IEEE 802.15.4 Wireless Conference Manager System

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Abstract— **In this paper, we describe a wireless system infrastructure made for data collection and sharing during educational and business conferences. The system is designed to be flexible and rapidly reprogrammable, while keeping low-power and low-cost as the primary design objectives. The system comprises of three distinct components - embedded nodes with user interface, network coordination and routing unit, as well as the WWW and database subsystem. The hardware and the software were designed to be modular and expandable. Our Wireless Conference Manager – WCM has already been deployed at two high-profile IEEE[1] international conferences. Testing and verification results collected at these events demonstrate its suitability as well as expendability for new requirements and applications.**

I. Introduction

Emerging low power wireless technologies and protocols open up the possibilities to radically change the daily life through omnipresent wireless connectivity. A large number of such applications are exemplified in the Wireless LANs (WLANs), Personal-Area Networks (PANs) and Wireless Sensor Networks (WSNs). Common to all such technologies is a need to rapidly develop and deploy such networks for a wide range of disparate applications. While many sensing applications do not require the direct use of wireless units by humans, an interesting subset of applications would require an effective human interface, including sufficiently high-resolution touch-screen displays.

The platform consists of low power embedded nodes, a PAN coordinator that acts as a hub in star topology, and a remote (host) database controller with middleware (bridging software) for presenting the status of the tracked events on WWW or locally via a projector. High level application specific platform overview diagram is presented in Figure 1. The network structure and data is maintained by the PAN coordinator while the wireless nodes are kept stateless.

Our system aims to help conference organizers and managers to maintain and provide real time conference status information. The user has the option of fetching the relevant data i.e. authors and paper titles. For the ongoing presentation, the user is given the option to update the status of the paper that will be displayed on the projector or WWW in real time. In addition, the handheld unit, Figure 2 provides the conference session chair with a score sheet that is used for paper evaluations all accessible via the touchscreen-based graphical user interface (GUI). By having the applicable options available at a touch of the stylus using the system is intuitive and efficient. The UI consists of three main screens, which provide the following functionality:

- Loading the paper information from the database for the specific conference room
- Updating the status of the paper: started, discussion in progress and ended
- Sending the current attendance for the specific session
- Grading the paper according to the four different categories: technical content, interest, visual and verbal

A terminal console, always present in the bottom of the screen, displays network status information as well as broadcast messages sent from the PAN coordinator.

[1]International Conference on Parallel Processing and International Test Conference

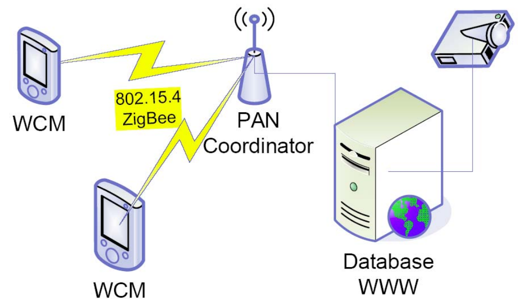

Fig. 1. Wireless Conference Management System

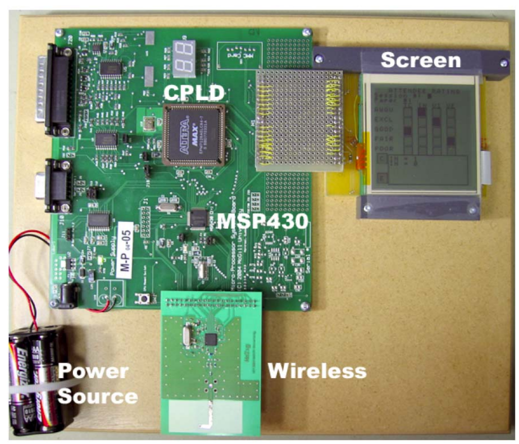

Fig. 2. WCM (Handheld unit) - Photo

Large Pervasive Computing applications are providing new challenges for the real-time community. One of these challenges is managing the power of the overall system in general, and specifically at each node in the system. By keeping the nodes stateless the memory requirements were lowered, which resulted in reduced power consumption. However, to truly maximize the power, one has to concentrate on wireless up time. The open standard that provides the basis for ultra-lightweight communication protocol that transmits only the few required bytes per second per node, enough to satisfy application requirements but no more than that is IEEE 802.15.4. At the start of the project, the IEEE 802.15.4/ZigBee standard was still not approved and no ZigBee compliant ASIC was available on the market. To overcome the lack of hardware the collision avoidance (CSMA/CA) mechanism for the 802.15.4, the media access control (MAC)unit was developed in VHDL. Shortly after, the first ZigBee enabled chip was introduced, which enabled us to design and test our own IEEE 802.15.4 protocol stack implementation.

II. Database and Backend Software

To facilitate the overall application by which the conference sessions were tracked in real time, we designed various software components for a remote host computer. The application-level software comprises of a MySQL database server, an Apache web server, and a control application created in "C++" that is responsible for communication between the PC and the PAN. The main design goals were to build the application that is flexible enough to deal with different types of end-user applications as well as for the in-field testing of the hardware.

For the conference management application, a general structure of the conference is assumed but is not a binding restriction on the overall operation of the system. The database assumes that the conference would be divided into sessions and can be spread over multiple days. It is also assumed that the duration of each presentation is known along with its title and the names of the authors. The tables in the database, thus, store the above information.

The process of entering the information in the database has also been streamlined with the use of a small TCL based GUI. The GUI parses text files containing the pertinent information to the MySQL database. The GUI also allows a direct entry to the MySQL tables [4]. This serves to abstract the database and MySQL commands from the conference administrator.

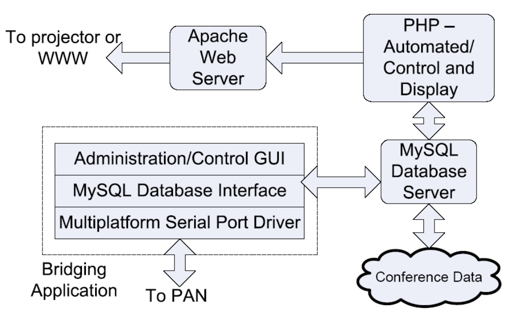

Fig. 3. Application-level Architecture

While the status of the conference can be managed via the handheld units, an automated system has been developed in PHP that can automatically update the status of the presentations not being monitored by the handheld users. Based on the start and end times of the presentation, the PHP script automatically updates the status of the presentation in the database. The script also formats the data such that it can be viewed on a web-browser. This is accomplished by execution of the PHP script on the Apache web server. The web-browser can be displayed to the audience at hand using a projector or webcast in real time on the WWW.

The bridging software has a dual role of providing communication between the PAN coordinator and the PC-side software applications as well as to provide administrative capability over the entire system. Information sent to the PAN via the handhelds such as signal strength and conference data are retrieved using the USB interface. It is a multi-platform application that works on Windows as well as Linux-based computers. In both cases the application uses threads for reading and writing to the port. Multi-threading was necessary for the considerably large data transfers that occur between the application and the PAN during signal strength tests.

A TCL based GUI is used to provide interaction with the user. The user has the ability to initiate signal strength diagnostics, edit data in the database, broadcast messages and toggle the presentation mode from handheld control to automatic update.

III. Hardware Design

The common-off-the-shelf (COTS) microcontroller-based system architecture was considered as the implementation technology of choice. We explored several processor architectures, and have found that the Texas Instruments' MSP430 processor is among the most energy efficient. Typical energy consumption is on the order of 1mW/MIPS [5] or less. Choosing this family of microcontrollers for our embedded nodes certainly was also heavily influenced by its low cost, Figure 4. However, since low-power systems are inherently RAM- and MIPS-limited, the embedded software component needed to be optimized to compensate for these shortcomings. Among the members of MSP430 family, we choose MSP430F149, featuring 60K FLASH and 2K RAM. To add flexibility and expendability, a complex programmable logic device (CPLD) was put in place. It acts as a router between the CPU and any added hardware. In the case of the Wireless Conference Manager, the applicable hardware is a 160x160 LCD screen with the touch screen controller, Figure 2.

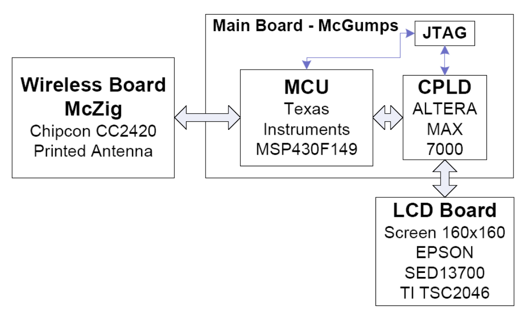

Fig. 4. WCM (Handheld unit) - System Diagram

The PAN coordinator is a USB-enabled device based on a more powerful ARM7TDMI-S controller from Philips, Figure 5. The MCU belongs to the LPC2100 family of devices and features 60KB of RAM and 128KB of FLASH. Contrary to the nodes which can be augmented with added modules, the PAN coordinator is a single purpose device.

A. Wireless Module

Recent advances in CMOS integrated circuits have allowed the integration of an RF front end onto the same die as the digital demodulation and media access control components. The

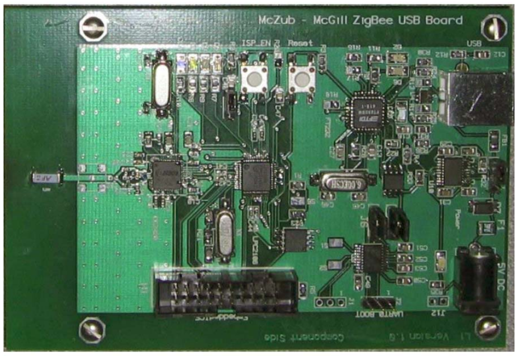

Fig. 5. PAN coordinator with ARM7TDMI MCU

high level of integration tremendously lowered the cost of the overall wireless component. However, it brought antenna design decisions to the forefront since that became the major cost factor in adding the RF capability. We developed the novel methodology [1] for designing nodes in which a robust antenna is realized by printed circuit traces. Other benefits of printed antennas include extreme low cost and inherent ease in manufacturing. Antenna connectors and external antennas are notoriously fragile mechanical parts that often require protection against electrostatic discharge (ESD) as well as the additional steps in the system manufacturing. The antenna, Figure 6 was designed by combining 2.5D and 3D electromagnetic modeling (EM) tools. Our integrated resonant antennas feature omni-directionality and high cross-polarization rejection, 99.1% antenna efficiency, Table I and a good match to our simulation model, Figure 7.

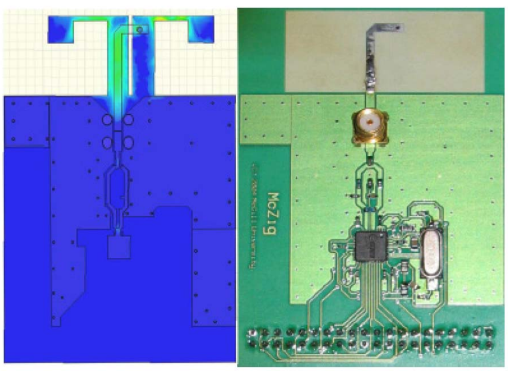

Fig. 6. Half-wave dipole antenna: simulation model showing peak currents (left) and photo (right)

TABLE I

Printed Antenna Properties

Property	Value	Method
Peak Gain	4.2dBi	Simulation
Efficiency	99.1%	Simulation
Center Frequency	2.368 GHz	Lab Measure
Bandwidth (2:1 VSWR)	290 MHz	Lab Measure

In addition to our PCB antenna, the wireless module features a single-chip 2.4 GHz IEEE 802.15.4 transceiver, Figure 6. Chipcon CC2420 includes a digital direct sequence spread spectrum base band modem providing a spreading gain of 9 dB and an effective data rate of 250 kbps [3]. Its main advantages are in its design for low-power and low-voltage wireless applications. Moreover, the CC2420 provides extensive hardware support for packet handling, data buffering, burst transmissions and data encryption.

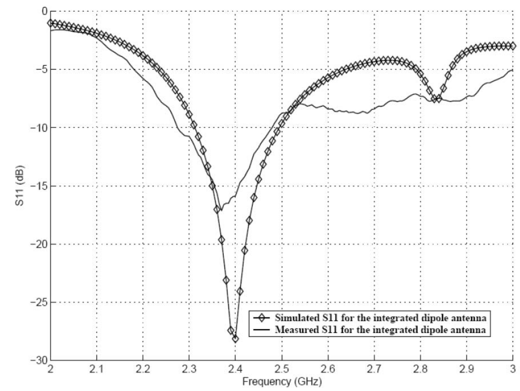

Fig. 7. Measured and simulated S11 response of the PCB antenna show 1% mismatch in resonant frequency

B. LCD Module

The LCD module, Figure 2 comprises of a FSTN LCD panel and a resistive 4 wire touch screen. The two were packaged together by MicroTips USA.

The screen controller can display both text and/or graphics on a midsize, dot-matrix LCD. It features a character code map as well as a 32KB SRAM buffer all built in. Majority of the command functions have been put to use to effectively display text and graphics as well as scroll the screen in different directions. The controller also supports grayscale or black and white graphics.

Touch screen measurements are taken by the touch screen controller. At first, we minimized hardware by designing our own discrete MOS circuitry to drive the touch screen lines and interface to the on-chip A/D converter to sample the analog values, all under the control of our software. Although this design worked well, we decided in the end to use the TI's TSC2046 integrated touch screen controller instead of an on-chip A/D converter to increase modularity and future compatibility with chips that lack the A/D converter and reduce the overhead to the embedded software.

C. PCB design and manufacturing

The whole infrastructure design was done using only 2-layer PCBs to reduce the development and production cost. The main drawback of a 2-layer approach is that more attention must be paid to the signal routing and power distribution [6], [7]. The use of ground return traces and ground area fill are especially critical in the RF section, where any discontinuity in the trace impedance can considerably affect the performance of the design. High frequency sections were simulated using Ansoft HFSS.

For modularity, cost and risk reduction, the hardware was developed and validated on three different boards. The main PCBs are the MCU board, wireless and LCD board (see Figure 4). Each board is re-usable in a different configuration. For example, an ARM-based CPU with more FLASH Memory and RAM replaced the MSP430 in one variation of the design, leading to a faster handheld unit at the expense of reduced battery life. Connections between boards is done using standard 0.1" header to reduce cost and allow easy probing of the buses. The PCB designed was carried using Mentor Expedition PCB.

IV. Embedded Software Design

Techniques used to design low power hardware had to be complemented with embedded software to truly maximize battery life. Embedded software includes our own IEEE 802.15.4 protocol layer implementation that is highly portable across different architectures. The implementation allows network nodes to operate on single battery for months or even years by using periodic synchronization packets - beacons. The nodes are only active during the synchronization phase and while transmitting data to the PAN coordinator. At other times, a countdown timer generates a wakeup call to the controller waiting for the beacons in one of its low power modes. In Figure 8, we show the current consumption for a single node in three different scenarios. Without forcing the powerdown mode, the battery life is severely shortened since most energy is used to operate the wireless receiver.

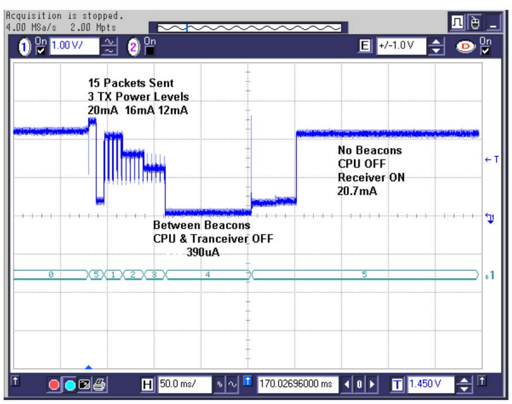

Fig. 8. Measured node current utilization in different modes

V. Validation and Verification

To facilitate large-scale deployment, we further designed a novel wireless test infrastructure for remote testing and remote reconfiguration that was demonstrated to offer significant reliability improvements [2]. Using such test interfaces and our wireless test procedures, we have obtained a large set of performance and characterization measurements, both in the lab and during actual WSN deployment. Among the properties measured, we used the relationship between reception rate and location (distance) under different test conditions i.e. TX power levels, frequency, polarization and variable packet sizes. In a typical situation, with two concrete walls in the signal path, the range exceeded 60 meters, Figure 9. In addition, we have ensured that an omnipresent interference from the 802.11b/g did not affect the performance of the system, even though it uses the same ISM frequency bands.

To achieve robust deployment we realized that wireless test and firmware upgrades are of paramount importance. To that end we decided to initiate an extension to the IEEE 802.15.4 standard to provide the mechanism in the MAC layer for larger

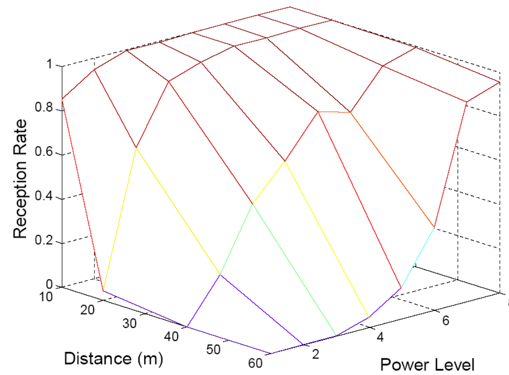

Fig. 9. Measured relation between reception rate and distance under different output power levels

data bursts. Assimilation of the ever emerging changes is only seamless if the updates are performed in the background - without suspending normal network activity i.e. periodic beacons.

VI. Conclusions

Embedded wireless applications are becoming more mainstream everyday. However, a major constraint for such applications is power consumption. There are many trade-offs that come into play when building software and hardware for pervasive computing nodes. Finding the right compromise between each item is a critical issue for the designer.

In this paper we have presented the implementation of our system that employs one of the newer wireless protocols specifically designed for low-power wireless applications. We also demonstrated how system level design decisions, such as the stateless operation of the WCM units and memory usage management, can affect the overall power usage of the system. The WCMs were deployed for over 250 hours without battery change, which is remarkable for a wireless mobile unit.

Using our tools and techniques, complete WSNs based on new IEEE 802.15.4 standard were successfully applied in real-life applications. We deployed two wireless conference management systems for tracking progress in real time that was used in the organization of 33rd International Conference on Parallel Processing (ICPP) and as a trial for 35th ITC. This is first such wireless management system used at any IEEE international conferences. Further, we validated our rapid development methodology in field, as we designed and deployed these systems in less than 3 months after the first silicon for 802.15.4 became available.

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