Executive Summary

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1. Title of the Project:

   Green/Sustainable IoT for Smart Environment

2. Date of Start of the Project:

   October 1, 2021

3. Aims and Objectives:

   Two aspects are of primary interest: *communication/storage resource efficiency* and *energy sustainability*. On energy sustainability, the focus has been on intelligent node-level and network-level strategies for energy-optimized operation and novel strategies for online energy replenishment. The targeted exercise has been divided into 3 core objectives:

   a) **Algorithms and technology development on smart IoT sensor nodes** for two target sensing applications: smart power metering and grid monitoring, and fine-grained pollution sensing.

   b) **Campus-wide deployment of indigenously developed nodes** for field data collection, for which appropriate network architecture are being considered for the two contexts.

   c) **Localization of events, such as pollution sources, for potential real-time actuation/ actionability** by using the sensed field data from the IoT nodes, including demonstration of the **online auto-calibration** feature of the IoT nodes.

4. Significant achievements (not more than 500 words to include List of patents, publications, prototype, deployment etc.)

   - **S. De, "Smart sensing technology," non-exclusive license transferred to i2SAGE Technologies Pvt. Ltd.**, New Delhi; licensed by Foundation for Innovation and Technology Transfer, IIT Delhi, Jan. 2023.
   - **S. De, "Smart real-time/non-real-time data handling technology," non-exclusive license transferred to i2SAGE Technologies Pvt. Ltd.**, New Delhi; licensed by Foundation for Innovation and Technology Transfer, IIT Delhi, Jan. 2023.
   - **Basic DLMS-enabled data-smart meter prototypes have been deployed in 10 places in IIT Delhi campus** for cloud-based smart meter data collection on 'real time' (please refer to Fig. 1).

Figure 1: Deployed DLMS server (data-smart meter) and DLMS client.

- We have **proposed an inventive learning-aided smart IoT device for non-invasive identification of power supply source and power quality** in a heterogeneous powered (AC power grid, solar power, diesel generator, etc.) appliance/system, such as wireless network base station, by measuring the DC signature at the DC-powered appliance/system input point (please refer to Fig. 2); Indian patent filed.

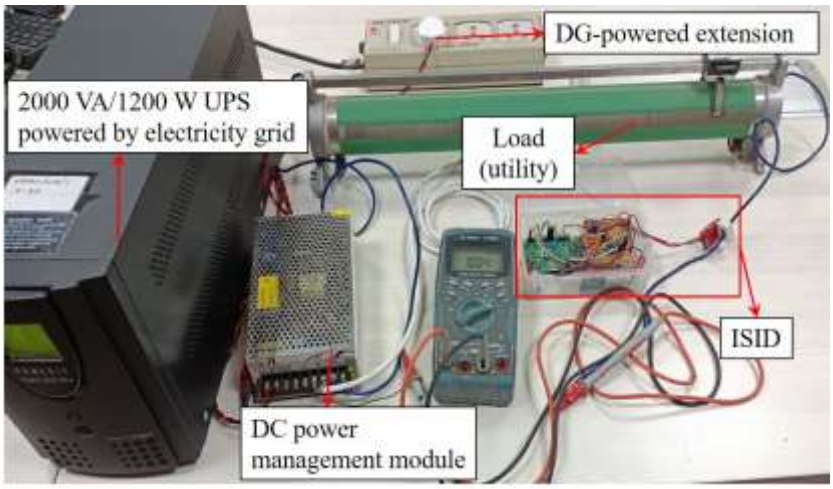
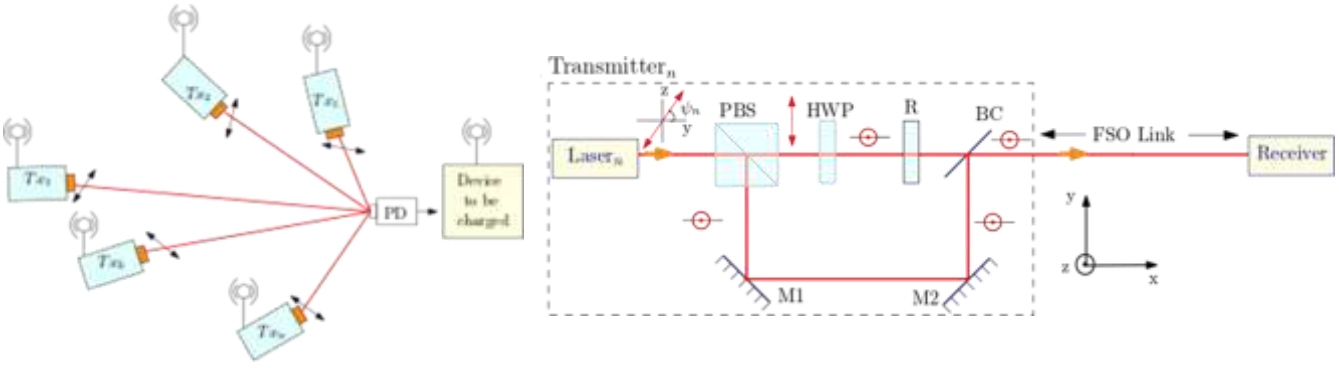


Figure 2: Laboratory set-up for studying the proposed power source identification module.

- In an allied direction of energy sustainability of wireless nodes, our inventive distributed polarization beamforming for optical wireless energy transfer has been filed for Indian patent (please refer to Fig. 3).



(a) (b)

Figure 3: (a) Generalized system model for distributed polarization beamforming; (b) block diagram of proposed transmitted-end polarization offset correction.

- Our proposed inventive technique for grid connected green cellular network base stations have also be submitted for an US patent.

Key publications:

[J1] A. K. Mandal and **S. De**, "Joint optimal PMU placement and data pruning for resource efficient smart grid monitoring," *IEEE Trans. Power Sys.*, (accepted, Sep. 2023).

[J2] S. Ghosh, A. K. Mandal, **S. De**, S. Chatterjee, and M. Portmann, "Light-weight ML aided autonomous IoT networks," *IEEE Commun. Mag.*, (accepted, Jan. 2023).

[J3] A. K. Mandal and **S. De**, "A novel learning-based estimation scheme for communication over impulsive noise channels," *IEEE Wireless Commun. Lett.*, vol. 12, no. 7, pp. 1154–1158, Jul. 2023.

[J4] N. Varshney and **S. De**, "AoA-based low complexity beamforming for aerial RIS assisted communications at mmWaves," *IEEE Commun. Lett.*, vol. 27, no. 6, pp. 1545–1549, Jun. 2023.

[J5] S. Sharma and **S. De**, "Impact of polarization on distributed optical beamforming," *IEEE Commun. Lett.*, vol. 27, no. 4, pp. 1180–1184, Apr. 2023.

[J6] A. K. Mandal, A. Malkhandi, **S. De**, N. Senroy, and S. Mishra, "A multipath model for disturbance propagation in electrical power networks," *IEEE Trans. Circuits Syst.–II: Express Briefs*, vol. 70, no. 4, pp. 1460–1464, Apr. 2023.

[J7] N. Varshney and **S. De**, "Design optimization for UAV aided sustainable 3D wireless communication at mmWaves," *IEEE Trans. Veh. Technol.*, vol. 72, no. 3, pp. 3274-3287, Mar. 2023.

[J8] A. K. Mandal and **S. De**, "Analysis of wireless communication over electromagnetic impulse noise channel," *IEEE Trans. Wireless Commun.*, vol. 22, no. 2, pp. 1187–1200, Feb. 2023.

[J9] A. Balakrishnan, **S. De**, and L.-C. Wang, "Networked energy cooperation in dual powered green cellular networks," *IEEE Trans. Commun.*, vol. 70, no. 10, pp. 6977-6991, Oct. 2022.

Patents filed:

[P1**] S. De** A. K. Mandal, R. Choudhury, K. Saha, K. Sirohi, and R. K. Mallik, "A system and a method for detecting a type of power source," applied for Indian patent, ref. no. 202311053470, Aug. 2023.

[P2] **S. De** and S. Sharma, "Synchronization methods and systems for distributed optical beamforming (DOB)," applied for Indian patent, ref. no. 202311009786, Feb. 2023.

[P3] **S. De**, A. Balakrishnan, K. Sirohi, and D. Mitra, "System and method for providing energy management in communication network," applied for Indian Patent, ref. no. 202111056238, Dec. 2021; applied for US patent, ref. no. 18/061,249, Nov. 2022.

5. Concluding remarks

In this translational research direction, we are continuing to explore newer ways to "smart" (learning-enabled) energy-sustainable communication and system performance. Two new patents have been filed, and a previously submitted Indian patent application has also been filed for an US patent. We are working on building industry partnerships for further productization and commercialization of the smart IoT and communication systems prototypes.