様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

平成　３０　年　　６　月　１８　日現在

機関番号：　３２６８９
研究種目：　若手研究(B)
研究期間：　2016～2017
課題番号：　１６Ｋ１８１０９

研究課題名（和文）Oligopoly Mobile Data Offloading Market Analysis and Intelligent Network Selection System

研究課題名（英文）Oligopoly Mobile Data Offloading Market Analysis and Intelligent Network Selection System

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交付決定額（研究期間全体）：（直接経費）　　1,900,000円

研究成果の概要（和文）：セルラネットワークの容量が足りない問題を解決する為に、本研究はモバイルデータオフロードという手法を提案しました。まず、ネットワーク側の観点から、複数モバイルネットワーク事業者のモバイルデータオフロードの問題を考察した。次に、モバイルユーザの視点からWi-Fiオフロード問題を検討した。ユーザの移動パターンが事前にわかっていると仮定し、ユーザのコストを最小化するために、ユーザのオフロード戦略を明らかにした。そして、ユーザユーザの移動パターンは未知であると仮定する。ユーザのオフロード戦略を深い強化学習に基づく方法で解明した。

研究成果の概要（英文）：Cellular network capacity cannot catch up with the pace of mobile traffic increase. Mobile data offloading is utilized to solve this capacity shortage problem because it enables inexpensive and fast deployment. We firstly consider mobile data offloading problem from network side perspective. A two-stage non-cooperative game is proposed to study the oligopolistic mobile network operators' mobile data offloading market. Then, we study Wi-Fi offloading problem from mobile user's perspective. Firstly, it is assumed that mobile users' mobility pattern is known in advance and we formulated the Wi-Fi offloading problem as a finite-horizon discrete-time Markov decision process (MDP). We proposed a dynamic programming algorithm to solve the MDP problem. Then, it is assumed that mobile users' mobility pattern is unknown. We proposed a deep reinforcement learning based offloading algorithm to solve the wireless LAN offloading problem to minimize the mobile users' monetary and energy cost.

研究分野：　通信・ネットワーク工学

キーワード：　mobile offloading　MDP　operators　reinforcement learning　mobile users

１．研究開始当初の背景

Cellular network capacity cannot catch up with the pace of mobile traffic increase. The mobile data traffic is growing rapidly (see Fig. 1), while traditional methods for increasing cellular network capacities such as deploying new cells or upgrading technologies from 3G to 4G are often costly and time-consuming. Mobile data offloading is the use of complementary network (such as Wi-Fi) for delivering data instead of using cellular network, which is one of attractive solutions to solve the wireless network capacity shortage problem because it enables inexpensive and fast deployment.

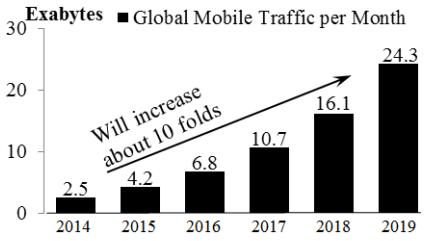

Fig.1. Global Mobile Data Traffic Forcast [1].

Access points (APs) deployed by each mobile network operator (MNO) are always closed; only available to each MNO's own users. Ubiquitous deployment of Wi-Fi or femtocell APs by the MNOs themselves is costly and often impractical due to the limitations of additional site spaces. In order to completely reap merits of mobile data offloading, it is important that MNOs can offload their traffic whenever needed. To reach this goal, a high coverage of Wi-Fi or femtocell networks is necessary.

Oligopoly mobile data offloading market where MNOs/APOs can share their APs has not been well studied yet. Monopoly market with only one MNO and perfect competitive market with many MNOs have been studied, but the MNOs market is actually always dominated by several big operators, which is called oligopoly market.

On the other hand, from user side perspective, traditional received signal strength indicator (RSSI) based network selection algorithm does not fulfill users' requirement on monetary budget, QoS and battery constraint when users face multiple networks in an offloading market.

２．研究の目的

Currently, MNOs do not share their mobile offloading networks (such as Wi-Fi APs or femtocell). Yet, it has been suggested that mobile data offloading would be a cost-efficient way to solve the problem of ever increasing mobile data traffic.

In this project, we provide for the first time a comprehensive study of the benefit of a market where MNOs can borrow mobile data offloading network resource from other MNOs or third-party AP operators (APOs) from network side perspective. Then, we will develop an intelligent network selection system that optimizes users' monetary costs, quality of service (QoS) and battery consumption from user side perspective.

３．研究の方法

Firstly, we studied the problem from network side perspective. A game theoretic based method was adopted for the mobile data offloading oligopolistic MNO market. We considered an oligopoly market for mobile data offloading, where multiple MNOs can lease APO's Wi-Fi resources to reach a high coverage (see Fig.2). Oligopoly competition behaviours among multiple MNOs and APOs were studied.

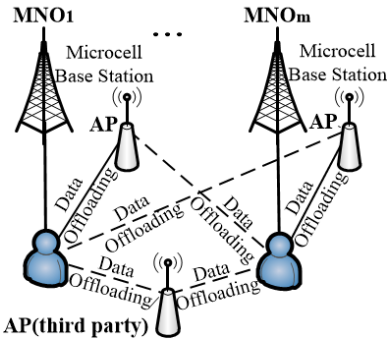

Fig.2. Markets with multiple MNOs and multiple APs.

Then, we studied the Wi-Fi offloading problem from MU's perspective by considering delay-tolerance of traffic, monetary cost, energy consumption as well as the availability of MU's mobility pattern (see. Fig.3). We first formulate the Wi-Fi offloading problem as a finite-horizon discrete-time Markov decision process (FDTMDP) with known MU's mobility pattern and propose

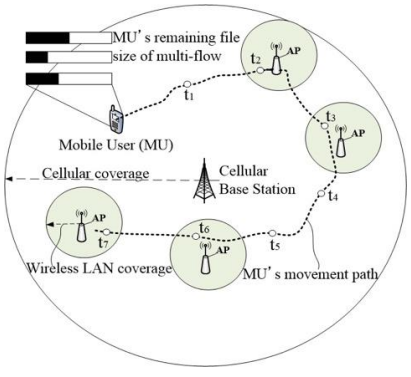

Fig.3 MU chooses cellular or Wi-Fi to offload.

a dynamic programming based offloading algorithm. The MU's mobility pattern is assumed as known in advance.

Thirdly, we studied the MU's policy to minimize his monetary cost and energy consumption without known MU mobility pattern. We proposed to use a kind of reinforcement learning technique called deep Q-network (DQN) for MU to learn the optimal offloading policy from past experiences (see Fig.4). In the proposed DQN based offloading algorithm, MU's mobility pattern is no longer needed. Furthermore, MU's state of remaining data is directly fed into the convolution neural network in DQN without discretization. Therefore, not only does the discretization error present in previous work disappear, but also it makes the proposed algorithm has the ability to generalize the past experiences, which is especially effective when the number of states is large.

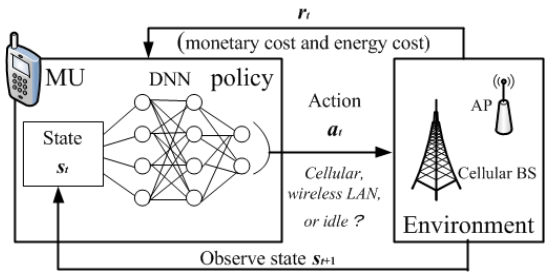

Fig.4 Deep reinforcement learning based network selection algorithm for MU.

４．研究成果

The research results are three folds.

(1) A two-stage non-cooperative game is proposed to study the MNO oligopoly mobile data offloading market. Subgame perfect equilibrium of the game was established by solving subgame of each stage. The analytical results are helpful when MNOs enter the market to lease APs from third party APOs.

(2) We study Wi-Fi offloading problem from MU's perspective. MU's target is to minimize its total cost under usage-based pricing, while taking monetary cost, preference for energy consumption, availability of MU's mobility pattern and application's delay tolerance into consideration. A general user offloading scenario is considered, the cost- and energy-aware Wi-Fi offloading problem is modeled as a finite-horizon Markov decision process under the assumption that MU's mobility pattern is known in advance. We propose a dynamic programming algorithm to solve the MDP problem. The simulation results have validated our proposed offloading algorithm.

(3) We studied the multi-flow mobile data offloading problem in which a MU has multiple applications that want to download data simultaneously with different deadlines. We proposed a DQN based offloading algorithm to solve the wireless LAN offloading problem to minimize the MU's monetary and energy cost. The proposed algorithm is effective even if the MU's mobility pattern is unknown. The simulation results have validated our proposed offloading algorithm.

５．主な発表論文等

（研究代表者、研究分担者及び連携研究者には下線）

〔雑誌論文〕（計 3 件）

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〔図書〕（計　0 件）

〔産業財産権〕

○出願状況（計 0 件）

名称：
発明者：
権利者：
種類：
番号：
出願年月日：
国内外の別：

○取得状況（計 0 件）

名称：
発明者：
権利者：
種類：
番号：
取得年月日：
国内外の別：

〔その他〕
ホームページ等
なし

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