LoRattle - An Exploratory Game with a Purpose Using LoRa and IoT

Marko Radeta[1](✉), Miguel Ribeiro[2], Dinarte Vasconcelos[2], and Nuno Jardim Nunes[2]

[1] ITI/LARSyS, Universidade da Madeira, Tigerwhale, Funchal, Portugal
marko.radeta@m-iti.org
[2] ITI/LARSyS, Instituto Superior Técnico, Lisbon, Portugal
{jose.miguel.ribeiro,dinarte.vasconcelos,nunojnunes}@tecnico.ulisboa.pt
https://iti.larsys.pt
https://tecnico.ulisboa.pt/

Abstract. The Internet of Things (IoT) is opening new possibilities for sensing, monitoring and actuating in urban environments. They support a shift to a hybrid network of humans and things collaborating in production, transmission and processing of data through low-cost and low power devices connected via long-range (LoRa) wide area networks (WAN). This paper describes a 2-player duel game based on IoT controllers and LoRa radio communication protocol. Here we report on the main evaluation dimensions of this new design space for games, namely: (i) game usability (SUS) leading to an above average score; (ii) affective states of the players (SAM) depicting pleasant and engaging gameplay, while players retain control; (iii) radio coverage perception (RCP) showing that most participants did not change their perception of the radio distance after playing. Finally, we discuss the findings and propose future interactive applications to take advantage of this design space.

Keywords: LoRa · Internet of Things · Tangible User Interfaces · Games with a purpose · Ubiquitous computing · Radio coverage

1 Introduction

Technologies like the Internet of Things (IoT), long-range (LoRa) wide areas networks (WAN) and tangible user interfaces (TUI) are opening new design possibilities in domains from home-automation to urban environments, industry 4.0 and precision agriculture. Mostly titled "smart" applications these range from smart-houses to smart-grids, smart-cities, smart-retails and smart-supply-chain among many others. Generally, they offer the ability to measure, infer and understand environmental indicators, from delicate ecologies and natural resources to urban environments. A critical component of IoT platforms is the evolution of the Internet into a networked of interconnected objects uniquely

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addressable based on standard communication platforms. This is a radical evolution of the current Internet but also potentially a change in how we as users and citizens understand the environment around us. When new technologies undergo widespread popularization, it is frequently an exciting opportunity to address open questions about the topic and its broader implications.

While HCI communities and citizen scientists are turning towards IoT and ubiquitous computing technologies [12], interactive applications based on IoT and long-range wireless communication remain greatly unexplored. In this study, we make a contribution into this new design space through a game with a purpose (GWAP), which was used to both study how people perceive these new technologies, as well as to explore how they could drive new interactive applications and games that span to the physical world around us taking advantage of IoT and LoRa technologies.

1.1 Study Motivation and Contributions

The main motivation behind our work is to explore the possibilities provided by IoT platforms and long-range communication protocols to support novel interactions. As these technologies become widespread new applications will move beyond personal devices into tangible computing devices based on IoT technologies and long distance communication. For this purpose, we test these new conditions with a GWAP which also serves to measure the performance of the game using the LoRa protocol and impact the knowledge of wide area network communication. Our study contributions are threefold: (i) we design and implement the first GWAP using LoRa and IoT devices, acting as a tangible user interface (TUI); (ii) using the provided apparatus, we study what kind of novel interactions emerge when exposing the participants to such technologies; and (iii) we perform the user study with these participants. With these motivations and contributions in mind, in this study we provide insights into the following research questions:

- **[RQ1].** How IoT and LoRa combined can be used for GWAP and entertainment?
  In proposed GWAP, we study the feasibility to crowdsource the LoRa radio coverage using the game participants as an alternative tool to outline the limitations of LoRa signal strength. We collect the Received Strength Indicator (RSSI) between two players.
- **[RQ2].** Which novel interactions emerge from such technologies?
  In this question, we study how participants will actually play the game. We observe whether they will play it indoor or outdoor setting, and if they will be hindering the signal to protect themselves, or exploring the greater distance by using it.
- **[RQ3].** How user perceive such GWAPs?
  Using usability and affective scales, we study the players' difficulties and engagement in such game. Moreover, we observe whether or not the radio coverage perception would significatelly increase after participating LoRa-based game.

2 Related Work

In this section, we describe the state of the art in IoT and usage of LoRa protocols in HCI (Sect. 2.1), suggesting the need for their coupling. Also, to raise awareness of the game and HCI communities about the potential of LoRa technology we provide an outline of this new standard, its potential and limitations (Sect. 2.2). Finally, we analyze the potential of IoT devices connected via LoRa to be used as Tangible User Interfaces (TUIs), in particular when applied in real-world gaming settings (Sect. 2.3).

2.1 Towards Interactive IoT on LoRa

In general, IoT's main drive is to "do more with less" [6] and its main focus is to enable the communication between devices while impacting the memory usage, processing power, bandwidth, and energy consumption. Previous work discussed the guidelines for embedding IoT interfaces in daily routines [20]. Others investigated the social side of the IoT [5], using social networking as a metaphor to provide solutions to mechanical problems. Interactive IoT embedded devices offer sophisticated methods to provide users with services to make use of the information and to interact with objects in the real world. Also, some scholars used identification radio technology for interactive purposes [16,26]. However, to the best of our knowledge the work described here is the first to explore long-range IoT protocols for interactive communication and gameplay. However, high-frequency radio communication is commonly used for many interactive devices such as gamepads, wireless mice and keyboards. Other interactive experiences supporting virtual reality use headsets, motion-capture devices, gloves and other engaging simulators [14]. In this case, motion capture devices use technology based on infrared waves and LEDs discreetly mounted around the perimeters of a display. Conversely, these systems have disadvantages, as they require highly specialized and expensive hardware/software (e.g. simulators or virtual reality environments). Also, in some games, impaired users may have difficulties actually allocating the specific information [15].

Finally, these devices are outside of the industrial, scientific and medical (ISM) radio bands assigned to the open radio spectrum. LoRa belongs to ISM using frequencies surrounding 868 MHz in Europe. Moreover, most other devices are still dependent on the physical connection and wiring with the gaming console and/or computer. Popular devices, such as the Wii Remote or PlayStation Move, were developed to improve the interaction between the user and game consoles, reducing the needs for cumbersome wiring. Work reported by Wilson et al. [30] used handheld pointing devices (using Bluetooth radio communication) for interaction. However, most of these devices have a high cost and are limited as participants have to remain in a predetermined physical space or to be constrained with additional wiring. LoRa is not just the solution to battery autonomy but it also challenges traditional communication methods (Bluetooth, wi-fi, etc). This study depicts more opportunities how LoRa can be brought to entertainment (opening new doors) and how it can overcome aforementioned limitations.

2.2 Brief Overview of LoRa for Game and HCI Communities

The growing widespread availability of IoT deployments is leading to an emergence of long-range communication protocols, which comply with the requirement of IoT platforms (wide area connectivity, low power consumption, and low data rate). Among the most popular are Low-Power Wide Area Networks (LPWANs) which offers radio coverage over large geographical areas. LP-WANs can have a range greater than 1000 m [6], and use base stations with adaptive transmission rates, transmission power, modulation, duty cycles, with two ultimate goals: (i) to keep very low energy consumption and (ii) to allow more end-devices to be connected. Between Sigfox and Weightless, LoRa is one of the LPWAN candidate protocols which use low-cost transceivers (with features not available for the majority of IoT applications [9]). They contain embedded crystals, which do not need to be manufactured to perform the extreme accuracy [6]. This makes LoRa a well-situated protagonist for low-power and long-range transmissions [6] and its' modulation is capable of extracting the data from weak signals found in noisy environments.

However, the features of LoRa come at the cost of important constraints: (i) maximum payload size (maximum 256 bytes, including the header); (ii) Bandwidth (BW 125 kHz, 250 kHz or 500 kHz); (iii) Spreading Factors (SF from 7 to 12, where the lower number has less time on air) [1]; (iv) number of channels (which are carefully designed to minimize the probability of collisions, while offering a quick alternative channel for nodes to retransmit the collided packets) [8]; and (v) maximum distance (which varies from urban to landscape to sea settings). Other limitations include the size of the network [21], reliability caused by the type of applications [2], throughput [1], etc. LoRa is certainly not ideal for every application scenario. Each network protocols have their pros and cons. Cellular networks provide high throughput and range, high power and high cost. Wi-Fi provides a high throughput, short range, and moderate power with relatively high cost [23]. A typical application scenario for LoRa technologies is citywide sensor collection where devices send readings at very low frequencies over longer distances. In our study, we argue that LoRa transceivers are useful to construct more generic IoT networks, incorporating not just bidirectional communication enabling only sensing and sharing the sensed information, but also interactive applications in the context of HCI and gaming.

2.3 Potential of TUIs in Outdoor GWAPs

Historically, physical games use tangible objects handled by the players (e.g. chess, rolling a dice, etc.) to support the game interaction. With the advent of computing devices new games emerged but also physical games were mapped into the digital interaction capabilities (e.g. keyboard, cursor control device) [4,25]. Aside from the popularity of exergames [27], Tangible User Interfaces

(TUIs) are known to be used in interactive real-world games for educational and in-the-wild environments. They are also increasingly important in children learning [24]. Moreover, reports show that physical tangible interactions can stimulate learning and allow participants to play games through natural interaction with objects in the real world [17]. Also, mobile location-based games in outdoor settings are gaining popularity [7]. Their expansion is due to the widespread use of smartphones with sensing capabilities, leveraging the GPS satellite positioning. These games are also known as "urban games" or "street games" and are typically in a multiplayer setting, played out on streets and urban environments. One of the games that made use of this approach is the Pokemon Go, where scholars study the motivational factors for walking [3,13,22]. Inherent in this type of games is also Augmented Reality (AR). Underpinning the fact that the activities take place in the real physical world, while games are seen through the lens of the mobile device. However, TUIs and AR geolocation games also have a big constraint which is the network connection, as gaming should avoid expensive mobile data usage. This poses a challenge for the network, especially in urban areas. In the remainder of this study, we will be focusing on the potential of using the TUIs as IoT LoRa devices, supporting our GWAP design.

When understanding GWAPs, they were commonly used for security, computer vision, content filtering, and traditionally seen as computer video games. Their goals were to impact the productivity while adding the gamification to the given tasks [28,29]. They emerged from the need to solve demanding computational problems which could be in return seem effortless for humans. These games have been also seen in crowdsourcing the data. Simple tasks for humans would be to classify or identify specific data, and these games would contain the proper incentives and rewards. The work reported by [18], focused on different rewarding strategies for engaging more users in the gameplay where the authors created the theoretical model of rewarding the users who classify the images on the web using the ESP game. To the best of our knowledge, there are no prior works creating GWAPs and combining them with LoRa and IoT. In our approach, we step away from the traditional computer GWAPs and focus on providing them as Tangible User Interfaces (TUIs), capable of real-time interaction using long-range wireless protocols. Our GWAP experience consists from a real-world setting game, LoRa protocol, and an IoT device acting as a TUI.

3 Methodology

In this section, we describe the design of our tangible IoT GWAP, used for leveraging the LoRa open radio protocol. In the next subsections, we describe our tangible GWAP apparatus (Sect. 3.1) as well as the game mechanics and the main interactions occurring throughout the game (Sect. 3.2). We then provide the information regarding our LoRa study setup (Sect. 3.3), describing the sample size, location, and methods for collecting the data inquiry using pre and post surveys, collected data used for monitoring and logging. From these data, we gain understanding about the LoRa performance and the game strategies used by the game participants.

3.1 GWAP Apparatus

Our design concept for the tangible GWAP interface encompasses two LoRa enabled interactive rattles. These devices embed IoT microcontrollers, their expansion boards containing sensors, additionally mounted actuators, as well as the antennas used to increase the range of LoRa communication. We opted for the metaphor of a rattle due to its familiar interaction usage. Moreover, contrary to the typical usage of antennas, we flipped the antennas upside-down to act as rattle holders, hindering the radio signal on purpose. While IoT LoRa enabled devices can be used without the antennas, in our design we flipped the antenna to provide game participants a more comfortable handling of the IoT device. Also, we were interested in understanding the performance of LoRa communication in a scenario where the antennas are integrated in the tangible device. In addition, the known shaking motion in rattles was used in our prototypes to take the full advantage of the accelerometers, serving as a sensory input to the microcontroller. More details of the sensors and actuators are described in the game mechanics section below. Our tangible IoT GWAP rattles are designed to act as low-power transceivers and to provide the peer-to-peer connection using LoRa (868MHz). The microcontrollers used were based on two low-cost 2 PyCom LoPy4[1] boards, coupled with 2 PySense expansion boards[2], used for power supply and sensory input. In addition, we also mounted the vibration actuator for the purpose of causing additional haptic feedback to the game participants. To each rattle, we also mounted external buttons, which will be used as the fire action. Also, each rattle was equipped with additional external GPS modules, serving to portray the outdoor location of participants during the gameplay. We mounted the GPS to deduce the understanding of the radiation coverage and players' game strategies. Lastly, each rattle was equipped with the rechargeable Li-Po 3.3 V battery, providing the power autonomy throughout the whole gameplay. The batteries were easily rechargeable using the external mini USB cable. Figure 1 depicts the apparatus and how participants used the IoT device for interaction in diverse settings.

3.2 GWAP Mechanics and Interactions

Two participants play the GWAP by carrying the IoT rattles. They start the game by facing back from each other while doing the countdown from 10 to 0, then participants go for 1 min in opposite directions of each other. These rules have been taken from previous known games, by merging Hide-and-seek and Pistol Duel games. Afterwards, participants are invited and instructed to explore larger distances from each other and hide behind the urban obstacles found around the campus used in the experiment. The rationale for instructing the participants to hide was to avoid being shot by the other opponent, as the radio signal should get weaker. After receiving the instructions, participants

[1] https://pycom.io/product/lopy4/.
[2] https://pycom.io/product/pysense/.

Fig. 1. LoRa IoT TUI GWAP apparatus (image to the left) and GWAP participants in outdoor and indoor settings exchanging payloads with IoT device (image to the right)

start to run and charge their devices by performing the shake gestures, which are captured by the microcontrollers' accelerometer. The LED indicator displays the current state of charge, using the variable intensity of the shake, being depicted from red (discharged), passing by yellow, to the green color (fully charged). Once the device is fully charged, the players can proceed to shoot by pressing the button on the rattle at the moment they find more appropriate for the signal to reach the opponent. This action sends the data using the LoRa protocol. Payload size used in our experiment varied between 3 to 10 bytes, relative to the type of action and words used (e.g. "hit", "got_hit|<life>"). Once a player receives a hit from the opponent, it also receives the haptic (e.g. 1 s of constant vibration actuator) followed with the visual feedback (constant rec LED indicator). The participant who successfully manages to send the payload and hit the other opponent receives solely the visual feedback (constant blue LED indicator). For the purpose of this study, we did not focus on providing the acoustic feedback, nor we did focus on the payload size. The game is played until one of the participants receives a total of 10 shots. When this happens, both of the opponents receive the visual and haptic indicators of the end of the game (LED and vibration feedback lasting for 10 s). Video of the gameplay can be found on-line[3].

3.3 Study Setup and Data Inquiry

Our tests were conducted in the urban area around the main campus building, as well as inside the corridors of a research institute. Our GWAP was successfully played by 20 participants (mainly from XYZ), with an average age of 32 (SD = 10). 12 participants were females, 6 were males and 2 participants preferred not to share their gender.

Pre and Post Surveys. Before the start of the game, we briefed the participants about the game rules, explaining that they will be wearing an object and

[3] https://goo.gl/dVnvaV.

using open radio communication for interaction, and that their goal is to choose a strategy weather or not they will play in attack or defense. Afterwards, we collected the demographic data. Participants were then invited to complete the pre-study, where we asked them to report their current understanding of long-range radio communication. We asked the users questions regarding the LoRa radio coverage range: "Using LoRa, which is the expected range of communication?". Participants were offered to select one of the following options: below 1 m, 1 m, 10 m, 50 m, 100 m, 1000 m, above 1000 m. Once the game was completed, we asked the participants to report back once again the range during the post-study. We also asked participants to report if they discovered something about the radio coverage during their gameplay. Additional questions were also given where we asked which of the game strategies they used. Finally, we asked the participants to complete the set of predetermined scales: (i) System Usability Scale (SUS) [11], a 7 point scale used for understanding the usability of the game; and (ii) Self-Assessment Manikin (SAM) [10], a 9 point scale used for measuring the arousal, valence and dominance of the game players. The purpose of collecting these data was to compare the affective states of the players and to understand their influence on the usability of our GWAP.

Data Monitoring and Logging. Using our GWAP IoT devices during the game, we obtained four different types of data: (i) Events, recorded upon game start, including charging payload, attempting to shoot, shoot, hitting the opponent, getting hit by the opponent, winning and losing the game; (ii) Timelines, used for all parameters throughout the gameplay, including life, charge load, pending shoot and charge shake counter; (iii) LoRa statistics, including rxtimestamp, rssi, snr, sfrx, sftx, txtrials, txpower, txtimeonair, txcounter, txfrequency; and (iv) Geographical information including the GPS timestamp, latitude and longitude. The purpose for collecting these data was to understand the power signal and the feasibility of using the GWAP players to crowdsource the signal strength.

4 Results

In this section, we report the several findings obtained through data inquiry techniques described in Sect. 3. We describe how game players evaluate their perception of range before and after the game. Also, we report results on usability and affective states of the GWAP players, and we depict the radiation coverage.

Usability. Using the System Usability Scale (SUS), we first modified the word "website" to "game" used in SUS scale to match our GWAP. Concerning the system usability, the final score obtained was 70.88/100. 75% (n = 20) of players reported the wish to frequently use this game. 95% of the participants found the game not to be complex, while 85% suggested that the game was easy to use. 40% of participants would use this game frequently, while 55% did not find anything complex during the game. Moreover, 75% of them, rated the game to be easy to use, while 80% of participants reported no need for any assistance of external persons using the GWAP game. Also, 70% of participants were in favor of the game not containing any inconsistencies, while all participants suggested that most people would learn to use this game very quickly.

Affective States of the Game Players. Using the Self-Assessment Manikin Scale (SAM), we asked the game players to rate their affective states after completing the game. They rated the valence (level of game being pleasant), arousal (level of game being exciting) and dominance (level of providing control of the game dominant feeling). We find: (i) valence score (AVG 7.0/9, SD 1.48) keeping the game very pleasant; (ii) arousal score (AVG 5.55/9, SD 2.14) suggesting the game to be slightly above average in terms of being exciting; and (iii) dominance score (AVG 6.10/9, SD 2.34) suggesting that players felt confident using the GWAP system.

Radio Coverage Perception (RCP). We asked the game participants to rate the expected radio coverage using LoRa before and after playing the game Our hypothesis was that the perception of the participants will change after playing the GWAP and influence the participants to select the higher coverage. Results indicate that the radio coverage perception increased to 35% of participants, remaining the same for 50%, while decreasing to 15%.

LoRa Performance Analysis [RQ4]. We compared the number of times the participants were charging and releasing the payload (shooting) against the geographical location (GPS) of the persons. We also analyzed: (i) the ratio of attempts to shoot (when the player does not have a full charge, resulting in an unsuccessful shot) versus effective shoots (resulted with sending the payload); – to understand if the players kept on always trying to shoot no matter what; (ii) the attempt to charge when the charge was already at maximum – to see if the users payed attention to the LED indicator (iii) Lastly, by observing the GPS and places from which participants were sending and receiving the payloads, we get the insight of the game strategies of our players. Observing the Received signal strength (RSSI) from signals of the players, we notice a tendency for a close range ($>= -70$) with a mode = median = -68.

Gameplay Analysis and Strategies. Using the storage on microcontrollers, we gathered the event logs from the played games, counting the numbers of reset parameters, shoot trials, shots, successful shots, received hits and shake counters. From the device logs, Fig. 2 depicts the location of the events using the GPS, where the color range represents the signal strength (in RSSI) and the circle size represents the number of events occurred in that location. It is worth mentioning that some of the marks are located inside of the building, where GPS accuracy may not be precise. Also some of the other points should be accounted as potential errors due to the game participants being located near the walls of the building, which may interfere with the GPS reception. Among all game players, only one participant decided to explore the distance (red circles at the lower right), and unlike the others, went even further away. Some participants managed to receive and send consecutive shots, while nearby buildings did not interfere much with the signal, nevertheless having the RSSI clearly weaker. Players varied their speeds in some game plays, while in other, players were more passively walking, focusing in charging and shooting, and trying to hide and to obtain a greater distance from each other. Most relevant parameters registered were: (1) play time (min) (AVG 2:34, STD 1:18); (2) RSSI (−64.14, SD 22.49); message time on air (ms) (AVG 36.02, SD 6.24);

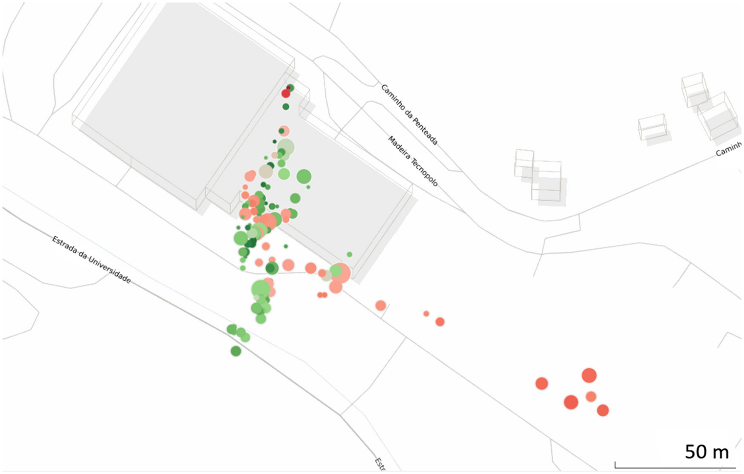

Fig. 2. Game heatmap - logged events during the gameplay in indoor and outdoor settings. Line in bottom right corner indicates the scale ruler of 50 m. Color range (green to red) represents the signal strength (in RSSI). Circle size represents the number of events occurred in that location. (Color figure online)

Regarding the game strategies, throughout the game, participants reported diverse game strategies: (i) using walls of the building to hide (12 participants); (ii) getting a bigger distance from the opponent (13 participants); (iii) (playing in attack mode, by shooting as fast as possible (13 participants); Also, 1 participant tried to cover the antenna and 2 participants did not have any strategy, reporting "...I did not have a strategy, nor I was thinking. I was just shaking and shooting". All of these reports we tried to compare against the collected data, however, we were not able to obtain more insights. Moreover, our field observations during the GWAP gameplay underpin that most of the strategies were in fact, for participants not to run nor hide, but rather to shake and shoot as fast as possible. What we also observed, is that the toy aspect of the IoT device seemed to inspire curiosity in most of the participants, inviting them to explore more the device than to explore the surrounding areas around them.

5 Discussion

Long range radio technology supports smart IoT applications to solve some of the biggest challenges on our planet such as energy management, natural source reduction, pollution control, infrastructure efficiency, disaster prevention, etc. In our case, we use LoRa for a real-world GWAP. In our study, we use the Internet of Things (IoT) as TUI devices capable of communicating through LoRa. Moreover, we use crowdsourcing to leverage the knowledge and awareness of LoRa technology. We ask participants to play a real-world GWAP and use our designed LoRa IoT devices for interactions. We study: (i) whether participants' perception of LoRa coverage range changes after participating the GWAP; (ii) system evaluation, including usability and affective states of the game players; and (iii) identification of LoRa coverage during the events of the game, depicted in the game heatmap (Fig. 2), understanding the game strategies of the players.

Usability and Affective States. Our implemented prototype shows that IoT devices can be used to design GWAPs by engaging the users in an open world physical gameplay. As reported by the SUS scale, the players found the game to be fairly easy to use and play, avoiding any potential inconsistencies. From the SAM scale, focusing on effective responses from our game participants, we found that players tend to fully enjoy the experience throughout the whole game. From the gathered inquires and post-study analysis, the participants shared with research authors couple of suggestions as follows: (i) hit counter would help them to improve the understanding of the game timeline; (ii) red LED indicator should be shown promptly after the hit success, as participants were expecting to have the blue LED indicator. This is intended to be corrected during the future release of our GWAP; (iii) to some participants, rattles were perceived to be more of fragile toys than a robust IoT devices, used as TUIs for interactions.

Coverage Perception and Performance. As it was aforementioned, LoRa protocol is using long range communication and frequencies which can obtain high distances. By default, we were aware of the challenge whether it would be actually possible for participants to use the urban obstacles to hinder the signal and thus to avoid getting hit. However, we were surprised in finding out that most of the participants did not actually explore the objects and terrain surrounding them, and instead rather chose to be within the vicinity of each other and observe what actually happens on the other rattle device. This also explains the phenomenon that most of the participants did not have the notion of the real radio range of LoRa protocol. Nevertheless, 35% of participants reported an increase of the radio range perception, while 15% experienced a decrease of the radio range perception. Observing the game results, all participants who reported the decrease in the radio range, fully coincide to participants who lost the game (both indoors and outdoors, as depicted in red in Fig. 2). This can be explained as their performance during the game was not successful. Thus, the perception of the decreased range is the byproduct of them losing the game, due to the amount of times being shot. As for the LoRa performance, from our metadata analysis, we found that two major groups were playing in close vicinity (RSSI ≥ -40) or farther against each other (RSSI ≤ -90). All game players stated that the interaction with the opponent was possible in most of the locations they were. We also find that flipped antennas allowed the interactions on longer range (within 100 m), as RSSI signal has been successfully caught by the opponents at greater distances. This suggests that more studies should be performed, with diverse other designs of the LoRa IoT devices, used for GWAP, where antennas can be hindered in other ways.

Field Observations. Our LoRa IoT devices (in further, rattles) seemed to have raised interest in participants causing the start of the GWAP as soon as they were instructed with the rules of the game, leaving no space for most of the players to run, but rather focus on fast shaking. We also noticed that our rattles were used for exploration of other interaction gestures. For instance, some participants did not just shake, but also used other curious techniques to charge the payload, including: (i) a metaphor and gestures used for magic wand, when casting a spell; (ii) turning the rattle into a pendulum by grabbing the edge of the antenna, allowing the rattle to hang and rotate; (iii) rolling the rattles between their hands causing them to rotate faster and trigger the accelerometers, using the centrifugal force. It was also interesting to see that some participants who were literate with telecommunication technologies tried to apply the principles of Faraday Cage [19], by placing our rattles inside of a trash bin. There were also participants who expressed the wish to play the GWAP several times (outside of the experiment), which we gladly accepted. Also, one pair of participants was very immersed in the game that they did not notice the game being completed several times, causing them to repeatedly play (also outside of the collected results).

Contributions. To the best of our knowledge, this study presents the first game with a purpose based on IoT and LoRa technologies. We use IoT as TUIs, and use them to communicate through LoRa protocol to raise its awareness and gather the radio coverage signal. We believe that this kind of GWAPs in real-world setting may find large appreciation due to the potential of interaction between more people in same physical environments. Our results from the questionnaires and conversation with the players support that the feasibility to engage and inform citizens about these technologies using GWAPs. In this study, we melded these technologies together and embedded them into a game. A game that allows the players to get both the insights of LoRa technology, as well as to gain awareness of how LoRa can be easily integrated in ubiquitous devices and environments. Ultimately, our GWAP empowers citizens to create solutions for their custom problems using long range communication without the need of any third party entities providing the expensive data plan coverage, and with a standardized open-access protocol. By showcasing this kind of GWAPs to citizens, in a concrete application using the different technologies, we are enabling the potential of novel ideas that can be implemented.

Limitations. However, it is also important to outline several technical and design constraints for future studies. Current indoor activities are subject to the errors in GPS location. The antenna used in our IoT device which was used as a rattle holder might not be the best practice when understanding the radio coverage. In addition, constant shaking caused damage to the wiring of the external modules (GPS, button, accelerometer) and our rattles had to be re-soldered again. Furthermore, we learned that our IoT devices needed to be more robust in order to resist the direct collision with the ground, as this was the case with one of the game participants being very excited and immersed in the gameplay. Therefore, more long-lasting encapsulation methods and designs should be more thoroughly explored. Also, haptic feedback obtained from the vibration actuator did not provide as much of force it could, as the participants during the shaking gesture sometimes reported not to have received any feedback, occurred when understanding if the opponent was shooting them. Moreover, the current version does not give higher rewarding incentives.

Future Studies. In our GWAP, rewarding is solely the sense of winning the game against another human player, and defeating the opponent as many times as the two players can play. In future studies, we envision the possibility of adding multi-step winnings that culminate in a larger victory, i.e. giving the players a sense of progression. We also plan a multiplayer version of the game, allowing the players to be in a radio mesh network from all-to-all instead of one-to-one. This will make it possible to get more metadata regarding the radio coverage from a larger population at once. It will also lead to more detail radiation heat map and can be used for identification of blind spots. Moreover, the multiplayer scenario will be used to test the mechanics allowing the possibility of forming diverse teams. We believe that this IoT GWAP and its design is useful not only for raising awareness and mapping signal coverages but could also be used for other types of applications, including other sensory input such as the interactive way of understanding the health of crops or preventing the fire.

Conclusion. The Internet of Things (IoT) is opening new possibilities for sensing, monitoring and actuating in urban environments. They support a shift from mostly human-centric connected devices into a hybrid network of humans and things collaborating in production, transmission and processing of data through low-cost and low power devices connected via long-range wide area networks. This paper explores the design possibilities provided by technologies such as IoT and LoRa and tangible computing in moving beyond traditional egocentric applications based on high cost, power and computing personal mobile devices. To illustrate and test this approach we designed a 2-player duel game based on IoT controllers and the LoRa communication protocol. Here we report on the main evaluation dimensions of this new design space: (i) game usability (SUS) leading to an above average score; (ii) Affective states of the players (SAM) depicting pleasant and engaging gameplay, while players retain control; (iii) Radio coverage perception (RCP) showing that most participants did not change their perception of the radio distance after playing.

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