The Future of Backscatter in Precision Agriculture

Spyridon N. Daskalakis*‡, Stylianos D. Assimonis†, George Goussetis‡, Manos M. Tentzeris* and Apostolos Georgiadis‡

*School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332–0250

Email: daskalakispiros@gatech.edu, etentze@ece.gatech.edu

†School of Electronics, Electrical Engineering & Computer Science, Queen's University, Belfast, BT39DT, UK

Email: s.assimonis@qub.ac.uk

‡School of Engineering & Physical Sciences, Heriot-Watt University, Edinburgh, EH144AS, UK

Email: g.goussetis@hw.ac.uk, apostolos.georgiadis@ieee.org

***Abstract*—Nowadays, the explosive growth of Internet-of-Things-related applications has required the design of low-cost and ultra-low-power wireless sensors; backscatter communication has been introduced as a cutting-edge technology that could address the above constraints. For sensing applications, the monitoring of plant water stress is of high importance in smart agriculture. Instead of the traditional ground soil moisture measurements, leaf sensing is an old technology, which is used for the detection of plant water stress. Considering the above topics, this paper aims to provide a contemporary and literature review on fundamentals, applications and research efforts/progress on backscatter systems for leaf sensing applications. It is described how backscatter technology could be exploited for "one sensor per plant" applications in future precision agriculture.**

I. Introduction

According to the UN Food and Agriculture Organization, food production must be increased to 70% by 2050. In order to meet this demand, the use of wireless sensor networks (WSNs) in agriculture is an essential way for larger production capabilities. Sensing environmental parameters as temperature, humidity and pressure over field areas can offer a precise analysis of the generated micro-climate conditions. Leaf sensing is an another clever way to measure the water status of plants. Leaf sensors can provide more accurate data than the other types of sensors since the measurements are directly taken from the plants and not through the soil or the atmosphere.

Today, one of the main challenges is to minimise the cost and energy consumption of the existing sensor-nodes. There is a variety of wireless sensor products in the market (i.e., ZigBee, LoRa) from 40 to 4000 USD per sensor-node. Thus, networking cost of 100 plants (e.g. one sensor/plant) becomes prohibitive, the solution on this problem is a novel technique, based on reflection principles and it's called backscatter communication. It is used in RFID systems where the sensor-node/tag receives a radio frequency (RF) wave from an emitter and sends its information back to a reader wirelessly by reflecting and modulating this incident RF signal.

This work discusses the existing implementations of a low-cost and low-power tags for agricultural applications that utilize novel leaf sensing and backscatter techniques at the same time. It is noted that all the proposed tags can be a part of a backscatter WSN, transmitting data to a reader as shown in Fig. 1 (Top).

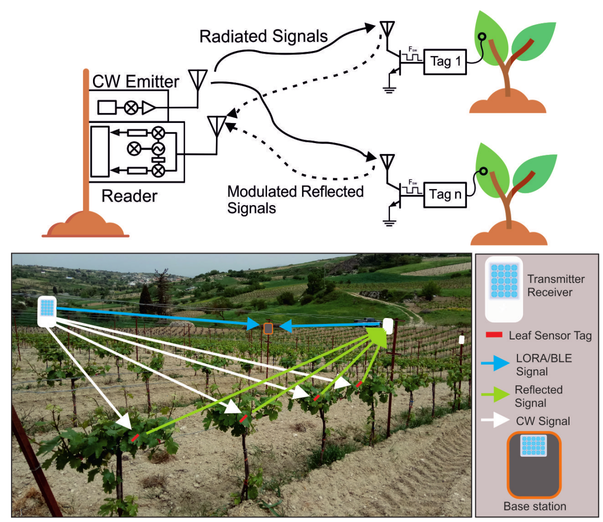

Fig. 1. Agricultural backscatter communication setup in monostatic (up) or bistatic (bottom) architecture. An emitter sends a pure carrier signal and a low-cost reader receives the modulated reflections of each tag. The tags could embedded on leaf sensors for precise water stress monitoring.

II. Leaf Sensing

Transpiration is an important physiological process of plants and it is defined as the evaporation of water from leaves (through stomata), stems and flowers. When the stomata are open, water vapour escapes from the leaves, increasing the local humidity on the leaf surface. Consequently, by installing humidity sensors on leaves surface is possible to monitor that humidity variation. In [1], the authors have developed graphene-based "tattoo" sensors in order to track the key time points at which significant water loss occurs at the leaves. The sensing is based on changes in the electrical resistance of graphene strips in different moisture levels.

Another approach is the use of leaf thickness variations to estimate plant water status. Leaf thickness appeared to be effected by the transpiration rate and thus the water deficit stress (WDS). In [2], [3] a leaf sensor is used to measure the leaf thickness in order to determine the WDS. The thickness measurement was taken with a Hall-effect sensor, placed between two magnets. In an extreme WDS scenario, the leaf thickness decreased dramatically by around $45\ \%$ within a period of 2 hours. Despite such good results, this types of sensors can only be used in controlled environments like greenhouses. This is because there is a direct relationship between leaf thickness and the relative humidity of the environment, light temperature, soil temperature and soil salinity [2].

Since a major role of transpiration is leaf cooling, canopy temperature and its reduction relative to ambient air temperature is an indication of how capable is transpiration in cooling the leaves [4]. Based on the above, a different type of WDS sensors are based on the temperature difference between the leaf and the air (T_{leaf}-T_{air}). One sensor can measure the canopy temperature on the leaf (T_{leaf}) and a second one measures the atmospheric temperature (T_{air}). The temperature difference is strictly related to the WDS [5] and can be used as decision parameter in a local irrigation system [6].

III. Backscatter in Agriculture

In last decade, backscatter radio has become a method that addresses the high cost and high power consumption of the hardware. A general backscatter system consists of three devices: a tag, a reader and a carrier wave (CW) emitter. Communication on tag, is implemented with an antenna, a control circuit and single a transistor between them. The tag do not need to transmit any signal, since it reflects and modulate the signals transmitted by the reader or another ambient RF source (Fig. 1).

In the recent literature, backscatter WSNs for smart agriculture purposes [7]–[10] were proposed. In [7], [8], soil moisture and humidity sensors were proposed. The tags send the data to a software-defined radio (SDR) reader. The WSNs employ semi-passive tags in bistatic topology where the carrier emitter placed in a different location from the reader, consuming less than 1 mW of power, with tag-to-reader range under 100 m. The tags were supplied by a small batteries and better communication distances can be achieved. In [9], electric potential (EP) signals of plants can be measured by the tag in order to estimate the water stress. The tags are batteryless and they harvest near-maximum energy from the plant itself. In [10] two UHF sensor nodes for soil moisture sensing were designed based on conventional RFID chips. In [11] was presented for the first time a novel plant leaf sensor based on a low-cost and low-power backscatter tag. The novel proof-of-consent prototype is batteryless and was powered by a flexible solar panel consuming power around 20 μW. The sensor measures the T_{leaf}-T_{air} which is strictly related to the WDS. The prototype cost was estimated under 15 USD and was demonstrated monostatic wireless operation up to 2 m distance. Similarly in [12] is presented a the same sensing concept based on a commercial RFID chip. The tag is fabricated on PLA flexible substrate and was able to operate in semi-active mode, supplied by a flexible solar cell.

IV. Conclusion

While backscatter principles have been restricted to communication ranges of up several meters; there is a challenge and an necessity for agricultural WSNs, how to increase the emitter-to-tag and tag-to-reader range. In order to address the small range problem, the WSN must utilize bistatic topology and semi-passive (i.e., battery-assisted) tags. Also in order to increase the receiver sensitivity and thus the range, conventional embedded radios could be used as low-cost receivers or emitters it is depicted in Fig. 1 (Bottom). In [13] it is shown that using a commercial FSK transceiver and 13 dBm emitter transmission power, 246 meters tag-to-reader distance is possible. Finally LoRa-based backscatter is a well promising approach for outdoor big agricultural applications. In [14] they showed that can be achieved reliable coverage in a one-acre (4046 m^2) farm using only one emitter and receiver. They presented a design of a LoRa backscatter chip that consumes only 9.25 μW of power, which is more than 1000x lower power than LoRa radio chipsets.

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