WI-FI LOCATION-BASED SERVICES (LBS) FOR OCCUPANCY SENSING IN BUILDINGS: A TECHNICAL OVERVIEW

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Occupancy Sensing

Many commercial buildings currently use motion sensing via passive infrared (PIR) sensing to detect occupant presence (often for lighting control and building automation system [BAS] temperature controls) or volumetric sensing using the space CO_2 concentration level to estimate the number of occupants in a space to control the ventilation levels. But these methods do not provide the precision or continuous, real-time resolution to make full use of the capabilities already present in modern building automation controllers. While a BAS can be more finely tuned to better manage building operations and optimize energy savings, many existing sensors do not support this. For example, although many fan motors are capable of fully modulated operation, heating, ventilation, and air conditioning (HVAC) systems with occupancy sensing are typically configured to operate according to the following modes: 1] unoccupied space, lower ventilation; 2] occupied state with full ventilation; and 3] an “emergency override” ventilation for high occupancy (high CO_2). This leads them to over-ventilate when occupancy is low, and to produce reduced comfort when occupancy is high because they wait for the emergency condition to increase ventilation levels. Monitoring CO_2 concentrations also suffers from latency issues that adversely affect occupant comfort and accuracy issues due to sensor drift and the need for routine calibration. Passive infrared sensors require direct line of sight viewing and can have issues with low motion and false positives or negatives.

Fully optimized ventilation strategies require much more precise occupancy counting to maximize energy savings while improving occupant comfort and productivity. The ability to count the number of occupants in a predefined HVAC zone of a building allows both temperature and ventilation savings. A recent DOE/EERE RFI has a targeted commercial sector energy savings goal of 30% for HVAC and 40% for lighting via occupancy counting sensors and controls.[1]

Using the monitoring devices that individual occupants carry with them while in the building is a new approach that could provide the necessary occupant count and location sensing to help achieve this level of control. The device’s geographical location is used as a proxy for the occupant’s presence and location. Location Based Services (LBS) is the general term used for this approach which can be adapted to the occupancy count and location information needed for building operations.

Location-Based Services (LBS) and Real-Time Locating Systems (RTLS)

Location-based services (LBS) have been used successfully in a variety of applications in healthcare, retail, and hospitality buildings to track and in some cases interact with individuals.

[1] DOE EERE, “DE-FOA-0002117: Request for Information (RFI): Research and Development Opportunities for Innovations in Sensors and Controls for Building Energy Management”, *EERE Funding Opportunity Exchange*, April 17, 2019. https://eere-exchange.energy.gov/#FoaIda15ee998-ee10-488a-880e-c882279cca16, https://eere-exchange.energy.gov/FileContent.aspx?FileID=345de548-9ace-49a6-982b-8c3f7e600b1c (accessed December 9, 2019).

These services include wayfinding, asset tracking, marketing, information, and push notifications. Specific applications include:

- *Wayfinding* in shopping malls[2] and in the office,[3]
- *Asset tracking* applications in manufacturing,[4] retail,[5] and healthcare,[6]
- Proximity *marketing* in stores where advertising content such as coupons or offers is provided wirelessly through apps to shoppers when they stand near specific items and brands in the aisle,[7]
- *Information* provided in self-guided museum tours,[8, 9] and
- Location-based *push notifications.*[10]

LBSs use real-time locating systems (RTLS) that identify and track the location of objects and people through the use of wireless technology. Within the defined space, fixed reference points (a "beacon" also sometimes called a reader, or access point (AP)) receive signals transmitted by the devices or tags that the object or person is carrying. Signal strength of the tag to a

[2] Mall of America, "Mall of America® mobile app integrates live navigation", *Mall of America* [web site], October 23, 2017, https://mallofamerica.com/press/press-releases/OCTOBER-23-2017, (accessed January 7, 2020).

[3] S. Castellanos, "Waze for Work? Navigation Apps Come to Mazelike Offices", *Wall Street Journal* [web site], January 7, 2020, https://www.wsj.com/articles/waze-for-work-navigation-apps-come-to-the-office-11578398400, (accessed January 7, 2020).

[4] A. Reddy, "The Growing Use of RTLS by Manufacturers", *RFID Journal* [web site], April 19, 2015, https://www.rfidjournal.com/articles/view?12958, (accessed January 7, 2020).

[5] C. Swedberg, "Concept Store Delivers Product Content via NFC, RFID", *RFID Journal* [web site], December 30, 2019, https://www.rfidjournal.com/articles/view?19118/, (accessed January 7, 2020).

[6] S. Yoo, S. Kim, E. Kim, E. Jung, K.H. Lee, and H. Hwang. "Real-time location system-based asset tracking in the healthcare field: lessons learned from a feasibility study." *BMC Medical Informatics and Decision Making*, 18, 80, 2018, https://bmcmedinformdecismak.biomedcentral.com/articles/10.1186/s12911-018-0656-0, (accessed January 7, 2020).

[7]S. Mittal, "Proximity Marketing Examples: 28 Retail Companies Nailing it with their Campaigns", *beaconstac blog* [web blog], June 19, 2019, https://blog.beaconstac.com/2016/02/25-retailers-nailing-it-with-their-proximity-marketing-campaigns/, (accessed December 9, 2019).

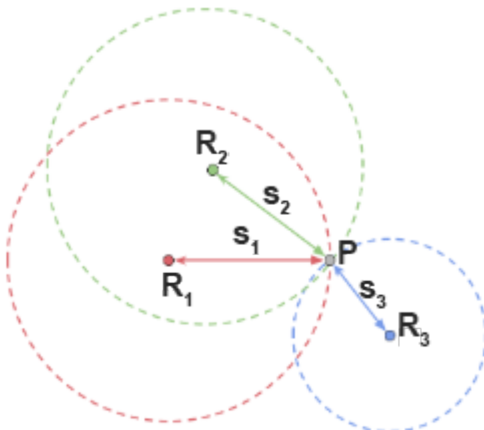
[8] R. Chun, "The SFMOMA's New App Will Forever Change How You Enjoy Museums", *Wired* [website], May 5, 2016, https://www.wired.com/2016/05/sfmoma-audio-tour-app/, (accessed December 9, 2019).

[9] S. Pau, "Audio That Moves You: Experiments With Location-Aware Storytelling In The SFMOMA App", *MW17: Museums and the Web 2017* [website], April 19–22, 2017, https://mw17.mwconf.org/paper/audio-that-moves-you-experiments-with-location-aware-storytelling-in-the-sfmoma-app/, (accessed December 9, 2019).

[10] K. MacFarlane, "18 Inspiring Location-based Push Notification Examples & Ideas", *Taplytics blog* [web blog], April 8, 2019, https://taplytics.com/blog/location-based-push-notification-examples-ideas/, (accessed January 16, 2020).

specific reference point is a measure of proximity and, using multiple beacons, the location of the tag can be determined through trilateration. In Figure 1 below, the three reference points denoted by R_1, R_2, and R_3 each read a signal (s_1, s_2, and s_3, respectively) from the tag. Where the radial signal strengths s_1, s_2, and s_3 intersect indicates the location of P.

Figure 1. Determining Location via Trilateration



A number of technologies have been used for real-time locating such as RFID (radio frequency ID), Bluetooth Low Energy (BLE) beacons, and Wi-Fi. Each system has advantages and disadvantages when applied to occupancy sensing and building operation-related LBS.

RFID systems

For RFID systems, there is a transponder ("RFID tag") that contains a microchip with a unique identifier (usually a serial number) which wirelessly communicates with a reader via radio waves. There are two types of RFID systems, passive and active. Door entry card readers are a common passive system application. Figure 2 shows examples of an RFID tag, card, and card reader.

Figure 2. RFID Tag, Card, and Reader

For passive systems, the tag or card does not have a power source. The powered RFID reader generates an electromagnetic field that activates the RFID tag or card when it is located within the field. Passive systems require close proximity between the tag/card and the reader, up to one meter for low and high frequency tags and provide point in time location. The tags are inexpensive and can last forever since they are not powered. Passive RFID systems can be very accurate for RTLS but require the tag to be within the limited range of the reader; because of this limited range, they are not very useful for occupancy sensing, as the number of readers would be unreasonably high. Also, each individual must be provided with a tag/card in order to be counted, located, and identified.

For active RFID systems, the tag has an internal power/energy source (i.e., a battery) and a transmitter that continuously broadcasts a radio signal, typically UHF. These serve as beacons, which can be continuously tracked by readers with a range of up to 100 m. This is a peer to peer system where the tag sends out a signal over short intervals of time to communicate with fixed reference point beacons and readers. Tag location is determined by trilateration either by the tag or the reader. The advantages of active RFID over passive RFID are that fewer readers are needed but tags are more expensive, and the batteries need to be replaced over time.

Bluetooth Low Energy (BLE)

BLE beacon systems can be considered an active RFID system and in the same way, use battery-powered tags to detect proximity. Figure 3 shows examples of BLE tags.

Figure 3. Examples of BLE Beacons

BLE beacons have a range of up to 70 m. If BLE tags are used, individuals may need to be issued tags for RTLS occupancy sensing. In addition to BLE tags, mobile devices, fitness trackers, smart watches, and wireless headphones use Bluetooth to communicate and can also be used for occupancy sensing. However, for mobile devices, privacy and opt-in are potential barriers to adoption. Bluetooth must be enabled, an app needs to be installed and opened, and the app must also allow location detection. Dedicated BLE beacons need to be placed within the space for occupancy sensing although there are now Wi-Fi access points available that have an integrated BLE radio to scan and locate BLE devices.

Wi-Fi

Wi-Fi-enabled mobile devices constantly seek Wi-Fi networks that are in range. Wi-Fi Access Points (APs) that are in range receive the Media Access Control (MAC) address and Received Signal Strength Indicator (RSSI) of each device whether that device is logged on to the Wi-Fi network or not (i.e., associated with the network). Figure 4 shows examples of Wi-Fi APs.

Figure 4. Examples of Wi-Fi Access Points

The MAC address is a hardware identification number that uniquely identifies that specific device on a network. For privacy, some mobile devices transmit randomized MAC addresses over time to anonymize the device. The RSSI is a measure of the power level of the signal that is being received by the AP. For the purposes of RTLS, information already gathered by the existing Wi-Fi access points can be used. Once a device is within range of an AP, device presence and identity are immediately sensed and location can be determined from the RSSI via trilateration. Occupant activity might also be inferred by the space where the device is located and/or the movement of the device around the space.

Wi-Fi RTLS is well suited for occupant sensing in commercial buildings because:

1. A large majority of the occupants will be carrying a mobile device on them or within their close proximity. For instance, in higher education a factor of 2.5–3 devices/person could be used to account for a student’s cell phone, laptop, and tablet/other devices.[11]

[11] B. Kult, personal communication, 2019.

2. Tracking does not require the individual to carry additional hardware (like a badge for RFID beacons) or to have a native app loaded on their device and connected to the network (like Bluetooth beacons).
3. Wi-Fi access points engage all Wi-Fi-enabled smartphone users (iPhone or Android), whether they are logged onto the Wi-Fi network or not.
4. Minimal additional infrastructure is required since existing Wi-Fi hotspots (installed for the communications needs of cell phone users) provide the coverage that can be used for the location tracking.

Wi-Fi RTLS can provide this level of detail based on occupant mobile device presence and provides the following capabilities for occupant sensing:

1. There is virtually no latency between the time when a new device has entered the room and when an updated occupancy count is calculated (as with CO_2 sensors). The frequency of the count is based on the time interval chosen to rescan the AP data.
2. Failure rates that occur with motion sensing are avoided when the device is at rest.
3. Wi-Fi LBS can map mobile devices across rooms and other areas of interest and trigger customized operating conditions. If individuals choose to opt in, Wi-Fi LBS can identify them and further customize their experience.

Wi-Fi RTLS is limited by the resolution of the occupant's sensed position. Scholarly research generally agrees that a resolution of ±10 feet is achievable indoors. This resolution is acceptable when occupants reside well within a single area of interest, but presents a challenge when occupants reside near the edge of two or more areas, as the Wi-Fi RTLS system cannot confidently resolve the appropriate area of the occupant. Nonetheless, this level of resolution is well matched to the area (500 to 3,000 square feet) typically served by a single zone in a building HVAC system.

Recently, a new Wi-Fi standard has been introduced that increases the location accuracy above RSSI. Known as Wi-Fi round trip-time (RTT), RTT makes use of the Fine Timing Measurement (FTM) protocol within the IEEE 802.11-2016 standard.[12] The RTT protocol uses the more precise time measurement provided by FTM to measure the time a Wi-Fi signal takes to make a round trip (RTT) between the mobile device and AP and then calculate the distance between two devices.[13] The Wi-Fi Alliance® formally announced the IEEE 802.11mc Wi-Fi standard in 2017 under the name "Wi-Fi Certified Location".[14] Currently, it is available on the Android 9 operating system but is not yet available for Apple iOS or Windows mobile devices. Therefore,

[12] B. Manz, "Wi-Fi Will Soon Provide Position Accuracy of One Meter", *Mouser Electronics blog* [web blog], August 3, 2018, https://www.mouser.com/blog/wi-fi-will-soon-provide-position-accuracy-of-one-meter, (accessed December 19, 2019).

[13] B.K.P. Horn, "WiFi Fine Time Measurement (FTM) Round Trip Time (RTT)", *Indoor positioning using time of flight with respect to WiFi access points* [website], http://people.csail.mit.edu/bkph/ftmrtt_intro, (accessed December 19, 2019).

[14] B. Manz, op. cit.

full implementation of this protocol requires a major update of mobile devices' operating systems along with installation of Wi-Fi RTT APs. Given the market share of Wi-Fi RTT-compatible mobile devices and the amount of legacy equipment that will need to be replaced, it may be quite a few years before Wi-Fi RTT will replace RSSI as a viable means to apply RTLS to building controls and operation.

The following table compares the advantages and disadvantages of RFID, BLE, and Wi-Fi RTLS:

Table 1. Pros and cons of RFID, BLE, and Wi-Fi RTLS Technologies[15]

Technology	Pros	Cons
RFID	• Very high accuracy • Immunity to interferences • No battery needed	• Short range (< 1 m) • Only provides a "point-in-time" location • Installation requires significant planning • Infrastructure can be expensive
BLE	• Cost-effective, unobtrusive hardware • Low energy consumption • Flexible integration into the existing infrastructure (battery-powered or power supply via lamps and the domestic electrical system) • Works where other positioning techniques do not have a signal • High accuracy (up to 1 m)	• Additional hardware • Relatively small range (up to 70 m) • Instability with layout changes and radio interferences • Signal attenuation can occur through materials such as walls and furniture
Wi-Fi	• Most people already carry transmitting devices • Existing Wi-Fi access points can be used • Enabled Wi-Fi is sufficient (Wi-Fi connection not necessary) • Large range (up to 150 m)	• Relatively inaccurate compared to RFID/BLE • Signal attenuation can occur through materials such as walls and furniture • Use of randomized MAC address if mobile device is not connected to Wi-Fi network

[15] infsoft, Indoor Positioning Services, infsoft White Paper EN 2019-7, infsoft GmbH, 2019. https://www.infsoft.com/Portals/0/Images/solutions/basics/whitepaper/infsoft-Whitepaper-EN-Indoor-Positioning_download.pdf (accessed December 9, 2019)

	• Detects floor level	

Process to Apply Wi-Fi LBS for Occupancy Sensing and Building Control

In order for the data collected from Wi-Fi APs to be used for LBS occupancy sensing and building control, a number of steps need to be performed. These include:

I. Mapping the building
   a. Map spaces and define zones
   b. Map location of APs
II. Setting up system to collect and organize Wi-Fi data
III. Assigning occupancy count to zones of the buildings
IV. Processing the occupancy RTLS data for delivery to and use by the building automation system (BAS)

I. Mapping the building

The building space that is of interest for the occupancy sensing must be accurately defined to place the mobile device's calculated location within the building. This includes:

1. spatially mapping the floor plan of the building using latitude, longitude, and altitude and floor dimensions to define locations on the floor and floor level,
2. defining the exact location of each AP in the space (to be used for the trilateration calculations that will be performed), and
3. defining the zones of the floorplan (with all associated APs) that correspond to the zones controlled by the BAS.

II. Collecting Wi-Fi data

The device Wi-Fi data will be used to determine the real-time location of the occupant's mobile device and by inference, the location of the occupant. The following information should be collected for each mobile device whose signal is being received by a specific AP:

1. MAC address (unique identifier of the mobile device, possibly randomized over time)
2. RSSI (signal strength from the mobile device measured by the AP)
3. AP MAC address (unique identifier of the AP associated with the data point)
4. timestamp (to provide a reference for the real-time location)
5. association status ("1" if the device is connected to the local area network and "0" if not connected).

This data is collected by the network management software and is stored on the network server.

III. Assigning occupancy count to zones of the buildings

This step requires data filtering and processing to determine the occupant counts and locations and then to attribute their locations to specific zones of the building. The following tasks must be performed:

1. Assign each device/signal to a location, then aggregate by building zone using a defined sampling time interval/point in time (e.g., seconds, minutes).
2. Calculate the device location using trilateration from multiple Wi-Fi AP output data.
3. Filter the devices to exclude certain Wi-Fi enabled devices from the analysis, such as:
    a. Stationary or background devices that will not be associated with the presence or location of an occupant. Examples of these devices are desktop computers, printers, and wireless security cameras.
    b. Redundant Wi-Fi enabled devices carried by some individuals such as tablets, laptops, smart watches, and multiple smartphones.
4. Assign each device's location to a building zone that is defined by the BAS.
5. Tabulate an occupancy count for each building control zone.

Wi-Fi network solution providers such as Cisco CMX, Cisco Meraki, and HP Aruba provide application program interfaces (APIs) that allow data aggregation and real-time location analytics. These interfaces communicate the Wi-Fi RTLS data to the BAS gateway.

IV. Processing the occupancy RTLS data for delivery to and use by the BAS

The real-time occupancy data must be delivered to the BAS using communications protocols such as the ANSI/ASHRAE Standard 135-2016 BACnet™ - A Data Communication Protocol for Building Automation and Control Networks,[16] Modbus, LonWorks, KNX.[17] A BAS gateway communicates with the specific BAS network(s) of the building to control occupant-related building systems such as lighting, HVAC, and security. Common largescale commercial BAS providers include Johnson Controls, Siemens, Delta Controls, Honeywell, Schneider Electric, and Tridium Niagara. Integration of RTLS data will require the use of APIs for each of these systems.

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[16] BACnet International. “BACnet Standard.” *BACnet International* [website], https://www.bacnetinternational.org/page/BACnetStandard, (accessed January 2, 2020).

[17] Optigo Networks “Which is ‘Better’? BACnet, LonWorks, Modbus, or KNX”, *Optigo Network blog* [web blog], July 26, 2019, https://optigo.net/blog/which-better-bacnet-lonworks-modbus-or-knx, (accessed January 21, 2020).

Two Wi-Fi LBS Occupant Counting Approaches

Currently, two Wi-Fi occupancy sensing approaches have been developed and demonstrated: Implicit occupancy sensing (Lawrence Berkeley National Laboratory [LBNL])[18] and Virtual Occupancy Metering (VOM) (Sensible Building Science [SBS]).[19,20]

Implicit Occupancy Sensing

The LBNL approach uses existing network infrastructure. It is termed "implicit (or inferential) sensing" because it applies data obtained from existing devices and networks although they were not originally deployed to provide occupancy sensing. This type of virtual sensing can be low to no cost since the system is already serving the building for its primary purpose and the needed data is already being collected. It does not require the installation of additional hardware or software packages. This approach keeps track of devices that are connected to the Wi-Fi network in the building. Since this approach uses the space's existing devices, the APs are located to optimize the Wi-Fi coverage for users within the space. The collected Wi-Fi data are:

- the timestamp of the recording,
- the connected device's MAC address, and
- the MAC address of the Wi-Fi AP connected to the device.

The only output data from each AP is device count and location. MAC addresses are not included to preserve user privacy. Depending on the type of connection, the type of device or occupant can be inferred. Table 2 shows how Wi-Fi usage behaviors can be mapped to devices and their owners.

[18] M.Pritoni, B. Nordman, and M.A. Piette. Accessing Wi-Fi Data for Occupancy Sensing. Lawrence Berkeley National Laboratory, Energy Technologies Area, LBNL-2001053, March 2017. https://escholarship.org/uc/item/7sm90837 (accessed December 16, 2019)

[19] L. Corpuz-Bosshart. "Innovative software converts Wi-Fi data to energy savings." *UBC News* [website], May 30, 2017, https://news.ubc.ca/2017/03/30/innovative-software-converts-wi-fi-data-into-energy-savings/, (accessed December 16, 2019).

[20] Contractor magazine, "Interview with Stefan Story: Sensible Building Science", *Contractor* [website], May 10, 2017, https://www.contractormag.com/iot/article/20882662/interview-with-stefan-story-sensible-building-science, (accessed December 9, 2019).

Table 2. Types of Wi-Fi Connections and Mapping Rules for Occupant Counts[21]

Duration of Wi-Fi Connection	Type of device or owner	Mapping rules of inferring occupant counts from Wi-Fi connection counts
Always connected	Office equipment or appliances such as printers, servers, or always-on computers	Cannot be used to infer occupant counts
Long-term connected	Inhabitants with mobile devices such as office workers	Each occupant count on average corresponds to two Wi-Fi connected devices (cellphone and computer)
Short-term connected (1–3 hrs/day)	Visitors with mobile devices for a meeting or conference	Each occupant count on average corresponds to one Wi-Fi connected device (cellphone)
Occasionally connected (>1 hr/day)	Passerby with mobile devices	Not residing in the space and should not be counted

The approach has been applied to a number of college campus buildings and office buildings. Recently, Wang et al. (2019) have applied machine learning algorithms to increase inference accuracy. They tested the approach on two floors of a four-story office building in California where they compared the results of the implicit occupancy sensing approach against camera-based occupant count sensors. Seven and nine APs were installed in the two test areas, respectively. The estimation accuracy for the implicit approach was within two person counts of the camera-based sensing for more than 70% of the estimations and within six person counts for more than 90% of the estimations.[22] A project is under way at a college campus in California.[23]

[21] Z. Wang, T. Hong, M.A. Piette, and M. Pritoni. "Inferring occupant counts from Wi-Fi data in buildings through machine learning", *Building and Environment*, 158 (2019) 281–294.

[22] Ibid.

[23] M. Pritoni, personal communication, 2019.

Virtual Occupancy Metering (VOM)

Sensible Building Science (SBS) employs Wi-Fi RTLS occupancy detection using existing network platforms with location analytics. This system includes applications of the latest RTLS methods to provide energy efficient building operation. The SBS Bridge software receives real-time Wi-Fi data using the location analytics provided by the network platform, specifically the Cisco Connected Mobile Experiences (CMX) software solution. The collected Wi-Fi data from the CMX-provided APIs are:

- the timestamp of the recording,
- the connected device's MAC address,
- the RSSI of the signal from the connected device, and
- the MAC address of the Wi-Fi AP connected to the device.

To ensure privacy, all occupancy information is anonymized. Ideally the APs are located within the space to optimize location while still providing good Wi-Fi coverage. This could mean the placement of additional APs within the space.

The only information needed for the BAS is occupant count in a defined space or zone. The system provides over 90% accuracy in occupancy sensing and a response time of 180 seconds. The Bridge software then sends the zone occupancy data to a gateway (produced by Chipkin Automation Systems) which then communicates using BACnet to the BAS to control HVAC and lighting. This approach has been integrated in buildings with Johnson Controls, Siemens, and Delta systems. Figure 5 shows how the data flows from the Wi-Fi APs to the BAS controls.

Figure 5. VOM data flow from Wi-Fi data to BAS

Originally tested in buildings on the University of British Columbia campus, SBS is piloting their environmental control systems in buildings in Canada, the United Kingdom, and the United States. As of 2017, SBS has used their approach in over 1 million square feet of commercial and institutional space, serving over 100 thousand occupants in real-time. Preliminary results indicate an average annual savings of 5% in whole-building energy use and have found that buildings with variable occupancy and demand control ventilation (DCV) offer the greatest potential for savings. For example, in lecture halls with periodic classes, SBS were able to reduce fan runtime by 20%–40%.[24] SBS is currently working on Bridge solutions for the Cisco Meraki and HP Aruba ALE network platforms.[25]

Privacy

The collection of personal data is a source of potential concern that requires our attention.[26] The resolution and quantity of location tracking data that can be collected by location data companies, especially collected from cell phones, raises privacy issues since individuals can be identified by tracing their movements.[27] This data comes from GPS sensors, Bluetooth beacons, and other RTLS sources which can pinpoint location by latitude and longitude and movement. While there is formal user consent when location services are enabled on selected mobile device apps, some users remain uncomfortable with this status quo.

In the U.S., there is no single overarching Federal law for personal privacy and data security. Instead, there are many Federal and state laws that regulate the collection, use, processing, and disclosure of personal information. Some of them apply to particular sectors or types of activities (e.g., Health Insurance Portability and Accountability Act for medical information protection); the other broad laws, although not specifically for personal information protection, provide guidelines that are not legally binding but considered as best practices (e.g., Federal Trade Commission Act). Based on the study of these regulations, the Federal Trade Commission's Behavioral Advertising Principle provides a Federal level requirement with regard to precise geographic location information. It suggests that "website operators obtain website affirmative express consent from consumers before collecting or using sensitive consumer data (including precise geographic location information) in connection with online behavioral advertising".[28] Of course, it is common practice for users to agree to service agreements for apps or software without reading or understanding these agreements.

In addition to laws, industry groups have developed guidelines and recommendations for mobile carriers, app developers, app platform providers, and operating system developers to better

[24] Contractor magazine, op.cit.

[25] S. Storey, personal communication, 2019.

[26] L. Matsakis. "The WIRED Guide to Your Personal Data (and Who Is Using It)." *Wired* [website], February 15, 2019, https://www.wired.com/story/wired-guide-personal-data-collection/, (accessed December 23, 2019).

[27] S.A. Thompson and C. Warzel. "Twelve Million Phones, One Dataset, Zero Privacy." *New York Times* [website], December 19, 2019, https://www.nytimes.com/interactive/2019/12/19/opinion/location-tracking-cell-phone.html, (accessed December 23, 2019).

[28] I. Jolly. US Privacy and Data Security Law: Overview. Westlaw, Thomson Reuters, 2016. https://blog.richmond.edu/lawe759/files/2016/08/US-Privacy-and-Data-Security-Law-Overview.pdf, (accessed December 23, 2019).

protect user privacy.[29] [30] These guidelines encourage LBS providers to empower users with control over their location information.[31]

Although there is no regulation prohibiting the collection of geolocation information, a technique known as MAC address randomization is widely built into mobile devices to protect the owner's personally identifiable information by replacing the device's unique Media Access Control (MAC) address with a randomly generated value. Wi-Fi providers see this randomized MAC instead of the device's unique MAC address up until the device associates with the Access Point (AP). A study done by the U.S. Naval Academy showed that both Apple iOS and Android operating systems allow devices to use randomized MAC address during active scans. The research showed that a large percentage of tested iOS systems actually implemented the randomization technique by default, whereas the majority of Android system devices do not have the technique enabled.[32] However, the latest Android operating system, Android 10 released in 2019, does randomize the MAC address by default with per-network customization.[33] Besides the two common mobile device operating systems, Windows 10 used by tablets and laptops also implements a similar scheme by having MAC randomization as the default setting.[34]

Despite a general concern regarding privacy, there currently appears to be a general trust that the location data is protected and safe. Pew Research performed a survey dealing with cybersecurity in May 2016 where 92% of the respondents used cell phones and 76% of them were using smartphones. While 70% of Americans expected the United States to experience significant cyberattacks in the coming five years (since 2016), 54% of online adults still used public Wi-Fi networks and 70% of people were somewhat (47%) or very (23%) confident in their

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[29] K. Harris. Privacy on the Go: Recommendations for the Mobile Ecosystem. California Department of Justice, January 2013. https://oag.ca.gov/sites/all/files/agweb/pdfs/privacy/privacy_on_the_go.pdf, (accessed December 23, 2019).

[30] CTIA. "Best Practices and Guidelines for Location Based Services." *CTIA* [website]. https://www.ctia.org/the-wireless-industry/industry-commitments/best-practices-and-guidelines-for-location-based-services, (accessed December 23, 2019).

[31] Ibid.

[32] J. Martin, T. Mayberry, C. Donahue, L. Foppe, L. Brown, C. Riggins, E.C. Rye, and D. Brown. "A Study of MAC Address Randomization in Mobile Devices and When it Fails." Proceedings on Privacy Enhancing Technologies, 2017, pp. 365–383. https://www.researchgate.net/publication/314361145_A_Study_of_MAC_Address_Randomization_in_Mobile_Devices_and_When_it_Fails, (accessed December 23, 2019).

[33] J. Wallen. "How to enable a randomized MAC address in Android 10." *TechRepublic* [web blog], September 23, 2019, https://www.techrepublic.com/article/how-to-enable-a-randomized-mac-address-in-android-10/, (accessed December 23, 2019).

[34] L. Hervieu. "MAC Address Randomization: How User Privacy Impacts Wi-Fi And Internet Service Providers." *INFORM[ED] blog by CableLabs* [web blog], July 28, 2019, https://www.cablelabs.com/mac-address-randomization-how-user-privacy-impacts-wi-fi-and-internet-service-providers, (accessed December 23, 2019).

cell phone manufacturers to protect their data. This is a larger proportion than was found for those that trusted their credit card companies, email providers, companies/retailers they do business with, the government, or social media sites.[35]

It has been found that consumers are willing to share their personal data if they receive value in return, especially with companies they do business with.[36] An example of this would be retail company credit cards that can provide consumers with points, rewards, coupons, or discounts in return for valuable purchasing information.[37] The same could be true with location data if the advantages to the individual outweigh the concerns or make the issues comparatively benign. For example, indoor location data in commercial buildings can be a part of the metrics that companies are beginning to keep to evaluate space use, productivity, and performance. This could benefit both the bottom line for the company and the working conditions for the staff. With company provided badges or phones, businesses are already capable of greater levels of employee tracking. Whether this effort is worthwhile will depend on the purposes, benefits, and implications of the tracking.[38]

In the meantime, a number of steps can be taken by device users to mitigate location tracking:

1. Disable Wi-Fi on the mobile device.
2. Disable Bluetooth on the mobile device.
3. If you have any apps on your mobile device that provide location tracking, restrict or disable location sharing to those apps.[39]

For Wi-Fi LBS methods to be effective for occupancy sensing, it is essential to understand these factors and take actions that:

1. Provide transparency and ensure privacy to the employees.
2. Result in clear, definable benefits to both the business and employees.

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[35] K. Olmstead and A. Smith. Americans and Cybersecurity. Pew Research Center White Paper, January 26, 2017. https://www.pewresearch.org/internet/wp-content/uploads/sites/9/2017/01/Americans-and-Cyber-Security-final.pdf, (accessed December 23, 2019).

[36] G. Pingatore, Ph.D., V. Rao, K. Cavallaro, and K Dwivedi. “To share or not to share: What consumers really think about sharing their personal information.” *Deloitte Insights* [website], September 5, 2017, https://www2.deloitte.com/us/en/insights/industry/retail-distribution/sharing-personal-information-consumer-privacy-concerns.html, (accessed December, 23, 2019).

[37] C. Duhigg. “How Companies Learn Your Secrets.” *New York Times* [website], February 16, 2012, https://www.nytimes.com/2012/02/19/magazine/shopping-habits.html, (accessed December 23, 2019).

[38] R. Eveleth. “Your Employer May Be Spying on You — and Wasting Its Time.” *Scientific American* [website], August 16, 2019, https://www.scientificamerican.com/article/your-employer-may-be-spying-on-you-and-wasting-its-time/, (accessed December 23, 2019).

[39] S.A. Thompson and G. Wezerek. “Freaked Out? 3 Steps to Protect Your Phone.” New York Times [website], December 19, 2019, https://www.nytimes.com/interactive/2019/12/19/opinion/location-tracking-privacy-tips.html, (accessed December 26, 2019).

3. Mitigate any concerns to all parties.

Next Steps

The application of Wi-Fi LBS for building operation occupancy sensing is still in its developmental stages. The specific opportunities for energy savings and their impact have not yet been fully defined or quantified. That is a primary goal of this project. Table 3 defines the types of occupancy sensing information that RTLS enables along with the most likely areas of application for use as inputs that can save energy in commercial buildings.

Table 3. Occupancy Information Resolution Levels[40]

Resolution Level	Functional Definition	Technical Definition	Application
Occupancy status	Is the space occupied?	Are the number of qualified Wi-Fi devices greater than 0?	Lighting, HVAC schedule optimization
Occupant count	How many people are in the space?	How many qualified Wi-Fi devices are in the space?	HVAC control optimization: DCV, MPC; Energy benchmarking, M&V, FDD
Occupant identity	Who is the person?	Who owns the device?	Personalized work environment management
Occupant activity	What is the person doing?	What activity can be inferred based on the location of the device and its travel?	Personalized work environment management

The use of occupancy sensing with lighting and HVAC control has become standard practice in building operation since passive infrared (PIR) and CO_2 sensors have been introduced into buildings over the past 20 years. The more granular occupancy sensing provided by Wi-Fi RTLS can result in additional control options for lighting, HVAC, and even miscellaneous electric loads (MELs). In addition to greater spatial and temporal precision for occupancy status and count, the possibility of identity and activity can help define and characterize space use. With

[40] Z. Wang, et al., op. cit., p. 282.

proper consideration for privacy concerns, this location data can bring more finely tuned and personalized space settings that can enhance comfort, increase productivity, and optimize energy use.

With the continuing development of Wi-Fi standards, AP deployment will change as RTLS becomes more widespread. Table 4 shows the current state of AP options to provide Wi-Fi RTLS.

Table 4. Access Point RTLS State of the Art

Type of AP	Mobile Device Output	No. of APs Needed in Zone	Type of Wi-Fi RTLS Approach	AP Placement Type
Standard AP	1. MAC address 2. AP Basic Service Set Identifier (BSSID) or AP MAC address	1+	Implicit occupancy sensing (LBNL) (occupancy status, counting)	Coverage
AP w/ Wi-Fi Location Analytics	1. MAC address 2. Wi-Fi RSSI *3. Wi-Fi FTM (in development)*	3+	VOM (SBS) (occupancy status, counting, location, and activity)	Location Services

The building's existing AP equipment, their deployment, and the installed network system platforms will define the opportunities of savings that Wi-Fi LBS can provide to building operation for that base system and the potential savings and return on investment obtained if the system is upgraded.

Specific building systems will offer a range of savings opportunities that may or may not justify the use of Wi-Fi LBS occupancy sensing. Table 5 shows the typical systems that may be encountered.

Table 5. Access Point RTLS State of the Art

Tier	Mechanical System Types	HVAC Controls	Air Supply	Lighting Controls
0	Constant Air Volume	Local Thermostatic	Central or Single zone	Manual
1	Variable Air Volume (VAV)	Building Automation System	Single or Multi-zone	Occupancy Status/Photocell Sensor Control
2	VAV with Variable Speed Drive (VSD)	Grid-interactive Efficient Building	All	Advanced Lighting Controls via Digital Addressable Lighting Interface (DALI)
3	Variable Refrigerant Flow (VRF)		All	

For instance, greater savings potential will exist in multi-zone buildings that are equipped with VAVs using VSDs and DALI lighting systems than in buildings without. Networked control of MELs will add an additional layer of opportunities. The location data can help optimize the operation of these systems as they interact, providing new opportunities and strategies for efficiency.

Device development, emerging technologies, and improved data analytics will bring improvements in accuracy and coverage to RTLS approaches. Hobson et al. (2019) have investigated the use of sensor fusion to improve the accuracy of occupancy-count estimation.[41] They combined data from PIR motion detectors, CO_2 sensors, Wi-Fi APs, lighting and plug loads to estimate occupancy levels. The addition of BLE data could add an additional layer of location analytics to buildings. The adoption of 5G cellular networks, which will require indoor

[41] B. Hobson, D. Lowcay, B. Gunay, A. Ashouri, and G. Newsham. “Opportunistic occupancy-count estimation using sensor fusion: A case study.” *Building and Environment*. 159 (2019).

cellular towers, can add greater precision for cellular mobile device positioning.[42] 5G could complement or compete with Wi-Fi LBS systems. As RTLS continues to develop, these opportunities can be tested and assessed.

[42] M. Grothaus. "5G means you'll have to say goodbye to your location privacy." *Fast Company* [website], March 1, 2019, https://www.fastcompany.com/90314058/5g-means-youll-have-to-say-goodbye-to-your-location-privacy, (accessed December 23, 2019).

References

BACnet International. *BACnet Standard*. BACnet International [website], Retrieved January 2, 2020, from http://www.bacnetinternational.org.

Castellanos, S. (2020, January 7). *Waze for Work? Navigation Apps Come to Mazelike Offices*. Retrieved January 7, 2020, from http://www.wsj.com.

Chun, R. (2016, May 5). *The SFMOMA's New App Will Forever Change How You Enjoy Museums*. Retrieved December 9, 2019, from http://www.wired.com.

Contractor magazine. (2017, May 10). *Interview with Stefan Story: Sensible Building Science*. Retrieved December 9, 2019, from http://www.contractormag.com.

Corpuz-Bosshart, L. (2017, May 30). *Innovative software converts Wi-Fi data to energy savings*. Retrieved December 16, 2019, from http://news.ubc.ca.

CTIA. *Best Practices and Guidelines for Location Based Services*. Retrieved December 23, 2019, from http://www.ctia.org.

DOE EERE. 2019. DE-FOA-0002117: Request for Information (RFI): Research and Development Opportunities for Innovations in Sensors and Controls for Building Energy Management. U.S. Department of Energy.

Duhigg, C. (2012, February 16). *How Companies Learn Your Secrets*. Retrieved December 23, 2019, from http://www.nytimes.com.

Grothaus, M. (2019, March 1). *5G means you'll have to say goodbye to your location privacy*. Retrieved December 23, 2019, from http://www.fastcompany.com.

Harris, K. 2013. Privacy on the Go: Recommendations for the Mobile Ecosystem. California Department of Justice.

Hervieu, L. (2019, July 28). *MAC Address Randomization: How User Privacy Impacts Wi-Fi And Internet Service Providers*. Retrieved December 23, 2019, from http://www.cablelabs.com.

Hobson, B., D. Lowcay, B. Gunay, A. Ashouri, and G. Newsham. (2019). *Opportunistic occupancy-count estimation using sensor fusion: A case study.* Building and Environment, 159.

Horn, B.K.P. *WiFi Fine Time Measurement (FTM) Round Trip Time (RTT)*. Retrieved December 19, 2019, from http://people.csail.mit.edu/bkph.

Infsoft. 2019. Indoor Positioning Services, infsoft White Paper EN 2019-7, infsoft GmbH.

Jolly, I. 2016. US Privacy and Data Security Law: Overview. Westlaw, Thomson Reuters, 2016.

Manz, B. (2018, August 3). *Wi-Fi Will Soon Provide Position Accuracy of One Meter*. Retrieved December 19, 2019, from http://www.mouser.com.

Mall of America (2017, October 23). *Mall of America® mobile app integrates live navigation*. Retrieved January 7, 2020, from http://mallofamerica.com.

Martin, J., T. Mayberry, C. Donahue, L. Foppe, L. Brown, C. Riggins, E.C. Rye, and D. Brown. 2017. *A Study of MAC Address Randomization in Mobile Devices and When it Fails*. Proceedings on Privacy Enhancing Technologies, 365–383.

MacFarlane, K. (2019, April 8). *18 Inspiring Location-based Push Notification Examples & Ideas*. Retrieved January 16, 2019, from http://www.taplytics.com.

Matsakis, L. (2019, February 15). *The WIRED Guide to Your Personal Data (and Who Is Using It)*. Retrieved December 23, 2019, from http://www.wired.com.

Mittal, S. (2019, June 19). *Proximity Marketing Examples: 28 Retail Companies Nailing it with their Campaigns*. Retrieved December 9, 2019, from http://beaconstac.com.

Olmstead, K., and A. Smith. 2017. *Americans and Cybersecurity*. Pew Research Center White Paper.

Optigo Networks. (2019, July 26). *Which is "Better"? BACnet, LonWorks, Modbus, or KNX*. Retrieved January 21, 2020 from http://optigo.net/.

Pau, S. (2017, April 19–22). *Audio That Moves You: Experiments With Location-Aware Storytelling In The SFMOMA App.* Retrieved December 9, 2019, from http://mw17.mwconf.org/.

Pingatore, G., Ph.D., V. Rao, K. Cavallaro, and K Dwivedi. (2017, September 5). *To share or not to share: What consumers really think about sharing their personal information*. Retrieved December 23, 2019, from http://www.deloitte.com.

Pritoni, M., B. Nordman, and M.A. Piette. (2017). Accessing Wi-Fi Data for Occupancy Sensing. Lawrence Berkeley National Laboratory, Energy Technologies Area, LBNL-2001053.

Reddy, A. (2015, April 19). *The Growing Use of RTLS by Manufacturers*. Retrieved January 7, 2020, from http://www.rfidjournal.com.

Swedberg, C. (2019, December 30,). *Concept Store Delivers Product Content via NFC, RFID*. Retrieved January 7, 2020, from http://www.rfidjournal.com.

Thompson, S.A., and C. Warzel. *Twelve Million Phones, One Dataset, Zero Privacy*. Retrieved December 23, 2019, from http://www.nytimes.com.

Thompson, S.A., and G. Wezerek. *Freaked Out? 3 Steps to Protect Your Phone*. Retrieved December 26, 2019, from http://www.nytimes.com.

Wang, Z., T. Hong, M.A. Piette, and M. Pritoni (2019). *Inferring occupant counts from Wi-Fi data in buildings through machine learning.* Building and Environment, 158, 281–294.

Wallen, J. (2019, September 23). *How to enable a randomized MAC address in Android 10*. Retrieved December 23, 2019, from http://www.techrepublic.com.

Yoo, S., S. Kim, E. Kim, E. Jung, K.H. Lee, and H. Hwang (2018). *Real-time location system-based asset tracking in the healthcare field: lessons learned from a feasibility study.* BMC Medical Informatics and Decision Making, 18, 80.