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A Realities simulation platform of LR-WPAN in Smart Home Grid

Abstract. *Applications of LR-WPAN in Smart Home Grid bring difficulties and challenges on the field designs and assignments. Simulation is important for analysis of a complex and harsh network environment in order to provide the performances of it. In this paper, we research on several realities models to develop an enhanced simulation platform to analysis the network performances of a real smart home grid which can advise a field engineer how to build a grid network or make it more reliable and effective.*

Streszczenie. *Przedstawiono zastosowanie platformy LR-WPAN w inteligentnej sieci domowej. Zbadano kilka przykładów zastosowania w celu oceny możliwości tego typu sieci. (**Symulacja platformy LR-WPAN w inteligentnych sieciach domowych**)*

Keywords: simulation platform; smart home grid; LR-WPAN; ZigBee
Słowa kluczowe: WPAN – Wireless Personal Area Network, sieci domowe.

Introduction

Traditional electrical grid has been used for almost a century. In home using, growing customer demands, equipments aging, and shortage of energy resources require a revolution in the grid [1]. A new concept of smart home grid has emerged which is the application of Smart Grid in home buildings. The technology of Low-Rate Wireless Personal Area Network (LR-WPAN) is integrated in the home grid which realizes device-to-device information exchange. Unlike the wired communication, IEEE wireless network technologies require no expensive and strenuous cables installation which supports a cost-effective controlling and real-time monitoring system.

As the convenience of intelligent wireless controlling, the employment of LR-WPANs also brings some new challenges and opportunities. Growing device nodes in a LR-WPAN will increase the scale of a wireless network and the existence of various obstructions will deteriorate the links quality. In practical using, many field engineers have puzzled by these undefined characters for a long time and must spend much time on trying various assignments of a LR-WPAN.

Simulation gives the behaviour of the network and the various applications and services it supports in which various attributes of the environment can also be modified in a controlled manner to assess how the network would behave under different conditions [3]. Simulation is used to predict the performance of a wireless network's architecture, protocol, device, topology, etc [2].

In this paper, we propose a platform to simulate real scenarios (villa, office, workshop, etc) which have different structures and deployments just with simply and quickly parameters inputting. A series of function blocks and models have been developed to obtain the realities performances analysis. The famous advantages are shown as follow.

- Simple user interface

User interface is an important estimation for application software. The simple and convenience nature of the usage will make the software widely used by person on all levels.

- Various link losses of realities radio propagations

The radio propagation model used in the simulators is just free-space path loss (FSPL). In real network, many impact factors such as multipath loss, obstruction declining should be considered.

- Limit of hardware performances

The hardware performances have not been considered in the simulators. Actually, the limit of hardware highly impact on the simulation results. For example, flow- control is one of the limits occurred by the resources of wireless MCU which will make the sending traffic can not increase infinitely.

- Variable user traffic

The traffic models provided by the simulators have some limits which are not well described the real one. More traffic types, multiple destinations should be added to discuss.

These four aspects decrease the difficulty of software using and realize the simulation of a real system. All these will benefit the engineers doing field design of a LR-WPAN or estimating the behaviours of an exiting network.

A Description of Simulation Platform

The simulation platform developed for network performances analysis of smart home grids is divided into three parts: user interface, model API and assistant software. Fig.1 shows the system diagram of a model simulation platform.

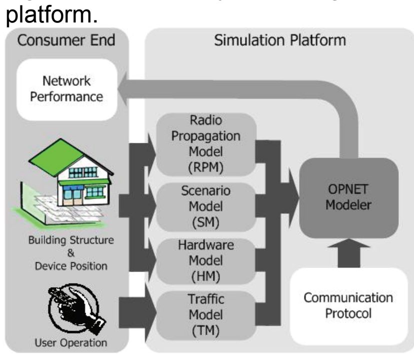


Fig.1. System diagram of model simulation platform

A. User Interface

User interface is a convenient data-exchange between platform and users. No need of professional knowledge, a user can only input architecture drawing, device installations and user operation requirements. The simply usage will make the platform suitable to all users. Through data calculation, statistics and analysis, the network performances of the grids can be obtained, including control latency, average network hops, packet reception rate, network structure or so on, which are changeable with different conditions.

B. Model API

Model API is exacted from a series of experiments in various examples. With characters abstraction of the key factors, we set up Propagation Model (RPM), Scenario Model (SM), Traffic Model (TR) and Hardware Model (HM). It is used TI CC2530 test bench to carry out the field measurement.

1) Radio Propagation Model (RPM)

RPM describes the characters of communication channel. Radio propagation will bring the signal kinds of transmission loss, declining and multipath fading. In real systems, there are numerous obstructions such as partition, wall, brick and large device which will affect the radio propagation of signal. So a semi-empirical method is adopted to set up the RPM. Three kinds of RPMs are discussed as follow.

When the medium is air, the radio propagation is referred to that in free-space. According to FSPL, the equation for the reception power with radio propagation through air is

$$P_{rair} = P_t G_t G_r \left(\frac{\lambda}{4\pi d} \right)^2 \tag{1}$$

where: P_{rair} – reception power in air, P_t – transmission power, G_t –transmission antenna gain, G_r –reception antenna gain, λ – wave length, d – distance between antennas.

A single obstruction can decline the signal intensity only one time. So through the measurement of different obstructions, a single obstruction model can be set up.

In an office, the concentrated distribution of desks requires a large amount of declining calculation. In view of the distances between every two desks are equal and the decline value of one desk is fixed, the declining through desks array is related to the distance. So the reception power through desks is

$$P_{rdesk} = P_{rair} + \frac{d}{D} K \tag{2}$$

where: P_{rdesk} – reception power through desks, P_{rair} – reception power in air, d – distance between antennas, D – distance between desks, K – declining value of one desk.

2) Scenario Model (SM)

SM provides the information of device positions, obstruction types and positions in a scenario. As the user's inputs are just the professional drawings, the model should calculate the propagation path between devices or the type and number of obstructions in this path. To avoid large amount of work implemented by the software, the radio propagation should be optimized to cut off the impossible communications.

3) Traffic Model (TM)

User traffic is not fixed in various applications. Traffic model provides a large database to record the user traffic which will changed by different people. The information of user traffic required for the simulation consists of frame length, device type (transmission node or reception one), operation frequency, etc.

C. Hardware Model (HM)

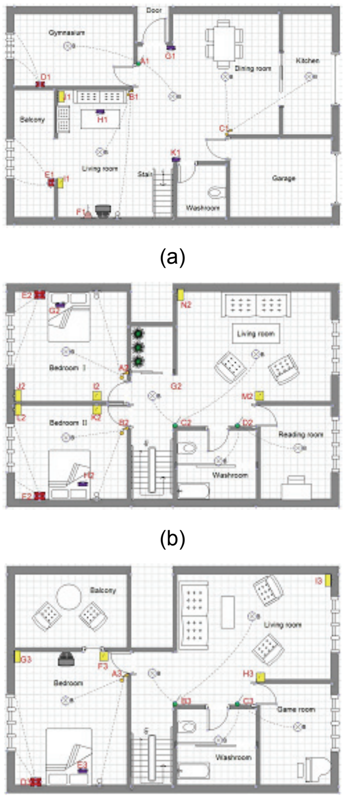
In practical using, the hardware does not have infinite resources which will increase the limit conditions of simulation. So flow control mechanism described in HM should be added to make the simulation results close to the real ones. Each layer of protocol has its own flow control mechanism which is related to different hardware platforms.

D. Assistant Software

OPNET Modeler is selected as the assistant software the engine of which is a finite state machine model in combination with an analytical model. It has strong adaptation skills which can make the coordinate positions importing convenient to create a scenario and professional functions of data collecting and analyzing. The statistic parameters of each layer can be corrected directly which makes drawing conclusion convenient [4]. In this paper, ZigBee is selected as the wireless technology to give an example for platform using [6], [7], [8], [9].

Modeling of a real system

A villa example is given which has the characters of large area coverage, plenty rooms composition and multi-storey structure. The villa is a 3-storey building incorporating 300 m^2 of living space. The size of each storey is 12 m × 8 m and the height is 3 m. Fig.2 shows the electrical assignment of each storey. The villa consists of 3 bedrooms, 3 living rooms and some spaces for other functions with at most 6 persons living. Using the scenario model, the construction drawing and electrical assignment is transformed into the network one.



(a)

(b)

(c)

Fig.2. Building architecture and electrical installation drawing in a villa

As shown in Table I, it is assumed 12 possible traffic sources delivering commands in unicast way and the operating interval should be larger than 100 ms which is selected as packet inter-arrival time of each traffic source, and then the corresponding network load is 10 pkts/s. The performances need to be concerned are changed by the number of traffic sources and various packet inter-arrival times.

Table 1 Parameter of User Operation

Source	Destination	Operation Interval (s)
G1	A1,C1,D1	≥0.1
H1	B1,E1,F1,J1	
I1	J1	
K1	J2,L2,N2,G3,I3	
G2	A2,C2,D2,E2,J2	
H2	B2,C2,D2,F2,L2	
I2	J2	
K2	L2	
M2	N2	
E3	A3,B3,C3,D3,G3	
F3	G3	
H3	I3	

Table 2 Obstruction Declining Value

Obstruction Type	Declining Value (*dB*)
Crossing through one floor	12.9
Crossing through two floors	18.7
Wall I (thickness<10 cm)	3.4
Wall II (thickness≥10 cm)	6.9

In the villa, three kinds of obstructions exit including floor, Wall I (thickness<10 cm) and Wall II (thickness⩾10 cm) the declining values of which are shown in Table II.

What performances can be get

Simulation results output by the platform includes control latency, average network hops, traffic packets and reception rate. According to various demands of users, the results analysis can be focused on different aspects. Some of the normal performances are sampled as follows.

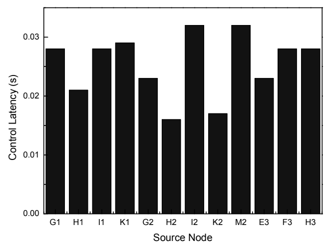


Fig.3. Control latency by different source under traffic of 10 pkts/s

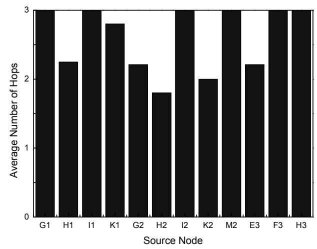


Fig.4. Average hops by different source under traffic of 10 pkts/s

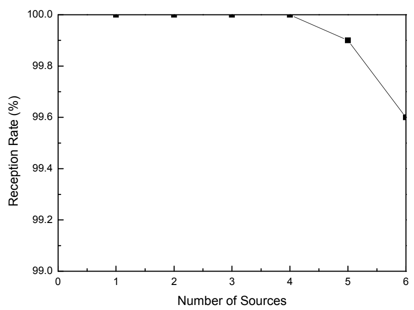


Fig.5. Reception rate by various number of sources under traffic of 10 pkts/s/source

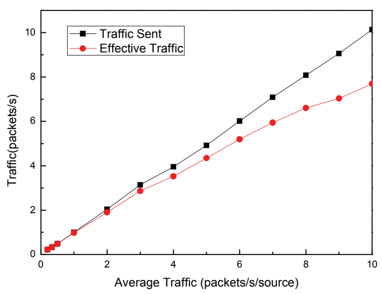


Fig.6. Total packets and effective sending packets by one source under variable traffic

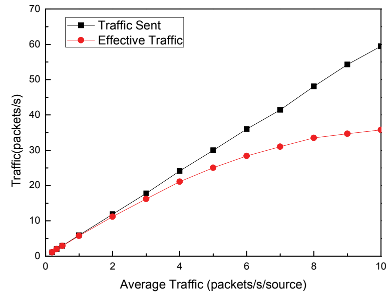


Fig.7. Total packets and effective sending packets by six sources under variable traffic

The control latency and the average number of hops corresponding to different traffic source node under fixed packet inter-arrival time are shown in Fig.3 and Fig.4. The control latency of every service transmission is between 16ms and 32ms when the average network load is 10pkts/s/soure, while the average number of hops is between 1.8 and 3.

Fig.5 shows the packet reception rate with variable sources. From the trend of curve, it is found that the number of traffic sources must be limited to four or less to ensure that no packet loss when average traffic of the network is 10 pkts/s/source. If the number of traffic sources reaches 5 and 6, more traffic will be put into the network which may raise the congestion and decrease the possibility of reception. So the packet reception rate drops to 99.9% and 99.6% correspondingly.

Fig.6 and Fig.7 show the packets by different number of sources under variable traffic. The black curve describes the total packets which are increased in proportion of the growing average traffic. And the red one describes the effective sending packets. While the operating interval is smaller, some packets will be dropped due to the APS flow control and user operation will not be responded successfully. On the other hand, faster the frequency of user operation grows, more packets will be dropped which will decline the effective sending rate and increase the difference value between these two packets. When one source exists and the operation interval time is 1 s, the traffic packets at APS layer could be effectively sent to NWK layer. As the sources increases to 6, these packets could be sent to NWK layer successfully if the packet inter-arrival time is at most 0.5pkts/s/source. If not, the traffic packets of the redundant operations will be dropped by APS data flow control.

In conclusion, if the minimum interval is 100 ms in a villa, one remote control can deliver single control commands without loss of control. And the control latency is no more than 32 ms, within the toleration of human vision. If the operating interval keeps 100ms, it is allowed at most four remote controls in a villa to ensure the transmission correctly. Moreover, when 6 remote controls are enabled to deliver commands at the same time, the operating interval must be more than 2 s, which will cause the latency of 17ms. And the average latency of all traffic is no more than 23 ms. Otherwise, the operation to control the devices can not be guaranteed to be valid all the time.

Conclusion

A model simulation platform has been developed with models building to support the realistic network performances analysis of smart home grid. It can provide field engineers useful advices about network building, devices assignment or the other related. Simple user interface decrease the professional demands for users.

Design by models makes the platform update more quickly and reliably which will keep in step with the development of Smart Grid.

The model simulation platform also can be used in the industrial network or commercial one based on various network technology. To be close to the performances in practical using, more models should be considered which can benefit not only the field engineers but also the device manufacturers and network managements.

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