Poster Abstract: Enhancing Reliability of Community Internet-of-Things Deployments with Mobility

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***Abstract*—In this work, we aim to address the reliability issues in community-wide large-scale Internet-of-Things (IoT) deployments. Traditional IoT systems depend heavily on infrastructure thus are difficult to scale up and operate reliably to cover wide areas like communities and cities, leaving them vulnerable to dynamics in long-term operation. Given the increasing number of mobile devices with sensing capabilities in communities, we argue that the reliability of community IoT systems can be improved by leveraging mobility. We highlight essential research challenges in building integrated community IoT ecosystems with mobile nodes, and propose several possible approaches to improve sensing coverage and information quality. Based on our experience in building resilient IoT middleware systems, we designed SCALECycle, a mobile sensing and data collection platform applicable in bike-friendly communities. We illustrate our initial experiences through measurement studies on three real-world testbeds (in the US and Taiwan) and show the value of intelligent scheduling policies through extensive simulations.**

I. Introduction

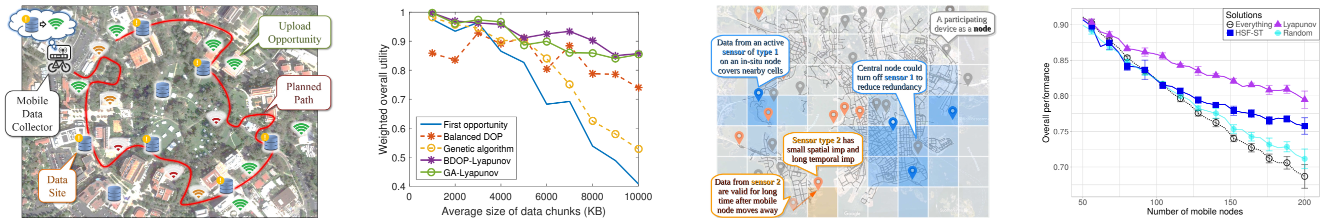
In recent years, improvements in Internet connectivity and advances in smart personal computing devices have enabled the rise of Internet of Things (IoT) deployments in real world communities. For example, our Safe Community Awareness and Alerting Network (SCALE) project has designed, implemented, and deployed inexpensive end-to-end IoT solutions for public safety [1], [2] in vulnerable communities; efforts such as SCALE are showcased at SmartCity forums [3]. However, community IoT deployments depend heavily on public infrastructure, especially for communication – continuous operation of IoT services are hampered when there are gaps in connectivity. When large events such as disasters strike public network facilities [4], the lack of accurate and timely information can lead to loss of life and property. Interestingly, the phenomenal growth in mobile computing has made mobile sensing feasible in real world communities. Mobile devices today are equipped with a range of multimodal sensors to observe local context and multiple communication modalities. Report has shown that approximately 46% US adults own smart-phones by 2012 [5] and the data increased to about 77% by 2017 [6]. Mobility creates opportunities for expanded coverage of IoT deployments, reduced dependency on infrastructures as well as increased cost-efficiency.

Our research aims at the integration of IoT and mobile sensing, leveraging advantages of both, to create an ecosystem of smart devices with enhanced awareness for communities for faster and more accurate sensing and response, better coverage, and higher reliability against failures. As new types of communication and the integration of multiple networks are made possible [7], and new platforms for mobile sensing are exploited, the idea of improving efficiency and enhancing reliability of large-scale IoT systems with mobility is practical. Several research challenges arise in creating an integrated IoT and mobile data collection platform including (a) scalability, (b) dynamicity at the application and systems levels and adaptations to deal with this, and (c) information consistency.

Related Work: Research on architectures for IoT-based smart community and smart city systems [8], [9], [10] have revealed the growing popularity of large-scale IoT deployments in cities. CarTel [11] is a delay-tolerant mobile sensing platform that collects and delivers data acquired from sensors installed on cars. BikeNet [12] is a sensing and tasking platform for cyclists to contribute to public sensing during their cycling activities. ZebraNet [13] is an energy efficient mobile sensing network design for long-term tracking of wild animals. These works mostly focus on a single purpose instead of building a complete ecosystem of IoT. Piggyback crowdsensing (PCS) [14] demonstrate the effectiveness of participatory sensing and largely improved the energy efficiency of such participations. Message ferrying [15], [4] is the approach of using mobile nodes to help data exchange in sparse mobile ad hoc networks. This can also be applied to large-scale IoT systems.

II. Novel Research Issues

Design of a Scalable Integrated Architecture: When we bring mobility to community IoT deployments, a large number of heterogeneous devices need to operate as an integrated system. Challenges exist in the utilization of multiple networks and the coordination of in-situ and mobile nodes. To support these large-scale deployments, centralized event forwarding protocols (typically from IoT device to cloud) may need to be replaced with more decentralized architectures to avoid single points of failure. An interesting tradeoff arises in how and where coordination must happen - unbounded redundancy can lead to excessive cost. An initial effort in exploring such a tradeoff through effective use of hierarchy is developed in MINA [7], a framework to manage changes in heterogeneous



(a) Upload planning for data collection in smart community IoT systems

(b) Upload planning simulation results on data utility vs. chunk size

(c) Spatiotemporal scheduling for crowd augmented urban sensing

(d) Spatiotemporal scheduling overall perf. vs. node heterogeneity

Fig. 1. Problem scenario pictures and simulation results of (a,b) upload planning and (c,d) spatiotemporal scheduling for crowd augmented urban sensing

network settings. When both in-situ and mobile nodes are present (Fig. 1c), an online spatiotemporal scheduling framework can be applied to keep the overall efficiency while maximize the coverage of sensing capability.

Adaptation to Dynamicity in Network and Application Environments: Mobile platforms can be used as data collectors (MDCs) to facilitate the data exchange in community IoT deployments. However, in real community settings the network availability is varying and intermittent, and the environment is dynamic. For an MDC with a given path, we formulate upload planning as a constrained optimization problem [16] to maximize the overall timeliness of collected data (Fig. 1a). We proposed a two-phase approach, which consists of a static planning phase on the server, and a dynamic adaptation phase on mobile devices. During the static planning phase, based on the prior knowledge of system deployments and network connectivity, we use a greedy-based heuristic (balanced deadline-opportunity-priority) to determine what to upload at each upload opportunity. During the dynamic adaptation phase, we use a Lyapunov control based algorithm to alter the plan based on dynamic conditions. Extensive simulations based on real-world data demonstrated its effectiveness.

Information Consistency within Deployments over Time: Device heterogeneity leads to inconsistency in response among devices exposed to the same phenomena. Low cost sensors on community participatory devices degrade and drift over time. Large-scale environmental changes and emergencies can affect accuracy of event detection processes. To ensure consistent behavior in long-term operation of IoT deployments, periodical calibration is required. The in-situ plus mobile IoT setup also brings new approaches and challenges to sensor calibration. We dispatch personnel with well-calibrated sensors to visit and calibrate deployed multi-sensor IoT nodes. We propose to carefully plan the trajectories of mobile agents to ensure the accuracy and reduce the traveling distance of mobile agents.

III. Prototype Platform and Results

SCALE is an IoT platform we implemented to extend smart communities with commodity sensor devices. We already have SCALE deployments in four real testbeds: (a) UCI campus, (b) the Thingstitute lab and the Victory Court Senior Apartments in Montgomery County, MD, (c) NTHU campus in Taiwan, and (d) Dhaka, Bangladesh. SCALE uses a pub/sub message exchanging protocol, currently based on MQTT [17].

To better understand the issues in integrating community IoT deployments with mobile devices, and collect real-world measurements to drive experiments, we built a mobile sensing platform on top of SCALE called SCALECycle, adding a GPS module and multiple analog sensors for air quality monitoring. Based on data collected with SCALECycle, we conducted extensive simulations to test our proposed approaches in Section II. For upload planning, our two-phase approach with proposed algorithm combination significantly improved the overall utility of collected data by 30-60% percent (Fig. 1b). For spatial temporal scheduling, our online planner achieves higher overall performance especially with large number of devices and higher degree of device heterogeneity (Fig. 1d).

Future Work: Future work will concentrate on support of multi-network settings and context-aware partitioning and scheduling in mobility augmented community IoT systems. Security and privacy in community IoT deployments are also interesting directions for research in the future.

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