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Abstract of Thesis

Name (劉 錦 (Jin Liu))	
Title	A Study on Spatial Spectrum Reuse Methods by Dynamic Sensitivity Control in Dense WLANs (密な無線LANにおける動的感度制御による空間スペクトル再利用法に関する研究)

Abstract of Thesis

Recently, an increasing number of wireless local area network (WLAN) access points (APs) are deployed to serve an ever-increasing number of mobile stations (STAs). Due to the limited channels, more and more AP and STA nodes try to access the same channel. Dynamic sensitivity control (DSC) is proposed by the IEEE 802.11ax task group to coordinate cochannel operation. Under the DSC mechanism, prospective transmitting nodes (PTNs) are permitted cochannel operation when the received signal power at the PTN is lower than an adjusted carrier sensing threshold (CST). On the one hand, if the CST is adjusted to a high level, more PTNs will deem the channel available and start cochannel simultaneous transmissions. More transmissions are good for total throughput. On the other hand, more cochannel simultaneous transmissions will induce more frame losses, which decrease the total throughput. Therefore, the main objective of DSC is to appropriately adjust the CST in order to achieve the best total throughput.

This work proposes three DSC methods for adjusting the CST. They are based on frame loss avoidance and node grouping, deep belief network (DBN), and long short-term memory (LSTM). Furthermore, this work implements simulations under all six standard scenarios proposed by IEEE 802.11ax task group.

First, the node grouping based TO-DSC algorithm is proposed. In the conventional DSC algorithm, only the CST of STA is adjusted. Moreover, the CST calculation method only considers the received signal strength indication (RSSI) arriving from the associated AP. In the proposed TO-DSC algorithm, the CSTs of both AP and STA are considered. Moreover, to protect a surrounding ongoing transmission, the CST is calculated according to the status of the ongoing transmission. This is because, when the ongoing transmission cannot be disturbed easily, the PTN will start the simultaneous transmission. Thus, more successful simultaneous transmissions and higher total throughput can be achieved. It is shown that, when the TO-DSC algorithm is implemented under the six standard static scenarios, the throughput gains of the TO-DSC algorithm are higher than those of the conventional DSC algorithm by 12.4%, 24.1%, 71.6%, 17.7%, 31.7%, and 63.5%, respectively. On the other hand, the fairness gains of the TO-DSC algorithm are higher than those of the conventional DSC algorithm by 13.4%, 18.3%, 35.7%, 14.1%, 22.3%, and 10.1%, respectively.

Second, a deep learning based DBN-DSC algorithm is proposed. Under the conventional carrier sense multiple access with collision avoidance (CSMA/CA), the hidden node problem and the exposed node problem [1] are the two classical problems that deteriorate the total WLAN throughput. The DBN-DSC algorithm aims to solve these two problems by using the DBN. This is because the DBN can help the PTN learn that, when some surrounding nodes are transmitting, the prospective transmission will be unsuccessful, whereas, when some other surrounding nodes are transmitting, the prospective transmission will be successful. Thus, it is important for the PTN to predict whether the prospective transmission will be successful and to decide whether to start transmission. The CST is then adjusted accordingly. It is found that, when the DBN-DSC algorithm is implemented under the six static standard scenarios, the throughput gains of the DBN-DSC algorithm are higher than those of the conventional DSC algorithm by 22.8%, 14.3%, 86.5%, 45.9%, 35.1%, and 23.8%, respectively. On the other hand, the

fairness gains of the DBN-DSC algorithm are higher than those of the conventional DSC algorithm by 15.1%, 41.7%, 34.8%, 23.2%, 54.3%, and 2.5%, respectively.

Third, another deep learning based LSTM-DSC algorithm is proposed. In dynamic scenarios, all STAs can move continuously, and the deployment of the WLAN can change. With the changing environment, the conditions that determine whether the PTN starts transmitting are also changing. Due to the movement of all nodes, the RSSIs received at a PTN from the surrounding nodes are in the form of a number sequence. Since the LSTM is used for processing number sequences, it can be used to predict the prospective RSSIs arriving from the surrounding nodes. Because the RSSI from a surrounding node determines whether or not the PTN should start transmission, the LSTM-DSC algorithm aims to predict whether the prospective RSSI is feasible for transmission. Accordingly, the PTN can decide whether to start transmission and adjust its CST. It is shown that, when the LSTM-DSC algorithm is implemented under three dynamic scenarios, the throughput gains of the LSTM-DSC algorithm are higher than those of the conventional DSC algorithm by 21.3%, 10.6%, and 71.5%, respectively. On the other hand, the fairness gains of the LSTM-DSC algorithm are higher than those of the conventional DSC algorithm by -33.5%, -23.7%, and 95.8%, respectively.

In summary, this work proposes three DSC algorithms for CST adaptation at each PTN: the TO-DSC algorithm, the DBN-DSC algorithm, and the LSTM-DSC algorithm. A high CST may induce more simultaneous transmissions but also more frame losses, whereas a low CST may induce fewer simultaneous transmissions but also fewer frame losses. Therefore, when enhancing spatial spectrum reuse, it is essential to adjust the CST appropriately. The TO-DSC algorithm mainly focuses on collision avoidance and calculates the CST using the information in the frames arriving from the local basic service set (BSS). The DBN-DSC algorithm focuses on predicting whether the prospective transmission will succeed and helps the PTN decide whether to start transmission. The LSTM-DSC algorithm focuses on dynamic scenarios, which are more practical. These three DSC algorithms have distinct characteristics and are, thus, suitable to different scenarios. The simulation results demonstrate the following:

1. The TO-DSC algorithm is suitable to the more dense scenarios such as the enterprise office scenario, and the stadium scenario, when the scenarios are static.
2. The DBN-DSC algorithm is suitable to the less dense static scenarios such as residential building scenario, indoor small BSS scenario, the outdoor large BSS scenario, and the outdoor large BSS + residential scenario, when the scenarios are static.
3. The LSTM-DSC algorithm is suitable to the scenarios such as the indoor small BSS scenario, the outdoor large BSS scenario, and the outdoor large BSS + residential scenario, when the scenarios are dynamic.

様式７

論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

本論文は、無線LAN環境での多重アクセスを効率化する空間スペクトル再利用法に関する研究の成果をまとめたものであり、以下の主要な結果を得ている。

1. **ノードグルーピングに基づく動的感度制御手法の提案**

従来からの動的感度制御では、アクセスポイントから受信した受信信号強度のみを用いて、移動端末のキャリア検出閾値を設定する手法が一般的であった。本研究では、アクセスポイントと移動端末双方のキャリア検出閾値を設定する手法を提案している。同時送信を可能として無線システム全体での通信容量を向上させるため、ノードグルーピングを行い、適切なグループの通信中のフレームに関する情報も加味するものである。無線LANの国際標準で用いられる6種の静的シナリオで評価した結果、従来手法より高い12.4%～63.5%の性能向上を達成している。

2. **深層学習を用いた動的感度制御手法の提案**

一般的な無線LANにおける搬送波感知多重アクセス／衝突回避方式では、隠れ端末問題やさらし端末問題が性能律速に繋がる問題となっていた。本研究では、深層信念ネットワークを用いて、送信端末が近隣端末の通信状態を学習することにより、衝突が発生せず送信が成功するか否かを予測する手法を提案している。本方式により、前述の6種の静的シナリオで評価した結果、従来手法より高い14.3%～86.5%の性能向上を達成している。

3. **回帰型ニューラルネットワークを用いた動的シナリオ向け動的感度制御手法の提案**

実際の無線LAN環境において、通信端末が移動することは頻繁に発生し得る事象である。このような状況下では、各通信の受信信号強度もまた変化することになり、動的感度制御はより困難となる。本研究では、長・短期記憶に基づく回帰型ニューラルネットワークを用いて各通信の受信信号強度を予測することにより、動的シナリオにおける動的感度制御の高精度化を図っている。本方式により、無線LANの国際標準で用いられる3種の動的シナリオで評価した結果、従来手法より高い10.6%～95.8%%の性能向上を達成している。

以上のように、本研究による動的感度制御による空間スペクトル再利用法に関する一連の研究成果は、近年頻繁に用いられているマルチユーザMIMO無線LAN環境において、無線システム全体の性能向上を達成する有用なものである。また、無線LAN環境は今後も多重アクセス化および大容量化が進展していくと予想され、本研究成果が今後さまざまな環境下で活用されることも期待できる。従って、博士（情報科学）の学位論文として価値あるものと認める。