10-2019

# Evaluation of Sigfox LPWAN for sensor-enabled homes to identify at risk community dwelling seniors

Crys TAN

Hwee-pink TAN
*Singapore Management University*, hptan@smu.edu.sg

## Citation

TAN, Crys and TAN, Hwee-pink. Evaluation of Sigfox LPWAN for sensor-enabled homes to identify at risk community dwelling seniors. (2019). *Proceedings of the 44th Annual IEEE Conference on Local Computer Networks, Osnabrueck, Germany, 2019 October 14-17*. 26-33.
**Available at:** https://ink.library.smu.edu.sg/sis_research/6868

# Evaluation of Sigfox LPWAN for sensor-enabled homes to identify at risk community dwelling seniors

Crys TAN
SMU-TCS iCity Lab
*School of Information Systems*
Singapore Management University
*Singapore*
Email: crys.nazo.tan@gmail.com

Hwee-Pink TAN
SMU-TCS iCity Lab
*School of Information Systems*
Singapore Management University
*Singapore*
Email: hptan@smu.edu.sg

***Abstract*—It is projected that Singapore will become superaged (where 20% of its population will comprise seniors) by 2025. Although various community programs are available to promote active ageing among seniors who are well, provide befriending services for seniors at risk of isolation and care and support for frail and vulnerable seniors, it is not easy to differentiate between 'well' seniors and 'at risk' seniors. While privacy-preserving z-wave based sensor-enabled homes have been piloted in 100 homes of seniors living alone and have been successful in the timely detection of at-risk seniors, they have limited scalability due to high costs, reliability issues and high maintenance needs. In this paper, we experimentally evaluate Sigfox-based sensor-enabled homes for detecting of at-risk seniors, benchmark our results against the incumbent system, and study the tradeoffs between battery lifespan and detection accuracy. From the evaluation, we observe that while maintaining a similar battery lifespan, the Sigfox-based system is able to match the accuracy in detecting at-risk seniors at a fraction of the cost of the incumbent sensor system.**

***Keywords—Sigfox, LPWAN, sensor-enabled homes, at risk community dwelling seniors, system costs, system lifespan***

## I. INTRODUCTION

Singapore is one of the most rapidly ageing nations in the world. In 1998, it became an ageing society, with 7% of its population comprising seniors (aged 65 and above). In less than 10 years, Singapore became an aged society, with seniors making up 14% of its population. It is projected that Singapore will become superaged (where 20% of its population will comprise seniors) by 2025.

With global shortages and rising costs of institutionalized resources and facilities for healthcare and eldercare, it is important for seniors to be able to age-in-place, where they can continue to live in their own home and community independently, safely and comfortably [1] without compromising their desire for independence, autonomy and privacy. This can be achieved by leveraging on (i) support from the community as well as (ii) technology.

In 2016, the government of Singapore introduced the Community Network for Seniors (CNS) initiative to support seniors in staying active, healthy, engaged and connected to needed health and social care. This is achieved through the **ABC** program as follows: (i) **Active ageing**: Encourage seniors who are well to stay active, healthy and socially engaged by participating in active ageing activities; (ii) **Befriending**: Connect seniors who are lonely or at risk of social isolation with befrienders or neighbor volunteers in their neighborhood and (iii) **Care and Support**: Ensure frail and vulnerable seniors get necessary health and social support services. With a successful pilot in three estates, CNS is expected to reach nationwide coverage by 2020 [2].

The increasing pervasiveness of sensor, communication and computing technologies, as well as data science, enables the (i) continuous and passive monitoring of day-to-day activities of seniors, both within and out of the home and (ii) sense-making for intelligent detection and notification of anomalous events so that affected seniors can benefit from the ABC program. Examples of such events include prolonged inactivity at home, prolonged inactivity of main door, and reduced level of participation in active ageing activities, to name a few.

SHINESeniors [3] investigated the actual use of sensor-enabled homes to enable senior Singaporeans who live alone to age-in-place in the community. Each home (typically a one-bedroom apartment) is instrumented with commercially off-the-shelf and battery-powered wireless sensor devices as well as a mains-powered gateway. The sensor devices include z-wave [4] enabled passive infrared (PIR) motion sensors in each zone of the home and a contact sensor at the main door. The gateway receives data from the sensor devices via a z-wave dongle, aggregates the data, and sends it to the cloud-based server via a 3G dongle. This setup is shown in Figure 1.

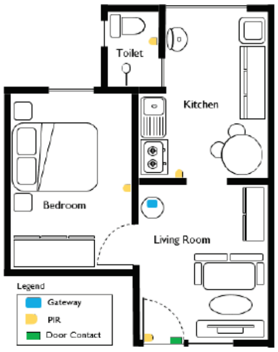
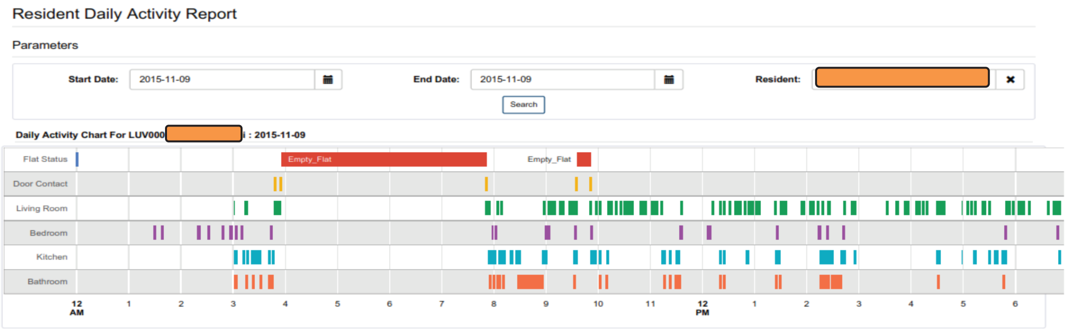


*Fig. 1: Deployment of sensor-enabled home in SHINESeniors*



Resident Daily Activity Report

Parameters

Start Date: 2015-11-09

End Date: 2015-11-09

Resident: [redacted]

Daily Activity Chart For LUV000[redacted]i : 2015-11-09

Fig. 2: Resident Daily Activity Report

Based on raw sensor data captured by the setup shown in Fig. 1, we can understand the daily activity pattern of the senior as illustrated in Figure 2. Each vertical bar within each row indicates motion detected in that location at a specific time. Analysis of this data from 100 community dwelling seniors, alongside psychosocial survey data as well as ad-hoc observations made during home visits, enables a holistic study that address the: (i) immediate and personal safety needs of the senior (reactive care); (ii) long-term health and social needs of the senior (preventive care); and (iii) technology-centric and care-centric challenges for sustainable technology-enabled community eldercare [5]. In relation to the ABC program, the sensor-enabled homes in SHINESeniors can help community caregivers to identify seniors who may be at risk of social isolation [6], depression [7], frailty [8] or poor sleep quality [9] so that befriending or care and support (which we collectively refer to as caregiving for the rest of the paper) can be triggered respectively.

Despite the potential value of sensor-enabled homes, there are current challenges to scale-up from 100 homes to nationwide scale of at least 40,000 homes (representing seniors living alone in Singapore). These challenges include:

*1)* **Set-up and operating costs:** We adopted a Capital Expense (CAPEX) model for the deployment of sensor-enabled homes, where sensor devices, gateway devices, cloud services and mobile data plans are procured separately. As the seniors in our project do not have home broadband subscription, a monthly recurring cost (about $10) per home is incurred. Also, the z-wave components are costly as z-wave is a proprietary low-power, short-range wireless communications standard specifically developed for smart homes,

*2)* **Reliability:** Our deployment is dependent on the gateway to receive data from each sensor device, aggregate the data and transmit the data via 3G to our cloud server. However, as our seniors are mostly in the low/no income group, they sometimes turn off the gateway to save electricity (and hence utility bills), resulting in loss of data,

*3)* **Maintenance needs:** The sensor devices are battery-powered as they need to be deployed according to where the senior is likely to be at, or at the main door, where there may not be mains-power nearby. When the battery level falls below a certain threshold, they need to be replaced – this is costly, and may also introduce inconvenience to the seniors as access into their homes is needed. Based on actual maintenance data from SHINESeniors, the distribution of the lifespan of z-wave motion sensors (i.e., number of days between successive battery replacements) is plotted in Figure 3. The average lifespan of each motion sensor is about 300 days (10 months), and most of them have a lifespan exceeding 240 days (8 months).

However, with the maturing and availability of Low Power Wide Area Network (LPWAN) technologies [10] such as Sigfox, LoRaWAN and NB-IoT, it is now possible to address some of the gaps listed above. In particular, with the operator model for Sigfox and NB-IoT, we can potentially achieve savings in cost as well as maintenance needs while improving reliability, as there is no longer a need to deploy a mains-powered gateway in each home.

In this paper, we evaluate the performance of Sigfox-powered sensor-enabled homes to support the befriending aspects of community network for seniors, based on real experiments as well as simulations. In Section II, we present related work on Sigfox LPWAN applications. In Section III, we present our methodology for the evaluation. Preliminary results and discussions are presented in Section IV, and we present our conclusions and outline future work in Section V.

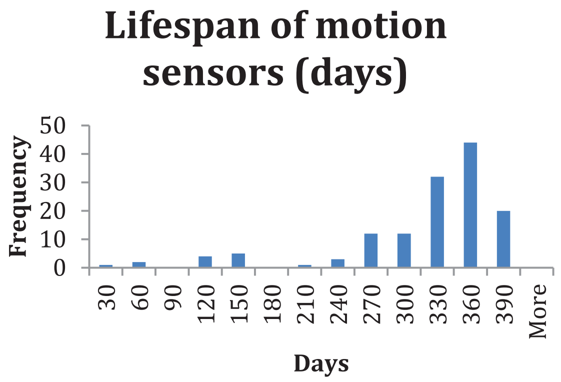


Fig. 3: Battery lifespan of deployed motion sensors in the SHINESeniors project

## II. RELATED WORK

Among various LPWAN technologies, Sigfox, LoRaWAN and NB-IoT are the most promising [10]. Operating in unlicensed spectrum, the Sigfox technology was developed in 2010, while LoRa was standardized in 2015. On the other hand, NB-IoT was standardized by 3GPP, where its specifications were published in June 2016. As Sigfox has the richest sensor device ecosystem at present, we decided to explore and evaluate Sigfox LPWAN for our eldercare application. However, to the best of our knowledge, literature on the large scale deployment and evaluation of Sigfox applications is scarce.

In [11], the authors designed a Sigfox-based drifter with a kinetic energy harvester to be deployed at coastal areas to provide information of the surface currents for a long period, and evaluated its power consumption in different modes of operation. In [12], the authors presented an analytical model that characterizes device current consumption, device lifetime and energy cost of data delivery with Sigfox, based on measurements carried out on a real Sigfox hardware module. Evaluation results show that the considered Sigfox device, powered by a 2400 mAh battery, can achieve a theoretical lifespan of 1.5 or 2.5 years while sending one message every 10 minutes at 100 bit/s or 600 bit/s, respectively, and an asymptotic lifespan of 14.6 years as the message transmission rate decreases.

## III. SYSTEM DESCRIPTION AND EVALUATION

In this section, we discuss the requirements, design consideration and evaluation methodology for a LPWAN-based in-home sensor system that can potentially address the cost, reliability and maintenance challenges identified in Section I.

### *A. Sensing Requirements*

With reference to the SHINESeniors set up in Figure 1, each battery-powered PIR motion sensor has two slots in it, where each slot is made of a special material that is sensitive to IR within a sensing area that spans approximately 120 degrees up to a distance of 5m. When the sensor is idle, both slots detect the same amount of IR, the ambient amount radiated from the room or walls. When a warm body such as a human or animal passes by the sensing area, it first intercepts one half of the PIR sensor, which causes a positive differential change between the two halves. When the warm body leaves the sensing area, the reverse happens, whereby the sensor generates a negative differential change. These change pulses are detected as a motion event.

On the other hand, each battery-powered contact sensor comes in two parts. As the main door is typically hinged on the side, the smaller piece (magnet) will be attached either along the top edge or the non-hinged side of the door. The larger piece containing the battery and reed switch (sensor) is fixed onto the wall so that it is adjacent to the magnet when the door is closed, activating the reed switch and generating a door closed event. As soon as the magnet separates from the sensor as a result of door opening, an internal reed switch inside the sensor trips, generating a door open event. Figure 4 illustrates an actual installation of a door contact sensor and motion sensor in the living room in SHINESeniors.

Working on the challenges faced in the SHINESeniors project, we appreciate that there is a requirement to bring down the costs and maintenance needs while upholding the reliability of the sensor setup in the home to aid in scaling the project nationwide. To do so would require us to rethink the minimum sensor setup, from which the data can help us determine whether the senior is lonely and at risk of social isolation. To that end, we conducted interviews with caregivers involved in the CNS program, and learnt that the proportion of time the senior spends out of home and the frequency with which a senior leaves his home are good proxies for triggering the befriending program.

*Fig. 4: Actual deployment of door contact sensor (left, red arrow) and living room PIR motion sensor (right, red arrow) in the SHINESeniors project*

With reference to Figure 1, we note that whenever the senior leaves /arrives home, the last/first sensors to be triggered are the living room motion sensor and the door contact sensor. With this pair of sensors alone, we will be able to accurately estimate the above proxies. This represents an important first step towards cost reduction compared to the SHINESeniors setup in Figure 1.

### *B. Connectivity options*

Given the sensing requirements, we first identify the limitations in reusing the SHINESeniors' z-wave based setup, and then justify and describe our proposed Sigfox-based setup.

#### *1) Z-wave based setup*

The reduced setup from the original SHINESeniors configuration will comprise battery-powered PIR motion sensor [13] and door contact sensor [14] from Aeotec, as well as a mains-powered gateway implemented using the Raspberry Pi 3 Model B embedded platform [15]. The sensors transmit their data to the gateway via the proprietary z-wave protocol, which is optimized for short-range (20 to 30m) communications. In addition to a z-wave dongle, a 3G dongle is also attached to the gateway to transmit data to our cloud backend.

Although the Aeotec MultiSensor 6 [13] is able to read motion, temperature, humidity, light, ultraviolet light and vibration changes, only the motion detection functionality is enabled for battery efficiency reasons. To further conserve battery, the Aeotec MultiSensor 6 also employs smart processing in motion detection in the following ways: Whenever motion is detected, a value of '255' is transmitted and a timer is activated; if motion is detected within this interval, the timer is reset; else, a value of '0' is transmitted. In the SHINESeniors project, the timer is set at 4 minutes.

### 2) Sigfox-based setup

Despite the reduction in setup cost and the positive experience with the z-wave based system, the challenges of high operating costs, reliability issues, as well as maintenance needs, as described in Section I, remain. However, some of the challenges may be addressed with a LPWAN-based approach with Sigfox, LoRaWAN or NB-IoT.

Among the above options, we decided on the operator models provided by Sigfox and NB-IoT as the maintenance requirements will be lower compared to LoRaWAN, where apart from the in-home sensor devices, LoRa gateways need to be deployed and maintained.

Between Sigfox and NB-IoT, the Sigfox communication protocol was released in 2009 [16], while the NB-IoT protocol standards [17] were only released in June 2016. In fact, in February 2017, UnaBiz, the exclusive licensed Sigfox network operator in Singapore and Taiwan, became fully operational to deliver commercial grade connectivity and services for IoT in the city-state, starting from as low as S$1 per device per year. At the time of our study, Sigfox boasts a richer device ecosystem (in terms of end sensor devices) as compared to NB-IoT, whose pricing model in Singapore remains unavailable. As such, we decided to evaluate the Sigfox-based system and evaluate its efficacy in addressing the impending challenges with the z-wave solution.

## C. Sigfox-based sSystem Description

The Sigfox-based system for each home comprises a UnaMotion sensor as well as a UnaProtect sensor [18] as illustrated in Figure 5. The UnaMotion sensor was placed above the main door, and will capture any motion inside the home at the vicinity of the door. The UnaProtect (door contact) sensor was placed on the side of the door, capturing all door open and close events.

The UnaMotion sensor is configured to transmit a reading of 201 once motion is detected within its range, together with the device ID, timestamp, sequence number and link quality. During transmission, it does not scan for motion. Once the transmission is complete, it starts scanning for motion again. Based on the manufacturer's tests, the sensor sleep period between transmissions is approximately 5 seconds by default. The UnaProtect door contact sensor sends a reading of either 201 or 202 corresponding to a 'door open' or 'door close' event respectively. Together with this event reading, there is a device ID, timestamp, sequence number and link quality.

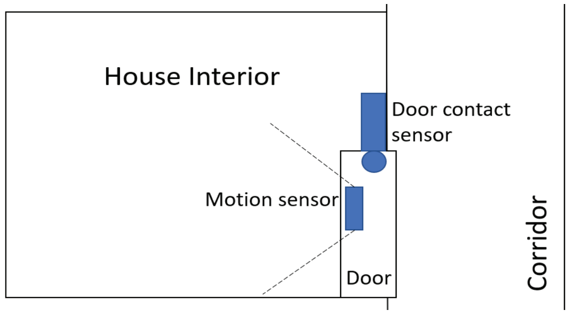


*Fig. 5: Sigfox-based Sensor placement*

Due to the positioning of the sensors, both the Sigfox sensors as well as the Aeotec sensors are powered by batteries. The Aeotec sensors use a CR123A lithium battery as compared to the AAA alkaline batteries used by the Sigfox sensors. Based on the data provided from the SHINESeniors project, the average lifespan of the Aeotec sensors is about 300 days, with a standard deviation of 73 days. The manufacturer for the Unabiz sensor has predicted a 2-year (730 days) lifespan for their sensors based on normal use, though this is yet to be verified.

Both the UnaMotion sensors and Aeotect sensors allow tuning of the duration between transmissions of motion detected for battery saving purposes; however, the tradeoff for doing so is potential missed event detections. The UnaMotion sensors default at 0 seconds, and the Aeotec sensors default at 4 minutes.

In addition, although Unabiz has deployed Sigfox base stations and has achieved 95% outdoor coverage islandwide in Singapore (based on drive tests), the coverage at specific locations (e.g., residential homes where we deployed our sensors) is yet to be evaluated.

## D. Performance Evaluation

In this paper, we evaluate the Sigfox-based in-home sensor setup in two aspects: (i) projected battery life of the UnaMotion sensor and (ii) reliability and accuracy in detecting events that can help us determine whether a senior is at risk of social isolation, so that the befriending program can be triggered in a timely manner. The average lifespan of the Aeotec sensor (300 days) will be used to benchmark the UnaMotion sensor, while we evaluate if the resulting accuracy in event detection is within an acceptable range.

We conducted this study using a mix of experimental (Phase 1) and simulated approaches (Phase 2), which will be described next.

### 1) Experimental Study

The Sigfox-based system was installed in the homes of two existing research participants of the SHINESeniors project, MP0012 and MP0055. This means that the SHINESeniors setup in Figure 1 is still active and collecting data from these homes, which can provide useful ground truth to our study.

Both research subjects are male, married, unemployed and staying alone. MP0012 is in his 70s, while MP0055 is in his 80s. During the installation of the Sigfox system, fresh AAA batteries and default sensor settings were used. The data collection experiment would continue until the battery of either sensor ran flat. This is the time instance when no new sensor readings was received by the Sigfox server despite movement being detected by the Aeotec motion sensor deployed in the living room.

According to the manufacturer, this should represent a utilization of 10,000 sensor readings sent. However, in the case of MP0012, 6,658 readings were received over 14 days and 5 hours, while 7,606 readings were received from MP0055 over 40 days and 14 hours. This difference in battery lifespan can be attributed to a difference in activity patterns between the two seniors. As illustrated in Figure 6, MP0012 is quite active in the living room, even at night, resulting in more motion sensor readings on average each day, thus reducing the battery lifespan. The number of readings fall short of the 10,000 as indicated by the manufacturer due to external factors such as intermittent poor connectivity between the sensors and the nearest Sigfox base station(s). As

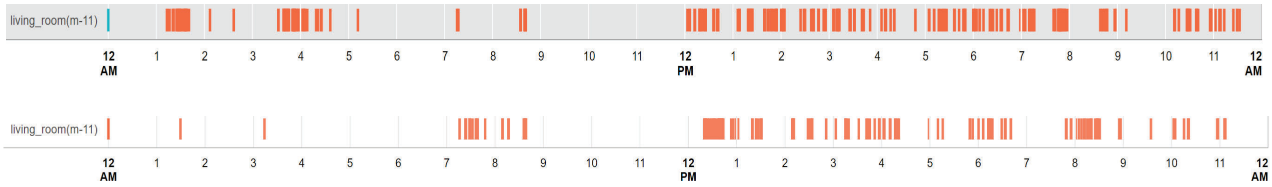


*Figure 6 Typical lifestyle pattern of MP0012 (above) and MP0055 (below)*

external factors are difficult to control, we will use 7,500 readings, which is 75% of the manufacturer's ideal-case lifespan, for our simulations in the second phase as it is closer to the experimental data we have collected.

With the collected data, we formulate the ground truth of the lifestyle of our seniors. A custom script is formulated to translate the sensor readings to a second-by-second simulation of the senior in his abode. The script works by storing a binary state in memory (home / away) and writes that state into a file for every second of time of the experiment period. The binary state changes depending on the sensor reading read by the file, according to the following rules:

i. When a 'door close' event is detected, change state from 'home' to 'away'. Set a flag to indicate that the senior has left home and store the time.
ii. When a 'door open' event is detected, clear the flag.
iii. When motion is detected, set the state to 'home'.
    - If the flag is not cleared, backtrack to that time and rewrite 'away' state to 'home'.

The output file generated by this script is a binary equivalent of the senior's activity (home or away) for the period of the experimental study. For the purpose of this paper, this will be known as the *Life* file.

### 2) Simulation Study

Next, we proceed with the simulation study. To begin, a first script is written to compute, based on the lifestyle pattern, the proportion of awake time that the senior spends in the living room near the main door – henceforth known as the **detection zone**. From Figure 6, we noticed that MP0012 does not have any patterns of long periods away from the detection zone. On the other hand, MP0055 seems to be asleep in his bedroom between 10pm and 7am, and this period of time will be excluded from the awake time.

A second script is then run on the *Life* file to generate sensor readings. This second script simulates a sensor overseeing the senior based on his *Life* file, with the sleep period between scans of the sensor as a variable in the script.

The script stores a binary state of whether the motion sensor is in 'sleep' and does not scan for motion. When the sensor is not in sleep, if the state of the senior is 'home', it will write a sensor reading and sleep for $x$ seconds depending on the experiment variable. If the state of the senior is 'away', it will advance to the next second in time and continue reading the next state of the senior. This step repeats itself until the end of the file, which represents the end of the experimental data.

The purpose of this script is to determine the number of sensor readings generated during the period of the experimental study, from which we are then able to extrapolate the expected lifespan of the sensor based on an estimated 7,500 transmissions per fresh set of batteries in the sensor. This is obtained using the following equation:

$$L = \frac{R}{x.p} \, .d$$

where

$L$ = lifespan

$R$ = Maximum number of readings by sensor

$x$ = number of generated sensor readings per day

$p$ = proximity factor

$d$ = days of data parsed

We first divide the number of sensor readings generated by the simulated sensor by the number of days of data that it is parsing to get a value for the number of transmitted readings in any given day. This value is then multiplied by the proximity factor, which is the amount of time that the senior spends in the detection zone. We then divide the maximum number of sensor readings (7,500) by this calculated value. Finally, this sum is multiplied by the number of days of data parsed in the simulation to obtain the projected lifespan.

### 3) Accuracy of detecting at-risk seniors

Apart from sensor lifespan, accuracy of the sensor in determining whether the senior is home is equally important in this study. In theory, the generated *Life* file from the sensor should be the same, and any difference would be due to the sensor's sleep period not capturing the senior at the moment he left home.

Calculations for accuracy are done by doing a comparison of the 2 generated *Life* files- the first of which was generated by the original sensor readings collected (ground truth); the second of which is generated by the simulated sensor readings given a pre-determined sleep period.

In more detail, a script is run that does a character by character comparison of the 2 *Life* files that it is reading. It returns a percentage for the amount of similarities between both files. This forms the accuracy of the new sensor compared to the original data that was collected. A simple formula of (number of seconds where state differs between files / number of seconds scanned) is used to determine the accuracy associated with the new sensor sleep time.

## IV. PRELIMINARY RESULTS AND DISCUSSIONS

### A. Accuracy vs Lifespan

The more frequently the sensor senses and transmits readings, the more accurate the sensor readings and the shorter the lifespan of the sensor. As such, the focus of the study is to determine the optimal sleep period of the sensor between scans to maximize its lifespan with minimal compromise to its accuracy. The simulation results obtained from the experimental data from MP0012 and MP0055 are shown in Figure 7 and 8 respectively.

We first consider MP0012. In Figure 7, we see that the accuracy of the sensor is approximately linearly negatively correlated to the lifespan of the sensor. Since the manufacturer used sensor transmissions as a determinant unit for its lifespan, we surmised that it is likely that the battery of the sensor is mainly used during sensing and transmission, and that in an idle state, the battery life should not fall significantly.

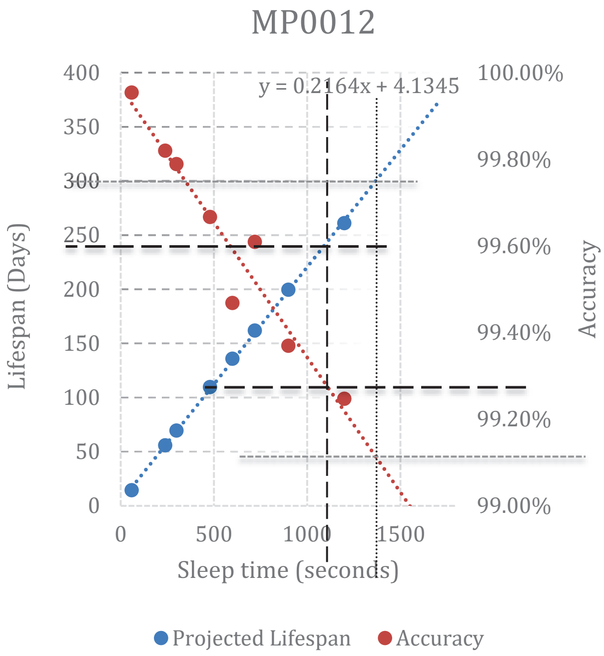


*Figure 7 MP0012 Data*

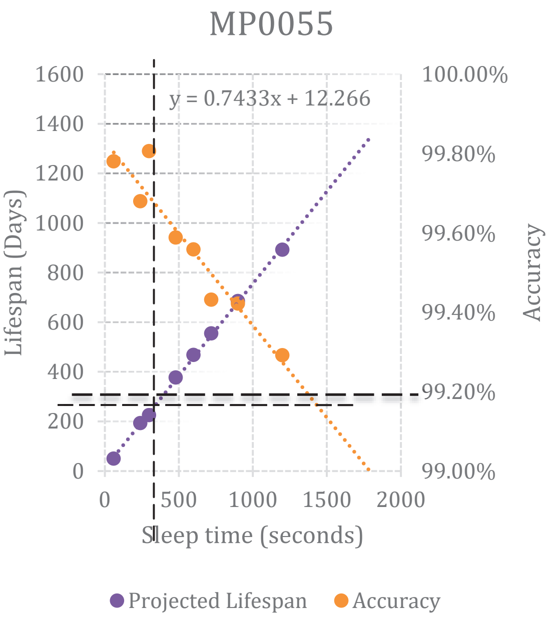


*Figure 8 MP0055 Data*

We verify this against the data from MP0055 (c.f., Figure 8), and see that it too follows a linear negative correlation. Within the range of sleep time we have used, it seems that the accuracy as well follows a linear trend.

To achieve a target lifespan of 240 days, the sleep period of the sensors in the home of MP0012 should be set at 1,100 seconds that provides an accuracy of 99.3%. With MP0055, the same lifespan can be achieved with a sleep period of 310 seconds, providing an accuracy of approximately 99.7%.

By setting the sleep period to be 1,350 seconds and 390 seconds, the sensors can achieve a lifespan of 300 days (which is the average lifespan of the Aeotec sensor in the SHINESeniors deployment) with accuracy of 99.16% and 99.6% for MP0012 and MP0055 respectively.

In considering the accuracy tradeoff, we need to understand the use case that the sensor is deployed, as well as the impact of inaccuracy of the results. The sensors deployed serve to detect when the senior has left home, which is in turn used as a proxy for whether the senior is at risk of social isolation. This allows the community befrienders to prioritize their visits for seniors under their care who are at risk.

To this end, it stands that the ability of this sensor to achieve an accuracy >99% is reasonable. Further experimentation would likely be required to understand the minimal accuracy required to get data that is sufficiently actionable, yet allowing for maximal sensor lifespan.

### *B. Optimal Sleep Time*

We define the optimal sleep time as the number of seconds that the sensor stops scanning between sensor reads, so as to maximize its lifespan with a minimal loss in accuracy. In the SHINESeniors setup, the motions sensors sent results to the gateway, which in turn pushed readings every 4 minutes or longer to prevent excessive data transmissions. This was sufficiently accurate in detecting the movements of the seniors.

However, by observing Figure 7 and 8, we notice that the optimal sleep time differs quite significantly between both seniors. This can be attributed to different patterns of living observed, a factor that was not explored significantly in the SHINESeniors project,

In Figure 6, we show an average day in the life of MP0012 and MP0055. In the figure, each colored line is an indication that the senior is in the vicinity and the sensor sends a reading. We see that MP0012 spends much more time around the living room compared to MP0055, and this causes the sensor to be more active in comparison and thus send more data. From our calculations, we estimate that senior MP0012 spends 41% of the time at home in the sensor detection zone. In comparison, MP0055 spends only 18% of the time in it.

The effects of this proximity is observed in the lifespan graphs in Figure 7 and 8 - The sensor lifespan of MP0055 is approximately 3 times longer than that of MP0012, given the same sensor sleep period.

We originally aimed to find a general optimal sleep period of the motion sensor for the seniors that would allow for sufficiently accurate readings while maximizing the time between maintenance visits for the sensors; instead, we realized that the proximity factor of the senior- that serves as a proxy of his lifestyle- affects the optimal sleep period quite significantly.

It might instead make more sense to segment the seniors into various groups with an approximately equal proximity, and derive optimal sleep times for each group. This might mean, for example, to put in separate groups those who like to spend the bulk of the time in the living room, those who spend much of their time out of home and those who spend more time at home but not near the living area.

With 3 groups of roughly more closely related proximity factors, we would be able to use better sleep periods on the sensors that would allow for maximal sensor uptime with minimal accuracy loss.

### C. Sigfox vs Z-wave sensors

The experiment set out to explore the use of Sigfox sensors as a lower cost alternative to z-wave sensors for deployment in the homes of seniors living alone. The main considerations were the asset cost, reliability of data as well as operational cost of maintenance. The Sigfox setup inherently has a relatively lower cost due to the longer transmission distance allowing for far fewer base stations required.

In addition, the Aeotec z-wave sensors deployed in the SHINESenior project use the CR123A battery, a relatively expensive battery that is not commonly found. In comparison, the Sigfox sensor uses AAA batteries, which are cheaper and easily obtainable.

For maintenance cost, the ease of battery replacements might also be a factor for self-managed sensors in the future, where the seniors or caregivers are able to assist in the change of battery instead of having a dedicated maintenance team heading to the seniors' homes for simple battery replacements. Furthermore, the Sigfox base stations are managed by the Sigfox service provider via an Infrastructure-as-a-Service model, and hence, signal strength and stability are assured under those terms.

From the evaluation, we observe that with some tuning, while maintaining a similar lifespan, the Sigfox sensors are able to match readings provided by the z-wave sensors more than 99% of the time (i.e., for accuracy considerations), at a fraction of the cost.

### D. Known limitations

In the current study, the details of power consumption have not been considered as we relied on the power lifespan given by the service provider, which is solely based on transmissions. Future studies more focused on power consumption of the sensor would allow for a more comprehensive calculation of optimal sensor usage.

For example, the deployed Sigfox sensors were running at constant scanning mode, where power consumption due to scanning without transmission was assumed to be negligible. This might not be valid for user groups that have a low proximity factor, and further experiments are needed to investigate this. In addition, the sensor sleep period where there is (theoretically) no scanning and hence may result in potentially lower power consumption should be considered.

The sensor transmission in itself may have a different power consumption depending on the proximity of the sensor to the base station. While this could be ignored in this study since both seniors live in the same district, it should be considered for subsequent deployments in different areas.

Lastly, while the study enabled us to understand ideal sleep periods for other seniors that have similar living patterns as these 2 seniors, the results may not be generalizable to the population.

## V. CONCLUSIONS AND FUTURE WORK

In this paper, we evaluate the performance of Sigfox-powered sensor-enabled homes to support the befriending of community dwelling seniors living alone, based on real experiments as well as simulations.

Based on real data obtained from sensor deployment in the homes of two seniors, we conducted a simulation study and observed that the amount of time the senior spent in proximity to the sensor affects the number of readings taken and transmitted, thereby affecting the lifespan of the sensor.

From the evaluation, we observed that while maintaining a similar lifespan, the Sigfox sensors were able to match the accuracy in detecting whether the senior is at home at a fraction of the cost of the incumbent z-wave sensor system. In addition, the results indicate that different seniors with different lifestyles would likely require different sensor sleep periods to determine accurately whether he is home, while maximizing the sensor's lifespan.

Ongoing and future work involves (i) taking into consideration details of power consumption and (ii) scaling up the study to collect real data from more homes over a longer duration to validate and extend the results to a broader group of seniors.

## REFERENCES

[1] Farber, N. et al. (2011), 'Aging in Place: A State Survey of Livability Policies and Practices', paper presented at National Conference of State Legislatures, AARP Public Policy Institute, December.

[2] Toh, Y. (2019). ''Singapore Budget 2018: Support network for seniors to be expanded', assessed on 4 April 2019 at https://www.straitstimes.com/politics/support-network-for-seniors-to-be-expanded.

[3] N. Goonawardene, Pius Lee, Hwee-Xian Tan, Alvin Valera and H. P. Tan, "Technologies for Ageing-in-Place: The Singapore Context", Living in Smart Cities, World Scientific, January 2018.

[4] https://www.z-wave.com/

[5] A. Valera, P. Lee, H. P. Tan, H. X. Tan and H. Liang, "Real World, Large Scale IoT Systems for Community Eldercare: Experiences and Lessons Learned", Elderly Care: Options, Challenges and Trends, Nova Publishers, Q2, 2018.

[6] N. Goonawardene, X. Toh and H. P. Tan, "Sensor-Driven Detection of Social Isolation in Community-Dwelling Elderly", HCI International, July 2017.

[7] J. Ou, H. Liang and H. X. Tan, "Identifying Elderlies at Risk of Becoming More Depressed with Internet-of-Things", HCI International 2018.

[8] N. Goonawardene, H. P. Tan and L. B. Tan, "Unobtrusive Detection of Frailty in Older Adults", HCI International 2018.

[9] X. Ma, N. Goonawardene and H. P. Tan, "Identifying Elderly with Poor Sleep Quality using Unobtrusive In-Home Sensors for Early Intervention", ACM GOODTECHS 2018, November 2018.

[10] Mekki, K., E. Bajic, F. Chaxel and F. Meyer (2019), ‘A comparative study of LPWAN technologies for large-scale IoT deployment’, Elsevier ICT Express, Vol 5 (1), pp 1-7, March.

[11] Carandell, M., D. Mihai, J. Rio, K. Ganchev and J. Peudennier (2018), “Evaluation of Sigfox LPWAN technology for autonomous sensors in coastal applications”, Marine Technology Workshop, 10-11 December.

[12] Gomez, C., J. C. Veras, R. Vidal, L. Casals and J. Paradells (2019), “A Sigfox Energy Consumption Model”, MDPI Sensors Journal, Vol 19 (3), 7 February.

[13] Aeotec Multisensor 6 basic manual at https://www.vesternet.com/mwdownloads/download/link/id/1882/

[14] Aeotec Door/Window Sensor Gen5 at https://aeotec.com/z-wave-door-window-sensor

[15] The Raspberry Pi 3 Model B at https://www.raspberrypi.org/products/raspberry-pi-3-model-b/

[16] https://www.sigfox.com/en

[17]https://www.gsma.com/iot/narrow-band-internet-of-things-nb-iot/

[18] https://www.unabiz.com/solutions/unasensors/