Wi-Fi Tags for the Remote and Virtual Laboratory

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Abstract—**With the advancement of computer technologies to faster processors and more memory, the WorldWideWeb, wireless communication, and miniaturization of sensor technology, it is now possible to simulate and execute engineering and science laboratory projects on a remote computer. With Internet connection, students have access to "virtual laboratories" via the www, experiment-oriented problems can be now offered without the overhead incurred when maintaining a full laboratory. This paper investigates the opportunity that a new wireless sensor technology brings to remote laboratories.**

G2 Microsystems of Campbell, California, USA, released in 2007 the first ever ultra-low power Wi-Fi System on a Chip (SoC) named G2C501. This SoC includes a 32-bit CPU, crypto accelerator, real-time clock and a versatile sensor interface that can serve as a standalone host subsystem. The G2C501 goes beyond today's basic radio frequency identification (RFID) technology to offer intelligent tracking and sensor capabilities that leverage IEEE 802.11 (Wi-Fi) networks. Due to its support for multiple location technologies, small form factor and ultra-low power consumption, the G2C502 SoC can be integrated into Wi-Fi sensor tags that lower cost of ownership and meet the needs of a variety of industries including consumer electronics, pharmaceuticals, chemical manufacturing, cold chain and more.

A battery powered, small size ultra low-power Wi-Fi wireless measurement node name IP Sensor has been built using the G2C501 SoC. Sensors for measurement of temperature, humidity, light, and vibration or motion are currently mounted on the IP Sensor board. The node is able to read a sensor and send data to the network by using an IP-based application protocol such as UDP.

This paper describes the new IP Sensor device and how it can be used in Remote Laboratories.

Index Terms—**Wi-Fi tags, IP Sensors, Remote laboratories, wireless sensors.**

I. WI-FI SENSORS IN LABORATORY EXPERIMENTATION

Active learning by means of remote laboratories is especially valuable for distance education students and learners in the workplace. They can access the labs without traveling. This flexibility is important for life long learning, because it allows learners in the workplace to fit learning phases into a full work agenda. Using remote (online) laboratories has the potential of removing the

Figure 1. IP Sensors

obstacles of cost, time-inefficient use of facilities, inadequate technical support and limited access to laboratories [1].

New technologies (such as the Internet, wireless communication and systems) offer new possibilities to increase the number of experiments which can be conducted and also provide access to experimental equipment for the public with the aim of inspiring people to study science and technology. Today, many academic institutions offer web-based experimentation environments that support remotely operated experiments.

Online labs are typically organized in a Client-Server-Architecture. In most cases every experiment needs its own server. If the experiments and their corresponding servers are at different locations, the laboratory will be called a distributed lab.

Due to recent technological advances in computer technology and software, it is now feasible to implement more advanced, more efficient, highly interactive and very user-friendly systems without using very costly custom written software and tools.

In laboratory applications, from a technical point of view, all engineering problems deal with some type of physical quantities such as temperature, speed, position, current, voltage, pressure, force, torque, etc. A computer equipped with the suitable interface circuits, data acquisition systems and software, can give these quantities a visual look, and can process the acquired data. We can develop today complex applications using Graphical Programming languages (like LabVIEW from National Instruments, VEE-Pro from Agilent Technologies, etc.).

The idea is to use the graphical programming technology to create virtual instruments for laboratory experiences that are made available to the remote area user via Internet link or satellite link.

Wi-Fi wireless sensing, as a technology, has the potential of revolutionizing remote laboratory experimentation by leveraging the ubiquitous IEEE 802.11b/g Wi-Fi installed base. Wi-Fi sensor tags bring data to the network for further distribution. There are two main scenarios of sensor tags and network ownership, each imposing different requirements on the sensors and network configuration [2]. These are:

– the "enterprise network" model, where a single organization has control of all sensor tags, networks and data servers which can be engineered to meet the requirements of this particular organization needs for applications. This model is primarily found where an enterprise wishes to track its people and assets within its facilities, e.g. hospital, warehouse, etc.

– the "distribution network" model, where sensor tags and data servers may be owned by different organizations. Within one network there may be sensor tags owned by several companies, and one sensor tag may move through networks owned by several companies. This configuration is primarily found where an organization wishes to track items held by sub-contractors, e.g. goods in a supply chain that are shipped from factory to warehouse to customer.

Both these models can be applied to the field of remote laboratory experimentation to define setup ownership, usage privileges, supervision duties, distribution of measurement data, reports generation and distribution, etc.
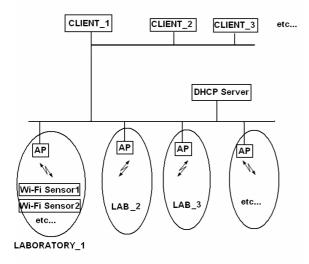

Figure 2. Wi-Fi Sensors for Virtual Laboratory – Setup 1

A remote laboratory unit is an experimentation facility that makes (sensor) measurements and sends data to computers on the network running client applications. An experimentation facility that uses Wi-Fi sensors to monitor physical or chemical processes located in the neighborhood of a Wi-Fi Access Point qualifies as a remote laboratory unit. Wi-Fi wireless sensors will associate with the nearest Access Point and use it as a gateway to the Internet to create a data path to the

application computer. The client application computer may run a web page or LabVIEW software or some other programming environment to get access to sensor data. This computer may belong to the same building as in the enterprise network model or it may be located somewhere else on the Internet.

A more robust embodiment of this setup will have a dedicated computer – the Sensor Measurement Manager - run the sensor measurement tasks, and also interact with other applications that are available at the same network level, like the Location Based System Server (LBS). The LBS server associates location information to mobile Wi-Fi sensors. Data from the Sensor Measurement Manager computer is served to client user computers for further processing. Again, the two network ownership models will apply to these client computers.
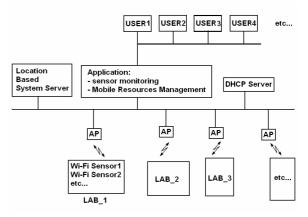

Figure 3. Wi-Fi Sensors for Virtual Laboratory – Setup 2

A third embodiment of the same setup is obtained when the Sensor Measurement Manager computer is replaced by an Access Point. The Wi-Fi sensor measurement and DHCP server software modules can be downloaded into an Access Point that runs Linux OS. This "Master" Access Point will also have a Web Server installed. Client users will browse to the web page served by the Access Point to get access to sensor monitoring data.
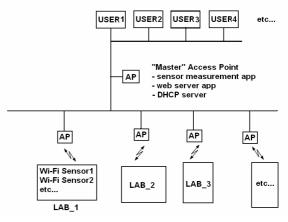

Figure 4. Wi-Fi Sensors for Virtual Laboratory – Setup 3

All three setups allow client users to access measurement data from Wi-Fi sensor tags located in different laboratory facilities. The Remote Laboratory facility is the physical place of residence for the process under investigation and Wi-Fi sensors. Experimentation is done in this location, and data is sent from this location to

the network via one or several Access Points. The Remote Laboratory does not include client user computers. Client user computers are located anywhere on the network and run applications that use measurement data from the Remote Laboratory.

When a Client computer starts getting data from sensors located in a Remote Laboratory a new entity named Virtual Laboratory is formed.

Virtual Laboratories are alive only during the period of time when one or several Client computers are getting data from sensors located in an experimentation location of a Remote Laboratory. Sensor data routing is done by local Access Points. Data arrives at client user PCs as raw numbers or as a web page served by the Sensor Measurement Manager application. The following two client user experiences have been envisioned:

Figure 5.   Web based User Application

User Experience 1:

- Client User opens a Web Browser on the Data Client PC,
- User browses to the IP address of the Access Point containing the Data Server, say http:/192.168.1.1/IP_Sensor
- Data Server sends Data Client PC a web page containing data from IP Sensors, as seen in Fig. 5.
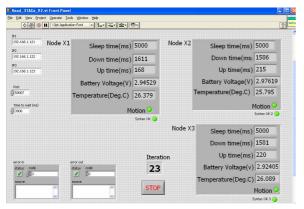

Figure 6.   LabVIEW based User Application

User Experience 2:

- Client User opens LabVIEW or some other programming environment running on the Data Client PC,
- User develops and starts application,

- Data Client PC gets data from IP Sensors, as seen in Fig. 6.

II.   THE IP SENSOR

The IP Sensor is a Wi-Fi sensor tag that is battery powered and it has been designed around the G2C501 ultra-low power 802.11b 32-bit SoC. The G2C501 SoC was designed for the mobile asset tracking market that is in need of active tags with a battery life time of 1 to 5 years.

Figure 7.   IP Sensor tags next to a LinkSys Access Point

In a supply chain asset tracking application it is very useful to be able to monitor temperature to avoid overheating, especially for foodstuffs, security seals for containers, shock and acceleration for fragile goods, humidity for food, etc. The SoC used in tags that serve this market has to implement signal conditioning and digitizer elements in order to be capable of performing all these measurements. The IP Sensor is using and extending tag SoC functionality to create a multitude of measurement devices that monitor light, radiation, pressure, movement, humidity, vibrations and other physical or chemical processes. The IP Sensor is an asset tracking tag with a sensor attachment which is interfaced to the SoC using signal lines like SPI, analog-to-digital inputs, DIO and current I/O.

The IP Sensor [3] has two distinct parts: the Core and the Sensor(s) Attachment. PCB size is 42.5 mm x 23.5 mm and has the circuitry described in Fig. 8.
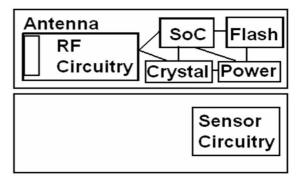

Figure 8.   IP Sensor tag Core and Sensor(s) Attachment

The IP Sensor is powered by a 3.2V, lithium battery, model CR123A. The IP Sensor has two modes of operation, sleep and wake-up modes [4].
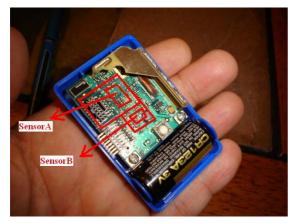
Figure 9.   IP Sensor tag Core and Sensor(s) Attachment

Sleep is the low-power mode in which the IP Sensor will use an average of 100uW of battery power. This amount of power is used by the SoC to perform sensor circuitry current sourcing, sensor readings and access of a small non-volatile memory location. uC OS does not run, communication does not run, everything regarding SoC intelligence is shut down in sleep mode. An IP Sensor hardware timer which is pre-programmed will trigger the SoC to wake-up and enter a high-power mode state for very short intervals of time at fixed time intervals. Other causes of transition from sleep to wake are preconfigured threshold values 'seen' by the motion, temperature, magnetic and other sensors. In wake or high power mode the IP Sensor starts eCos OS on the 32-bit uC and enables full intelligence including communication capabilities using UDP. The amount, length, and complexity of tasks performed during high-power periods vary depending on the application. From short term periods of 1ms to 10 seconds during which the IP Sensor consumes about 100mW average while it makes measurements, receives 802.11 data and executes code on the CPU, to very short periods of say 500us where the IP Sensor consumes in the range of 1W while it transmits 802.11b data via UDP. It should be mentioned here that the 802.11b communication capability of the IP Sensor operates autonomously from the CPU and it can execute direct reads/writes data to system RAM in low-power mode.

During a lifetime period of 1 month to 5 years the IP Sensor may repeat the task of each waking up for high-power mode event every 10 to 300seconds. IP Sensor power consumption is dictated by battery capacity and the frequency and length of the wake or high-power mode states of the application.

There is no explicit step for node assignment to an Access Point in an application that uses Wi-Fi sensors. The sensor registers with an Access Point and uses the DHCP protocol to request dynamic allocation of an IP address from a DHCP server that may reside in the Access Point or in a networked PC [3]. If the IP Sensor does not have access to a wireless network, it could store sensor data, complete with timestamp. Measurement data will be uploaded to a PC or Access Point Data Server when Wi-Fi access becomes available again.

III.   FIRMWARE

The IP Sensor contains a 32-bit processor (or CPU) that runs on a 44MHz external clock. The slower and lower power sensor measurement operation is controlled by an

external 32 KHz oscillator. The CPU incorporates full 802.11 PHY, MAC and encryption engine. The IP Sensor CPU has internal 80Kbytes of RAM and 320Kbytes of ROM that comes loaded with the following firmware components:

- Boot loader
- eCos OS
- TCP/IP stack
- 802.11b stack
- Encryption and decryption support
- Application/deployment specific sensor drivers and communication protocol
- Power-saving support

The IP Sensor has 1Mbit of external flash memory that is controlled by the CPU via an SPI interface. User defined firmware, like sensor drivers, can be downloaded in this memory.

IV.   APPLICATION SOFTWARE

Application software is written by the sensor user and it is not part of sensor firmware. The typical application software scenario is that of a Data Server, or MRM (Mobile Resource Management) server. The Data Server can be a dedicated networked computer that collects measurement data from a set of IP Sensor nodes which it sees on the local WiFi LAN. The networked computer may be a regular PC, or an Access Point running Linux OS and custom software which allows it to act as a Data Server in addition to managing the Wi-Fi network. The Access Point Data Server collates measurement data from these multiple sensor tags and presents them as a web page to Data Client PCs.

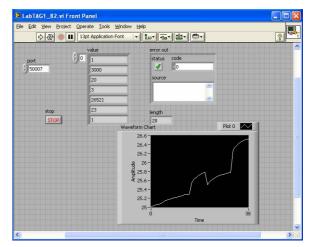| Number of active TAGs :5	Date: 2/1/2008	Time: 14:21:28	
TAG01: 192.168.1.121	Temp: 27.3C	Light: 0.034	Static
TAG02: 192.168.1.122	Temp: 27.3C	Light: 0.374	Static
TAG03: 192.168.1.123	Temp: 29.8C	Light: 0.332	Static
TAG04: 192.168.1.124	Temp: 29.1C	Light: 0.391	Static
TAG05: 192.168.1.125	Temp: 27.0C	Light: 0.190	Static

Figure 10. Data Client Web Page

Figure 11. LabVIEW Virtual Instrument Panel

In another application scenario one may use a graphical programming language like LabVIEW from National Instruments. The virtual instrument is created and runs in the Client computer [5].

The virtual instrument panel shows that this application is talking to an IP Sensor on PC Port 5007. Sensor data packet is displayed in the "value" indicator. Sensor temperature readings are shown on the "waveform chart" graph.
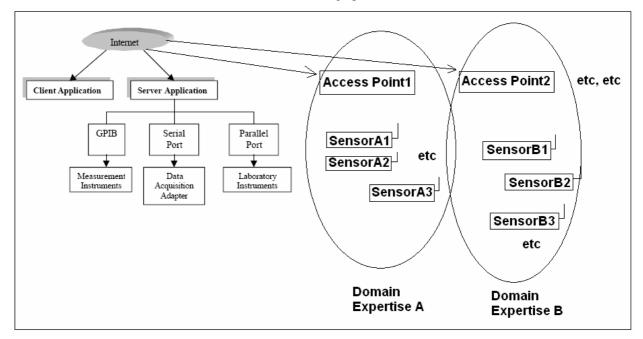

Figure 12. The Virtual Laboratory

V. VIRTUAL LABORATORY

The virtual laboratory idea as described in this article is based on a client-server architecture that makes the exchange of data between sensors and computers possible. This architecture is capable of integrating "expertise" Access Points that are located in physical places where there is human expertise or knowledge in a certain area. Experiments are conducted in this place by using one or several IP Sensors mounted on the process under study. Sensors send their measurement data to the Access Point which makes it available to Internet clients. The client, who in this case is the learner or student, will have access to "laboratory instruments" (IP Sensors) via the Internet, by accessing the IP address of the expert Access Point. The IP Sensor inside the experimentation room can be triggered to enter a wake-up period based on an internal clock or an event notification. There are two levels of triggering in such a Virtual Laboratory application: a) client user wants to access some sensors inside the remote laboratory and therefore issues a wake-up trigger to these sensors via the expert Access Point, and b) the client application that is running sensors inside the Remote Laboratory may only want to communicate back with client computers when a sensor event takes place therefore even that the application is running nothing happens at network level until this event takes place.

A Virtual Laboratory [6] will be formed when a group of students participates in a laboratory session using Domain Expertise A. Another Virtual Laboratory will be formed when a different group of students located somewhere else participates in a laboratory session using Domain Expertise B, and so on. Virtual Laboratories come to life as students and their advisors decide to access

a Domain Expertise under a certain period of time in order to perform a specialized experiment. Tutors and instructors will manage and supervise these groups by managing Access Points and client applications.

VI. CONCLUSIONS

This paper presents an ultra-low power sensor tag named the IP Sensor and its use in a Virtual Laboratory implementation. IP Sensors bring sensor measurements to Access Points inside Domain Expertise centers. IP Sensors have a flexible architecture that consists of one Core and multiple sensor attachments that can be connected to this Core. Remote Laboratories will greatly benefit from the IP Sensor technology because this is a native way of leveraging the ubiquitous IEEE 802.11b/g Wi-Fi installed base for sensor measurements. The concept of Virtual Laboratory has been introduced to define the entity formed when a group of students participate in a laboratory session via the Internet using a certain Domain Expertise.

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