# The SCALE2 Multi-network Architecture for IoT-based Resilient Communities

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*Abstract*—**Safe Community Awareness and Alerting Network (SCALE) is a community government/academic/industry partnership effort that aims to deploy, actuate and evaluate techniques to support multiple heterogeneous IoT technologies in real world communities. SCALE2, an extension of SCALE, engages a multi-tier and multi-network approach to drive data flow from IoT devices to the cloud platforms. While devices are used to gather data, most of the analytics are executed in the cloud. Managing and utilizing these multiple networks, devices and technologies is a big challenge that calls for an integrated management. In this context, we propose to leverage a related effort, MINA (Multi-network INformation Architecture), that aims at integrating operations of multi-networks IoT deployments in a hierarchical manner. This paper discusses the mapping of the SCALE2 heterogeneous platforms in the MINA environment and argues for a hierarchical approach to extending and managing community IoT multi-networks. We discuss resilience methods that can be employed at different tiers in the hierarchical architecture. We illustrate examples of how multiple applications can be supported in this heterogeneous setting; example applications include co-operative seismic event detection, mobile data collections for air quality information and assisted living for elders. Finally, we discuss novel research challenges associated with managing multi-network IoT architecture.**

*Keywords*-**Internet of Things (IoT), multi-networks, edge networks, cloud infrastructure, Software-defined Networking (SDN).**

## I. INTRODUCTION

The emerging Internet of Things (IoT) ecosystem envisions instrumenting our known world with tiny devices, sensors and actuators that are capable of communicating over the Internet. Over the recent years, IoT deployments are emerging—these deployments vary across the devices they use and the network/communication technologies they leverage. A key question that arises as these deployments scale in size and number is how to leverage these new and diverse technologies for addressing larger community goals, i.e to enable resilient services to communities and cities worldwide. This includes dependable operation of civil infrastructures (e.g. buildings, transportation networks, energy delivery, water and wastewater systems) and community scale services (e.g., healthcare, public safety, emergency response, etc.). Resilience mechanisms must be designed that allow us to scale to large populations as well as deal with minor (broken water pipes and leaks) and systemetic (e.g. due to large disasters) failures in community

services. In this paper, we document our experience with real world IoT deployments in the context of the SCALE2 Global Cities Challenge Project deployment in Montgomery County, Maryland. We focus specifically on the plethora of communication technologies that have been brought together to operate simultaneously and reliably and also elaborate on the SCALE2 IoT multi-networking architecture.

SCALE2 is a community government/academic/industry partnership effort that aims to deploy, actuate and evaluate techniques to support multiple heterogeneous IoT technologies in real world communities. Through SCALE, significant public benefits can be enabled in the areas of emergency preparedness/response at the individual and community scale. The SCALE2 end-to-end IoT platform leverages cheap off-the-shelf sensors and communication platforms for a broad range of applications. SCALE2 has been successfully deployed in the Victory Senior Housing facility in Montgomery County, MD for a wide variety of sensing applications, such as personal safety, building/space safetyseismic, fire events and environmental monitoring (air quality). It entails assorted access network technologies and their integration into a common platform for resilient data collection. SCALE2 technologies are also deployed in Irvine, California where it leverages the I-Sensorium testbed in UC Irvine and the surrounding community in efforts focusing on building safety/security and campus-level activities.

SCALE2 engages a multi-tier and multi-network approach to drive data flow from IoT devices to the cloud platforms where the information is stored, analyzed and used for decision making by various stakeholders (local governments, infrastructure operators and citizens). While devices are used to gather data, most of the analytics are executed in the cloud. Managing and utilizing these multiple networks, devices and technologies is a big challenge, which calls for an integrated management point. In this context, we leverage a related effort, MINA (Multi-network INformation Architecture) that aims at integrating operations of multi-networks IoT deployments. MINA, a reflective architecture proposed for multi-network management, is organized into 3 layers. Tier 1 incorporates end devices (stationary or mobile) with limited resources (computational, storage, power and network bandwidth) where access methods include WLAN, WiFi adhoc, Bluetooth, PANs, etc. Tier 1 devices communicate using heterogeneous access technologies (3G, WiFi,

via gateways, edge elements and network controllers for various access networks) in Tier 2. Tier 3 incorporates the distributed cloud platforms and servers where information about and from networked devices is gathered, stored and analyzed. MINA realizes a reflective OOA (observe, analyze and adapt) control policy in its operation that allows better provisioning of network resources among the participating nodes and promptly adapts to any dynamics that can arise amid operation.

This paper discusses the mapping of the SCALE2 heterogeneous platforms in the MINA environment and argues for a hierarchical approach to extending and managing community IoT multi-networks. We discuss resilience methods that can be employed at different tiers in the hierarchical architecture. We illustrate examples of how multiple applications can be supported in this heterogeneous setting. Finally, we discuss novel research challenges associated with managing multi-networks IoT architecture.

## II. THE SCALE2 PLATFORM AND ASSOCIATED EDGE NETWORKS

In response to SmartAmerica Challenge [1], the multi-organization Safe Community Awareness and Alerting Network (SCALE) team, which includes partners from both academy and industry, convened to envision, design, build and demonstrate a system for addressing community and resident safety by leveraging IoT devices and services. SCALE deploys wide range of sensor devices and connects these end devices to the cloud backend through a wide range of edge networks. In the following, we briefly describe SCALE architecture along with the edge network choices in its various deployments.

### A. SCALE Architecture

SCALE is an event-driven middleware platform where devices upload sensed events to a cloud data exchange and the analytics service retrieves these events, scan for possible emergencies and send residents alerts to confirm or reject the emergency. SCALE was designed and implemented in the course of four months and so was predominately an exercise in service composition and device interoperability as we integrated devices from our various partners all in the same system. Aside from SCALE, the team also has experience deploying a local instance of the Community Seismic Network (CSN) [2] in the UCI campus. CNS is another IoT deployment from CalTech that uses a multitude of inexpensive accelerometers to rapidly detect earthquakes.

The well-received SCALE project is currently continuing into a second phase targeting the Global City Challenge [3] and goes by name SCALE2. The team plans to deploy SCALE devices from various partners in a senior living facility to experiment with various personal and community safety-oriented applications. We plan to expand the deployment of SCALE devices on the UCI campus, merging them
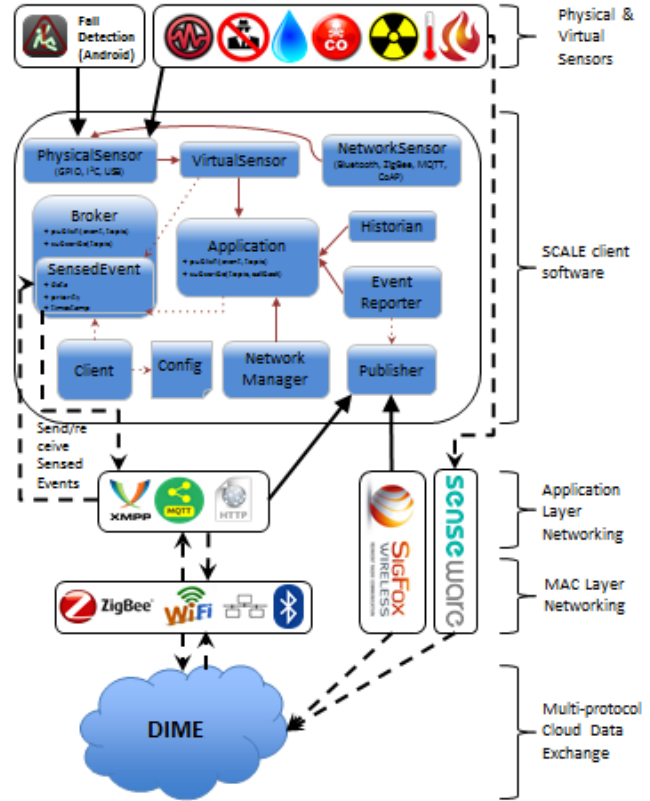


Figure 1. An overview of the SCALE2 system: clients send data to a cloud data exchange where it can be retrieved by the analytics service for event-detection and the dashboard for visualization.

with the CSN deployment, to conduct more experimental tests without disrupting those in active use by real people. SCALE2 data collection and integration architecture is depicted in Figure 1

### B. SCALE2 Access/Edge Networks and their uses

SCALE2 uses various types of networking technologies in order to facilitate communications among sensor devices. The specific choice of networking technology typically depends on the sensor application as well as the constraints of the facility in which the sensors are deployed. In most installations, the limited reach of the facilitys cabling infrastructure to the sensor installation points precludes the widespread use of wired networking technologies (e.g., Ethernet) to support the sensor network. In that, wireless seems to the most viable option.

Various wireless networking options exist, such as Wi-Fi, Bluetooth and ZigBee. Wi-Fi is the most well-known wireless networking technology, but its high power profile can be a limiting factor. Bluetooth, on the other hand, has one of the lowest power profiles, yet has a limited range. ZigBee represents an intermediate solution built on IEEE 802.15.4, which incorporates a low-power wireless specification enabling mesh networking of sensor devices.

3G is good for outdoor deployment where WiFi access is limited, but it is costly. Ultra narrow band (UNB) can be used for long range communication. It, however, supports only low bandwidth communication and requires additional infrastructure (such as base tower). As these examples illustrate, the power envelope and distance between sensors in a particular sensor application can dictate the choice among wireless networking options.

Table I shows the list of edge networks that SCALE2 used in its various applications.

Table I
SCALE2 ACCESS/EDGE NETWORKS

| Network | Features | Application |
|---|---|---|
| UNB | Ultra narrow band, long range radio, low bandwidth | CSN |
| Zigbee | Low power wireless mesh networks | Senseware |
| WLAN | High bandwidth wireless with infrastructure support | CSN |
| WiFi Adhoc | Mesh networking, adhoc networks | CSN |
| BlueTooth and BLE | Low power, low data volume | Assisted living, fall detection for elderly |
| 3G/Cellular/GPRS | Wide area coverage, outdoor deployment | Air quality monitoring, noise sensing |
| Wired Ethernet | Wired infrastructure | Configuration and management |

## C. SCALE2 Management of Edge Networks

SCALE2 leverages a handful choice of network management approaches in its various deployments done by its different partners. These choices span from IoT Gateway option for merging multiple heterogeneous applications to software-defined (SDN) approach of network management.

*1) Senseware Approach:* Senseware, a valued partner of SCALE2 project, has certain proposal of making vertical integration of sensing devices with their associated networks (when several much deployments are working together but in isolation). Senseware observes that sensors are often introduced into a commercial facility (e.g., office building) based on a value proposition linked to a single vertical market. For example, an energy monitoring value proposition can promote the introduction of power management sensors into the commercial facility for sub-metering analysis. In contrast, a resource management value proposition promotes the introduction of environment monitoring sensors into the commercial facility for light, temperature and air quality analysis. Each individual value proposition promotes different types of sensors that can be interconnected using a networking technology chosen particularly for that vertical market. Fragmentation of the sensor networks in a commercial facility often occurs as different value propositions are addressed in incremental fashion. For example, new sensors

supporting a new sensor application may not be able to leverage the existing sensor network infrastructure used by sensors in a previous sensor application. The result is an environment where multiple sensor networks operate in a facility to address different vertical markets.

To address this fractured environment, Senseware has focused on developing a platform-as-a-service (PaaS) model that enables evolutionary expansion across different vertical markets. Senseware has developed a proprietary wireless networking protocol built on IEEE 802.15.4. Sensewares solution achieves an efficient sensor network node infrastructure that can adapt for connect to and control of any sensor, meter or device. Senseware believes that by making it easy to deploy sensors and to add new sensors when new value propositions warrant, customers of all types will be able to create a homogeneous sensor network environment that obviates the need for expensive middleware. Senseware repairs the fractured sensor network model with a homogeneous solution that combines plug-and-play sensor bridges, wireless connectivity and cloud-hosted software. The integrated solution is designed for ease of use and rapid deployment to enhance the value proposition of connecting everything.

*2) Internet of Things Gateways:* IoT gateways is another management proposal made by MachFu Inc. (another SCALE2 partner). The proposal presents a simple API to the developer and uses as much standard frameworks as possible. The platform is supposed to provide seamless network connectivity over cellular, Ethernet, WiFi, 802.15.4 (6LoWPAN/ Zigbee), and other technologies that enables the developer to focus solely on application development. Further, it supports a wide range of applications, including those which leverage local storage and endpoint intelligence. It also provides necessary end-to-end security while being able to interface with simple and complex devices on one end and any cloud platform on the other end.

The gateway architecture (Figure 2) allows independent development and deployment of applications, leveraging sandboxing, isolation and security features. Applications need to be developed in familiar frameworks that encourage ease of development, testing, porting, and reuse. The underlying features of the platform and OS are well abstracted to the application APIs to provide for clear architectural separation and modularity. The architecture provides a clear delineation between application logic and underlying device protocols, allowing for a clear path to support present standards-based protocol implementations as well as to extend support for future implementations without constraining the application to change in common use cases.

The platform is built such that each application task runs independently within the user space. Kernel and user space controls can be extended for provisioning the application sandbox in order to provide a granular means to separate applications from each other and to extend only the func-

tionalities needed to each application.

In summary, IoT gateways that are implemented in SCALE2 includes the following:

- A software platform that abstracts the details of developing applications. The APIs should decouple application logic from device-specific interfaces, protocols and data models. This allows application developers to shorten their methods for accessing, configuring and operating edge gateways from the internal implementation details of the edge device.
- Standardized and open development tools that permit large communities of developers to rapidly create many new innovative IoT applications, similar to how consumer applications were developed on smart phones.
- An enterprise facing application management framework (similar to an application store infrastructure for consumer smart phone apps) that will enable thousands of applications to be managed and deployed based on compliance with regulatory, IT and corporate policies.
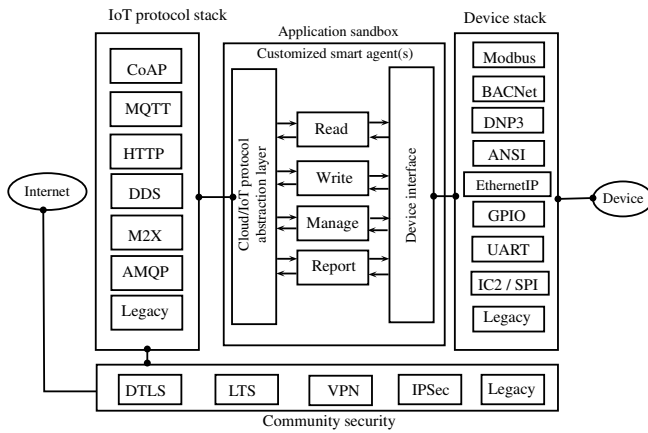


Figure 2.   IoT Gateways.

### D. Software-Defined Netwoking (SDN)

In an another management effort in SCALE2, we propose a network-aware IoT edge service architecture that utilizes Software-defined Networking (SDN) and edge computing concept to improve reliability and performance of current cloud-based IoT applications. As a proof of concept, a prototype upon the proposed architecture has also been implemented in one of our local lab networks.

Most of the applications running on SCALE platform are cloud-based IoT applications. While they benefit from all the advantages that cloud service gives, they also suffer from several drawbacks. Two major issues are i) the outage of our cloud service and ii) the failure of link between local network and cloud server. Both of the issues disrupt the service and cause the loss of sensor data. To solve outage of cloud server, one intuitive solution is to add edge servers in the local network to make a three or more levels architecture.

This method, however, may break the simplicity of client program design that cloud-based IoT service architecture promises. Eventually we would like to have a service existed in edge network that is able to provide service in addition to cloud keeps the client program design simple and the whole system easy to scale up.

To meet the above mentioned requirements, a network-aware IoT edge service architecture is proposed. As shown in Figure 3, the conventional IoT service includes two parts: IoT client devices that are deployed in local environment and the cloud server. The IoT client devices are connected to local network and further communicate with cloud server through the Internet. Our proposed architecture adds/changes two components to this current scheme. First, it replaces the local network switches with SDN enabled switches and connects switches to a central SDN controller. The SDN controller is able to change the flow entries and query the statistics on these switches by southbound protocols like OpenFlow while exposing the northbound APIs to authorized users or applications. Second, for each cloud-based IoT service which is planned to be enhanced with network-aware IoT edge service, a correspond edge server capable of calling SDN controllers APIs is deployed in the local network.
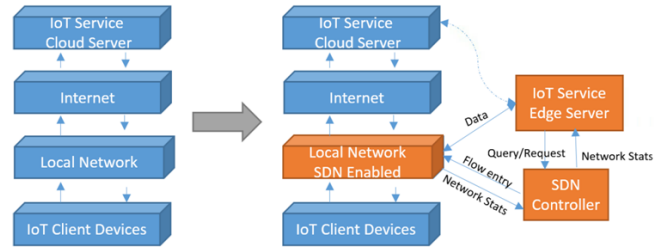


Figure 3.   Software-defined networking for IoT deployment.

This proposed network-aware IoT edge service runs as an "Observe-Analyze-Act" (OAA) loop. In the "observe" phase, the edge server measures both local networks condition and cloud links condition by running network performance testing tool and make queries for local network statistics from SDN controller. According to the network statistics gathered, in "analyze" phase, the edge server decides if the current networks meet the requirements that the IoT service needs, and then triggers the proper actions in the "act" phase to help improve the service.

### III. Challenges in Managing Multi-networks in Community Setting

The recent surge in popularity of the Internet of Things (IoT) across multiple domains has stemmed from the spread of networking-enabled consumer devices that are deployed on a geographically wide-scale. These scenarios give rise to many technical and organizational challenges—from the

monitoring of current road traffic to the optimization of travel paths based on recharging availability; from the locating of target vehicles to the dissemination of alert message in an audio or text format; from the identification of spatio-temporal recharging patterns for enabling mass scale user behavior prediction to the optimization of smart grid management in order to adequately sustain the expected patterns of recharging requests from different geographical areas.

Real world IoT deployments are fundamentally heterogeneous; they are often derived from the integration of already independently deployed IoT sub-networks, characterized by very heterogeneous devices and connectivity capabilities. The co-existence of different types of network technologies is due to legacy motivations and to different specializations in different sub-domains. The above heterogeneity poses novel challenging issues for both academic and industrial researchers, especially in order to synergistically exploit the heterogeneous network resources dynamically available in an open IoT deployment scenario. While opportunities for new classes of applications are created in this heterogeneous setting, new challenges are introduced.

The first issue involves shared provisioning of network and sensor resources across applications for efficiency. In the heterogeneous IoT setting, different user-defined tasks may run simultaneously. Given the shared space they operate in, they often share the same sensing/networking resources, with differentiated quality requirements in terms of reliability (packet loss), latency, jitter, and bandwidth. Given the randomized nature of which IoT tasks are required, these applications are often developed, deployed, and triggered in an uncoordinated manner. Optimizing sharing of sensing and communication resources and coordinating messaging in this context is challenging.

The second issue is an interoperability challenge that arises when heterogeneous devices exploit different data formats for modeling information and diverse protocols for machine-to-machine (M2M) data exchange, often dictated by legacy needs and the specifics of the domain in which they are applied. The varying requirements of applications in terms of throughput, latency and jitter raises the complexity of state capture and resource provisioning.

## IV. RESILIENCE APPROACHES IN SCALE2 MULTI-NETWORKS

Now, we describe a few of our deployment cases where we achieved resiliency in multi-networks operation in a variety of ways.

### A. Use Case 1 (insitu networks): tiered networking for seismic sensing

As communicating sensor data and other messages are the centerpiece of IoT applications, we must enable resilient machine-to-machine communications in a manner that application programmers need not concern themselves with. For Community Seismic Networks (CSN) application, it has been observed that a massive earthquake and the resulting power outages could render the system unusable due to its reliance on communicating data from the sensors to a centralized cloud server. This motivated one of our ongoing works that established a location-aware resilient overlay network for improving sensor data delivery during such a scenario. The key idea is to use the plethora of Internet-connected IoT devices as overlay peers to enable source routing and to trick the underlying routing infrastructure to make use of available routes that are not otherwise used. Figure 4 shows resilient overlay routing. This technique was originally proposed in [4] but did not consider geo-location information in choosing candidate peers.
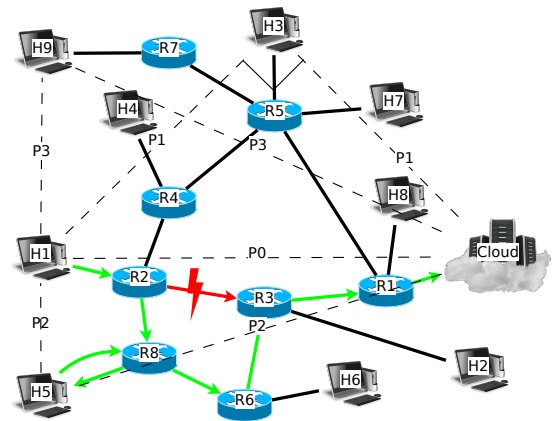


Figure 4. Geo-correlated resilient overlay networks exploit location information of nodes to improve data delivery to a cloud server.

In our previous work [5], we proposed the Geographically-Correlated Resilient Overlay Network (GeoCRON) system and showed the efficacy of this approach through simulations using simple heuristics. These heuristics exploited the knowledge of overlay peers and their locations in choosing alternative routes. We explored various choices of peers based on the angle they make with the source and destination (routing along an indirect trajectory), their distance from the source, and the geographic region they occupy. This work assumed the peers knew nothing about the underlying network topology. However, this resulted in minimal improvement and worked only for certain topologies. So, we next explored techniques for choosing peers based on the knowledge of the underlying network topology and the locations of the routers and links therein. Some previous work [6], [7] looks at choosing geo-diverse paths along which to send information, thereby increasing the chances of successful delivery and thus achieves resilience. We borrowed some of these techniques and adapted them in choosing overlay peers rather than directly specifying the route for a packet

to traverse through the physical routers.

We compared these various heuristics in two different theoretical IoT deployments: a CSN-style seismic monitoring network and a wireless-enabled public water infrastructure sensor network. Using a realistic water network provided by EPANet [8], we created a realistic deployment of both IoT networks as well as a communications network by using water demand as an estimate of population density. According to this population density, we placed seismic sensors running in home/business networks and linked them all to a two-tier realistic communications topology created using the techniques presented in [9]. Wireless base stations supported the water sensor network and were connected to the backbone routers. We studied the improvement of communications reliability in this deployment due to the use of the GeoCRON overlay during an earthquake scenario and presented our results in [10].

### B. Use Case 2 (mesh networks): In-network data processing and redundant multipath for data reporting

Another resilience approach is attempted through using mesh networks for connecting local sensors among themselves in addition to their connection to the cloud. Mesh allows redundant paths toward the central backend as well as enables in-network computation for collective decision. The idea is to allow client nodes to connect with other peer nodes to form a local wireless mesh network. This local network can be used to buffer sensing data and exchange traffic for local data analysis and aggregation. Low-cost sensing devices can be programmed to collaborate with each other over their own network to accomplish their assigned jobs. This concept has been implemented and evaluated in SCALE2 through the design of a decentralized EEW (Early Earthquake Warning) system that is fueled and managed by the members in the community. To this end, one of our works (Masters thesis of a student of our group) proposed a platform in which residents of the earthquake sensitive regions can establish and run a decentralized EEW system by themselves. The main objective is to come up with a clever way to build a resilient wireless seismic sensor mesh network which can detect potential seismic activities in a specific target region using low-cost electrical devices. In order to achieve the goal, the following algorithms are designed and tested:

- Forest-based accelerated dissemination scheme for wireless ad-hoc sensor networks;
- Network adaptive STL/LTA algorithm to ensure the accuracy of earthquake detection;
- Consensus network voting algorithm to enhance the certainty of peer nodes decision

### C. Use Case 3 (mobile networks): opportunistic mobile data collection for community monitoring

In the direction of improving flexibility and resilience of SCALE deployments, we designed and built SCALECycle, a mobile sensing and data collection platform. SCALECycle contains a mobile data collector (MDC), which is a SCALE sensor box augmented with necessary components for mobile sensing and data collection, including different types of sensors and communication interfaces, location tracking units, user interfaces, and power supplies. It can be mounted on bicycles or carried with backpacks to conduct sensing in communities on the go. As the mobile extension to SCALE, SCALECycle helps with extending the coverage of sensing capabilities, responding to instant queries, and collecting data from in-situ sensors when the network infrastructure is down. Figure 5 shows its architecture and a prototype.
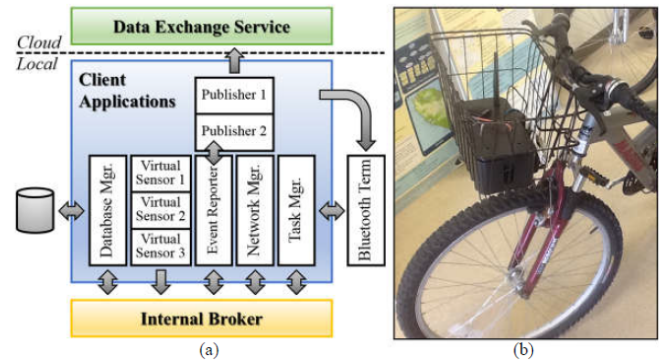


Figure 5.   SCALECycle (a) platform architecture and (b) prototype

In our prototype of SCALECycle, the mobile node has an air contaminant sensor, a mini Wi-Fi adapter, and a Bluetooth adapter. The user can interact with the node using an Android phone running a Bluetooth terminal. A Bluetooth GPS module is used to collect coordinates, so the sensed events can be associated with geotags. With the current implementation, we have collected Wi-Fi signal strength/quality and air pollution data on our testbeds on University of California, Irvine campus, and in Victory Court Senior Apartments of Montgomery County. From the measurements we collected in these real-world testbeds, we observed unpredictable nature of mobile sensing environments. Therefore, we proposed and formulated an upload planning problem for mobile data collection in community IoT deployments. To this end, we came up with a *two-phase* proactive approach that combined planned operation and dynamic adaption, and proposed algorithms for both phases to improve the overall performance of mobile data collection in community settings with uncertainty in environments and network capabilities. Our next step is to support a wider range of sensor types, including microphones and cameras, so that we can deploy SCALECycle for broader community scale applications. More ways of wireless communication

are being tested, e.g. cellular networks, to keep the mobile node connected to the cloud.

### D. Use Case 4 (community water infrastructure): fixed sensors with dedicated networks

In this particular deployment, SCALE2 is planning to leverage in fixed sensors with dedicated networks in the context water distribution networks. Urban water distribution systems are essential for sustaining the economic and social viability of a community [11]. The generation, treatment, distribution and maintenance of water workflow are typically managed by local governments and water districts. Over the years, these critical infrastructures have become complex and vulnerable to natural, technological and manmade events. The failure of water network often causes disruptions ranging from temporary interruptions in services to extended loss of business and relocation of residents. Because modern water networks typically do not have sensors (e.g. flow rate sensors, pressure sensors), instrumentation currently built into them. The objective of this deployment is to extend the SCALE2 platform to study how to inexpensively yet accurately represent and observe the state of water systems in real world and adapt water lifelines for improved efficiencies. Initial deployment puts pressure sensors on water distribution pipes underneath the ground and utilizes AT&T's dedicated cellular connection for data collection.

## V. DESIGNING A MULTI-NETWORK MANAGEMENT ARCHITECTURE FOR COMMUNITY IOT SYSTEMS

The ability to deploy multiple networks ensures resilient operation of IoT/CPS platforms. However managing and utilizing these multiple networks effectively remains challenging and is specific to the networks being integrated into a composite communication framework.

### A. MINA

Wide-area deployment of IoT incorporates multiple heterogeneous networks: from multiple access networks such as cellular, WiFi, ZigBee, and Bluetooth, to multi-hop adhoc and mesh networks. Managing these geographically distributed and heterogeneous networking infrastructures is very challenging, especially in dynamic environments. In order to take advantage of multiple networks, techniques to concurrently provision data traffic across a set of end devices and edge networking resources must be designed. To achieve this goal, multi-network INformation Architecture (MINA) has been proposed [12], which is a reflective (self-observing and adapting via an embodied Observe-Analyze-Adapt loop) middleware with a layered IoT SDN controller. In a subsequent work [13], an extension to MINA has been made in the form of a software-defined framework for the IoT deployment. The proposed framework dynamically achieves differentiated quality levels to different IoT tasks

in various heterogeneous access networks. The developed controller supports the following—

- It incorporates commands to differentiate flow scheduling over task-level, multi-hop, and heterogeneous adhoc paths;
- It exploits network calculus to provision and optimize currently available network resources.

### B. Mapping SCALE2 to MINA

Managing multiple networks through MINA can have a timely application in the context of SCALE2 deployments. MINA provisions optimal network resources across heterogeneous access networks that can be utilized by different SCALE deployments because they also support multiple access networks for greater reliability and availability. The following gives an outline how MINA can be incorporated in its different tiers.

- **Tier 1 (MINA Top Layer)**: At the top level, resilient overlay networking (RON) methods in the wired infrastructure allows data from devices to reach cloud platforms through *any* available Internet path. This leverages peer-assisted data routing inspired from peer-to-peer (p2p) communication paradigm. The idea is to route around failures in underlying infrastructure by passing message to a known reachable intermediate peer, which then forwards the data packets to the destination (the cloud server).
- **Tier 2 (Intermediate level)**: Resilience to failures can be realized via edge components. In this case, SDN (software defined networking) can be used. A SDN controller can be configured as an edge server, and OpenFlow Capable switch redirects sensor data to the edge server in the event of network failures to the cloud server. Custom edge servers can also configured for other services, such as—i) in-network data management, ii) prioritize IoT packets based on value/type, iii) dynamically adjust network configuration to meet the IoT datas QoS requirement, and iv) maintain local network states.
- **Tier 3 (At the device end)**: Multiple access networks can exist at the device layer. MINA gathers information about these multiple networks and provision collection of information for different applications across them in a cost-effective manner.

## VI. NOVEL RESEARCH CHALLENGES IN MULTI-NETWORK IOT DEPLOYMENTS

In this section, we describe a few research challenges in the direction of multi-networks IoT deployments.

### A. Multi-network management in the cloud

This challenge entails representation, storage and analysis of multi-network data. This asks to develop and design a

modeling framework and tool for community scale multi-networks at multiple levels of abstraction and organization. Specific devices (sensor/actuator, processor, and network devices) need to be modeled accounting for their resource needs and limitations, the information produced, and the interface to control their operation. As part of the system environment, application requirements including load, QoS needs, and urgency will be modeled. A general system model can be developed to capture the overall structure, interfaces, interactions, and devices that make up a particular system configuration. The general model is instantiated with components that make up the validation case studies and can be used in several ways. At design time, models are analyzed at multiple levels of detail to determine possible system behaviors and QoS characteristics. They can be used in the distributed cross-layer analyses to determine parameter settings that cooperatively achieve system-wide goals.

### B. Network provisioning techniques

This task considers local provisioning techniques at local sensor box and hints for provisioning from cloud analytics. State-of-the-art Software Defined Networking (SDN) technologies can be adopted to achieve flexible resource matching and efficient flow control. In this purpose, we propose a novel IoT multi-network controller, based on a layered architecture, that makes easier to flexibly and dynamically exploit IoT networking capabilities for different IoT tasks described by abstract semantics. Moreover, we plan to modify and exploit the network calculus to model the available IoT multi-network and hence devise algorithms to optimize its exploitation through differentiated dynamic management of heterogeneous application flows. The benefits of employing SDN techniques in IoT environments is being recognized in multiple domains both by researchers and industry practitioners.

### C. Developing a multi-networking module for SCALE2

This direction calls for development of a community based sensing, awareness and alerting platform for public safety using heterogeneous edge networks such as Wifi, cellular, and mesh. This requires understanding issues related to co-existence and interference of devices as they share communication channels. These different types of wireless networks usually share the same frequency band, hence we need to understand and optimize issues of co-existence and interference. In addition, to get a deeper understanding of the different types of networks, we also need to collect the network state information from each network in an efficient manner in terms of overhead and delay.

## VII. Conclusion

This paper outlines research efforts undertaken by SCALE2 group in the direction of leveraging multi-networks in IoT deployments. SCALE2 has been deployed for a bunch

application contexts whose appropriate narration would benefit research community to understand challenges and prospects of IoT deployment for community welfare. We discuss various resilience techniques we leveraged as a part of our design of the system. We also provide related research challenges that we aim at addressing in our future efforts.

## References

[1] SmartAmerica. http://smartamerica.org/.

[2] (2012, Jul) Community Seismic Network. http://www.communityseismicnetwork.org/.

[3] (2014) Global City Teams Challenge. https://us-ignite.org/globalcityteams/.

[4] D. Andersen, H. Balakrishnan, F. Kaashoek, and R. Morris, "Resilient overlay networks," in *Proceedings of the eighteenth ACM symposium on Operating systems principles*, ser. SOSP '01. New York, NY, USA: ACM, 2001, pp. 131–145.

[5] K. E. Benson and N. Venkatasubramanian, "Improving Sensor Data Delivery During Disaster Scenarios with Resilient Overlay Networks," in *PerNEM 2013*, 2013.

[6] J. P. Rohrer, A. Jabbar, and J. P. G. Sterbenz, "Path diversification for future internet end-to-end resilience and survivability," *Telecommunication Systems*, vol. 56, no. 1, pp. 49–67, Aug. 2013.

[7] K. Kim and N. Venkatasubramanian, "Assessing the Impact of Geographically Correlated Failures on Overlay-Based Data Dissemination," in *2010 IEEE Global Telecommunications Conference GLOBECOM 2010*. IEEE, 2010, pp. 1–5.

[8] (2016, Mar) United states environmental protection agency. https://www.epa.gov/water-research/epanet.

[9] (2016, Mar) Igen. informatique.umons.ac.be/networks/igen/.

[10] K. Benson, Q. Han, K. Kim, P. D. Nguyen, and N. Venkatasubramanian, "Resilient Overlays for IoT-based Community Infrastructure Communications," in *International Conference on Internet-of-Things Design and Implementation*, 2016.

[11] N. I. of Standards and Technology, "Community resilience planning guide for buildings and infrastructure systems," *NIST*, vol. 1, 2015.

[12] Z. Qin, G. Denker, C. Giannelli, P. Bellavista, and N. Venkatasubramanian, "A software defined networking architecture for the internet-of-things," in *IEEE/IFIP Network Operations and Management Symposium*, 2014.

[13] Z. Qin, L. Iannario, C. Giannelli, P. Bellavista, G. Denker, and N. Venkatasubramanian, "MINA: A reflective middleware for managing dynamic multinetwork environments," in *IEEE/IFIP Network Operations and Management Symposium*, 2014.