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CAMERA-ASSISTED RADIO RESOURCE MANAGEMENT

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ABSTRACT

Current Radio Resource Management (RRM) implementations usually do not respond quickly to changes in the coverage area environment. Accordingly, techniques are described herein for making a reliable decision on applying different RRM functionalities in an optimal time and reducing latency on changing the network parameters. This fuses the information extracted from real-time video streams of the environment into the RRM unit to predict the network load and adapt algorithms accordingly.

DETAILED DESCRIPTION

Radio Resource Management (RRM) enables continuously analyzing existing Radio Frequency (RF) environments while automatically adjusting each Access Point (AP)'s power and channel configurations to help mitigate co-channel interference and signal coverage problems. RRM reduces the need to perform exhaustive site surveys, increases system capacity, and provides automated self-healing functionality to compensate for RF dead zones and AP failures.

Current RRM implementations do not respond quickly to changes in environments. This design reduces the risk of sacrificing associated users' performance when any unnecessary decision is made by RRM. Therefore, most of the main functionality of RRM, such as Flexible Radio Assignment (FRA), Dynamic Channel Assignment (DCA) and Transmit Power Control (TPC), are triggered by default every ten minutes to one hour. Also most parameters of the RRM, such as Optimized Roaming, are set at the planning and installation phase of network for the normal or worst case scenarios and are usually unchanged unless a rearrangement is required.

In high density Wi-Fi® / Wireless Local Area Network (WLAN) environments, user experience can change significantly with user density. The high fluctuation on the load

of the WLAN system normally occurs in various scenarios such as the arrival of a train in a station and large classrooms where the density of users varies greatly.

Therefore, the problem is the lag of RRM in a fast-changing environment. Any knowledge or prediction regarding the number of users joining or disassociating from the network helps RRM in making more reliable decisions and in reducing the latency of changing the network parameters.

The techniques described herein further enhance the performance of RRM in WLAN with the aid of computer vision. The real-time video streams are captured by cameras (preferably wide-angle). A Vision Processing Unit (VPU) performs algorithms for event detection, object recognition and motion tracking.

Figure 1 below illustrates two different deployments of camera-assisted RRM. As shown in Figure 1(a), the camera can be embedded on the AP, which is practical for ceiling mounted models. In this deployment, the VPU is built into the AP and the final report is transmitted to the WLAN Controller (WLC) to be used for RRM. The installation and planning is simplified in this deployment while the cost and power consumption of the AP is higher because of additional processing. As shown in Figure 1(b), a concurrent video surveillance system may be used to extract useful information from the environment. In this case, a separate VPU reports the real-time status of the coverage area to the WLC. This deployment is cost-efficient if the enterprise customer already has a working video surveillance system.

Camera-assisted Network Deployment

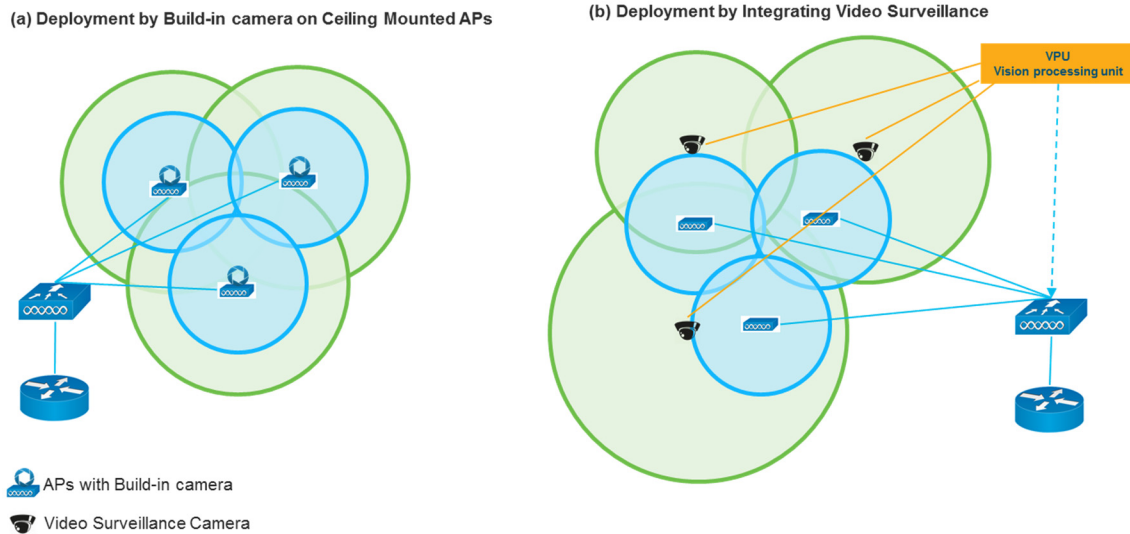


Figure 1

The reported information from the VPU includes a number of people entering an AP coverage area, a predicted number of people exiting a cell based on direction and walking speed, and a calculated motion behavior (mobility factor) of users in the coverage area. In addition, certain events may be recognized depending on the environment, such as train arrival/departure in a station, lecture start and end in classrooms, and conferences.

One aspect of the techniques described herein is predictive Dynamic Channel Assignment (pDCA). In current RRM implementations, the following metrics are tracked for each AP in the RF group: Co-Channel Interference (CCI), Foreign Channel (Rogue), Noise, Channel Load, and DCA Sensitivity. CCI refers to other APs/clients on the same channel. Rogue refers to other non-RF group APs operating on or overlapping with the served channel. Noise refers to non-Wi-Fi sources of interference such as Bluetooth®, analog video, or cordless phones. Channel Load may be determined through the use of industry standard Quality of Service (QoS) Basic Service Set (QBSS) measurements, and may be gathered from the physical layer, similar to Call Admission Control (CAC) load measurements. DCA sensitivity refers to a sensitivity threshold selectable by the user that applies hysteresis to the evaluation on channel changes.

A Cost Metric (CM) represents a complex signal to noise plus interference ratio (SNIR) of a specific channel and is used to evaluate the throughput potential of one channel

over another. The goal is to be able to select the best channel for a given AP/radio while minimizing interference. Using the CM, the group leader may evaluate every AP and every channel for maximum efficiency. Because conditions change in RF environments, these statistics may be continuously and dynamically collected and monitored.

The impact of each of these factors is combined to form the CM, which is a single Received Signal Strength Indication (RSSI) based metric. DCA may operate by default every ten minutes (i.e., 600 seconds) in steady state once it has been initialized unless some other interval is defined and the DCA is running in scheduled mode. Moreover, the DCA algorithm may only run at this selected time and may not evaluate the user environment at peak loads.

The camera-assisted method described herein improves the performance of DCA in at least two ways. First, the predicted incoming and outgoing users can be directly normalized to be applied to the calculation of CM. For example, the real-time image processing user count may directly pre-estimate the CM by considering whether a certain percentage of incoming people are going to be associated with APs. Second, the RRM triggers DCA when an event is reported by the VPU. The event may be a prediction of a sudden jump in the number of users. The CM is unchanged during this time.

Figure 2 below illustrates a simplified model of pDCA. The Run DCA block includes the main functionality of DCA in switching to the next channel based on the Channel Plan Change Initiator (CPCI). Each channel plan, which yields improvement, is subjected to another gating feature referred to as the normalized cumulative cost function (NCCF). This non-RSSI based function evaluates the resulting channel plans for overall CPCI group quality. In other words, the CPCI must observe an improved CM, but only if its neighbors, as a group, either improve or stay the same for the channel plan to be recommended.

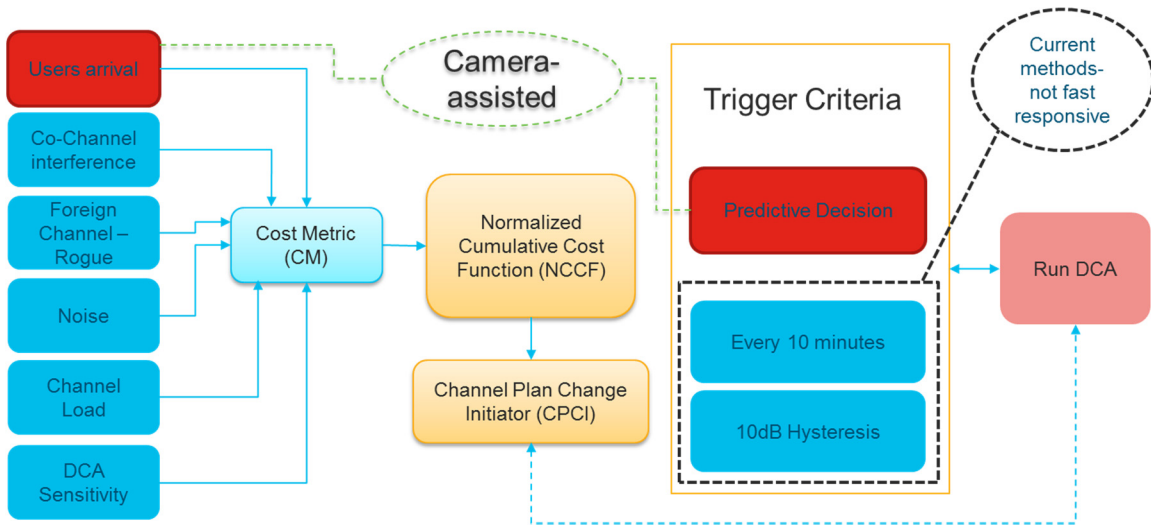


Figure 2

Figure 3 below illustrates an example pDCA.

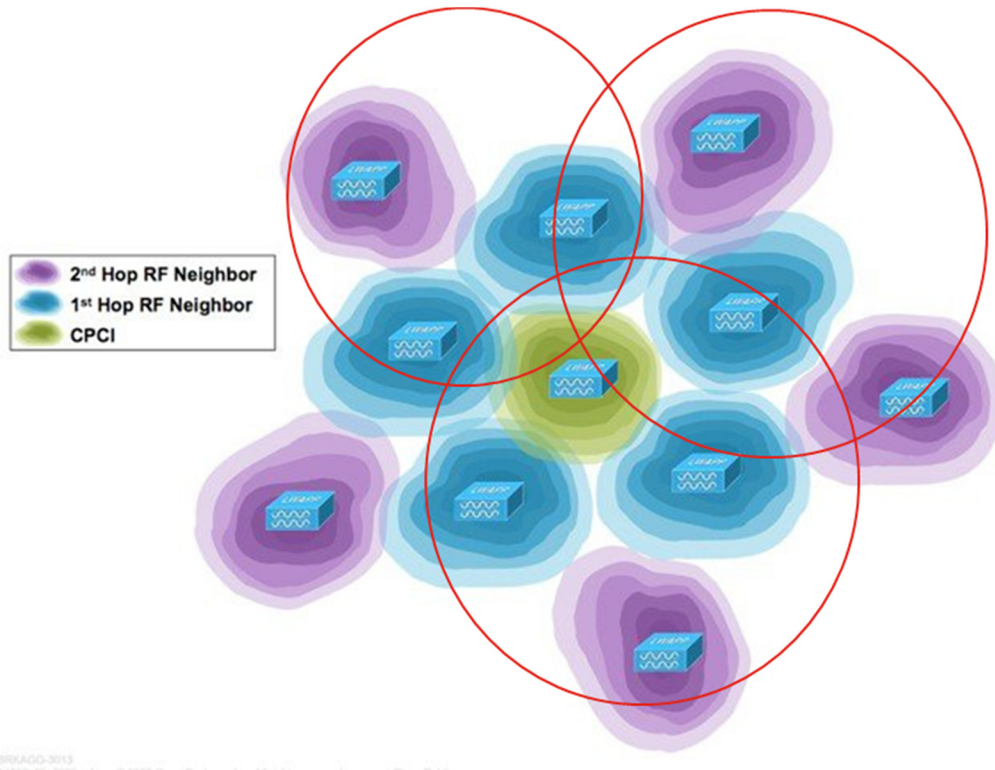


Figure 3

Another aspect of the techniques described herein is highly optimized roaming. Optimized roaming addresses the sticky client challenge by pro-actively disconnecting clients, thus enabling clients to move to a nearby AP that offers stronger connectivity. It achieves this functionality by actively monitoring the RSSI of packets, and enforcing client

disassociation when the RSSI is lower than the set threshold. The current optimized roaming algorithm considers three fixed parameters to achieve the highest performance: optimized roaming threshold, optimized roaming value, and optimized roaming data rate threshold.

An example of an optimized roaming threshold is provided by way of example. By default, if optimized roaming is enabled and more than 25% of at least fifty packets in a five second period is less than -80 dBm, the AP will disassociate the client once the reporting interval of 90 seconds expires. The optimized roaming interval is the time interval at which the AP reports the client statistics. This value may be defaulted to, e.g., ninety seconds. The optimized roaming data rate threshold applies the optimized roaming feature to clients connected at this data rate or lower. By default, this is disabled, meaning optimized roaming applies to all clients.

Figure 4 illustrates a block diagram of highly-optimized roaming. The VPU extracts the movement behavior of all users to produce a final metric. The metric may be the average speed of mobile users normalized by the ratio of mobile users to fixed users. The roaming parameters may be adjusted based on this report. If users are highly mobile and approaching the edge of the cell, the thresholds may be higher in shorter time intervals.

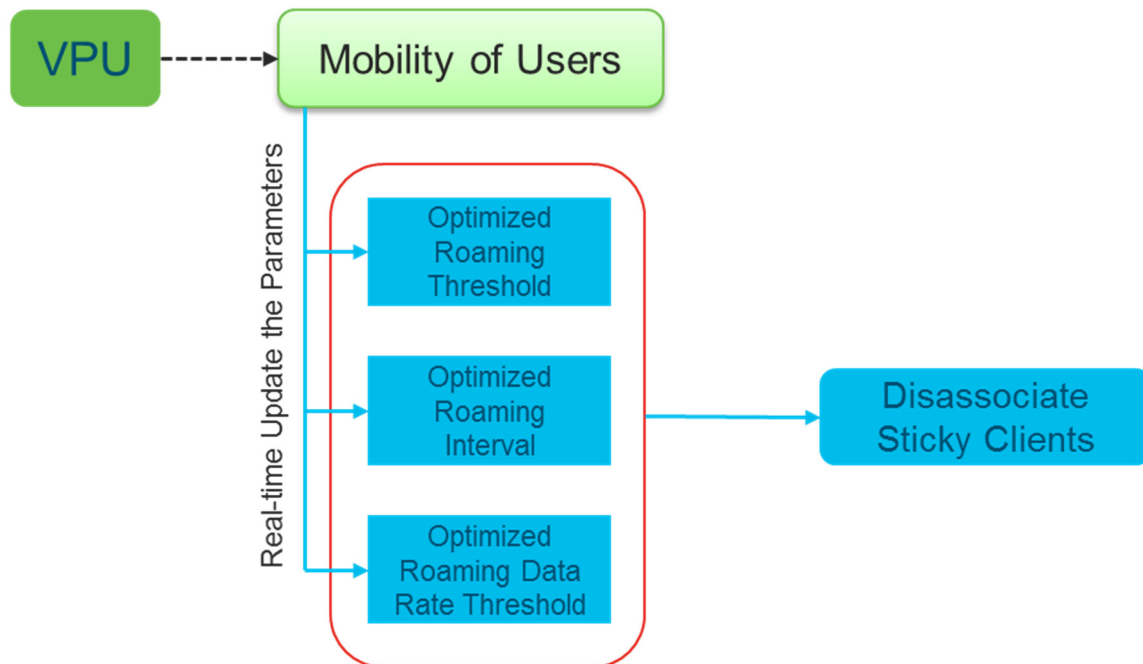


Figure 4

A third aspect of the techniques described herein is Environment-aware Transmit Power Control (EaTPC). The TPC uses transmission (TX) neighbor and RF neighbor lists generated by Neighbor Discovery Protocol (NDP). RSSI organized lists may be built based on how a given AP hears other APs (receiver (RX) Neighbor) and how the other APs hear the given AP (TX Neighbor) to form a picture of how every AP is heard by every other AP within the RF neighborhood and RF group. Based on this information, the TPC sets the transmit power of each AP to maximize coverage and minimize CCI. The TPC may adjust the TX power up or down to meet the required coverage level indicated by the TPC threshold.

Consider a classroom scenario, which is considered a high density network and depends on changes in the environment. Generally, the human body absorbs RF waves, and when a room is full of people, the amount of RF energy at the floor may be attenuated by 5-10 dB in extremely dense cases. In current TCP implementations, power is not optimized, and the RF signal bleeds, causing interference.

When the room is empty, the power levels of the APs may drop because the propagation has improved. When the room is full, APs may need more power (e.g., 5-10 dB more). The current TPC implementation may eventually apply enough power, but that could be thirty minutes into a class that lasts one hour.

One solution to prevent this problem is to set a TPC minimum at the required full class level, which will ensure that there is sufficient signal at the beginning of class. However, the APs will also be louder at all other times, which can cause large CCI. Decreased power limits interference and improves application performance.

The EaTPC method described herein constantly monitors the status of the class with cameras using computer vision algorithms. The transmit power of the APs are eventually adjusted based on the number of incoming and outgoing people instead of send NDP messages every 10-30 minutes. This way, the transmit power is changed step by step based on the environment and does not suddenly jump to the minimum power level when the class is empty.

The techniques described herein may be used in conjunction with services that sense and understand the context of everything that is happening across all applications, users, and devices in a network. The captured video streams or just some frames in

important time instances may be transferred to the service server to show an image of the users in the network. For example, any disruptions from RRM updates that cause spikes in service statistics may be paired with the images capturing moments when the number of users change.

Since only a fraction of detected people are actually Wi-Fi users, a probability may be used to estimate a more realistic user count.

In summary, techniques are described herein for making a reliable decision on applying different RRM functionalities in an optimal time and reducing latency on changing the network parameters. This fuses the information extracted from real-time video streams of the environment into the RRM unit to predict the network load and adapt algorithms accordingly.