Colloquium on Polymer Science and Molecular Engineering Zhejiang University and the University of Chicago
12-16 April 2017

Thoreau: a wireless underground sensor network for environmental sensing

Xufeng Zhang[1,2], Arseniy Andreyev[1], Monisha Ghosh[1], Supratik Guha[1,2]

1. Institute Molecular Engineering, University of Chicago, 5640 South Ellis Avenue, Chicago, IL, 60637, USA
2. Division of Nanoscience and Technology, Argonne National Laboratory

Abstract: Long-term continuous monitoring of the environment (water, soil) is of critical importance for modern civilization. Particularly, water and soil nutrients are related to various aspects of human society ranging from food production and water safety to manufacturing cost and energy conservation.[1,2] However, nowadays nutrient sensors are still very underdeveloped, facing various challenges including cost, sensitivity, selectivity, etc.[2-6] Here we show our approach in developing novel nutrient sensors, and demonstrate our efforts in establishing a wireless underground sensor network platform which can be utilized for future deployment of large-scale continuous soil nutrient monitoring networks. We also demonstrate the great performance of our sensing system, and the application of machine learning in wireless sensor network data processing.

Introduction

- Thoreau: first large-scale, cloud-based wireless underground sensor network deployed in an urban area (on the campus of University of Chicago). Thoreau.uchicago.edu
- A plug-and-play testbed for developing new environment sensors
- Fully underground, does not obstruct aboveground activities
- Great network performance in spite of harsh underground wireless environment

- Low power consumption: battery powered, up to five year operation lifetime
- Low cost: unlicenced frequency band
- Long-range: rural areas: 30-50km; urban areas: 3-10km
- Long-term continuous monitoring of soil properties

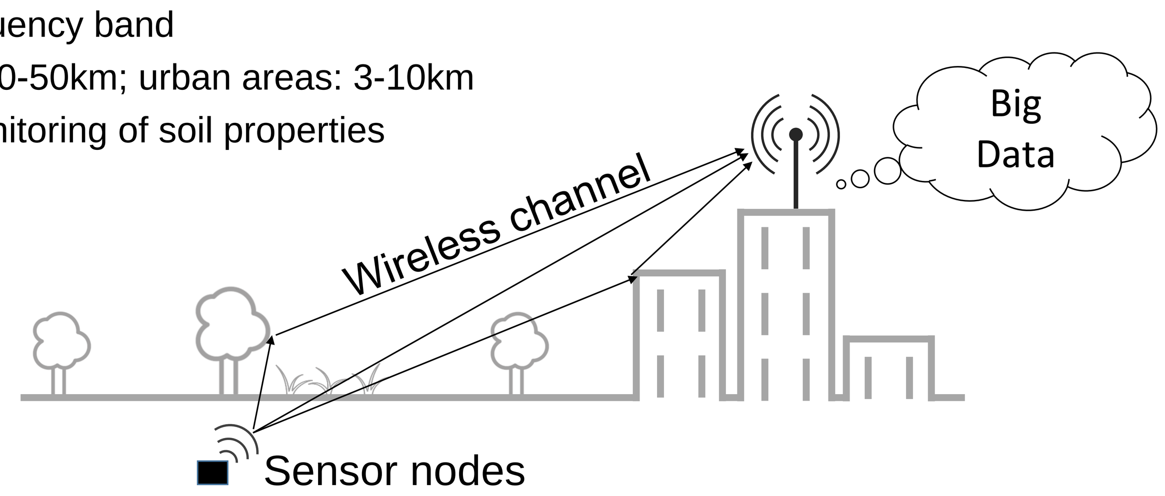

Fig. 1. Schematics of wireless underground sensor networks for environment monitoring.

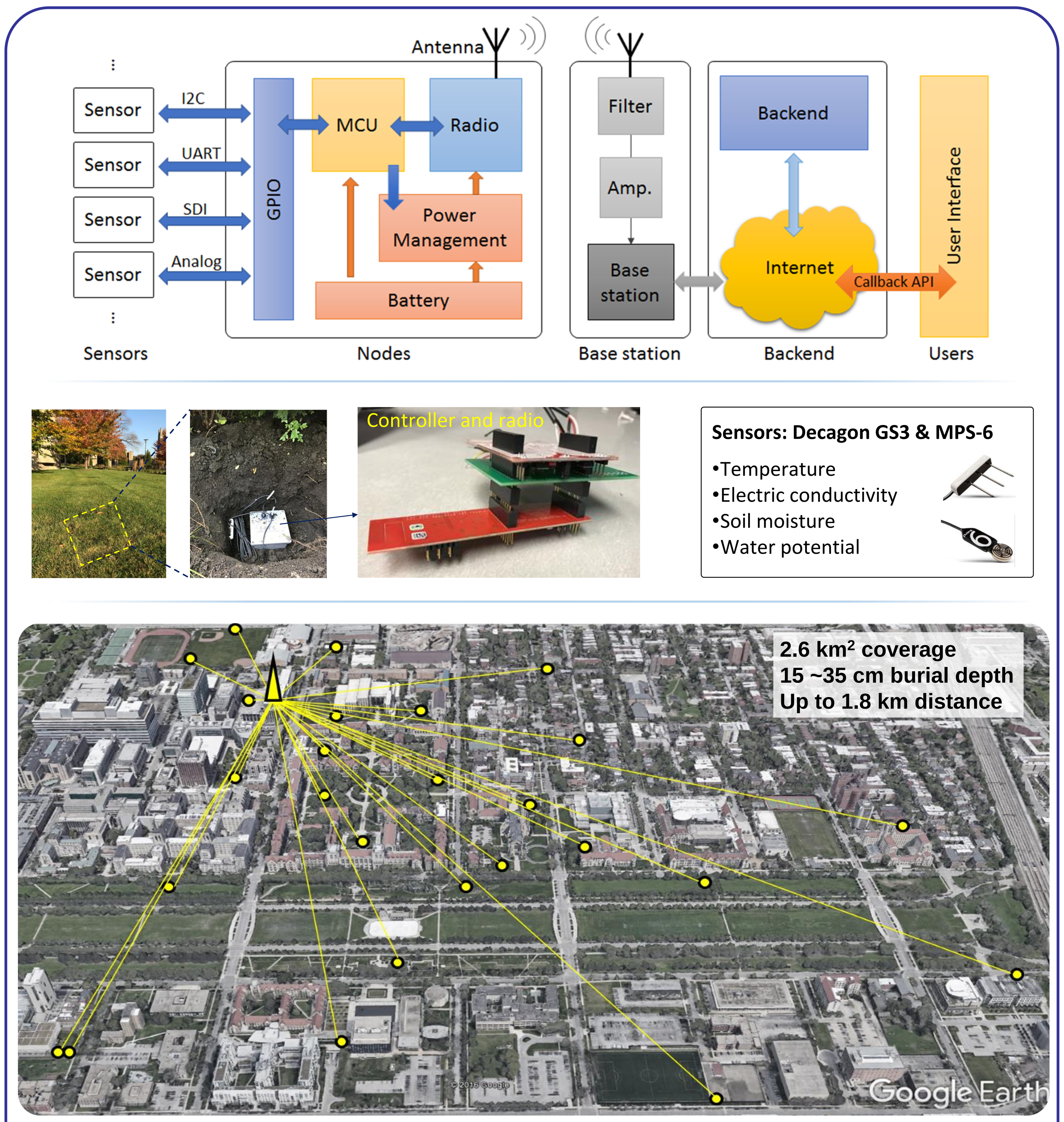

Fig.2 System diagram (top), sensor node (middle), and deployment map (bottom) of Thoreau wireless underground sensor network.

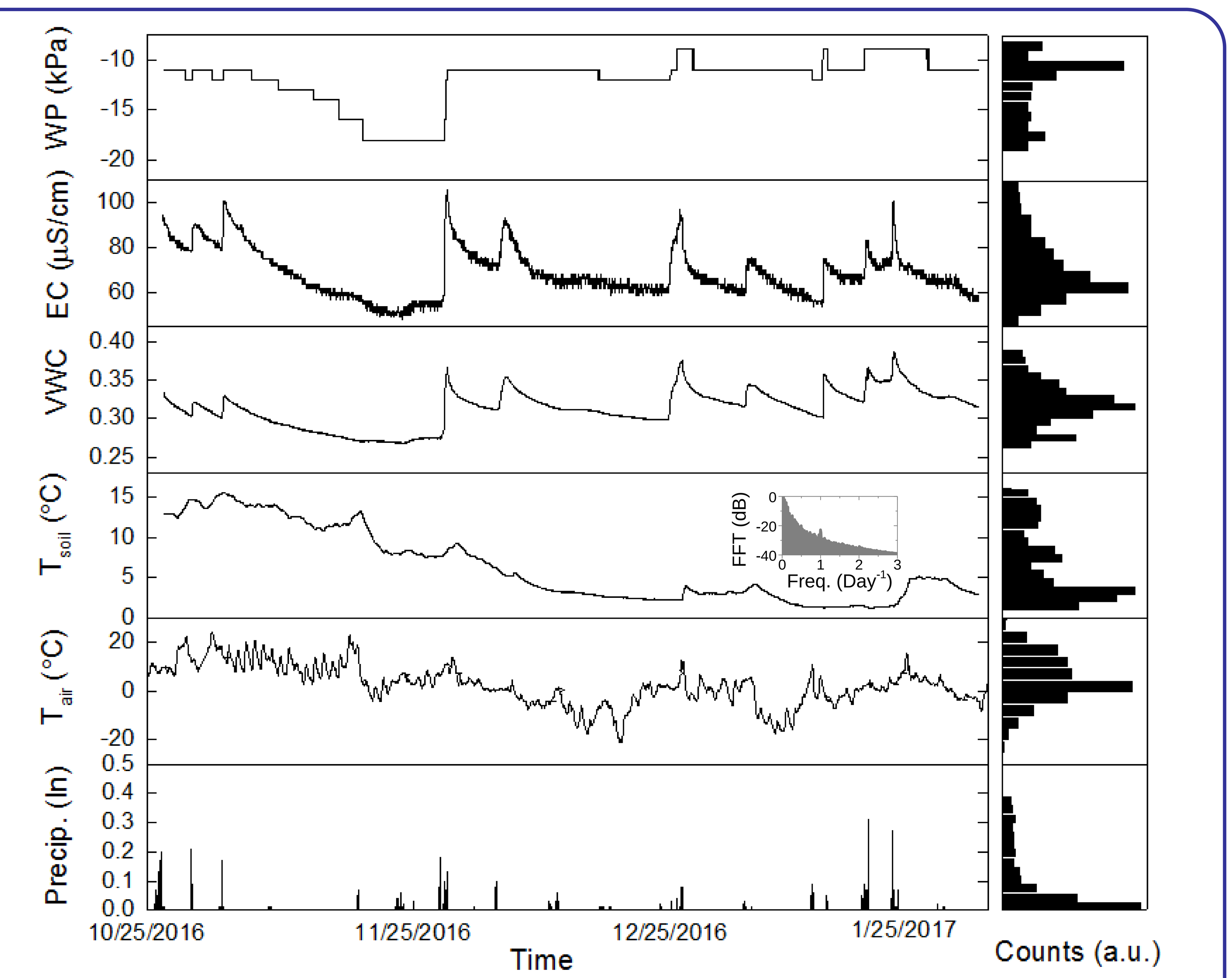

Fig. 3. Measured soil properties (left column) and their histograms from a single sensor node over a period of three months. WP: water potential; EC: electric conductivity; VWC: volumetric water content; T_{soil}: soil temperature; T_{air}: air temperature; Precip.: precipitation. Inset shows the Fourier transform of soil temperature, showing its daily variation.

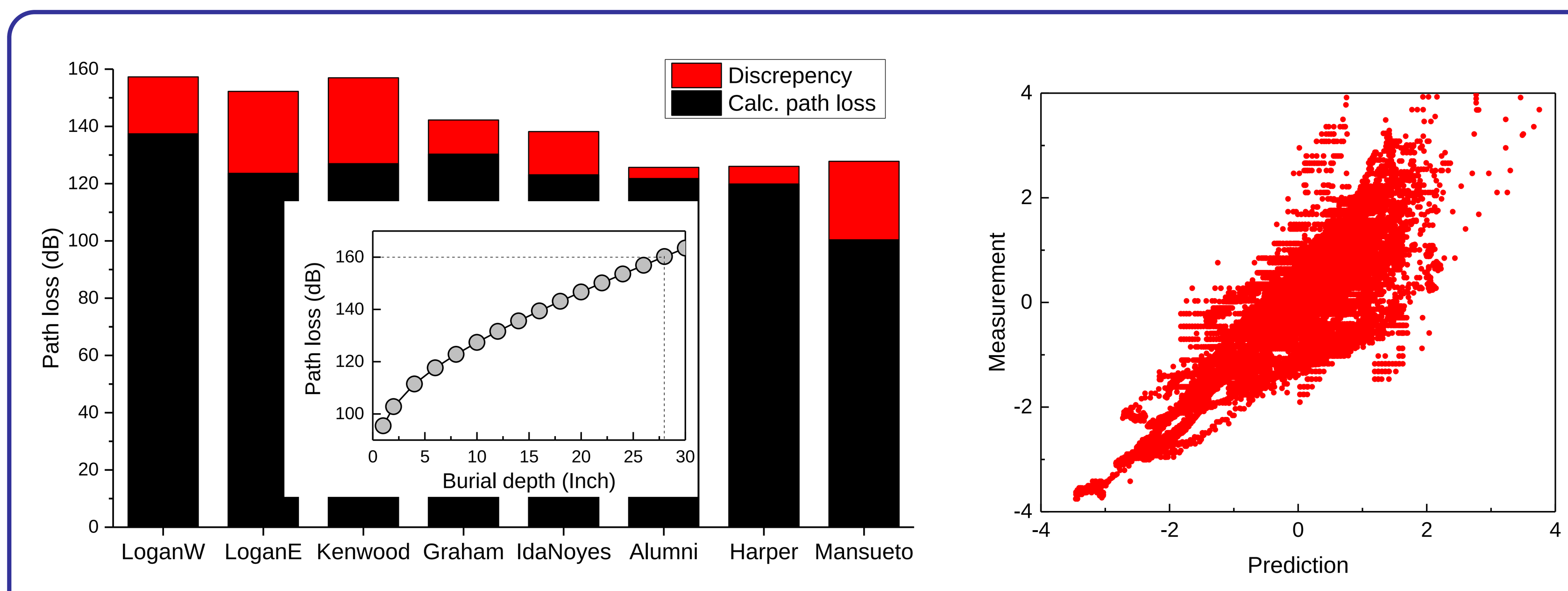

Fig. 4. Left: calculated and measured path loss for underground sensor nodes (inset: path loss versus burial depth). Right: prediction of electric conductivity from soil temperature and soil moisture using machine learning algorithm for all 27 sensor nodes.

- **Challenges**: New soil sensors are needed to enrich the functionality of soil sensor networks. Currently no good solutions for important soil properties such as nutrient content.
- **Our approach**: Use integrated photonic device for soil nutrient sensing, which reduces the cost of conventional optical sensing methods while preserving their high sensitivity and selectivities.
- **Key**: Find proper materials such as functionalized polymers for device integration.

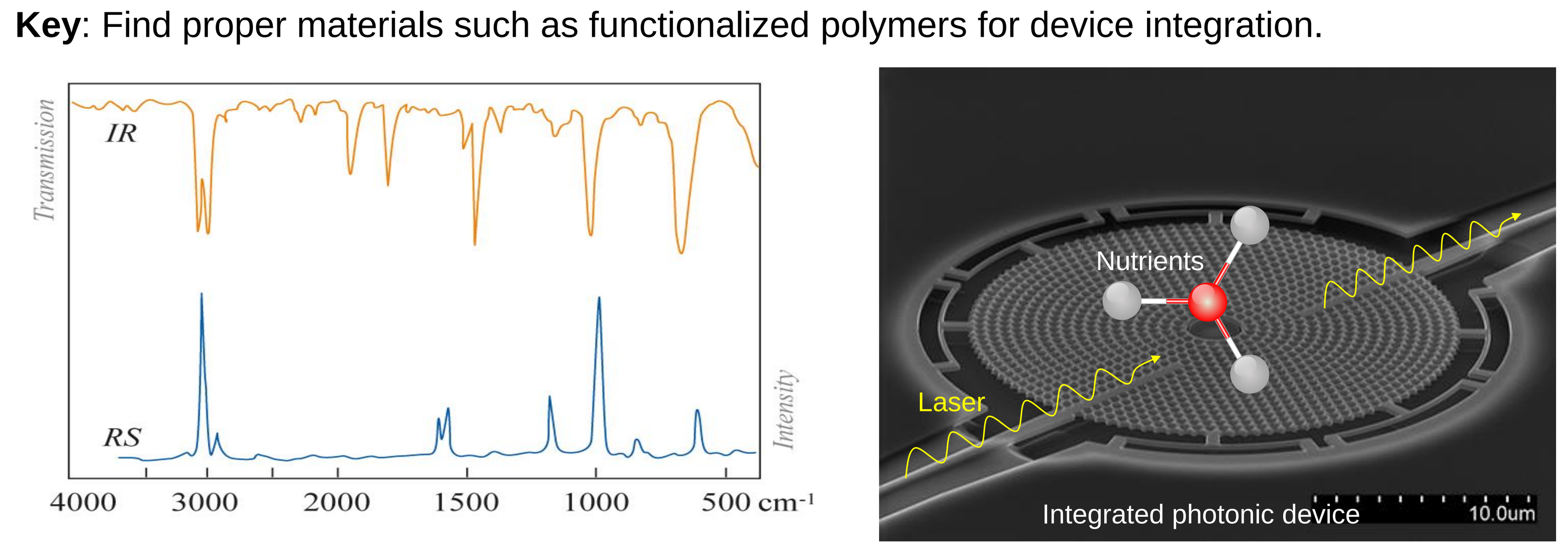

Fig. 5. Optical characteristics of nutrient molecules (left) and conceptual illustration of soil nutrient sensing using integrated photonic devices[7] (right).

Conclusions: We demonstrated the concept of using integrated photonics devices for high-sensitivity low-cost nutrient sensing and building affordable environment sensing systems based on such sensors. Our wireless underground sensor network (Thoreau) has been well established and can readily incorporate newly developed sensors for field or lab test. It covers 2.6 km^2 area in an urban area with distances up to 1.8 km, and can operate for five years with battery power supply. We showed the curated data from this system, showing its capability of real-time, continuous environment monitoring.

Acknowledgement

- Sigfox: providing base-station, antenna and ongoing technical support
- The University of Chicago Grounds and Landscape Services: assistance in network deployment

References

1. W. K. Dodds, et. al., Environmental Science and Technology, vol. 43, no. 1, pp. 12-19, 2009.
2. D. J. Sobota, et. al., Environmental Research Letters, vol. 10, p. 025006, 2015.
3. B. A. Pellerin, et. al., Journal of the American Water Resources Association, pp. 993-1008, 2016.
4. M. R. Gartia, et. al., Journal of Environmental Monitoring, vol. 14, pp. 3068-3075, 2012.
5. W. L. Daniel, et. al., J. Am. Chem. Soc., vol. 131, no. 18, pp. 6362-6363, 2009.
6. C. Fiske and Y. Subbarow, J. Biol. Chem., vol. 66, no. 2, pp. 375-400, 1925.
7. X. Zhang, X. Sun and H. Tang, Optics Letters 37 (15), 3195-3197, 2012.