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Early Warning System: Relay Sensor Deployment & Network Reliability Analysis

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EARLY WARNING SYSTEM: RELAY SENSOR DEPLOYMENT & NETWORK RELIABILITY ANALYSIS

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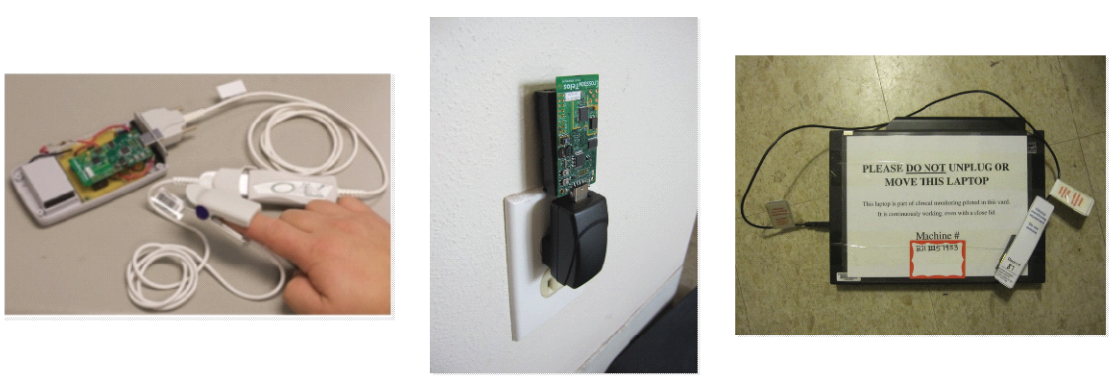
ABSTRACT:
In this project, we continued Dr. Chipara's study, which developed an early warning system (EWS) to detect the vital signs of patients in order to help doctors to intervene in time [1]. Since the number of wards increased, the environment our system faced with became more complicated and our network became more sensitive. This project focused on finding reasons on the relays that didn't work and doing a reliability analysis on the network in one ward our study covered.

1. Background:

Clinical deterioration of patients in hospital is a major concern. Of the hospitalized patients, 4% – 17% suffer from adverse events, like cardiac or respiratory arrests. A former study found that 70% of such events could have been prevented. Thus, detecting clinical deterioration early is so important that doctors can intervene before a patient goes worse. Most patients can show variations in their vital signs hours prior to an adverse event. [1]

This project was a continuous study based on Dr. Chipara's study, which focused on only one ward in Barnes-Jewish Hospital (BJH). We expanded our previous study to more wards. It meant the enrolled patients became more but also the network became more complicated. There are three parts in our system, patient node, relay node and base station node. A patient node (shown in Figure 1(a)) measures and transmit the heart rate and blood oxygenation of patients. A relay node (shown in Figure 1(b)) forms a mesh network that provides connectivity between a patient nodes and a base station. A base station node (shown in Figure 1(c)) receives data from patient nodes and relay nodes.

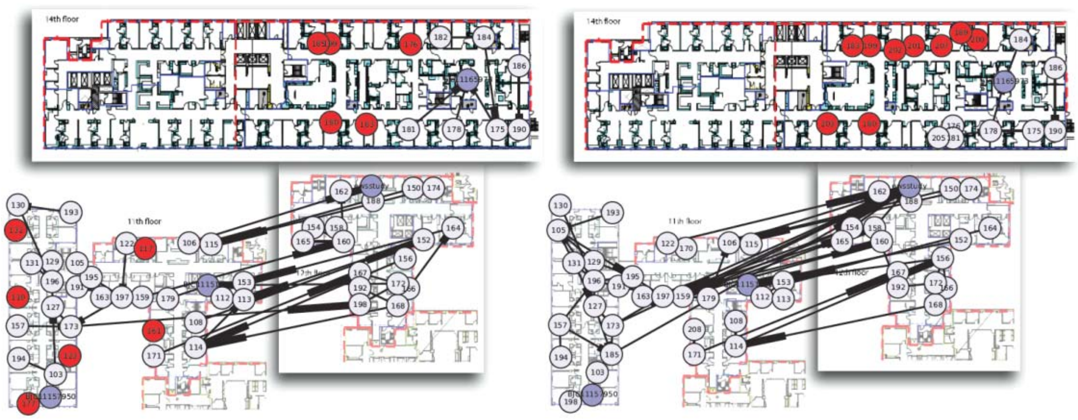


(a) patient node (b) relay node (c) base station node

Figure 1: Hardwares used in the wireless early warning system.

2. Relay sensor deployment

Dr. Greg and Rahav had already deployed relays on the 11th and 12th floors before I joined this project and I deployed relays on the 14th floor. When we wanted to check the status of our relay network, we could generate a topology map. Although we could see the exact details of every relay in our database, including the times of disconnection and the paths to base station, but a topology map could give us a visual touch to our network reliability.



(a) Topology map A from February **(b) Topology map B from March**

Figure 2: The purple spots are base stations. The light blue relays work well. The red relays mean they are disconnected. The black lines represent hop links.

A shortcoming of the topology map generation was that the generation was not automatic, that is, we don't generate it until we need. However, we couldn't monitor the network in time by this way. For example, when we see a red spot on it, it may have already been red for several days. Thus, an automated topology map generation is developed, which was generated every 15 minutes. So even though missing a critical point, we can track the storage folder to see what happened.

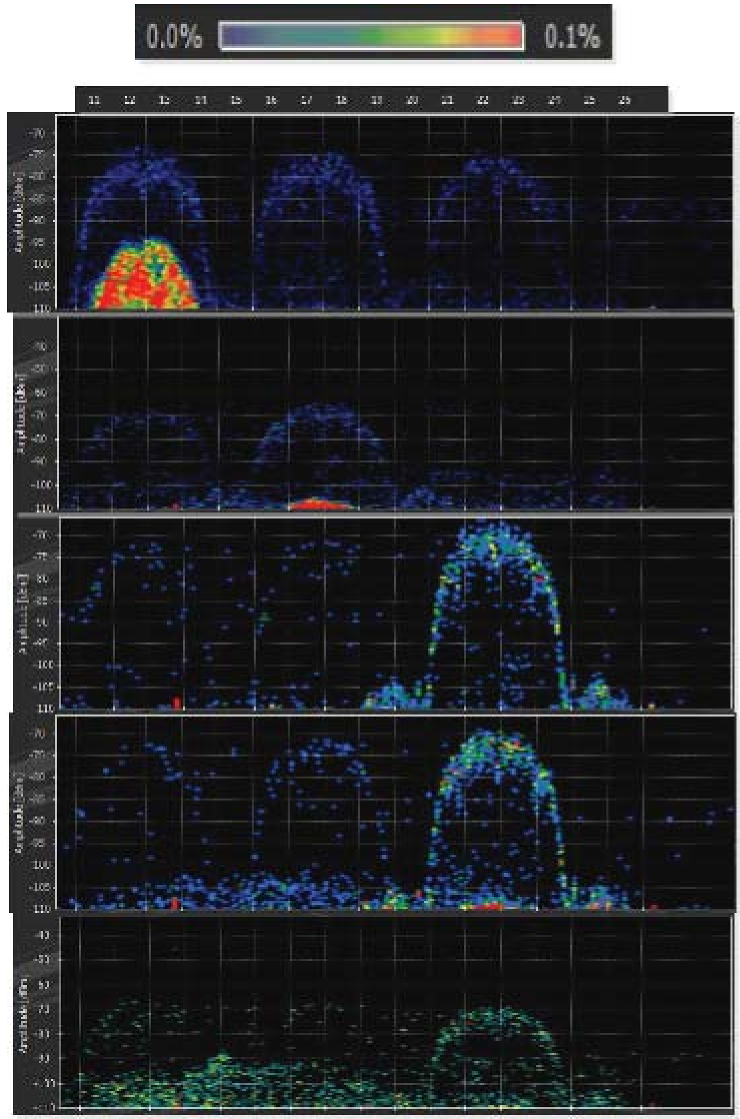
3. Network Reliability Analysis

When the replacement of red relays on 11th and 12th floors was done on February, the network on these two floors always stayed perfect (shown in Figure 2(b)). But there was still a network issue on the 14th floor -- sometimes the network had a big part failure. After more relays were added at patient rooms, the issue still occurred. In order to find the reasons, some hypotheses were provided.

3.1 Is the channel clean?

Because the relays worked so well on the 11th and 12th floors, our system had no problem. The first possible reason for the failure happened on the 14th floor is the channel interference. Wi-spy is a device, looking like a USB flash drive with antenna, used to test the signal strength of each wireless channel. Our device uses #26 channel. In this project, five rooms were tested, including good connection rooms and bad connection rooms. Each room had a 30-minute testing. Figure 3 shows the #26 channel is always clean.

(a)Wi-spy 2.4x



(b) Wi-spy Spectrum in five rooms.

Figure 3: The signal density distribution in channels is shown on the Figure 3(b). The darker the color is, the higher the signal density is. The x axis is the channel number. The y axis of each figure is the amplitude and the interference below 85 can be ignored [2].

3.2 People movements

According to my observation, during eating times, the network became more vulnerable, compared with it is in midnight. The possible reason is people movements influence the network. A breakfast time and a housekeeping time are in the morning; a lunch time is at noon and a dinner time is in the evening. In those time slots, people movements are increased. Besides, a potential time slot is the visitor time which is officially from 9am to 9pm, however, it's difficult to know which rooms visitors go in and how long they stay there.

3.3 Floor structure

The relays on the 11th and 12th floors prefers vertical connections, even though a neighbor relay in the next room. But on the 14th floor, there is only horizontal connection. So the floor structure and people movements are much more critical aspects than they are in the two other floors. The length and width are much larger than the wards on the 11th and 12th floors. And the restroom area is between two rooms, which could be regarded as a thick wall, rather than besides the front doors as it is on the 11th and 12th floors. The packet reception rates (PRRs) between several rooms were tested in order to investigate the interference of the walls. Two sensors were used in this test: one is the sender and the other one is the receiver. The sender sends #1-100 packets repeatedly. The packet sending rate is 1/4 second, so the sender spends 25 seconds to finish one full round (1-100 packets). East room test lasted about 2 minutes, thus, about 4 full rounds of packet sending were obtained, and then the average PRR value was calculated. Figure 4 shows details.

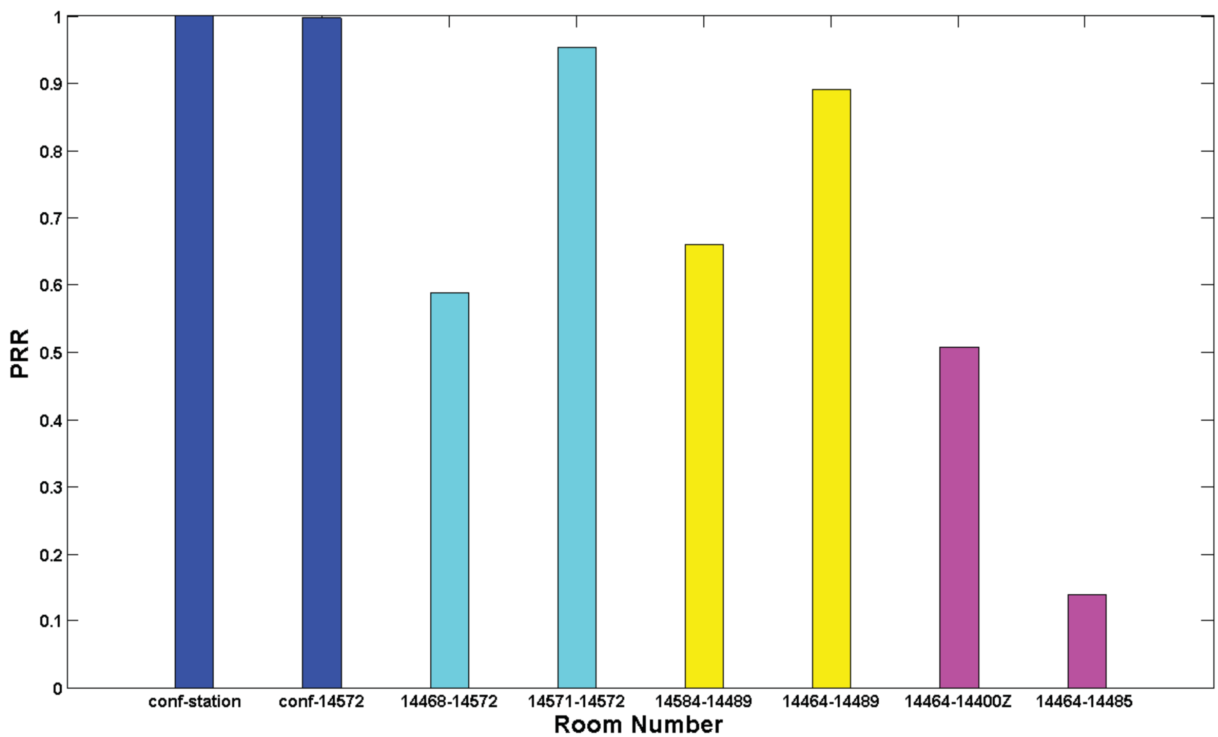


Figure 4: PRR tests for several rooms on the 14th floor

In Figure 4: (1) The blue bars show single wall is not a big deal (base station--Relay #184); (2) The bright blue bars show the restroom area's influence (14468--14572 means Relay #189--#184); (3) The yellow bars show a relay prefer another relay on the other side rather than its neighbor if the central area has no working block (14464 is on the other side. 14489--14584 means Relay #180--#181. 14489--14464 means Relay #180--#202); (4) The pink bars show the central block's dramatic influence (Relay #202--the room between 180 and 205 and Relay #202--#205).

Based on Figure 4, the walls indeed impacts the connection, also, the central working area is a big deal. According to our previous experience, we just deployed the relay in patient rooms. But due to the wall and central working area, some relays prefer to connect some other relays on the other side rather than the neighbor ones. If there is no better choice, a relay has to connect to the neighbor relay. So there are some critical links, if these links failed, part of network will turn red.

3.4 Distance

The next thing need to be verified the distance is another element influencing our network. The database from

March 1st to March 31st was chosen. Since after February, we got an excellent network on the 11th and 12th floors and good network on the 14th floor, most of relays had their stable locations and status. Every relay sends a beacon per minute to the base station. Figure 5 shows every relay's beacon reception rate (BRR) on the 14th floor in March.

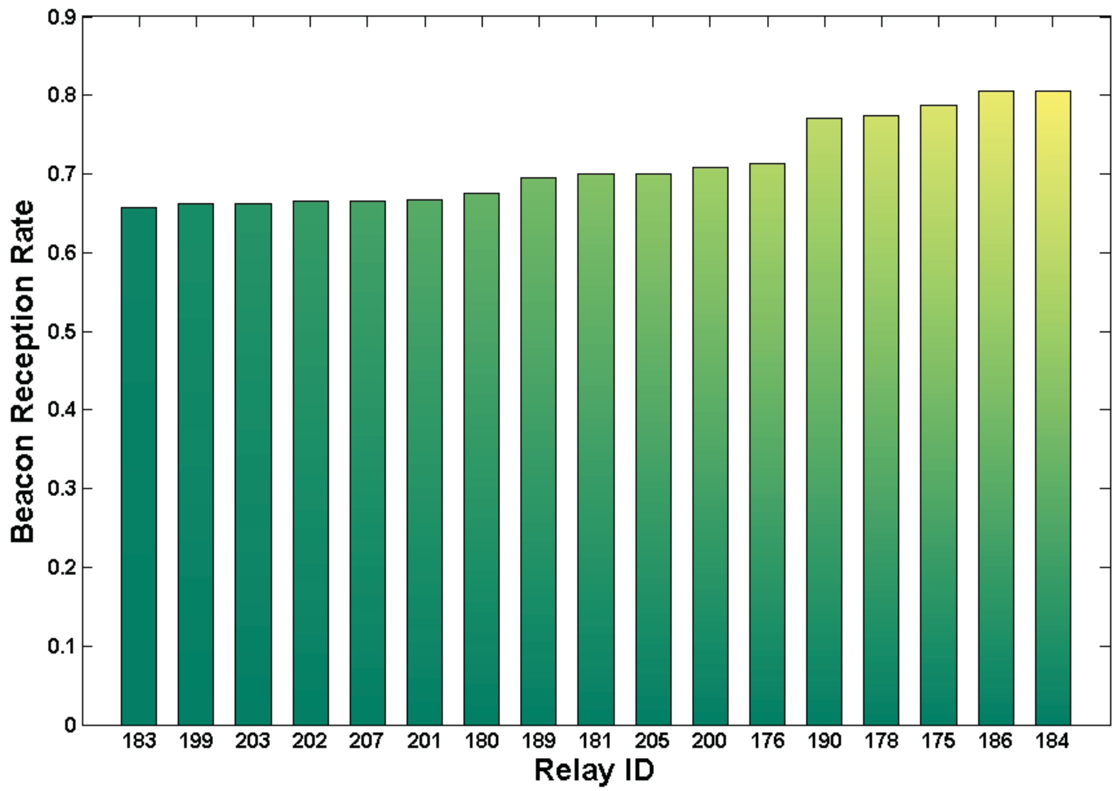


Figure 5: BRR of all relays on the 14th floor

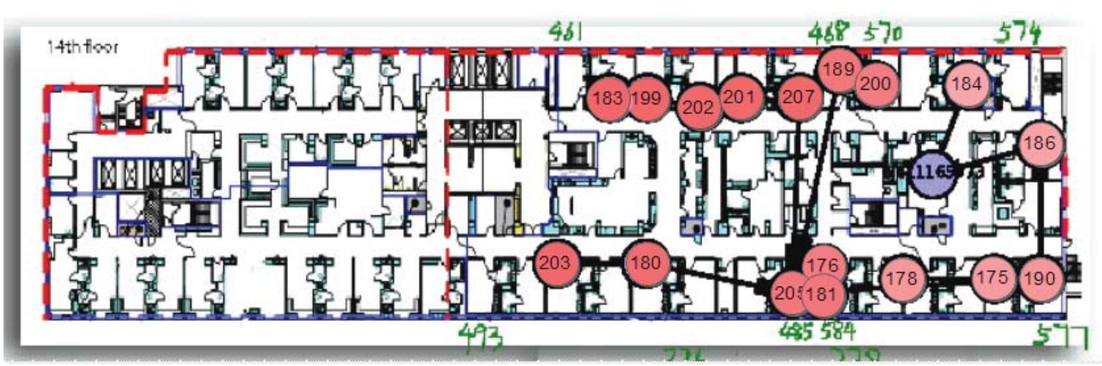


Figure 6: A sketch based on the BRR value (-100 to 100 is black color to white color and 0 is red, the color for each relay is calculated by the formula: "BRR value×200－100".)

Figure 6 helps to see when the distance between relay and base station is farther, the color is darker and the BRR is lower. This result matches our perception. Since the relays which are more closed to the base station have less hops to connect it, the risk of disconnection is lower.

3.4 Solution

To deal with the network issue, from April 15th, I moved most of relays from Ward 145 to Ward 144 and put them in the central part in order to build more critical links. Figure 7 is a current map on the 14th floor. Based on several 24-hour observations, the network has been improved. If the network on the 14th floor is still not perfect, we will move the base station to 144.

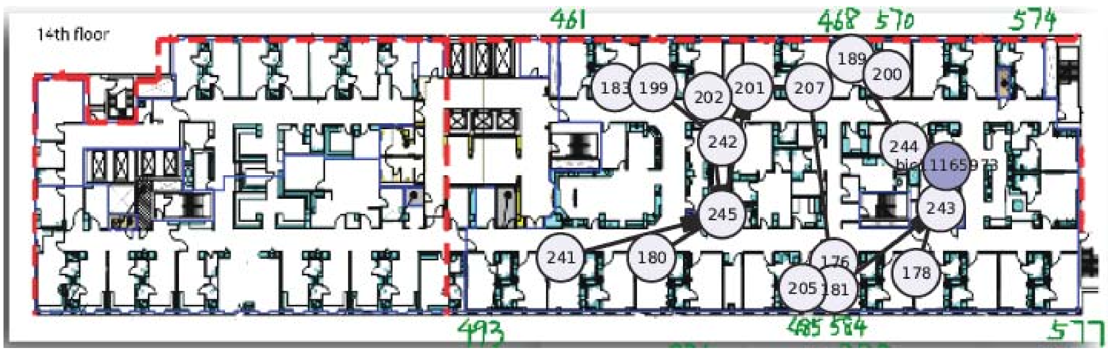


Figure 7: A 14th floor topology map from April

4. Conclusion

For several hypotheses above, (1) The #26 channel is clean, so this possible reason is eliminated. (2) Human movements seems influence our network, especially during the eating time, but more investigation should be put on this part. (3) Floor structure on the 14th floor indeed influence out network. The restroom area between two neighbor rooms hinders the wireless connection and the central block is such a big deal. Both of these two aspects lead to our network has several fragile critical paths, if those paths are disconnected, a big part failure will occur. (4) When the distance between a relay and the base station is longer, the connectivity is lower.

The feasible way to improve our network is to move relays to the central part in order to enhance the connectivity in the central block and relieve the burden of critical paths. At the same time, keep enough amount of relays around, because the horizontal connection need more neighbor relays.

5. Future Work

For the hypothesis of human movements, more analysis need to be studied. Some data analysis by hourly should be investigated. For example, we can divide one day into different time slot, and specially hourly watch the connectivity of each relay per hour. And then compare the same time slot in each day in one week in order to see if the eating time indeed influence our network. Another way is to physically track the stuff who sends food to every room. The trace should be recorded and then retrieve our database and see what happened on the network then. Finally, we can get a more convincing conclusion on this hypothesis.

REFERENCE:

[1] "Reliable Clinical Monitoring using Wireless Sensor Networks: Experiences in a Step-down Hospital Unit", O. Chipara, C. Lu, T. C. Bailey and G.-C. Roman. ACM Conference on Embedded Networked Sensor Systems (SenSys 2010).

[2] "Multi-Channel Reliability and Spectrum Usage in Real Homes: Empirical Studies for Home-Area Sensor Networks", Mo Sha, Gregory Hackmann and Chenyang Lu. The 19th IEEE International Workshop on Quality of Service (IWQoS 2011).

[3]"Wi-spy" http://www.metageek.net/products/wi-spy/

The source code, slides, write-up and figures used in slides can be downloaded from:
http://students.cec.wustl.edu/~zy4/master_project/