesh, E., and Lavanya, V., IoT based wearable device to monitor the signs of quarantined remote patients of COVID-19, *Informatics in Medicine Unlocked*, vol. 24, pp. 100588, 2021.
- Al Balushi, T., Al Hosni, A., Omar, H. A. T. B., and Al Abri, D., A LoRaWAN-based camel crossing alert and tracking system, 2019 IEEE 17th International Conference on Industrial Informatics (INDIN), vol. 1, pp. 1035-1040, IEEE, 2019.
- Abdulsalam, H. M., and Kamel, L. K., W-leach: Weighted low energy adaptive clustering hierarchy aggregation algorithm for data streams in wireless sensor networks, 2010 IEEE International Conference on Data Mining Workshops, pp. 1-8, IEEE, 2010.
- Betke, M., Hirsh, D. E., Bagchi, A., Hristov, N. I., Makris, N. C., and Kunz, T. H., Tracking large variable numbers of objects in clutter, 2007 IEEE Conference on Computer Vision and Pattern Recognition, pp. 1-8, IEEE, 2007.
- Cheng, X., Xu, C., Liu, X., Li, J., and Zhang, J., Leach protocol optimization based on weighting strategy and the improved ant colony algorithm, *Frontiers in Neurorobotics*, vol. 16, p. 840332, 2022.
- Cotrim, J. R., and Kleinschmidt, J. H., An analytical model for multihop LoRaWAN networks, *Internet of Things*, vol. 22, p. 100807, 2023.
- Centelles, R. P., Freitag, F., Meseguer, R., and Navarro, L., Beyond the star of stars: An introduction to multihop and mesh for LoRa and LoRaWAN, *IEEE Pervasive Computing*, vol. 20, no. 2, pp. 63-72, 2021.
- Dorrazehi, Y., Mehrjoo, M., and Kazemini, M., A warning system design for camel-vehicle collisions mitigation, 2020 10th International Conference on Computer and Knowledge Engineering (ICCKE), pp. 203-208, IEEE, 2020.
- Garcia-Sanchez, A.-J., Garcia-Sanchez, F., Losilla, F., Kulakowski, P., Garcia-Haro, J., Rodríguez, A., López-Bao, J.-V., and Palomares, F., Wireless sensor network deployment for monitoring wildlife passages, *Sensors*, vol. 10, no. 8, pp. 7236-7262, 2010.
- Heinzelman, W. R., Chandrakasan, A., and Balakrishnan, H., Energy-efficient communication protocol for wireless microsensor networks, *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences*, pp. 10-pp, IEEE, 2000.
- Islam, M. R., Bokhtiar-Al-Zami, M., Paul, B., Palit, R., Grégoire, J.-C., and Islam, S., Performance evaluation of multi-hop LoRaWAN, *IEEE Access*, vol. 11, pp. 50,929-50,945, 2023.
- Lalle, Y., Fourati, M., Fourati, L. C., and Barraca, J. P., Routing strategies for LoRaWAN multi-hop networks: A survey and an SDN-based solution for smart water grid, *IEEE Access*, vol. 9, pp. 168,624-168,647, 2021.
- Mammeri, A., Zhou, D., and Boukerche, A., Animal-vehicle collision mitigation system for automated vehicles, *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, vol. 46, no. 9, pp. 1287-1299, 2016.
- Nižetić, S., Šolić, P., López-de-Ipiña González-de-Artaza, D., and Patrono, L., Internet of things (iot): Opportunities, issues and challenges towards a smart and sustainable future, *Journal of Cleaner Production*, vol. 274, pp. 122877, 2020.
- Panda, K., Kumar, C. S., Vivek, B. S., Balachandra, M., and Dargar, S. K., Implementation of a wild animal intrusion detection model based on Internet of Things, 2022 Second International Conference on Artificial Intelligence and Smart Energy (ICAIS), pp. 1256-1261, IEEE, 2022.

*Proceedings of the 3rd GCC International Conference on Industrial Engineering and Operations Management
Tabuk, Saudi Arabia, February 2-4, 2026*

Sharma, S. U., and Shah, D. J., A practical animal detection and collision avoidance system using computer vision technique, IEEE Access, vol. 5, pp. 347-358, 2016.