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Using Internet of Things for Wildlife Tracking

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Abstract

This paper provides a comprehensive examination of the utilization of Internet of Things (IoT) devices in wildlife management and tracking, their evolutionary trajectory, and practical implementation in data acquisition. Central to the discussion are key components of IoT networks, including Sigfox, Wi-Fi-enabled devices, and IoT-based wireless sensor networks, each analyzed for their role and efficacy. Communication modalities within IoT frameworks, coupled with an evaluation of protocol performance are evaluated.

Furthermore, this seminar also addresses challenges inherent in wildlife data collection methodologies, such as memory constraints, battery life, transmission range and rate, and security vulnerabilities within IoT ecosystems. By delving into potential solutions and technological advancements, this paper aims to contribute to the refinement of wildlife monitoring practices, fostering a more robust and effective approach to conservation efforts.

This is a preliminary abstract, I mainly added it just so I had something.

Keywords: IoT, networking, Wi-Fi, data transmission, data collection, animal trackers, Sigfox, WildFi, Biologging, ecology

1 Introduction

2 Background

Comprehending the foundational technology behind the Internet of Things (IoT) is paramount in grasping its applications in wildlife tracking. This section aims to furnish a concise overview of biologging, the IoT, and their intersection in wildlife tracking. Additionally, it will explore current and past technologies employed in biologging, shedding light on their operational mechanisms and comparative advantages. By delving into the workings of traditional wildlife tracking technologies, we can evaluate their merits and demerits, thereby establishing a framework for evaluating the suitability of IoT solutions for wildlife tracking.

2.1 What is Biologging?

Biologging is a concept that gained popularity in the early 2000's and has continued to play a pivotal role in understanding animal behavior and ecology. Biologging can be defined as "The investigation of phenomena in or around

free-ranging organisms that are beyond the boundary of our visibility or experience. [2]" It is a method of tracking animals in the wild using electronic devices that are attached to the animal. These devices can be used to track the animal's movements, monitor its behavior, and collect data on its environment. Biologging emerged as a powerful tool in ecology in a similar way genomics did for the study of cell and organ function. The obvious difference being that biologging provides insights into the behavior and functions of various organisms in environments that can be hostile or difficult to reach for the observer, rather than the function of cells and organs [2]. The ability to track animals in their natural environment has provided researchers with a wealth of data that was previously unattainable. This data has been used to study animal behavior, migration patterns, and the effects of climate change on various species[3]. The data collected from biologging devices has also been used to inform conservation efforts and to help protect endangered species [4]. It is important to understand that biologging is simply the collection of data from animals in the wild, and it is then up to scientists or conservationists to use the data to answer questions about the animals or to inform conservation efforts.

2.2 What are the Other Biologging Methods?

Various strategies have been used in the past to track animals in the wild. Many implement variations of the same technology within the tracking sensors; GPS, accelerometers, and magnetometers are the most common sensors used in biologging devices. These data from these sensors help researchers understand the animal's speed, direction, and position, which allows for a 3D mapping of positions[11]. The compilation of this data can be seen in Figure 1 from the Smithsonian's National Zoo and Conservation Biology Institute, which shows the 3D movement of a prairie dogs. Most biologging trackers will implement these types of sensors, but the implementation of these sensors can vary greatly. More importantly, the communication of the data from these sensors can vary greatly. One of the most popular methods for transmitting data is the use of cellular networks. A study conducted by a professor from UC Irvine tested the use of cellular networks to analyze the pollution levels in the San Jose area by using pigeons equipped with GPS and automotive emissions sensors [14]. Professor Da Costa had to pay about 10 cents for each message transmitted, and two messages are

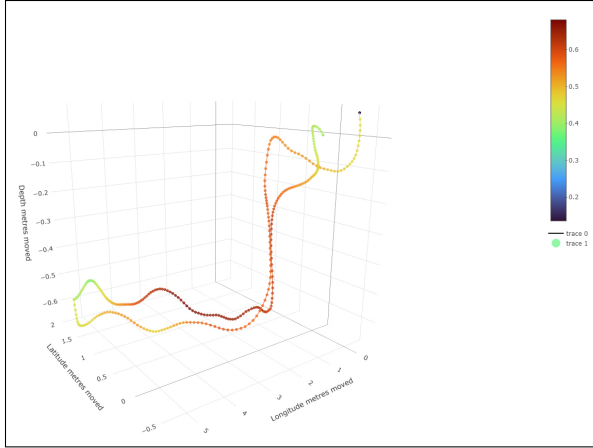


Figure 1. 3D movement of a prairie dog [11]

sent every minute by each pigeon[14]. This leads into one of the biggest disadvantages of using cellular networks: cost. Another obvious disadvantage is that cellular networks are not available in all areas, and the range of cellular networks is limited. It is also practically impossible for researchers to improve the range of cellular networks by adding more cell towers to cover their study area. Radio frequency is another technology that has been used to transmit data from biologging devices for decades. The use of radio frequency to transmit data from biologging devices requires a receiver to be within range of the transmitter, and the range of the transmitter is limited by the power of the transmitter and the frequency of the radio waves. The receiver and transmitter used by Cooke et al. on marine animals had an effective range of 5 to 1000m and is only able to transmit periodic tracking records or time stamped data from loggers [5]. This falls short of the capabilities of IoT enabled biologging devices using LPWAN networks, which are able to transmit data in real time, and can transmit data over much longer distances.

2.3 What is WLAN?

Understanding the basics of how a wireless networks transmits data is important to understanding the reasoning behind using it for biologging. Wireless networks, like WLAN (WiFi), works by encoding data into a binary form so it can be sent across a radio frequency to another wireless enabled device. Ones and zeroes are represented by different amplitudes of radio waves and are received by another device[8]. There are many frequencies that can be used as a medium to send this data, the most popular being 2.4GHz and 5GHz. However, 6GHz frequencies are becoming more popular for it's ability to transmit data at faster rates. In general, as frequency increases, range is sacrificed for higher data rates[17]. Data rates are higher because the radio waves are being received in higher frequency, meaning more ones and zeroes

are being received every second. In some cases, speed is not everything, and range is more important, in this case, a lower frequency is a better choice. Sub gigahertz(GHz) frequencies are used in LPWAN networks for this reason. They are able to achieve ranges upwards of 40km at the cost of data rates, LPWAN networks are explored futher in section 4.1

2.4 What is the Internet of Things?

The Internet of Things (IoT) represents a transformative shift in the realm of technology, encompassing a vast array of physical objects empowered with sensors and software to interact autonomously. These objects collect and exchange data through network connectivity. In essence, IoT devices, ranging from commonplace gadgets to sophisticated systems, have the capability to interface with the internet or communicate wirelessly, thereby facilitating seamless integration into various facets of daily life. The IoT has been applied to a wide range of fields, including healthcare, agriculture, manufacturing, and most important to this paper, wildlife monitoring. The fundamental structure of an IoT system is comprised of three interconnected layers: the perception layer, the network layer, and the application layer[12]. The perception layer is responsible for collecting data from the environment, which is then transmitted to the application layer via the network layer. The transmission layer can use a variety of different methods to transmit data, the two most common being ethernet/WiFi, and cellular networks like 5G and LTE[10]. Lastly, the application layer is responsible for doing something with the data, such as graph positional data from an animals GPS sensor. The physical implementation of these layers can vary greatly, but in general, the perception layer consists of a sensor or device that can output a signal to be received by a gateway device(the most common gateway device for the average person would be a wireless router). The gateway device is connected to the internet using one of the aforementioned methods, and it is responsible for receiving the data from the perception layer device and transmitting it to the application layer, which could be a database to store the data, or a web application to display the data[12]. These three theoretical layers are important in understanding the IoT, and how it can be used in wildlife tracking. The Wild-Fi biologging tag, is a prime example of how these three layers are implemented in a biologging device and is visually explained by figure 4.

3 Components of a IoT Biologging System

3.1 The Sensor Device

4 Networking

The networking of a IoT based biologging system is crucial in ensuring safe and efficient data transmission. The networks used in a biologging system are responsible for transmitting data from the sensor device to the application layer, and are also responsible for ensuring that the data is

transmitted safely and securely. The two most popular types of networking protocols used in biologging systems are Low Power Wide Area Networks (LPWAN) and Traditional Wifi. These two types of networks have their own advantages and disadvantages, and the choice of which network to use is dependent on the specific use case. No matter what method is used, the networking must be able to transmit data over long distances, and they must be able to do so in a secure way. The security of the data is especially important in a biologging system, as the data being transmitted is often sensitive and can be used to track the location of an animal, which in the hand of an illegal hunter, could be disastrous.

4.1 Low Power Wide Area Networks (LPWAN)

LPWAN networks provide a few benefits compared to a traditional mesh wifi network, the primary benefit being that LPWAN networks are able to transmit data over much longer distances than a traditional mesh wifi network. This is especially important in a biologging system, as the animals being tracked are often in vast, remote areas where a 200m range would not be sufficient. LPWAN networks typically utilize sub GHz frequencies and ultra-narrow band modulation to transmit data over long distances [21]. Proprietary LPWAN networks like the SigFox network are popular and designed to handle up to a million IoT devices using only a single gateway. These services are subscription based, and the cost of the service is based on the number of devices that are used in the network. On the other hand, there are LPWAN standards that exist to allow in house development of an LPWAN network. The LoRaWAN protocol is one of the most popular LPWAN standards, and it is used by many to implement their own LPWAN networks[1]. Both of these network solutions are explored further in subsections 4.1.1 and ??.

4.1.1 SigFox. The SigFox network is a proprietary LPWAN network that is used for IoT systems, and it can be used to cover an area as big as Belgium ($30,600\text{km}^2$) with only seven base stations [19]. The node device in a SigFox network is able to transmit 6 messages per hour, each having a maximum size of 12 bytes. While 12 bytes may seem limiting, it is sufficient for transmitting the GPS coordinates of an animal, as well as other sensor data such as temperature[19]. The SigFox company also offers the Atlas technology which uses the signal strength and location of the receiving base station to calculate an approximate location of the node device, which frees up the node device from having to explicitly send GPS data, allowing for other sensor data to be sent instead[19]. Ultra-Narrow bands (UNB) are used in the SigFox network and many other LPWAN networks, which allows for the transmission of data over long distances, and the use of UNB also allows for the use of low power transmitters, which is important in a biologging system, as the devices are often

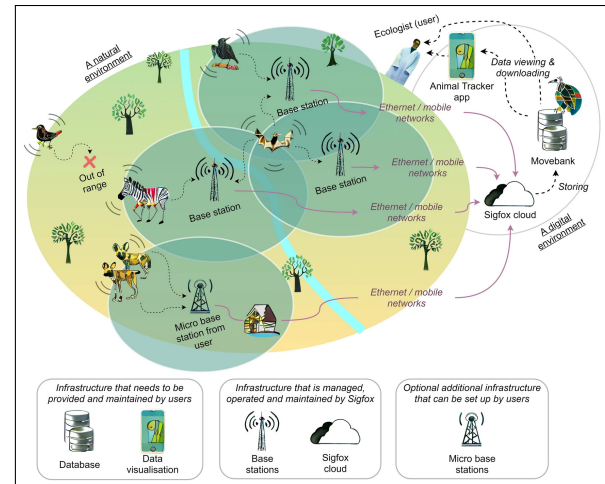


Figure 2. SigFox network infrastructure[19]

attached to animals and must be as small and light as possible. UNB works by using a low radio frequency(868.034MHz to 868.226MHz), and transmits data three times on different channels at different times, which ensures a message is received and robustness to interferences[13]. One of the greatest benefits of UNB is that it allows for the use of low power transmitters, which are able to have incredibly long battery lives. Using the specifications of SigFox’s UNB network, a node is able to send 140 packets per day, and the power consumption is between 19 and 49 mA, two AAA batteries are able to power a node up to 6.5 years [13]. Because SigFox is a proprietary network, end users do not maintain the base stations or connection to the SigFox cloud: they only need to design their devices within the SigFox specifications and connect them to the SigFox network. An overview of the SigFox infrastructure and how it can be applied to biologging is shown in Figure 2.

4.1.2 LoRa. The LoRa and SigFox networks have many similarities in how they are structured and operated, however there are some key differences. The transmission modulation technique used by LoRa is called CHIRP(Compressed High Intensity Radar Pulse) spread spectrum, and it is different from the frequency hopping technique that the SigFox network uses. Where frequency hopping transmits signals at a constant frequency before hopping to a different frequency, chirp modulates by increasing or decreasing it’s frequency over time, this can be done both linearly or not[9]. The spreading factor determines how quickly this modulation takes place; LoRa uses spreading factors SF7 to SF12, the larger the spreading factor, the slower the modulation. How these spreading factors compare to each other is shown in Figure 3. The main tradeoffs between spreading factors is the range and data rate of the network, as the spreading factor increases, the range of the network increases, but the data rate decreases[6]. The spreading factor then becomes a

critical factor in the design of a LoRa network, as the spreading factor is directly related to the range and data rate of the network, so it should be chosen wisely to fit the needs of the specific use case. Because the frequency is constantly changing, chirp is able to tolerate interference better than that of the frequency hopping technique that the SigFox network uses.

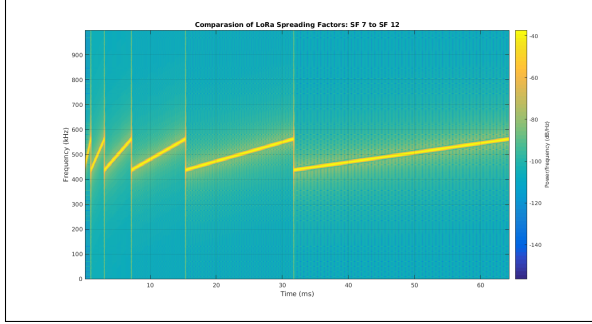


Figure 3. Chirp Spread Spectrum Spreading factors[9]

4.2 Traditional Wifi (WLAN)

A more traditional Wifi network is another method that is used by some companies to implement biologging systems. There are some useful benefits to using a traditional Wifi network over an alternative like LoRa or LPWAN; The biggest of which is data transfer rate. However, because traditional Wifi uses 2.4/5/6 GHz frequencies, the range is much more limited than that of a LPWAN network, and the power consumption is higher. The WildFi biologging system designed by Timm Wild and his colleagues is just one example of a device that uses traditional WLAN to collect data from a biologging device. Wild is also the leading member of the team that studied the use of the SigFox network for a IoT based biologging system, and claimed that the data transmission capacity was one of the reasons that they chose to investigate the use of a traditional Wifi network for biologging[20]. The WildFi tags and others like it, connect and communicate by using a traditional wireless local area network (WLAN), which provides a versatile way for tags to offload collected data. As seen in Figure 4, the WildFi tag has the capability to connect to a WLAN router, smartphone hotspot, specially designed gateway, and more. When the tags establish a connection to one of these devices, data is packaged, encrypted, and transmitted to the receiving device. From there, the data can either be stored on device to be physically collected, or uploaded to a remote database. When connected to a ESP32 CAM gateway and the data is stored locally, a transmission rate of 230 kByte/s can be achieved at a distance up to 200m and only consume 108mA using a WildFi tag[20]. This is more power consumption than a LPWAN based device, however the energy cost per byte transmitted is lower than a

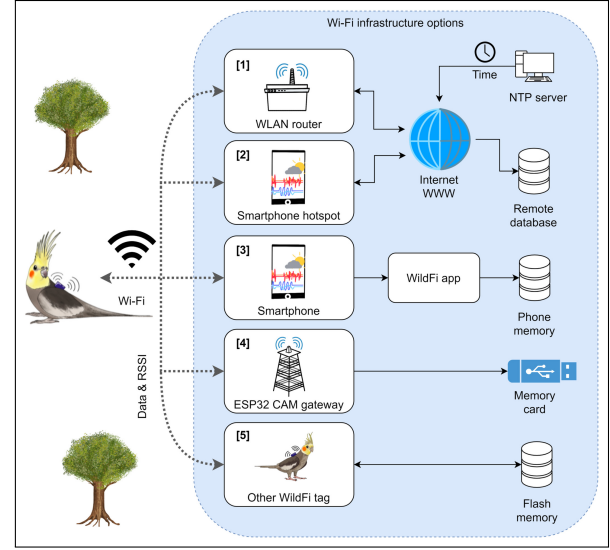


Figure 4. Wild-fi IoT infrastructure overview [20]

LPWAN based device. Wild et. al claim that using a traditional Wifi network with a logging device that has a 70mAh battery and a small solar panel, data can be transmitted 24 hours a day for an entire lifetime of an animal[20].

4.3 Security

The security of these networks is a critical factor in the design of a biologging system, as the data being transmitted is often sensitive and can be used to track the location of an animal, which in the hand of an illegal hunter, could be disastrous. While much of the security of the data is in the design of the physical device and it's software, the networks being used also need to be secure and safe. The security of the physical device is important in the event that a node device is lost or stolen.

4.3.1 SigFox and LoRa Security. Both the SigFox and LoRa network ensure safe data transmission by using AES (Advanced Encryption Standard) 128 for end-to-end encryption. With this encryption method, a 128 bit key is used to encrypt the data from node device and a key is shared with the application server so that it can decrypt the data[18]. This ensures that the data is encrypted at the source, and the data is decrypted at the destination, and the data is encrypted in transit. This is important for the security of the data, as it prevents the data from being readable by anyone who has access to the data, and it also prevents the data from being tampered with in transit. There are many benefits to using AES 128 for end-to-end encryption, including it's proven track record for being secure and efficient. Compared to other encryption methods, AES 128 has a small encryption key which makes it less computationally intensive; This leads into another reason why it was chosen for use in these

	SigFox	LoRa	WiFi
Frequency	868MHz(EU) / 915MHz(NA) / 433MHz(AS)	868MHz(EU) / 915MHz(NA) / 433MHz(AS)	2.4GHz/ 5GHz/ 6GHz
Data Rate	100bps	50kbps	1840kbps
Maximum messages/day	140	Unlimited	Unlimited
Range	10 km (urban), 40 km (rural)	5 km (urban), 20 km (rural)	200m
Security	AES-128	AES-128	WPA2/ HTTPS (AES128)

Table 1. Characteristics of explored networks, data from [15] and [20]

two LPWAN networks. Due to it being computationally efficient, it is a great choice for a system designed around being low power. For a deeper dive into AES 128 encryption and how it is used in LPWAN networks refer to Kun-Lin Tsai's article on the matter[18].

4.3.2 Traditional Wifi (WLAN) Security. The security mechanisms of a IoT based biologging device that uses a traditional Wifi network can vary depending on the developer of each device and their own preference on how to safely transmit data to the gateway device. In the case of the WildFi devices discussed in section 4.2, data transmissions are encrypted with WPA2 and HTTPS[20]. These two methods allow for ease of use for the developer because they are widely supported by most WLAN devices that would be used as gateway devices. WPA2 and HTTPS, similar to the LPWAN networks, uses AES 128 encryption, this provides the same benefits as previously discussed[16].

4.4 Comparison and Selection Criteria

Examining the benefits and pitfalls of each IoT network in relation to what is important in a biologging system is important to understand what network to choose for a given application. While many factors are important when accessing these networks for capabilities as IoT network solutions, range, data rate, battery life and security will be the focus of this comparison because they are the most critical for a biologging system.

5 Conclusion

Acknowledgments

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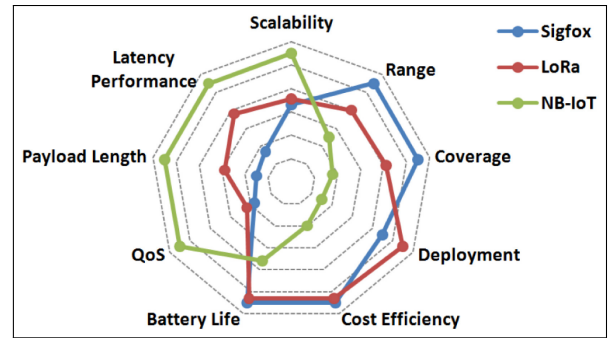


Figure 5. Respective advantages of Sigfox, LoRa, and NB-IoT in terms of IoT factors. [15]

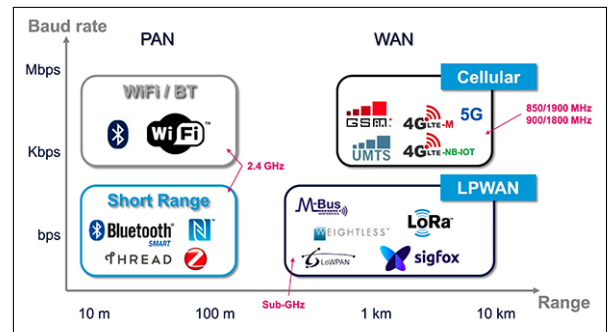


Figure 6. Data rate vs range for different network technologies. [7]

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