

# Internet of Things

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

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November 9, 2013

### 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 Initial proposal of our 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.

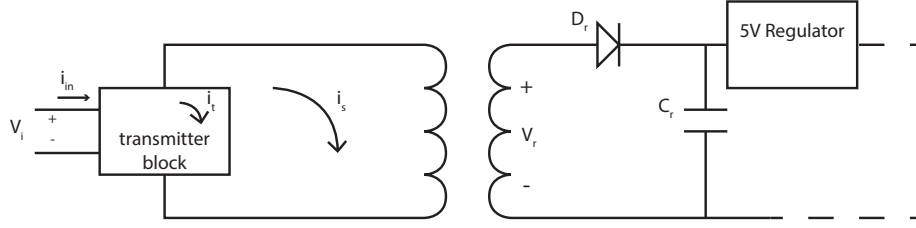


Figure 1: Design of the system

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 Protocols to account for a real-world application

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 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.

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.

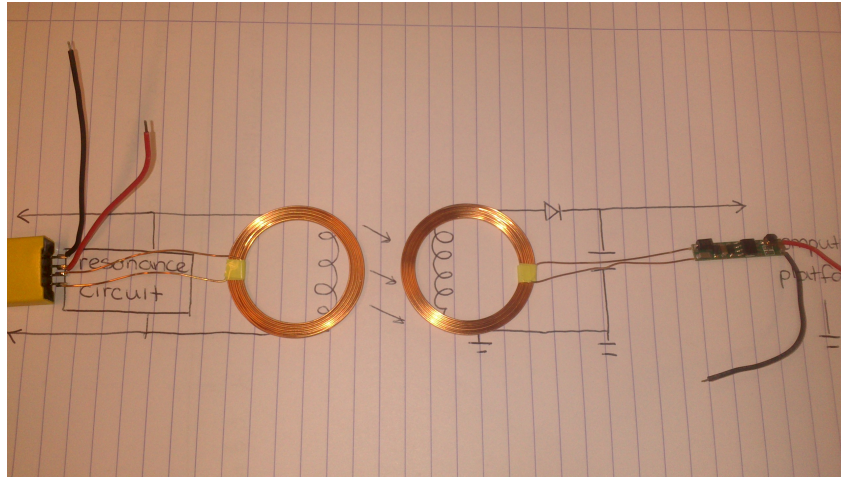


Figure 2: Engineeringshock Electronics Wireless power transfer set

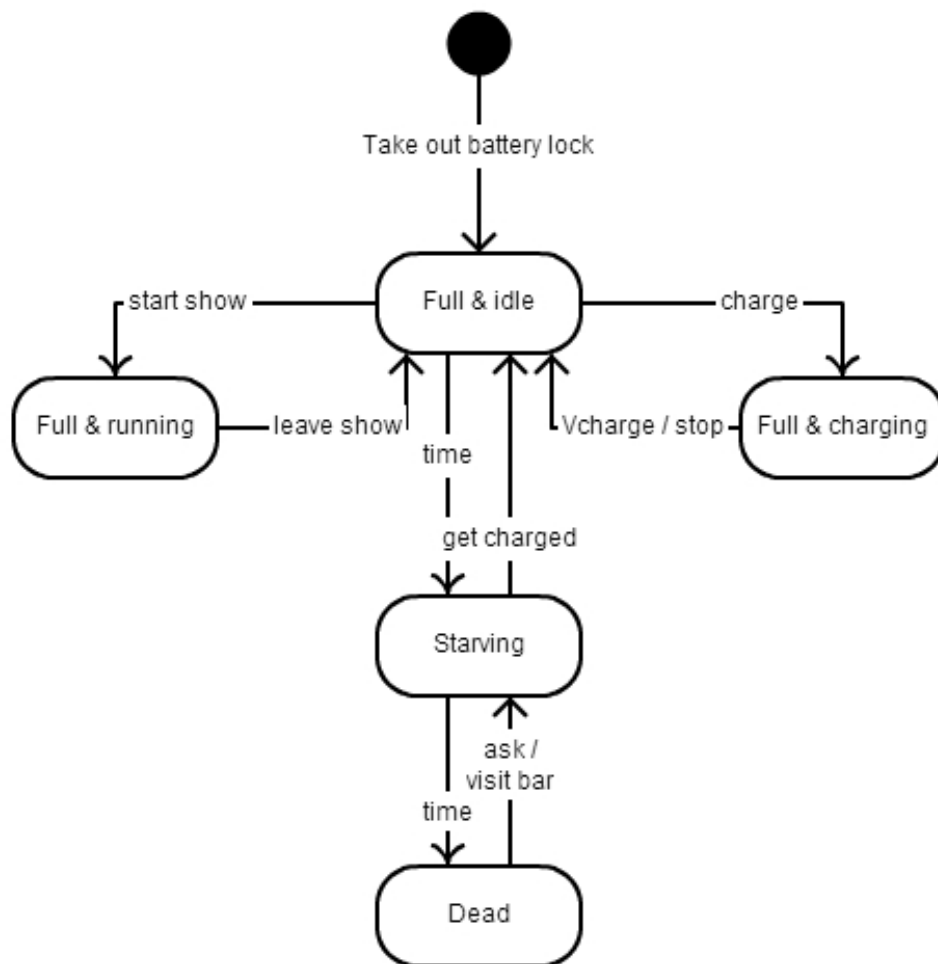


Figure 3: State diagram of a transceiving wireless power transfer system

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 lighting 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 discuss 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.

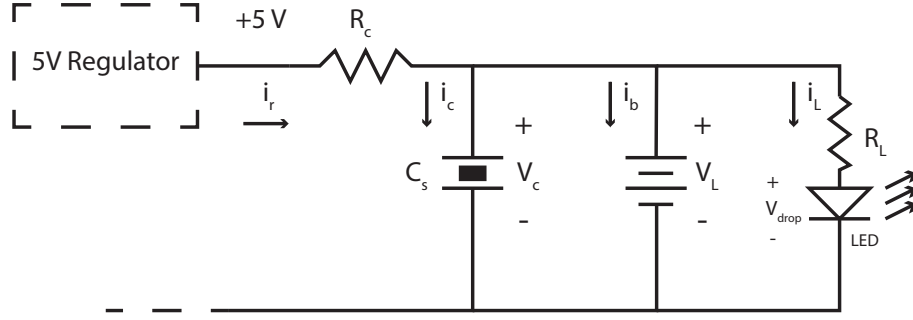


Figure 4: Design of the Receiver of the wireless power transmitting system

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  $\eta$  of the circuit. If  $P_o$  is the power 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:

$$\eta = \frac{P_o}{P_i} \quad (1)$$

where  $P_o = V_{reg} \times i_r$  and  $P_i = V_i \times i_s$ . The receiving battery can provide  $V_i = 3$  Volts when fully charged. For a 3 Volts lithium-ion battery the output voltage normally drops by 0.2 Volts when the battery is at 40% of its capacity and can go to 2.6 Volts when it is almost drained [8]. Therefore 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  $R_L = 65\Omega$

$$R_L = \frac{V_i - V_{drop}}{i_L} \quad (2)$$

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  $V_i$  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 shoot 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  $P_c = i_L \times V_i$  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  $0.07\Omega$  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

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

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  $R_c = 12.5\Omega$

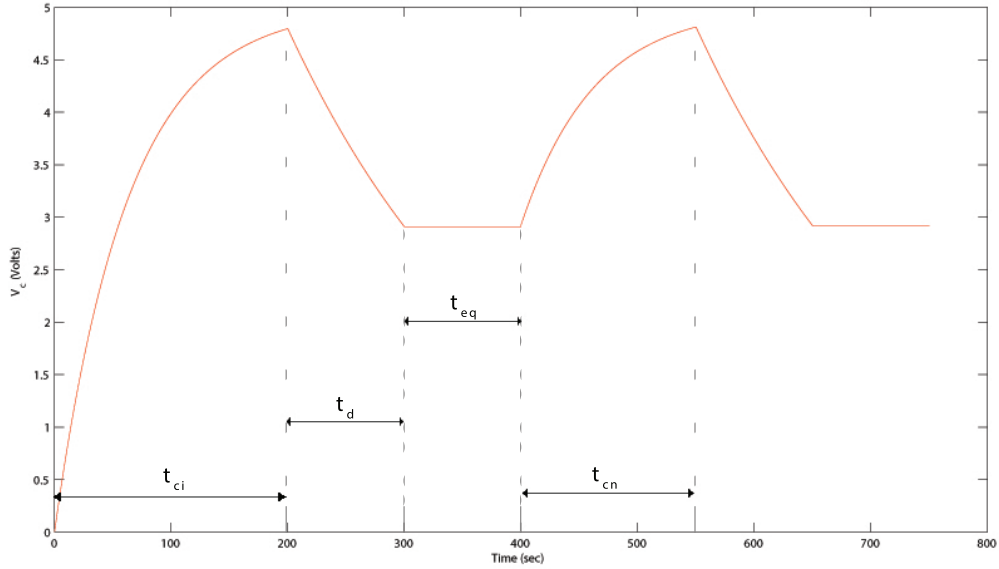


Figure 5: Charging profile of the super capacitor

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  $V_{reg}$  until 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

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

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

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

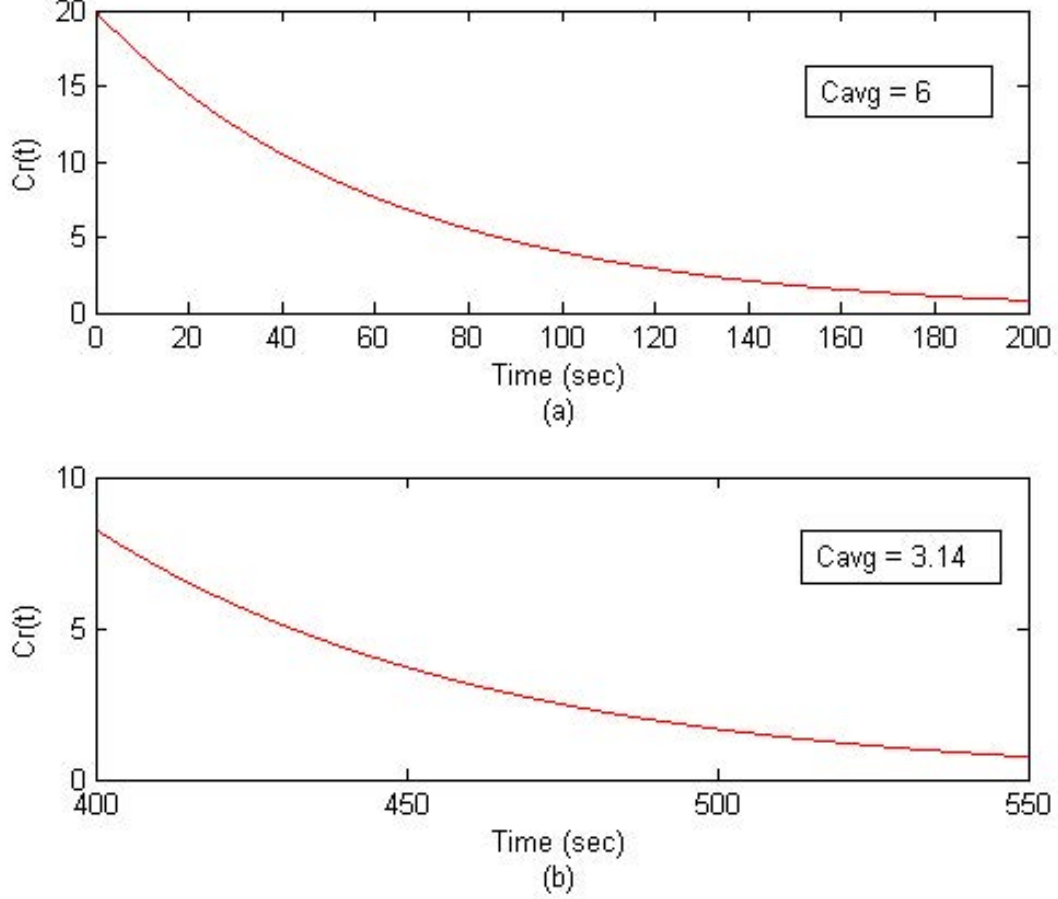


Figure 6: (a) Charge to discharge ratio for  $t_i$  cycle. (b) Charge to discharge ratio for  $t_n$  cycle

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

$$C_{avg} = \frac{1}{T} \int_t C_r(t) dt. \quad (6)$$

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 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

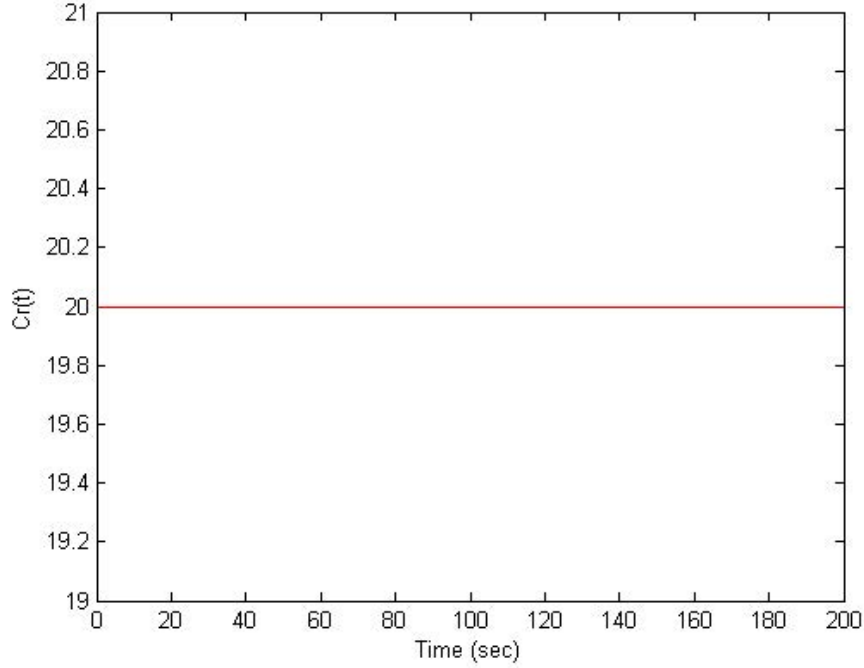


Figure 7: Charge to discharge ratio with constant charging current  $i_r$

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 constant  $i_r$ ,  $C_r(t)$  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  $i_c = 100\text{milli} - \text{Amps}$ .  $i_s$  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  $i_s$  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  $300 - 400\text{KHz}$  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  $V_{reg} = 5\text{Volts}$ .

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 scientiffic 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 entrepreneurial aspect of the idea.

The Internet of Things refers to uniquely identifiable 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 available by SXSW [5]. It has further been introduced at Coachella and Bonnaroo. [4] [3] RFID now even support cashless payments and integration with social networks, allowing people to upload pictures to facebook via the so-called "Live Click Stations" [9]. We can conclude 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 cashless 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.

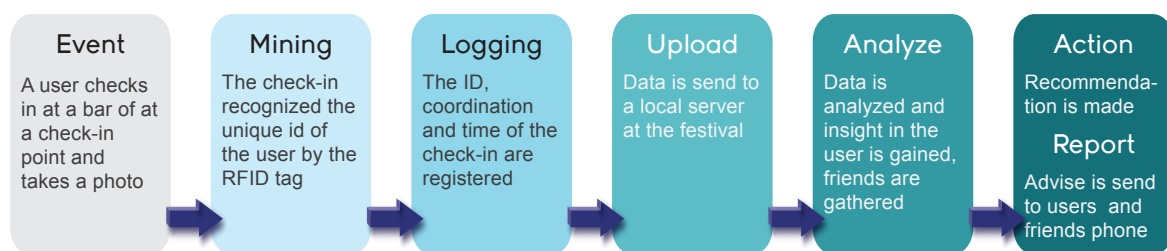


Figure 8: Internet of things chain of actions

Our system goeod 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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