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IEEE 802.11 무선 랜 밀집지역에서의 중앙 집중식 채널 할당 기법

Centralized Channel Allocation Scheme in Densely Deployed IEEE 802.11 Wireless LANs

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Abstract

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Wireless local area networks based on IEEE 802.11 standard have been widely deployed to provide pervasive Internet access. In densely deployed WLAN environment, the WLAN can experience severe inter-cell interference which may cause a considerable performance degradation. In addition, to provide high-capacity wireless local area network system, the inter-cell interference should be more carefully managed from the network setup stage of deciding the operating channel. Therefore, in order to mitigate the inter-cell interference, we propose a centralized channel allocation scheme considering the uncontrolled neighboring access points. The proposed scheme estimates the channel utilization based on the received beacon signals without any help from clients. The channel allocation problem is formulated by finding maximum weight matching on bipartite graph. The proposed scheme has been implemented and the performance of the proposed scheme has been evaluated by the experiment. Despite the simplicity of the proposed scheme, it shows the best performance within compared schemes.

keywords : **Channel assignment, Allocation, Centralized, Interference mitigation**
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Chapter 1

Introduction

Wireless local area networks (WLANs) based on IEEE 802.11 standard [1] have been widely deployed to provide pervasive Internet access. The large-scale deployments of WLANs by mobile operators and broadband Internet providers have increased the densely deployed WLANs [2]. Wireless hand-held devices supporting 802.11 standard also have come into wide use in our daily lives (i.e., smart phones and tablet PCs). Recently, various Internet of Things (IoT) application demands such as multimedia material distribution in lecture room, video group communication, and wireless video surveillance monitoring have been rapidly growing.

However, in densely deployed WLAN environments, each WLAN can experience severe inter-cell interference from neighboring WLANs, and the interference may result in considerable throughput degradation. To provide satisfactory wireless communication environment for the demanding applications, the inter-cell interference should be more carefully managed from the network setup stage of deciding the operating channel. In this paper, we focus on the channel assignment as an approach to mitigate the interference.

In general, an access point (AP) tries to select a channel with the expected lowest interference or a lightly loaded channel, as its operating channel. In [3], each AP estimates the channel load on the basis of the number of associated users. To find out the most lightly loaded channel which the fewest users are on, the AP collects the beacon broadcasted by each neighboring AP, which contains the number of associated users. In the automatic channel selection scheme (ACS) [4], each AP first surveys the channel to examine how much interference was detected, and then picks the channel with the lowest interference. Additionally, in the channel selection based on the received signal strength indicator (RSSI) which has been widely adopted in many WLAN systems, an AP selects a channel with the lowest RSSI. Although the APs in these schemes select their respective best channels, since the channel selection is performed individually by each AP, the duplicated channel selection among APs may occur as the number of neighboring APs increases. This can result in significant throughput degradation because the same channel may be shared by multiple adjacent APs. Therefore, in selecting the operating channel, the coordination among neighboring APs is needed. The authors in [5] suggested a cooperative channel assignment scheme, which is performed in a distributed manner. This scheme has the limitation that the communication overhead for exchanging the channel information gets higher as the number of neighboring APs increases. Furthermore, since each AP shares the information based on IEEE 802.11k standards [1], this scheme can be applied only to IEEE 802.11k supported WLANs. In [11], each AP shares the information of neighboring APs and its associated users and selects the optimal channel through cooperative communication among them. However, this scheme also has the limitation of the communication overhead as the number of APs increases, and it does not considered of neighboring uncooperative APs which may exist in densely deployed WLAN environment.

In general, in densely deployed WLAN environment, the schemes that a centralized controller (CC) allocate the channels to APs can outperform the self-channel assignment schemes. They are usually applied to the place such as universities, companies, and hot-spot areas of certain service provider, where some adjacent APs can be grouped and managed by a CC. In [6], APs are treated as vertices of a graph, and a single edge of the graph represents potential interference induced by a pair of adjacent interfering APs. The channel allocation problem is then solved by the graph coloring. However, uncontrolled APs in different domain are not considered since the CC should be aware of the whole network topology to construct an accurate graph. The authors in [7] suggested a channel allocation scheme using interference measurement results collected from APs and their associated clients. While the measured interference is useful to monitor the real channel condition, clients may not always be permissive to install a new feature to measure the channels in their devices. The work in [8] allocates the channel that maximizes the utility function which represents the ratio of achievable throughput of an AP by the channel monitoring. However, in [8], due to the burst and random traffic pattern of neighboring APs, the monitoring overhead to estimate the total time that each AP can occupy each channel may be very high.

In this paper, we propose a centralized channel allocation scheme which simply estimates the load of each channel by using the scan results (i.e. active scan or passive scan result [1]) of APs. Since the proposed scheme uses the original functions of

802.11 standard without any help from the clients, it can be applied to any densely deployed WLAN environment without additional consideration. We implement the proposed scheme and evaluate its performance based on the experiment results. Despite the simplicity of the channel load estimation, the proposed scheme outperforms the existing channel allocation schemes in [4], [8] as well as a well-known RSSI-based scheme.

The remainder of this paper is organized as follows. Section II describes the system model and the proposed scheme. In Section III, we present the implementation details and evaluate the performance of the proposed scheme. Finally, the paper is concluded with Section IV

Chapter 2

Centralized Channel Allocation Scheme

A. System Model and Assumption

We consider a WLAN system consisting of multiple APs managed by a CC. Let A denote a set of these managed APs (MAPs) and let C be a set of orthogonal channels that can be allocated to the MAPs. Each MAP a can scan any available channel c and find out a set of neighboring external APs (EAPs) operating on the channel c, $E_{a,c}$ The received beacon signal (or probe response) strength (in mW) from the EAP e is denoted by $b(e,a,c)$. In this paper, we assume that the CC knows all of the above information.

Note that in a large WLAN deployment, we may divide the network into several components (e.g., lecture room, conference room), to reduce the signal attenuation by wall and floor. Our channel allocation scheme can be applied to each component. We call this component a "service area" and will focus on a single service area.

In the Figure 1, as an example, 4 MAPs are installed in the service area, and managed by the CC. 34 EAPs exist around the service area, and operate on 8 orthogonal 20MHz channels in 5GHz band. ($A=\{a_1,a_2,a_3,a_4\}$, $C=\{36,40,44,48,149,153,157,161\}$)

It is assumed that the signal from an MAP reaches anywhere in the service area with enough power so that each MAP chooses the different channel to achieve the higher channel utilization. Thus, we merely consider the number of MAPs which is smaller or equal to the number of available channels (i.e., $|A| \leq |C|$). In addition, since downlink traffic volume is typically even more dominant than uplink traffic volume, we only consider the downlink traffic from EAPs. Lastly, we assume that an MAP can achieve the higher utilization on the channel where the fewer EAPs are operate on.

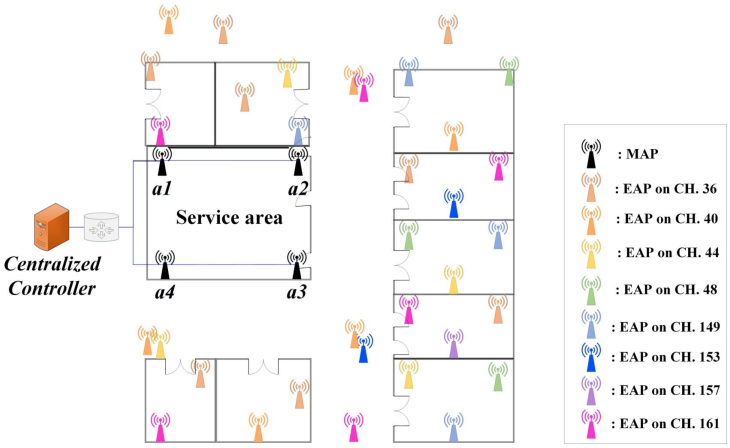

Figure 1. An example of the service area, MAPs and EAPs.

Assumptions and considerations in this paper may not lead to optimal performance in the certain environment. However these can be a reasonable trade-off for feasible implementation, when considering the overhead.

B. Problem formulation and solving technique

Since each MAP uses the different channel for the throughput maximization, channel allocation can be formulated as a problem for finding the maximum weight matching on bipartite graph. To build the graph, A and C are represented to the separate group of vertices. Each vertex a in A is connected to any vertex c in C and the edge from vertex a to vertex c has a weight of $w_{a,c}$. This weight, as a metric, represents an estimated channel utilization when a is allocated to c.

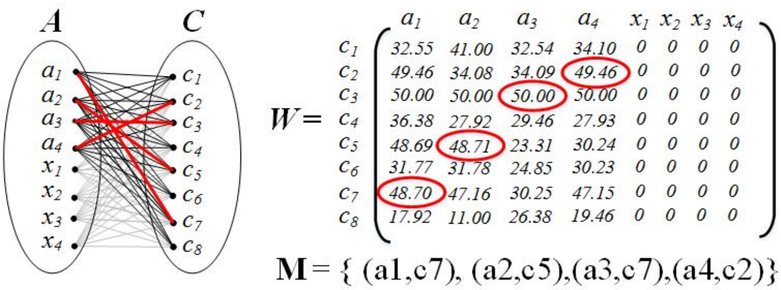

Figure 2. An example of the bipartite graph for the channel assignment and the maximum weight matching result which is denoted by M. The matrix of $w_{a,c}$ and dummy vertices are denoted by W and $\{x_1, x_2, x_3, x_4\}$ respectively.

On this bipartite graph, the channel allocation problem is solved by finding a matching case which maximizes the sum of weights. We use the Hungarian method [7] to solve the maximum weight matching on the bipartite graph. Since the Hungarian method can be applied to a complete bipartite graph, we add dummy vertices and edges of zero weight so that both A and C have the same number of vertices. Figure 2, as an example, shows a complete bipartite graph which has the groups of vertices A and C and the maximum matching as an channel allocation result.

C. Weight Model

Since we formulate the channel allocation problem as maximum weight matching on the bipartite graph, the weight should be modeled. The weight $w_{a,c}$ should be higher if the fewer EAPs share the channel c with the MAP a. To model the weight, we first estimate the number of EAPs using the channel c, which are adjacent to the MAP a.

Let us denote the set of EAPs from which the AP a has detected the RSSI higher than Γ, by $E_{a,c}^{\Gamma}$. When Β is the threshold of the received signal strength (RSS) to detect a busy channel condition (i.e., threshold for clear channel assessment) specified in [1] (e.g., Β = −82 dBm for 20 MHz channel spacing in OFDM PHY), if an EAP in $E_{a,c}^{\mathrm{B}}$ transmits traffic, the AP a regards the channel c as being busy. When the MAP a chooses the channel c as its operating channel, the MAP a should share the channel c with the EAPs in $E_{a,c}^{\mathrm{B}}$. Thus, the number of EAPs in $E_{a,c}^{\mathrm{B}}$ becomes an important factor in modeling $w_{a,c}$.

On the other hand, since the stations detecting the RSSI higher than Β also cannot access the corresponding channel, we also should estimate the number of EAPs giving the RSSI higher than Β to the stations. Note that, in the proposed scheme, only the MAPs scan the channels. Thus, $E_{a,c}^{\mathrm{B}}$ is obtained directly from channel scanning of the MAP a but the EAPs sharing the channel c with the stations are indirectly estimated by using the scan results of MAPs. We consider the worst case that the farthest station s from the MAP a receives the RSSI higher than Ρ (see Figure 3).

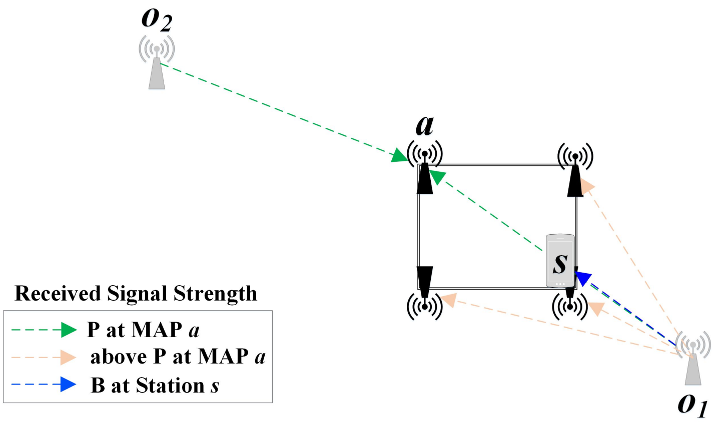

Figure 3. An example of the EAP estimation. o_1 and o_2 are the EAPs out of the service area. s is a station and others are the MAPs. All the devices in this figure operate on the channel c.

Let P be the average RSSI for the same beacon signal that the MAP a is expected to receive, when the station s receives the RSSI of B. It is noted that P depends on several factors such as not only B but also the size and shape of service area and the wireless channel characteristics. In the proposed scheme, a set of the EAPs sharing the channel c with the stations is given as $E^{\mathrm{P}}_{a,c}$ (e.g., P = −88 dBm is used in this paper for the experiment).

On the other hand, as guessed from Figure 3, although the MAP a receives the RSSI higher than P from the EAP o_2, the station s can receive the RSSI lower than B from o_2. This is because the EAPs are determined only by the RSSs from them without knowledge on the position of EAP. If all MAPs in service area receive the RSSI higher than P, it is highly probable that the stations can receive the RSSI higher than B. Thus, to improve accuracy, only when all MAPs receive the same beacon signal with RSSI higher than P, we regard the stations as being affected by the EAP. Let U_c be a set of EAPs which have the possibility to share the channel c with the stations. Then,

$$U_c = \bigcap_{a \in A} E^{\mathrm{P}}_{a,c}.$$

When r^d_a and r^u_a ($\forall a \in A$) denote the average ratio of downlink and uplink traffic volume (i.e., $r^d_a + r^u_a = 1$) for each a) respectively, the number of EAPs sharing the channel c with both MAP a and its associated stations can be expressed by $n_{a,c}$, as follows.

$$n_{a,c} = |E^{\mathrm{B}}_{a,c}| r^d_a + |U_c| r^u_a$$

We can determine the value of $w_{a,c}$ based on $n_{a,c}$ ($\forall a \in A, c \in C$). However, if all the values of $n_{a,c}$ are monotonic, there may be more than one matching result. Therefore, to obtain a single matching result, we add a small value to each $n_{a,c}$ as a second factor, denoted by $\delta_{a,c}$. For the second factor, we consider the strongest interfering EAP with the RSSI lower than B. When the RSSI from this EAP to the MAP a on the channel c is denoted by $\hat{i}_{a,c}$,

$$\hat{i}_{a,c} = \max_{e \in E_{a,c} \setminus E^{\mathrm{B}}_{a,c}} b(e,a,c).$$

Then, the second factor is set as $\delta_{a,c} = \epsilon\ \hat{i}$, where has a small value (e.g., ϵ=0.001). Let $f_{a,c}$ be the sum of the first factor and the second factor, i.e., $f_{a,c} = n_{a,c} + \delta_{a,c}$. The smaller value of $f_{a,c}$ is more preferable in channel selection. However, note that the Hungarian method can be applied to get a maximum matching for all positive weights. Thus, we should set the larger positive $w_{a,c}$ for the smaller $f_{a,c}$. It is noted that any mapping from $f_{a,c}$ to $w_{a,c}$ which satisfies this condition can be used. In this paper, we take a very simple linear mapping to subtract $f_{a,c}$ from its maximum $f_{\max}$.

$$w_{a,c} = f_{\max} - f_{a,c}$$

Chapter 3

Performance Evaluation

In this section, we present the implementation details and the experimental results for evaluating the performance of the proposed scheme. For the comparison, we also conduct the experiment with RSSI-based, ACS [4] and the scheme in [8]. Note that in the RSSI-based selection scheme, each AP selects a channel with the lowest RSSI. In the ACS scheme [4], each AP surveys the channels to examine how much interference was detected, and then picks the channel with the lowest interference. The scheme in [8], the CC allocates the channel that maximizes the utility function which represents the ratio of achievable throughput of an AP. Each scheme spends the same time to monitor or scan a channel (i.e., 108ms). For the [8], the number of iteration R is set to 10^4 (i.e., in [8], R = 104 was suggested for the best performance).

A. Implementation

We have implemented the proposed scheme on two different entities. The specification of these entities and implementation details are as follows.

1) Centralized Controller: We implemented the CC on a laptop PC powered by Intel i7 with 8G RAM. The CC application was written in Java programming language. The application worked as a client which requests the channel scan and the channel change to each MAP, and communicates with each MAP using TCP socket interface.

2) Managed AP: We used OpenWRT [10] framework on TP-Link TL-WDR4300. In each MAP, application was written in lua programming language, and worked as a server which responds the channel scan result and the channel change result.

B. Test-bed Environment

In our indoor test-bed, as shown in Figure 4, 4 MAPs are deployed at each corner in the large lecture room which has 21.3 meter x 15.3 meter dimension. Each MAP can operate on eight orthogonal channels with bandwidth of 20 MHz in 5GHz. A total of 34 EAPs are scanned by all the MAPs. The transmission power of each MAP is 14 dBm. The MAPs and the stations operate in the IEEE 802.11n mode. Each MAP has an associated station (i.e., Samsung SM-P600), which is 5 meters far away from its associated MAP. r_a^d, r_a^u (8a 2 A) are 0.83, 0.17 and the threshold B and P are set to -82 dBm, -88 dBm respectively.

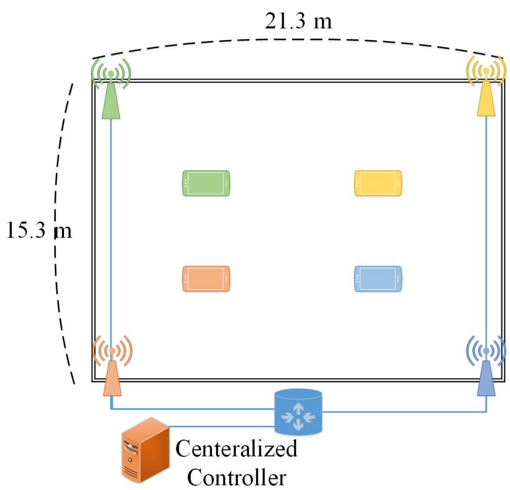

Figure 4. The test-bed environment. 4 MAPs and 4 stations exist in the 21.3 meter x 15.3 meter service area

The experiment measuring the throughput is progressed for 60 seconds for each scheme, and the measurement is repeated 30 times. At the beginning of each measurement, each scheme executes its channel assignment scheme, and reallocates the channels if needed. For the throughput measurement each MAP and its associated station transmit 1,500 bytes UDP packets continuously in the separate intervals.

C. Experiment Result

Figure 5 shows the aggregate system throughput of each scheme, which is the total sum throughput in the service area. In this figure, we can see the proposed scheme outperforms other schemes. The proposed scheme achieves about 65% and 82% higher performance in the average aggregate throughput than ACS and RSSI-based schemes, respectively. Since with the ACS and RSSI-based schemes APs often select the channel used by other APs, the proposed scheme can achieve much higher throughput than these schemes.

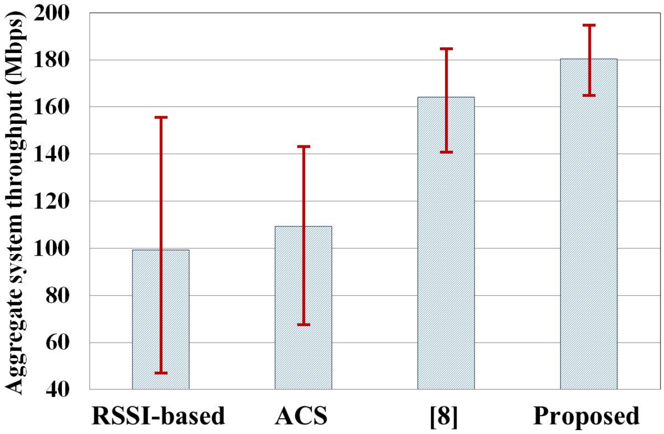

Figure 5. The average, maximum and minimum of aggregate system throughput

The scheme in [8] could not always allocate the low-loaded channel to MAPs, since random and burst traffic generation of neighboring EAP may lead to the wrong traffic estimation. Thus, the proposed scheme tends to allocate the lower-loaded channels than [8]. This results in 10% higher performance. Next, let us investigate the average number of EAPs on the selected channel of each MAP. The fewer EAPs mean the lower interference from these EAPs to the corresponding MAP.

RSSI-based	ACS	[8]	Proposed
3.6	6.6	8.0	3.7

Table 1. The average number of EAPs on the selected channel of each MAP

As shown in Table I, with the proposed scheme, the MAPs have the fewer interfering EAPs on their operating channels. This results in the higher throughput performance of the proposed scheme, as compared with the ACS scheme and the scheme in [8].

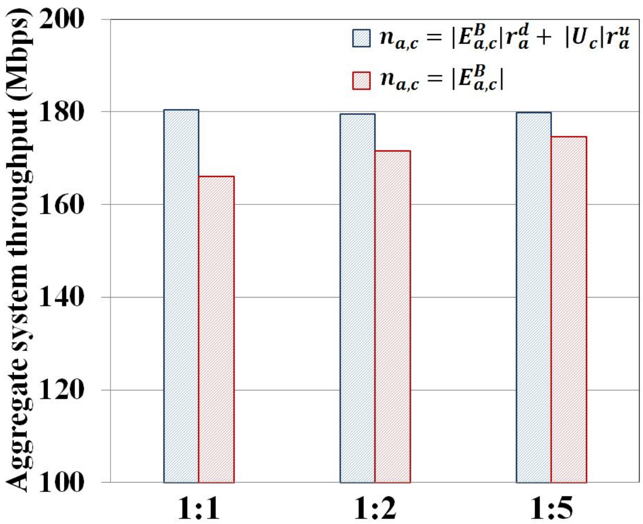

Figure 6. The average aggregate throughput with various ratio of uplink and downlink volume ($r^u_a : r^d_a$).

Finally, in Figure 6, we investigate the influence that the ratio of uplink traffic volume and downlink traffic volume (i.e., $r_a^u : r_a^d$) has on the throughput performance of the proposed scheme. In addition, the effect of the second term in (2), which is taking account of EAPs with possibility to share the channel with the stations, is examined. As shown in Figure 6, when this factor is included, the throughput performance of the proposed scheme is improved, and the effect of the second term is more prominent as the ratio of the uplink traffic volume increases. From this, it can be driven that the channel assessment from the viewpoint of not only the APs but the stations is very effective in selecting a good channel.

Chapter 4

Conclusion

In this paper, we have proposed the centralized channel allocation scheme considering the uncontrolled neighboring APs. Especially, the proposed scheme estimates the channel utilization using received beacon signal without any help from clients. We have formulated the channel allocation problem as graph matching and have designed the weight model based on the number of neighboring APs as the metric for the channel allocation. Experiments conducted on the test-bed shows that the proposed scheme outperform other compared schemes used in this paper. We also have shown the impact of both metrics and weight factors on the experiment results.

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요 약

IEEE 802.11 표준 기반 무선 랜은 사용자들에게 어디서나 이용 가능한 Internet 접속 환경을 제공하기 위해 밀집된 형태로 존재하게 되었다. 밀집된 무선 랜 환경에서는 하나의 무선 랜은 인접 무선 랜들로부터 상당한 간섭을 받을 수 있고, 이로 인해 무선 통신상에 심각한 성능 저하 문제가 발생될 수 있다. 그리고 높은 데이터 전송 용량을 가지는 무선 랜 환경을 제공하기 위해, 인접 무선 랜들로부터의 간섭은 어떤 채널을 사용할지 결정하는 네트워크 설치 단계부터 고려될 필요성이 있다.

그러므로 본 논문에서는 인접 무선 랜으로 부터의 간섭을 경감시키기 위해, 중앙 제어기에 의한 채널 할당 기법을 제안한다. 제안된 기법은 인접 무선 액세스 포인트로부터 수신된 비콘 신호를 바탕으로 클라이언트의 도움 없이 채널 이용률을 추정하고, 채널 할당 문제를 이분 그래프 상에서 최대 가중치의 합을 가지는 최대 매칭을 찾는 문제로 구성한다. 채널 할당에 따른 성능을 비교하기 위해 실험을 통해 네트워크 처리량이 측정 되었으며, 제안된 기법이 비교된 다른 기법들 보다 더 우수한 성능을 보였다.

주요어 : 채널 할당, 중앙 시스템, 간섭

학 번 : 2014-21792