LAMBS: Light and Motion Based Safety

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ABSTRACT
Light and Motion Based Safety (LAMBS) is a sensor utilizing the Long Range Wide Area Network (LoRaWAN) to send light and motion data to a central database for public use. This is a prototype of the Atlanta Array of Things initiative, a city-wide sensor network with publicly accessible data. Current challenges in creating a large and sustainable sensor network include power conservation, cost effectiveness, and availability. In particular, a public sensor network in an urban area should not require too much maintenance or funding, and should avoid interference from the urban environment. We characterize the LoRaWAN network in terms of these factors and show that urban sensor networks communicating through LoRaWAN must use low power devices as nodes and be placed in strategic areas that lower interference and increase longevity and range.

INTRODUCTION
We are prototyping a sensor specifically designed to be part of AT&T's Low Range Wide Area Network (LoRaWAN) in order to test the feasibility of LoRaWAN as a sustainable city-wide network protocol. This is a preliminary step in the larger Atlanta Array of Things (AoT) initiative, which aims to create a network of sensors that can gather data in a central repository for public viewing. However, there are many obstacles to creating a feasible sensor network, particularly one that will be a public project implemented in a city. A major challenge is power use. Sensor networks will likely need to do computations with the data they sense as well as communicate with a central point. The power source for the network should be sustainable, so as to avoid constant upkeep. These requirements make low power use a key constraint to work around [3]. Additionally, as a system designed to be funded and implemented by local city governments, the network hardware, such as network interface cards and conduits, must be low cost in order to be a financially viable project to propose and undertake. Finally, the network must also perform well over a long range, without a drop in availability, so that data can be updated in a useful and timely manner [1]. This characteristic is especially key if the data is being used for emergency situations, like public alerts or safety information. Testing LoRaWAN for these characteristics allows us to make recommendations for its use in smart city projects like AoT.

RELATED WORK
Many studies have shown that low power and long range sensor networks are possible. Similar Internet of Things applications have used Bluetooth, ZigBee, 6LowPAN, and Wi-Fi for short and medium range communications [2]. Wireless Wide Area Network (WWAN) technologies, like cellular data and SIGFOX, have primarily been used for long range communication [2]. However, communication based on these network protocols tend to use too much power or rely on expensive or high quality devices to work over long distances [2]. Additionally, cellular networks are not built to provide service for an extremely large number of devices that sporadically send packets of data across the network (like sensors). These traditional networks would be flooded and the network performance for smartphone and mobile computing users would be reduced. LoRaWAN, a protocol released in June 2015 by the LoRa Alliance, is increasingly being touted as a low power, long range protocol for Internet of Things applications. Most recently, Patavina Technologies in Italy successfully tested LoRaWAN for a sensor network in a private building, showing that it can withstand interference from elevators or being on different floors. Projects in Italy and Amsterdam [8] attempted to characterize LoRaWAN for a smart city that can support multiple “things” per resident, essentially creating a free network to which people can connect their devices [1]. However, we will be characterizing AT&T's development of LoRaWAN specifically for a network of embedded devices in an urban environment, where the sensors cannot be replaced

or recharged manually and where there will be interference from buildings and other structures, compared to indoor or environmental sensor networks.

Additionally, we made an effort to keep the project low cost in order to estimate the price of a LoRaWAN based sensor network on a larger scale. Chicago's AoT project that inspired LAMBS has a cost estimate of $500 to $2000 for individual nodes [7]. These costs would be in addition to LoRaWAN technology. Our goal was to design the platform in such a way that a basic sensor box similar to LAMBS could be set up for $100 or less, including the incorporation of the mDot for LoRaWAN implementation. This is critical for enabling average citizens and small organizations to contribute to Atlanta's AoT.

OUR WORK

The Device

To test a sensor on the LoRaWAN network, we have created a device called **LAMBS** (Light and Motion Based Safety). The device incorporates a passive infrared (PIR) motion sensor and a lux sensor. The readings from the PIR sensor are used to test what percent of the time the are in front of LAMBS is active. The lux sensor takes periodic readings of the ambient light around the LAMBS system. LAMBS is encased in a watertight electrical box with an acrylic window to allow light readings. LAMBS currently runs on solar power collected by a solar panel attached to the outside and then diverted to both power the microcontoller and charge the battery. LAMBS contains a 2500 milliamp hour lithium ion battery pack for storing power when the sun is not out. On the networking side, LAMBS sends motion, light, and identification data using LoRaWAN to a local Rails server. Overall, LAMBS represents a device that collects potentially useful data for residents in urban areas and provides a easy access to said data.

Network Characteristics

The first iteration of LAMBS utilized an ESP8266 Wi-Fi module connected to the Georgia Tech campus Wi-Fi network. This consumed roughly 170 milliamps for each transmission, and required that the device was positioned near a Wi-Fi router. Future iterations switched to LoRaWAN, and power consumption of the device using the LoRaWAN network was approximately 19 milliamps, consuming roughly 10 times less power. The sensors take up negligible amounts of power in the microamp range. The mDot also only takes up 30.9 microamps while in standby [5]; this is our best estimate of power consumption since it transmits very infrequently. These power consumption reductions enable roughly 24 hours of operation off a fully charged battery, assuming the solar panels are generating no power. However, because of the limited time we had to work with AT&T's resources, a Teensy and pre-built libraries for the sensors were used to connect with the sensors rather than the mDot itself.

Another key aspect of LoRaWAN is that it has a maximum payload size of 64 bytes, which includes network metadata, so information that may be useful for a smart city must be able to fit within the payload. This meant that our application needed to compress the three scalar values into a shortened format

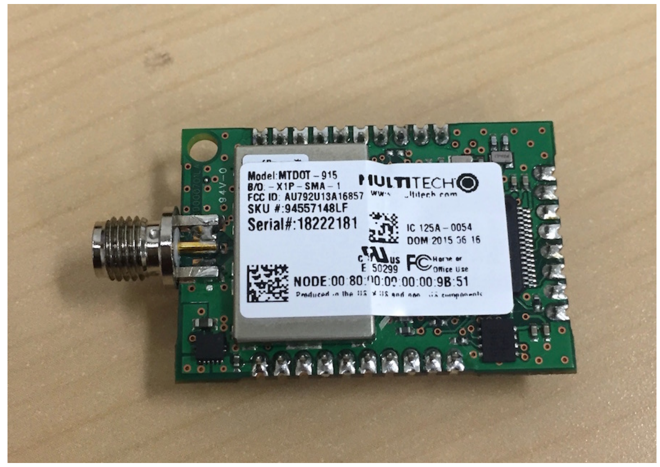

Figure 1. The Multitech mDot chip.

that could be transmitted in a single LoRaWAN transmission. We had to use a 40-bit hexadecimal string to contain the data from the sensors while still complying with LoRaWAN standards. The MultiTech Conduit includes an application layer which decompresses the data into a JSON object that is then transmitted to the Rails server storing the data.

The cost of our overall system to build the endpoint prototype was roughly $130. By using better sourcing and buying in bulk, this price can be brought below $80. The main restricting factor in this cost per unit was the mDot used to connect to LoRaWAN, costing $40 per unit. The other main costs where the Teensy 3.2 microcontroller ($20) and the solar charging setup ($60). Therefore, better sourcing puts our cost below the desired ($100) for the base system.

Our endpoint transmits data to a MultiTech Conduit gateway which costs around $440 for a single unit. While this may seem expensive, a single Conduit claims to be able to handle thousands of endpoints within a one to three miles radius through obstacles such as buildings [4]. Additionally, the Conduit is designed for prototyping LoRaWAN across a variety of interfaces, including Ethernet, Wi-Fi, cellular, and LoRaWAN, and includes many features not necessary for a full-scale rollout of the network. A city-wide implementation would use an industrial-ready access point for the LoRaWAN gateway, along with a dedicated application for parsing the data. Limiting the cost of the gateways can be done by limiting the quantity of gateways, which could be achieved through strategic placement to provide service to as many endpoints as possible.

DISCUSSION

Power

The solar panel was used to provide a renewable power source. This decision was made for a few reasons. A device interfacing with the mDot that AT&T used to develop LoRaWAN can supposedly last "years" on a single battery [5]. However, even though LoRaWAN is low power, using about 10 times less power per hour compared to Wi-Fi, power consumption of the devices on the network themselves matters greatly. Because the activity readings required constant polling of the PIR sensor, the microcontroller was forced to remain active. By switching to sensors that do not need to be always on, a similar project could greatly reduce power consumption by only taking readings once every few minutes. Additionally, the mDot allows for a deep sleep mode that allows it to be woken up by another microcontroller sending an interrupt on a pin. Replacing the Teensy with the mDot's processor, adjusting the standby settings of the mDot, and only using periodic sensing could further increase the system's lifespan without charging.

On a related note, ensuring LoRaWAN is indeed low power is important particularly for a smart city project. With respect to city-wide information technology projects, 85% of projects fail not because of the technology itself, but because of inability to manage and maintain the project [6]. Using solar panels would hopefully reduce the servicing the sensor network would need.

Another characteristic of LoRaWAN affecting power consumption is its maximum payload size of 64 bytes. LoRaWAN has one of the smallest maximum payload sizes of other low power protocols [2]. We had to send very simple and small pieces of data to comply with the LoRa protocol. Our application protocol compressed the sensor data from three scalar values into a 40-bit hexadecimal string, in order to transmit the data in a single packet. Sending a higher volume or more complex information would require more transmissions or more manipulation of raw binary data, which would increase power consumption on the processor.

Cost
The cost of the sensors was negligible for this particular sensor suite, but could change if others were added. We have identified sources to lower the cost of the solar setup to $30, and the Teensy 3.2 can be eliminated entirely if we utilize the processor on the mDot itself. With industrial-grade sensors purchased in bulk and by utilizing the microcontrollers more efficiently, the cost per device can be reduced considerably. Future changes to the LoRaWAN hardware and protocol may also lower the cost, enabling more devices to connect to the array of things with diverse sensor suites. Additionally, devices purchased by the city would not be built on the Arduino or Teensy prototyping platform; they would be built using the specialized components needed for gathering, processing, and transmitting data, which may further reduce cost.

Enclosure
With respect to design, the enclosure we used for the LAMBS prototype was a generic electrical box purchased at a local hardware store for $12. The box had holes cut for the sensors and wiring, and the openings were waterproofed to safeguard the electronics from the elements. The solar panels were mounted on the box in such a way that they could be adjusted to better face the sun. Unlike the initial prototype, which most people ignored, the final prototype was more noticeable due to the solar panel and the fact that it was mounted at eye level. We believe that mounting the solar panel being mounted flush against the surface of the enclosure and mounting the enclosure higher up would make it more inconspicuous. This would require slight modifications to the mounting point for each sensor in the enclosure. It would also mean the solar panel cannot be adjusted to the ideal angle for generating maximum power.

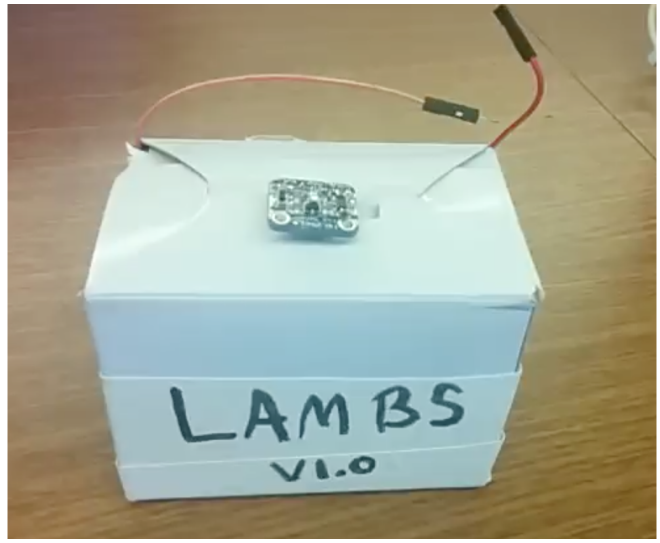

Figure 2. The initial LAMBS prototype.

Availability
Despite being advertised to have a long range and a high tolerance for interference, our experiences with the mDot and Conduit suggest that they may not be as robust as necessary in an outdoor urban environment. In testing the sending of a single packet from an endpoint to the gateway and receiving an acknowledgment back to the endpoint, we were able to reach a straight line distance of about 330 feet before we stopped receiving acknowledgments. The gateway was inside a building next to a window, and the endpoint was across a courtyard and around the corner of a different building relative to the same window. We speculate that better coverage can be achieved by using better antennas on the gateway and endpoint, placing the gateway antenna outside, and eliminating as much straight line interference as possible. At the same time, lower interference would mean fewer Conduits (gateways) are necessary to cover the city, further reducing the cost of the AoT system.

Compared to other public networks like Xfinity by Comcast, LoRaWAN is decentralized and is less subject to large scale outages. Xfinity requires more infrastructure to be maintained and requires an account to access the network. Meanwhile, a LoRaWAN based sensor network would be free to access (for now) and needs much less hardware to work. As a result, it is also easier to crowdsource an array of things connected through LoRaWAN.

FUTURE WORK
LoRaWAN could be made more effective if we changed particular design choices such as antenna size and placement. We could remove the Teensy microcontroller from LAMBS and use the mDot itself as the processor for the sensors. This could significantly lower cost since the mDot could serve multiple

Figure 3. The final LAMBS prototype enclosure mounted on a lamp post.

purposes and an entire microcontroller would be removed. Power consumption would also be lowered, but the mDot would not be able to take advantage of its standby mode because it would need to be constantly reading sensor data. We could also test the availability of the network when the Conduit antenna is outside of a building; the range may increase and therefore, reduce the number of gateways needed to cover a city. Due to restrictions from AT&T and GT-RNOC, we were not able to test the range of the network when the Conduit antenna were placed outside of a building. After gaining a better understanding of what kind of range a single gateway could handle, we could build and deploy more LAMBS within the vicinity of our singular gateway to begin moving towards an actual array of LAMBS devices. The LoRaWAN protocol is also still in its infancy and is being rapidly developed by the LoRa Alliance. Future revisions of the protocol and specification may increase the bandwidth and/or reduce the power consumption of end devices.

On the front end, an idea for an application that would use the raw data gathered from a LAMBS array would be to provide a "safest route" within a GPS application as opposed to the default "fastest route." The enclosure also presents a large opportunity for future work. Such an enclosure is not only beneficial to the Array of Things project, but could be used in many different applications where people or businesses want to mount electronics outdoors that need to be protected from the environment and potential thieves. Designing LAMBS with as few components that protrude outside the enclosure would hopefully make it appear to be as uninteresting as possible to pedestrians. Additionally, getting permission from the city of Atlanta or Georgia Tech Facilities could allow LAMBS to tap into the power grid. This would allow the system to entirely remove the renewable energy sources and battery system. Alternative energy sources such as wind or nuclear could also be considered to provide power to LAMBS in a variety of different conditions.

CONCLUSIONS

We created LAMBS to test the practicality of creating a city-wide sensor network that runs on LoRaWAN. Although it was inspired by the Chicago Array of Things project, our project aims to be more lightweight by taking advantage of the LoRaWAN range and low overhead for transmission. The power consumption and cost of our current prototype of LAMBS can be reduced by moving sensor and network logic from the Teensy microcontroller to the mDot itself. With or without this modification, the solar power setup on LAMBS is capable enough to handle power consumption for all components within the device while also providing the benefits of portability and sustainability. Despite the lower than expected results from testing the range of endpoints, we believe that further testing with placement of gateway antennas needs to be done to accurately estimate the effective service range of a single Conduit gateway. With realistic range estimations of LoRaWAN, more LAMBS endpoints could be created and deployed with the gateway that we already have. Eventually, we would end up with an array of LAMBS units transmitting raw data to a central location to be used for smart city applications.

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