A Study on IoT Solutions for Preventing Cattle Rustling in African Context

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ABSTRACT

Cattle Rustling is a recurrent phenomenon observed in many in African countries today. This scourge cause significant losses to farmers and governments. Confronted with this problem farmers have generally no solutions. Internet of Things can be a real solution to defeat this nuisance by first allowing theft detection and further prevent it with an accurate analysis on cattle's behavior . Many solutions emerged these last years but they are generally design for European countries and these solutions do not fit the real constraints related to African rural context. The main constraint in these rural areas is the difficulty farmers to access the internet and the knowledge on how to use it. These zones are generally not covered by the 3G/4G network. This paper discusses the possible challenges of cattle rustling in Africa and how technology like the internet of things can be used to counter fight the existing menace by unfolding some preventive solutions. We also proposed a prototype based on LoRa (Long Range) technology that allow to identify if an abnormal situation is occurring in a herd. This prototype consist of low power LoRa end-devices and a LoRa Gateway in a single hope communication.

KEYWORDS

Cattle Rustling, IoT, LoRa, LPWAN, Low Power, Low Cost, RFID, WSN.

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1 INTRODUCTION

Cattle theft is a recurrent and singular phenomenon that is observed in many African countries. In recent years, it is increasingly the main concern of farmers. It is a typically regional phenomenon, but according to the latest observations [3, 9, 14], it tends to become sub-regional. It is, for African countries, one of the major constraints to livestock development. Indeed the problems posed by this scourge affect both farmers and government. Its impact has a social, safe, and economical dimension. For farmers, the practice of animal husbandry has always been and will remain their livelihood. They derive their incomes in this activity. Economic losses due to this problem is quite significant. For example in Senegal, cattle theft is valued by the government at $ 2 billion per year [21]. A social stability problem is observed between ethnic groups in the same country and between countries because of transhumance. Cases of violence are rated between transhumants from Mauritania and the inhabitants of Mali. In Kenya too, recurring violence are observed between North and Rift and parts of the North East [28]. A study by Cheserek et al. [20] on the nature and causes of this phenomenon in Kenya shows that illiteracy is a factor that increases the severity of the problem. Among other factors that contribute to theft of cattle rustling, we can also cite : the need for easy money, unattended grazing in search of pasture area. In Senegal it has been observed that most of the areas where the phenomenon impacts really, are out of electrical coverage. Furthermore the missing of infrastructure and the seasonal activity of farmers are also important elements to consider. For instance it has been observed that in some dark areas (without electricity), cattle are more subject to theft in rainy seasons, due to the fragility of farmers to guarantee the safety of their herd in such circumstances. Getting to the end of this problem will therefore help to significantly reduce the pauperization of the rural world in general and farmers in particular.

Confronted with this problem, farmers generally remain without solutions. To prevent theft of livestock, farmers find solutions to mark each animal, counting the herd before and after grazing, to put fence to the grazing area. These solutions are clearly far from being enough efficient to combat this phenomenon in large scale. Moreover, thieves are using more sophisticated and smarter techniques to get what they want. In addition, finding the stolen animals seem almost impossible, as they may be just after, killed or sold. The means presented so far by governments seem to be insufficient. The only main weapon is to deter thieves by increasing the prison sentence for theft. In Senegal punishment for cattle theft has been hardened by passing from 5 to 10 years.

The use of new technologies including those related to the Internet of Things could be a good solution in the prevention and fight against cattle rustling. The technologies revolving around the Internet of Things as wireless sensors and actuators networks (WSAN), the Radio Frequency Identification (RFID) and Big Data could help re-cover the limits of traditional solutions for the fight against cattle rustling by facilitating the identification and location of the animals, the management of farms and herds, management of grazing areas, the study of the behavior of animals, thefts prediction etc. Although, the use of these technologies in this sector for the prevention and fight against cattle theft has a considerable profit, their application does not come without constraints. Several challenges related not only to the complexity of the phenomenon but also to these technologies must be identified and addressed in order to have a better prevention system and to fight against cattle theft in a effective, efficient way, especially suitable to the socio-economic conditions of the farmers in the rural areas.

In this paper, we provide a detailed study of existing IoT solution for preventing cattle rustling in african context. We analyze in Section 2 the enabling technologies for cattle rustling before discussing on challenges to design a solution for preventing the cattle rustling (Section 3). These are followed by a presentation of our proposed prototype in Section 4. In Section 5, an analysis and discussion on existing solutions is provided, and finally Section 6 concludes the paper, with some clear perspectives.

2 ENABLING TECHNOLOGIES FOR CATTLE RUSTLING

Internet of Things is not a new technology, it is just the integration of several technologies that have matured, to communicate almost all objects to collect more data that are used in improving decision making [12]. These technologies can be found at all levels of the structure that define the Internet of Things. On all architectures that exist on the Internet of Things, we always have end-devices that collect data and route them to one or more processing center through the Internet or another network that may or not go through Internet. These technologies are then those related to hardware for end-devices and gateways, sensors for data collection, communication for different networks, and also data processing. Thus, implementing a solution of Internet of Things is somehow an adequate technological choices regarding the domain and the needs of this solution. The choice of technologies may involve several criteria like cost, commercial or free, the nature of the data to be collected, deployment type etc. The choice of technologies to prevent and combat cattle theft in the African context should be made taking into account specific criteria to the rural areas and also the social conditions of farmers in this environment. In this context, the major criteria include cost and internet access. Indeed, the rural farmers are mostly poor and so they will be less skeptical to a solution if it does not require high costs. In addition, they live in areas where Internet access is difficult and they are not generally covered by 3G or 4G operators. In the following, we will describe our technological choice in this study.

2.1 Communication

The choice of communication technology depends in most cases on the type of architecture you want to set up. In the case of cattle theft many deployments are possible.

First deployment : a typical wireless sensor network where the animals are mobile nodes. In this case, each animal is at the same time sensor and router. The captured measurements are relayed to a gateway. This gateway can be placed in the farm and is connected to the internet or a network that is connected to the internet to transmit the data to a processing center. This gateway could directly send notifications to the farmer.

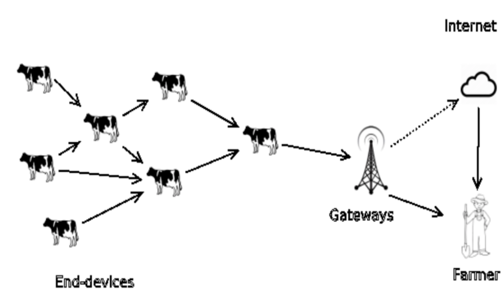

Figure 1: Multi-hop communication

Second deployment : here each animal is an end-device which directly sends these measurements to the gateway. As in the first case, the gateway can connect to the Internet or communicate directly with a mobile phone to notify the farmer.

In the first deployment, we have communication between animals and this should be short range but sufficient and should also consume little power. The most suitable technology will probably be ZigBee. Bluetooth could be a solution but its range is very short. WiFi contrariwise, offers good range but it is very energy intensive. The choice of ZigBee

Table 1: Summary of LPWAN technologies

feature	LoRa	Sigfox	Weightless (three standards)			LTE Cat-M	IEEE P802.11ah	Dash7	Ingenu RPMA	nWave	WavIoT
			N	W	P						
Power efficiency	Very high	Very high	High	High	High	Medium	Medium	Very High	Low	High	Very High
Range	2-5km (urban) 15 km(rural)	30 - 50km (rural) 10km (urban) 1000km LoS	5km+	5km+	2km+	2 - 5km	+1km	1km+ (Mid-range)	+500km LoS	10km (urban), 20 - 30km (rural)	16km (urban), +50km (open area)
Modulate	CSS	BPSK UNB	DBPSK UNB	16-QAM, BPSK, QPSK, DBPSK	GMSK, offset-QPSK	OFDMA	DSSS/OFDMA	GFSK	Random Phase Multiple Access	DBPSK	NB coding gain principles based
Data rate	300bps - 50kbps	100bps	100bps	1kbps - 10Mbps	Adaptative data rate 200bps - 100kbps	200kbps - 1Mbps	150kbps - 350Mbps	27.77kbps	624kbps	100bps	8 - 10bps
Capacity	thousand of noeuds	5M (200kHz)	unlimited	unlimited	unlimited	+20 000	8191	-	+384 000	1M	2 M
Cost	Low	Low	Medium	Medium	Medium	Very High	Low	Low	High	Low	Low
Mobility	YES	Yes (Medium)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

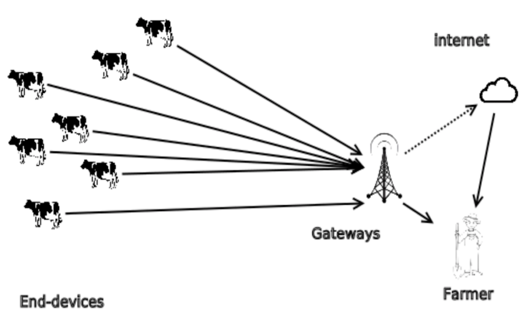

Figure 2: Single-hop communication

for this deployment assumes that the animals are in a limited area and they are never far from the gateway. This type of deployment is more suitable if the animals are in a farm. Contrariwise, for pastoralists such deployment would be absurd. In addition, animals of a herd are almost always together, meaning the same distance from the gateway, therefore relay data would be as absurd. The second deployment seems to be the most appropriate in the fight against cattle rustling. However, for the nomadic herders, the range between an animal and the gateway must be very long because their grazing areas can be very broad. In this case, we must adopt technologies that offer long range communication like LPWANs (Low-Power Wide Area Network), long range and low power consumption technologies. Recently, it has been observed an emergence of several technologies relating to these ones, but most of them are proprietary and therefore too expensive for an African farmer. Today the most known of such technologies are LoRa [40], Sigfox [43], and Weightless [48] with its three standard : Weightless-N, Weightless-W, Weightless-P. There are also others one that are emerging and that offer interesting features like Ingenu RPMA [25] , nWave [36], Long Term Evolution for M2M communication [34], Dash7 [4] etc. All these technologies have the same goal regarding the range range and low power factors, but there are some subtle differences between them. Table 1 depict some factors of certain of these technologies [4, 7, 11, 25, 32, 34, 36, 37, 40, 43, 48]. LPWANs offer good communication range, they allow to have at least a range greater than 1 000 meters. LPWANs are designed to have low data transfer rates, to use generally less bandwidth, and to be low cost with great power efficiency. Most of them provide large network capacity which is a good feature in cattle management, more particularly with a large number of animals in the herd, that is generally the case in african rural livestock management. Most of the LPWAN technologies adopt star topologies where end devices communicate directly with a gateway. In african context, LoRa seems to be more suitable. It allows good range, low cost deployment, supports mobility, good signal robustness. It is also an open standard.

More details are given for LoRa technology in the description below.

LoRa is a new LPWAN technology designed mostly for IoT communication. Its main purpose is to focus on some critical LPWAN characteristics to improve their use on IoT. These features are : battery lifetime, network capacity, range, and cost. These aspects are very important for designing any IoT application mostly when designing an IoT solution for cattle rustling in rural African areas where the cost and network range remain the most critical issues. LoRa technology consists of LoRa as a modulation technique and LoRaWAN which is a communication protocol and system architecture.

LoRa as modulation technique : the long range of LoRa is provided by this physical layer. It is a modulation technique that uses the CSS (Chirp Spread Spectrum) which is a technique of spread spectrum used in military to achieve secure and stable communication. This technique allowed to achieve low power like FSK modulation and is more robust to interferences than other spread spectrum techniques like FHSS used in Bluetooth and BLEE and DSSS used by WiFi, and Zigbee.

LoRaWAN :. while LoRa provide long range LoRaWAN is responsible to manage battery lifetime, network capacity, quality of service, security, and variety of applications served by the network [5, 6].

(1) battery lifetime: the long range allows to set up a star network architecture where end-devices communicate directly with the gateway and then avoid loosing energy caused by store and forward mechanism in mesh architecture that is generally the one adopted in WSN. In addition, communication in LoRaWAN is asynchronous. Nodes communicate with the gateway when they have data ready to be send, no need to synchronize. This mechanism deletes energy loss due to synchronization, and then increase battery lifetime.
(2) Network capacity: loRa has a large network capacity. One LoRa gateway can communication in a same channel at the same time with multiple nodes. It achieves this performance thanks to two features: mechanism of adaptive data rate and the use of multi channel, multi modem transceiver in the gateway.
(3) Cost: the benefits that bring LoRa characteristics allow to have deployment that cover large area with minimal infrastructure. Only one LoRa gateway can cover hundreds of square kilometers. That means, we can have an effective solution with the minimal cost. In addition, LoRa uses ISM Band frequency that is free, hence there is no need for a license for a LoRa deployment, and then no additional cost.

LoRa, compared to other communication technologies used in IoT like WiFi, BLEE, Bluetooth, Zigbee, presents some advantage in its use on rural area. Table 2 gives a comparison of these technologies according to some important factors. This table shows that, Blee and Zigbee offer low cost and low power but their range is enough limited to be not suitable in defeating cattle rustling in which we need to cover large area. WiFi have a good data rate but it is very costly and needs more energy. Furthermore, in cattle management context, we do not need high data rate . However it is a good option for the communication between the established network and the internet. The ideal values are given by LoRa which offer low cost, low energy consumption, long range, and high network capacity.

2.2 Hardware

The hardware solution to be adopted depends on the chosen technology and how to integrate these in animals. As technology solution we have RFIDs, the WSAN and RSN (RFID Sensor Network) [15] which is a combination of the first two.

2.2.1 WSN. For WSNs, choosing the hardware solution focuses on three components: the terminal nodes, the gateway, and the radio module for communication. The important criteria to consider for end-devices are without any doubt the size of micro-controllers, the size of the radio module, how animals carry the device, and price. With clamps, terminal size should not be high likely to be a source of stress for the animals. Note that, with the size of LoRa radio modules that exist, it is not possible to have subcutaneous end-device or that can be hosted within animal bolus.

2.2.2 RFID. RFID or radio frequency identification is an automatic identification technology that uses electromagnetic waves to identify carriers of labels objects (or tag) when they pass near an interrogator (or reader). This technology is used in many field especially in animal identification. RFID tags can be classified into three categories [46] :

Passive : this tag is based on a feedback module of the electromagnetic wave from the reader to transmit data. It does not use an RF transmitter. It does not use battery, the energy that powers the integrated circuit is taken from the electromagnetic wave.

Battery assisted passive : this type of tag embeds a battery. This battery is used for powering the integrated circuit. However, the principle of communication is always the retro-modulation.

Active : this tag embeds a source of energy. It communicates with the reader in a peer to peer manner using an RF transmitter.

For animal identification, transponders can be classified into four types depending (Ear tag, Bolus, Collar, Microchip) on how they are worn by the animal and the transceiver in two types (Fixed and portable reader)[44].

Fixed reader : a fixed reader can be placed in a desired place in the farmer. It will be used by identifying tagged animal when they go to grazing and when they come back. This allow to now that an animal that went to grazing is safety return or not to the farm.

Portable reader : with portable reader farmer can periodically identify animals even if they are in grazing area. The portable reader can embed digital screen to automatically display the results of identification.

Table 3: RFID for animal

Type	Tags	Reader
Active Battery assisted passive Passive	Ear Tag Bolus Collar Microchip	Fixed Reader Portable Reader

3 CHALLENGES TO DESIGN A SOLUTION FOR PREVENTING CATTLE RUSTLING

The design of a system using new technologies around the IoT for preventing cattle rustling faces several issues. These challenges must be addressed accurately in order to have an efficient system that take into account all aspects related to this scourge. We describe below the most critical issues we identified.

The number of sensors to be deployed : the number of sensors to be deployed to manage a herd in order to avoid theft can be a big issue due to two aspects. The first one is related to cost which is a very important issue in rural context. In Africa, farmers generally have herd with many beats, often more than one hundred. Then, If we want to have low cost deployment with a vast herd, it will not be realistic to have one collar for each beat. Otherwise, if we reduce the number of sensor to lower the cost, the risk is to fail to achieve the goal. The second aspect is more technical, it means, since the beats in the herd are most of time flocking together and they move all the times in no controlled manner, it will be difficult to avoid or manage interferences mostly when every beat embed a sensor. If we want to reduce the number of sensors to minimize cost and reduce the complexity of managing interferences, how many sensors will we use? how to deploy them among the herd? According to what criterion will we choose the number of sensors and the beats which will wear a sensor? According to farmers, in most cases in a herd there is an animal which is the leader. The leader guides and all the other animals follow him. With this configuration, attaching one sensor to the leader to track a herd can be envisaged. In such deployment, how to recover a theft that concerns one or more animals different to from leader?

Large grazing areas : in traditional farming, the food system is mostly based on grazing mode. In rural areas, the grazing areas are almost not limited and often very large. This characteristic addresses the problem of coverage. Which communication technologies can fix in best this problem? If we want to defeat cattle theft in these conditions, we must have a good communication mechanism with a good range, flexibility, and resistance.

The behavior of the animal : to best defeat cattle theft, it is imperative to have at first a good understanding on animal behavior. In rural context, there is a few study in animal behavior. Most of the study about animal behavior are done in wild environment or in industrial farming. It's very different in traditional farming where animal behavior depends on the environment (grazing area, drinking point) and on farmer's behavior (decision to guide). When theft is occurring the behavior of the herd may change. Understanding animal behavior in order to establish the normal behavior is then imperative and will be a great issue to avoid cattle theft.

Transhumance : farmers travel from one region to another to find grazing areas. The place they are depends on the seasons. Some seasons they can be at home and another they are far away from it, in another region. According to this, in what manner IoT can help to prevent the rustling. If we establish a system for a farmer in his grazing area, in his home region, we can prevent cattle theft only if it remain within this region. If the boundary of the grazing area can be delimited for the herd it will be more easy to prevent steal. Now the issue is how we can have an IoT solution than can follow the farmers during seasons and among his usual grazing areas. A system to resolve this problem will be described further.

Mobility : in cattle management sensors are mounted on animals which are always moving. Their position changes frequently. Depending on the communication technology, the network topology and routing path must be dynamic. The consideration of this parameter can be different if we have a network with direct communication (end-device to gateway) like LoRa or if we have multi hop communication network (ZigBee).

Cost : cost is an important aspect for any solution designed for african rural context. It is generally difficult to change farmers'habits, then very hard to convince them using technology within their business. So, presenting an expensive solution to them could increase their skepticism. More, their incomes is not very high, then they don't need a solution that will decrease it. Having a low cost solution is not easy. In order to have a good solution that will be accepted by farmers, all the components must be low cost.

4 PROPOSED PROTOTYPE

In order to prevent cattle rustling phenomenon in Africa a prototype based on LoRa has been proposed. This prototype relies on a built low-cost LoRa IoT platform that consist of a single connection low-cost LoRa gateway with post-processing task and link with IoT cloud platforms and low-cost LoRa end-devices.

4.1 Principle

The prototype is based on LoRa network with a single hop communication where cow are assimilated as end-nodes that send data to a LoRa gateway. This gateway send informations related to cows situation to farmer through an IoT cloud if internet connectivity is available or directly to the farmers' smartphone or tablet via WiFi or Bluetooth if he can not access to internet. A designed collar that integrate our built LoRa end-device is fixed to the cow around neck. This collar is built with a beacon system that will help to prevent cattle rustling by raising an alarm if a risk is observed.

4.1.1 Designed collar. Most of designed collars for cattle management is not suitable in the context of cattle rustling because of this reason : they are easily removable and thieves can cut the collar without farmers' awareness. To overcome this problem we design the collar so that when cut or removed farmer will be informed. We first choose a robust belt and more important we passed the alimentation wire of the LoRa end-device around the neck with the belt as shown in Figure 3. A beacon message is sent to the gateway when the male connector (MC) and the female connector (FC) of the alimentation wire are connected. When the gateway receive the beacon message this mean everything is fine with the collar.

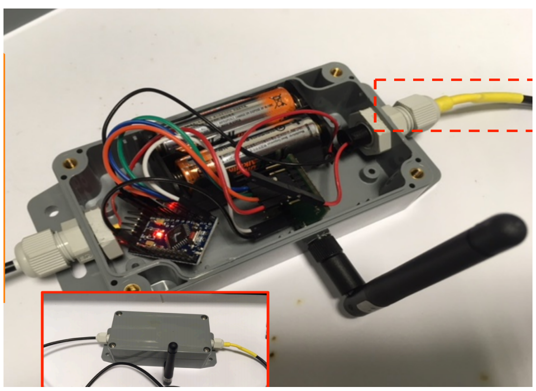

Figure 3: Designed collar

4.1.2 Beacon system. As said above a beacon message is sent by end-devices to the gateway when the MC is connected to the FC. The beacon message is a counter maned BC (Beacon Counter) that takes value between 0 to 65536. The BC start to 0, increases by 1 at each beacon, returns to 0 after 65536 beacons. The end-device is design to send, when powered on, a beacon message every 10 min. The LoRa gateway stores the received beacon message and process it in order to detect whether an alarm should be raised or not. The processing result can be sent to the cloud if internet connectivity is available or directly to the farmer's smartphone or tablet (via bluetooth or wifi) if not. The reception of a beacon message means that the end-device which send it is in the range of the gateway. If cows are out of range or collar disconnected or damaged an alarm will be raised. Figure 4 shows received beacons information at the gateway's side.

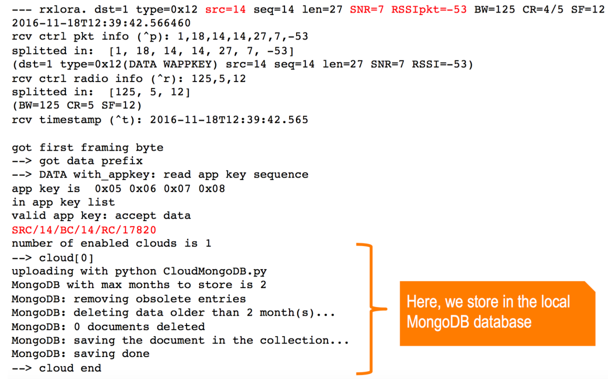

Figure 4: Received BC on Gateway

From there, we can check Beacon Counter to see for gaps (packet losses) and check the time between two beacon. If BC comes back to 0, that means the beacon system has been reset (disconnected and reconnected) which is likely an alarm. Received beacon data are also stored in the local MongoDB and can be accessed through a local web server. For instance, informations about the RSSI of received beacons can be used to estimate the collar distance, see Figure 5.

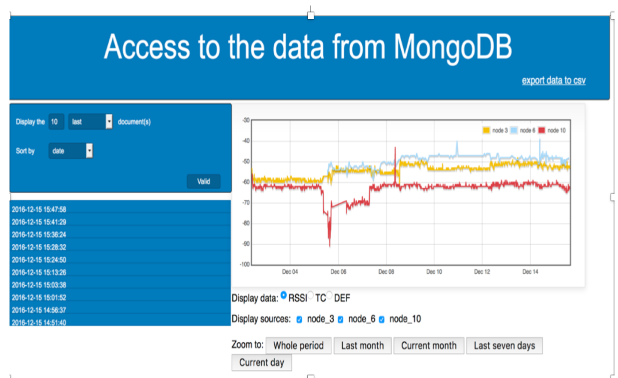

Figure 5: Visualize RSSI values from MongoDB

4.2 Low-cost LoRa IoT platforms

4.2.1 Single-connection low-cost LoRa gateway. Our low-cost gateway [39] is based on a Raspberry PI (1B/ 1B+/ 2B/ 3B). For the LoRa radio, there are many SX1272/76-based modules available and we currently tested with 6, from 4 manufacturers: the Libelium SX1272 LoRa, the HopeRF RFM92W/95W, the Modtronix inAir9/9B and the NiceRF SX1276. Most SPI LoRa radio modules can actually be supported without modifications as reported by many users. In all cases, only a minimum soldering work is necessary to connect the required SPI pins of the radio to the corresponding pins on the Raspberry GPIO header. The total cost of the LoRa gateway can therefore be less than 45 Euro. Note that our approach can deploy more than 1 gateway to serve several channel settings if needed. This solution presents the advantage of being more optimal in terms of cost as incremental deployment can be realized and also offer a higher level of redundancy which should be taken into account in the context of developing countries.

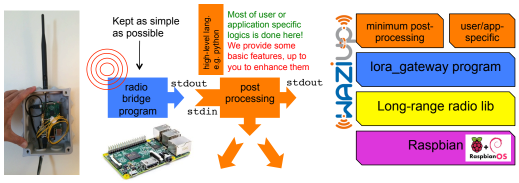

Figure 6: Our gateway software architecture

In our gateway architecture we clearly want to decouple the specific lower level radio bridge program from the higher-level data post-processing stage that must be easily customized by third parties. The data post-processing stage is written in high-level language such as Python and we provide a template that already supports a number of publicly available IoT clouds as it will be explained in the next section. As can be seen in the right part of the figure, the WAZIUP project will provide most of the gateway software logic, with the last layer being highly customizable for specific application's needs.

4.2.2 Post-processing and link with IoT cloud platforms. The gateway can be run in standalone mode in which case received data will simply be displayed to the standard output as shown in Figure 7(left).

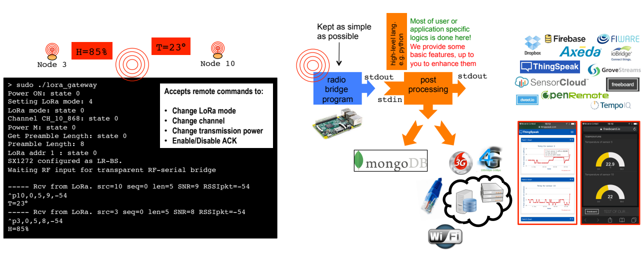

Figure 7: Post-processing data from the gateway

Advanced data post-processing tasks are performed after the radio stage by using Unix redirection of gateway's outputs as shown by the orange "post-processing" block in Figure 7(middle). The post-processing template shows how to upload data on various publicly available IoT cloud platforms. Examples include `Dropbox™`, `Firebase™`, `ThingSpeak™`,`freeboard™`, `SensorCloud™`, `GroveStream™` & `FiWare™`, as illustrated in Figure 7(right), and most of them use simple REST API interface. As stated previously, this architecture clearly decouples the low-level gateway functionalities from the high-level post-processing features. With public IoT clouds "out-of-the-box" surveillance applications can be deployed in minutes as most of these platforms propose free accounts. For instance, a small farm can deploy the sensors and the gateway using a free account with `ThingSpeak` platform to visualize captured data in real-time.

4.2.3 Gateway running without Internet access. As can also be seen in Figure 7, our gateway can also handle cases where Internet connectivity is not available as data can be locally stored on the gateway in a NoSQL MongoDB database. The gateway can either be used as an end-computer by just attaching a keyboard and a displayer, or it can also interact with the end-users' computing device (smartphone, tablet) through WiFi (through a web server) or Bluetooth (with an Android app on a smartphone) as depicted in Figure 8. WiFi or Bluetooth dongles for Raspberry can be found at really low-cost (the Raspberry PI3 also comes with embedded WiFi and Bluetooth) and the smartphone can be used to display captured data and notify users of important events without the need of Internet access as this situation can clearly happen in very isolated areas.

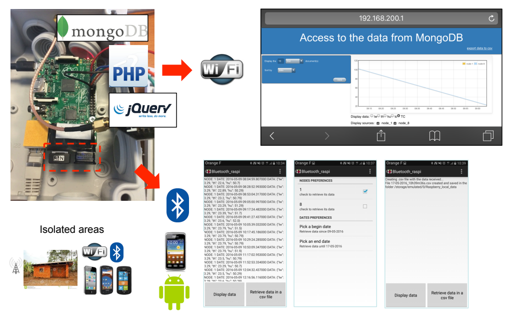

Figure 8: Fully autonomous LoRa gateway

4.2.4 Low-cost LoRa IoT devices. Arduino boards are well-known in the microcontroller user community for their low-cost and simple-to-program features. These are clearly important issues to take into account in the context of developing countries, with the additional benefit that is due to their success, they can be acquired and purchased quite easily world-wide. There are various board types that can be used depending on the application and the deployment constraints and we support most of them. However, the Arduino Pro Mini, which comes in a small form factor and is available in a 3.3v and 8MHz version for lower power consumption, appears to be the development board of choice to provide a generic platform for sensing and long-range transmission. It can be purchased for less than 2 Euro a piece from Chinese manufacturers with very acceptable quality and reliability level.

Following the same approach than for the low-cost gateway, all programming libraries are open-source and we provide building blocks for quick and easy new behaviour customization and physical sensor integration as shown in Figure 9. With the radio module connected to the Pro Mini board, there are still plenty of analog and digital pins for various sensors. For out-door usage, the board is powered by 4-AA batteries and is put into a water-proof case.

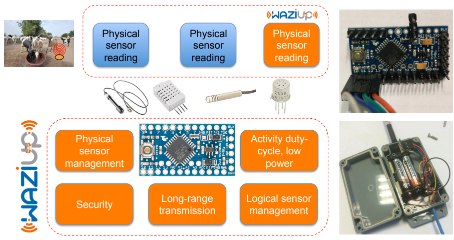

Figure 9: Low-cost LoRa end-device for customization

The duty-cycle building block can be configured to trigger sensor reading every M minutes. All sensors connected to the board will be polled and the returned values concatenated into a message string for transmission. Then, the low-power building block provides a deep-sleep mode to run an Arduino Pro Mini with 4AA regular batteries. With a duty-cycle of 1 sample every hour, the board can run for almost a year, consuming about $146\mu A$ in deep sleep mode and 93mA when active and sending, which represents about 2s of activity/hour.

4.2.5 Collar with autonomous gateway. As said above a gateway can be designed to act like an Access Point (AP) or with a Bluetooth support to allow accessing data directly to the gateway with a smartphone or a tablet. With a such terminal we can display captured data and notify users of important events without the need of Internet access as this situation can clearly happen in very isolated areas.

If such a gateway is operated with a high-capacity battery that can power the gateway for about 10 hours, then one can imagine fully autonomous long-range sensing applications such as cattle rustling device based on beacon-collar as illustrated by Figure 10: an autonomous gateway powered with a high-capacity battery pack/solar panel is used by a farmer to collect beacons from collars placed on cows of the herd. The embedded web page provided by the gateway is accessed on the farmer's smartphone and alerts can be indicated if some beacons are not received. The RSSI can also give some indications on the distance of the cows (The RSSI issues will be investigated in more detailed in the future for the Cattle Rustling Use Case).

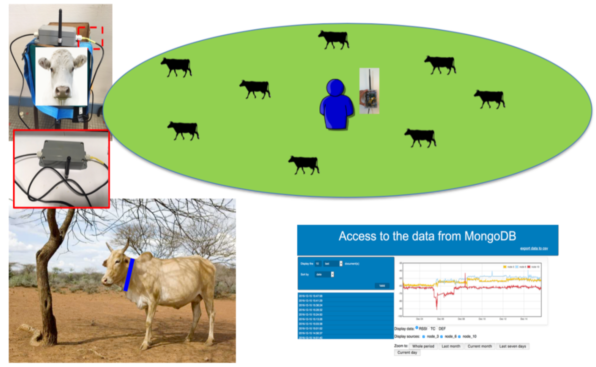

Figure 10: Fully autonomous cattle rustling application

5 EXISTING SOLUTIONS

For several decades now, the technologies of identification and communication are used to identify and track objects in many areas, where they have already reached a good maturity. These technologies mainly revolve around RFIDs and WSNs. Their applications are diverse and varied. We found them in the Anti-Theft [16, 19, 26], the supply chain tracking, Agri-Food Supply Chain [2, 8], tracking library books [29, 41] , home health care [13, 18]. In the animal environment, they are mainly used in tracking and study of animal behavior. Several studies have already been made in this direction for pets [1, 42] and wild animals [22, 27, 30]. However, few studies exist to address the problem of cattle rustling especially in the African context. Indeed, in the field of livestock, solutions are mostly focused on animal behavior to improve their health [10], the production of milk and meat [17, 31, 38]. However, in some areas of Africa researchers began to look at cattle theft problem and attempt to provide solutions based on these technologies. In Kenya, Lazarus et al. [28] give some ICT (Information and Communication Technologies) usage options to fight against cattle rustling. These options are based on traceability technologies such as GPS and RFID. They identified three options for implementation of a traceability system. These three systems are: RFID-based traceback system, GPRS-based traceback system, GPS-based traceback system. This solution is primarily based on the identification and localization. Others may be based on the behavior of animals, like the one developed in South Africa by Nkwari et al. in [33]. In Their study, the authors Investigate how cow behavior can be modeled using global positioning wireless nodes to get the expected position of a cow. The objective of their work is to determine abnormalities in behavior that could indicate the presence of the thieves. Their analysis are based on two factors: the position and the speed of cows. They assume that the probability for a cow being stolen increase more at the defined boundaries. A random walk model is applied to the cow's position in order to determine this probability. The closer are the animal to the boundaries the higher is the probability for being stolen. The Continuous

Time Markov Processes (CTMP) is applied to the movement pattern of an individual cow to find the probability that cow will be at the boundary position. The system designed in their work give an analysis of the modeled behavior of just one cow, this is limited to address the main problem related to a group of cows. It does not address the problem of interference that can be occurred when a sensor is placed in every cow. Is the modeling of the behavior of just one cow is enough to predict behavior of the cattle? In the state of Katsina, a solution is proposed by Sani Ibrahim et al. [24] . It is a little different from the others. Although, even it uses RFIDs, it is based on a new approach that the authors call Community Ranch. It involves having a close rural ranchs where farmers raise their herd and each animal is identified in relation to its owner. The contribution of the authors is primarily on the study of the feasibility and acceptance by the farming community of the solution based on surveys from it.

Nor et al. [35] provides an android application to attend farmers to track their lost or stolen animals. The application is based on a system that uses a GPS collar which gives the positions of the animals to be stored in a ThinkSpeak database. This is the minimal system one can have in the fight against cattle rustling. It is therefore very limited. Siror et al. [45] provide elements of a global system to combat cattle rustling in Eastern Africa especially in Kenya and adjacent areas of Uganda, Sudan, Ethiopia, and Somalia. They provide for tagging, identification and information management system supported by a centralized database system. Informations about the livestock can be obtained remotely using internet, Sort Messaging (SMS) or GPRS technology. This is the first study providing large-scale solution that encompasses several areas of sub-regions. This is the solution which comes closest to the problem of transhumance in the fight against cattle rustling. More importantly, it leads to the direct involvement of the authorities of that sector, whether government or security. In order to automate the monitoring and control of animals, Guo et al. in [23] study their behavior based on understanding and classifying of different states of the activity of an animal. They use end-devices as a collar around the neck of the animals. These end-devices stir in sensors that will allow to collect individual animal information such as position, speed, temperature, 3-axis acceleration values, and 3-axis magnetic field strength. The study of dynamic states of the animal's body provided by the measurements of the accelerometer and the magnetometer allows knowledge of animal behavior like if an animal is stationary or traveling, if it is sitting, walking, standing or running, or if it is sleeping, ruminating, grazing or drinking. The system developed by Tim Wark et al. [47] to avoid bulls fighting by applying the right stimulus to guide them, could be used to prevent theft at best keeping animals in a safe area. This area is created independently and virtually putting the stimulus that redirects any animal exceeding a critical threshold. This system requires, as noted by the authors, a dynamic estimation of the state of the animals, operating in real time, and an efficient wireless mobile transmission system. In this system, an animal that is not redirected by the stimulus is probably being stolen. The effectiveness of this system is based on its character to operate without human intervention and more importantly the ability to find a good stimulus that is not static as all animals do not necessarily respond in the same way to a stimulus.

Table 5: **Summary of existing technologies**

	Technologies		
	Localisation	Identification	Network
Ibrahim et al., 16 (Nigeria)	Keep cattle in community (public) ranche	RFID	—
Lazarus et al., 10 (North Rift Kenya)	GPS	RFID	GSM
Joseph K. et al., 09 (East Africa)	GPS	RFID	GPRS
NKWARI et al., 14 (South Africa)	GPS	—	ZigBee, GSM
Nor et al., 15	GPS	—	—

Each solution has its advantages and its weakness. Table 4 presents the existing solutions that address cattle rustling issues in African context. Presently, none of these solutions take the problem globally. Generally, they address only the localization and the identification issues. None of them give an assessment in a real deployment that permit to know if the solution can reduce or not cattle rustling phenomenon. The identification, localization , and communication technologies used by these solution are presented in table 5.

6 DISCUSSION

The study of cattle rustling problem reveals interesting research problematics. The more we analyze the problem, the more complex it appears to us. Establishing a good, global, and efficient solution for preventing cattle theft requires taking into account all involved aspects to this scourge. The problem is not just about animals and thieves. It's also about farmers, environment, and cultural aspects. It comes to understand animal's behavior compared to environment, farmers and thieves behaviors. The questions are : how understanding animal, farmers, and thieves' behavior, and environment where animal evolve could allow to prevent and defeat cattle theft? What is the normal behavior of a cattle? How to establish it? How farmer and thieve's behavior and environment, influence animal behavior? The problem of cattle rustling can be turned to modeling environment, farmer, thieve, and animal behavior in order to prevent the moment and the place of a theft.

The problem is also about hardware and communication technologies. As we described above in section 2, there are many issues in cattle management in rural context that make very important the choice of hardware and communication technologies. The hardware we choose will mostly depend on the solution we adopt and how to integrate it on the animal. Establishing a solution is difficult when we are in hostile terrain with inadequate physical and communication infrastructure. The coverage is a very important issue mostly if we are in pasturage case. With LoRa technologies we can achieve good coverage thanks to its range that can reach 10 kilometers in line of sight and its robustness to environmental perturbation. LoRa is more suitable if we want to cover a wide grazing area, but if we are in a small deployment zone it can be enough to use ZigBee or RFID.

However, with the RFID, there are not many deployment options for cattle rustling. For RFID tags, collar, electronic tag, and the tag of the ears can be used to identify animals but they are very vulnerable, so, thieves could remove them before stealing animals without the farmer's awareness. The safest remains the choice of the bolus which is housed in the rumen. However, in all cases, if there's theft the farmer could realize that by identifying animals through the RFID reader when they come back to grazing. In these case we assume that we place RFID tags on animals (Bolus, ears, collar, electronic) and a fixed reader somewhere in the farm. We could think of another deployment where the farmer will have a portable RFID reader and periodically identifies animals but this is of course tiring and may be somehow not reasonable.

LoRa can be a good candidate for designing an application to defeat cattle rustling. But having one LoRa gateway may not be enough because as we say above, the grazing area of african farmers can cover many regions. One LoRa-gateway can be good for just a large area but limited to the gateway range. That means nomadic farmers must change their habits to a sedentary lifestyle. Another solution is to envisage a large area that cover many regions and divide it into a grazing zone like cellular concept and each grazing zone will be managed by one LoRa-gateway. In this system a pastoral region is defined according to transhumance habits of farmers. This pastoral region is divided into pastoral zones that are a large areas which in turn can be divided into grazing areas. Each grazing area is a cell (5 or 10 kilometers squared) managed by a cellular gateway (GWC). All herds in this area are in the responsibility of this gateway (GWC). Then in a pastoral zone we could have many GWCs that will be managed by a pastoral gateway (GWZ, gateway zone). All these elements will be specifically integrated in a single system managed by one application.

7 CONCLUSIONS

In this paper we discussed and analyzed existing IoT solutions for preventing and defeating cattle rustling in african context. Cattle theft is big scourge that causes many problems to african farmers. Existing traditional solutions can not really defeat this flail. The ICT remain now their final hope. In the literature there is not many solutions that address the problem and at the same time taking into account the specific characteristics of rural african areas. Most of existing solutions are based on RFID and WSN technologies. It appears that, many particular issues have to be focused on to have an adequate and efficient solution to defeat cattle theft in african environment.These challenges concern the large grazing area, number of sensors to be deployed, transhumance, animal behavior, the cost etc. Regarding to this, existing solutions have their advantages and their limits. LoRa is a new LPWAN that offer low cost, low power, and long range communication. With its characteristics, it can be a good choice to improve existing solutions and cover their limits. There is not yet any solutions for cattle rustling that use LoRa technology. However, this comes also with challenges to be surpassed. In a future work, we will present a new solution for preventing and defeating cattle rustling based on LoRa technology. It will be a whole livestock management system that uses a predictive theft algorithm to prevent cattle rustling.

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Table 2: Comparaison of communication technologies

	Range	Frequency	Data Rate	Energy consumption	Cost	Modulation technique	Network capacity
Bluetooth	30 - 300ft	2.4GHz	1Mbps	Mdedium	Low	FHSS	7
Blee	Up to 10ft	2.4GHz	1Mbps	Low	Low	FHSS	2- 5 917
ZigBee	30- 1.6km	2.4GHz	250kbps	Low	Low	DSSS, CSMA/CA	256+
WiFi	100 - 150ft	2.4GHz	11 - 54Mbps	High	High	DSSS/CCK, OFDM	65 000+
LoRa	2 -15 km	ISM Band 868, 915MHz	0.3 - 50kbps	Low	Low	Chirp Spread Spectrum	Thousands of nodes

Table 4: Summary of existing solutions and synthesis

Solution		Main featurs	advantages	Limits
RFID	Ibrahim et *al., 16 (Nigeria)*	Cattle community ranches	Permet to fixed well the problem. Have valuable and accurate data on the solution to be established.	No concrete solution (just a survey), Not general:solution based on survey did in a particular area (Katsina State) in a particular region (Nigeria)
	Lazarus et *al.*, 10 (North Rift Kenya)	Modern ICT options: RFID and GPS traceability applications.	Demonstrate that using ICT application in livestock identification and traceability will significantly reduce the menace of cattle rustling in the North Rift region.	Conceptual solution. Give no assessment element for the feasibility. Not address problem of internet access in this area.
	Joseph K. et *al.*, 09 (East Africa)	Global system. Management Framework (User, Tag, Livestock, Transfer, Owner, administration management).	Cover large area. Address transhumance problem.	Only effective within an administrative region. Depend on cooperation of other country. Instability of government administration in this area.
WSN	NKWARI et *al.*, 14 (South Africa)	Based on study of animal behavior by understanding and classification of different states of animal activity.	Can give the probability to have an animal reach an expected boundary in any area based on the position and the speed of the animal.	Zone of study very limited. Study the behavior of only one cow. That can be limited because behavior of a cow can also depend on the behavior of other cow and other parameters.
	Nor et *al.*, 15	Smart livestock tracker (online database: Thingspeak, GPS Collar, and Android application).	Give an android application	Very limited solution. Give the minimal we can have.