A Wireless Network Sensor and Server Architecture for Legacy Medical Devices

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***Abstract*—Modern medical devices have the facility to output data such as device settings and readings. Such devices include Vital Signs Monitors, Ventilators and Infusion Pumps to name a few. Wirelessly networking these types of devices has the advantages of patient mobility, device mobility and central data storage. This has led us to develop wireless sensors, gateways, servers and clients to support legacy medical devices.**

In this paper we present results from a hospital usability trial of this newly developed technology. We present the final wireless sensor network architecture used in the trial which also supports other compatible sensors we have developed. This also includes the architecture detail that supports the addition of future medical devices.

***Index Terms* — Biomedical Telemetry, Medical Devices, Bioinformatics, Wireless Sensor Networks, Healthcare Information Systems.**

I. Introduction

In today's hospitals there are several different types of electronic medical device equipment in operation at the bedside in both the hospital ward and ICU (Intensive Care Unit). Among these are Vital Signs monitors used for measuring blood pressure, body temperature and Pulse Oximetry; Electrocardiograph (ECG) monitors for analysing the activity of the heart; Infusion Pumps electronically control the delivery of fluids and medication to patients. Also, another medical device widely found is the Ventilator, used to assist patients in respiration. It is desirable to collect settings and data from these specific devices automatically and store this information centrally in a patient's Electronic Health Record (EHR). However, hospitals have often heavily invested in devices that may not support networking. Even when a device has a networking option, a compatible server specific to that manufacturer's brand of medical device must be purchased. One of the goals of our work is to support central data collection from all these types of devices regardless of type.

Even if a medical device does not support networking, typically it will have a data output feature. This can be in the form of a serial port or USB interface, for example. We have developed a piece of hardware called the Medical Device Interface (MDI) that will connect to the serial port on any medical device and transmit and receive data wirelessly. This allows the collection of data centrally from any medical device that has an MDI attached. The MDI design supports any medical device regardless of protocol for retrieving data or particular serial port settings. Additionally, there are plans to expand the hardware to support other types of interfaces.

By networking medical devices it is possible to collect data centrally and by networking wirelessly there are additional benefits. Firstly, it is easy and cheap to expand your networking capability by simply installing additional routers. Secondly, by using wireless technology the devices are now mobile. This enables data collection from any bedside and also while patients are on the move. On this project we selected Zigbee [1] wireless sensor network technology as it meets these requirements in addition to having other benefits. It is built on a widely adopted IEEE standard, 802.15.4 [2]. It is a self-forming, self-healing mesh network which means data can find its way to a gateway via other nodes in the network. This type of redundancy is important when dealing with medical data. It is designed for low data rates and it features low power consumption. By entering a sleep mode between transmissions battery life can be increased. The advantages of Zigbee and how it bests fits this projects requirements are outlined in our paper entitled "Using Zigbee to Integrate Medical Devices" [3].

This paper examines related work which is being carried out elsewhere. We aim to highlight the advantages of our system and how it can benefit hospitals today. We discuss the network and software architecture surrounding our technology that was used in our hospital usability testing. More specifically we examine the MDI, the Gateway and the Server. Finally we present the results from the trial. The results show how we were successful using the MDI to communicate and collect data from a critical care ventilator. We also discuss feedback from the clinical engineers in the hospital and the next steps forward for the project.

II. Related Work Review

There has been much advancement in the research and development of solutions for the medical industry using Wireless Sensor Networks. Some have focussed on home care

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solutions while others have looked at using wireless sensor technology in emergency situations both at the accident scene and in the emergency room. Also, there is currently a large amount of research in the area of wearable sensors for measuring vital signs data.

The CodeBlue project at Harvard University have developed a wireless sensor network infrastructure intended for deployment in emergency medical care, integrating low-power, wireless vital sign sensors [4].

The paper entitled “IEEE 802.15.4 Wireless Mobile Application for Healthcare System” applies the use of cellular networks to transmit vital signs data from people in their homes [5].

The developers of ALARAM-NET have successfully implemented wireless sensors for use in the home [6]. They have been able to prove the robustness of their system.

In this project one of our objectives is to deliver a wireless sensor that will support legacy medical devices. While similar technology is in use by other researchers as detailed above, we are using wireless sensor networks for a different application.

A few commercial ventures have achieved success in supporting legacy devices. Philips Medical have a product called the Device Link II [7]. This device allows the connection of bedside devices to a Clinical Information System using a fixed network. Sensitron have recently announced their CareTrends solution [8]. This solution connects Welch Allyn bedside monitors to the Clinical Network using Bluetooth [9] technology. The fact that these commercial ventures are in existence indicates a viable market.

Zigbee is becoming widely adopted as Wireless Sensor Network technology with more and more companies joining the Zigbee Alliance every day. There is widespread availability of Zigbee hardware development kits and there are already several commercial applications in the buildings management sector, for example. Other wireless technologies have functions in the medical device sector, however Zigbee has proven most suitable for our requirements. Bluetooth and IEEE 802.11 [10], allow high transmission rates, but at the expense of power consumption, application complexity, and cost. The research carried out by the authors at Medical Design [11] explore this point and highlight the suitability of Zigbee and wireless sensor networks in the medical device sector.

III. System Architecture

A. High-Level Architecture

The system architecture shown in Figure 1 consists of a Zigbee network that contains sensors such as the MDI. Within the same Zigbee network there exists 1 Gateway and as many routers as determined necessary to provide the desirable coverage. More Gateways can be added as the user wishes to scale their network. Each Gateway connects to the Server using a wired or wireless LAN. The Server maintains a persistent state for each Gateway and the associated sensors with each Gateway in the network. Clients on the LAN are used to perform associations between sensors and patients and also to provide graphical feedback of data captured from the sensors.

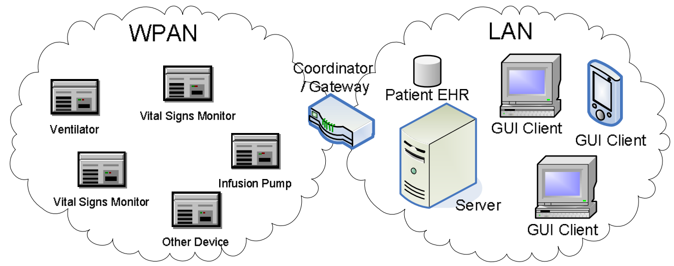

Figure 1. High-Level Architecture

B. Medical Device Interface

When the MDI is powered on, the Zigbee stack will automatically join a Zigbee network within range. Next, the MDI will announce an ID which is also visible on the external surface of the device. This is done using the application layer protocol we designed for this project. At this point it is possible to make an association with the MDI. To achieve this, the administrator selects the ID from an automatically generated list on screen, a patient demographic and a type of medical device which is supported in the system. This process results in the server sending the correct RS232 settings to the MDI for the medical device that it is connected to. Now that the system can communicate directly with the medical device the server will send any necessary commands to initiate a data stream from the device.

C. Gateway Functionality

The Gateway has three Zigbee interfaces so it can support three separate networks. As shown in our previous work [3] the Ventilator can be considered one of the most bandwidth intensive devices supported by the MDI. This is because we must send requests and also as the responses are relatively large. Typically, these periodic requests can be 40 bytes and the responses can total 100 bytes, including application level protocol overhead. The total bandwidth available to an application on a Zigbee network can vary depending on implementation (Specification 250 KBits/sec including Zigbee protocol overhead). In this project we are using the Zigbee implementation provided by Ember Corporation [12] who state that the application bandwidth is approximately 15 KBits/sec (conservatively) in order to support a sensible number of hops when roaming within the mesh network. Given these figures we have calculated the number of MDIs that a Gateway can support. This is dependent on how frequently the user wishes to retrieve data and also how many Interfaces on the Gateway they wish to allocate to MDIs. Table 1 below shows a sample range of these calculations. The No. of Channels column indicates the number of Zigbee interfaces used to support MDI sensors.

No. Channels	Interval (sec)	No. MDI
1	60	500
2	60	1000
3	60	1500
1	30	250
2	30	500
3	30	750

Table 1. Gateway Specification

D. Server Functionality

The Server maintains the state of Gateways and their associated sensors. When a user wishes to add a new MDI to the network they perform an association between the MDI, the type of device it is connected to (eg. ventilator) and a patient, on a client.

Each type of device has a unique DLL (Dynamic Link Library) which the server can use to communicate with the device. The DLL is concerned with the device specific protocol. Any future device can easily be supported within the DLL framework by simply inheriting from the appropriate class for that particular type of device.

When the DLL is loaded by the server application it will receive a timer value to represent how frequently the Client wants data. When the timer expires the DLL raises an event containing the request data command. The server application accepts this event through its event handler, encodes it in the application level protocol and sends it to the medical device.

When the medical device returns a response to the server this data is passed to the DLL. If the DLL does not receive any data within a specified timeout period the DLL will re-initiate communication with the medical device. Data that is received by the DLL is checked to see if it is consistent with the format expected. If the DLL has received a complete response, the data is analysed and saved in a generic data structure that can be shared with Clients by raising another event.

IV. Trial Results

The trial was carried out in December 2007 in the University College Hospital, Galway, Ireland with the aid of the Biomedical Engineering staff in the hospital. We developed a DLL specific to the Maquet Servo-i [13] Ventilator, the critical care Ventilator used in this hospital, for the purpose of the trial. We performed a series of functional tests. We also asked the Engineering staff to experiment with the MDI and assess its usability within the hospital.

The following tables show a sample set of results captured from the ventilator. The results are divided into 2 sets or Readings and Settings. Settings are parameters a user can set on the ventilator, for example a user might set the Oxygen percentage at 40%. Readings are values displayed on the ventilator which are obtained from sensors on the unit. Therefore the reading may vary slightly from the setting depending on how well the unit is calibrated. We captured result set A and then changed the settings on the ventilator before capturing result set B to produce this subset of results. The purpose of presenting the results below is to show the actual values received, which correspond to the row named Data, and also that the values received correspond to the actual Reading or Setting on the Ventilator.

	Breath Rate	Exp. Tidal Volume	Insp. Tidal Volume	Peak Pressure	O2 %
Ventilator	30b/min	201ml	199ml	16cmH2O	19
Channel	200	201	202	205	209
Interval	1s	1s	1s	1s	1s
Data	0299	0202	0198	0162	0188
Value	29.9	202	198	16.2	18.8

Table 2. Readings A

	Minute Volume, Set	PEEP, Set	O2 %, Set	Tidal Volume, Set	Breath Duration, Set
Ventilator	6000ml	2cmH2O	21	200ml	2s
Channel	305	308	323	334	346
Interval	1s	1s	1s	1s	1s
Data	0600	0020	0210	0200	0200
Value	6000	2	21	200	2

Table 3. Settings A

	Breath Rate	Exp. Tidal Volume	Insp. Tidal Volume	Peak Pressure	O2 %
Ventilator	20b/min	306ml	298ml	22cmH20	31
Channel	200	201	202	205	209
Interval	5s	5s	5s	5s	5s
Data	0200	0307	0297	0217	0315
Value	20	307	297	21.7	31.5

Table 4. Readings B

	Minute Volume, Set	PEEP, Set	O2 %, Set	Tidal Volume, Set	Breath Duration, Set
Ventilator	6000ml	3cmH2O	35	300ml	3s
Channel	305	308	323	334	346
Interval	5s	5s	5s	5s	5s
Data	0600	0030	0350	0300	0300
Value	6000	3	35	300	3

Table 5. Settings B

The results show that we successfully captured data from the unit using the MDI and they also validate our DLL implementation. For example Table 4 shows a Ventilator On-Screen Reading of 22cmH2O for peak pressure, we received a Data value of 0217 which corresponds to a Value of 21.7cmH2O. On-Screen readings are rounded on this device for this parameter, therefore, we have shown our data to be valid.

Figure 2. Ventilator with MDI

We carried out other performance type tests on the system during this visit. While capturing data at 5 second intervals from the Ventilator we also captured data from 2 ventilator simulators running on PCs. This demonstrated the networking features of the system to the Engineering staff. Furthermore we moved the Ventilator down the hall to demonstrate mobility.

The Engineering staff assessed the installation procedure of the MDI. They were impressed with how small the MDI is and how easy it was to connect it to the serial port of the ventilator. They also assessed how using the MDI could improve on their existing system of capturing data from the Ventilator. At present they connect the Ventilator to a monitor at the bedside using a serial cable. Our system could enable them to use the Ventilator at any bedside without the need for a new monitor or serial cable.

V. Conclusion

Previously we have shown how Zigbee is a valid selection for Medical Device Integration. In this paper we have shown how it can be used to successfully capture data from a medical device in the hospital. The novelty of this solution is that existing medical devices can be integrated alongside new wireless sensors. This means hospitals can protect their investment in such devices while moving towards centralised Electronic Patient Records.

Next steps are to develop new DLLs to support other devices found in the hospital. This would increase the capability of our system and introduce the opportunity to perform further hospital trials and case studies.

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