Evaluation of IEEE 802.15.4 for Use in Smart Home Medical Care

Abstract

The IEEE 802.15.4 wireless standard has been identified as a potential candidate to be used in smart home medical care. This undergraduate research project evaluates the performance of IEEE 802.15.4 under interference from other wireless devices that operate in the same frequency band. Specifically, we focus on two very common wireless interfering systems in typical home environments: IEEE 802.11 WLANs and microwave ovens. The measurement results give a rough indication about the mutual interference of different systems and showcase the challenges of utilizing IEEE 802.15.4 for smart home medical applications.

1. Introduction

Recently, there has been a growing interest in applying wireless technologies in medical applications. A diverse range of medical services can be supported by current wireless technologies. For example, body sensor networks can be formed by placing low-power wireless devices on or around the body, enabling long-term monitoring of physiological signs.[1] The collected data can be passed onto the Internet through a PDA, a cell-phone, or a home computer. The caregivers thus have remote access to the patient's health status. If the physical activities of patients can be monitored reliably at home and at a low cost, it will have a tremendous effect on reducing the gap between the need and the capability of the current health care systems.

Among the available wireless standards, IEEE 802.15.4 is especially promising for smart home medical care, as it was specifically designed for supporting low-power, low-cost, and low-speed ubiquitous communication. IEEE 802.15.4 operates in the 2.4GHz license-free industrial scientific and medical (ISM) band, which is shared by several other wireless networks and devices, such as IEEE 802.11 wireless local area network (WLANs), IEEE 802.15.1 wireless personal area network (WPANs), and even household microwave ovens. Wireless monitoring system at home using IEEE 802.15.4 standard will unfortunately face interference from these devices. Therefore, using IEEE 802.15.4 for smart home healthcare faces special challenges as most medical monitoring applications require high reliability in data collection.

The objective of our undergraduate research project is to perform a measurement study on the interference that IEEE 802.15.4 devices experience from other wireless devices that operate in the same frequency band. Specifically, we focus on two very common wireless interfering systems in a typical home environment: IEEE 802.11 WLANs and microwave ovens. The measurement results give a rough indication on the mutual interference of different systems and showcase the challenges of utilizing IEEE 802.15.4 for smart home medical applications.

The remainder of this paper is organized as follows. Section 2 gives a description of the IEEE 802.15.4 standard and its coexistence with other wireless signals. Section 3 presents our measurement study, including the selection of IEEE 802.15.4 wireless devices, the measurement method, and the measurement results. Section 4 summarizes the project and concludes this paper.

2. Overview of IEEE 802.15.4

A short-distance wireless communication system is more appropriate for the wireless monitoring systems that are used indoor such as in an apartment, a house, or a nursing home environment. If the wireless device needs to be portable and battery operated, the power consumption is also a major concern. The IEEE 802.15.4 wireless standard has been identified as a promising candidate to be used in smart home medical care because of its short-range, low-cost, and low-power characteristics. In this section, we give an overview of IEEE 802.15.4 and its coexistence issue with other wireless standards.

IEEE 802.15.4 versus Other Wireless Standards

The IEEE 802.15 standards aim to create low cost and low power wireless personal area network (WPANs) that typically extends up to 10 meters in range. There are currently three classes of WPANs that are differentiated by data rate, power consumption, and quality of service. These WPANs are currently defined by three classes of standards: the high data rate WPAN (IEEE 802.15.3),[2] the medium rate WPAN (IEEE 802.15.1/Bluetooth),[3] and the low rate WPAN (IEEE 802.15.4/ZigBee).[4] Since IEEE 802.15.3 targets at multi-media applications that require very high quality of service, the other two are more suitable for smart home healthcare applications.

IEEE 802.15.1 is adapted from Bluetooth, which is a telecommunications industry specification for short-range RF-based connectivity for portable devices. Since Bluetooth is geared towards handling voice, images, and file transfer, it has a data transfer rate on the order of 1Mbps with a relatively complex protocol. The operational range for Bluetooth is around 10 meters. With amplifier antennas its range can be boosted to 100 meters, but with higher power consumption.

IEEE 802.15.4 is designed for equipments that need a battery life as long as several months to several years but do not require a data transfer rate as high as those enabled by Bluetooth. The 802.15.4 compliant devices have a transmission range between 10 and 75 meters and a data transfer rate of 250kbps (if operating at 2.4GHz frequency band). 802.15.4 supports a basic master-slave configuration suited to static star networks of many infrequently used devices that talk via small data packets. Compared with Bluetooth, 802.15.4 is more power-efficient because of its small packet size, reduced transceiver duty cycle, reduced complexity, and strict power management mechanisms such as power-down and sleep mode.

Coexistence Issue of IEEE 802.15.4

Medical monitoring applications require high reliability in data collection. However, IEEE 802.15.4 operates in the 2.4GHz license-free ISM frequency band, which is shared by several other wireless standards, one of which is the IEEE 802.11 adopted by WLAN. With the growing popularity of home devices with WLAN interfaces, wireless monitoring system at home using 802.15.4 standard will unfortunately face interference from these devices.

WLANs allow users in a local area, such as a university campus or an office building, to form a network with high throughput and reliable data delivery. Compared with WPANs, WLANs have a longer transmission range (around 100 meters) and higher power consumption. IEEE 802.11

standard specifies the medium access layer and physical layer mechanisms for WLANs.[5] Among the set of 802.11 standards, 802.11b and 802.11g have become extremely popular since their introduction because of their lower cost and longer range compared to 802.11a. Therefore, we focus on investigating the interference from 802.11b and 802.11g, thus from this point on in this paper 802.11 refers to 802.11b/g. Both 802.11b and 802.11g operate on the 2.4GHz frequency band with the same channel allocation. The overlapping frequency allocations of 802.11 and 802.15.4 are shown in Figure 1. Most WLAN wireless routers operate on one of the non-overlapping channels (*i.e.*, channels 1, 6, or 11) with a 25MHz bandwidth. 802.15.4 devices in the 2.4GHz band have 16 non-overlapping channels to choose from, each with a 5MHz bandwidth. The output power of 802.15.4 is typically as low as 0dBm, whereas the 802.11 devices usually operate with a much higher power at 15dBm or above.

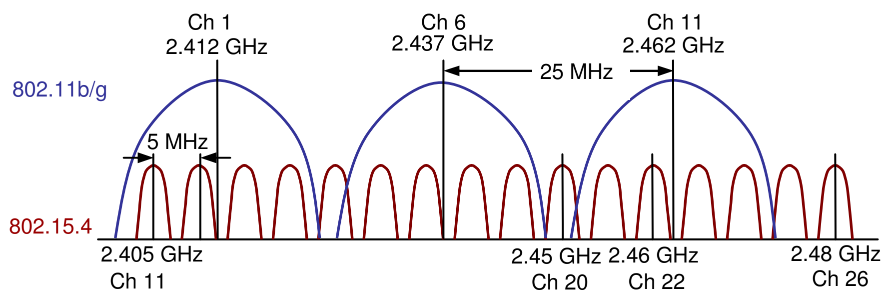


Figure 1. 802.11 and 802.15.4 channels in the 2.4GHz band

Moreover, as most household microwave ovens operate on a frequency of 2.45GHz, the interference from microwave ovens at home cannot be ignored either.

3. Interference Measurement Test

The objective of our undergraduate research project is to perform a measurement study on the interferences of nearby 802.11 WLANs and microwave oven on the performance of 802.15.4 devices. There have been some experimental tests to evaluate the impact of 802.11 on the performance of 802.15.4 performance.[6,7,8] Their work focuses on the worst case by deliberately putting 802.11 and 802.15.4 devices right next to each other. On the other hand, we perform the measurement tests in typical home environment, where the interferences come from the WLAN inside the home and those of surrounding neighbors. We believe that our test environment is closer to the proposed smart home medical application scenario. This project involves one senior student with an Electrical Engineering major.

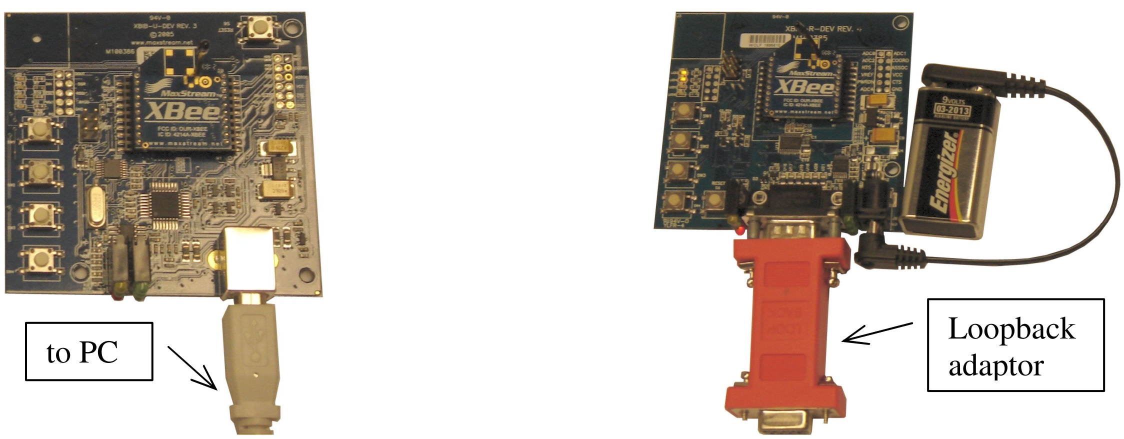
Selection of IEEE 802.15.4 devices

For our measurement study, the Digi/MaxStream's XBee 802.15.4 OEM RF modules[9] from Digi/MaxStream were chosen as the wireless transceiver, as shown in Figure 2. It can operate under transparent mode with a simple connection with a microcontroller. With a chip antenna, it operates up to 30 meters indoor. The transmission range can be further increased to 90 meters by using a whip antenna. The XBee module has a low maximum transmit power of 1mW and a high receiver sensitivity of -92dBm. Our tests were done using an XBee 802.15.4 starter development kit with two XBee RF modules and a software program. The operating channel and transmit power of the RF modules can be easily adjusted through the software program.

Figure 2. Digi/MaxStream XBee 802.15.4 radio modem with a chip antenna

Measurement Tests and Results

We have performed a series of experimental tests to evaluate the impact of WLANs and microwave ovens on the performance of 802.15.4 transmission. The Digi/MaxStream XBee 802.15.4 starter development kit comes with two XBee RF modules: One module (*i.e.*, the "base" module) is mounted to a USB board that connects to a PC; The other module (*i.e.*, the "remote" module) is portable and functions as a repeater by looping data back for retransmission. The measurement test-bed is shown in Figure 3. We used this kit for a point-to-point test, where data are transmitted from the base module, the remote module receives and retransmits data back, and the base module picks the data and compares with the data sent. In every test run, the base module sends out 1000 identical data messages, each with 32 characters in length. The timeout value for data reception is set as 100 msec.



(a) base module *(b) remote module*

Figure 3. The measurement test-bed

<u>Test 1: Coexistence with 802.11 in an apartment scenario</u>

The first set of tests was performed in a one-bedroom apartment on a weekend afternoon. The longest distance between two points in the apartment is about 10 meters (~33 feet), which is within the transmission range of the XBee module. So the two modules should be able to receive each other's data successfully if no interference is present. In this test scenario, neighbors live close in the apartment building. During our measurement tests, eight 802.11g networks were consistently present. Among them, three were with good to very good signal strength (Two were operating on channel 1 and one was on channel 11). The ones with fair but recognizable signals were scattered in channels 1, 6, and 11. Besides these eight networks, a total of nine other different WLAN networks have also appeared during the tests.

We first set our XBee module to work on channel 12 with a center frequency of 2.41GHz. This is a worst case that the offset to the strongest 802.11 channel (*i.e.*, channel 1 in our case) is only 2MHz. We tested the data success ratio under different power levels and the results are listed in Table 1. The result for each test case is an average of 10 runs. When the XBee modules are transmitting at a lower power of -10dBm, the average data success ratio is slightly lower and the standard deviation is higher. Next, we let XBee modules operate on channel 20 with a center frequency of 2.45GHz, which is in the middle between 802.11 channel 6 and channel 11. In this case, there is only minor interference from surrounding 802.11 devices: The data success ratio is always 100% even when the XBee modules are transmitting at a low power level of -10dBm.

Table 1. Coexistence test results for 802.11 and 802.15.4 in the apartment scenario

Power level of Xbee modules	**802.15.4 Channel**	**Data success ratio**	
		mean	**std.**
0dBm (1mW)	12	99.36%	0.39%
-10dBm (100μW)	12	99.21%	0.75%
-10dBm (100μW)	20	100%	0%

Test 2: Coexistence with 802.11 in a single-house scenario

The same test was performed in a single house with two floors and a basement. This house is about 80 square meters (750 square feet) base size and 12 meters (40 feet) from all neighbors. The base module was in the living room and the remote module was in a bedroom in another floor. The distance between the two modules was roughly 6 meters (~20 feet), which is also within the transmission range of the XBee module. During the measurement tests, one 802.11g WLAN was on with the wireless router inside the house and three other different 802.11g neighborhood networks were present. Most of them were using channel 11 including the strongest network inside the house. Therefore, to test the performance of XBee module in the worst case, 802.15.4 channel 22 was selected with a center frequency of 2.46GHz. Moreover, we also tested a better case where the XBee modules are operating at 802.15.4 channel 20, just like in test 1. The data success ratio of the tests in this scenario is shown in Table 2, where the result for each test case is an average of 10 runs.

Table 2. Coexistence test results for 802.11 and 802.15.4 in the single-house scenario

Power level of Xbee modules	**802.15.4 Channel**	**Data success ratio**	
		mean	**std.**
0dBm (1mW)	22	99.89%	0.15%
-10dBm (100μW)	22	99.66%	0.23%
-10dBm (100μW)	20	99.91%	0.08%

The results of test 1 and test 2 show that 802.15.4 devices did experience interference from 802.11 signals. If the user application requires a high reliability, the 802.15.4 devices can select a channel that is further away from the busiest 802.11 channels nearby to avoid the interference. If the 802.15.4 devices can scan the channels to detect the interference and adaptively change their operating channel over time, the performance of the 802.15.4 link would be greatly improved.

Test 3: Coexistence with Microwave Oven

Since microwave ovens operate on the frequency of 2.45GHz, we set the XBee modules to work on channel 20 with a center frequency of 2.45GHz. To test the worst case, we put the XBee remote module right next to the microwave and set the transmit power to -10dBm. The microwave oven has a power of 800 Watts when it is on. Table 3 shows that when the microwave oven is OFF, there is no data loss (Note that channel 20 also experiences less interference from WLAN). When the microwave oven is ON, the data success ratio is reduced to 96.85% with a high standard deviation of 3.22%. However, if we put the remote module to about 2 meters away, the influence from the microwave oven can be removed. Therefore, when used in a smart home health care application, 802.15.4 devices should avoid channel 20 when they are close to a microwave. We also tested the interference of a microwave oven on the two nearby 802.15.4 channels (*i.e.*, channel 19 with a center frequency of 2.445GHz and channel 21 with a center frequency of 2.455GHz). The test results are listed in Table 3, showing that the data success ratio is increased to above 99% when channel 19 or 21 is selected. Therefore, the effect of microwave oven interference can be greatly reduced even if the 802.15.4 devices choose a channel that is close to 2.45GHz.

Table 3. Coexistence test results for microwave oven and 802.15.4 (power level = -10dBm)

802.15.4 channel	**Microwave status**	**Data success ratio**	
		mean	**std.**
20	OFF	100%	0%
	ON	96.85%	3.22%
19	OFF	100%	0%
	ON	99.51%	0.31%
21	OFF	100%	0%
	ON	99.34%	0.19%

4. Summary and discussion

In summary, in this undergraduate research project, a senior Electrical Engineering student performed a measurement study on the use of 802.15.4 devices in smart home health care. Specifically, the student started with a background study of the application of 802.15.4 devices in smart home medical systems. The application of 802.15.4 in enabling body sensor networks for long-term monitoring of human physiological signs was especially explored. Next, the student studied the physical features of 802.15.4 and its coexistence with some other wireless standards and signals in the same frequency band. Last, a plan to evaluate the performance of 802.15.4 in home scenarios was made. The student first selected an 802.15.4 transceiver for the measurement study. This transceiver comes with a starter development kit and a software program that can easily change the operating band and power of the 802.15.4 devices. The student then used this kit to measure the data success ratio of the 802.15.4 transceiver in two typical home scenarios: an apartment and a single house. In these two scenarios, interferences from nearby 802.11 WLANs always present. We find that although 802.15.4 devices experience interference from nearby 802.11 networks, such impact can be reduced by selecting an appropriate operating channel. Furthermore, channel 20 should be avoided when 802.15.4 devices are in close proximity to a microwave oven. This measurement study gives a rough indication on the mutual interference of different systems and showcases the challenges of utilizing IEEE 802.15.4 for smart home medical applications.

In our measurement tests, both the apartment and the single house are wooden frame buildings. The radio frequency signal is not affected too much by the house structure. For example, according to an electromagnetic signal attenuation test performed at the U.S. National Institute of Standards and Technology (NIST)'s Gaithersburg laboratories, the signal attenuation for ½ inch drywall and plywood is below 1dB around 2GHz frequency band.[10] However, if a house is built using steel frames or with a concrete structure (*e.g.*, high-rise apartment buildings and hurricane-resistant houses), the 802.15.4 transmission performance is expected to experience greater degradation by the house structure than from the nearby wireless signal interference, especially when the 802.15.4 signal needs to be transmitted over a long range and pass through walls. This is because steel frames partly reflect radio signals and create multipath propagation effect, and concrete walls absorb radio signals significantly. For instance, the same test by NIST showed that for plain concrete walls and reinforced concrete walls the signal attenuation at the 2GHz band can easily go over 30dB.[10] In such cases, the utilization of IEEE 802.15.4 for smart home medical applications needs to be re-evaluated.

Bibliography

1. E. Jovanov, A. Milenkovic, C. Otto, and P. de Groen, "A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation," Journal of NeuroEngineering and Rehabilitation, 2:6, 2005.
2. IEEE 802.15.3 WPAN Task Group 3, http://www.ieee802.org/15/pub/TG3.html, accessed in February 2009.
3. IEEE 802.15.1 WPAN Task Group 1, http://www.ieee802.org/15/pub/TG1.html, accessed in February 2009.
4. IEEE 802.15.4 WPAN Task Group 4, http://www.ieee802.org/15/pub/TG4.html, accessed in February 2009.
5. IEEE 802.11 Wireless Local Area Networks, http://www.ieee802.org/11/, accessed in February 2009.
6. M. Petrova, J. Riihijarvi, P. Mahonen, and S. Labella, "Performance study of IEEE 802.15.4 using measurements and simulations," IEEE Wireless Communications and Networking Conference, April 2006, pp. 487-492.
7. K. Shuaib, M. Alnuaimi, M. Boulmalf, I. Jawhar, F. Sallabi, and A. Lakas, "Performance evaluation of IEEE 802.15.4: Experimental and simulation results," Journal of Communications, vol. 2, no. 4, June 2007, pp. 29-37.
8. S. Pollin, I. Tan, B. Hodge, C. Chun, A. Bahai, "Harmful coexistence between 802.15.4 and 802.11: A measurement-based study," The 3rd International Conference on Cognitive Radio Oriented Wireless Networks and Communications, May 2008.
9. XBee® & XBee-PRO® 802.15.4 OEM RF Modules, http://www.digi.com/products/wireless/point-multipoint/xbee-series1-module.jsp, accessed in February 2009.
10. W. Stone, "Electromagnetic signal attenuation in construction materials," NIST Construction Automation Program Report No.3. NISTIR 6055. Building and Fire Research Laboratory. National Institute of Standards and Technology, Gaithersburg, Maryland, 1997.