# 1. Model the Network

## 1.1 Global Configuration

This network is implemented based on choice of Modules ‘Ieee802154Narrowband-ScalarRadio’, ‘Ipv4NetworkConfigurator’ and ‘IntegratedVisualizer’. Setting of the Address Resolution Protocol has two options, ‘Arp’ and ‘GlobalArp’. The configuration in this case is ‘GlobalArp’, because ‘Arp’ provides service for IPv4 and IEEE 802 6-byte MAC addresses [3], ‘GlobalArp’ provides a resolution not requiring packets exchange [5].

## 1.2 Physical Environment Configuration

To simulate the correct condition of system, the structure of building should be considered. As the topography and elevation are not considered, type of ground is set to ‘FlatGround’, and elevation is set to 0m. The temperature of simulation is set to 298.15 K.

Omnet provides two default options for obstacle, ‘DielectricObstacleLoss’ and ‘IdealObstacleLoss’. The previous one simulates power loss through consideration of accurate dielectric and reflection loss along the straight path influenced by shape, position and material of physical objects [4]. Another one calculates power loss by checking whether there is any obstacle along the straight propagation path or not [6]. The environment in this model is setting to ‘DielectricObstacleLoss’ to provide a better simulation.

## 1.3 Parameters of Communication

Each node in simulated network is assumed as the NXP JN516X radio module/system-on-chip. All original parameters from radio module have been summarized in left side of Table 1.1, while practical configurations are listed in right side.

Table 1.1 Comparison between original data and practical settings

| Original Data [2] | | Practical Settings | |
|---|---|---|---|
| Frequency | 2.4 – 2.485 GHz | Frequency | 2.4 – 2.485 GHz |
| Modem | O-QPSK | Modem | O-QPSK |
| Receiver Sensitivity | -95dBm | Receiver Sensitivity | -85dBm |
| Bit Rate | 250 kbps | Bit Rate | 250 kbps |
| Transmit Power | 2.5dBm | Transmit Power | 25dBm |
| Snir Threshold | 3dB | Snir Threshold | 3dB |
| MAC | CSMA/CA | MAC | CSMA/CA |
| Data Capacity(RAM) | 32 kb | Data Capacity | 32 kb |

### 1.3.1 Radio Configuration

As previous design, Radio type in this model is set as 'Ieee802154Narrowband-ScalarRadio'. To simulate practical operation of NXP JN516X radio module, the radio frequency and queue type should be configured. The range of radio frequency (2.4 – 2.485 GHz) is imported by setting 'centerFrequency' to 2.4425 GHz and 'bandwidth' to 0.085 GHz. The queue type has many default options and, because of MAC configuration described in following sub-section, it is set to 'DropTailQueue', which drops packets at the tail of the queue.

### 1.3.2 MAC Configuration

To detect whether channel is available, Carrier sense multiple access with collision avoidance (CSMA-CA) channel access is configured into MAC layer in IEEE 802.15.4 LR-WPAN, which also provide frame acknowledgment, and data verification to improve successful transmission of asynchronous packet flow [1].

In Omnet, 'Ieee802154NarrowbandScalarRadio' module provide a default MAC config with 'Ieee802154NarrowbandMac'. To improve the quality of simulation model, 'CsmaCaMac' is invoked and configured to MAC layer. The default but optional acknowledgements and a retry mechanism is turned off to reduce energy consumption and latency. The probability of successful transmission would be also reduced. However, in this model with multi-hop routing, turning it off is an appropriate choice to reduce transmission pressure.

## 1.4 Application Configuration

The communication protocol of this model is UDP protocol. In this model, the requirements of transmission are low latency, restricted network resource and overloading transfer, while the conditions are short length of signals (10 bytes) and few need of reliability. Features of UDP could satisfy these requirements with few influences from its disadvantages. Therefore, UDP is more suitable for this situation.

The simulation of 'Switch-Hub-Smart Light' architecture is implemented by configure application layer. Different to Switch and light that only need one application for sending or receiving signals, Hub should be configured with 20 applications, which contain different local port addresses for receive and destination addresses for sending. The reaction of Hub is implemented by setting 10s sending interval.

The Smart Lights are divided into 10 groups, which means under control of 10 Switches placed in different rooms. Based on division, corresponding addresses of Lights are set as destination address of sending applications in Hub.

With such configuration, when Switches send generated packet to corresponding destination port in Hub in a random timepoint per 10 second, the applications of Hub will also send a packet to their destinations respectively within 10s, and then received by Smart Lights. This simulation is similar to practical operation so that this model could provide an appropriate result of concerned parameters (e.g., latency).

### 1.5 Energy Configuration

INET Framework provide two options for power model: simpler model ‘Ep’ deal with energy and power quantities and more realistic model ‘Cc’ deal with charge, current, and voltage quantities [7]. For convenience, power simulation in this model would begin with ‘Ep’ model. The following paragraphs would discuss configuration of energy consumer, storage, since there is no need to discuss energy management, which only have one option, and undeployed generators/harvesters.

#### 1.5.1 Energy Consumer and Storage Models

The ‘StateBasedEpEnergyConsumer’ module is considered suitable for this multi-hop network, because transmission and reception frequently happen in this model.

As requirement, the Switches would be powered by battery while Hub and Smart Lights are powered from mains. The implementation of such difference is based on different choice between module ‘IdealEpEnergyStorage’ and ‘SimpleEpEnergyStorage’. The config of Switches is set as ‘SimpleEpEnergyStorage’, while configs of Hub and Smart Lights are both ‘IdealEpEnergyStorage’, which would simulate mains with infinite energy capacity and infinite power flow. The capacity of battery in NXP JN516X is calculated as 100J [2].

## Section 2: Confirming and Validating Model

To simulate partial ability of network, the room 1 and 5 (controlled under Switch 1 and 5) have been kept with connected nodes for multi-hop simulation. As a comparison, room 1 is chosen to perform situation of far terminal nodes, while room 5 is chosen for close situation. Room 1 consists of switch 1 and smart light 1-3, and room 5 consists of switch 5 and smart light 13-16. The arrangement is placed in Figure 2.1.

Figure 2.1 arrangement of room 1 and 5


2.1 Bit Error

To conclude the ability of model in high transmission pressure condition, statistic results of Error Bits Level (EBL) are proposed to present the reliability of model rather than ‘Bit Error Ratio’(BER), which is a statistic result of all transmitted bits. Because, in situation of error message transmission, EBL refer to proportion of wrong bits in messages, which means the severity of errors and difficulty of recovery for this network. In mathematics method, the measure of EBL is filtering those BERs that larger than 0.001 and then calculate the average or median.

The statistic result of EBL is placed in Table 2.1, which contain average and median of EBL (AEBL and MEBL). It indicates that the EBL of far terminal nodes and frequently used communicate nodes are general higher.

Table 2.1 statistic result of Error Bits Level

| module | average | median |
|---|---|---|
| hub.wlan[0].radio | 0.17639 | 0.091677 |
| smartlight1.wlan[0].radio | 0.187085 | 0.247027 |
| smartlight2.wlan[0].radio | 0.104365 | 0.027579 |
| smartlight3.wlan[0].radio | 0.07787 | 0.0312 |
| smartlight4.wlan[0].radio | 0.184347 | 0.111498 |
| smartlight5.wlan[0].radio | 0.160498 | 0.204666 |
| smartlight6.wlan[0].radio | 0.086572 | 0.025606 |
| smartlight7.wlan[0].radio | 0.050604 | 0.012628 |
| smartlight8.wlan[0].radio | 0.10087 | 0.120076 |
| smartlight9.wlan[0].radio | 0.102394 | 0.09297 |
| smartlight10.wlan[0].radio | 0.158282 | 0.179308 |
| smartlight11.wlan[0].radio | 0.137005 | 0.114826 |
| smartlight12.wlan[0].radio | 0.092987 | 0.036273 |
| smartlight13.wlan[0].radio | 0.034147 | 0.046933 |
| smartlight14.wlan[0].radio | 0.031353 | 0.016862 |
| smartlight15.wlan[0].radio | 0.00386 | 0.00284 |
| smartlight16.wlan[0].radio | 0.035337 | 0.016471 |
| smartlight20.wlan[0].radio | 0.1037 | 0.070214 |
| smartlight21.wlan[0].radio | 0.077448 | 0.016442 |
| switch1.wlan[0].radio | 0.224408 | 0.254891 |
| switch2.wlan[0].radio | 0.133638 | 0.161673 |
| switch3.wlan[0].radio | 0.172151 | 0.096171 |
| switch4.wlan[0].radio | 0.06036 | 0.011541 |
| switch5.wlan[0].radio | 0.104605 | 0.064345 |

The farthest nodes (smart light 1, 5) provide highest AEBL. If using MEBL to measure the result, it is apparent that these two nodes have more than 0.2 EBL in at least half times of all operations. The closer distance between nodes and Hub, the fewer EBL those have, because fewer hop it needs.

However, there is a particular situation that nodes (including Hub) for frequent transmission also provide approximate 0.16 EBL average level but fewer median level than farthest nodes, which means the average level is raised by some particularly high data and most data is lower than average level. It indicates that bit error in these nodes is caused by communication traffic.

Therefore, it could be concluded that result of switch 1 is caused by not only far distance and communication traffic, but also sending UDP application from itself, which make traffic more congested.

2.2 Latency

The statistic result of end-to-end delay is placed in Table 2.2 and that of latency of a single room is placed in Table 2.3, which is calculated by adding switch-hub and hub-smart lights based on average or median respectively.

Table 2.2 end-to-end delay

| end-to-end delay | average | median |
|---|---|---|
| switch1-hub.app[1] | 0.314736 | 0.016854 |
| switch5-hub.app[3] | 0.030484 | 0.004881 |
| hub-smartlight1.app[0] | 2.619102 | 1.555534 |
| hub-smartlight2.app[0] | 2.969112 | 1.533612 |
| hub-smartlight3.app[0] | 3.343674 | 1.5582 |
| hub-smartlight13.app[0] | 0.642628 | 0.371319 |
| hub-smartlight14.app[0] | 1.22482 | 0.363825 |
| hub-smartlight15.app[0] | 1.618986 | 0.344343 |
| hub-smartlight16.app[0] | 0.744296 | 0.020737 |

Table 2.3 latency

| latency | average | median |
|---|---|---|
| room 1 | 3.292032 | 1.572388 |
| room 5 | 1.088167 | 0.358965 |

These indicate that the far distance between nodes, the more hops is need, the longer delay it would have. Nodes in same room would share a similar latency level. For instance, smart light 1-3 are placed in room 1, those median of delay are approximate in 1.5-1.6s.

2.3 Power Consumption

The statistic result of power consumption is placed in Table 2.4. It is apparent that those far terminal nodes (e.g., Smart Light 1 and 3) cost fewer power than others. Because, in this model, the power would be cost by transmission and reception of signals. Those middle nodes would be used for both tasks, while far terminal nodes take fewer responsibility of transmission. Moreover, those nodes that must be traversed also require more energy than other middle nodes. For instance, smart light 4 and 7 must be used for shortest route to room 1.

Table 2.4 power consumption

| module | consumption |
|---|---|
| smartlight1.wlan[0].radio.energyConsumer | 57.336 |
| smartlight2.wlan[0].radio.energyConsumer | 72.222 |
| smartlight3.wlan[0].radio.energyConsumer | 52.814 |
| smartlight4.wlan[0].radio.energyConsumer | 96.536 |
| smartlight5.wlan[0].radio.energyConsumer | 62.63 |
| smartlight6.wlan[0].radio.energyConsumer | 82.32 |
| smartlight7.wlan[0].radio.energyConsumer | 97.586 |
| smartlight8.wlan[0].radio.energyConsumer | 60.71 |
| smartlight9.wlan[0].radio.energyConsumer | 79.018 |
| smartlight10.wlan[0].radio.energyConsume | 98.936 |
| smartlight11.wlan[0].radio.energyConsume | 100.664 |
| smartlight12.wlan[0].radio.energyConsume | 99.014 |
| smartlight13.wlan[0].radio.energyConsume | 88.192 |
| smartlight14.wlan[0].radio.energyConsume | 99.314 |
| smartlight15.wlan[0].radio.energyConsume | 102.614 |
| smartlight16.wlan[0].radio.energyConsume | 104.194 |
| smartlight17.wlan[0].radio.energyConsume | 70.806 |
| smartlight18.wlan[0].radio.energyConsume | 90.084 |
| smartlight19.wlan[0].radio.energyConsume | 95.336 |
| smartlight20.wlan[0].radio.energyConsume | 99.914 |
| smartlight21.wlan[0].radio.energyConsume | 95.336 |
| hub.wlan[0].radio.energyConsumer | 100.514 |
| switch1.wlan[0].radio.energyConsumer | 81.268 |
| switch2.wlan[0].radio.energyConsumer | 93.236 |
| switch3.wlan[0].radio.energyConsumer | 90.898 |
| switch4.wlan[0].radio.energyConsumer | 80.856 |
| switch5.wlan[0].radio.energyConsumer | 100.586 |

Section 3: Explore the Network

3.1 Full Network

To evaluate the full ability of network, the whole model is still set into high transmission pressure condition, which means the send time points of switches and hub would approximate close. The overview of full network arrangement is placed in Figure 3.1, and the outcome of full network would be presented in following paragraphs.

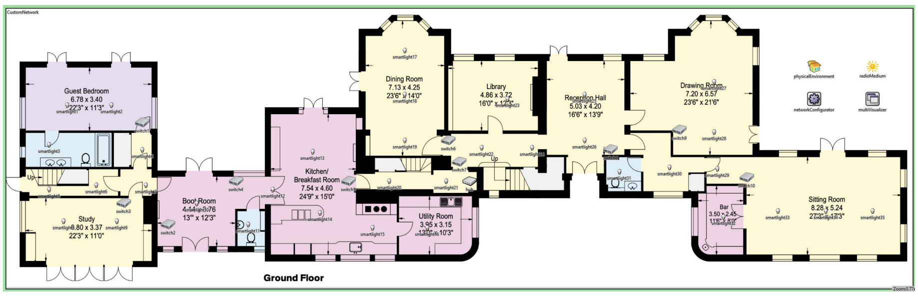


Figure 3.1 full network arrangement

3.1.1 Bit Error

The statistic results of EBL have been placed in Figure 3.1, which illustrates some important information. Above all, it supports the previous conclusion that the reasons of bit error are communication traffic and the number of hops a route need, which is relative to distance. Majority of averages and medians are less than 0.2 and the maximums are less than 0.5. Those means this network could perform well in error situation, especially the average of BER in this model is 0.012. Therefore, the reliability of full network is appropriate.

The outcome of component of room 1 and 5 perform similarly to outcome presented in Section 2, which make the conclusion conflicting as the more transmission do not cause worse bit error. However, there is another point should be highlighted that ‘Aodv require’ signals occupy majority of transmission. To optimize the performance, the ‘Aodv’ signals would be reduced in optimization work.

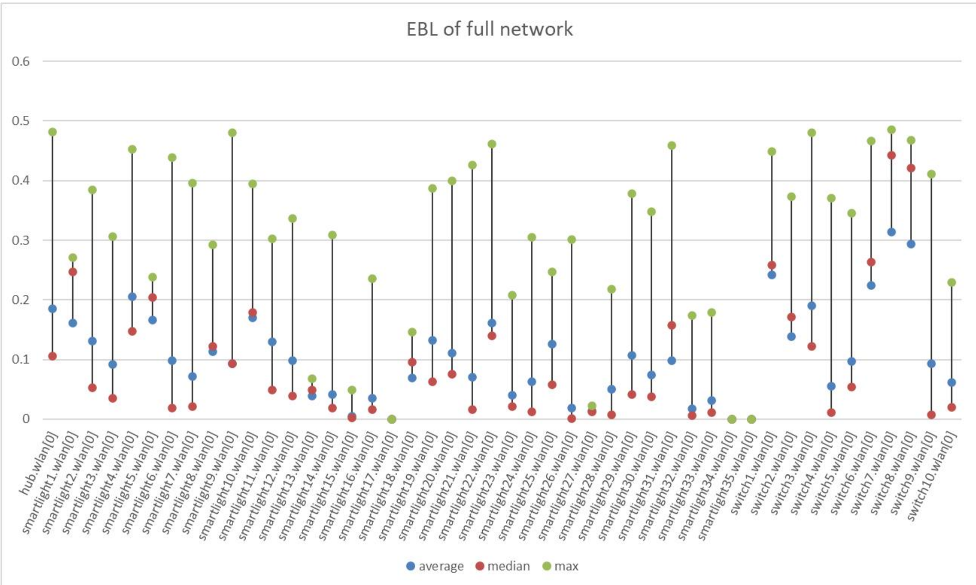


Figure 3.1 EBL of full network

### 3.1.2 Latency

The latency of full network, which is placed in Figure 3.2, has not only supported the conclusion in Section 2 that latency depends on the number of transfer hops, but also provide another important conclusion from the maximum in each node.

The maximums indicate different level of latency, which could be summarize in Table 3.1. It presents how much influence a node would have for latency in condition of both traffic congestion and transmission distance. In the most serious condition, which is the farthest terminal nodes have a packet when channels have been occupied by packets for other nodes, the upper limit of delay would not larger than 8s.

Comparing the data in Section 2.2, the medians do not have apparent differences while averages have a slight increase. This phenomenon presents that the congested situation would not always happen, even the situation has been assumed that all switches are pressed at almost the same time.

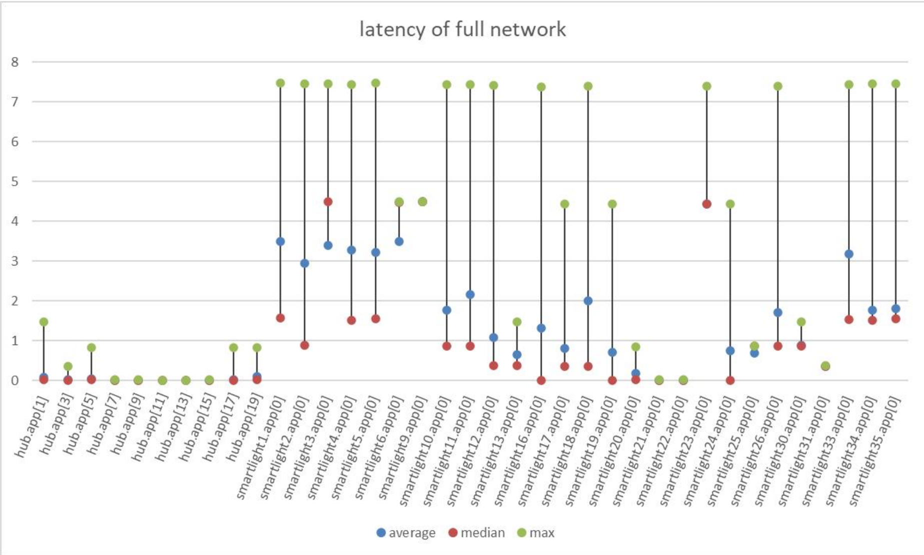


Figure 3.2 latency of network

Table 3.1 latency level

| Level | Latency range |
|---|---|
| 1 | 0-0.5 |
| 2 | 0.5-2 |
| 3 | 4-5 |
| 4 | 7-8 |

### 3.1.3 Power Consumption

The energy consumption outcome of full network (Figure 3.3) makes the conclusion in Section 2.3 more robust. In this case, those nodes around the Hub generally cost more energy than other nodes, because all transmission will implement through them. For instance, Smart Lights 19-23 rank first degree in consumption of light nodes.

Moreover, the general trend of consumption is decreasing with increasing distance from Hub to room. The specific nodes in room cost less energy since it is not frequently used in transmission. Therefore, setting optional nodes for transfer could be a method for the optimization of energy consumption.

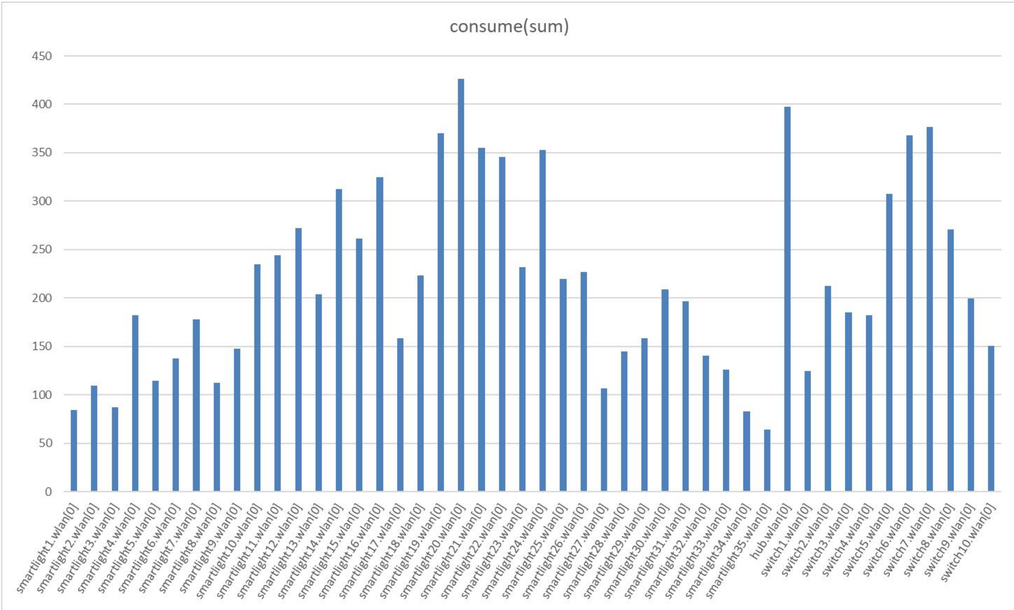


Figure 3.3 energy consumption of full network

## 3.2 Practical Environment Simulation and Optimization

To evaluate performance of this model in practical environments, obstacles should be added into model and the reflection from obstacles should also be considered. Corresponding optimizations consist of three parts. Overall view of rearrangement nodes is illustrated in Figure 3.4.

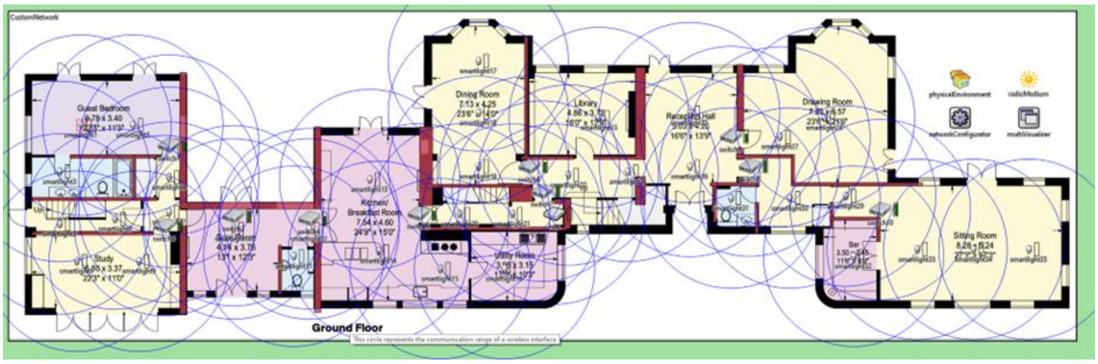


Figure 3.4 overall view of rearrangement

The arrangement of nodes should also be reconsidered to appropriate position. Since some packets are failed to arrive their destinations, especially Smart Lights 1-10, it is necessary to arrange optional nodes for transfer route to release network pressure and change positions of some nodes to bypass obstacles.

The parameters of radio module should be changed to reconnect nodes to each other. Furthermore, the signals of ‘Aodv requires’ bring too much pressure. Reducing that is also an optimization task. The config of parameters is listed in Table 3.2.

Table 3.2 config of parameters

| | |
|---|---|
| transmitter. power | 4 dBm |
| receiver. sensitivity | -85 dBm |
| receiver. energyDetection | -70 dBm |
| aodv. helloInterval | 5 s |

The config of obstacles is added into through XML file and module of pathloss is set to 'RicianFading', which simulate a stochastic path loss with a dominant line-of-sight signal and multiple reflected signals between nodes [8].

3.2.1 Bit Error

The average of BER in exploration model is 0.0034, and the EBL of each node in that is generally reduced, as shown in Figure 3.5. Although there are still some nodes keeping in high level, partial routes have optional nodes to transfer data. This model provides an expected well performance in high transmission pressure condition. Therefore, this model is recoverable when error occurs and is reliable in practical operation.

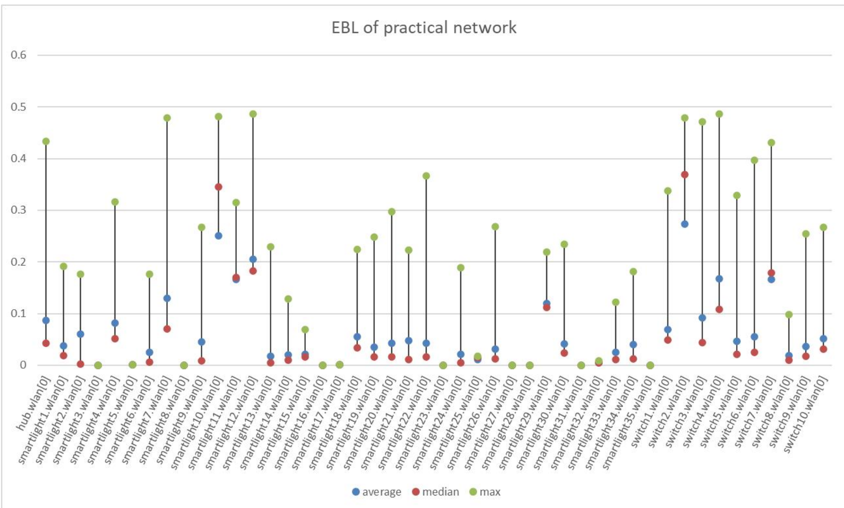


Figure 3.5 EBL of practical network

3.2.2 Latency

Figure 3.6 illustrates the operation latency of model in simulation of practical environment. Apparently, the delay of various nodes has not reduced as expectation since the occupation of channel should have been reduced. It points out one phenomenon that this network has taught its upper limitation of processing transmission.

Another problem should be noticed that some nodes are not presented in the illustration as packets fail to arrive. Because the simulation is assumed into sending all packets in 1 second, which is seldom happening. When the congestion of channels has been severe, the far terminal nodes also require more transmission hops than other nodes. Consequently, the packets are possible to be dropped and failed to arrive destination.

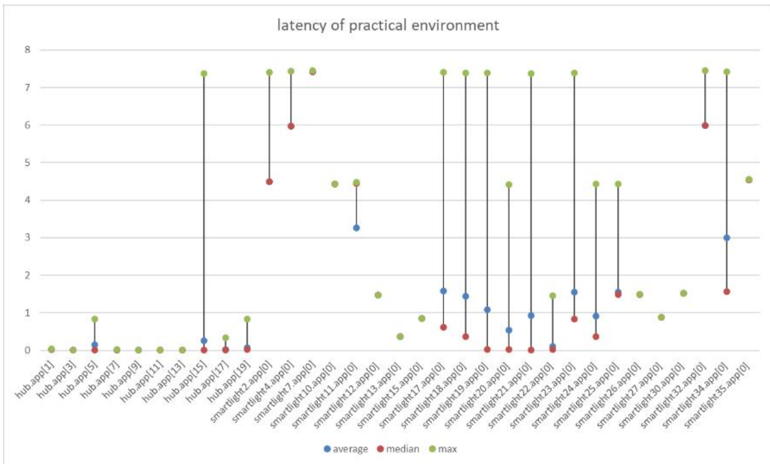


Figure 3.6 latency of practical environment

### 3.2.3 Power Consumption

As transmit power in practical situation have been amplified, which means the energy consumption should be larger, optimization in consumption makes distinct progress. The cost of Lights nodes decreases significantly, as Figure 3.7 illustrates. As the Hub plays an important role in this network, even its cost is also fewer than before, it remains in high demand of power. The exceptions of switches with higher demand, which are Switch 4, 6 and 7, are caused by more frequent data transmission. Because rearrangement of nodes and environmental limitation of routes make these Switches more responsible for transmission. Consequently, the decrement of total power consumption is absolutely higher than increasement of partial nodes.

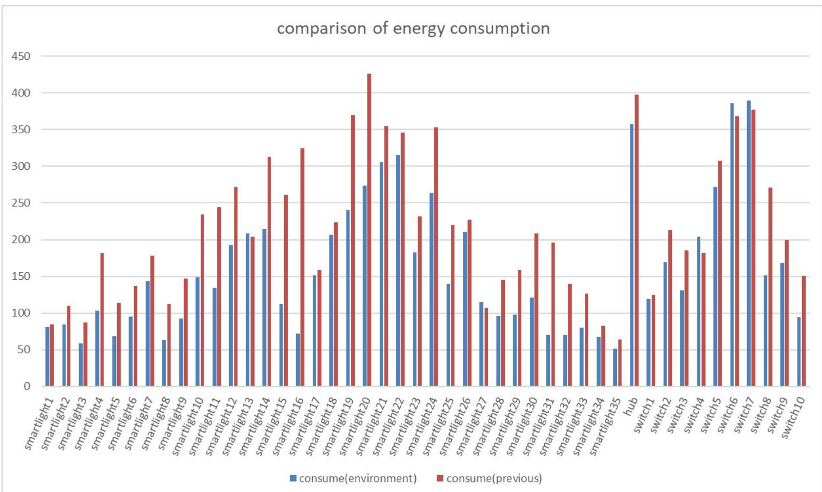


Figure 3.7 comparison of energy consumption

Reference


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