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LETTER

Primary Channel Selection in Dynamic Channel Bonding using Laser Chaos Decision Maker

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Abstract Channel Bonding is a technique used to aggregates multiple wireless communication channels in order to enhance data transfer speeds. Initially introduced in IEEE 802.11n, it has been adapted to the newer IEEE 802.11ax standard, and so on. While this technology enables faster communications, it also suffers from interference issues due to increased bandwidth utilization. Previous studies have extensively focused on bandwidth selection to minimize channel interference, often requiring significant time. This paper proposes an approach that utilized the Laser chaos decision maker to rapidly determine optimal channel channel for dynamic channel bonding. We design our algorithm based on scalable laser chaos decision maker and evaluate its performance through computer simulations. The results demonstrate that proposed method has the capability to make more accurate selections than other algorithms.

Keywords: Channel Bonding, Primary Channel Selection, Multi-armed Bandit(MAB), Laser Chaos, IEEE 802.11ax
Classification: Wireless communication technologies

1. Introduction

In recent years, wireless LAN devices based on the IEEE 802.11 wireless communication standards have become widely popular. The IEEE 802.11ax [1] standard enables high-speed communications up to 9.6 Gb/s. One of the technologies for accelerating communication in the IEEE 802.11ax standard is the channel bonding function, which allows the simultaneous use of multiple adjacent channels. However, by using a wider bandwidth through bundling multiple channels, there is a risk of radio interference with other wireless access points, which could potentially decrease communication throughput. Therefore, the bandwidth used for channel bonding needs to be appropriately set based on the communication status of other access points and devices.

To address this issue, the technique of dynamic channel bonding [2] has been introduced since the IEEE 802.11ac standard. Unlike the static channel bonding, which always attempts to communicate using the full bonded bandwidth and may leave some channels in a waiting state due to communication conditions, the dynamic channel bonding sets a primary channel as the main axis of communication. It dynamically changes the bonding channel width by using only the channels available for transmission if busy states are not detected in corresponding channels.

Appropriate selection of the primary channel is important in wireless LAN using dynamic channel bonding to enhance the performance. Ref. [3] introduced online algorithm for primary channel selection in dynamic channel bonding within wireless LAN. This method consider both the occupancy and the activity levels of potential primary and secondary channels, thereby enhancing the expected wireless LAN throughput. In [4], they proposed a method for rapid optimization of transmission bandwidth selection in dynamic environments for wireless channel bonding, showed that the laser chaos decision maker outperforms other multi-armed bandit algorithms in optimizing channel bonding in 20, 40, 80MHz.

The laser chaos decision maker has been demonstrated to solve the multi-armed bandit (MAB) problem at GHz speeds [5]. The primary goal is to maximize the rewards obtained from multiple options in an environment where the reward probabilities change dynamically. The Scalable laser chaos decision maker has shown capability for ultra-fast decision making even in multi-armed bandit problems with up to 64 options [6].

In this paper, we proposed the ultra-fast primary channel selection method using the scalable laser chaos decision maker. We regard the problem of primary channel selection as a MAB, where each arm represents a primary channel. This study approach leverages the inherent speed and scalability of optical decision-making to outperform traditional methods. We evaluate the effectiveness of our proposed method through simulations tailored to dynamic environments, demonstrating its performance in rapidly changing scenarios.

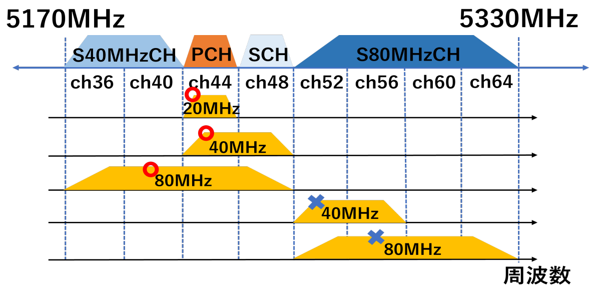

Fig. 1 Dynamic channel bonding in 5.17GHz to 5.25Ghz.

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2. Dynamic channel bonding

Fig. 1 shows Dynamic channel selection in 5.17GHz to 5.33GHz using in IEEE 802.11ax. In dynamic channel bonding, two types of channels are used: "Primary Channel(PCH)" which serves as the main channel for starting communication and transmitting control messages, and the "Secondary Channel(SCH)" which is used in conjunction with the primary channel to provide additional bandwidth for data transfer. As illustrated in the example in Fig. 1, by bonding up to eight channels which is a bandwidth of 20 MHz. it is possible to create a channel with maximum bandwidth of 160 MHz.

Dynamic channel bonding in this study leverages the RTS(request to send)/CTS(claer to send) protocol to ensure channel availability and prevent collisions. By sending an RTS signal and receiving a CTS response, only channels which are able to receive CTS are bonded to the primary channel. This efficient use of channels allows for dynamic bandwidth adjustment even in busy network conditions.

If the primary channel is not selected correctly, significant bandwidth loss can occur when only the secondary channels closest to the primary channel are busy, while other secondary channels remain unoccupied. Also, choosing a channel that becomes busy frequently as the primary channel inevitably includes busy channels in the bonding, which significantly degrades performance of channel bonding. For these reasons, selecting the appropriate primary channel is crucial in wireless communications using channel bonding.

3. Laser Chaos Decision Maker

This section briefly describes the decision-making principle using laser chaos [5]. Laser chaos refers to the chaotic output produced by semiconductor lasers, generated using an optical feedback loop and occurring at ultra-high speed chaotic random signals. And laser chaos decision maker, a decision-making system utilizing laser chaos, is capable of solving multi-armed bandit (MAB) problems at ultra-high speeds, since its decision is made based on the ultra-high frequency laser chaos signals. Fig. 2 shows decision-making principle using laser chaos. It involves comparing the sampled values of the laser chaos time series with a threshold to decide between two slot machines. If the laser chaos time series $s(t)$ exceeds the threshold $TH(t)$, Machine A is selected; conversely, if $s(t)$ is below $TH(t)$, Machine B is chosen. The threshold $TH(t)$ is updated based on whether the selected machine results in a 'hit' or 'miss'. The threshold $TH(t)$ at iteration t is given as follows:

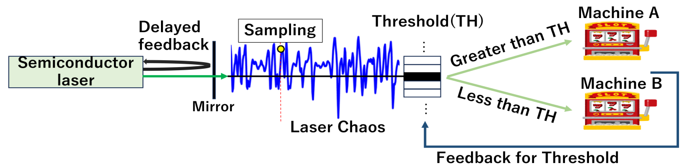

Fig. 2 Laser Chaos based Decision Making.

$$TH(t) = k \times \lfloor TA(t) \rfloor. \quad (1)$$

Here, $\lfloor TA(t) \rfloor$represents the closest integer value rounded to zero of the threshold adjustment function $TA(t)$ at iteration t, and k denotes the step width of the threshold adjustment function $TA(t)$. The values of $\lfloor TA(t) \rfloor$ range from $-N$ to N, where N is a natural number, thus taking values $-N, \cdots, -1, 0, 1, \cdots, N$. Consequently, the range of threshold values is given by $2N + 1$. When $\lfloor TA(t) \rfloor$ exceeds N, the threshold $TH(t)$ is set to kN; if $\lfloor TA(t) \rfloor$ is less than N, then $TH(t)$ is set to $-kN$. In this way, the range of $TH(t)$ is limited from $-kN$ to kN. The reward-based threshold adjustment function $TA(t)$ is defined as follows:

$$\begin{cases} TA(t+1) = -\Delta + \alpha TA(t) & \text{When slot machine A hits} \\ TA(t+1) = +\Delta + \alpha TA(t) & \text{When slot machine B hits} \\ TA(t+1) = +\Omega + \alpha TA(t) & \text{When slot machine A misses} \\ TA(t+1) = -\Omega + \alpha TA(t) & \text{When slot machine B misses.} \end{cases} \quad (2)$$

where, $\alpha (0 \leq \alpha \leq 1)$ is the forgetting parameter used to reduce the influence of past experiences. Δ and Ω represent the rewards obtained from the slot machine for 'hit' and 'miss', respectively. Ω is given by the following equation:

$$\Omega = \frac{P_A(t) + P_B(t)}{2 - (P_A(t) + P_B(t))}. \quad (3)$$

where, P_i represents the estimated probability of reward for slot machine t at iteration i, and is expressed as follows:

$$P_i = \frac{R_i(t)}{N_i(t)}. \quad (4)$$

where, N_i is the number of times slot machine i has been selected up to iteration t, and R_i is the number of times a 'hit' was obtained when slot machine i was chosen up to iteration t. These parameters, referred to as reward parameters, are important in this decision-making mechanism.

4. Proposed Method

This study aims to identify the primary channel that achieves higher throughput in an environment where specific frequency bands are loaded at each time. The selection of this primary channel is conducted by applying the Laser Chaos Decision Maker. The primary channel is determined by the scalable laser chaos decision maker, which we have designed, as illustrated in Fig. 4.

The decision-making system consists of the following three steps: **STEP1**: Decide primary channel based on

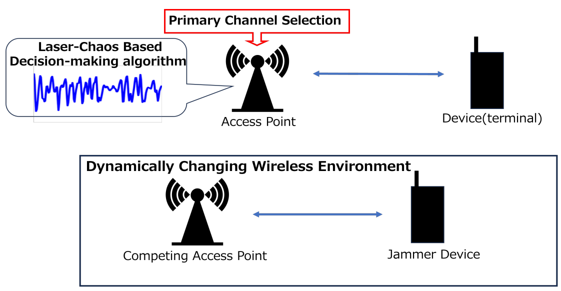

Fig. 3 System model.

thresholds. **STEP2**: Measure the throughput of the channel based on the selected primary channel. **STEP3**: Update the thresholds.

STEP1:Decide primary channel based on thresholds
The selection of the primary channel is determined bit by bit as illustrated in Fig. 4, starting from the most significant bit (MSB) to the least significant. Initially, at $t = t_1$, the chaos signal $s(t_1)$ is compared with the threshold TH_1. The MSB is determined based on the comparison of the sampling value with the threshold, Here, assuming that $s(t_1) > TH_1$, the MSB is set to 0. Otherwise it is set to 1. Based on this decision of the MSB, the process moves to the next bit. the chaotic signal $s(t_2)$, measured at $t = t_2$, is compared with the threshold $TH_(2,0)$ if the MSB is set to 0. If $s(t_2) > TH_2$, the next bit(2nd MSB) is also set to 0. Otherwise it is set to 1. If the MSB was 1, a different threshold $TH_(2,1)$ is applied. Applying this comparison between the threshold and the sample chaotic signal to all bits, we determined the primary channel.

STEP2: Measure the throughput of the channel based on the selected primary channel
Based on the selected primary channel, we form a channel using the method described in Section 2, and measure its throughput.

STEP3: Update the thresholds
We update the threshold using the Eq. (5).

$$\begin{cases} TA(t+1) = \alpha TA_1(t) \pm \Delta & \text{if } \Lambda_t > \frac{1}{\tau}\sum_{i=t-\tau}^{t-1}\Lambda_i \\ TA(t+1) = \alpha TA_1(t) \mp \Omega & otherwise. \end{cases} \tag{5}$$

If the selected primary channel exceeds the average throughput, the selections is determined ”correct” and thresholds will be adjusted so that it is likely to be selected again in the next time. For instance, if the MSB of the chosen machine is 0, increasing the threshold TH1 makes it more likely to obtain a decision where the MSB is 0 again. When a player wins, the threshold is adjusted by a parameter Δ, and when losing, it is adjusted by a parameter Ω, which is determined based on Eq. (3). Recognizing the need to adapt to dynamically changing environments, forgetting parameters α are introduced for all threshold levels.

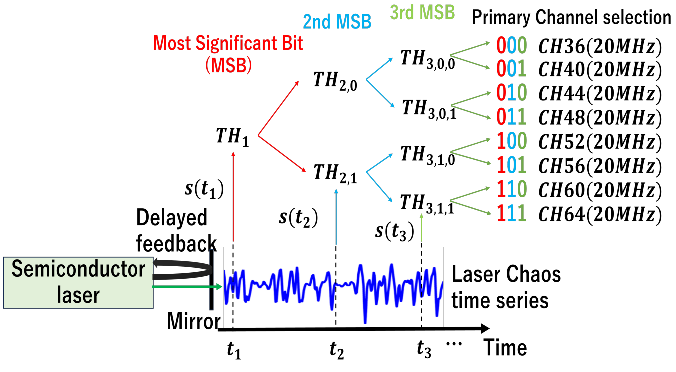

Fig. 4 Primary channel selection using Laser Chaos Decision Maker.

5. Result

We assume that proposed method will be implemented in an access point. One access point featuring the proposed method and three closely placed jammer access points (jammerAPs) are used. External traffic is sent to the jammerAPs from jammer stations(jammerSTAs) to create interference on specific channels: CH36-CH64. Channels under load from jammerSTAs are treated as busy channels in this simulation. Therefore, it is optimal for the access point with the proposed method to select a primary channel that maximizes the bonding width avoiding the channels loaded by jammers. We run simulations on the EXata 8.1.1 network simulator.

Firstly, there is only one channel loaded in each iterations. the values Δ is set to 1. Ω is defined by Eq. (3). The forgetting rate α is set at 0.9, threshold range k is set to 32, threshold stages were is at 4, and τ is set to 50. The channels loaded in each iteration and simulation result are described in **??**.

Table I Loaded channel in each iteration and estimated optimal primary channels.

iteration	Loaded channel	Optimal channel
1-200	CH36	PCH52,56,60,64
201-400	CH52	PCH36,40,44,48
401-600	CH40	PCH52,56,60,64
601-800	CH56	PCH36,40,44,48
801-1000	CH44	PCH52,56,60,64
1001-1200	CH60	PCH36,40,44,48
1201-1400	CH48	PCH52,56,60,64
1401-1600	CH64	PCH36,40,44,48

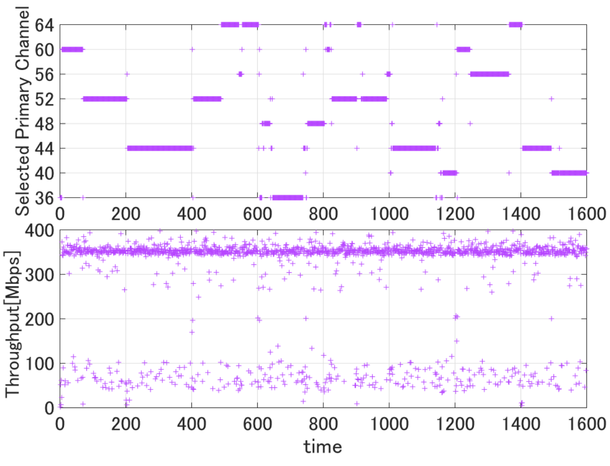

Fig. 5 Selected primary channels and throughput.

Fig. 5 shows the primary channel selected and the throughput at that time where an external load is applied to one channel by JammerAPs in each iteration. As shown in fig. 5, immediately after switching the loaded channel, there are some incorrect choices; however, the access point with the proposed method is able to select appropriate primary channels as demonstrated in Fig. 5. The proposed method can achieve a high average throughput almost of all the time.

Secondly, we add traffic loads to three channels with dynamic changes. The channels loaded in each iteration is shown in 5. and simulation result are demonstrated in Fig. 6.

Table II Loaded channels in each iteration and estimated optimal primary channels.

iteration	Loaded channel	Optimal channel
1-200	CH44,52,60	PCH36,40
201-400	CH36,52,60	PCH44,48
401-600	CH36,44,60	PCH52,56
601-800	CH36,44,52	PCH60,64

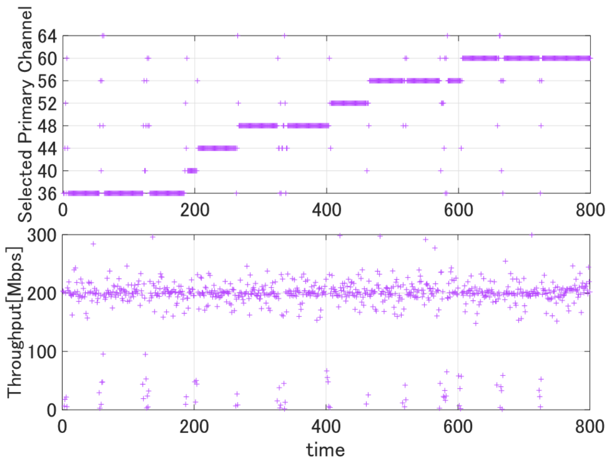

Fig. 6 Selected primary channels and throughput.

Fig. 6 shows result in the case where the external load on each time point is greater than previous simulation. As shown in fig. 6, immediately after switching the loaded channel, there are some incorrect choices; however, the access point with the proposed method can select from the group of optimal primary channels displayed in Fig. 5. at almost time, and achieved a high average throughput same as previous simulations.

Finally, we compare the proposed method with e-greedy, UCB1-tuned [7], and the general example fixing on PCH36.

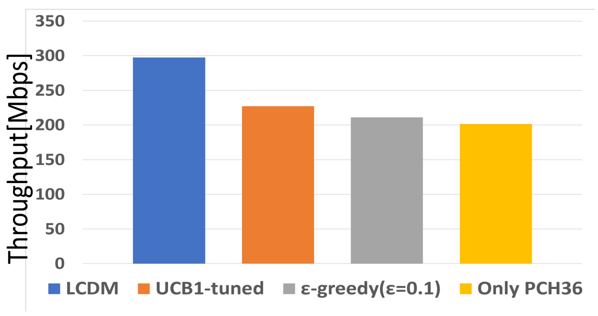

Fig. 7 Average throughput in each algorithm.

Fig. 7 demonstrates that the proposed method has superior average throughput compared to other methods and adaptive primary channel selections to get high throughput.

6. Conclusion

This paper proposes a method for selecting primary channels for dynamic channel bonding using decision-making with laser chaos. This method was evaluated using simulations in an IEEE 802.11ax network. As a result, it was demonstrated that the proposed method makes more autonomous and appropriate decisions compared to conventional algorithms ϵ-greedy, UCB1-tuned. Our future works includes the implementation of the proposed system. In [4], we have already implemented the static channel bonding using the laser chaos decision maker on IEEE802.11ac wireless LAN access point. However, it was using sampled laser chaos time series, and did not operate in the GHz order. On the other hand, threshold circuitry for the laser chaos time series has already been proposed in [8], it will be our future goal to implement the wireless channel decision maker, which runs in realtime.

Acknowledgments

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