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Method of Selecting an Optimal Set of Citizens Broadband Service Devices (CBSDs)

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Abstract:

This publication describes an algorithm that enables a user equipment (UE) to use scattered citizens broadband radio service (CBRS) networks while reducing the need for the UE to continuously scan for CBRS coverage and limiting stored data for the numerous citizens broadband radio service devices (CBSDs). The algorithm allows the UE to decrease battery use and optimize the UE's use of its memory resources.

Keywords: user equipment (UE), citizens broadband radio service device (CBSD), citizens broadband radio service (CBRS), geofence, wireless access point, access point, access node, long-term evolution (LTE)

Background:

With advancements in communication technologies and with computing/sensing electronics embedded in a myriad of devices, the ability for devices to collect and exchange data with one another is escalating. Devices such as smart phones, voice-recognizing personal assistants, computers, automobiles, home entertainment systems/appliances, and the like, are able to communicate with one another either directly, in a machine-to-machine environment, or indirectly over a network. Such communications and exchange of data across the myriad of devices is commonly referred to as the Internet-of-Things (IoT). The communications and exchange of data can have purposes that include, for example, collecting usage data for vendor analytics, remote initiation/shut-down of an operating system, automating a home environment, monitoring a person's health, and so forth.

A view of an example IoT environment is represented in Fig. 1 below:

Internet of Things (IoT)

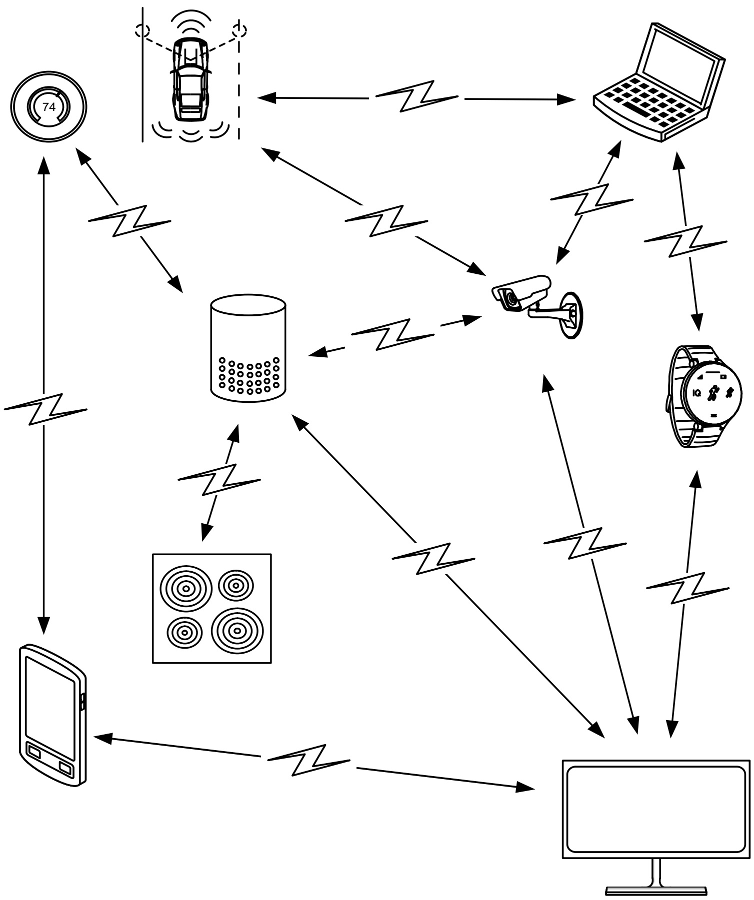

Fig. 1

In the IoT environment of Fig. 1, data may be collected by sensors of a device and shared with another device. Processing of data may be performed local to the device collecting the data or remote from the device collecting the data. Combinations of hardware (*e.g.*, sensors, microprocessors, memory), software (*e.g.,* algorithms, GUI's), and services (*e.g.*, communication networks) may be used to sense, collect, and exchange data. Large amounts of data are expected to be exchanged, as part of the IoT, across a horizon that is developing and changing frequently.

Detection mechanisms that may be built into IoT devices, such as light sensors, radar systems, proximity sensors, imaging sensors, cameras, or microphones, may measure conditions of an environment surrounding the IoT devices. Furthermore, and in some instances, computing algorithms may be applied to the conditions, as measured by the IoT devices, to assess aspects of the environment, examples of which include identifying a person who might be within the environment, quantifying movement of an object within the environment, or detecting a manufacturing anomaly within the environment.

As noted, IoT networks may use high-speed communication. In some cases, citizens broadband radio service (CBRS) networks offer an economical and helpful way to supply high-speed IoT networks. The CBRS is a 150 MHz-wide broadcast band of the 3.5 GHz-frequency band (3550MHz to 3700MHz). Various operating systems (OS) enable a user equipment (UE) to use this frequency band. CBRS networks have existed for some time, but their adoption has been rather slow. Nevertheless, many companies have stepped up efforts to increase the availability of CBRS networks, which enable a user to have long-term evolution (LTE) coverage at the 3.5GHz-frequency range. The ever-increasing need for fast network speeds, combined with frequency bands being a limited resource, make the adoption of CBRS networks a valuable tool to create high-speed networks, while offloading network traffic from other spectrum bands.

Fig. 2 shows an example CBRS network that one may soon use while traveling by air.

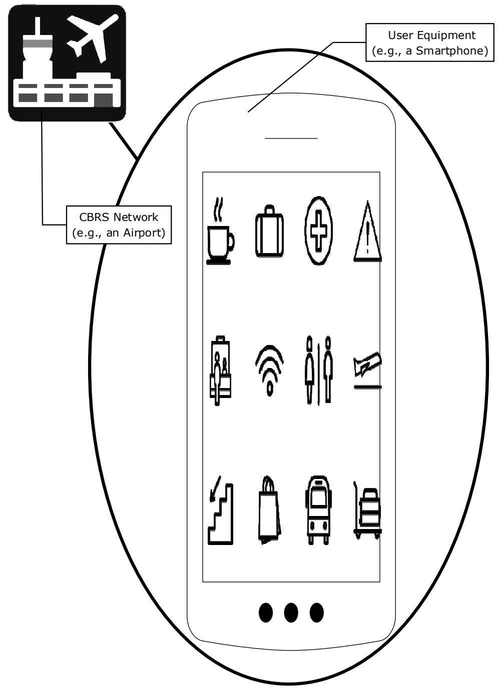

Fig. 2

Airports often offer free (or inexpensive) Wi–Fi™ networks, as shown in Fig. 2. The Wi–Fi™ network often prompts a user to download a profile to access the network. Airports may offer such services (often free-of-charge) to enhance a passenger's experience. These downloaded Wi–Fi™ profiles may have quick links to airport-specific services (e.g., transportation, gate location, flight itinerary, restroom location, restaurant location, duty-free shop location, etc.). Recently, however, several major airports have experimented with CBRS networks. One goal may be that CBRS networks, at times, may be substituted for use of Wi–Fi™ networks since CBRS networks may offer higher speeds at competitive prices.

To be able to support opportunistic use of CBRS networks when available, the user equipment (UE) may continuously scan for CBRS network coverage. Nevertheless, CBRS network coverage may be sparse and the UE's continuous-scan for an extended period wastes the UE's battery power. Furthermore, the CBRS networks use small-cell deployments, therefore, operators deploy many citizens broadband radio services devices (CBSDs) for each CBRS network. The UE, however, has limited volatile (e.g., dynamic random-access memory (DRAM)) and non-volatile (e.g., NAND flash) memory resources, therefore, the UE may keep a record on a limited number of CBSDs. Because of this, it is desirable for the UE to select an optimal set of CBSDs.

Description:

This publication describes an algorithm that allows a user equipment (UE) to select an optimal set of citizens broadband radio service devices (CBSDs) to keep track of a network coverage geofence. The algorithm describes which CBSDs are selected by the user equipment in a geofence (virtual geographic boundary). While this algorithm uses circles to describe the shape of a geofence, a geofence may have any size or any shape. In addition, a geofence may be associated with an entity (e.g., government institution, academic institution, company, home, airport, etc.). Only when the UE enters a CBSD covered area does the UE boot up, after which the UE activates a citizens broadband radio service (CBRS) profile.

The algorithm uses the following *data* and *parameters* to select an optimal set of CBSDs:

- The UE's current location (X). The UE may use various methods to determine the location, such as: cell tower triangulation or the global positioning system (GPS). The current location X may include latitude, longitude, and altitude.
- The geofence's initial radius (R_{init}) — a configurable value.
- The geofence's maximum radius (R_{max}) — a configurable value.
- The geofence's minimum radius (R_{min}) — a configurable value.

- A count of active CBSDs ($CBSD_{active}$) inside a circle with radius $R=R_{init}$ centered at a current location X.
- A pre-determined maximum count of active CBSDs ($CBSD_{max\_active}$) — a configurable value — it gives confidence in determining a CBRS network.
- A delta count of CBSDs (Δ_{CBSD}) — a configurable value — it is an allowed deviation from the $CBSD_{max\_active}$.

The algorithm is an iterative process and works as follows:

As the user boots up the UE and actives a CBRS profile inside a region with current location X and with initial radius $R=R_{init}$, the algorithm prompts the UE to select a first set of active CBSDs ($CBSD_{active}$).

If the UE fetches a count of active CBSDs ($CBSD_{active}$) that is less than the difference between the $CBSD_{max\_active}$ and the Δ_{CBSD}, the UE saves the fetched count of CBSDs ($CBSD_{current\_count}$). In this scenario, algebraically stated, $CBSD_{current\_count} < CBSD_{max\_active} - \Delta_{CBSD}$.

The UE continues to update and save the $CBSD_{current\_count}$, while increasing the search radius R, until that count is greater or equal to the difference between the $CBSD_{max\_active}$ and the Δ_{CBSD}. Algebraically stated, this operation continues until $CBSD_{current\_count} \geq CBSD_{max\_active} - \Delta_{CBSD}$ and $R \leq R_{max}$.

If the UE fetches a count of active CBSDs ($CBSD_{active}$) that is more than the sum of the $CBSD_{max\_active}$ and the Δ_{CBSD}, the UE saves the fetched count of CBSDs ($CBSD_{current\_count}$). In this scenario, algebraically stated, $CBSD_{current\_count} > CBSD_{max\_active} + \Delta_{CBSD}$.

The UE continues to update and save the count of active CBSDs ($CBSD_{current\_count}$), while decreasing the search radius R by half ($R = R_{init}/2$), until the fetched count of active CBSDs is less than or equal to the sum of the $CBSD_{max\_active}$ and the Δ_{CBSD}. Algebraically stated, this operation continues until $CBSD_{current\_count} < CBSD_{max\_active} + \Delta_{CBSD}$ and $R \geq R_{min}$.

If the UE fetches a count of active CBSDs ($CBSD_{active}$) that is more than or equal to the $CBSD_{max\_active}$, the UE sorts the CBSDs in increasing order of distance from the current location (X) and drops a number of CBSDs until it reaches the $CBSD_{max\_active}$. Then the UE saves the remaining count of CBSDs ($CBSD_{current\_count}$).

The UE registers geofences to monitor the saved active count of CBSDs ($CBSD_{current\_count}$) and creates a monitoring geofence with center current location X and with radius $R = \frac{2}{3} R_{max}$, as illustrated in Fig. 3.

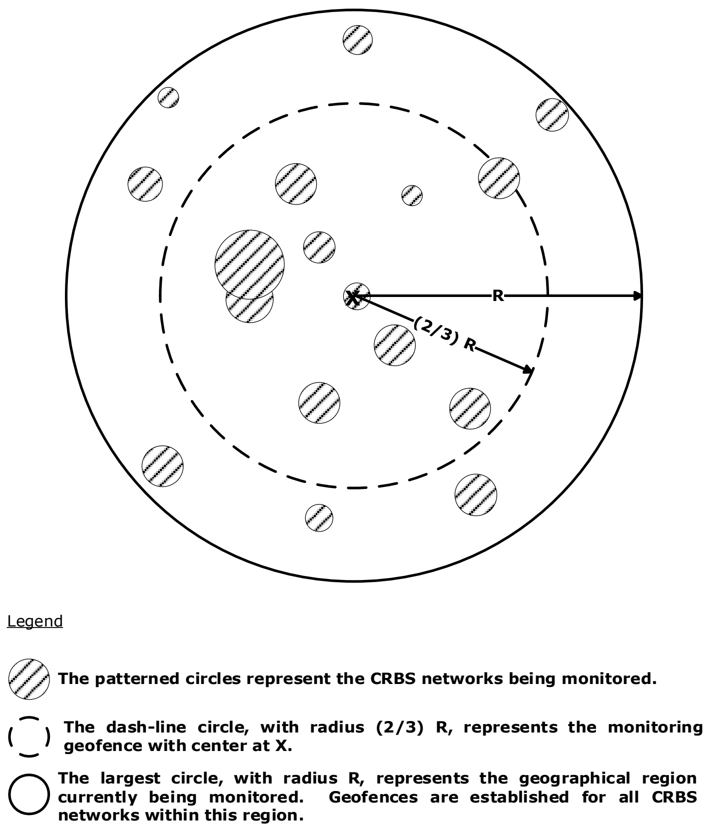

Fig. 3

In Fig. 3, the largest circle represents the geographical region currently being monitored. In this example, the geographical region being monitored is a circle with current location X and a radius $R = R_{max}$. Nevertheless, the geographical region may be any shape, size, or political or geographical entity (e.g., republic, country, state, city, continent, part of a country, etc.). The smaller of the patterned circles in Fig. 3 represent the various CBRS networks that exist in the monitored area. Finally, the dash-line circle represents the monitoring geofence with current location X and a radius $R = \frac{2}{3} R_{max}$. Nevertheless, the algorithm may change by using a different radius for the dash-line circle (e.g., $\frac{5}{8} R_{max}$).

If the user exits the monitoring geofence centered at current location X, the UE reselects another set of $CBSD_{max\_active}$, as illustrated in Fig. 4.

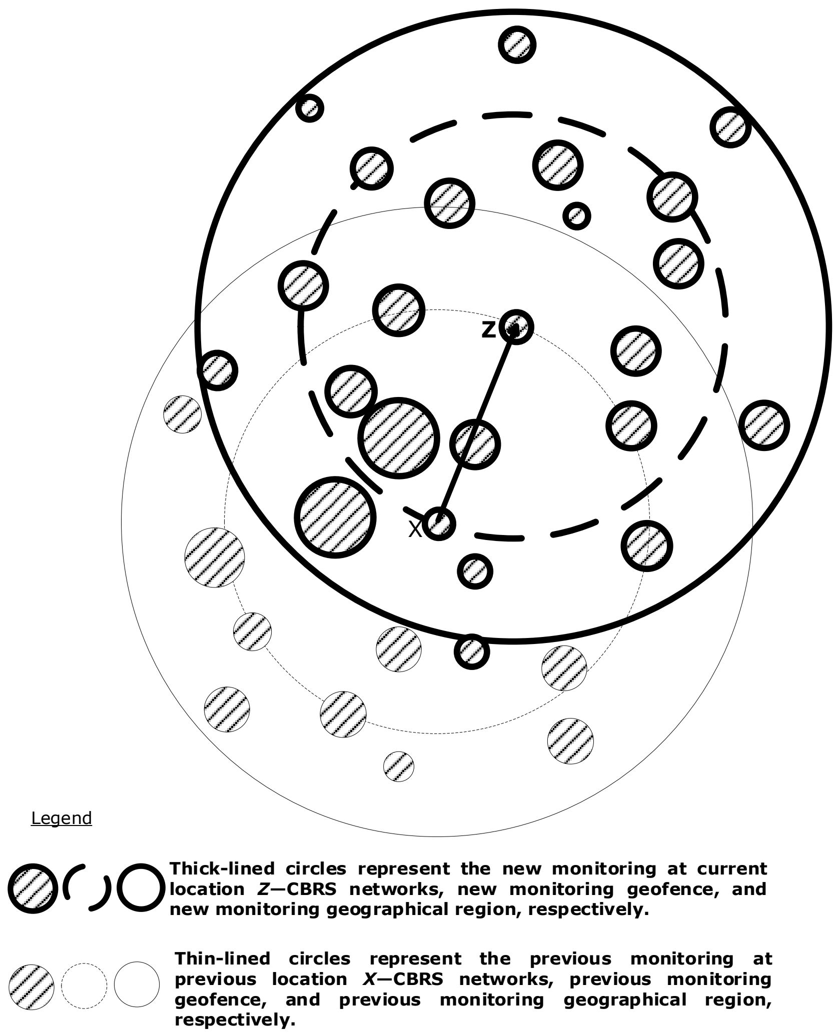

Fig. 4

As illustrated in Fig. 4, the monitoring geofence is a moving target based on the location of the user. When the user exits the monitoring geofence, the UE's new location becomes the new center of the monitoring geofence. In this scenario, the current location *Z* is different from the earlier location *X*, and it is at the boundary of the earlier monitoring geofence. The algorithm, however, does not need to change based on the location of the user. Furthermore, the algorithm keeps its effectiveness in selecting an optimal set of CBSDs regardless of the location of the user.

When the new CBSD information is added within the new monitoring region, the UE registers the corresponding geofence until the number of registered CBSDs reaches the $CBSD_{max\_active}$.

If an existing CBSD information is removed from the monitoring region, the UE reselects the new set of $CBSD_{max\_active}$. When the existing CBSD information is deleted from the monitoring region, the UE deregisters the corresponding geofence until the number of registered geofences reaches half of the pre-determined maximum count of active CBSDs ($\frac{1}{2}CBSD_{max\_active}$).

In summary, the described algorithm enables the UE to use scattered CBRS networks while reducing the need for the UE to continuously scan for CBRS coverage and limiting the stored data of the numerous CBSDs. This algorithm allows the UE to reduce power use and optimize the UE's use of its memory resources.