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LEVERAGING WI-FI INFRASTRUCTURE FOR INCREASED POWER SAVINGS IN IOT DEVICES

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ABSTRACT

Mining is one of the oldest industries known to man, and it continues to remain essential for the prosperity of modern civilization. Compared to surface mining, a large number of disasters are likely to occur during underground mining. To ensure the safety and security of an underground working environment, it is critical for underground mining operations to employ a robust and efficient monitoring infrastructure. To address that need, techniques are presented herein that support an increase in power savings in Internet of things (IoT) devices by leveraging a Wi-Fi infrastructure to determine when, and how frequently, such devices should wake up to send or receive data. Aspects of the presented techniques employ an access point's (AP's) channel state information (CSI) data, in conjunction with data from an AP's on-board sensors (for metrics such as air quality, altimeter, temperature, and humidity), to detect indoor occupancy which, in turn, may drive the Target Wakeup Time (TWT) for selected IoT devices.

DETAILED DESCRIPTION

Mining is one of the oldest industries known to man and it continues to remain essential for the prosperity of modern civilization. Compared to surface mining, a large number of disasters are likely to occur during underground mining. Figure 1, below, illustrates the scale of the logistics that are typically involved in an underground mining environment.

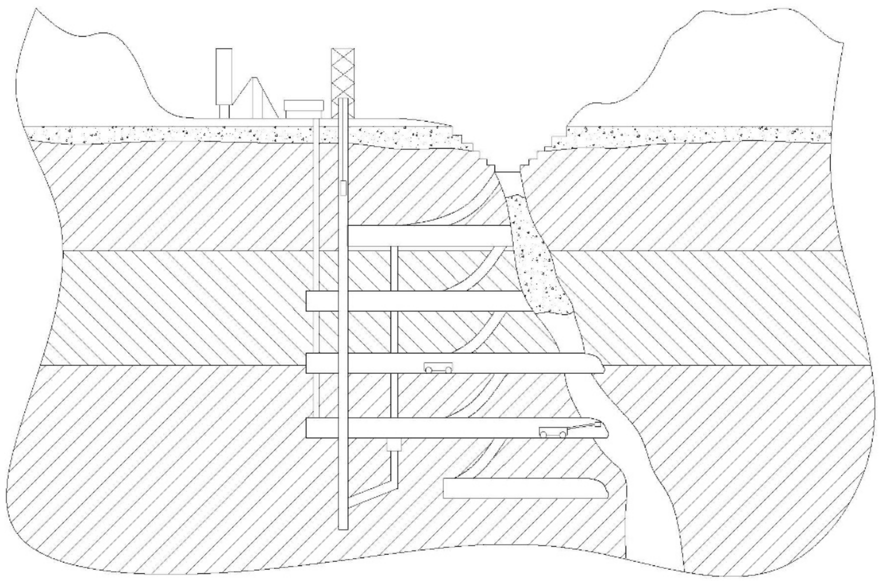

Figure 1: Illustrative Underground Mining Environment

To ensure the safety and security of an underground working environment, it is critical for underground mining operations to employ a robust and efficient monitoring infrastructure. Internet of things (IoT) sensors that are capable of withstanding extreme environments bridge such a gap and play a crucial role in enabling the remote monitoring of underground mines. Such IoT-enabled remote monitoring systems have recently grown in popularity, especially in industries like underground mining where miners are discouraged from using mobile phones underground in order to prevent accidents.

However, IoT devices are constrained in terms of energy and computational capabilities. Low-power operation is critical for those devices in order to achieve a long battery life, thereby reducing the cost for an underground infrastructure and the frequency of its maintenance. In essence, such underground IoT sensors need to operate according to an efficient schedule whereby they require minimal operational power (e.g., by maximizing their sleep cycle) while at the same time not compromising their effectiveness to report changes in their surrounding environment.

To address the challenge that was described above, techniques are presented herein that leverage a Wi-Fi infrastructure to efficiently manage the sleep time for IoT sensors (thereby prolonging their battery lifespan) and optimize those sensors' spectral efficiency by reducing contention.

Wi-Fi is an appealing technology for IoT connectivity mainly because it is practically ubiquitous and it provides a ready-made infrastructure for IoT connectivity in license-free bands, it supports high data rates as opposed to other low-power technologies like Bluetooth Low Energy (BLE), and it allows for a significant reduction in energy consumption through techniques such as Target Wake Time (TWT).

TWT allows Wi-Fi stations to determine when, and how regularly, they will wake up to send or receive data. Additionally, TWT enables access points (APs) to efficiently increase (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11ax) device sleeping time and significantly preserve the battery lifespan of such devices as illustrated in Figure 2, below.

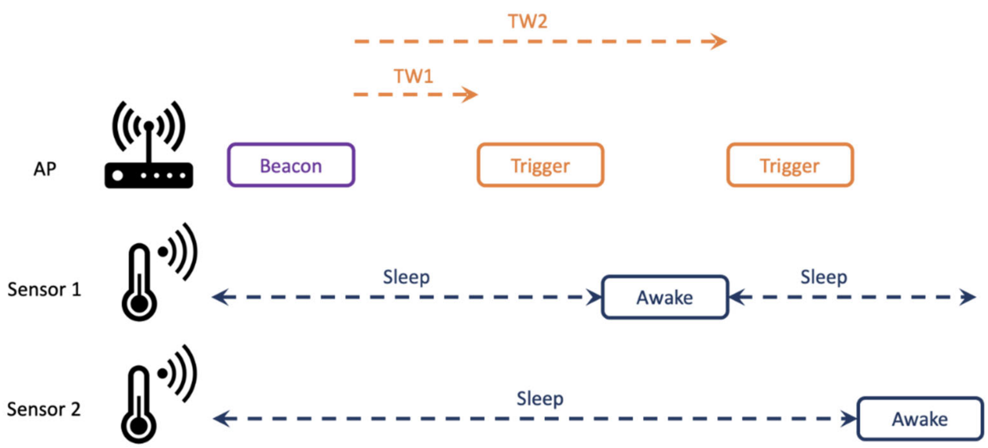

Figure 2: AP Negotiating Different Sleep Intervals for 11ax Clients Using TWT

In addition to saving device power, TWT also enables a wireless AP and devices to exchange and define precise times at which the medium will be accessed. Such an approach optimizes the spectral efficiency by reducing any connection and overlap between users.

An upcoming generation of APs will support converged hardware, where a single hardware stock keeping unit (SKU) may be deployed either through a physical wireless local area network (LAN) controller (WLC) or through a public/private cloud infrastructure as depicted in Figure 3, below.

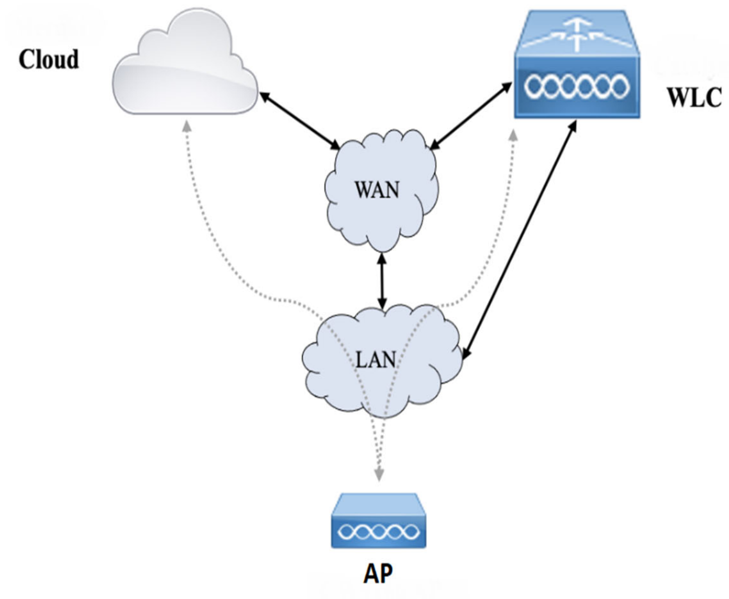

Figure 3: Converged Hardware Single AP SKU

Such APs will also support sensors (for metrics such as air quality, altimeter, temperature, and humidity) that are designed to enable environmental monitoring within a deployment.

Aspects of the techniques presented herein employ such sensors in conjunction with Wi-Fi channel state information (CSI) data to detect conditions that may be used as triggers for dynamically varying the TWT intervals for IoT devices in order to increase their power savings. For example, an occupancy level in an underground mine may serve as a trigger that can be used to shorten the TWT intervals for IoT sensors making them wake up more frequently to report their measurements since the mine is occupied. Similarly, non-occupancy in an underground mine may also serve as a trigger that can be used to lengthen the TWT intervals for IoT sensors allowing such devices to conserve their limited energy until the mine is once again occupied.

In radio communications, a transmitted signal typically reaches a receiving antenna through numerous paths in a phenomenon that is known as multi-path propagation. Under CSI, a fine-grained value that is derived from the physical layer refers to the known channel properties of each subcarrier in a wireless communication link. Such information describes how a signal propagates from a transmitter to a receiver and represents the combined effect of scattering, fading, and power decay with distance. Additionally, it consists of the attenuation and phase shift that are experienced by each spatial stream on every subcarrier in the frequency domain. Therefore, CSI is more sensitive to any variance in a radio frequency (RF) environment. The presence and the movement of human bodies intercept a multi-path propagation between neighboring APs, imprinting new information in the RF environment. Such discrepancies may be detected using CSI, making it possible to recognize human occupancy without requiring the wearing of any device or sensor as highlighted in Figure 4, below.

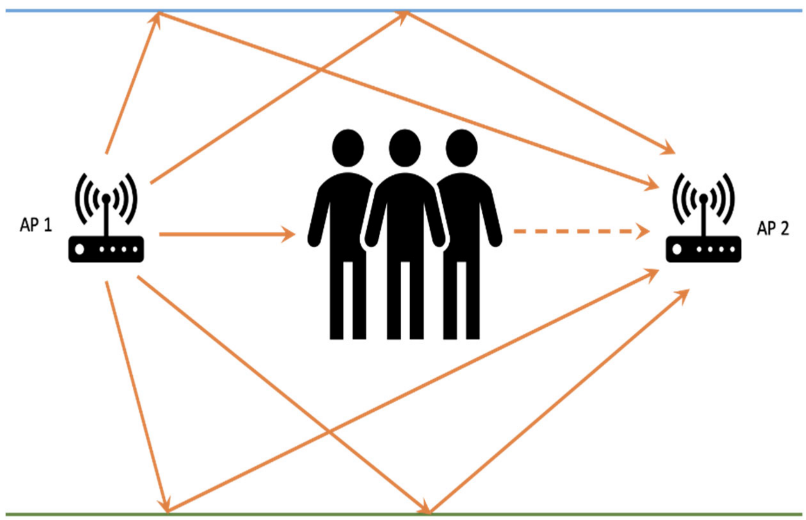

Figure 4: Human Bodies Imprint Information in RF Environment Through Intercepted Multi-path Propagation

Similarly, the measurement of a concentration of carbon monoxide (CO), a temperature, and a relative humidity can all be considered as relevant indicators for occupancy in indoor spaces.

To make a prediction regarding occupancy in an indoor space such as an underground mine, the techniques presented herein develop a reliable statistical classification model using CSI data along with the measurements of CO concentration, temperature, and relative humidity from environmental sensors on the new generation of APs. To achieve this objective, aspects of the presented techniques consider several well-known classifiers, construct models for each of them, and then evaluate those models for prediction accuracy using a comparison matrix before selecting the model that has the greatest accuracy. Once a model has been selected, its predictions regarding occupancy and non-occupancy of an underground mine may be used as triggers for varying the TWT for the relevant IoT devices as summarized in the exemplary process flow that is presented in Figure 5, below.

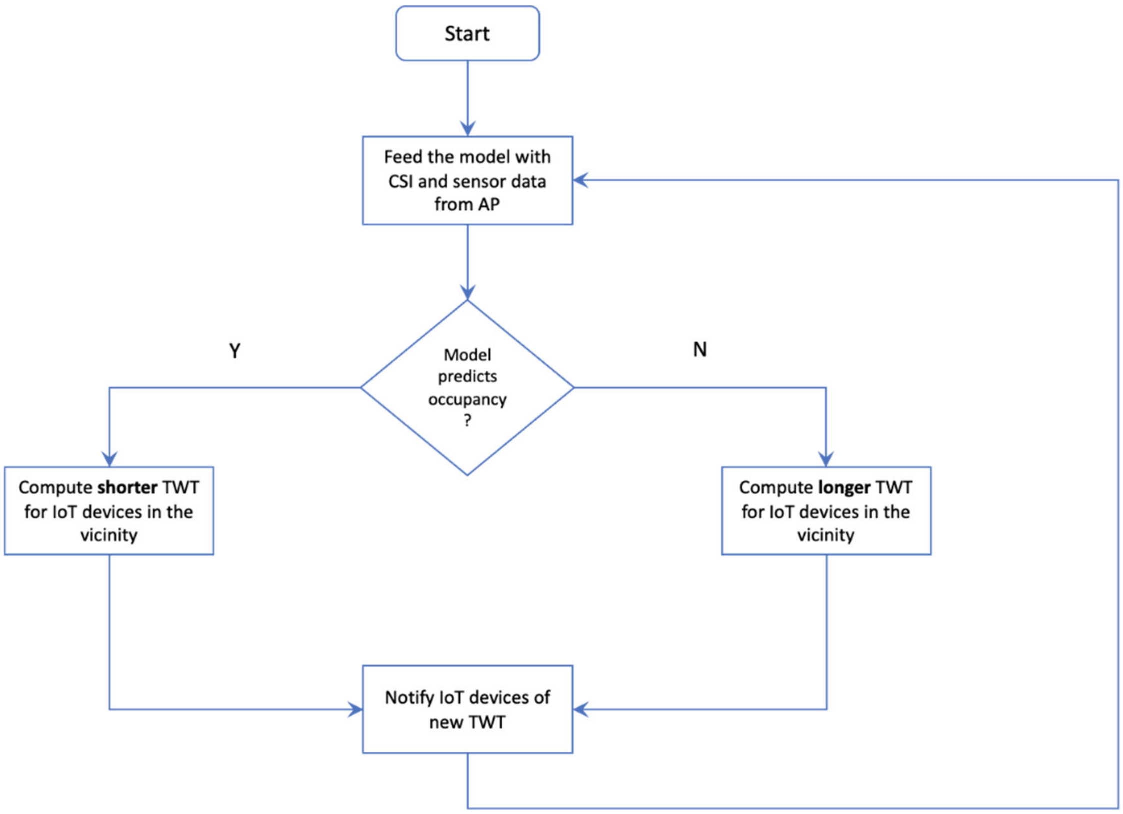

Figure 5: Exemplary Process Flow

According to further aspects of the techniques presented herein, an AP may use CSI data to vary the frequency of reports from onboard sensors to achieve additional power savings. Since operating its onboard sensors increases the overall power consumption for an AP, the AP's CSI data may be used to determine when to wake up its onboard sensors, thereby reducing its actual consumed power. Such a strategy may also be used to dynamically limit the power requirement of the AP based on the available power resources at a switch.

It is important to note that it is well established that TWT allows APs to efficiently regulate the sleep times for IoT devices, thereby considerably prolonging the devices' battery life. The techniques presented herein support dynamically throttling TWT sleep times for IoT devices based on environmental conditions that are assessed using a Wi-Fi infrastructure. For the exemplary (underground mine) use case that was described and illustrated above, the battery life of IoT devices may be extended by dynamically throttling a device's TWT sleep times based on the presence or the absence of individuals as detected in an AP's vicinity.

One network equipment vendor recently launched a self-locating AP with the aim of locating APs and end user devices indoors with pinpoint accuracy. While the effectiveness of the Global Positioning System (GPS) in indoor environments is debatable, not all use cases require information on the precise location of end users. Moreover, in some use cases end users cannot be presumed to be carrying Wi-Fi capable devices with them. Under such scenarios, according to the techniques presented herein (and as described and illustrated above) the presence or the absence of individuals may be deduced using fluctuations in a radio's CSI data and correlating such fluctuations with readings from sensors (such as air quality, temperature, and humidity) that already reside on an AP.

While existing approaches attempt to address different elements of the challenges that were described above, the techniques presented herein offer a complete solution. Aspects of the presented techniques support detecting human activity in an IoT environment (where, for example, a user does not carry a wireless device due to safety reasons) using Wi-Fi CSI data and then sending commands to environmental sensors to increase or decrease their sampling rate or go towards a longer sleep cycle. Such an approach helps to reduce the overall energy consumption within an underground infrastructure.

In summary, techniques have been presented herein that support an increase in power savings in IoT devices by leveraging a Wi-Fi infrastructure to determine when, and how frequently, such devices should wake up to send or receive data. Aspects of the presented techniques employ an AP's CSI data, in conjunction with data from an AP's on-board sensors (for metrics such as air quality, altimeter, temperature, and humidity), to detect indoor occupancy which, in turn, may drive the TWT for selected IoT devices.