Demo Abstract: A Wi-Fi Based Occupancy Sensing Approach to Smart Energy in Commercial Office Buildings

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Abstract

Buildings account for a considerable part of energy consumption. Prior research has shown that much energy could be saved by using occupancy based building automation techniques. One of the remaining challenges is how to collect real-time occupancy information that is practically accurate yet without incurring high deployment costs. We will demonstrate a prototype system that is being experimented in a typical IT office building. Our system derives coarse-grained occupancy information by sniffing wi-fi signals and fine-grained information by wi-fi based indoor positioning. The synthesized information provides sufficient accuracy for zone-based HVAC and lighting control. Due to wide-spread usage of wireless APs and mobile devices in IT buildings today, the deployment cost of our system is low.

1 Background

According to [6], commercial buildings account for 19% of total energy consumption in the US in year 2010. As an example, in a large IT company that we studied, their four office buildings at one campus spent over $2.6 million on electricity in year 2011. There is a large space for improvements in energy efficiency across commercial real-estates.

Researchers have shown that occupancy-based building automation techniques could achieve about 40% energy saving in HVAC systems alone[1, 2]. One of the remaining challenges is how to collect occupancy information in real time that is both accurate enough for actuating a building and cheap enough for large-scale deployment.

Agarwal et al. [1] used a combination of motion and door sensors to sense occupancy in single-room offices. The occupancy information gathered was used to duty-cycle the zone-based HVAC systems. Their evaluation showed that inoccupancy within buildings provided for opportunity to turn OFF building systems, and they estimated about 40% energy savings in the HVAC systems alone.

Erickson et al. [2] developed an occupancy sensing solution using ceiling-mounted camera based sensor network. Occupancy was detected by analyzing the motion of people on entrance and egress points. They estimated annual energy savings of 42% in HVAC energy consumption compared to static scheduling policies prevalent today.

Krioukov et al. [5, 4] developed a personalized building control system in one of their campus buildings. A combination of activity detection and coarse-grained wi-fi localization, based on per-floor BSSID fingerprints, is used to automate the process. They observed a 50% reduction in lighting power [5] after the system was deployed.

2 Our Project

The longer-term goal of our project is to systematically instrument legacy commercial buildings to harvest the energy savings as projected in the literature. We start from the office building in which we work and plan to extend our solution to other buildings. One of our top priorities is to keep deployment costs low by leveraging network assets.

In an office building, the main components of power consumption are normally HVAC, lighting, and plug loads. In some buildings, there are server rooms and labs that also energy hungry but require specialized energy optimization techniques. While HVAC and lighting are typical subjects for building automation, plug loads such as PCs often cannot be turned off automatically. Our strategy is to exercise auto-control of HVAC and lighting, while providing users information such as how much their plug loads cost to help them make energy efficiency decisions, e.g., to turn off personal lamps and shut down PCs while leaving offices.

Further, HVAC and lighting control is zone-based in the building system. The office area is often a mix of wall-separated spaces, such as private offices and meeting rooms, and partially-enclosed spaces, such as cubicles. A zone may cover several rooms/cubicles but a large room may include multiple zones. Hence we must be able to distinguish those *user spaces* and relate them to the *system spaces*.

Our occupancy sensing technique builds on the fact that wireless access points are widely deployed in commercial buildings and the fact that wi-fi enabled devices are widely used indoors. We use wi-fi sniffing to derive general occu-

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pancy information in an inexpensive manner. Meanwhile we expect users to run a mobile app on their smartphones to achieve more accurate indoor positioning. The two parts work together to provide information for control of zone-based HVAC and lighting systems and personal loads.

2.1 Wi-Fi Sniffing

We have implemented a wi-fi sniffer that monitors APs in a building and their communications with wi-fi devices. An office building usually has multiple APs, each serving a physical area. We choose to monitor APs that are deployed by building authorities with known and relatively stable coverage areas. When a user with a wi-fi enabled mobile device is in the building, the device talks to a nearby AP to establish connections. Even when the device is sleeping, liveness reports may be sent periodically to the AP. Signals like those correlate to the whereabouts of mobile devices, esp. smartphones, and their owners. We analyze the signals in real time to estimate occupancy information such as how many people are in the building and approximately which areas at any time. The information, although at a coarse granularity, helps identify and predict occupied and unoccupied areas.

2.2 Wi-Fi Based Indoor Positioning

Wi-Fi sniffing alone does not achieve zone-level accuracy that is required for HVAC and lighting control. For example, an AP coverage area may include a number of offices, meeting rooms, and cubicles. Hence it must be augmented with a complementary indoor positioning system (IPS) to achieve higher accuracy. In our office building, a wall-separated room is usually one standalone HVAC/lighting zone, while in an open cubicle area often a zone covers 4-6 adjacent cubicles. Current wi-fi based IPS [3] can already distinguish wall-separated rooms with over 90% accuracy. We have extended [3] with a new IPS algorithm. Our experimental results showed that our new IPS is able to distinguish cubicles that are one or more cubicles apart at over 90% accuracy.

Although the IPS alone seems to satisfy our needs, in practice not all occupants in an office building would install and run the IPS. Hence the wi-fi sniffer is complementary and necessary for a more complete coverage. Moreover, to address those who use feature phones and those who do not turn on wi-fi on their smartphones, we plan to extend our system to work with cellular signals in future work.

3 Demo Setup

The system is set up remotely in an office area, which includes 4 meeting rooms and 50 cubicles. The area is covered by 2 official wi-fi's each served by 2 APs. The system has a server, a wi-fi sniffer, and a number of Android phones running our IPS. To illustrate, some smart meters are installed with color lights to indicate occupancy of selected cubicles and HVAC zones.

As shown in Figure 1, the live demo will be given from a Web UI. A few colleagues will be walking around in the office area each holding a phone running the IPS and with wi-fi turned on. The Web interface visualizes a floor map of the office area, including positions of the APs, the HVAC zones, and the installed color lights. When a user is near his cubicle, the color lights representing his cubicle and the enclosing HVAC zone will be turned on. When the user is detected in a meeting, the lights representing the meeting room and its HVAC zone are turned on, while light representing his cubicle is turned off. When nobody is in a HVAC zone, the light representing that zone will be turned off.

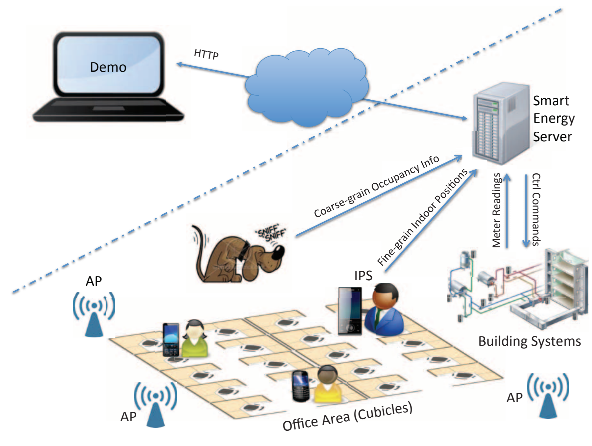

Figure 1. A live demo of the smart energy project.

The Web UI will also display occupancy information inferred from wi-fi sniffing, such as presence and mobility patterns of the devices that are indicative of their owners' presence. In addition, all the installed smart meters will be highlighted on the floor map. When clicked, each meter shows the energy consumption of devices or equipment the meter measures. Energy savings will be estimated basing on the meter readings and occupancy patterns.

4 References

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