Smart Room Monitoring through Wireless Sensor Networks in Software Defined Infrastructures

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***Abstract*—Software-Defined Infrastructure (SDI) provides a unified framework for managing heterogeneous virtualized resources in cloud infrastructures. In this paper, we demonstrate the design of our monitoring system called MonArch that tackles the above challenge in a smart room infrastructure. A real-time wireless ad-hoc sensor network system for carbon dioxide monitoring at a complex indoor environment is supported. The system aims to detect and monitor the level of carbon dioxide on a real-time basis and provide overall air quality alerts timely.**

I. Introduction

An important health issue in buildings and structures is Indoor Air Quality (IAQ). Common issues associated with IAQ include improper or inadequately maintained heating and ventilation systems as well as contamination by construction materials (glues, paints, etc.) and other chemicals. The increase in the number of building occupants and the time spent indoors directly impact the IAQ [1]. IAQ problems are more prevalent in indoor infrastructures such as houses, offices and schools. As can be inferred, the development of an accurate system for IAQ monitoring is of great interest.

An attractive solution to this problem is the use of Wireless Sensor Networks (WSNs). The potential of an easily deployed and inexpensive WSN consisting of thousands of nodes has attracted a great deal of attention. Inch scale and low cost nodes can monitor rooms and report the data on time through wireless transmission. However, an efficient IAQ monitoring system should be able to record data non stop. At the case of any network disruption, the system should provide uninterrupted data collection.

Smart Applications on Virtual Infrastructure (SAVI) is a project that aims to investigate the future applications platforms. The SAVI testbed is an implementation of the Software-Defined Infrastructure (SDI) concept [2]. It has a three-tiered architecture: core, Smart Edges and virtual Customer Premise Equipment (vCPE)/sensors. Core is a conventional remote data center, Smart Edges are agile and mid-size data centers located closer to users and the vCPE/sensors are extensions of the Smart Edges to the customers' site to host applications and provide cloud functionalities. To efficiently resources monitor and manage in a multi-tiered infrastructure, a monitoring manager, called MonArch, is created for integrated monitoring and analytics of heterogeneous resources [3]. MonArch provides a scalable and extensible framework for flexible monitoring data collection, storage, and analytics.

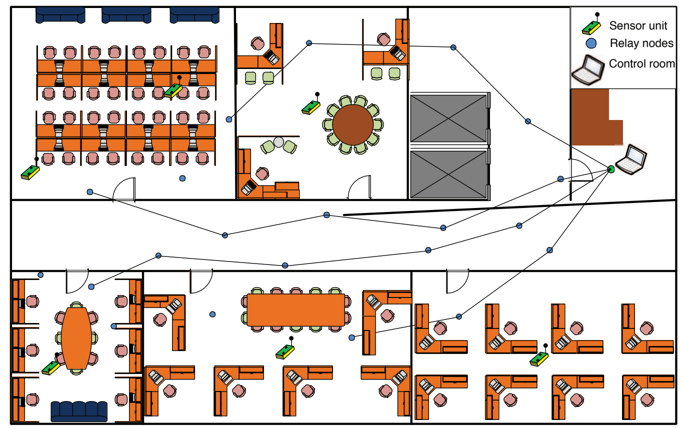

Fig. 1: A smart room with CO_2 detection and monitor system in a complex indoor environment. The sensors transmit the data to the relay nodes which forward them to the control room.

In this demonstration, we present a WSN for real-time carbon dioxide (CO_2) monitoring at a complex indoor environment, with the use of MonArch. The system reports collected monitoring data to the cloud and provide uninterrupted data collection and queueing when there is any network disruption.

II. System Architecture

In this section, we describe the proposed monitoring application scenario. We highlight the wireless system framework, the hardware infrastructure and the MonArch architecture.

A. Application scenario

We consider an indoor monitoring application for CO_2 monitoring and detection as illustrated in Fig. 1.

A number of wireless sensor nodes and simple relay nodes, are deployed in an indoor environment. The wireless sensor nodes are equipped with a CO_2 module and a wireless transmission module. The data from the sensor nodes are passed to the relay nodes. The relay nodes forward all the data to the control room, following a specific routing protocol [4]. Both the sensor and the relay nodes are powered with batteries, however, since the relay nodes have only communication capabilities, they have lower energy requirements.

B. Wireless System Framework

The system concept and the design principles were built into an application specific framework. The system framework, as

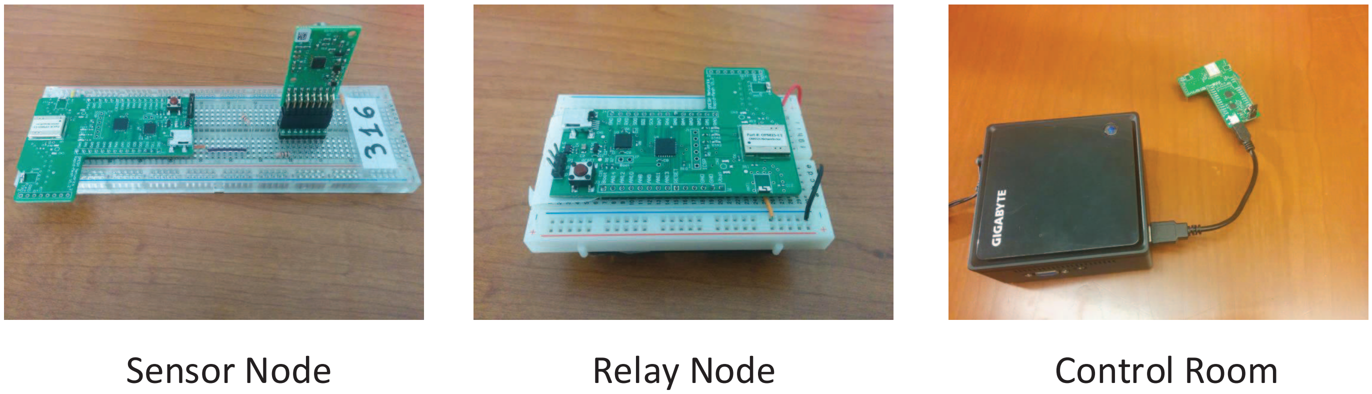

Fig. 2: Wireless system framework of indoor CO_2 monitoring system.

shown in Fig. 2, has the following three units:

- **Sensor nodes.** The sensor nodes monitor the concentration of CO_2 in the room [5]. Each node has two main parts: the sensor unit, which is a carbon dioxide sensor and the radio module, which forwards all the data to the relay nodes, towards the control room. Each sensor node continuously monitors the area around it.
- **Relay nodes.** The relay nodes forward any received packet towards the control room. Each relay node follows an opportunistic routing protocol and cognitive networking techniques for every packet transmission [4]. The protocol supports real-time sensor data transmission from various sources. The protocol was designed to adapt quickly to dynamic changes. Hence, the number of nodes, sensor or relay, can change over time, without the need to reconfigure the network.
- **Control room.** The control room consists of a vCPE where monitoring data are collected, a storage and an analytics system that resides in the cloud. vCPE is responsible to transmit collected monitoring data to the cloud and provide uninterrupted data collection and queueing when there is any network disruption. Advanced analysis and visualization of the monitoring data are executed in the cloud.

C. Hardware Infrastructure

The system is decomposed into the following three parts:

1) Sensor unit: For CO_2 detection, IAQ sensor modules from Applied Sensor are used. Table I shows the specifications of an iAQ-2000 sensor unit. It is a sensitive, low-cost solution for detecting poor air quality in an indoor environment.

The sensor unit continuously monitors CO_2 concentration (ppm) in the environment. All the data from the sensor unit are passed to the radio module for an initial processing, packet forming and transmission.

2) Radio module: Radio module performs all the data exchange between different nodes. A RapidMesh OPM15 board from Omesh is used. The specification of the radio module can be seen in Table II. The radio is based on the IEEE 802.15.4 standard to realize Opportunistic Mesh (OPM) dynamic networking with multi-frequency. OPM 15 has a microchip PIC18F26K22 programmable micro controller.

Type	MOS
Substances Detected	CO, CH_4, LPG
Power supply	$5V$
Power Cons.	$30mA$

TABLE I: Sensor Specifications

Radio range	$20m$
Frequency range	$2.405 - 2.483GHz$
Channels	3
Bandwidth (per channel)	$5MHz$
Receiver sensitivity	$-94dBm$
Transmitting power	$-25dBm$
Power supply	$3.3V$
Power Cons. (Sleep)	$1uA$
Power Cons. (Work)	$25mA$

TABLE II: Radio Specifications

The radio modules act as relay nodes in the framework. The integration of the sensor unit with the radio module creates the sensor node.

3) vCPE: The vCPE is used to collect data from the network and transmit them to the cloud or queue the data when there is a network disruption. A Gigabyte Brix Mini-PC is used in this implementation as the vCPE. SAVI vCPE software is installed in the vCPE for virtual machine hosting, auto network configuring and data collection and queueing.

4) Control room: All the data packet from the sensor units are forwarded towards the destination node at the control room. This module decodes the packets and extract all the useful information. A Graphical User Interphase (GUI), as illustrated in Fig. 3, is developed and runs at the control room. The radio module passes all the data to the laptop which display all the data in real-time through the GUI. The application can support large scale networks with simultaneous packet decoding from multiple sensors.

D. MonArch Architecture

MonArch is a scalable monitoring system that is capable of storing and processing monitoring data. One of the re-

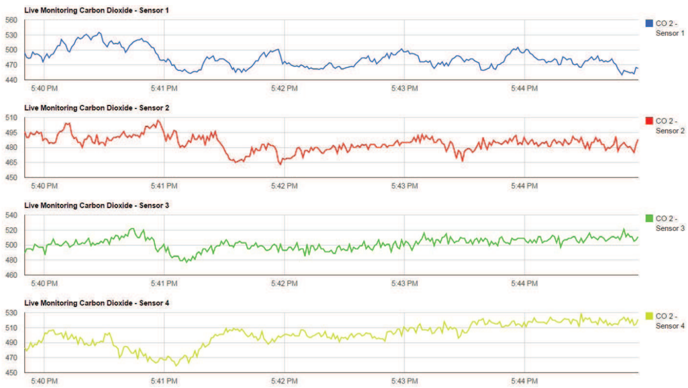

Fig. 3: Graphical User Interphase.

quirements of MonArch is Monitoring as a Service (MaaS), which means the system should allow users to access the stored monitoring data and analytics results on demand. Since the system is extensible, sensor data can also be stored and processed by MonArch. In this demo, we demonstrate how to use MonArch to collect, store sensor data and allow them to be access on demand.

The MonArch architecture is shown in Fig. 4. There are four main layers in this architecture: acquisition layer, streaming layer, batch analytics layer, and user access layer.

In order to use MonArch to collect and store sensor data, we deploy the MonArch User Agent in the server where the sensor data are acquired. Then sensor data are sent to Kafka for queueing and then to HDFS for storage. When accessing the sensor data, a user can send a request to the API module, which will retrieve data from HDFS and send it to the user.

Since data is replicated in MonArch using HDFS, sensor data can tolerate machine failure (i.e. no data lost due to some machine failures). Another benefit of using MonArch for collecting and storing sensor data is MonArch's scalability. The MonArch system can handle higher throughput (collection rate) of sensor data by partitioning sensor data into multiple stream, and having more Kafka server handle the message queuing. For storage, the storage size can be increased by adding more servers running HDFS.

III. Demonstration Goal

In this demo, MonArch is deployed in the SAVI Testbed, and the sensor receiver is attached to a vCPE which is connected to the SAVI testbed. Kafka is running in the vCPE for queueing sensor data in case of network disruption between the vCPE and servers running in the SAVI testbed Smart Edge. When network is disconnected between vCPE and SAVI Smart Edge, the sensor data is queued in the Kafka server running in the vCPE, and as soon as the network recovers, MonArch agent will retrieve data from the vCPE and submit to MonArch queueing and storage.

The goal and the technological advantages of the proposed demonstration are summarized in the following:

- Real-time data aggregation. The packets related to the CO_2 levels, are delivered to the destination in real-time.

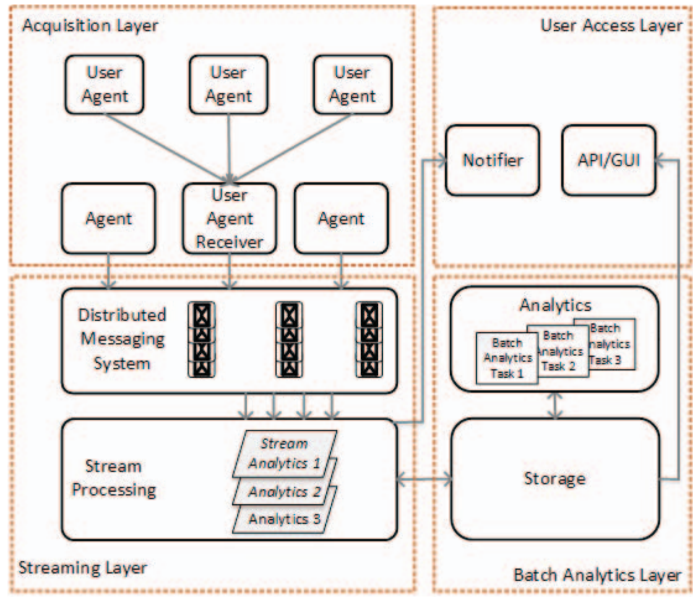

Fig. 4: MonArch Architecture

- Robustness to interferences. The use of the opportunistic routing along with cognitive networking, can provide the necessary robustness toward interference within unlicensed bands.
- Drop-and-play units. The units are able to join or leave the network at anytime, without the need of special configuration.
- Offline monitoring. The proposed system stores data during network failures and successfully resumes after after network connectivity issues resolved.

IV. Conclusions

In this work a real-time carbon dioxide monitoring system over MonArch is demonstrated. The system composed of three main units. The sensor units, the relay modules, the control room. Prototypes were built to examine the performance of the system. The system is running at the University of Toronto over SAVI testbed.

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