Towards Adaptive Network Resource Orchestration for Cognitive Radio Networks

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Abstract

This work proposes an adaptive resource orchestration system for a Wireless Local Area Network (WLAN) that is based on the operating principle of Cognitive Radio (CR) technology. By collecting environmental parameters, including the retransmission rate and the channel occupancy rate, the proposed system has "knowledge" of overall transmission behavior and can regulate transmission resources. An Adaptive Connection Assignment (ACA) mechanism is proposed for end devices; it find out target end devices with poor transmission performance, analyzes their alternative Access Point (AP) availability and causes them to change connections to improve transmission performance. An Adaptive Channel Utilization (ACU) mechanism is designed for APs to identify a target AP that is suffering from interference, to analyze its alternative channel availability and to require it to change its working channel to improve transmission efficiency. Results of simulations of various scenarios indicate that the throughput of end devices is increased by 15 to 24%, the throughput of APs is increased by 6 to 47% and the retransmission rate of APs is reduced by 0.4 to 5.3%.

Keywords: Cognitive Radio Networks, Resource orchestrator, Resource availability, Adaptive resource allocation

1 Introduction

A. Motivation

Nowadays, the rapid progress of wireless network technology is making wireless devices and equipment increasingly mature. With large-scale developments of the Internet of Things (IoT), Machine-to-Machine (M2M) and Device-to-Device (D2D), several technical investigations of the prospects of future networks have been performed [1-4].

To satisfy the huge demand for data transmission in future networks, wireless access and transmission must be smooth and unimpeded. However, resource utilization and assignment in a traditional wireless network is typically not ideal. In problem A, most end devices used that an AP with better Received Signal Strength Indication (RSSI) has higher signal quality [5-9]. If many end devices choose an AP based on RSSI in this way, some APs are likely to become overloaded, causing some of the end devices to access APs in a high-contention situation. In problem B, the working channel of the APs are normally fixed, so APs cannot change channel smartly in response to variations of its surrounding. When any signal interference occurs in a specific channel, transmission efficiency on that channel decreases until the spectrum interference disappears [10-11]. In above problems, wireless transmission resources cannot perform appropriately adjustment for end devices. Therefore, adjusting wireless transmission resources is an important research issue in pursuit of improve transmission performance. The assignment of network resources should be reliable and flexible to accommodate growth in the number of end devices [12-13].

This study is inspired by operation concept of CR technology which makes decisions after a complete resource observing and availability analysis [14-15]. In this study, all of end devices and APs have cognitive capabilities which allow them recognizes their transmission states and transmission resource of surrounding effectively, especially channel occupied situation. This is implemented by having an adaptable physical layer based on Software Defined Radio (SDR) [16-18]. With those recognition of information, there are two mechanism in the proposed system, ACA and ACU, designed to deal with the corresponding problems of traditional wireless network. The ACA mechanism adjusts end devices' connection appropriately and ensures that each end device get transmission with best efficiency. The ACU mechanism regulates working channel adaptively and ensure that each AP resist signal interference from surrounding. This study proposes a solution to improve transmission performance of end device and APs, and enhance ability of resistance to external interference.

B. Research Concept

This analyzes the efficiency of use of wireless transmission resources by end devices and wireless nodes. Both end devices and nodes periodically send network transmission information to the adaptive resource orchestrator to determine the transmission status of the network. A comparison, analysis and processing are performed to decide for each end device or wireless node to ensure effective dynamic adjustment of transmission resources to improve the efficiency of wireless transmission.

When a new end device is added to communication field, a default connection is made based on a wireless node with a higher RSSI value than others APs or a wireless node that has been connected before. The end device periodically sends

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transmission status messages to the resource orchestrator to obtain data transmission and connection information. Once the resource orchestrator determines that the transmission status of an end device is poor, it triggers a resource scheduling analysis. After the resource allocation strategy has been determined, information about it is sent back to the end device, which automatically performs switching of the wireless node connection to optimize the wireless transmission service.

Like end devices, mentioned above, wireless nodes also periodically transmit transmission status messages to a central resource coordinator. Once a resource orchestrator discovers that a wireless node has poor transmission status on account of external interference, it triggers a resource scheduling analysis. After the resource allocation policy has been determined, information about it is sent back to the wireless node. Then wireless node automatically performs switching of the working channel to resist the external interference and maximize the quality of wireless transmission.

C. Contribution

This work proposes an adaptive resource orchestration system, including an end device layer, a transmission layer and a resource orchestrator layer. By collecting environmental parameters, the system has knowledge of the transmission behavior all of devices and regulates transmission resources. The contributions of this study are summarized as follows.

1) This study uses retransmission rate and channel occupancy rate to estimate the availability of wireless resources.
2) This study develops a resource orchestrator whose architecture supports the setting of an overall plan for managing the connection of end devices and the working channel of APs for wireless transmission.
3) This study proposes an ACA mechanism, which uses threshold filtering, includes an alternative resource analysis and selects algorithm for AP assignment, to ensure that each end device transmits with the best possible efficiency.
4) This study proposes an ACU mechanism, which uses threshold filtering, includes an alternative resource analysis and selects algorithm for channel assignment, to ensure that each AP resist signal interference.
5) Four scenarios are simulated to evaluate the performance of the proposed mechanism. With the ACA mechanism, the range of improvements of the end devices' throughputs is approximately 15 to 24%; With the ACU mechanism, the range of improvements of APs throughputs is approximately 6 to 47%. The AP retransmission rate is reduced by approximately 0.4 to 5.3%.

2. Background Knowledge

A. Cognitive Radio and Software defined Radio

As Software Defined Radio (SDR) hardware gradually evolves, CR is becoming a mainstream basis for optimized radio communication. The idea of CR technology is based on transmission requirements to make more efficient use of the radio spectrum and to provide and maintain the most efficient form of wireless communication. CR can obtain the state of the spectrum, detecting "holes" in it to optimize the frequency band, modulation mode and signal power for transmission, improving utilization of the spectrum [19-23].

Radio communication components are traditionally hardware, but in SDR, they are software [24-25]. SDR combines hardware and software to achieve radio operations through programming processes, such as software modification and firmware operation. The integration of these technologies supports the development of existing radio systems to add wireless features and functionality without the need for new hardware.

B. Related Works

Many researches on AP selection, channel interference and allocation have been published. Schemes that are based on mean transmission time have been developed to estimate throughput. However, because coverage regions of end devices differ from those of APs, end devices cannot always decode all frames that are exchanged between them and other APs. Therefore, the lower accurate on the estimation makes throughput capacity becomes lower, potentially resulting in incorrect AP selection. Since, in this method, end devices must be fully trained using previous measurements, wrong decisions regarding AP selection are likely to be made until enough experience is accumulated [26-28]. S. Gamage et al. [29] propose a flexible cognitive networks architecture for 802.11based WLANs and a novel secondary channel allocation algorithm. They considered only the choice of suitable channel pieces for peak traffic loads but their method enabled the transmitter to change the working channel frequently.

3. Adaptive Resource Orchestration System

A. System Architecture

Figure 1 shows the architecture of the proposed adaptive resource orchestration system. The proposed system consists of three layers, based on data transmission, which are the resource orchestrator layer, the transmission layer and end device layer. The end device layer contains mobile equipment that support SDR functions, which in turn support wireless transmission features. All end devices consist of an environmental parameter module and an AP assignment module. The environmental parameter module collects information about surrounding resources and transmission conditions close to end devices and sends it to the resource orchestrator. The AP assignment module stands by to reassign the AP connection.

The transmission layer refers to normal wireless access points, which support SDR functions and use transmitter to forward traffic of end devices to Internet. All wireless APs comprise an environmental parameter module and a channel assignment module. The environmental parameter module collects information about surrounding resources and transmission conditions near an AP and sends it to the resource orchestrator. The channel assignment module stands by to reassign a used channel.

The resource orchestrator is the core of the proposed adaptive resource orchestration system. It monitors and controls all APs and end devices. It has four components, which are the collector module, the resource analysis module, the orchestration strategy module and the database. The collector module receives and resolves packets from the transmission layer or the end device layer and then saves them in the database. When collection is complete, data are sent to the resource analysis module. Once the resource analysis module has received those data, it calculates whether any end device or AP requires resource reassignment. After target end devices or APs that require reassignment have been identified, the orchestration strategy module takes over from the resource analysis module. By acquiring relevant data from the database and computing the availability of alternative resources, the orchestration strategy module makes the best decision about resource reassignment for target end devices and APs. It then sends reassignment strategies to the target AP assignment module or the channel assignment module. Finally, the resource orchestrator completes resource regulation to improve the overall transmission quality of all end devices and APs.

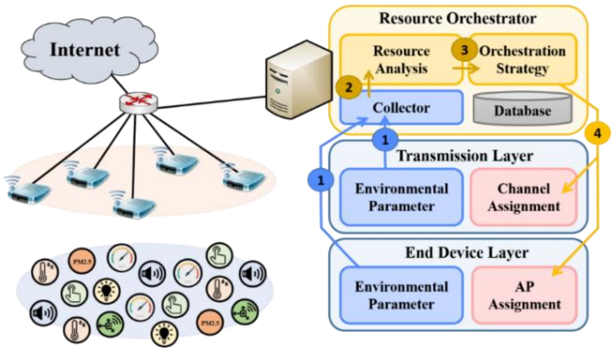

Figure 1. System architecture

1) End Device Layer

There are two critical components in each end device layer, including environmental parameter module and AP assignment module.

➢ Environmental Parameter Module

The environmental parameter module received an end device's transmission state and the frequency of nearby resources. Table 1 presents the collection parameters of the end device.

Table 1. Collecting parameters of each end device

Parameter description	Unit
Throughput of end device	Mbps
SSID of nearby access points	-
RSSI of nearby access points	dBm
Channel occupied rate of surrounding	%

According to the definition of energy detect in Clear Channel Assessment (CCA), indicates a busy state of communication channel with a sensitivity of at least -62dBm in a 20MHz channel. Whether the signal energy at the center frequency of each channel exceeds -62dBm is checked. For example, the signal energies at the center frequencies of channels 7, 8, 10 and 11 clearly exceed -62dBm. Therefore, channels 7, 8, 10 and 11 are regarded as occupied at this sweep time. When the results of numerous spectrum sweeps have been used to generate the relevant statistics, the occupancy rate of each channel near an end device can be calculated. Finally, the collection parameters of the environmental parameter module are included into data packets and sent to the resource orchestrator.

➢ AP Assignment Module

The AP assignment module receives the AP reassignment strategy from the resource orchestrator. It is responsible for parsing received packets into corresponding execution commands and implementing them. After execution commands are executed, an end device stops transmitting data to change a connected AP into an indicated AP.

2) Transmission Layer

There are two critical components in each AP, including environmental parameter module and channel assignment module.

➢ Environmental Parameter Module

The environmental parameter module acquires an AP's transmission state and the state of nearby resources. Table 2 presents the collecting parameters of APs whose values are collected by environmental parameter module.

Table 2. Collecting parameters of each access Point

Parameter description	Unit
Working channel of access point	-
Throughput of access point	Mbps
SSID of other access points	-
Retransmission rate of access point	%
Channel occupied rate of surrounding	%

The environmental parameter module has five parameters. The working channel of the access point is an elemental parameter, which is controlled by the adaptive resource orchestration system. The throughput of access point parameter quantifies the transmission performance and is used to evaluate the AP's load. By learning about the potential channel interference of nearby APs, the SSID of other access points parameter used to identify a channel with less interference in the making of subsequent decisions. Two parameters indirectly indicate channel quality; they are retransmission rate of access point parameter and the channel occupancy rate of surrounding parameter. The retransmission rate of access point parameter is the percentage error in transmission as determined by data retransmission. The channel occupancy rate of surrounding parameter is collected by the environmental parameter module, as does the end device layer. After all parameters have been acquired, the environmental parameter module includes them into data packets, which it forwards to the resource orchestrator.

➢ Channel Assignment Module

The channel assignment module receives the working channel reassignment strategy from the resource orchestrator. It is responsible for parsing received packets into corresponding execution commands and implementing them. After these commands have been executed, the AP stops forwarding data, changing the working channel to the indicated channel.

3) Resource Orchestrator

The resource orchestrator has an important role in making decisions about resource reassignment in the proposed adaptive resource orchestration system.

➢ Collector

The collector gathers uploaded packets from each end device and AP. It is responsible for parsing received packets into corresponding environmental parameters. After they are collected and parsed, the environmental parameters of each end device and AP are forwarded to the resource analysis module and saved in the database.

- Resource Analysis Module

The resource analysis module is used to identify the end devices or APs that are operation in an unfavorable situation. End devices and APs have different throughput threshold formulas. When the resource analysis module acquires throughput data from the database, it inputs them to the corresponding throughput threshold formula. The resource analysis module uses the results of that calculation of throughput threshold to filter the current states of the end devices and APs that are forwarded by the collector. If the current throughputs of the end devices or APs is lower than the corresponding throughput threshold, then those end devices or APs are regarded as targets that must be checked further. The resource analysis module checks whether target end devices have a satisfactory current transmission throughput. It also checks whether the retransmission rate of the target APs is increasing. The target end devices or APs are confirmed to perform resource orchestration only if end devices do not have a satisfactory transmission throughput or target AP's retransmission rate increases. Eventually, the identities of those target end devices and APs sent to orchestration strategy module for follow-up.

- Orchestration Strategy Module

To achieve effective resource reassignment, the orchestration strategy module is used to determine which alternative AP or channel should be provided to the target end devices and APs. An availability formula is designed for target end devices to determine whether any alternative AP can improve transmission. This formula considers the RSSI of the alternative AP, the load, the retransmission rate and the state of the used channel. Another availability formula for target APs is used to determine whether better, alternative channel exists. This formula for alternative channel availability takes usage, percentage occupancy and the overlap effect coefficient into account. After calculating the availability of alternative resources, the orchestration strategy module tentatively chooses the alternative resource with the highest score for reassignment. When all decisions about every target end device and target AP have been made, the orchestration strategy module do final execute selection. The selection avoids amount end devices assign to same AP or amount AP selecting the same working channel. Finally, the orchestration strategy module forwards the decision of reassignment to target end devices and APs to regulate the system.

- Database

The database stores environmental parameters that are transmitted by the collector. An independent table is built for each end device or AP.

B. Adaptive Connection Assignment Mechanism

The ACA mechanism ensures that each end device transmits with the highest possible efficiency. This ACA mechanism involves cyclic operation that regulates the connections of the end devices. The ACA mechanism involves the following procedure.

1. Obtain Environmental Parameters:

The resource analysis module inside the resource orchestrator acquires the newest environmental parameters from the collector and the previous environmental parameters from the database.

2. Calculate the Throughput Threshold of End Devices:

The resource analysis module uses the previous throughput performance of all end devices in a system to calculate the their throughput threshold. Equation (1) is the designed formula for end device throughput threshold ($TP_{EDthres}$).

$$TP_{EDthres} = TP_{EDavg} - 1 \times \sigma_{ED} \quad \textbf{(1)}$$

TP_{EDavg} represents the mean throughput of all end devices and σ_{ED} represents standard deviation of the throughput of the end devices. $TP_{EDthres}$ formula is expanded to Eq. (2).

$$TP_{EDthres} = \left(\frac{1}{N_{ED}}\sum_{i=1}^{N_{ED}} TP_{avg_i}\right) - \left(\sqrt{\frac{1}{N_{ED}}\sum_{i=1}^{N_{ED}}\left(TP_{avg_i} - TP_{EDavg}\right)^2}\right) \quad \textbf{(2)}$$

N_{ED} represents the total number of end devices in the system is, and TP_{avg_i} represents the average throughput of the i^{th} end device. Accordingly, Eqs. (1) and (2) divide the data distribution at approximately 16.8% and 83.2% approximately, such that about 16.8% of end devices operate at low throughput in the system, as determined using the specified threshold value.

3. Filter the End Devices:

After calculating $TP_{EDthres}$, the resource analysis module uses this threshold to check the current throughput of all end devices. If the throughput of any end device is less than $TP_{EDthres}$, then that end device is normally considered to be a target that requires adjustment. However, throughput is a fluctuating value so avoid false triggering must be prevented. The end device is a target only when its throughput is below the threshold for more than a predefined time period (T_{ED}).

4. Check Throughput Satisfaction of End Devices:

Target end devices that work at low throughput are identified by threshold filtering, but the connections of these target end devices do not necessarily require adjustment. Therefore, the resource analysis module check whether the current throughput of these targets end devices whether is satisfactory, by applying predefined lowest required bandwidth. If the throughput of the target end devices exceeds the least required bandwidth, then later steps of check satisfied are skipped and the analysis ends. Otherwise, resource analysis module are sent to orchestration strategy module to perform the next step of the connection adjustment.

5. Calculate Transmission Availability of Aps:

The orchestration strategy module in the resource orchestrator extracts the previous values of the environmental parameters of the end devices and the APs from database. From the environmental parameters for the end devices, the orchestration strategy module identifies alternative APs to which target end devices are connected. To choose the AP that provides the greatest benefit to end devices, knowledge of the availability of both alternative and currently connected APs is required. Equation (3) is the designed formula AP transmission availability (A_{AP}).

$$A_{AP\ i} = w_{ssr}S_i + w_{alv}L_i + w_{str}T_i + w_{ccs}C_i \quad \textbf{(3)}$$

Equation (3) has four terms, each with a specific weight value, which are the signal strength ratio (S_i), the available load (L_i), the successful transmission rate (T_i) and the channel state (C_i). To guarantee the existence of a feasible solution, inequality (4), Eq. (5) and Eq. (6) must be satisfied as constraints.

$$w_{ssr},\ w_{alc},\ w_{str},\ w_{ccs} \leq 1 \quad \textbf{(4)}$$

$$w_{ssr} + w_{alc} + w_{str} + w_{ccs} = 1 \quad \textbf{(5)}$$

$$S_i,\ L_i,\ T_i,\ C_i \geq 0 \quad \textbf{(6)}$$

For a target AP to be analyzed, Eq. (7) is the normalized function of the signal strength ratio (S_i). The RSSI of the target AP that is received by the end device is $RSSI_i$. The maximum RSSI of the surroundings that is received by the end device is $RSSI_{Max}$. If the target AP's RSSI is the maximum RSSI of the end device, then S_i equals unity.

$$S_i = \left(\frac{RSSI_i}{RSSI_{Max}}\right) \quad \textbf{(7)}$$

Equation (8) presents the normalized available load (L_i) function. TP represents the throughput of the target AP and TP_{Max} represents the maximum possible throughput of the target AP. Using these two parameters, the current load of the target AP is represented as $\frac{TP}{TP_{Max}}$. Therefore, the available load of the target AP is calculated as follows.

$$L_i = \left(1 - \frac{TP}{TP_{Max}}\right) \quad \textbf{(8)}$$

Equation (9) is the normalized success transmission rate (T_i) function. ReT is the retransmission rate of the target AP. The AP triggers retransmission when the transmission includes missing or damaged packets. Therefore, the success transmission rate of the target AP is calculated as follows.

$$T_i = 1 - ReT \quad \textbf{(9)}$$

Equation (10) is the normalized function of the channel state (C_i). O_{APCH} represents the occupancy rate of the target AP's working channel that corresponds to the target end device. A lower channel occupancy rate favors end device transmission. The equation is as follows.

$$C_i = 1 - O_{APCH} \quad \textbf{(10)}$$

6. Choose the AP with Maximum Availability:

After A_{AP} is calculated, the orchestration strategy module picks the AP with the highest A_{AP} as decision for the target end device, according to Eq. (11).

$$Decision\ of\ AP = Max(A_{AP\ 1}, A_{AP\ 2}, \ldots, A_{AP\ n}) \quad \textbf{(11)}$$

7. Select Algorithm of AP Assignment:

The above method may yield the same chosen APs for different target end devices. If many target end devices connect to the same AP and move to this AP simultaneously, then the AP may be overloaded and transmission performance worsened. A ping-pong effect will likely cause those target end devices to connect to different APs frequently. A selection algorithm is used to avoid this problem. The selection algorithm associated with AP assignment has the following pseudo code. The final value of ED_assign is the total number of end devices that are assigned to an AP. Other end devices will keep their original APs.

C. Adaptive Channel Utilization Mechanism

The ACU mechanism ensures that each AP in the proposed system architecture resists signal interference from its surroundings. This ACU mechanism is a cyclic operation but it is used to adjust the APs' working channel. The temporal relationship between the collection of parameters and threshold filtering in the ACU mechanism is the same as that in the ACA mechanism.

The adaptive spectrum utilization mechanism involves the following processes.

1. Obtain Environmental Parameters:

The resource analysis module in the resource orchestrator acquires the newest environmental parameters from the collector and previous environmental parameters from the database.

2. Calculate the Throughput Threshold of each AP:

In the ACU mechanism, the throughput threshold of each AP has to be calculated. The mean AP throughput is used as the threshold throughput for filtering APs. Therefore, the resource analysis module acquires the throughput records of various APs to calculate their throughput thresholds. Equation (12) is the formula for AP throughput threshold ($TP_{APthres}$).

$$TP_{APthres} = TP_{APavg} = \frac{1}{N_{AP}}\sum_{i=1}^{N_{AP}} TP_i \quad \textbf{(12)}$$

TP_{APavg} represents the mean AP throughput. The total number of AP is N_{AP} and the i^{th} throughput record is TP_i.

3. Filter the Aps:

After calculating $TP_{APthres}$, the resource analysis module uses each threshold to evaluate the current throughput of each AP. In the ACU mechanism, an AP is selected as a target only when its throughput is below the threshold for more than a predefined time period (T_{AP}).

4. Check Retransmission Rate of AP:

Threshold filtering is used to identify target APs in the system with decreasing throughput. However, these target APs may not necessarily suffer from interference or require channel adjustment. Therefore, the resource analysis module must check whether the retransmission rates of these target APs has increased above that in the preceding ACU work cycle. Only a target AP with an increased retransmission rate has is considered in the next step of process.

5. Calculate Transmission Availability of Channels:

The orchestration strategy module extracts previous values of environmental parameters from the database. To choose the channel that provides maximum benefit to APs, the availability of both the currently used and alternative channels must be known. Equation (13) is the designed formula for AP transmission availability (A_{CH}).

$$A_{CH\,i} = w_{cu}CU_i + w_{ca}CA_i + w_{cs}CS_i \quad \textbf{(13)}$$

Equation (13) has three features with specific weights; they are channel users (CU_i), access channel availability (CA_i) and channel signal overlap (CS_i). To guarantee the finding of a feasible solution, inequality (14), Eq. (15) and inequality (16) must be satisfied as constraints.

$$w_{cu},\ w_{ca},\ w_{cs} \leq 1 \quad \textbf{(14)}$$

$$w_{cu} + w_{ca} + w_{cs} = 1 \quad \textbf{(15)}$$

$$CU_i,\ CA_i,\ CS_i \geq 0 \quad \textbf{(16)}$$

For a target channel to be analyzed, Eq. (17) is the normalized function of the number of channel users (CU_i). The number of APs that use a target channel close to the AP under adjustment is N_{ch}. If no AP is working with the target channel, then that AP under adjustment has no potential competitors that share channel resources. Therefore, when more APs use the target channel, fewer of the target channel resources can be acquired by the AP under adjustment.

$$CU_i = 1/(1 + N_{ch}) \quad \textbf{(17)}$$

Equation (18) is the normalized function for access channel availability (CA_i). O_{ch} represents the occupancy rate of the target channel close to an AP under adjustment. A lower occupancy rate of the target channel corresponds to an easier access of the AP under adjustment to the channel for transmission. The access channel availability of the target channel calculated as follows.

$$CA_i = (1 - O_{ch}) \quad \textbf{(18)}$$

Equation (19) is the normalized function for channel signal overlap (CS_i). C_{ov} is the overlap effect coefficient of the target channel. For a working channel, a smaller C_{ov} favors transmission by the target AP because the channel suffers less interference by a signal in nearby channel. Channel signal overlap of the target channel is calculated as follows.

$$CS_i = 1/C_{ov} \quad \textbf{(19)}$$

The target channel suffers from overlap signal interference from three nearby channels (CH^{u1}, CH^{u2} and CH^{u3}). Th interference varies with the overlap ratio (α_1, α_2 and α_3). Equation (20) defines the overlap effect coefficient.

$$C_{ov} = \frac{1}{2}(\alpha_0 CH^{+0} + \alpha_2 CH^{+1} + \cdots + \alpha_n CH^{+n}) + \frac{1}{2}(\beta_0 CH^{-0} + \beta_1 CH^{-1} + \cdots + \beta_n CH^{-n}) \quad \textbf{(20)}$$

The terms $\alpha_0, \alpha_1, \ldots, \alpha_n$ represent the weight values of the upper channels' overlap ratios and$CH^{+0}, CH^{+1}, \ldots, CH^{+n}$ are the occupancy rates of those upper channels. The terms $\beta_0, \beta_1, \ldots, \beta_n$ represent the weight values of the lower channels' overlap ratios and $CH^{-0}, CH^{-1}, \ldots, CH^{-n}$ are the occupancy rates of the lower channels. Equation (20) is simplified to Eq. (21).

$$C_{ov} = \frac{1}{2}\left(\sum_{i=0}^{n} \alpha_n CH^{+n}\right) + \frac{1}{2}\left(\sum_{i=0}^{n} \beta_n CH^{-n}\right) \quad \textbf{(21)}$$

This equation is constrained by inequalities (22) and (23).

$$1 > \alpha_0 > \alpha_1 > \cdots > \alpha_n > 0 \quad \textbf{(22)}$$

$$1 > \beta_1 > \beta_2 > \cdots > \beta_n > 0 \quad \textbf{(23)}$$

6. Choose the Channel with Maximum Availability:

After calculating A_{CH} for each target AP, the orchestration strategy module identifies the five channels with the highest A_{CH}, as follows.

$$Decision\ of\ working\ channels = Largest\ 5(A_{CH\,1}, A_{CH\,2}, \ldots, A_{ACH\,n}) \quad \textbf{(24)}$$

7. Select Algorithm of Channel Assignments

The above method involve a selection algorithm to prevent too many APs from using a single channel.

4. Performance Analysis

Two scenarios are simulated for each mechanism. The simulation data in the total of four scenarios inside are analyzed and discussed below.

A. Simulation Equipment and Metrics

Three methodologies are used to evaluate the performance of the proposed ACA and the ACU mechanism. These methods are based on the real-time throughput, mean throughput, and the retransmission rate of the target end devices or APs. Each case is measured using the following metrics.

The throughput is the number of bits that pass through a data communication system in a particular period.

The retransmission rate is the number packets sent by a source minus the number of received, all divided by the number received, expressed as a percentage.

B. Performance Analysis of ACA Mechanism

The performance of the ACA mechanism is evaluated using the designed simulation. It is compared with that of the Access Point Selection (APS) mechanism, which determines the connections of end devices connection only in the beginning of system.

1) Single User at APs' Coverage

Figure 2 shows simulated topology of end devices and coverage of APs. The topology comprises one resource orchestrator, one 100M switch, two APs (AP1, AP2) and eight end devices (ED1-ED8). Each wired link has a bandwidth of 100M. In this topology, ED2 is the only device that is covered by AP1 and AP2. However, the distance of ED2 to APs is much longer than other end devices to APs. The simulation proceeds as follows.

- Initially, ED2 has already been running FTP download and ED1, 3, 4 and 5 have already been streaming videos.
- At 30s, ED6, 7 and 8 begins FTP downloading.
- At 90s, ED6, 7 and 8 stops FTP downloading.

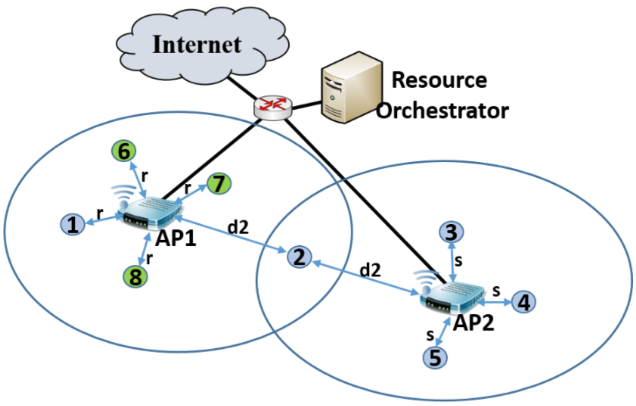

Figure 2. Simulation topology of single user at APs' coverage

Because of the distance factor of APs and end devices, when ED6, 7 and 8 are added to the environment, ED1, 6, 7 and 8 consume much bandwidth. The throughput of ED2 dropped dramatically. With the APS mechanism, ED2 retains its original connections at all times and is directly affected by ED6, 7 and 8 flows. In contrast with the APS mechanism, the proposed ACA mechanism yields an ED2 throughput that is much lower than the end device throughput threshold and less than the lowest required bandwidth. At approximately 45s, the ACA mechanism calculates the availability of the APs and then assigns ED2 to change the connection from AP1 to AP2. As a result, the throughput performance of ED2 is improved.

At 46 to 104s, the ACA mechanism continues to function. It continues to calculate and find alternative connection resources several times, because the throughput of ED2 remains less than the lowest required bandwidth. However, no solution is better than connecting to AP2. At 90s, when ED6, 7 and 8 have stopped FTP downloading, the ACA mechanism does not ask ED2 to change its connection back to AP1 immediately. The throughput threshold is used in checking ED2 for a fixed period before this cycle of the ACA mechanism is completed. At approximately 105s, ED2 is asked to connect back to AP1 to improve throughput. Therefore, the mean throughput of ED2 with the ACA mechanism is 1.7Mbps, which is better than the 1.45Mbps that is obtained by the APS mechanism.

In the ACA mechanism, the throughput of ED3, 4 and 5 decreased as ED2 is connects to AP2. At 90s, the throughput of ED1 is as high as 21Mbps for approximately 15s because ED6, 7 and 8 stop and ED2 remains connected to AP2. Table 3 presents statistics concerning the total transmission of ED2 and APs. The ACA mechanism improved the performance of ED2 by 17.6% and imposes overall system throughput.

Table 3. Throughput statistics

	APS	ACA	Variation
ED2	21.6 MB	25.4 MB	+17.6%
AP1	318 MB	325 MB	+2.21%
AP2	325 MB	324 MB	-0.3%

2) Multiple Users at APs' Coverage

Figure 3 shows simulated topology of end devices and coverage of APs. It consists of one resource orchestrator, one 100M switch, two APs (AP1, AP2) and ten end devices (ED1 – ED10). Each wired link supports a bandwidth of 100M. In this topology, ED2, 3 and 4 are covered by AP1 and AP2. However, their connection distance form end device to APs is much longer than other end devices to APs. The ACA mechanism with or without the selection algorithm in this scenario is discussed.

- Initially, ED2, 3 and 4 have already been FTP downloading and ED1, 5, 6 and 7 have been streaming videos.
- At 30s, ED8, 9 and 10 begins FTP downloading.
- At 90s, ED8, 9 and 10 stops FTP downloading.

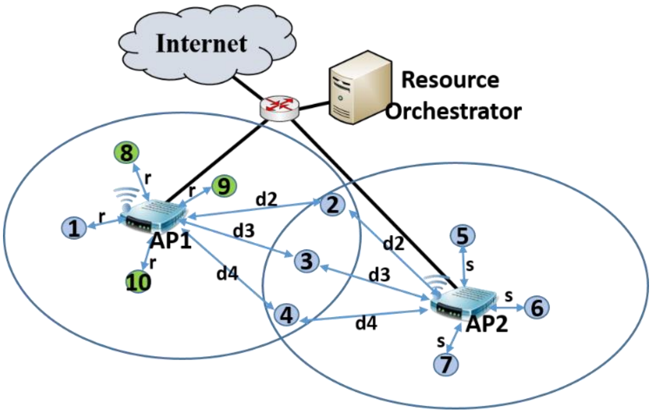

Figure 3. Simulation topology of multiple users at APs' coverage

Because the variations in their distances to APs, the throughput performances of ED2, 3 and 4 were not equal. ED3 had the best throughput performance and ED4 had the worst. With the APS mechanism, ED2, 3 and 4 retained their original connections and were directly affected by ED8, 9 and 10 flows.

Unlike APS mechanism, the proposed ACA mechanism identifies and solves the following problem at approximately 45s. The ACA mechanism without the selection algorithm makes a decision to ask ED2, 3 and 4 to change their connections simultaneously. The throughput performance of ED2, 3 and 4 is thus improved, but not by much. Since AP2 does not handle all throughput requirements from ED2, 3 and 4, the throughput performance of all end devices that are connected to AP2 is reduced.

The ACA mechanism with the selection algorithm effectively changes responsible for end devices. It requires ED2 and ED4 to connect to AP2 while ED3 remains connected to AP1. By distributing the throughput requirements to APs, the throughput performance of each of ED2, 3 and 4 was greatly improved.

Figure 4 shows the throughput of end devices. In the ACA mechanism with the selection algorithm, the effects of flow on ED5, 6 and 7 were smaller than that in the ACA mechanism without the selection algorithm when the ED2 and 4 were connected to AP2. By considering tolerable loading of APs, the former avoids the reduction of throughput of the end devices connect on AP2. Table 4 presents statistics concerning the total transmission of ED2, 3, 4 and APs. Without the selection algorithm, the normal ACA mechanism slightly improves throughput performance. However, the ACA mechanism with the selection algorithm improves throughput performance by up to 15%, 18% and 24% on ED2, 3 and 4 separately, while having almost no negative effect on overall system throughput.

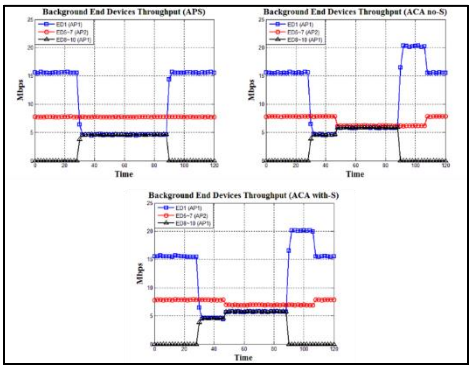

Figure 4. Throughput variation of other end devices

Table 4. Throughput statistics

	APS	ACA (no-S)	Variation	ACA (with-S)	Variation
ED2	10.7 MB	11.2 MB	+4.67%	12.3 MB	+15%
ED3	15 MB	15.6 MB	+4%	17.7 MB	+18%
ED4	7.9 MB	8.1 MB	+2.53%	9.8 MB	+24%
AP1	290 MB	306 MB	+5.51%	317 MB	+9.31%
AP2	348 MB	331 MB	-4.89%	344 MB	-1.15%

C. Performance Analysis of ACU Mechanism

The performance of ACU is evaluated using a simulation. A scenario with the ACU mechanism is compared to one without ACU.

1) External APs Interference

Figure 5 shows the simulated topology and interference of external APs. The topology consists of one resource orchestrator, one 100M switch, three system APs (AP1 – AP3) and three external APs (Ex-AP1 – Ex-AP3). Each wired link has a bandwidth of 100M. Both system APs and external APs have uniformly distributed end devices that generate data flows.

- Initially, AP1, AP2 and AP3 have already been operating.
- At 30s, Ex-AP1 and Ex-AP2 are added to experiment environment.
- At 90s, Ex-AP1 stops working and leaves experiment environment.
- At 120s, Ex-AP3 is added to the experiment environment.

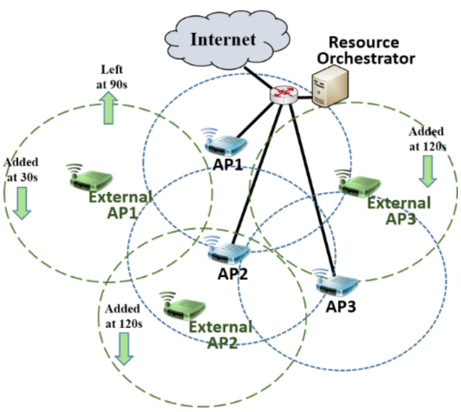

Figure 5. Simulation topology of external APs interference

At 30s, when the Ex-AP1 and Ex-AP2 are added to the environment, AP1 and AP2 begin to suffer from channel interference, losing almost half of their throughput. Without the ACU mechanism, AP1 endured interference until Ex-AP1 left experiment environment while AP2 was disturbed by Ex-AP2 at all times. AP3 faced this problem at approximately 120s. The fixed channel setting preventing APs from flexibly dealing with contention of channel.

In contrast, the proposed ACU mechanism caused throughput variations of AP1 and AP2 at approximately 42s. After calculating and analyzing experiment result, the resource orchestrator required AP1 and AP2 to change their working channel. The throughputs of AP1 and AP2 dropped to zero for approximately 3s because all APs needed to be reconfigured to change channels. When the working channels had been changed, AP1 and AP2 exhibited greatly improved throughput. However, the throughput of AP3 declined slightly perhaps because the changing of the channel of AP1 or AP2 caused a little interference, such as signal overlap. This occurrence also explains why the throughput of AP1 and AP2 did not return to its initial value after the working channel was changed. At 120s, to solve a similar problem on AP3, the ACU mechanism was used again to change its working channel. Consequently, the average throughput of all APs with the ACU mechanism was better than that without ACU mechanism.

Table 5 presents the throughput statistics for AP1, AP2 and AP3. In this simulation scenario, the AP2 exhibited the most improved performance by 33%. The throughputs of AP1 and AP3 were increased by 6.8% and 10.1%, respectively. The overall transmission performance of the system was increased by 15.2%.

Table 5. Throughput statistics of Aps

	Without ACU	ACU	Variation
AP1	382 MB	408 MB	+6.8%
AP2	290 MB	386 MB	+33%
AP3	395 MB	435 MB	+10.1%
Overall	1,067 MB	1,229 MB	+15.2%

Figure 6 plots retransmission rate of each AP. Since the ACU mechanism can rapidly respond to channel contention and adjust APs appropriately, when each AP in a system suffers from interference by external APs, increase in the retransmission rate is effectively reduced. Table 6 presents the retransmission rate statistics of APs. The retransmission rates of AP1, AP2 and AP3 were reduced by 0.5%, 2% and 0.4%, favoring overall system transmission quality.

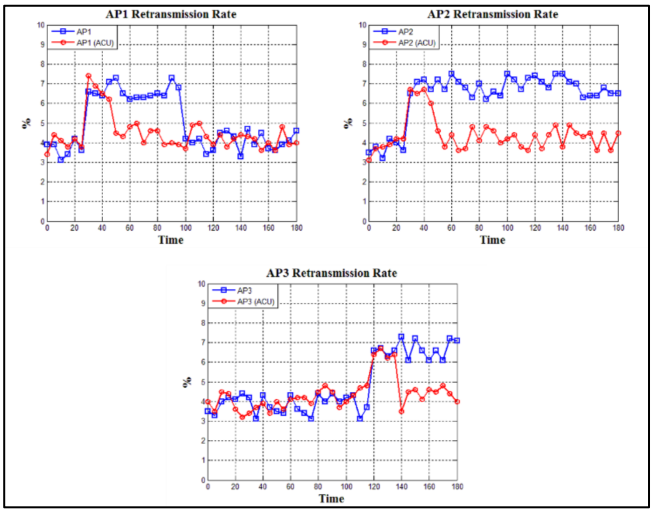

Figure 6. Retransmission rate of AP1, AP2 and AP3

Table 6. Retransmission rate statistics of Aps

	Without ACU	ACU	Variation
AP1	5%	4.5%	-0.5%
AP2	6.4%	4.4%	-2%
AP3	4.8%	4.4%	-0.4%
Overall	5.4%	4.4%	-1%

2) External AP & Energy Interference

Figure 7 shows the simulated topology and interference of external APs. It consists of one resource orchestrator, one 100M switch, three system APs (AP1 – AP3), one external AP (Ex-AP1) and two external signal interference (Ex-interference_A, Ex-interference_B). Each wired link supports a bandwidth of 100M. The external signal interference is with a randomly generated non-Wi-Fi whose signal power greatly exceeds that of APs. Both system APs and external APs have uniformly distributed end devices that generate data flows.

- Initially, AP1, AP2 and AP3 have already been working.
- At 30s, Ex-AP1 and Ex-interference A are added to experiment environment.
- At 90s, device of Ex-interference A leaves experiment environment.
- At 120s, Ex-interference B is added to the environment.

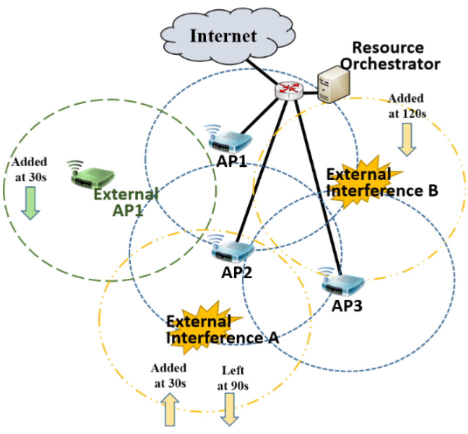

Figure 7. Simulation topology of external AP & energy interference

At 30s, AP1 suffers mostly from channel contention with Ex-AP while AP2 and AP3 are disturbed by Ex-interference A. Owing to a difference in signal power, Ex-interference A causes the throughput of AP2 and AP3 to drop more than that of AP1 and to become more unstable. At 100s, the throughput of AP2 and AP3 recover quickly because the Ex-interference A leaves. Finally, the throughput of AP1 and AP2 drop again when the Ex-interference A is added to the environment. Without the ACU mechanism, all of the APs were affected by external interference until the interference disappeared. The fixed channel setting causes the APs not to resist interference effectively.

The proposed ACU mechanism identified a worsening of AP performance by threshold filtering and retransmission rate checking at approximately 42s. After the availability of channels was analyzed, the resource orchestrator required AP1 to retain its working channel and AP2 and AP3 to change their working channels. Thereafter the throughput of AP2 and AP3 was improved. However, that of AP1 decreased slightly because the large bandwidth of Ex-interference caused AP2 or AP3 to be assigned close to the AP1 working channel. At 100s, the disappearance of Ex-interference A did not significantly affect APs so the ACU mechanism kept their working channels. At 120s, AP1, AP2 and AP3 suffered from Ex-interference B. At approximately 132s, the resource orchestrator required AP1, AP2 and AP3 to change their working channels.

As a result of experiment, the average throughput of all APs apply the ACU mechanism was better than that without ACU mechanism. Table 7 presents the throughput statistics for AP1, AP2 and AP3. In this simulation scenario, the total throughputs of AP1, AP2 and AP3 were increased by 10%, 47% and 7.1% respectively. Transmission performance was improved by 19.3%.

Table 7. Throughput statistics of Aps

	Without ACU	ACU	Variation
AP1	241 MB	265 MB	+10%
AP2	217 MB	319 MB	+47%
AP3	309 MB	331 MB	+7.1%
Overall	767 MB	915 MB	+19.3%

Figure 8 plots the retransmission rate of each AP. Clearly, the Ex-interference caused a larger variation than the Ex-AP in the AP retransmission rate. At 30s, the retransmission rates of AP2 and AP3 increased sharply. With the ACU mechanism, their retransmission rates were controlled, falling by approximately 10% at about 42s. However, since the working channel of AP2 and AP3 moved close to the AP1, which used channel 1, the retransmission rate of AP1 was slightly increased. When Ex-interference B occurred 120s, the retransmission rates of all APs increased again. After the ACU mechanism was implemented, their retransmission rates were controlled and improved once more. Table 8 presents the retransmission rate statistics of the APs. The retransmission rates of AP1, AP2 and AP3 were reduced by 3.5%, 5.3% and 2.2%, respectively, favoring the overall system transmission quality.

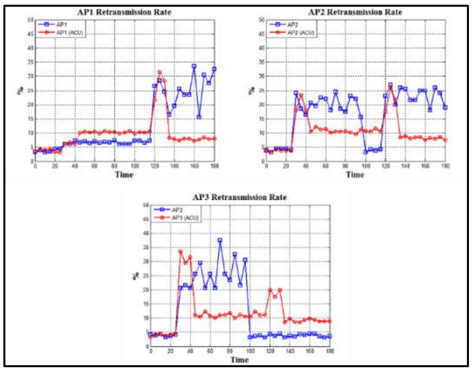

Figure 8. Retransmission rate of AP1, AP2 and AP3

Table 8. Retransmission rate statistics of Aps

	Without ACU	ACU	Variation
AP1	13.1%	9.6%	-3.5%
AP2	16.4%	11.1%	-5.3%
AP3	13.7%	11.5%	-2.2%
Overall	14.4%	10.7%	-3.7%

5. Conclusion

This study proposed an adaptive resource orchestration system, which included an end device layer, a transmission layer and a resource orchestrator. The system has good knowledge of overall transmission behavior by collecting the radio state of transmission and has two characteristics, retransmission rate and channel occupancy rate, to estimate the availability of alternative to wireless resources. Two resource orchestration mechanisms, ACA and ACU, are designed for use in identical system architecture. The ACA mechanism, unlike legacy wireless transmission, causes each end device to transmit at the highest efficiency in the system by flexibly changing their connection APs. The ACU mechanism, also unlike legacy wireless transmission, causes each AP to resist signal interference from the surroundings by adjusting its working channel. A performance analysis demonstrates that the proposed mechanisms improve the throughput of both end devices and APs. The proposed mechanisms are simulated in four scenarios. With the ACA mechanism, the throughput improvements of the end devices are from 15 to 24%. With the ACU mechanism, the throughput improvements of the APs were from 6 to 47%. The AP retransmission rate was reduced by 0.4 to 5.3%. The simulation results verify that the ACA and ACU mechanisms provide effective resource orchestration in wireless transmission.

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