# Turn Me On! Using the "Internet of Things" to Turn Things On and Off

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## Abstract

*The "Internet of Things" is the paradigm of connecting physical objects (things) with digital intelligence to the Internet. People have been connecting to the Internet for decades. It is only recently that things have been able to connect to the Internet. There are many examples of things posting their status on Twitter and allowing uni-directional access. TurnMeOn is an example of allowing bi-directional access between people and things using Internet protocols. Users can query the status of a light bulb. In addition, users can turn a light bulb on and off.*

## 1 Introduction

The "Internet of Things" (IoT) is the phenomenon of an increasing number of physical objects (things) having the ability to connect to the Internet (and often having an associated cyber representation). Using computational devices, people (as opposed to things) have been connecting to the Internet for decades. It is only recently that things have been given the requisite digital intelligence to do the same [1, 2].

This digital intelligence is the result of advances in material technology that has shrunk the size of digital circuitry and reduced its power requirements to such an extent that it is now possible to add sensors and actuators to almost any object. A case in point is Ossevoort's limited edition augmented books that combines motion sensors, a microphone, and thermo-chromatic ink to create an object that adjusts its behavior based on past events [3].

Cars (via satellite tracking devices), pets (via embedded chips), items in the supermarket (via RFID tags), weather stations (via wireless) and cell phones (via 3G, etc) have long been connected to the Internet. Larger things such as telescopes, dam walls, and bridges have started to automatically post their status on the Internet using Twitter and/or Facebook [4]. Even a human heart has been connected to the Internet [5].

But these examples have all been uni-directional. The thing in question is automatically posting data to a location on the Internet for people to read.

Bi-directional communication between people and things via the Internet is less common.

This paper describes a project TurnMeOn where people can switch electrical appliances on and off via the Internet.

## 2 Motivation

Since late 2005, South Africa has had an on-again-off-again regime of rolling blackouts (also called load shedding) which reached crisis level in 2008 when an estimated generation short fall reached 5000 MW [6]. Public radio announcements asked residents to save electricity in order to avoid future load shedding. Existing research has shown that providing antecedent information about electrical consumption or electrical conservation can create significant energy savings [7]. Stern argues that what makes information effective is not so much its accuracy and completeness as the extent to which it captures the attention of the audience, gains their involvement, and overcomes possible skepticism about is credibility [8].

It is not simply the information content given to the electricity consumer that is important, but the way in which the information motivates the consumer into action. And, of course, if the consumer is motivated into action, then it is important that the consumer can, in fact, act on that motivation.

This paper describes a research project investigating how best to allow people to switch electrical appliances on and off via the Internet.

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# 3 Research Question, Objective and Methodology

Being able to switch electrical appliances on and off is important to general IoT projects. The research question for this project, therefore, is:

> "How can people turn electrical appliances on and off via the Internet?"

This research question can be subdivided into four sub-questions:

1. What mechanism could be used or developed to interact with people?
2. What mechanism could be used or developed to route requests between people and things?
3. What additional hardware could be used or developed to actually switch electricity on and off?
4. What mechanism could be used or developed to link these three items together?

The research objective was, therefore, to:

> "Develop a means by which people can turn electrical appliances on and off via the Internet"

This research objective can be decomposed into four sub-objectives:

1. Find or develop a mechanism to enable people to request to turn electrical items on and off.
2. Find or develop a mechanism to route requests between people and things.
3. Find or develop the appropriate hardware to interact with electrical appliances
4. Link these three items together in a unified architecture.

By satisfying the sub-objectives, the primary object would also be satisfied. In so doing, the research question would in turn be answered.

A Design and Creation Research Methodology as defined by Oates [9] was used for this project. Oates defines this methodology as an iterative processing normally consisting of five steps:

1. Awareness – the recognition and statement of the problem.
2. Suggestions – initial ideas about how this problem can be solved.
3. Development – implementation of these initial ideas.
4. Evaluation – assessment of the developed item.
5. Conclusion – consolidation of results.

Steps one through four were traversed numerous times in this project leading to a final conclusion step.

# 4 General Architecture

There are three major components of the platform: ThingMemory, Beachcomber, and UrbanControl. ThingMemory supplies the web interface and a mechanism to host the cyber representation of the thing. Beachcomber supplies an XMPP interface, a MXit interface, a Twitter interface, and routes the data via HTTP to the UrbanControl. UrbanControl switches the electricity on and off and senses the ambient light level. The general architecture is shown in Illustration 1.

A rich graphical interface to TurnMeOn is supplied via ThingMemory. A text interface to TurnMeOn is supplied via XMPP (Jabber) and MXit. These three interfaces are bi-directional meaning that the user can both view and change the status of the light bulb using these interfaces. A limited interface is supplied via Twitter with which the user can just check the current state of the light bulb.

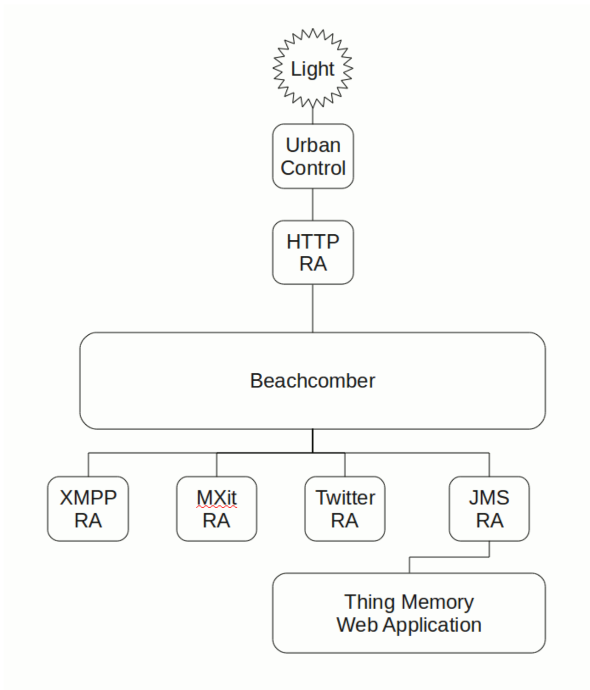


*Illustration 1: General architecture*

TurnMeOn allows users to check the state of the light bulb, switch the light bulb on, switch the light bulb off, and subscribe to changes in the light bulb. Subscribed users are notified whenever the light bulb changes state.

## 5 Beachcomber

Beachcomber is a bearer agnostic switch which can route information according to flexible requirements. It is a service building block running under Mobicents in a JEE (Java Enterprise Edition) environment. Beachcomber supports communication through a wide range of protocols including XMPP (Jabber), MXit, Twitter, HTTP, JMS (Java Messaging Service) and POP3 email [10]. These different protocols are implemented as resource adaptors (Ras) under Mobicents.

Messages can be sent to Beachcomber using the above mentioned protocols which are received by the appropriate resource adaptors. The resource adaptor converts these varying message formats into a common format and forwards them to a the central Beachcomber routing component. That routing component then forwards the message to the appropriate business application (in this case TurnMeOn). Any messages from the business application are sent back to the routing component which forwards it to the appropriate resource adaptor. The resource adaptor converts the message back into a protocol specific message format and forwards it as necessary (e.g. to UrbanControl to control the light or to ThingMemory to update the cyber representation of the light).

The architecture of Beachcomber and TurnMeOn can be found in Illustration 2. In the case of this application, Beachcomber has been configured to use five resource adaptors supporting input and/or output via XMPP, MXit, Twitter, JMS, and HTTP. Input from any of those resource adaptors is forwarded via Beachcomber to the TurnMeOn service building block. TurnMeOn accesses its own logic and database in order to decide what must be done and where the information must go.

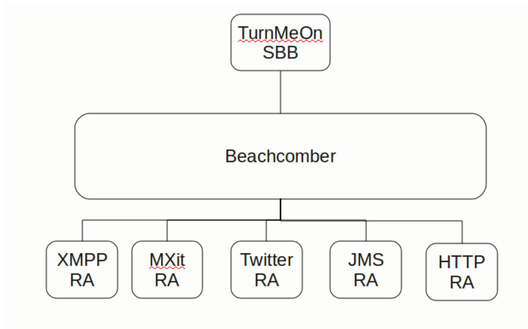


*Illustration 2: Beachcomber architecture*

For example, a user accessing Beachcomber and TurnMeOn via an XMPP chat account may type in a command as simple as `on` to turn the light bulb on. That incoming data is forwarded to the TurnMeOn application. The application would then send the appropriate commands via the HTTP resource adaptor to instruct UrbanControl to switch the light bulb on. The application would also send appropriate information via JMS to the web application. It would update the Twitter account appropriately. In addition, depending on which XMPP and MXit users have subscribed to the light bulb, additional messages may be output via those resource adaptors.

The commands which are supported through Beachcomber and TurnMeOn can be seen in Table 1.

| | |
|---|---|
| `help` | Provide a list of valid commands |
| `status` | Display the current status of the light bulb |
| `alias` | Provide an alias for the user |
| `monitor` | Subscribe or monitor this light bulb |
| `on` | Turn the light bulb on |
| `off` | Turn the light bulb off |

*Table 1: TurnMeOn commands*

## 6 ThingMemory

One important concept in the Internet of Things vision is the ability to link a physical object to a cyber representation containing relevant information regarding that specific physical object. In addition, these physical entities often also have a state (e.g. the light is “on” vs. the light is “off”) which is saved and can be changed. In the IoT vision, the physical is controlled from the cyber representation [11]. ThingMemory has been designed to store the cyber representation (its state) and also provide the ability to change the state, by selecting one of the possible states associated with the physical object. Through the web interface, action can be taken on the physical object, resulting in a Java Messaging Service (JMS) message being generated which is processed by Beachcomber (through the TurnMeOn service building block).

ThingMemory utilizes a hierarchical tree structure to model the various cyber representations of physical objects. By navigating the tree, a specific object can be accessed. Higher level "things" can be created through the composition of lower-level things.

Illustration 3 depicts the cyber representation of the "light" with its two commands ON and OFF as rendered by ThingMemory.

ThingMemory is developed as an enterprise application hosted in a JEE (Java Enterprise Edition) environment. It makes use of Jboss Seam for the developed back-end functionality and Java Server Faces and AJAX for the rich interface.

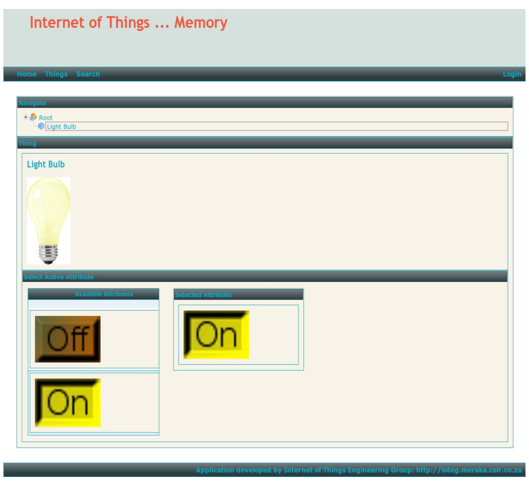


*Illustration 3: Cyber representation of light bulb*

## 7 Urban Control

UrbanControl is an open source electromechanical device that serves as an interface between the digital and physical worlds [12]. It was designed as a generic device that can receive information via the Internet and also send information to the Internet. Embedded in the information are commands and data. Commands are used to control devices in the physical world, and data reflect properties of the physical world as well as supplement the commands.

Illustration 4 shows the conceptual components of UrbanControl and Illustration 5 shows a photograph of the hardware.

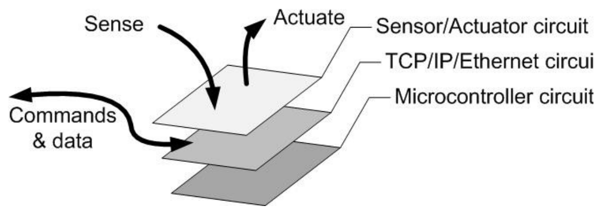


*Illustration 4: UrbanControl conceptual overview*

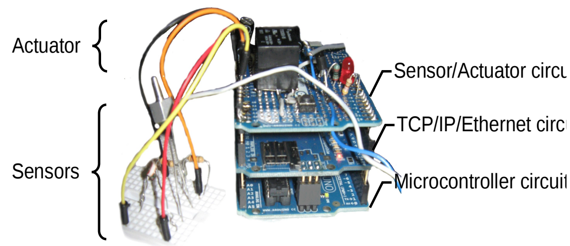


*Illustration 5: Photograph of the UrbanControl hardware*

### 7.1 A Logical Device

When considered as a logic device, UrbanControl can be described as consisting of two major sections:

1. a TCP/IP connection to the Internet,
2. electronic circuitry to interface with the physical world.

### 7.2 A Physical Device

As a physical device UrbanControl is comprised of three major electronic components:

1. an Internet interface,
2. an embedded micro-controller circuit
3. a circuit to sense the physical world and actuate devices in the physical world.

These three electronic components are shown in Illustration 5. Illustration 7 shows the flow of information to and from UrbanControl.

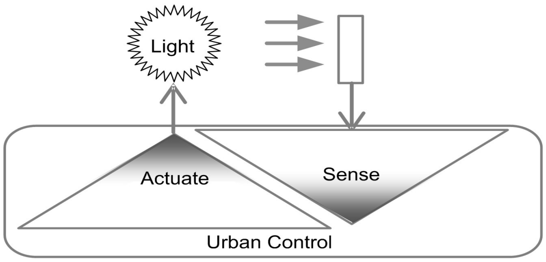


*Illustration 6: UrbanControl flow of information*

### 7.3 Application Domain

UrbanControl has been applied in a context which is currently very relevant to South Africa, that is the domain of electrical energy management. Illustration 7 shows UrbanControl applied in the context of this paper. By rerouting the electricity supply to an incandescent light bulb through UrbanControl, instructions received via the Internet can control the light bulb.

In addition to controlling the state of a light bulb, UrbanControl has the ability to sense the immediate environment using light and temperature circuits. Indications of the light and temperature levels are then made available via the Internet.


*Illustration 7: UrbanControl in context*

### 7.4 Communication

Communication with UrbanControl is done using the HTTP/TCP/IPv4 protocol over an Ethernet physical interface. Commands are received in the form of a parameter which is appended to the URL that points to UrbanControl. As example of a command is:

```
http://address/?light=on
```

The connected light will be switched on when this command is received. Conversely, the command '`light=off`' will turn it off.

Data is returned using the same Internet socket as used for commands. Temperature and light-level data is made available to the IoT in this way.

Table 2 is an example of the information returned by UrbanControl when it is accessed via the Internet. Data is contained in an HTML formatted webpage and can be interpreted by Beachcomber to extract the relevant information such as the temperature and light levels.

```
     UrbanControl: UrbanLight
Connection detected with the
following sent:

GET /?light=on HTTP/1.1

Host: 146.64.28.155 User-Agent:
Mozilla/5.0 (Windows; U; Windows NT
5.1; en-US; rv:1.9.0.6)
Gecko/2009011913 Firefox/3.0.6 (
.NET CLR 3.5.30729; .NET4.0E)

Accept:
text/html,application/xhtml+xml,appl
ication/xml;q=0.9,*/*;q=0.8 Accept-
Language: en,en-us;q=0.5 Accept-
Encoding: gzip,deflate Accept-
Charset: ISO-8859-1,utf-
8;q=0.7,*;q=0.7

Keep-Alive: 300

Connection: keep-alive
ON request received

Available useful readings
analog input 0 -> temperature
indicator
analog input 1 -> light-level
indicator

analog input 0 is at level 196
analog input 1 is at level 157
analog input 2 is at level 219
analog input 3 is at level 300
analog input 4 is at level 295
```

*Table 2: An example of the information returned by UrbanControl when an `on` command is received*

### 7.5 Title and Debugging Information

Information returned to Beachcomber includes a HTML page header and information about the connection request. In this example the HTML page header is "UrbanControl: UrbanLight", and the connection request reveals that a "GET" method was used by FireFox browser running on a Windows operating system.

### 7.6 Data

UrbanControl returns data from the attached sensors, in human-readable form, as part of the web page. In Table 3, data from temperature and light-level sensors, connected to two analog inputs on the Urban Control device, are made available. The other returned values are not of any use because the corresponding inputs have intentionally been left unconnected.

```
Available useful readings
analog input 0 -> temperature indicator
analog input 1 -> light-level indicator

analog input 0 is at level 196
analog input 1 is at level 157
analog input 2 is at level 219
analog input 3 is at level 300
analog input 4 is at level 295
analog input 5 is at level 291
```

*Table 3: An example of the returned temperature and light sensor data*

## 8 Evaluation

The research sub-objectives have been satisfied in the following manner:

1. ThingMemory has been developed to allow people to request information about things or to request things to change. In addition, the XMPP resource adaptor and the MXit resource adaptor in Mobicents can be used for the same purpose.
2. Beachcomber has been configured to route information from people (coming in via many different communication channels) to things.
3. UrbanMemory has been developed to interface with the physical word and to actually switch electrical items on and off.
4. TurnMeOn has been developed to integrate these three components.

As such, the primary research objective has been satisfied. A mechanism has been developed to allow people to switch things on and off via the Internet.

In satisfying these research objectives, the research questions and research sub-questions have been answered:

1. ThingMemory and the XMPP and MXit resource adaptors for Mobicents can be used to allow people to interact with things.
2. Beachcomber can be used to route information and requests between people and things.
3. UrbanControl can be used to switch electrical appliances on and off and to sense their state
4. TurnMeOn can be used to unify these three components

Therefore, the primary request question can also be answered:

> A combination of TurnMeOn, Thing Memory, Beachcomber, and Urban Control can be used to allow people to switch electrical appliances on and off via the internet.

## 9 Ongoing Research

The project described in this paper is an ongoing research project. Since the original success of this project, TurnMeOn has been enhanced to include the continuous monitoring of electrical consumption of appliances.

For actually monitoring the electrical consumption, “Current Cost” equipment was installed. “Current Cost” has been previously used by other organisations in GreenIT applications [13].

As can be seen in Illustration 8, “Current Cost” monitoring equipment includes sensors and associated clamps which go around cables. No electrician is required to install the equipment. The “Current Cost” equipment comes with a USB Base station which communicates with the clamps via a wireless protocol. The consumption values are also forwarded to Beachcomber for processing.


*Illustration 8: Current Cost hardware (Image credits www.currentcost.co.uk)*

Our immediate research is to combine the data captured by the “Current Cost” monitoring equipment with the UrbanControl switching devices to enable intelligent load leveling of electricity consumption.

## 10 Further Research

Further research can be done in the following fields:

1. Ease of Connecting – Further research is invited into developing a mechanism to allow people to easily connect their appliances to the TurnMeOn network.
2. Authentication and Security – As more and more people connect appliances to the TurnMeOn network, a security model needs to be in place to allow participants to give other participants permission to turn appliances on and off and to subsequently remove that permission
3. Identity – With the explosion of connected things, mechanisms are required for identity management
4. More than two states – Further research needs to be done in allowing things to have more than two states.
5. The current implementation of UrbanControl makes use of the IPv4 protocol when assigning an address. Unfortunately the IPv4 addresses space (which is approximately 4.3 billion addresses) is all but depleted, making IPv4 obsolete if the IoT vision were to be realized. A good candidate for replacing IPv4 as the preferred internet protocol, is IPv6. IPv6 allows for approximately 3.4x10^38 addresses which equates to approximately 5x10^28 addresses for each person alive in the year 2010. In order to harness this address space, an IPv6 protocol stack has to be developed that will execute on a network interface circuit which is compatible with the Arduino architecture and cost-point.
6. A wired Ethernet connection is the current physical interface used to connect the UrbanControl hardware to the Internet. We plan to migrate UrbanControl to a wireless connection, using the IEEE 802.11 standard, which we anticipate will simplify the integration of everyday appliances with the IoT.

## 11 Conclusion

In this paper, the design and implementation of a system which connects the digital and physical worlds is presented. Not only are the worlds connected, but a representation of the physical world is maintained in the digital world. It is envisaged that the use of the Internet for this purpose will eventually dominate all others, including social networking and data storage.

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