An Intelligent Lighting system

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1 Introduction

The major cause of environmental disruption is the high consumption of scarce resources. This high rate of consumption can be attributed to three factors: population, per capita consumption and efficiency of consumption. The first is not a technical problem any longer, the second a normative one. The only part of the puzzle that technology can address is efficiency of consumption, and this project proposal aims to do this.

Energy is a scarce resource, especially in these days of cartelisation of oil and pressure to pollute less due to climate change. Therefore, it requires our immediate attention. One of the highest consumers of energy in the form of electricity in urban areas is night lighting. In Bangalore, there are apartment complexes which run into lighting bills in excess of a lakh a month just for basement, hallway and stairwell lighting. CFLs are a solution, but they do not not address the problem of lighting empty basements and stairwells.

This report delineates a proposal for an intelligent lighting system which relies on multi-modal sensing for switching on lights only when required. This report is divided in the following manner:

1. High level description of the system.
2. Description of the components.
3. Progress made.
4. Work remaining.
5. List of supporting documents.

2 High Level Description

The proposed system uses both Passive Infra-Red (PIR) Sensors and Accelerometers to detect presence of a person and switches on lights for a preset amount of time. Other sensors, especially the E-Field Imaging sensor can be used, but those are not addressed here. For lighting, both traditional and new lighting paradigms (White LEDs) are discussed.

The system was conceived from the ground up to be user friendly and simple to install and/or extend so that user acceptance is increased. For a discerning user, a number of system parameters can be tweaked for optimal performance in a given setup.

PIR based lighting is not a new concept, but all existing products in the market are stand alone or with limited connectivity. None of the have a robust and flexible networking system built in to make full use of all available sensors in an area. Since they are not connected to each other, each requires a sensor, which drives up system cost and have to be individually configured, which makes them unviable for large deployments. The present proposal, based on the MC1321x family of 802.15.4 compliant devices, tries to address this issue by using sensors at strategic locations(like entry/exit points) to maximise coverage with the least amount of sensors. Accelerometers on doors are another way of reducing cost since they cost less than PIR sensors and require no signal conditioning circuitry.

The system is designed to seamlessly integrate with the pre-existing lighting system available so that no extra cost is added. Incremental deployments are also an option so that users get to try out the system in a small way before committing to a complete deployment. There is no overhead of configuration when devices are incrementally added which makes this an attractive option. Since the network is device agnostic, one can also add features like automatic Air Conditioning control later. In short, this proposal can be used to do more than just control lighting.

For more efficient lighting, one can also use the option of White LED lighting, which can be far more distributed and efficient when compared to traditional lighting sources. This option is also explored in this report.

Not least, the design tries to minimize exotic components other than the critical sensors and MCU, to facilitate ease of maintenance.

2.1 Network

The network is mesh type with no ‘end devices’, i.e, all nodes act as routers. This is a tradeoff between flexibility and power consumption. For a typical lighting system, the power consumed by the nodes will be negligible.

The nodes automatically form a logical grouping based on Received Signal Strength (RSS). Each node maintains a list of neighbors ordered according to decreasing signal strength and and event sensed is transmitted to a (configurable) predefined number of these nodes.

There is a *source* and *sink* concept used here which is similar to the ’service provided by a node’ concept in Zigbee. Each node can be considered a source or a sink for a particular type of event and they let the other nodes know about this by a broadcast. This information percolates through the network and eventually meets a node which has information about a complementary event and a route is established. This information is used to route data. In this proposal, however, multihop networks are not needed to fulfill the application requirements. This type of routing is called **Rumor Routing** in literature and a slightly modified version is used here.

Rumor routing is more concerned with delivery of data than time/hops taken to do the same. This adds robustness in lieu of response time which is anyway in milliseconds, too small to be noticed by the user.

2.2 Sensing

Like mentioned before, two types of sensing are used. PIR sensors to detect humans and accelerometers to detect opening and closing of doors. The former is useful in open areas like basements and the latter in hallways and can also be integrated into lift doors.

PIR motion sensors consist of a differential sensing element which are differentially illuminated by human IR emission when in motion. Otherwise, the output of the differential elements is zero. PIR sensors are sensitive to all radiation in the human emission band, so animals are also detected. This system provides an option to set sensitivity level of the sensor so that small animals are ignored. The sensors have a tested detection distance of 20 feet and cover an area of 15×15 feet.

Accelerometers are standard fare nowadays and are simple to use. Installing accelerometers on doors enables detection of movement of the door, switching on lights on either side of the door (since it cannot be determined easily whether a person is entering or exiting.)

Due to the connectivity between nodes, one can use a minimal number of sensing elements which increase system cost. One can argue that using MCUs on every node will drive up cost, but it still is lesser than having sensors on every node, and also adds flexibility of configuration and maintenance which make it cheaper in the long run.

2.3 Lighting

Two kinds of lighting are considered here: traditional flourescent lamps and White LED based lighting. The system is designed to use the same PCB for both, populating only certain parts of the board. Again, this is suitable for mass production.

White LED based systems can be dimmed to arbitrary levels, which is taken advantage of and this is also configurable. Traditional lamps, on the other hand, are standard amenable only for on/off kind of control, but give higher wattage capability and are much cheaper as of today.

Sometimes, choosing lights to switch on the basis of RSS may give unexpected results. Thus, there is also an option of manual configuration using a handheld device which eliminates trouble of configuration of hard-to-reach lights.

3 Technical Description

3.1 Network

The 802.15.4 radio in a non-beaconed mode form the underlying basis for the network. Short addressing is used, limiting the number of devices to around 64,000. Realistically, a lighting system may not contain more than a few hundred nodes. Address allocation is done using a hierarchical addressing scheme described in the Zigbee specification for tree networks. This tree structure is not used for reasons other than address allocation and passing on routing information.

The MC1321x platform used is the Y-connect platform from AllGo Embedded Systems in Bangalore (*www.allgosystems.com*). It contains a reference board called Kumbha - 2 which allows application development along with Freescale's BeeKit SDK.

The solution was not built upon the Zigbee Stack that Freescale provides to reduce footprint and enable use of cheaper MCU's. Also, Rumor Routing fit the requirements better than AODV which forms the network layer in Zigbee.

3.1.1 Network start

Network start is by a designated coordinator node which starts a network after scanning a predefined number of channels.

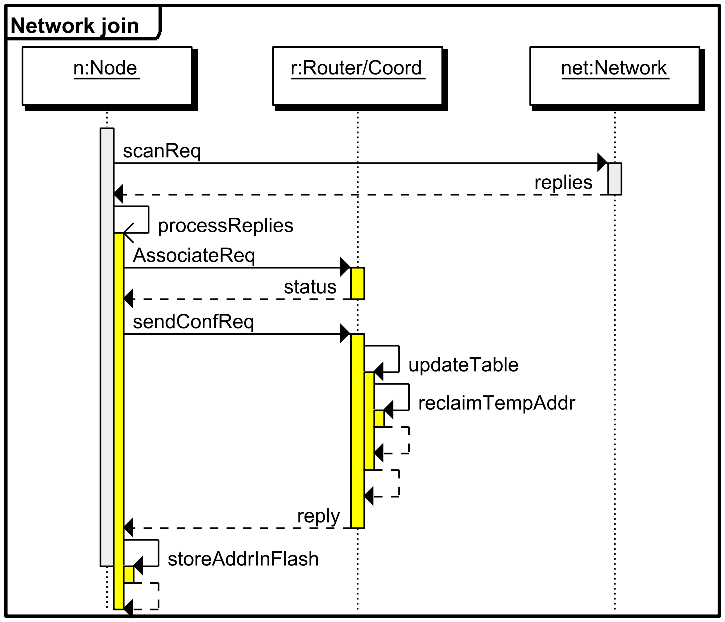

Figure 1: Network Join

3.1.2 Network join

When a non-coordinator node is switched on, it scans for available parents to associate to and associates with one of them based on RSS. Upon association, the node is assigned a temporary address by the parent. This address is used by the node to request configuration from the parent. If the node has no address, it requests for an address and gets one from the parent's pool. If it already has an address, it is indicated in the configuration request and the parents makes a note of this child's address in its neighbor table. The neighbor table is sorted by RSS so that transmissions preferentially reach the nodes with highest probability of reception. The address is then stored in Flash by the child to use for subsequent transmissions. Thus, a new address need not be assigned to a child every time it switches on, conserving the address pool. The temporary address is reclaimed by the parent. This is shown in Figure 1.

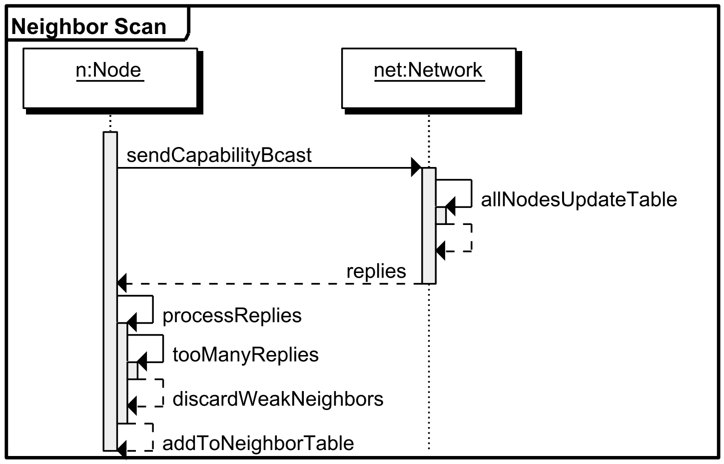

Figure 2: Network Scan

3.1.3 Neighbor Scan

After joining the network, the node broadcasts a 'capability' packet in which it advertises itself as a source and sink for certain predefined events. It then receives 'capability reply' from all nodes which hear the broadcast. It makes a note of as many nodes as practically possible (since allocation happens from a static buffer) and then adds neighbors only if they have a higher RSS than some other node in the neighbor table and removes the last one.

Events are of the form **MOTION_SENSE, LIGHT** for lighting and new ones can be added by nodes designed to perform other types of functions. These may not be predefined which makes it possible to add functionality to the network which was previously not thought of. This is shown in Figure 2.

3.1.4 Event Notification

When nodes generate an event, like motion being sensed, they send out a packet announcing the same to nodes in its table that have advertised a complementary capability. Those nodes which receive the packet know what to do on reception of such a packet and in this case activate the lights. If a node's neighbor table has no such nodes, it broadcasts the packet and this is in turn forwarded by other nodes after decrementing the **number_of_hops** field. When **number_of_hops** becomes zero, the packet is no longer for-

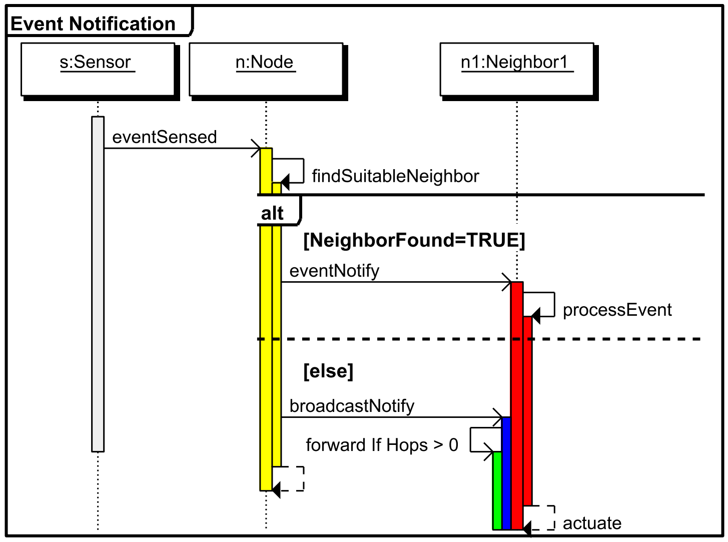

Figure 3: Event Notification

warded. Number of hops is a rough estimate of distance and the number of hops that a packet has represents the spatial influence of the event being sensed. A motion event may have only one hop importance, whereas a fire may have much more widespread importance. This is shown in Figure 3.

3.2 Sensing

The PIR sensor is a Murata E700ST0 sensor with a Fresnel Lens (PPGI0601) from the same manufacturer. This is a popular sensor-lens combination available easily from the online parts dealer Farnell. The signal conditioning circuitry consists of a first order low-pass filter and a level shifter. The analog output of this circuit is fed to pin AD0 of the MC1321x, which collects a sample every 100 ms. The first 256 samples are used to find the quiescent DC output of the circuit which is used as the reference voltage. This is done because the sensor has a initial settling time after which the DC value stabilises. This DC value is stored in Flash so that subsequent starts may not take as much time. DC value is calculated repeatedly and if the value varies significantly from the stored value, the new value is stored. This makes the sensing immune from component value drift due to age or environmental conditions. A (configurable) threshold is set taking into consideration fluctuations in output due to noise in the sensor and a motion event is triggered whenever the input crosses a certain threshold. Supporting schematics are present in Figure 4.

The PCB on which the accelerometer(MMA7260QR2) is mounted is fixed to the door so that the Z-axis values change whenever the door is opened. The output of the accelerometer is connected to AD1 pin of the MCU. Circuit design is according to the reference design given in the datasheet.

3.3 Lighting

Lighting using CFLs or flourescent tubes can be done using an electromagnetic relay. Lighting which uses White LEDs can be dimmed using PWM which can be generated by the MCU. A cluster of high power (1W) White LEDs are placed in an enclosure. These are held in place by a Teflon pad which has holes punched out for the LEDs and this is topped off by a Glass covering. Teflon is used to withstand the temperatures that are close to 100 degree celsius. However, this is a acceptable design for low wattage fixtures with around 6-8 LEDs. High wattage designs require elaborate cooling mechanisms.

3.4 Power

Since these are expected to be AC powered, a simple step-down and rectifier circuit is used. The transformer is chosen to supply maximum expected current. This rectified output is fed to a regulator (LM317T) from which the voltage is regulated to around 5.5 Volt. The supply to the Kumbha-2 is done using a 3.3V 500mA fixed regulator(LM2937). the LM317 is capable of a 1A output which makes it possible for it to drive high power LED loads as well. However, since the PIR sensing circuitry requires high quality DC power, we do not use this option.

Driving the White Power LEDs is done using an LM317T driver circuit. This results in almost an extra watt of power consumption at the normal drive current of 250 mA, but has the advantage of being an extremely simple system with no expensive components. The LM317T maintains a constant voltage of 1.25V between its V_{out} and V_{adj} terminals. Therefore we can setup a constant current by using a resistor of suitable value. For a drive current of around 260mA, a 4.7Ω, 0.5W resistor is used. The schematic is in Figure 5.

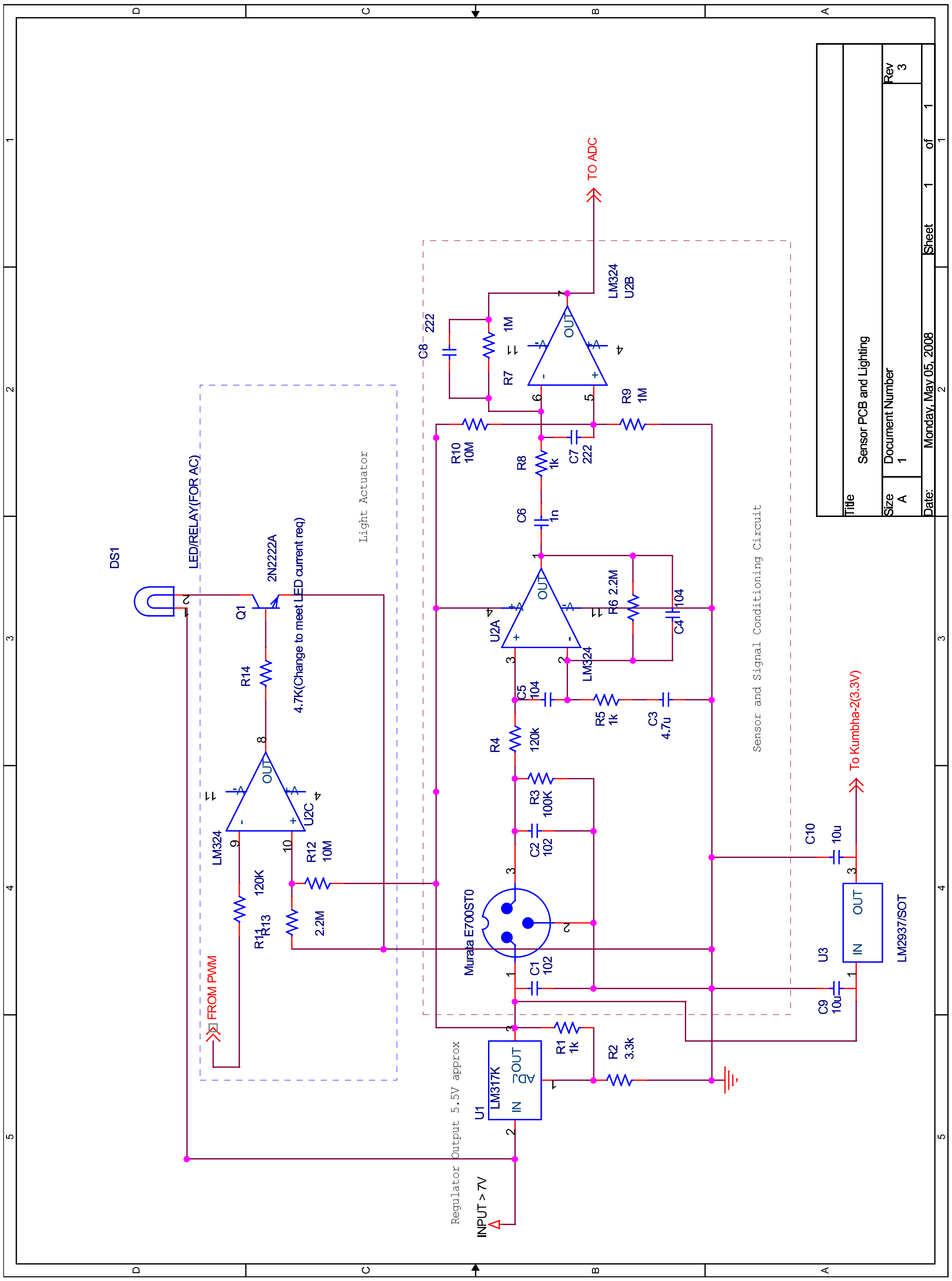

Figure 4: Sensor Circuit

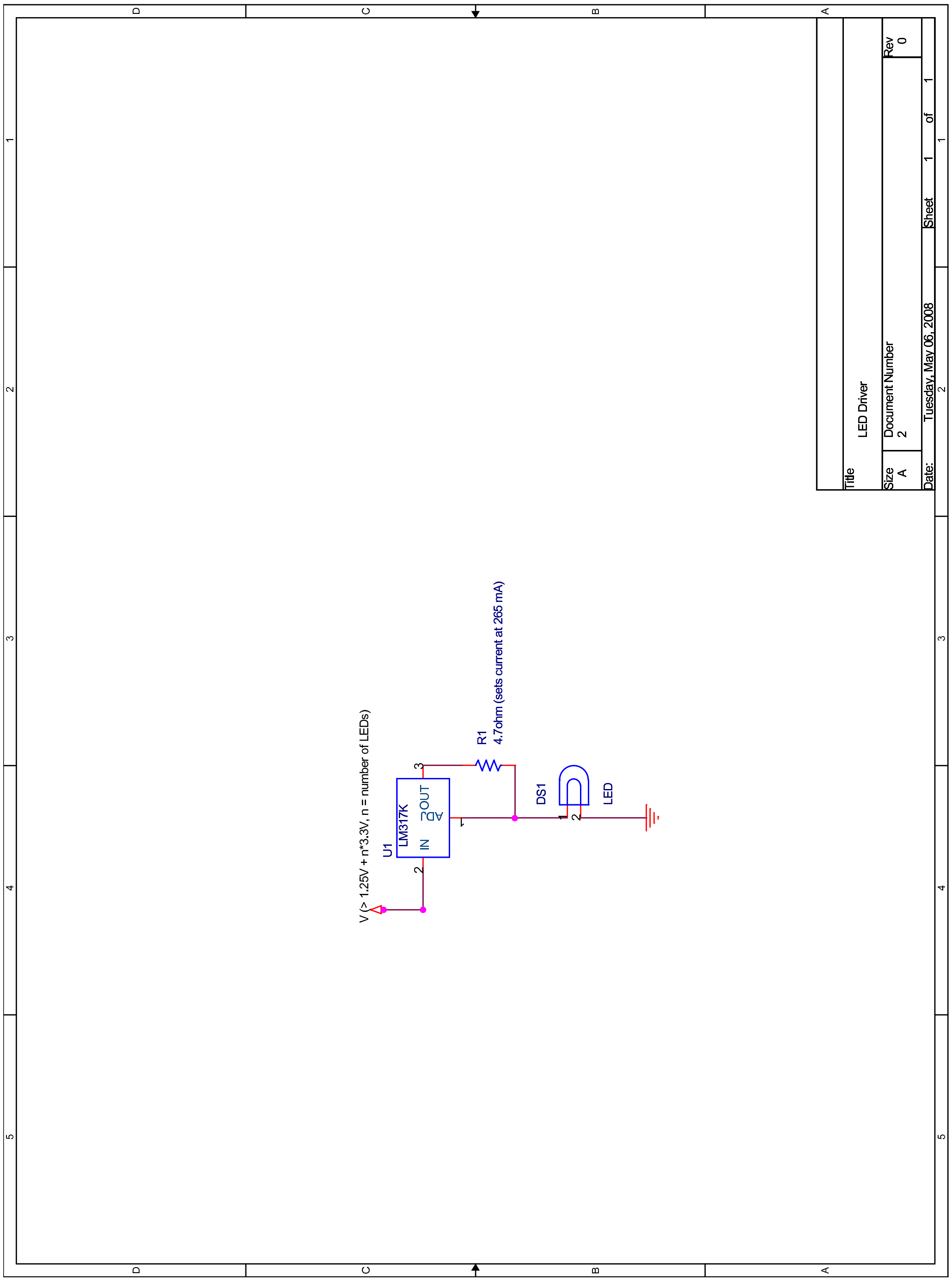

Figure 5: LED Driver Circuit

The actuation circuit from the PCB consists of a transistor (2N2222A) as a switch/current source. The transistor has a maximum current rating of 800mA and a typical gain of around 75. The current can be set by changing the resistor which couples the output of the buffer circuit (in place to protect the MCU) to the base of the transistor. The buffer circuit is active low so that the lights remain on if the MCU fails for some reason. Refer to Figure 4 for circuit details. Since the BJT acts like a constant current source, it can also be used to drive the LEDs without the driver circuit.

3.5 Configuration

The parameters that can be configured are:

1. Number of lights to switch on (subject to a maximum).
2. Which of the neigboring lights to switch on.
3. Time between two ‘activate light’ signals (a hallway can have a longer time, for an aesthetic effect). This is made possible by an internal transmission queue from which packets are periodically sent out.
4. Sensor output threshold to exclude small animals.
5. Number of samples/sec for the ADC. This is a tradeoff between a stable DC value and quick startup time.
6. Bright and Dim light levels in LEDs, i.e, set the duty cycles for bright and dim.

For configuration, a few control commands are defined of the form ‘Get’ and ‘Set’. ‘Get’ reads the present configuration and ‘Set’ modifies it. ‘Set’ can also be used to switch lights on and off to enable the user to see which lights are being affected during configuration.

The user walks with a handheld around the network of lights. The device, with a very low power output, transmits a periodic ‘Scanning’ packet to which it receives ‘Reply’ packets from those that can hear the packet. It presents a list of nodes which have replied and indicates their capabilities to the user (In this case, ‘Light’, ‘Motion Sensor’, ‘Door sensor’, ‘Light and Door sensor’, ‘Light and Motion sensor’). The nodes can also have a description tag which is a string which makes it easy to identify them. When the user chooses one of the options, a 'Begin Config' command followed by a 'Set Indicator ON' command is sent to the node. 'Set Indicator ON' switches on an indicator LED on the PCB so that the user knows by visual cue as to which light she is configuring.

Setting internal system parameters is a simple 'Set *param*' command. For neighbor configuration, the node sends a 'Set light ON' command to all its neighbors to indicate its entire neighbor table or one by one if the user requests a 'Cycle through neighbors' command. In the 'cycle' mode, the user selects those lights which she prefers turned on when motion is sensed. User preferred neighbors are stored in Flash for subsequent actuation.

Since the user may want activation of lights which are not necessarily with the highest RSS, a 'Get Neighbors' command triggers a broadcast from the node requesting all nodes which are a sink for motion events to reply. All neighbors' addresses (upto a predefined maximum) are temporarily stored for configuration purposes. These addresses are removed once configuration procedure is terminated using a 'End Config' command.

4 Work completed

1. The networking software is up and functional.
2. The PCB which is described in Figure 4 has been made and tested to be working fine.
3. The lighting fixture for White LEDs

5 Work to be done

1. Interface the sensor circuitry PCB with AC power and relay.
2. Design and fabricate a PCB for the MMA7260QR2 and test with the Kumbha-2.
3. Design and develop a simple handheld for remote configuration (use UART+computer for prototype).
4. Software for the configuration protocol.
5. Overall integration.

6 Supporting Documents

1. Schematics in Figures 4 and 5.
2. Photographs of Kumbha-2, Sensor and actuation PCB.
3. Photographs of LED fixtures with 2 and 3 LEDs.
4. Datasheet of the PIR sensor and lens.

7 Conclusion

This proposal delineates a very promising technology which looks at eliminating unwanted consumption of power which increases power bills as well as demand on the National Grid. Deployment is a win-win situation for all and calculated payback time on investment is quite low, if one assumes that it cuts power costs by 30-40% (which is likely), which makes it all the more attractive for adoption. ‘Green’ technologies which also benefit consumers have historically been the most easily adopted technologies, and this proposal aims at doing just that.