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Ambient Backscattering - An Efficient and Reliable Approach for Agriculture

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ABSTRACT

Radio Frequency Identification (RFID) systems have attracted increasing attentions from both academic circles and industrial communities over the past two decades. Energy harvesting is a key technique that can be used to overcome the barriers that prevent the real world deployment of WSN's. In particular, solar energy harvesting has been commonly used to overcome this barrier. However, it should be noted that WSNs operating on solar power suffer from energy shortage during night times. Therefore, to solve this problem, we exploit the use of TV broadcasts airwaves as energy sources to power wireless sensor nodes. This paper introduces a novel wireless leaf temperature sensor that utilizes ambient FM backscattering for smart agricultural applications. The sensor is based on an ultra low power microcontroller, a sensor board and a RF front-end for wireless communication. The sensor communicates using backscatter radio principles on ambient FM station signals using AM modulation with FM0 encoding. The prototype features an effective operation up to ranges of 0.5 m by backscattering sensor information at 50 bps and 500 bps using an ambient FM radio signal inside alaboratory setup. A high percentage of bits will be clearly visible up to 2 m at 50 bps.

Keywords : Ambient Backscattering, Backscatter Communication, Internet Of things, RFID, Sensors.

I. INTRODUCTION

Internet of Things (IoT), a vital component of the fifth generation (5G) mobile communications, aims to connect an enormous number of devices [1]. In practice, many devices such as tags and sensors, are usually powered by batteries. These devices restrict extensive IoT applications due to limited power supplies. Ambient backscatter, a new green communication technology, is suggested recently to provide a promising solution to the battery problem of IoT devices. Communication primitives such as coding and multiple antenna processing have provided significant benefits for traditional wireless systems. Existing designs, however, consume significant power and computational resources, and hence cannot be run on low complexity, power constrained backscatter devices.

Small computing devices are increasingly embedded in objects and environments such as thermostats, books, furniture, and even implantable medical devices. A key issue is how to power these devices as they become smaller and numerous; wires are often not feasible, and batteries add weight, bulk, cost, and re- quire recharging or replacement that adds maintenance cost and is difficult at large scales. Ambient backscatter is an emerging green communication technology that exploits the environmental radio frequency (RF) signals to enable passive devices to communicate with each other. Ambient RF from TV and cellular communications is widely available in urban areas (day and night, indoors and out- doors). Further, recent researches has shown that one can harvest tens to hundreds of microwatts from these signals. Thus, a positive answer would enable ubiquitous communication at unprecedented scales and in locations that were previously inaccessible. The main objective that our project is going to achieve is to make devices compact and making them independent in terms of power source. Hence when this device will be independent from power source there will be less need for regular maintenance and services. It has a very small environmental footprint because no additional energy is consumed beyond that which are already in air.

We are going to take advantage of existing unused ambient RF signals so it does not require the development of a special-purpose power infrastructure. This reduction in power requirements and components allows devices to not only be more compact but completely isolated.

This technology is also going to solve the problem of Costing. This will be cheap and easily available device. It will also provide device to device communication.

Ambient Backscatter uses existing radio signals, such as radio, television and digital telephony, to transmit data without the use of a battery. A group of Ambient Backscatters communicate with each other without generating their own radio waves. Instead, they communicate by backscattering existing wireless signals. Each such device uses an antenna to pick up an existing signal and convert it into tens to hundreds of microwatts of electricity. Multiple Ambient Backscatters can share their positions with each other by triangulation. One application would be if an Ambient Backscatter is attached to an item, then user will be able to easily track its location.

The system developed from ambient backscatter technology includes a harvester that will harvest power out from the ambient signals roaming freely in the environment. This system will be battery less as it will suck the ambient signals and generate power out from the signals. This feature of the system will make the system more compact with less cost and less maintenance.

II. BACKSCATTERING PRINCIPLES

Backscatter modulation is based on a multiple-antenna-load system reflection coefficient :

$\Gamma i = (Zi - Z*a)/(Zi + Za)$, with i = 1, 2, ... and Za is the antenna impedance. Typically, in RFID applications, in order to implemente a binary communication, a RF switch alternates the antenna termination load between two values (Z1 and Z2). The modulation is resulting from the change of Γi over time and the phase difference of Γ1 and Γ2 in Smith Chart diagram. Smith Chart Diagram is used to assist in solving problems with transmission lines and matching circuits

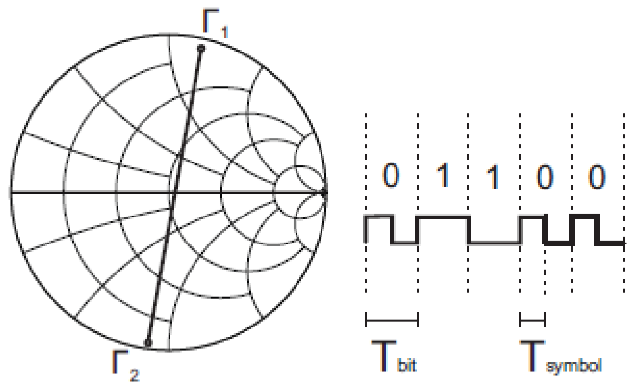


Fig 1. Left: Antenna S11 Parameters in Smith Chart

Different antenna termination loads offer different reflection coefficients that modulate the FM station signal with different amplitude. Right: FM0 encoding technique should be 180 degrees for the optimal backscatter performance. Typically, a tag communicates with a reader by time modulating the reflected waves due to the incident continuous wave (CW) carrier, that is supplied by the reader.

III. METHODS AND MATERIAL

A. Working

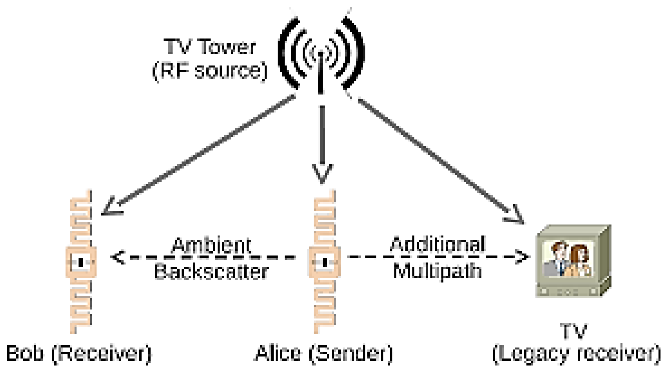


Fig 2. Working of Ambient Backscattering Receive and transmission

This method sucks power out of the air from TV and cellular transmissions, and then modulates this signal with its own data. These modulated signals are then picked up by other devices in the same ambient backscatter network. Requiring a battery or other source of power is probably the most prohibitive factor when it comes to the ubiquity of electronic technology. In theory, this could be the breakthrough to finally allow for a ubiquitous internet of things, where every location is blanketed with devices and sensors that communicate with each other, creating truly smart homes, offices, and cities.

You may or may not realize this, but much of the Earth is blanketed in high-power radio waves, mostly from television and cellular towers. These towers pump out broadcast RF radiation that is picked up by your TV or mobile phone. There's no intelligence or sophistication in such a method the radio waves aren't targeted directly at your television set or phone. The waves are just floating around in the atmosphere, waiting to be plucked out of thin air by a receiver that's tuned to the right frequency. In most cases, the receiver then processes these radio waves into useful data, which is then displayed on a screen or played through an earpiece.

The researchers have created a device that has an antenna tuned to UHF TV signals (539MHz in this case), but instead of displaying a picture, the signal's energy is harvested to power a small device. The device contains logic chip that controls the impedance (resistance) of the antenna. By altering the impedance of the antenna, the TV signal is reflected (backscattered) back into the atmosphere in a specific and controllable way. In other words, the device can generate a signal of its own - a signal that can be picked up by other local devices - without its own source of power, simply by reflecting TV signals in a clever way.

So far, the researchers have created multiple prototype devices, each around the size of a credit card, that use ambient backscatter to communicate with each other, at 1Kbps over 2.5 feet (76cm) outdoors and 1.5 feet (46cm) indoors. This might not sound very good, but 1 kilobyte per second is more than enough for sensor networks, or smart devices in your home/office - and for a prototype, 2.5 feet is pretty good. You only need to get it up to six or 10 feet to make a ubiquitous network, an internet of things, feasible. It goes without saying, too, that these ambient backscatter devices are cheap and easy to produce, too; as you can see in the picture above, it's essentially just an antenna and a simple microcontroller.

IV. System Model

In this work we develop a novel tag for leaf temperature measurements which uses for the first-time ambient backscattering over analog modulated (FM) signals. The tag, shown in Fig. 1, reflects ambient RF signals from nearby FM stations in order to communicate with the reader.

The sensing tag topology consists of a micro-controller (MCU) for processing, a sensor board for the plant sensing and a RF front-end consisting of a commercial switch and an antenna for the communication.

The proposed tag combines low power operation and connectivity with a low-cost RTL-SDR receiver.

Hence, Ambient backscattering has the potential to be the next new primitive approach for extremely low power communication.

The of the proof-of-concept sensing tag, based on a MSPEXP430FR5969 development kit (Fig. 3), generates the pulses that control the RF switch, so that amplitude modulation (AM)with FM0 encoding can be implemented via backscatter radio. The MCU was programmed at 1 MHz clock with active mode current consumption (IDD), 126 µA at 2.3 V (290 µW). For the temperature data acquisition, the embedded Analog to Digital Converter (ADC) is used. The sensor board consists of two high precision, (±0.1◦C) analog temperature sensors LMT70A (IDD : 10 µA at 2.3 V) in a clothes-pin prototype in order to be easily fixed on the leaf (Fig. 3(a)). The first sensor on top, measures the air temperature (Tair) and the second under the leaf surface, measures the leaf temperature (Tleaf). The RF front-end consists of a wire dipole antenna to transmit/receive for FM station signals and the single-pole, single-throw (SPST) RF switch ADG902 (Fig. 3(b)). Each arm of the dipole is 1.45 m long to resonate within the FM band. The sensor board and the RF front-end prototypes were fabricated using inkjet-printed technology on commercial photo paper. Finally, all parts of tag were powered by a 0.1F super capacitor which was embedded on MCU Launchpad. Energy harvesting technologies can be used to charge the super capacitor, such as for example solar or RF energy harvesting. Utilizing the embedded Real Time Clock (RTC) and the sleep mode of MCU the duty cycle of the tag (active mode percentage of time) can be reduced, thus reducing accordingly its average power consumption.

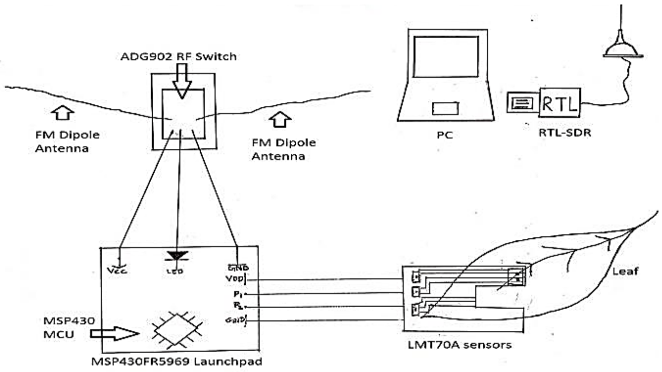
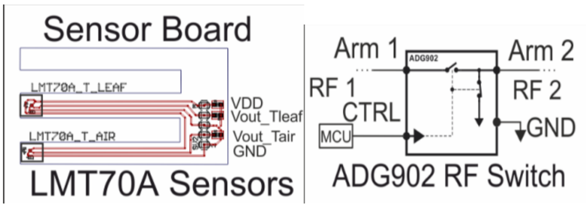


Fig 3.



(a) (b)

Fig. 3. The sensor node/tag consists of a MSP430 development board, a leaf Clothes-pin sensor board (a) and a RF front-end (switch and antenna) (b). The sensor board and the RF front-end prototypes were inkjet-printed on photo paper substrate. The tag was power supplied by a super capacitor. (c)Launchpad.

Changing the RF switch between -on and -off states, can easily create a binary amplitude modulated signal by backscattering the ambient FM station signals impinging on the dipole antenna. The proposed work employed the low consuming-power FM0 encoding and AM modulation. The switch state changes at the beginning and the end of every bit (-0 or -1) but only bit -0 has an additional state change in the middle as shown in Fig. 2 (right). The period of symbol (Ts) is the period of bit (Tbit) divided by two while the reflected signal has a bit rate of 1/Tbit bits per second (bps). The tag sends a data packet to the reader which consists of the preamble (16 bits), for bit-level synchronization at the receiver, the tag-ID (5 bits), the sensor-ID (8 bits) and the sensor-data (16 bits) section. The sensor-ID section is utilized so that the tag can support more than one sensor and the sensor-data section contains the uncoded data from the -IDrespective individual sensor only. A complete packet in time domain is depicted in Fig. 5(a). The receiver is a low cost RTLSDR USB dongle. The SDR with R820T radio tuner, has a 8-bit ADC and a tuning frequency range, from 24 MHz to 1850 MHz. The dongle down- converts the received RF signal to baseband with a sampling rate up to 2.8 MS/s. It also provides in- phase (I) and quadrature (Q) interleaved samples, directly to MATLAB software for extra data processing.

The received signal contains a distorted version of the transmitted rectangular pulses (bits of FM0 encoding) and, in order to effectively detect them it is necessary to compute the envelope of the received I and Q baseband signals (absolute value). After computing the envelope, a digital matched filter consisting of a square pulse with duration Ts is used to obtain the received symbols. The matched filter maximizes the symbol detection probability.

V. CONCLUSION

In this work, we introduce an ambient analog FM backscatter tag for agricultural purposes. The proposed tag combines low power operation and connectivity with a low-cost RTL-SDR receiver. The communication was implemented by backscattering analog modulated ambient RF signals from FM stations. Ambient backscattering has the potential to be the next new primitive approach for extremely low power communication.

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