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이종 무선 접속망에서의 과부하 분산을 위한 최적의 셀 선정 기법

이 형 준◆°

Optimal Cell Selection Scheme for Load Balancing in Heterogeneous Radio Access Networks

HyungJune Lee◆°

요 약

스마트폰의 급격한 보급에 따른 무선 접속망의 과부하 문제가 네트워크에서 중요한 문제로 부각되고 있다. 이 논문에서는 매크로 셀, 펨토 셀, 와이파이 접속망으로 다양하게 구성되어 있는 현재 이종 네트워크에서 접속망 과부하 문제를 해결하기 위한 최적의 셀 선정 기법과 리소스 할당 기법을 제안한다. 주어진 현재 서비스 부하 상태에서 네트워크가 동시에 추가 수용할 수 있는 사용자 수를 최대화할 수 있는 사용자-셀 간의 선정 기법을 제공한다. 이를 위해 이종 무선 접속망에서의 셀 선정 문제를 이진 정수계획 모형으로 최적화 문제를 수립하고, 이를 최적화 해법 도구를 이용하여 접속망 과부하를 억제할 수 있는 최적의 셀 선정 기법을 도출한다. 네트워크 레벨 시뮬레이션을 통해 이 논문에서 제안된 기법이 현재 무선 접속망에서 주로 사용되고 있는 국소적 셀 선정기법에 비해, 과부하가 걸린 무선 접속망에서 주어진 여러 셀들을 최대한 균등하게 효율적으로 활용함으로써 현저하게 네트워크 접속 장애율을 감소시킬 수 있음을 보인다. 또한 논문에서 사용된 이진 정수계획 모형의 최적화 문제를 푸는 데 소요되는 계산 복잡도에 대한 실험을 통해 제안된 알고리즘의 실용 가능성에 대해서 검증한다.

Key Words : Cell Selection, Resource Allocation, Load Balancing, Heterogeneous RAN

ABSTRACT

We propose a cell selection and resource allocation scheme that assigns users to nearby accessible cells in heterogeneous wireless networks consisting of macrocell, femtocells, and Wi-Fi access points, under overload situation. Given the current power level of all accessible cells nearby users, the proposed scheme finds all possible cell assignment mappings of which user should connect to which cell to maximize the number of users that the network can accommodate at the same time. We formulate the cell selection problem with heterogeneous cells into an optimization problem of binary integer programming, and compute the optimal solution.

We evaluate the proposed algorithm in terms of network access failure compared to a local ad-hoc based cell selection scheme used in practical systems using network level simulations. We demonstrate that our cell selection algorithm dramatically reduces network access failure in overload situation by fully leveraging network resources evenly across heterogeneous networks. We also validate the practical feasibility in terms of computational complexity of our binary integer program by measuring the computation time with respect to the number of users.

◆° 주저자 겸 교신저자 : 이화여자대학교 컴퓨터공학과 무선네트워크시스템 연구실, hyungjune.lee@ewha.ac.kr, 정회원

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Ⅰ. Introduction

As smartphone market explosively grows, voice and data traffic would dramatically increase up to 1800% for the next 5 years[2]. A number of people who carry smartphones attempt to access 3G UMTS or 4G LTE network to use voice and data services while walking in the streets and waiting in bus stop or cafe. As the intensive voice and data usage becomes more demanding, the overload problem in macrocell has been a hard challenge in wireless operator and consumer electronic device manufacturer. For example, in superball stadium and CES event, many people come together at a somewhat limited space. Concurrent call attempts from a number of people who want to use voice and data services at the same time will cause serious network access failure unless network operators pre-install additional macrocells in the hotspots before the event.

In order to mitigate the overload condition, wireless operators deploy femtocells, pico cells, and Wi-Fi access points (APs), considering its coverage area and the number of user equipments (UEs) to support at the same time. According to Juniper Research, Wi-Fi AP cells and femtocells will handle 63% of the mobile traffic by 2015[5]. This implies that efficient utilization of femtocells and Wi-Fi AP cells together with macrocell would be a crucial factor for sustaining network performance even under the overload situation.

There have been previous works for reducing network access failure and achieving better load balancing among macrocells[6,16] or Wi-Fi AP cells [7,20]. However, these works do not explicitly handle the overload situations where a number of UEs simultaneously attempt to access the network, and thus, which will lead to even more critical performance degradation. Moreover, in heterogeneous networks consisting of various cells of macro, femto, and Wi-Fi AP, there has been no clear answer for how to efficiently coordinate a number of concurrently accessing UEs over all different cells, without under-utilizing network resources.

In this paper, we focus on the problem of cell selection in heterogeneous networks of macrocell, femtocells, and Wi-Fi AP cells. Given the current power load level of all accessible cells nearby UEs, we want to find all possible mappings of which UE should connect to which cell to maximize the number of UEs that the network can accommodate at the same time. By distributing the intensive demands to nearby femtocells and Wi-Fi AP cells, we would like to achieve better load balancing, and thus, reduce the overload level on each cell.

We solve the cell selection problem by formulating it into an optimization problem of binary integer programming. With constraints of available power room for resource allocation, we find the optimal cell selection for all of concurrently accessing UEs and accommodate as many UEs as possible. We evaluate network performance of our algorithm compared to a local ad-hoc based cell selection scheme (as the baseline) of which the core mechanism is used in practical systems. We show that our proposed algorithm reduces network access failure with a factor of 8.8 compared to the baseline algorithm.

In summary, our contributions are the following:

- We propose a cell selection scheme that optimizes the coordination of concurrently accessing UEs over heterogeneous cells so that the number of UEs with network access failure should be minimized.
- We formulate the cell selection problem in heterogeneous networks of macrocell, femtocells, and Wi-Fi AP cells into a binary integer program, considering the current available power load over nearby accessible cells.
- We evaluate the proposed cell selection algorithms compared to a practical local ad-hoc based cell selection scheme using network level simulations, and show that our algorithm dramatically reduces network

access failure in overload scenarios by fully leveraging network resources evenly across heterogeneous networks.

The rest of this paper is organized as follows: In Sec. II, we discuss related work, and we formally define the problem of this paper in Sec. III. In Sec. IV, we present our proposed cell selection scheme for heterogeneous networks, and Sec. V provides network evaluation of our algorithm. Finally, we conclude this paper in Sec. VI.

Ⅱ. Related Work

The cell selection problem has actively been studied in the research areas of resource allocation, handover scheduling, and dynamic cell association in cellular and Wi-Fi networks. The purpose of most of previous works is to reduce user's access failure and achieve even load balancing among cells or Wi-Fi access points. We discuss relevant previous works in 1) cellular networks, 2) wireless LAN networks, and 3) heterogeneous networks.

In cellular networks, coordinated scheduling of UEs over a set of cells helps to improve load balancing throughout the cellular network[6,11,16]. Basically, this work aims to select one cell at a time by considering congestion level or channel quality measurement over multi-cell environment (categorized into a cell breathing approach), contributing to load balancing. Researchers[14] characterize radio resource allocation for 3G networks with an empirical study, and demonstrate that traffic patterns critically affect radio resource and energy consumption. This implies that previous work on resource allocation and cell scheduling cannot directly be applied to overload scenarios, which are the main focus of our paper. Resource management schemes in femtocell networks[19,21] are recently investigated.

In wireless LAN networks, load balancing approaches based on a cell breaching technique[4] or by checking the overload level[7,20] are taken for improving throughput and mitigating cell delay. To achieve efficient resource allocation for mobile users in wireless AP networks, the authors [12] propose a dynamic association scheme by predicting the next reliable AP cell that a mobile user will likely connect to and hand-overing to it. Recently, researchers have considered more on volatile wireless link due to relatively low power wireless vagary and mobility in the cell selection and resource allocation problem for wireless networks.

For load balancing in heterogeneous networks, efficient radio interface selection schemes between 3G and Wi-Fi, and among 802.11, Bluetooth, and ZigBee are studied in[3,15,17] and in[10], respectively. Also, the authors[13,18] focus on the radio resource management problem in 3G and WLAN for smooth transition between interfaces with QoS. However, the two crucial domains of efficient radio interface selection and resource management have not been tightly coupled, and accordingly need to be more explored although some researchers[8] recently started proposing a game-theoretical cell selection and resource allocation for LTE and WiMAX networks. Also, the cell selection and resource allocation problem explicitly considering overload scenarios has not been relatively well studied. We believe that there remains large room for the cell selection problem in heterogeneous networks for further follow-up research.

Ⅲ. System Model

This paper considers the problem of cell selection and resource allocation in heterogeneous wireless networks consisting of a macrocell, femtocells, and 802.11 Wi-Fi access points (APs) under network overload situation. The main objective of this work is to accommodate as many UEs as possible, while minimizing the number of hotspot cells that are overshooting above the maximum power limit. The transmission range of macrocell is larger than that of femtocell while the transmission range of femtocell is larger than that of Wi-Fi AP cell. We consider both circuit-switched (CS) data and packet-switched (PS) data types. PS data can be offloaded using any cell among macrocell, femtocell, and Wi-Fi AP, whereas CS data is to be routed only to macrocell or femtocell, not possible to Wi-Fi AP.

We assume UEs receive a pilot signal (CPICH: Common Pilot Channel) that includes the remaining power level from accessible femtocells, while also receiving a beacon signal that includes the remaining power level from accessible AP cells. Each UE reports all accessible cell information such as cell ID, type (i.e., femtocell or Wi-Fi AP), and the remaining power level to its governing macrocell. The macrocell can perform resource allocation for a UE by selecting a cell (among femtocell, AP cell, and macrocell itself as well) that has sufficient power capacity. If a cell reached its maximum power limit, it would deny any further request from UEs.

Under overload situation where a number of CS/PS calls are simultaneously initiated by UEs or paged from the network, we aim to coordinate cell selection and resource allocation for all UEs using femtocells and Wi-Fi AP cells distributed across a macrocell network. The cell allocation problem can then be described as finding a cell that each UE should connect to out of macrocell, femtocells, and AP cells for minimizing the number of UEs with network access failure in overload scenarios.

Ⅳ. Optimal Cell Selection Algorithm

In overload scenarios (e.g., near superball stadium, at the annual CES event venue), there are a number of calls simultaneously generated by users or paged from the network. Although additional deployment of femtocells and Wi-Fi AP cells can mitigate power overshooting in macrocell network and offload intense traffic toward them, the underlying cell selection and resource allocation scheme is usually ad-hoc based from the perspective of UE. If a macrocell receives a report of UEs' accessible cell information, it would have a complete view of the current power usage across cells for each UE. Given this knowledge, the macrocell coordinates cell selection and resource allocation for UEs, i.e., *which* UE should be connected *to which* cell, to alleviate call failure in the overload situation.

We find the optimal coordination algorithm such that given the same network deployment of a macrocell, femtocells, and AP cells, the number of UEs to accommodate at the same time should be maximized. Further, we take a crucial practical factor, the call type - CS vs. PS call - into account. Whereas PS calls can be routed to any type of cell out of macrocell, femtocell, and AP cell, CS calls cannot be routed to AP cells. In the next two sections, we describe the procedure of how the overall system operates in the protocol level (Sec. IV-A), and then we formulate the problem of cell selection and resource allocation into a binary integer program (Sec. IV-B).

4.1. Overview

We consider overload scenarios where a number of calls from UEs or network are simultaneously generated under a macrocell coverage. We provide an overview of the necessary steps to take in our proposed system as follows.

4.1.1. Power level collection

Macrocell and femtocell send a pilot signal (CPICH) that includes the remaining power level to UEs within the coverage. In the similar way, Wi-Fi AP cell sends a beacon signal with the power information to UEs. When a UE receives a CPICH signal or a beacon signal, it records RSSI (Received Signal Strength Indicator) or RSCP (Received Signal Code Power), and the remaining power therein with cell type and ID. To this end, each UE can have detailed information about neighboring cells with the current power usage.

4.1.2. Report of all neighboring cells from each UE

After each UE updates its neighboring cell list after receiving CPICH signals from macro/femto cells and beacon signals from Wi-Fi AP cells, it reports cell type, ID, and remaining power status of all connectable cells in the neighboring cell list (i.e., monitored set) to its governing macrocell.

4.1.3. Optimal cell selection and resource allocation

Given the received report from UEs within coverage areas, macrocell finds optimal cell selection for each UE based on all possible combinations to minimize the number of UEs with access failure. At the core of this procedure is an optimization procedure that the overall network consisting of macrocell, femtocells, and Wi-Fi AP cells can fully leverage resources to maximize the number of UEs to simultaneously support.

4.1.4. Decision announcement and data offload

Macrocell announces cell type and ID to each UE. If a UE receives the decision announcement from the macrocell, it starts initiating a call through the cell specified in the announcement. Now data traffic is routed to each UE through the selected cell, respectively. In this way, data will be offloaded by leveraging network resources of macrocell, femtocells, and Wi-Fi AP cells, contributing to better load balancing throughout the network.

4.2. Cell Selection Optimization

In traditional cell selection approaches, each UE determines a cell with the highest RSSI or RSCP, and selects it as the best cell with a certain period of time on its own. However, our method takes into account resource allocation status of other UEs as well, and chooses a set of one UE-to-one cell association map for UEs, which maximizes the efficiency of network resources.

We formulate the problem of cell selection and resource allocation in heterogeneous networks of macrocell, femtocells, and Wi-Fi AP cells into a binary integer program. The proposed scheme finds the optimal cell for each UE to connect to. A macrocell can compute the solution given the cell information of the remaining cell power status from received from UEs within the coverage areas.

To set up our binary integer program, let us first define indicator functions $I_i^{(T)}$ indicating whether the macrocell has determined that UE *i* should be connected to cell *T* where $T \in \{C^{(M)}, C^{(F_1)}, C^{(F_2)}, \dots, C^{(F_L)}, C^{(W_1)}, C^{(W_2)}, \dots, C^{(W_P)}\}$, and $C^{(M)}$ standing for the macrocell, $C^{(F_i)}$ for femtocell *i* out of total *L* femtocells, and $C^{(W_j)}$ for Wi-Fi AP cell *j* out of total *P* AP cells in the network. Note that *M* stands for macrocell, F_i for femtocell *i*, and W_j for Wi-Fi AP cell *j*.

Since a UE can connect to only a part of cells in the list due to limited coverage depending on cell type, the macrocell makes the following list for each UE based on reports of neighboring cell information from UEs. For UE *i*, the neighboring cell list is given by

$$\begin{aligned} NC_{UE_i} = \{ & C^{(M)}, \\ & C^{(F_{i_1})}, C^{(F_{i_2})}, \dots, C^{(F_{i_{L_i}})}, \\ & C^{(W_{i_1})}, C^{(W_{i_2})}, \dots, C^{(W_{i_{P_i}})} \} \end{aligned}$$

where $i \in I = \{1, 2, \dots, N\}$, and *N* is the total number of UEs. Please note that if UE *i* attempts a CS call, all connectable Wi-Fi AP cells are excluded from this NC_{UE_i} list. From a set of NC_{UE_i} for $i \in I$, we also construct the UE list that can access a specific cell as follows: $S^{(T)} = \{ i \mid \mathrm{UE}_i \text{ can access cell } T \}$. Also note that if *T* is one of Wi-Fi AP cells, UEs that attempt CS calls should not be in the $S^{(T)}$ list.

We introduce one more type of indicator

function J_i indicating whether UE i is assigned to any cell that can successfully allocate power for the UE where $i \in \{1, 2, \ldots, N\}$.

Based on this definition, we write the objective function to maximize the number of UEs to successfully allocate power in one of neighboring cells, which can be expressed as $f = \sum_{i=1}^{N} J_i$. Thus, the cell selection problem can be formulated as a binary integer program as follows:

$$\text{maximize} \quad \sum_{i=1}^{N} J_i \qquad (1)$$

$$\text{subject to} \quad \sum_{i \in S^{(M)}} p_{UE_i}^{(M)} \cdot I_i^{(M)} \le P_{rem}^{(M)} \qquad (2)$$

$$\sum_{i \in S^{(F_1)}} p_{UE_i}^{(F_1)} \cdot I_i^{(F_1)} \le P_{rem}^{(F_1)} \qquad (3)$$

$$\sum_{i \in S^{(F_L)}} p_{UE_i}^{(F_L)} \cdot I_i^{(F_L)} \le P_{rem}^{(F_L)} \qquad (4)$$

$$\sum_{i \in S^{(W_1)}} p_{UE_i}^{(W_1)} \cdot I_i^{(W_1)} \le P_{rem}^{(W_1)} \qquad (5)$$

$$\sum_{i \in S^{(W_P)}} p_{UE_i}^{(W_P)} \cdot I_i^{(W_P)} \le P_{rem}^{(W_P)} \qquad (6)$$

$$\sum_{T \in NC_{UE_i}} I_i^{(T)} = J_i \le 1 \qquad (7)$$

for each UE i where $p_{UE_i}^{(M)}$, which is the amount of power allocated for UE i by macrocell, $p_{UE_i}^{(F_j)}$ for UE i by femtocell j, $p_{UE_i}^{(W_j)}$ for UE i by Wi-Fi AP cell j, and $P_{rem}^{(M)}$, the total remaining power at macrocell, $P_{rem}^{(F_j)}$ at femtocell j, $P_{rem}^{(W_j)}$ at Wi-Fi AP cell j. In general, $p_{UE_i}^{(T)}$ can have a different power allocation depending on the QoS requirement of UE i.

The objective function (1) maximizes the total number of UEs for accommodating by power allocation throughout the network. $I_i^{(T)}$ and J_i are variables, which will be computed as the output of this optimization problem. Constraints (2) - (6) ensure that for each cell, all possible allocation for UEs cannot be executed beyond its given remaining power limit. Finally, constraint (7) forces one UE to connect to at most one cell at a time.

We solve this binary integer program to obtain the optimal cell selection scheme using AMPL/CPLEX[1], which is one of the most efficient optimization solvers.

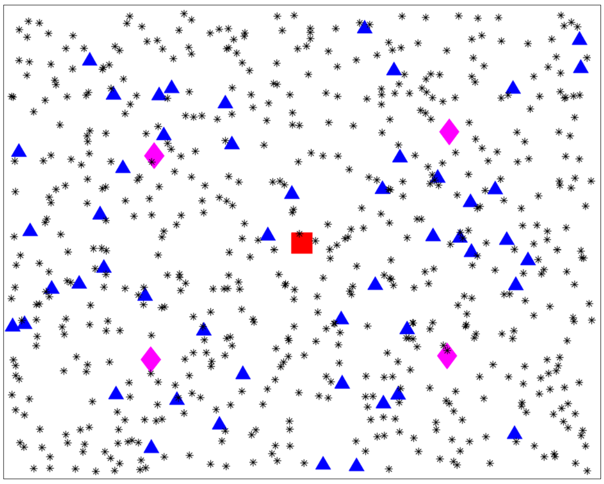


Fig. 1. Network deployment used in simulations. One macrocell marked with red square, four femtocells with pink diamonds, and 20 Wi-Fi AP cells with blue triangles are deployed in the area of 500 × 500 m^2, while 600 UEs with black asterisks will attempt to access the network.

V. Simulation Results

We validate our cell selection algorithm in a simulated network deployment shown in Fig. 1. The network consists of one macrocell in the center (red square), four femtocells (pink diamond), and 20 Wi-Fi AP cells (uniformly randomly distributed and marked with blue triangle) in a 500 × 500 m^2 area. To simulate the wireless propagation model, a combined path-loss and shadowing model is used with a path-loss exponent of 3, a reference loss of 46.67 dB, and an additive white Gaussian noise of N(0,5^2) in dB[9]. The transmission power of macrocell, femtocell, and Wi-Fi AP cell that we used in simulations is 15, 10, and 7 dBm, respectively. The maximum power capacity of macrocell, femtocell, and Wi-Fi AP cell is 50, 6.25, and 5 W, respectively, while the unit power consumption per UE at macrocell, femtocell, and Wi-Fi AP cell is 0.5, 0.125, and 0.1 W, respectively. In our simulations, a macrocell makes a one-time decision on which cell should be selected for each UE, based on reports from UEs that concurrently attempt to access the network. The simulator is implemented in MATLAB for the purpose of algorithmic validation. AMPL/CPLEX is used to solve our binary integer program. For the rest of the evaluation, unless otherwise noted, the results were obtained using four femtocells, 20 Wi-Fi AP cells, the current cell power load of 50%, and the CS call ratio of 0%.

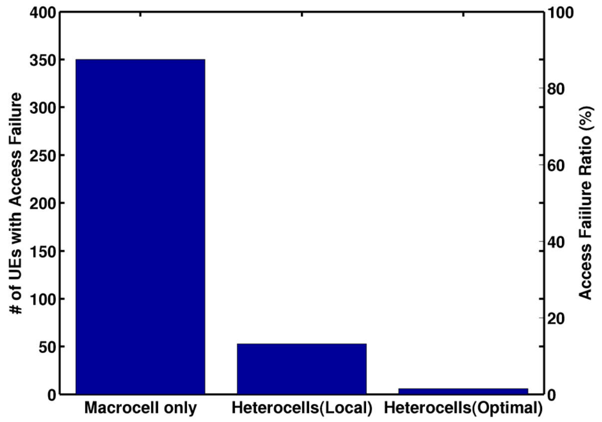
We evaluate cell selection in terms of the number of UEs that result in access failure, load balancing, and computation complexity for running the algorithm. We compare our proposed cell selection algorithm to an ad-hoc based cell selection approach of which the core mechanism is used in practical systems: each UE keeps updating a neighboring cell list based on CPICH signals from macrocell and nearby femtocells, and beacon signals from nearby Wi-Fi AP cells, and attempts to access to the best cell from which the UE receives with the highest RSSI or RSCP based on a *local* view; if the selected cell cannot admit the UE due to insufficient power capacity, it will deny the access from the UE, resulting in access failure.

We investigate network performance behavior by varying the number of UEs, cell power load status before UEs' access attempt, and CS call ratio, and show how our optimal cell selection scheme outperforms the baseline algorithm with respect to network metrics introduced above. Also, to evaluate the signalling overhead for one-time decision of macrocell's cell selection, we measure the number of bytes used for report from UEs to the macrocell.

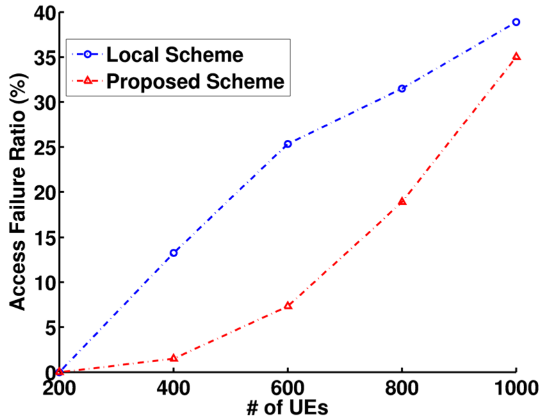
We evaluate access failure ratio when there are 400 UEs who simultaneously attempt to access the network, for three different cases: 1) utilizing only one macrocell, 2) utilizing heterogeneous cells (one macrocell, four femtocells, and 20 Wi-Fi AP cells) with the baseline ad-hoc based algorithm, and 3) utilizing the same heterogeneous cells with our proposed algorithm. Fig. 2(a) shows that if we deploy four femtocells and 20 Wi-Fi AP cells for offloading from macrocell, access failure ratio decreases with a factor of 6.6 using the ad-hoc based cell selection scheme (called *Local Scheme*) serving as our baseline algorithm. If the network utilizes our cell selection scheme, access failure ratio can be reduced with a factor of 8.8 compared to the baseline algorithm, and with a factor of 58.3 compared to the macrocell only scenario.

In order to investigate how the overload degree affects network performance, we vary the number of UEs which simultaneously attempt to access the network. As seen in Fig. 2(b), in very light load situation at 200 UEs, access failure ratio for both the baseline algorithm and the proposed algorithm is 0. As the number of UEs increases beyond 200, however, access failure ratio of the baseline algorithm significantly increases whereas that of the proposed algorithm slowly increases, meaning that it leverages network resources by the optimization process. In an extremely overload situation at 1000 UEs, our algorithm exploits all possible cells as much as it can, and then there is no more available power to accommodate other UEs beyond a certain level due to empty resource throughout the entire cells. Thus, it starts performing closer to the baseline algorithm.

We also analyze how the power load level before access demand from UEs affects access failure in Fig. 3(a). At the power level of 50% across all the cells before UEs' access, if 400 UEs attempt to access the network, the baseline algorithm does not accept 53 UEs (13.3%), whereas our proposed algorithm does not accept only 6 UEs (1.5%). This means that in a non-overload situation, the overall network can

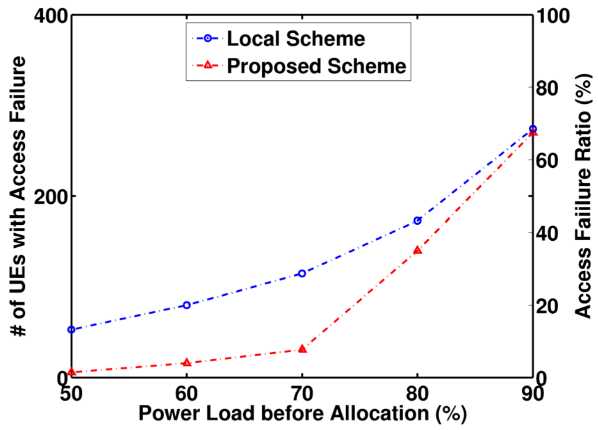


(a) Access failure for macrocell only, heterogeneous cells with the local ad-hoc based algorithm, and heterogeneous cells with the proposed algorithm.

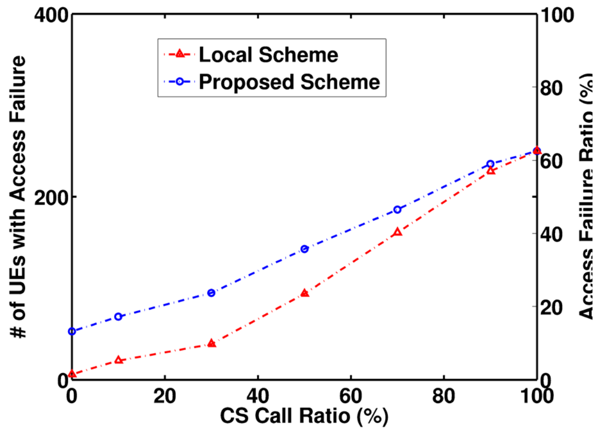


(b) Access failure with respect to the number of UEs.

Fig. 2. Access failure with respect to network deployment, cell selection algorithm, and the number of UEs. Even under a very large number of UEs' network access, using femtocells and Wi-Fi AP cells with the proposed cell selection algorithm significantly improves call access failure.



(a) Access failure with respect to power load level before attempts from UEs.



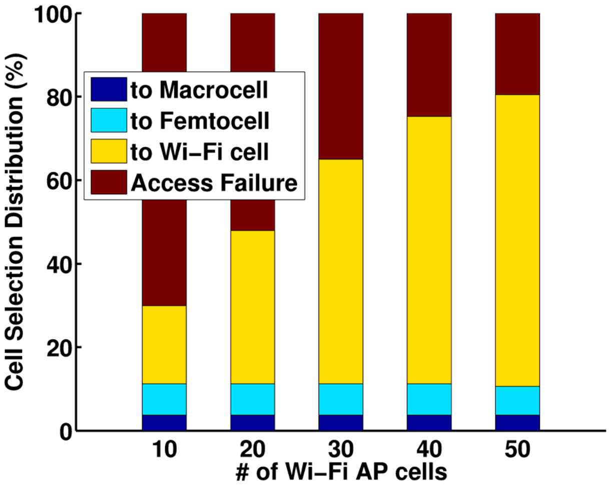
(b) Access failure with respect to CS call ratio.

Fig. 3. Access failure with respect to power status in cells and CS call ratio. For both evaluations, the proposed algorithm outperforms the baseline algorithm. At an extremely overload condition, the proposed algorithm starts performing closely to the baseline algorithm due to empty network resources after complete exploitation.

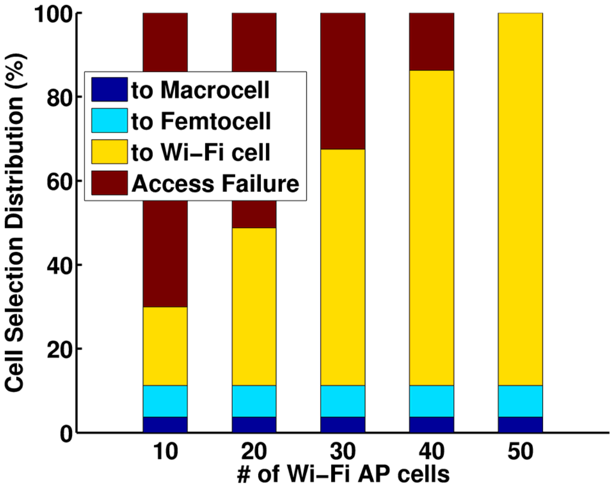
benefit from a cell selection strategy based on a *global* view. As the power level increases up to 70%, our proposed algorithm still keeps very low access failure ratio as opposed to the baseline algorithm, showing a significant performance improvement in an overload situation. After this point, since the overall network becomes extremely overloaded, the performance of the proposed algorithm starts degrading closely to the baseline algorithm with the similar reason described in the previous paragraph.

We evaluate how the CS call ratio affects access failure. Fig. 3(b) shows that for the CS ratio of 0%, i.e., for the 100% PS call scenario, our cell selection algorithm successfully allocates power by fully leveraging Wi-Fi AP cells in the network, and keeps very low access failure. As CS call ratio increases, the network starts under-utilizing Wi-Fi network resources, leading to increase in access failure ratio. When the CS ratio reaches 100%, Wi-Fi AP cells are totally useless, and thus, our algorithm performs very closely to the baseline algorithm.

We examine the distribution of selected cell type as we vary the number of Wi-Fi AP cells in the network deployment of one macrocell and four femtocells. At 800 UEs and the current



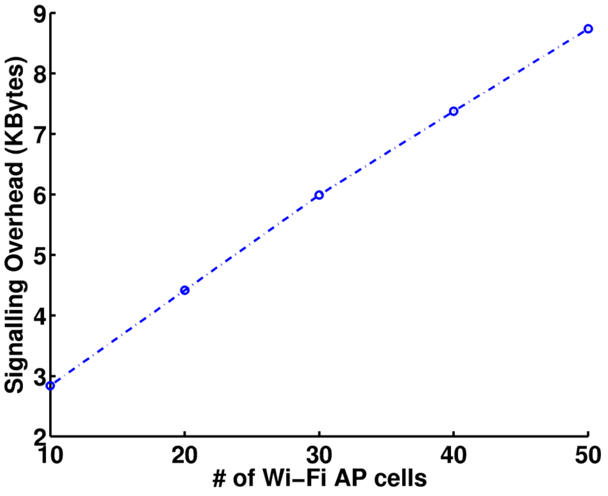
(a) Local ad-hoc based cell selection algorithm (baseline).



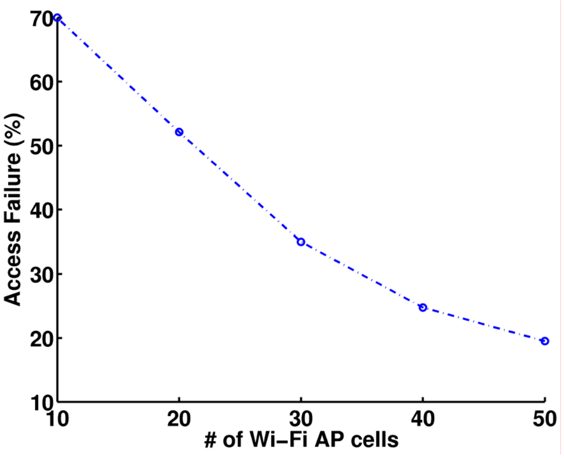
(b) The proposed optimal cell selection algorithm.

Fig. 4. Distribution of selected cell type. Even if many 800 UEs attempt to access the network, the proposed algorithm fully leverages the given network resources including Wi-Fi AP cells as well as macro/femto cells through optimization.

power load (before attempts from UEs) of 70%, the additional Wi-Fi AP cell deployment helps to reduce access failure, while increasing the percentage of Wi-Fi AP cell selection. As shown in Fig. 4, our proposed scheme fully accommodates 800 UEs when 50 Wi-Fi AP cells are deployed in the network, whereas the baseline algorithm does not fully utilize Wi-Fi network resources due to its local non-optimal allocation characteristic.



(a) Signalling overhead with respect to the number of Wi-Fi APs.



(b) Access failure with respect to the number of Wi-Fi APs.

Fig. 5. Signalling overhead for reporting cell types, cell IDs, and the remaining power levels of all neighboring cells from 800 UEs. As the number of cells in the network increases, our proposed algorithm requires a higher signalling overhead as a trade-off.

Since each UE reports cell types, cell IDs, remaining power levels of all neighboring cells to its macrocell in order for the macrocell to make a one-time decision of cell selection, the proposed algorithm requires signalling overhead. Our protocol uses 1 byte for cell type, 1 byte for cell ID, and 1 byte for remaining power level in percentage. Each UE needs to send its macrocell a signalling frame that includes multiple neighboring cells' information where 3 bytes per neighboring cell is used. In our simulation experiments with 800 UEs, 1 macrocell, 4 femtocells, and the current power load of 70% by

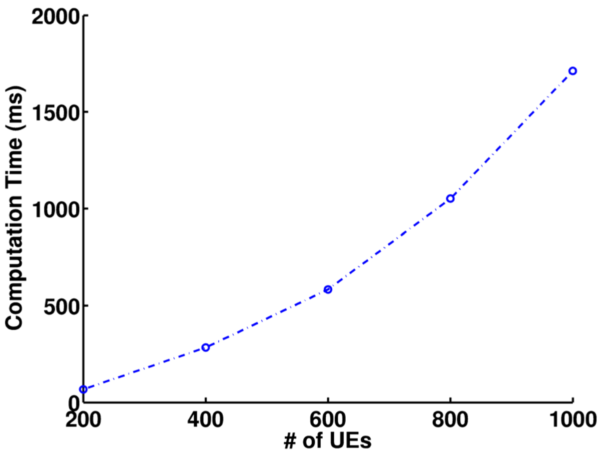


Fig. 6. Computation complexity for solving the cell selection optimization problem. As the number of UEs increases, the running time for solving the binary integer program increases (reaching 1.7 seconds at 1000 UEs).

varying the number of Wi-Fi AP cells as shown in Fig. 5, the proposed algorithm used a fairly small signalling overhead, i.e., 2.8 KBytes for 10 Wi-Fi AP cells, up to 8.7 KBytes for 50 Wi-Fi AP cells. This shows an interesting trade-off between performance and overhead in heterogeneous wireless networks. To drastically improve system performance in terms of access failure, we need a fair amount of signalling overhead as a trade-off.

Finally, we evaluate the feasibility of efficiently computing our proposed cell selection algorithm through optimization. We measure the running time as computational complexity for solving the binary integer program in Sec. IV. We tested the performance on Dell Precision 390 PC with 2.66 GHz Core 2 CPU 6700 and Ubuntu 12.04 Linux. Fig. 6 shows that as the number of UEs who simultaneously attempt to access increases, the required computation time also increases. In the case of 1000 UEs, it takes 1.7 seconds. Since the computing performance at macrocell is usually much more powerful than a normal PC, the computation time would be more reduced, making it more practically feasible.

Ⅵ. Conclusion

In 3G UMTS and 4G LTE networks, handling overload scenarios is a very critical factor for providing QoS to smartphone users. As femtocells and Wi-Fi AP cells are deployed and formed as the secondary tier for communication on top of macrocell network, it is important to co-organize resource allocation for concurrently accessing UEs over heterogeneous cells for reducing network access failure. We presented a cell selection and resource allocation scheme that universally coordinates UEs' cell assignment over accessible macrocell, and femtocells, and Wi-Fi AP cells. Our approach exploits an optimization process that maximizes the number of UEs for successfully allocating network resources, thereby dramatically reducing access failure in overload situation.

Our simulation experiments show that the proposed cell selection scheme outperforms a local ad-hoc based cell selection scheme with a factor of 8.8 in terms of the access failure metric. Our approach provided a globally optimal cell assignment solution that leverages the given network resources across heterogeneous networks.

In this paper, we considered the cell assignment problem at the time UEs attempt to access the network. In case that after the cell assignment is completed, there are call departures and another incoming peak call attempts afterwards, we would need an iterative cell selection scheme, but without too much ping-pong effect. For this reason, the optimal solution would not be practical, and thus, the cell selection scheme should be designed to avoid frequent cell re-assignments.

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이 형 준 (HyungJune Lee)

2001년 8월 서울대학교 전기공학부 학사

2006년 6월 Stanford 대학교 전기공학과 석사

2010년 8월 Stanford 대학교 전기공학과 박사

2012년 3월~현재 이화여자대학교 컴퓨터공학과 조교수

<관심분야> 무선 센서 네트워크, 이동 애드혹 네트워크, 네트워크 최적화, 임베디드 시스템