Internet of Things
Developing an optimal wireless power transfer system for a real-world low power LED wristband application

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Abstract

Keywords: Wireless power transfer, low power, real-world application

1 Introduction

introduction

2 Related work

related

3 Prior knowledge

by size of the battery we refer to the capacity of the battery

supercapacitor vs battery

4 Description of the proposed idea

decription idea

4.1 Scenario

Scenario's were developed to develop a charging protocol that accounts for all possible states. For these scenarios a user wearing a tranceiver wristband is considered. Other viewpoints for a scenario can be the user wearing a receiving wristband or the transmitting bar. However, these viewpoints are considerably easier to address and will implements parts of the protocol designed for a tranceiving system.

4.2 The wireless transfer system

Our major goal is to provide an efficient solution that best meets the challenges in battery charging systems using wireless power transfer. Those challenges include:

1. *Charging the battery as fast as possible.* Batteries can store a large amount of charge. Unfortunately there is a limit to how fast a battery can be charged, which gets smaller with the size of the battery. Exceeding the charging current limit will deteriorate the battery's life and is more likely to happen when using smaller batteries as they have a lower charging current limit. To overcome this difficulty we propose adding a supercapacitor parallelly with a battery. The supercapacitor will function as a small buffer for charging the battery as it can hold a smaller amount of charge compared to the same size battery. Using a powerfull combination of a battery in parallel with a supercapacitor will offer a much faster charging cycle as supercapacitors are know to charge fast and will provide a robuster system for they have a longer cycle life [7], [8].
2. *Ensuring a long battery life by creating a large charge to discharge ratio.* In our scenario we don't want the user to be waiting for a longer time than 15 minutes for the wristband to charge. This introduces the need to store as much charging current in short intervals as possible. Batteries have a relatively low cycle life, making them unfit to be frequently charged and discharged. By positioning a supercapacitor in parallel with the battery, it acts as a buffer to store a large amount of charging current. Sequentially the same supercapacitor can use this current to charge the battery with a slow pace. This ensures a longer battery life in terms of a large charge to discharge ratio.
3. *Developing an efficient protocol for sharing the available charge.* We don't want to develop a wastefull system in terms of energy. For this reason we want to propose an efficient protocol that enures the available energy is efficiently used. By using UML state and sequence diagram we will display the efficient flows of energy. Based on these diagram we will develop the protocols on an arduino to demonstrate our working fully functional system.

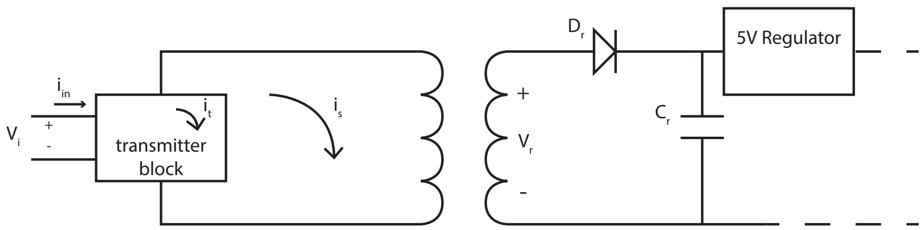

Figure 1: Design of the system

Figure 1 represents the general framework of a wireless power transfer system as proposed in the assigned paper [1]. In order to propose a system design applicable to the subject of wireless power transfer we will use this framework and come up with our own parameters and design for the application. The application that the wireless power system will supply for needs a regulated voltage of 5V and a maximum current of 300mA. Based on these specifications we found a wireless power transfer set online [2] and purchased this set as seen in figure 2 to build our system with. The specifications of this set are mentioned on [2], but will be discussed more detailed in Section 7.

4.3 A real-world application

blabla

4.3.1 State analysis

state diagrams

4.3.2 Protocols

The major goal of this report is to be able to develop a real-world application. In order to do this, all real-world implications need to be taken into consideration. There are certain states in which the system can reside depending on its own battery state, the battery state of neighbour nodes and the availability of

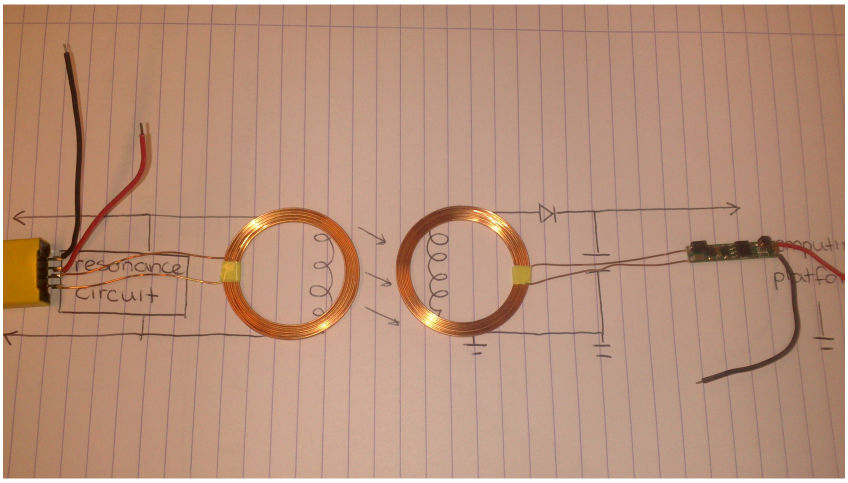

Figure 2: Engineeringshock Electronics Wireless power transfer set

a charging bar. These states and their transmissions are displayer in figure 3. It can either be sufficiently full defined as V_{full}, starving defined as V_{starve} or dead which is defined by V_{dead}. These parameters are further specified in section 6.

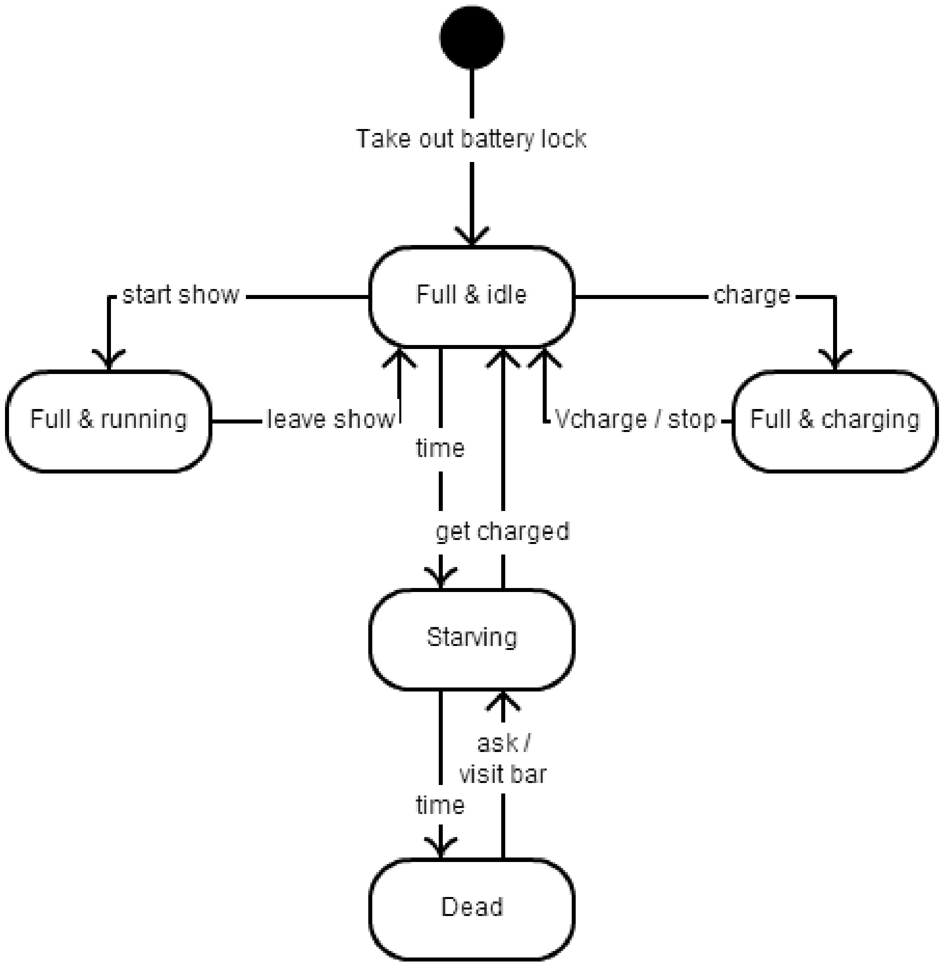

Figure 3: State diagram of a transceiving wireless power transfer system

A charging protocol has to be designed to account for these combinations. We considered three possibilities: an infinite network like design, a hop-to-hop spread of energy or an interactive behavior to selectively share energy. To stimulate interaction through this application we choose to apply a scenario where a user can choose to act upon energy requests and share with friends, or strangers.

To handle these protocols, an IC has to be added. This way whenever the battery reached V_{starve} it will send out a request for energy visually by litting a red LED embedded in the wristband. Neighbouring nodes can then choose to react on this or save their own energy. Whenever the battery dies, the user either has to verbally ask for energy or visit an energy bar.

5 Analysis of the system design

In this Section we will discusse the specifics of the system we propose and introduce our validated model of the system. With this model we were able to display the charging profile in Section 5.2 and optimized for a charge to discharge ratio in section 5.3.

Figure 4 shows a low level schematic of the receiver and charging circuit which will be the main focus of our project. The induction current i_r induced by the transmitter through magnetic coupling will be the main source of charging current. The current i_c charges the super capacitor C_s up to the capacity of V_c, in our case $V_c \leq 5$ Volts as this is the maximum voltage rating of our supercapacitor, i_b charges the battery and i_L is consumed by the current limiting resistor R_L and a light source LED. Where $i_r = i_c + i_b + i_L$. Now in analysis lets first consider the efficiency η of the circuit. If P_o is the power

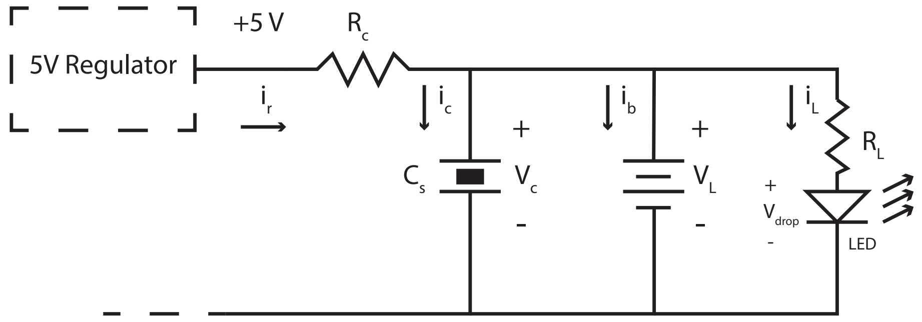

Figure 4: Design of the Receiver of the wireless power transmitting system

consumed by the receiver and P_i is the power provided by the transmitter, ignoring small power drops across D_r and C_r then:

$$\eta = \frac{P_o}{P_i} \tag{1}$$

where $P_o = V_{reg} \times i_r$ and $P_i = V_i \times i_s$. The receiving battery can provide $V_l = 3$ Volts when fully charged. For a 3 Volts lithium-ion battery the output voltage normally drops by 0.2 Volts whenthe battery is at 40% of its capacity and can go to 2.6 Volts when it is almost drained [8]. Therefor a slight dim in LED brightness can be observed as battery drains with time. To ensure a normal brightness of our *LED* with a forward voltage drop of $V_{drop} = 1.7$ Volts we choose need a current of $i_L = 20$ mA. To determine the required resistance we used equation 2 and found $R_L = 65\Omega$

$$R_L = \frac{V_l - V_{drop}}{i_L} \tag{2}$$

Using $P_L = {i_L}^2 \times R_L$ we can determine the power rating of R_L that gives us $P_L = 400\mu$ Watts. This is the power dissipated at R_L and can be avoided if we use a LED that has exactly the same forward voltage drop V_{drop} as the battery output V_l and thus remove the need for R_L. However, a LED is very sensitive to even small change in the applied voltage. A voltage change of 0.1 Volt can cause the LED current i_L to shot up beyond the limits hence a more careful consideration is required if one chooses to omit the current limiting resistor R_L.

5.1 Battery Life

The battery that we are using has a capacity of 50 mAh, which means if current I_B of 50 mA is continuously drawn from the battery then it can last for one hour. To find out total battery life for our circuit we need to consider the total power consumed P_c, for our case $P_c = i_L \times V_l$ from which we can calculate total life of fully charged battery.

$TotalBatteryLife = \frac{BatteryCapacity}{PowerConsumed} = \frac{I_B \times V_l \times 1hour}{i_L \times V_l} = \frac{50mA \times 3V \times 1hour}{20mA \times 3V} = 2.5hours$

5.2 Charging Profile

Now lets consider how the charging and discharging of the receiver circuit works. According to manufacturer specification $i_r \leq 400$ mA , which enforces the limit for the system to function properly. In figure the super capacitor C_s has very low series resistance of 0.07Ω compared to $R_L = 65\Omega$ hence during charging we can say that $i_c \approx i_r$ and if the $i_r(t)$ is not constant and depends on time then the capacitor charging is governed by the following equation

$$V_c = V_{reg}\left(1 - e^{\frac{-t}{R_c C}}\right) \tag{3}$$

where R_c is the series limiting resistance of receiver circuit whose value depends on the maximum value of i_r and C is the total capacitance of super capacitor which in our case $C_s = 5$ Farads R_c can be chosen using $R_c = \frac{V_{reg}}{i_r}$ for maximum allowed $i_r = 400$ mA which gives us $R_c = 12.5\Omega$

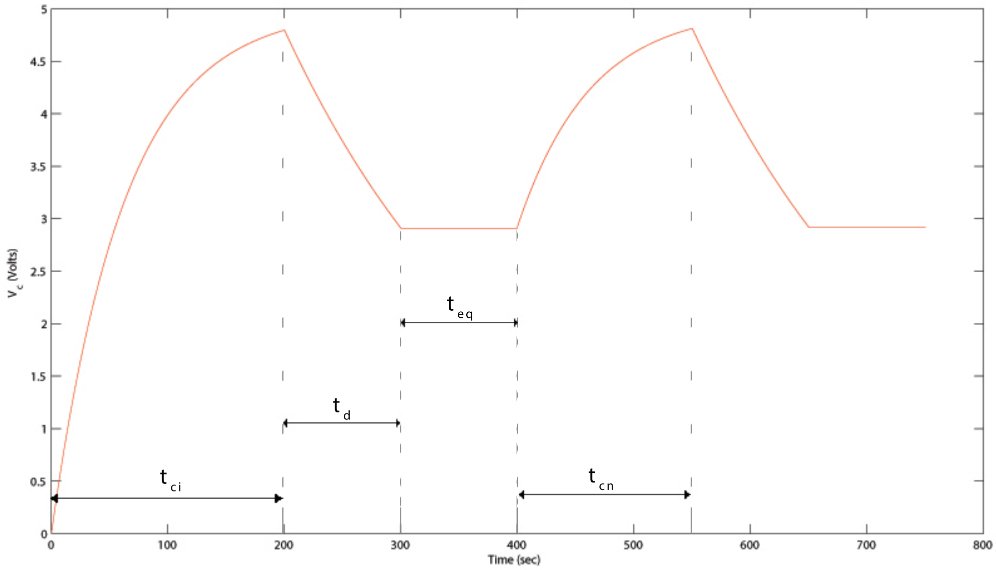

Figure 5: Charging profile of the super capacitor

Figure 5 shows charging, discharging and idle profile of the super capacitor during the system operation. In initial charging cycle t_{ci}, C_s is charged using $i_r(t)$ following equation 3 and during discharge cycle t_d, the $i_r(t) = 0$ and discharge current is supplied in the form of i_b and i_L. Finally during the equilibrium cycle t_{eq} the voltage is reduced to equal the battery voltage ($V_l = 3$ V) such that no current flows between the battery and super capacitor and $i_b = 0$, at this stage only battery's charge is used to power the LED. At last during the second charge cycle t_{c2}, the capacitor's charging starts from equilibrium voltage instead of 0 and is charged to V_{reg} un till the discharge cycle starts again.

5.3 Charge to discharge ratio

If current i_r is provided for a time period t then how long the system will keep running with this provided current is defined by the charge to discharge ratio C_r and is given as

$$C_r(t) = \frac{i_r(t)}{i_L} \tag{4}$$

where $i_r(t) = \frac{5-V_c(t)}{R_c}$ is the current provided for charging at time t and is given by

$$i_r(t) = \frac{5 - V_c(t)}{R_c} \tag{5}$$

As $C_r(t)$ is only meaningful during the time when $i_r(t) \neq 0$ which corresponds to time intervals t_i and t_n in the figure 5. Hence we can plot $C_r(t)$ for these intervals as shown in figure 6 (a) and 6 (b). From figures we can observe that $C_r(t)$ decreases with time till the value of 2. This is because of the capacitor's charging nature, as C_s starts to charge up,$V_c(t)$ starts increasing which decreases the value of $i_r(t)$ [eq:5] and eventually $C_r(t)$. To make more meaningful analysis of charge to discharge ratio one can find the average value of $C_r(t)$ using

$$C_{avg} = \frac{1}{T} \int_t C_r(t) \mathrm{d}t. \tag{6}$$

In figures 6 (a) and (b) for t_i and t_n we can see the value of C_{avg} to be 6 and 3.14 respectively. The value 3.14 for t_n is of more importance as this value represents the rest of the charging cycles through out the

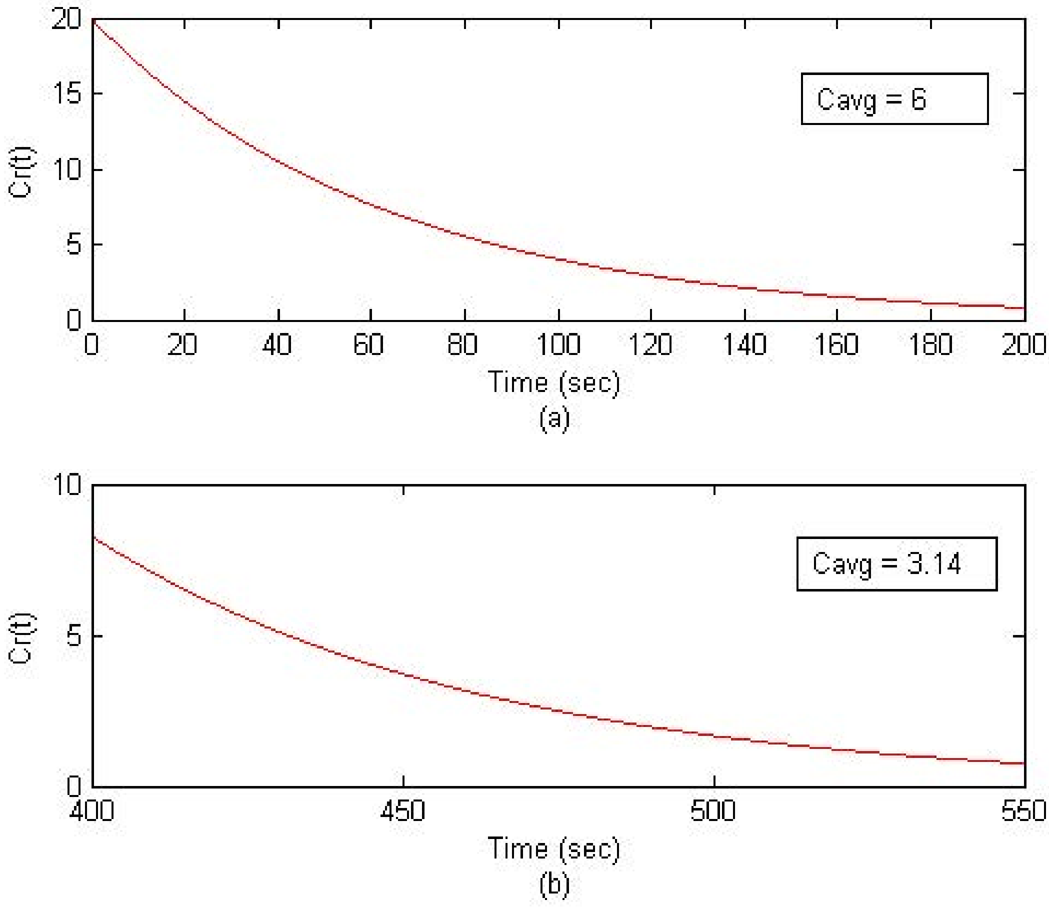

Figure 6: (a) Charge to discharge ratio for t_i cycle. (b) Charge to discharge ratio for t_n cycle

system operation. $i_r(t)$ is responsible for the decrease in $C_r(t)$ which means that the receiving energy is not fully exploited. C_{avg} can be further improved if we can somehow exploit the $i_r(t)$ to its maximum value for all times t. This can be achieved by using a component that can provide constant current regardless of the change at its output voltage. Such components have internal DC to DC convertor and are referred as constant current capacitor/battery chargers. If such a component is added to charge the super capacitor than it is possible to get $i_r(t)$ as constant maximum allowed value for all times t.

For constanti_r, $C_r(t)$ profile is shown in figure 7, we can observe that $C_r(t)$ value has been improved to 20 and it stays constant for all values of t.

6 The proposed system design

The Figure 1 shows the proposed design of the system. The system includes a transmitter and a receiver with transmission and receiving coil respectively. The wireless power transmission works on the principle of magnetic induction [8]. The transmitter is powered up by a voltage source V_i of 12 Volts capable of delivering 400 milli-Amps of i_{in} current. i_c is the constant current that is consumed by the transmitter circuitry and i_s is the induction current which flows through the transmitter coil such that $i_{in} = i_c + i_s$. i_c is constant and depends on the transmitter inner circuitry power consumption, in our case $i_c = 100milli - Amps$. i_s depends on the distance between the two magnetically coupled coils, greater the distance smaller the i_s will be. Another factor that i_s could depend is on adding an iron core between the two coils, adding a core makes the magnetic coupling stronger and increases the i_s

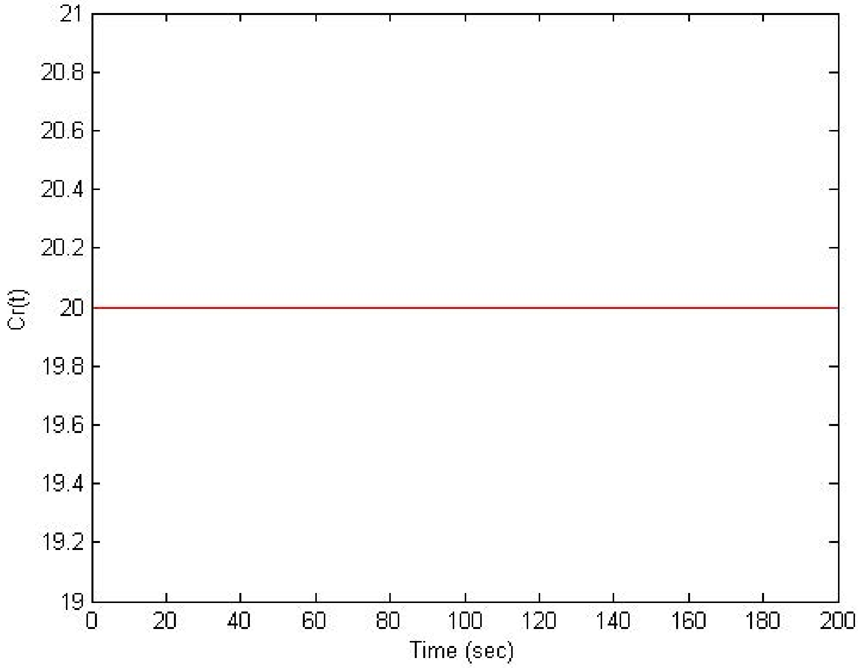

Figure 7: Charge to discharge ratio with constant charging current i_r

which enhances an overall efficiency of the system. The receiver circuit receives an induction voltage V_r, rectifies it through a rectifier containing a shotkey diode D_r and a capacitor C_r. A shotkey diode is used in order to have a good frequency response at the range of $300 - 400Khz$ the transmitter working frequency also shotkey has lower forward voltage drop. The rectified voltage is then fed to the voltage regulator that produces constant voltage $V_{reg} = 5Volts$.

$determine\ V_{starve},\ V_{dead},\ V_{full}$

6.1 The internet of things

The assignment of this report conveyed critizing and accessing system-level Internet of Things components in scientififc literature. Because the assigned paper [1] did not include anything IoT related, we will present our own idea. In this section we will provide a short introduction to the Internet of Things and its key features, we will also present our idea and focus on the practicality and entrpreneurial aspect of the idea.

The Internet of Things refers to uniquely identitfiable objects, or things, and their virtual representations in an Internet-like structure. [6]. The intelligent application is the key feature here. Important aspects to be taken into consideration when designing such systems are security, privacy and scalability.

The anatomy of Internet of Things is initiated by a certain event, that is detected and logged by devices that include self-properties [6]. This data is then uploaded by a ubiquitous and interoperable network. The unique feature of the internet of things is that this system is smart and can generate knowledge and by analyzing this data and understands the system. Certain events are then triggered and reported as response. The intelligence of these systems lie in the adapting mechanisms that analyse and understand the environment in order to deal with the complex dynamics of a real-world environment.

Internet of Things has already been employed at multiple festivals and initially used as a ticketing solution in 2004 at the SXSW festival in Austin. It emerged in the form of wristbands and cut down significantly on gate crashing and lost tickets [9]. SXSW announced that each tag contained a unique ID code, correlated with personal information availabe by SXSW [5]. It has further been introduced at Coachella and Bonnaroo. [4] [3] RFID now even support cashlesh payments and integration with social networks, allowing people to upload pictures to facebook via the so-called "Live Click Stations"[9]. We can conlude that it safe to say that the Internet of Things hasn't reached its peak yet concerning festival and concerts.

Because our scenario already portrays users wearing a wristband throughout the festival containing the discussed electronics, we can add some small features to play into current trends concerning Internet of Things and music festivals. By adding a RFID tag into each wristband, users are assigned unique IDs. These tags can be applied fairly easy and can obviously contain functionality such as a unique entrance ID or even cashlesh payments. In this report however, we want to focus on the fun factor of connecting with friends and strangers. Users can prior to arriving at the festival use their unique ID and optionally link it to all the accounts of their friends are the accompanying social media. When the users enter the festival site and receive their wristbands, these are connected to their unique id priorly received. Whenever they charge their wristband, either at the bar or at check in points near every site of interest, their friends that are not near them will receive a message containing their location and if made, an image at the check-in location. Based on certain check-in's at time in the schedule of the festival, the system can recognize their interests (if not already mentioned in their id page online) and even give them recommendations to go next to. The sequence of this Internet of things can be seen in figure 8.

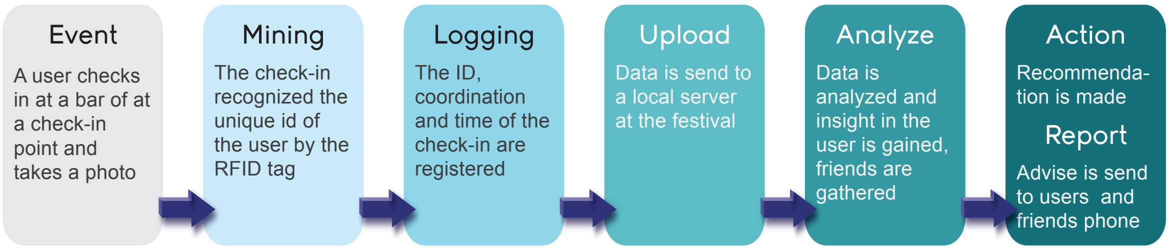

Figure 8: Internet of things chain of actions

Our system goed beyond simply assigning a unique id to a user, it also adds functionality and connects ids to exchange information. In this manner, it mines the data when users check in at charging points where they can even choose to make a picture. These check-ins are logged and send to a server, where the users ID is processed and connected IDs of friends are notified. The system can then analyze the data and generate knowledge by searching for common factors of interest. Based on this intelligence, the system can in turn return some recommendations back to the user. This doesn't just improve the experience of the user, but it gives the organization a better insight into the behavior of their visitors.

7 Results

results

8 Conclusion

conclusion

References

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