Abstract
A partnership between the city of Washington DC and George Washington University (GW) was established in 2015 in connection with the MetroLab Network, a Smart Cities initiative sponsored by the White House Office of Technology Policy. The purpose of the partnership was to work together to solve key city-wide issues related to traffic congestion, utilities management, environmental sensing and public health. In this light, the Pennsylvania Avenue 2040 (PA 2040) Initiative was launched to modernize an area of the park near the White House, making it a showpiece for innovative smart lighting and environmental sensing technologies. In supporting the PA 2040 project, the Principal Investigators have worked closely with several agencies in DC to assemble the team needed to plan and coordinate the multifaceted effort to place seventy-six low energy streetlights around the park that can house several types of cameras and environmental sensors. This system, made by Sensity Inc., is enable with WiFi for visitors, and is capable of transmitting sensor data to a hub site for streaming of raw data to storage or sending deidentified and processed data to open research data repositories accessible over the Internet.

For the last several years, Dr. J.H. Miller has worked on the design and construction of a purpose-built, low-cost Carbon Dioxide sensor (LuftSinn) that could be deployed in rugged environments, like in the Alaskan tiaga forest to measure the concentration changes of the gas as the permafrost thaws. Based on his lab's practical experience and field-testing of the device, plans have been made to improve the electronics and simplify the packaging of the sensor. As part of the Common Sense Metro DC Project, we propose to improve the sensor and case, and transition the unit from a one-off pilot technology to a production prototype. The only use of EPA Challenge funds will be for the improvement and scale up of the LuftSinn sensor. Third party investment will be sought to scale the device up from lot sizes of 10's to 100's and beyond if the product is successful in the market. In addition to field-testing the LuftSinn device, Dr. Miller has been working with Sensity Inc., the streetlight manufacturer for the PA 2040 effort, to design a mounting for the case to easily locate it on the pole and connect it to power, networking and data bus for the cameras and sensors.

Our proposal is to utilize at least 500 environmental sensors across DC beginning with the PA 2040 Project, officially launched on Oct 20, 2016 by Mayor Muriel Bowser. We will start with a small number of sensors from three manufacturers; Array of Things, Avanss Smart Sensor and LuftSinn to learn about the devices and develop best practices for working with city agencies to get sensors placed, calibrated and outfitted to match the environmental conditions of the local community. From there, sensor data will be collected and distributed to investigators using multiple approaches (e.g., Ethernet, WiFi, LoRa and LTE) to transmit streaming information to repositories in DC and MD designed to store the data and provide open science analysis tools for users to examine and image community environments, and ideally, develop new ways of using all the information to improve the lives of the residents. As knowledge and experience is gained and documented, we will expand the sensor count over the first year of the project by establishing Environmental Sensing Hubs (ESH) at several research campuses spread over the city and by piggy-backing on the efforts of the MetroLab partner institutions and government agencies in Montgomery County and The District. Currently, each community has its own plans to place hundreds of sensors in buildings, public areas, information kiosks and smart waste receptacles across the region. Our initial goal is to locate ~200 each of the Array of Things, Smart Sensor and LuftSinn units, depending on their availability as they are all going through

different stages of manufacturing scale up. Additional sensors will be added through the regional partnership with the Council of Governments - Clean Air Partners, Department of Energy and Environment, Department of Transportation and Montgomery County CIO's Office (see Letters of Commitment and Attachment A).

1) Introduction

The technological innovation of the Common Sense Metro DC Project relies on a comprehensive, high-performance end-to-end cyberinfrastructure platform for scientific research developed by The George Washington University (GW) under prior NSF awards. The open science platform, known as the Multi Service eXchange (MSX), is an advanced IT infrastructure for access and management of vast amounts of information from city-wide data streams and data repositories. The MSX research framework allows users to architect and deploy arbitrary sensor units, data processing algorithms and management and reporting tools for stitching together sensor data at a regional scale. By tying together the infrastructure with experience from several sensing projects in The District of Columbia (e.g., The PA 2040 Initiative, 11th Street Bridges Project and the Village Green Solar and Wind-powered Air Monitoring Station), the Common Sense Metro DC partnership is able to support the establishment of several Environmental Sensing Hubs (ESH) deployed throughout the city of Washington DC and in Montgomery County, MD. Each ESH will provide for sensor placement, power and networking to operate air quality and other sensors typically included in systems like the Array of Things (AoT) from Argonne National Labs[i], or as stand-alone devices, like GW's LuftSinn[ii] carbon dioxide sensor or the Avanss[iii] sensing platform; each in different stages of development and described below. An ESH can be a single node on a traffic pole or street lamp, or might house several different sensors in a rooftop shed at one of several Living Laboratories located across DC.[1] In this case, multiple sensors and sensor systems will be deployed to measure atmospheric gases plus other measures like temperature, humidity, wind, barometric pressure, vibration, light, sound and even vehicle and pedestrian traffic patterns from fixed cameras.

To support data collection, storage and processing at a city or regional scale, the MSX Open Science Platform is tightly integrated with GW's Capital Area Advanced Research and Education Network (CAAREN), a 100Gbps Regional Optical Network that is part of the Internet2 infrastructure and connects with the major academic and research institutions in DC, Maryland and Virginia. CAAREN peers with the District's DC-Net Office and is critical for effective collection, transport, storage, categorization of data from multiple dimensions, and dissemination of structured and unstructured data (where policies exist). From a future city perspective, we envision the Common Sense Metro DC Project as a means to investigate the ways to collect a wide variety of Smart-City/Internet of Things (IoT) data, appropriately use and parse this data, and establish future data management policies involved in the security, access and privacy concerns of openly sharing almost everything that's traversing a city's networks.

Once the research testbed and sensing hubs are established (through public-private-academic partnerships), users will be able to evaluate both raw and meta-data processing methods and researchers can begin the important work of establishing data use policies and procedures that can be implemented across the spectrum of "sensed" data systems available through networked

[1] Through participation in the MetroLab Network, GW, Georgetown U, Howard U, American U, University of DC

devices. Next, we envision education and training programs that will expand the basic understanding of sensors and how to gather and exploit IoT data for research as well as commercial purposes. Then, the Open Science Platforms receiving sensor, and other compartmentalized data, will be made available to third party developers and researchers alike as an application agnostic incubator for new orchestration tools to meet general consumption and commercial needs. Ultimately, the true contributions of this project will lie in the establishment of a scalable resource for brokered use of city-wide real-time data that can be coupled with many other repositories within a portal that provides analysis and visualization tools to easily investigate large amounts of regional data (e.g., Montgomery County's Safe Community Alert [SCALE] Portal[2]).

Given the inherent difficulties potential business and researchers face in deploying their own sensor systems in locations controlled by municipal governments, the Common Sense Metro DC effort will define the key relationships needed for cities, academic institutions and citizens to carry out joint Smart Communities research and create a working template for other entities to use. In that way, researchers and citizen scientists will have a process to access existing city infrastructure and the ability to deploy new sensors and experiments in ESH sites across the Metro DC Region. Without such brokered access, most groups would be limited to unrealistic laboratory experiments, or reliance on a small number of sensors independently positioned. Thus, there is an underlying educational component needed to inform research and teach others the required skills to develop a technologically savvy and well-trained workforce. Otherwise forcing the rapid implementation of smart city environments on unprepared governments would have disastrous consequences.

2) Community Goals

Environmental Sensing Hubs are research platforms for the placement, interconnection and operation of an open-access sensing network to be distributed in the District of Columbia and Montgomery County MD. The existence of ESH will yield several benefits, including bolstering our ability to investigate and identify best practices for managing big data at the community level. They will also help us understand the best mix of sensors and communications capabilities for a particular area of the city and will inform on how to engage citizens in collecting data from ESH in their community and using it to understand changing environmental conditions…and how that relationship might impact their health in urban and sub-urban parts of the city.

Our main goals are to create solutions and identify best practices that other communities can adopt and benefit from. In doing so, we rely on a tightly-coupled relationship with several of the District's key agencies and administrative leaders, including the city's Department of Transportation, Department of Energy and Environment, Office of the Chief Technology Officer and the National Capital Planning Commission and Council of Governments, as well as the Montgomery County CIO's Office (see Letters of Collaboration and Attachment A for details of these relationships).

By bringing together regional decision makers, commercial partners and research institutions to address key issues affecting the city, this Tiger Team is working together to create a plan for the

[2] http://smartamerica.org/teams/scale-safe-community-alert-network-a-k-a-public-safety-for-smart-communities/

implementation, placement and use of an increasing amount of sensor-generated data, as well as making analytical tools available for converting sensing data into knowledge and disseminating that knowledge for global consumption. Armed with such capabilities, citizens and scientists alike (local and remote) will be able to use environmental sensing data from all over the region and make it available for discovery and integration with information from thousands of sources making up living repositories searchable for raw and meta data from many overlapping sources.

3) Scientific Goals

The Common Sense Metro DC plan is to begin evaluating a small number of air quality sensors located around the Pennsylvania Avenue National Park, and expand the deployment of sensor hubs at other sites in DC and MD at the MetroLab Network partner campuses, including GW, Georgetown, American, Howard, UDC and Children's Hospital. For PA 2040, 76 intelligent streetlights and approximately 40 Access Points are being deployed providing ubiquitous gigabit public Wi-Fi service in the area. Our Phase I goal for the Common Sense Metro DC project is to begin with a small number of sensors and scale up 500 operational units across the city to evaluate sensor data related to atmospheric and environmental monitoring, vehicular and pedestrian traffic, utilities repair and cost containment, and the use of environmental sensors to improve public health. Initially, we will deploy the Array of Things system, the Avanss Smart Devices package and GW's LuftSinn sensor. In particular, the Luftsinn device has been piloted for the last two seasons evaluating CO_2 outgassing of permafrost in Fairbanks Alaska to demonstrate the accuracy and stability of the low-cost device. This field experience has led to a more robust and reliable design for the next stage in prototype development.

The LuftSinn field evaluation has led to several improvements in the design of the sensor electronics and enclosure, and here we propose to expand the sensor capabilities and streamline the manufacturing process to scale from single unit construction to a semi-automated manufacturing process (using a student kit-build program). Detailed plans for sensor construction and programming have been updated, including solar and DC power and wireless and Ethernet communications options. Additionally, a plan is in place, through separate funding, to interface the ESH network to a dedicated server operated by GW in the Cloud to house the streaming sensor data and also connect users to other open data repositories (e.g., SCALE, Data.gov or the ArcGIS Open Data portals). By leveraging this grant, the MSX platform will be available for organizing and orchestrating multimodal search and analysis tools allowing scientific exploration and development of novel applications with complex multidimensional data.

Today, a detailed plan exists for producing LuftSinn build kits that can be assembled by students within an hour[3]. As a key component of the Common Sense Metro DC project, we will work with the Council of Governments/Clean Air Partners to engage youth in sensor build events as part of their existing community education programs. In addition, college student events will be held at the MetroLab partner campuses to encourage participation in community activities. Thus, the goal of our science and community outreach efforts is to expand the capacity for manufacturing LuftSinn sensors, and potentially other purpose-built sensors, and building out a network of ESH's that are reliable and precise enough to provide a valuable tool for accessing pollutant emissions from a large, distributed city-wide community. The data from these and other

[3] http://chemwiki.cloud.ccas.gwu.edu/luftsinn/

open Smart City repositories ---sensor-based or otherwise--- will comprise a community-wide network of "Living Laboratories" accessible for measuring and monitoring urban and sub-urban environmental factors that can be used, for instance, to improve transportation, utilities management and public health services in the DC Metro Region. Specifics of our partner relationships with key agencies in the region are included in the Letters of Collaboration Section and Attachment A of this application. Through these relationships, which provide access to city infrastructure, calibration against the Ambient Air Monitoring Network and cross-divisional access to city officials, we are positioned to capitalize on the emergence of low cost sensors, general-purpose wireless platforms and cloud-based computational tools. We now have the advanced open science MSX platform available for use and we are looking to the Smart City Air Challenge to provide seed funding to take the grant developed LuftSinn sensor from a pilot project to a commercial prototype. We are also relying on the recognition of the EPA to help springboard our ability to fully fund the program through public-private investment and corporate sponsorship.

4) Description and Scope

The goal of the Common Sense Metro DC Project is to develop a framework that any city can use for establishing a large-scale, repeatable ESH network that involves university partners and core government agencies and citizens in the establishment and growth of a community-based sensing infrastructure. The success of this project will be leveraged on prior experience gained working with the sensor technologies that are included in the PA 2040 Environmental Sensing Phase I project. Here, DDOT has placed 76 LED streetlamps and 40 communications nodes around the Pennsylvania Avenue National Park to provide WiFi for pedestrians, and mounting, power and Internet connectivity for sensors. In this effort, we will place two (2) AoT devices with an initial configuration of 16 air sensors and 2 cameras and the capability to send the data wirelessly to a shared server at U. Chicago for access by scientists, educators and entrepreneurs. The nodes, based on Argonne's "Waggle" open source hardware and software stack, are designed as a "platform" that can support the integration of new technologies and uses. The Waggle software stack is already managed via a public open source Github site (https://github.com/waggle-sensor)[4]. As with the other sensors, these data will also be sent over CAAREN to a cloud repository accessible to the MSX Open Science Platform for data orchestration, signal processing and analytical reporting, as well as to the Safe Community Alert Network (SCALE) developed by Montgomery County for users to gather and analyze a wide range of environmental information.

The second sensor technology included in the PA 2040 project is the modular Avanss Adaptable Sensor System, which comes in several different sensor configurations depending on application scenario[5]. Two (2) of their environmental sensing configurations will be deployed as part of the PA 2040 project. Each unit is capable of using multiple communication options for sending and receiving data, depending on the location and capabilities of the ESH site. Finally, we will also locate up to six (6) LuftSinn sensors into the PA 2040 network to evaluate the performance of the devices under real world conditions. The LuftSinn is a purpose built carbon dioxide sensor developed by Dr. J.H. Miller from GW's Department of Chemistry as a low cost alternative to

[4] https://arrayofthings.github.io/

[5] http://avanss.net/

commercial technologies. The funds from the EPA Challenge, if successful, will be used to upgrade the existing design of the LuftSinn, based on field tests with the device, and to establish the manufacturing processes to transition the sensor from pilot to commercial prototype.

***5)* Demonstration Project: Luftsinn Sensor**

Within the last several years Dr. Miller has offered a section of the Scientific Reasoning and Discovery Course for the University Honors Program on Climate Change, and the design and construction of carbon dioxide sensors has been an integral part of that course's laboratory program. After several iterations in component selection, a design has evolved that provides at reasonable cost a sensor with sufficient computational and communications resources.

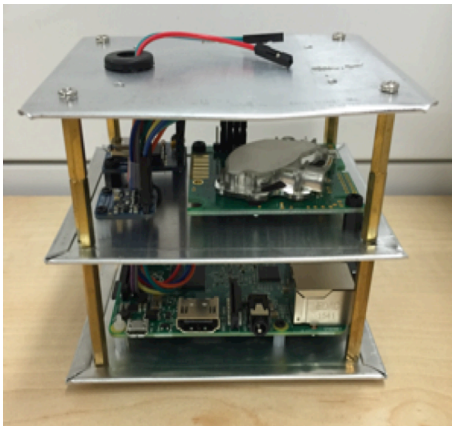

***Figure 1**: Core of a solar-powered Luftsinn unit deployed in the "fen" area of the Bonanza Creek Experimental Forest in June 2016.*

The current prototype generation, shown in Figure 1, consists of a RaspberryPi microcontroller (the latest sensors use RPi3, Model B+), a K30 non-dispersive infrared (NDIR) sensor from Senseair, and a Bosch combination pressure/temperature/humidity sensor. Because the NDIR signal is influenced by both temperature and pressure, adding these measurements improves the accuracy and precision of the K30 units beyond the manufacturer's specifications. Both sensors communicate with the Raspberry Pi using a I^2C serial interface. The Raspberry Pis are equipped with Ethernet ports and some of the deployed units utilize Power over Ethernet (PoE) for both power and connectivity. In initial prototypes, we have used Wi-Fi adapters and the units were packaged for solar powered operation. Programming on the LuftSinn units is done in Python and is largely based on open-source repositories maintained by component vendors (such as Adafruit CO2meter). However, most of the procedures required for calibration were developed from Senseair technical data and our own process development.

The assembled sensor packages consume only a couple of watts with Wi-Fi active, and a little less without. Nonetheless, providing power to the sensors on deployment (and negotiating the wireless security remotely around campus) has been a challenge. In our current design, we use a small (10W) solar cell connected to a seven amp-hour lead acid battery to provide nearly continuous power for a diurnal cycle. We have also experimented with a variety of weatherproof housing units, and have settled on a ≈0.5 ft^3 electrical enclosure from Bud Industries. Each of the assembled sensor units is anticipated to cost approximately $400.

6) Summary

Through the Common Sense Metro DC regional partnership, we will learn what it takes to integrate sensing hubs in communities and develop a repeatable plan for including the people in those communities with STEM education, job opportunities, expansion of community engagement around environmental sensing, and learning how it can all be used to improve safety and security as we expand the use of ESH in the Washington DC Metro Region.

7) Letters of Collaboration

GOVERNMENT OF THE DISTRICT OF COLUMBIA
Department of Energy and Environment

October 26, 2016

Donald P. DuRousseau
The George Washington University
Virginia Science and Technology Campus
44983 Knoll Square, Suite 322
Ashburn, VA 20147

J. Houston Miller
The George Washington University
Columbian College of Arts and Sciences
800 22nd Street NW
Washington, DC 20052

Re: Letter of Support and Collaboration on the U.S. Environmental Protection Agency Smart Cities Air Challenge *Common Sense Metro DC* Submission

To Mr. DuRousseau and Dr. Miller:

On behalf of several District of Columbia (District) agencies (the Department of Energy and Environment (DOEE), District Department of Transportation (DDOT), and Office of the Chief Technology Officer (OCTO)), I provide this letter of support and collaboration for the George Washington University (GWU) *Common Sense Metro DC* proposal to participate in the United States Environmental Protection Agency (EPA) Smart Cities Air Challenge. The *Common Sense Metro DC* initiative, or Community Sensing in the District of Columbia, will allow District communities to engage with air quality sensors, collect data, and better understand changing environmental conditions. These air quality sensors will contribute to the development of an open, regional, collaborative experimentation platform for aggregating, sharing, and analyzing sensor-based urban and suburban data that is accessible by all. Such a platform can be used, for instance, to improve transportation, utilities management, and public health services throughout the region.

Common Sense Metro DC is an extension of the National Institute of Standards and Technology Global Cities Team Challenge, where District agencies are currently partnering with GWU and others to create an urban living lab along western Pennsylvania Avenue in Washington, D.C. GWU's proposal to deploy more sensors will further enhance initiatives along Pennsylvania Avenue as well as expand this concept to additional environmental sensing hubs in the District such as the Southwest EcoDistrict, the Sustainable Congress Heights project at the St. Elizabeth's Campus, and the 11th Street Bridge Project.

EPA Smart Cities Air Challenge funds will allow GWU to improve the current design of its Carbon Dioxide sensor, which is a low-cost alternative to commercial technologies. Funds will also allow GWU to establish the manufacturing process to transition the sensor from a research pilot to a production prototype. As District agency partners, we offer access to property for the deployment of sensors, in-kind technical assistance to ensure their proper operation, help with calibrating and standardizing the use of sensors and sensor hubs throughout the city, and capabilities to harness the data.

On behalf of DOEE, DDOT, and OCTO, I express support for smart city applications to address local air quality challenges and hope that EPA finds the *Common Sense Metro DC* project suitable for a grant award. It will go a long way in empowering communities with near-real-time information.

Respectfully,

Tommy Wells, Director

cc: Leif A. Dormsjo, Director, DDOT
Archana Vemulapalli, Chief Technology Officer, OCTO

Metropolitan Washington Council of Governments

CLEAN AIR PARTNERS DC-MD-VA

National Capital Planning Commission

October 21, 2016

Ethan McMahon
Senior Innovation Advisor
U.S. Environmental Protection Agency Headquarters
1200 Pennsylvania Avenue, N.W.
Washington DC 20004

Re: U.S. Environmental Protection Agency Smart Cities Air Challenge Community Sensing in the District of Columbia Submission

Dear Mr. McMahon:

The Metropolitan Washington Council of Governments, Clean Air Partners, and the National Capitol Planning Commission support George Washington University's (GWU) Common Sense Metro DC (Community Sensing in Metropolitan Washington DC) submission for the U.S. Environmental Protection Agency's Smart Cities Air Challenge. As the regional partners on the project team, we are submitting a unified letter of support for smart city applications to address local air quality challenges.

Common Sense Metro DC is an extension of Washington D.C. and Montgomery County teams that participate in the National Institute of Standards and Technology Global Cities Team Challenge. Washington D.C.'s PA2040 team is currently partnering with GWU to create an urban living lab along western Pennsylvania Avenue in Washington DC. GWU's proposal will further enhance initiatives along Pennsylvania Avenue as well as expand this concept to additional environmental sensing hubs across Washington D.C. and Montgomery County, Maryland. The Common Sense Metro DC initiative supports the regional goal to create an open and collaborative platform for aggregating, sharing, and analyzing sensor-based urban data.

As regional partners on the Common Sense Metro DC team, we will support the project development and outreach strategies; promote student and community participation in sensor deployment and data gathering; and advance understanding of how policy-makers can use the data to support governmental decision-making. We look forward to partnering with GWU to develop and use real-time, neighborhood scale data to better understand and improve air quality in the urban environment.

Sincerely,

Steve Walz
Director, MWCOG Environmental Programs

Brian O'Malley
Chair, Clean Air Partners

Ken Walton
NCPC, Architect/Urban Designer