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学位論文題目 Framework Design and Job Scheduling for Vehicular Cloud  
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Summary (Abstract) of doctoral thesis contents

Vehicles nowadays are not just tools transporting people from one place to another. Drivers or passengers usually demand more features to be provided on the road, like driving assistance, multimedia services, etc. Many new applications, for example, heads-up display (HUD), field of view enhancing, road sensing and speech recognition are being proposed to provide a better travel experience for passengers or driver. As the development of the smart vehicle prevails, increasingly more applications will appear. The inherent problem is how to meet this ever-increasing computational demand in vehicles. Usually, more features mean more hardware to be installed, along with higher cost. However, the newly emerged cloud computing has shown another option instead of every user paying for more hardware that only serves a quite limited time, resources are aggregated, virtualized and provided as pay-as-you-go services. Cloud computing has been quite successful on the Internet.

However, traditional centralized cloud computing suffers from the long latency and unstable connections in vehicular environments. This greatly degrades the quality of the experience. For example, AR can provide helpful information and warnings in a heads-up display (HUD) for vehicles or provide a better field of view. AR requires high computation, which is typically beyond the computational capability of a single vehicle, and cloud services can provide efficient computational capability. However, AR also requires swift processing; hence, directly using traditional cloud services on the road is unrealistic due to the high latency. Other examples for computationally intensive applications in vehicular environments are like speech recognition and natural language understanding, which will be more widely utilized in applications for assisting drivers and passengers.

Edge computing, whose idea is pushing the frontier of computing services away from centralized nodes to the logical extremes of a network, like access points, base stations or even the end users, is a more suitable solution for enhancing the computational capability in vehicular environments. Although offloading the computational tasks to a remote cloud results in a long delay, accessing nearby nodes in an ad hoc manner is more feasible. The communication between vehicles can rely on dedicated short-range communications (DSRC) or device-to-device communication, for which communication quality has been greatly improved with recent continuous developments. Also, unlike the situation with resource sharing on mobile devices like laptops and smartphones, the energy consumption is a trivial problem on vehicles, making helping others essentially free. Vehicle users have enough incentive to join in such a framework. Therefore, a low latency edge cloud environment to support these applications becomes possible by efficiently managing the vehicles' resources.

How to efficiently utilize the vehicles' resources in the highly dynamic

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vehicular environment and how to provide a universal framework to all applications is non-trivial and has not been formally studied to the best of the authors' knowledge. Existing researches assume deployed infrastructures or relative static scenarios such as parking slots, which are not applicable in current road environment. To fill this gap, at first, we proposed an Autonomous Vehicle Edge (AVE) framework to allow vehicles pool their computation resources and help each other in processing. Different from the existing solutions, this framework does not rely on deployed infrastructures, which are not available everywhere at the moment, but utilizes the new DSRC standard and a decentralized algorithm to distribute computation tasks. It can be the fundamental of a more generic and scalable vehicular cloud computing framework.

In the framework, the software system is divided into 3 main components: application, backend, and manager. Application is the client side software interacting with end users, providing direct services to them. And backend is the software processing the tasks from corresponding applications. Then we introduce a middleware software to organize the applications and backends, and schedule jobs to achieve a larger amount of jobs finished in unit time. Realizing grouping up jobs and assigning them together might help increase the number of finished jobs and provide higher user satisfaction for high priority jobs, we propose a mechanism to cache multiple jobs for optimal assignment and an algorithm to solve the assignment problem. The framework also takes the predictable movement pattern in vehicular environment into account.

Beaconing is introduced to reduce neighbor discovery overhead, and a new Ant Colony Optimization (ACO) based algorithm is designed. The algorithm takes an idea from the behavior of ants searching the paths to food. In order to map the optimization problem to the path-finding problem, we convert the operation of constructing a solution to a series of consecutive transitions. Each transition is then evaluated by its part of the contribution to the final objective function. Preliminary evaluation shows the superiority of the algorithm comparing to brute force searching and random assignment.

Evaluation environment is built with Omnet++ network simulator, Simulation of Urban MObility (SUMO) traffic simulator and Veins simulation framework. Then realistic traffic scenario, Luxembourg SUMO Traffic scenario (LuST), with 24 hours traffic from real-world traffic demand data, in the Luxembourg City, Luxembourg is used. The evaluation is done on both the urban part and highway part of this scenario, each with a 15 minutes time span. Results from repeated experiment indicate the proposed framework outperforms competing schemes in both environments and achieving more than 90% optimal assigning solutions.

Then, we consider the scenario with already deployed infrastructures, like roadside units and cellular base stations. Hence the new framework, Hybrid Vehicular Cloud (HVC) is designed. HVC aims at the utilization of edge resources, like roadside

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units and idle neighbor vehicles, as augmentation of the remote cloud to provide computational services. With DSRC connections to roadside units and other vehicles, HVC also reduces communication costs in offloading with the cellular network. With more resources available in such environment, we assume hard deadlines on jobs instead of a flexible utility function, to limit the processing time of jobs and provide lower latency to users. To better adapt to the dynamics on road, we use the “available time” concept to model the connection status change with movements of vehicles. It is calculated based on vehicles' routes, speeds, and directions. Also, a handshaking procedure is introduced to eliminate offloading failure due to volatile connections in the vehicular network. Beacon message is also modified to include more information, eliminating the necessity and overhead from discovery phase in AVE. An online assignment algorithm is proposed to assign jobs in a heuristic way that as many as possible jobs are guaranteed to be finished in time, while still leaving time slots for jobs arriving in future.

Simulation is done with the aforementioned LuST scenario. Two roadside units are set in the traffic map and an ideal assumption on the cellular network is made. It is found that the new proposal achieves 100% job finishing ratio in almost all settings while reducing more than 50% cellular traffics in most cases. For reference, we also do extensive simulations with assumed millimeter wave communication technology. The result shows that there is great potential in such high bandwidth connections.

As a conclusion to our work, we listed our contributions at the end of the thesis, that is, two generalized vehicular cloud computing frameworks proposed for different scenarios, along with the algorithms to solve the scheduling problems in them.

Apart from it, some extensive topics are also discussed in the final chapter. We first explain the network issues, including small-scale fading and network congestions, that are not well simulated in our evaluations due to computational restrictions. The issues in the real world may reduce the efficiency of our proposals, but analysis suggests the loss is limited. We also propose extensions to the frameworks and alternative application scenarios, such as different scheduling problems and centralized control. While they are not our research focus, they may help research and development of future vehicular cloud computing. Finally, we also make some anticipations on the future development in this field.

Summary of the results of the doctoral thesis screening

本博士論文は「Framework Design and Job Scheduling for Vehicular Cloud Computing (車載モバイルクラウドコンピューティングのためのフレームワークとジョブスケジューリング)」と題し、車載環境において、モバイルエッジ・クラウドコンピューティングによるタスクのオフロードを実現するための研究内容をまとめたものである。

モバイルデバイスで移動しながらタスクオフロードを実現するモバイルクラウドコンピューティングや、タスクのオフロード先をクラウドにのみならず、利用者に近い場所に置くサーバや基地局などを利用するモバイルエッジコンピューティングに関する研究が行われている。一方、車載環境では、車の高速移動によって無線接続が不安定になる反面、同方向走行の車両間では相対速度が比較的小さくなるため、近隣車間でもタスクのオフロードが可能と考えられる。本研究では、車載環境においてタスク(ジョブともいう)のオフロードを実現するためのフレームワークとオフロード先を最適に選択するためのスケジューリングの課題を解決することが目的である。

論文は4つの章から構成され、第1章の研究背景と動機に続いて、第2章では、近隣車の計算資源を利用できるようにする自律的車載エッジコンピューティング、第3章では、車載エッジ・クラウドハイブリッド型コンピューティングのための実現方法と制御アルゴリズムに関する研究内容について述べている。

第2章では、まず、車載環境におけるタスクオフロードを実現するためのソフトウェアアーキテクチャについて述べ、オフロードの対象となるジョブと、利用できる近隣資源の概念を定量化した。次に、タスクオフロードの手順として、ビーコンによる近隣情報取得や、利用可能資源の発見、およびジョブの発生から実行終了までの一連の手順を、DSRC (Dedicated Short Range Communications) による車々間通信を利用して実現する方法を示した。さらに最適なオフロード先を自律的に見つけるためのスケジューリング問題を2-stageハイブリッドフローショップの最適化問題として数式化し、それを近似的に解くためのアルゴリズムとして、蟻コロニー最適化による解決方法を提案し、計算量の削減に成功した。最後に、実際の路上トラフィックを利用したシミュレーションで提案システムとアルゴリズムを評価し、タスクオフロードによる利得を確認した。

第3章では、前章の近隣車間でのタスクオフロードに加え、路側機やクラウドにも必要に応じてオフロードし、異種無線通信環境におけるハイブリッド型エッジ・クラウドコンピューティングの実現方法について述べている。問題設定として、DSRCに加え、有料のセルラー通信やクラウド環境も利用できる場合にコストを抑えながら、各々のジョブの期限までに実行を終了することを目標にオフロードの最適選択を行うとしている。また、そのためのオフロード手順を定義し、オンラインスケジューリングアルゴリズムを提案した。提案したアルゴリズムに対し、実トラフィックによるシミュレーション評価を行い、その有効性を示した。さらに、ジョブサイズが大きい場合にも対応できるように、近い将来に実現されるミリ波通信も車々間通信に利用できるとして、それによるオフロード性能の向上を評価した。

最後に、第4章では本論文の考察と結論についてまとめ、今後の展望と研究課題を提示した。

なお、研究成果として、出願者は主著で IEEE Transactions on Vehicular Technology 論文1篇、査読付き国際会議論文2篇の発表を行っている。

以上を要するに、本論文は車載環境におけるタスクオフロードに関する課題について、モバイルエッジ・クラウドコンピューティングの枠組みでの実現方法を提案し、その有効性を示したものである。近い将来の情報化社会における多種多様なアプリケーションの要求に対応するための重要な技術として、走行しながらさまざまな情報処理を行う車載環境の実現に貢献することが期待される。よって、本論文は博士の学位請求論文として合格と認められる。