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学位論文題目	A Study on Traffic-demand-aware Collision-free Channel Assignment for Multi-radio Multi-channel Wireless Mesh Networks
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論文内容の要旨

Wireless mesh network (WMN) is a communication network made up with radio nodes organized in a mesh topology. It is emerging as a promising technology for low-cost ubiquitous broadband Internet access with reduced dependency on the wired infrastructure.

Collision due to radio interference is a main cause of performance degradation in WMNs, and it should be avoided in practice. With the development of advanced radio technologies, multi-radio multi-channel (MRMC) technology can greatly reduce the collision and enhance network performance in WMNs. In the architecture of MRMC WMNs, each router is equipped with multiple radios, and each radio can be operated on one of the several distinct channels. Compared with single-radio and single-channel case, MRMC settings significantly increase network capacity, provide flexible connectivity, and reduce interference among neighboring links. IEEE 802.11 standard is currently the most commonly used radio protocol for MRMC WMNs, and a MRMC WMN based on the IEEE 802.11 2.4 GHz standards can utilize 13 distinct channels, but these channels are partially overlapping channels (POCs) rather than completely orthogonal, and only three channels out of them can be chosen as orthogonal channels (OCs). Therefore, to assign each radio on each node with an appropriate channel to maximize network performance is a great challenge. At present, there are tremendous amount of studies on channel assignment (CA) in MRMC WMNs, and routing configuration combined with channel assignment potentially reduces collisions, and it also contributes to the total network load balancing and controls. However, in the current state of the art, there is no joint channel assignment and routing scheme that achieves collision-freedom with 3-5 channels. Although Yoshihiro et al. proposed the first collision-free static channel assignment CASCA (CSMA-Aware Static Channel Assignment) for MCMR WMNs within 3-5 OCs, CASCA does not treat full-routing function so that it lacks flexibility in terms of traffic engineering, meaning that it can not cope with variation of traffic patterns, and it easily leads overload of some links under variation of input traffic demands. On other hand, POCs have not been applied to joint channel assignment and routing scheme completely, and the potential of the combination of channel assignment and routing under POC in MRMC WMNs has not been sufficiently explored.

Aiming at solving the problem stated above and improving network performance, in this thesis, joint channel assignment and routing to achieve collision-freedom is explored in MRMC WMNs. By incorporating a CSMA-aware interference model and a CSMA-shared capacity model, we formulate this problem as a MILP (Mixed Integer Linear Program), and achieve collision-free transmission under both the limited OCs and POCs in IEEE 802.11-based MRMC WMNs while considering traffic engineering. The main contributions of this thesis can be summarized in the following:

First, CASCA, which introduced CSMA-aware interference model, is analyzed in detail, and in-depth evaluation and simulation is conducted. Because the evaluation of CASCA is not enough (only optimization evaluation is done completely), whether it has good network performance or not is not clarified sufficiently. Therefore, we evaluate the performance of CASCA in both grid topology and random topology. The simulation results showed that CASCA outperforms the conventional channel assignment method CLICA (Connected Low Interference Channel Assignment), and revealed several specific properties of CASCA. However, we also see that collision-freedom does not always lead to optimal in throughput because of the trade-off between collisions reduction and capacity occupation due to longer forwarding paths.

Second, by incorporating the CSMA-aware interference model introduced in CASCA, we proposed TACCA (Traffic-demand-Aware Collision-free Channel Assignment), which is a new joint channel assignment and routing scheme that achieves collision-freedom with 3-5 orthogonal channels, which also minimizes the network-wide utility under a given traffic demand matrix. Different from CASCA, we formulated the optimization problem as MILP to introduce a traffic engineering function under the CSMA-aware link capacity sharing model, which enables capacity management in MRMC WMNs under traffic demand. Through evaluation with the MATLAB MILP solver, we confirmed that TACCA achieves collision-freedom with three channels in both grid and random topology scenarios, and has good traffic engineering performance. Results of traffic simulations show that the schedule computed by TACCA works without major collision under the up-to-date simulation models, and TACCA clearly outperforms the conventional schemes in them.

Third, by exploiting all the channels defined in IEEE 802.11 2.4 GHz band channels, we designed a new joint channel assignment and routing scheme using POC interference models. The proposed scheme called TAC-POCA (Traffic-Demand-Aware Collision-free Partially Overlapping Channel Assignment) significantly improved the spacial reuse of radios, and achieved collision-freedom in combination with the CSMA-aware interference model and the shared link capacity model extended for POCs. Although TACCA has already achieved a collision-free channel assignment and routing using OCs, TAC-POCA significantly improved the spacial reuse of radios and network capacity by applying POCs. We conducted two folds of evaluations, i.e., optimization and simulation evaluations. Through evaluation with the CPLEX MILP solver, we confirmed and showed that POCs improves the spacial reuse significantly in the context of joint channel assignment and routing. Especially, we found that the variation of distance in random layout exploits the ability of POCs. Furthermore, we confirmed that TAC-POCA keeps very low collision even in network simulation with SINR-based interference model, and the proposed CSMA-aware interference model with POCs actually work in networks.

In summary, we deeply study on jointing channel assignment and routing schemes in IEEE 802.11-based MRMC WMNs, and formulate this joint problem as a MILP with a few integer variables. Then, we proposed two traffic-demand-aware collision-free channel assignment schemes (i.e., TACCA and TAC-POCA) for MRMC WMNs. Without modifying IEEE 802.11 protocol, both schemes achieve collision-freedom under the OCs and POCs, respectively, and significantly improve the overall channel reuse and efficiently improve the network capacity.

論文審査の結果の要旨

本論文は、既存の CASCA（CSMA-Aware Static Channel Assignment、CSMA を考慮した静的チャネル割り当て方式）の詳細な評価として、シミュレーション評価を行い、CASCA の性能を明らかにした。さらに、CASCA の発展として、通信要求を考慮したチャンネル割り当て手法（TACCA）の提案および部分的な周波数の重なりを許すことにより高い空間利用率を実現する手法（TAC-POCA）を提案した。これらの手法は混合整数線形計画問題により定式化され、最適化によりチャンネル割り当てを決める。CPLEX ソルバによる最適化の程度の評価と、シミュレーションによる通信性能の評価を行い、これらの提案手法の有効性を示した。提案手法は、従来の方法に比べて高効率であり、高い新規性および有用性を有している。

本論文の学術的価値は高く、博士（工学）論文として、評価できる。

最終試験の結果の要旨

8 月 19 日に公聴会を実施し、論文、口頭発表および質疑応答を最終試験として評価した。最終試験では、主に、以下の事項について質疑がなされ、いずれについても明確な回答を得ることができた。

（1） 5 GHz 帯への拡張について

（2） コリジョンフリーの定義について

（3） チャンネル割当の変更時間、タイミングについて

以上のことから、3 名の審査委員が合議した結果、田 イ 氏は、大学院博士後期課程修了者として、博士（工学）の学位を授与するに十分であると判断した。