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研究成果の概要(和文)：本研究では、高密度ヘテロジニアスネットワーク(HDHN)における高エネルギー利用効率な無線リソース管理(RRM)モジュールの設計について注目し、以下の検討課題について考慮する。(I) HDHNにおける高精度な移動速度推定アルゴリズムの開発、(II) HDHNにおけるファジィ論理に基づくセル選択およびハンドオーバーアルゴリズムの設計、(III) HDHNのスペクトル効率(SE)およびエネルギー効率(EE)の向上、(IV) 無線データ収集のためのスマートフォンアプリケーションの開発し、RRMアルゴリズムの性能の検証。

研究成果の概要(英文)：In this research, we focused on the challenging task of designing energy-efficient radio resource management (RRM) modules for hyper dense heterogeneous networks (HDHNS). In brief, the following tasks were fulfilled: (I) Developing velocity estimation algorithms with high accuracy for HDHNS (II) Designing a fuzzy logic based cell-selection and handover algorithm for HDHNS (III) Aiming at improving the energy-efficiency (EE) and spectral-Efficiency (SE) of HDHNS (IV) Developing a smart phone application for wireless data collection, to verify the performance of RRM algorithms. For instance, one of proposed RRM algorithms was an intelligent and energy-efficient user association algorithm based on base station (BS)'s estimated load and signal to interference and noise ratio (SINR). Simulation results show that this algorithm yields significant performance gains up to 26.4% and 22% compared to the benchmark in terms of average energy consumption and BS load, respectively.

研究分野：Wireless Communications

キーワード：5G

1 . 研究開始当初の背景

Delivering high-speed, pervasive wireless services to an extra-large number of connected mobile devices warrants a significant transformation to today's wireless cellular networks. The notion of hyper-dense heterogeneous networks (HDHNs), enabled via a viral and large-scale deployment of small cell base stations (BSs) and user equipment (UEs), is seen as one of the cornerstones of this transformation and an essential part of next generation wireless networks, i.e., so-called 5G. In this research, we focus on the challenging task of designing energy-efficient radio resource management (RRM) modules for HDHNs.

2 . 研究の目的

This research aimed at achieving the following: (I) Developing velocity estimation algorithms with high accuracy for HDHNs (II) Designing a fuzzy logic based cell-selection and handover algorithm for HDHNs, using the mobility state estimation information which is obtained by the algorithm developed in task I. (III) Aiming at improving the energy-efficiency (EE) and spectral-Efficiency (SE) of HDHNs through designing RRM algorithms for BSs & UEs (IV) Developing a smart phone application for wireless data collection, to verify the performance of RRM algorithms.

3 . 研究の方法

(1) A closed-form expression for the Cramer-Rao lower band (CRLB) of sojourn-time based velocity estimation was derived, which is a function of small BS (SBS) density, UE velocity, and measured time interval. We also derived an asymptotically unbiased velocity estimator. Theoretically, we showed that the sojourn-time based velocity estimation outperforms the handover count based velocity estimation.

(2) a fuzzy logic based game theoretical framework for EE improvement in HDHNs was developed. Modified fuzzy decision rules were developed for the handovers and the target BS selection. Moreover, novel regret based game theoretical learning scheme was proposed for the energy efficient operation. It was shown that the proposed fuzzy-game theoretical technique improved the energy consumption significantly especially for the small number of active users considering the high user velocities with managing

ping-pong handovers and cell loads. The parameters of the proposed framework can be tuned flexibly by the operators in order to operate in the desired regime of EE, ping-pong handover rate, and throughput.

(3) **UE association based on BS's estimated load and signal to interference and noise ratio (SINR):** A UE association policy based on BS's estimated load and SINR at the location of UE was proposed. Furthermore, we applied a self-organizing mechanism to allocate the resource for jointly optimizing the power and channel allocation in a fully distributed manner. Simulation results show that the proposed joint UE association and resource allocation yields significant performance gains up to 26.4% and 22% compared to the benchmark in terms of average energy consumption and BS load, respectively.

(4) **UE association based on learning algorithm:** In this approach, the UE association problem is modeled as a non-cooperative game, in which each UE tries to associate to an appropriate BS. In order to solve the game, we have proposed a satisfaction based learning process. Simulation results show that the proposed mechanism reduces the number of unsatisfied UEs up to about 52.3%, and improves BS throughput up to about 15.4% compared to the benchmark algorithm.

(5) **The impact of the number of BS operation modes on a joint UE association and resource management mechanism:** In order to improve the energy efficiency, we deployed an energy-saving scheme by switching the maximum allowed transmission power of BSs, i.e., BS ON-OFF switching, adaptive to traffic load fluctuations. The mechanism is modeled as a Markov chain, in which increasing the number of switching (modes), increases the computational complexity, however, it improves the EE of the network and load balancing among BSs. For instance, the EE and average load per BS with 4 modes are improved, respectively, up to 27% and 11%, as compared to 2 modes, for a network with 10 SBSs.

(6) **Channel Assignment Mechanism: Gibbs Sampling-Based UE Interference-Aware (GUIA):** A dynamic channel assignment mechanisms i.e. GUIA was proposed. Later, it was combined with a BS ON-OFF switching algorithm in order to reduce the energy consumption of the network. In GUIA/ON-OFF switching algorithm, BSs utilize some information from their associated UEs to improve the

performance of the network. At the next step, they select their channels based on a Gibbs-sampler. GUIA/ON-OFF switching algorithm balances the load among BSs. Therefore, it improves system throughput, and consequently yields a better SE. As a result, our proposed algorithm achieves both high EE and SE.

(7) An Android Mobile Signal Detection App was developed which displays to the user relevant information about the cellphone. Among this information, the app offers: IMEI Number, Subscriber ID, Sim Serial Number, Sim Country ISO, Phone Type Network, Network Operator Name, the Locations Details provided by the cellphone's GPS and details about Wi-Fi Connection, such as the MAC and IP addresses, Signal Strength, and SSID. Furthermore, the program implements three algorithms for displaying the cellular towers in the range of the Android device. Due to shortage of space, in the following, we are going to elaborate more on part of results obtained in (6).

4 . 研究成果

The performance of networks hinges on cochannel interference (CCI), experienced at the UE's location which varies by the network's conditions. In light of this, we propose a channel assignment scheme, referred as GUIA. This scheme is based on the interference that the UEs of each BS experience. In the proposed approach, each UE k at the coverage area of BS b computes the average CCI power received over each channel from other BSs in the network. Using the first order filtering with a constant forgetting factor λ , the average CCI power at the receiver of UE k over channel q at time t is given by:

$$\bar{I}_{k,b}^q(t) = (1-\lambda)I_{k,b}^q(t) + \lambda \bar{I}_{k,b}^q(t-1), \quad (1)$$

where $I_{k,b}^q(t)$ denotes instantaneous CCI power received by UE k over channel q at time t . Each UE $k \in K$ has a CCI table which updates for all $q \in Q$. Then, UE k selects the channel with minimum CCI power from this table, and send it to its associated BS b according to:

$$q_{k,b}(t) = \underset{q \in Q}{\operatorname{argmin}} \bar{I}_{k,b}^q(t), \text{ subject to } k \in A_b^t \quad (2)$$

Each BS $b \in B$ selects its channel using the received reports. In this regard, BS b calculates the repetition of each channel (i.e. channel absolute frequency) $q \in Q$ in all received reports as follows:

$$f_{b,q}(t) = \sum_{\forall k \in A_b^t} \delta_{(q_{k,b}(t)=q)}. \quad (3)$$

Later, each BS assigns a probability distribution to all channels according to the reports received from the UEs. The channels which are mostly reported by UEs have a higher selection probability.

A common method for enabling this selection is to use a Boltzmann-Gibbs distribution. A Boltzmann-Gibbs is a probability distribution of particles over states, which can be expressed as:

$$\Lambda(x) \propto \exp\left(-\frac{E}{\theta}\right). \quad (4)$$

Here, E is the energy of state x , and θ is a constant which is proportional to Boltzmann's constant and thermodynamic temperature. This implies the probability which a system will be in state x , and it is proportional with the energy of states and system's temperature. In this regard, the Boltzmann-Gibbs distribution for BS b , $\Lambda_b = [\Lambda_{b,1}, \dots, \Lambda_{b,|Q|}]$, is given by:

$$\Lambda_{b,q}(f_{b,q}(t)) = \frac{\exp\left(\frac{1}{\theta_b} f_{b,q}(t)\right)}{\sum_{\forall q \in Q} \exp\left(\frac{1}{\theta_b} f_{b,q}(t)\right)}, \quad (5)$$

where $\Lambda_{b,q}(f_{b,q}(t))$ is the element of Λ_b which is related to channel q , $(1/\theta_b) > 0$ denotes the temperature parameter for BS b and balances between exploration and exploitation. Note that, by allowing $\theta_b \rightarrow 0$, it leads to selecting the channel which is mostly reported by the UEs associated to BS b . Therefore, this can lead to the strategies with zero probabilities. On the contrary, by allowing $\theta_b \rightarrow \infty$, it results in a uniform distribution over the strategy set of players b . Then, each BS $b \in B$ updates the probability assigned to each channel $q \in Q$ at time t according to:

$$\pi_{b,q}(t) = \pi_{b,q}(t-1) + \left(\frac{1}{t}\right)^v \times \quad (6)$$

$$\left(\Lambda_{b,q}(f_{b,q}(t)) - \pi_{b,q}(t-1)\right),$$

where $\pi_{b,q}(t-1)$ and v are the probability assigned to channel q at time $t-1$ and the learning rate exponent, respectively. Finally, each BS b chooses its channel using a mapping function which maps the probability distribution $\{\pi_{b,1}(t), \dots, \pi_{b,|Q|}(t)\}$ to an element in the set of channels.

• Simulation Results

For the simulations, the proposed mechanisms are validated in a single cell served by one macro BS (MBS) and a set of SBSs with the maximum transmit power of 46dBm and 30dBm. The proposed GUIA combined with ON-OFF switching approach (GUIA/ON-OFF switching), are compared with the following benchmarks:

- ✓ *Interference-aware dynamic channel selection (IADCS)*: Each BS transmits with its maximum power, and evaluates averages CCI power over each channel, and finally selects the channel with minimum average CCI.
- ✓ *IADCS/ON-OFF switching*: Each BS employs an ON-OFF switching mechanism, and evaluates average CCI power over each channel, and finally selects the channel with minimum average CCI.
- ✓ *Dynamic channel assignment based on learning algorithm (DCA-LA)/ON-OFF switching*: Each BS employs an ON-OFF switching mechanism, and selects the channel based on a no-regret learning algorithm.

Here, we present part of simulation results, pertaining to a stationary scenario, where UEs do not move.

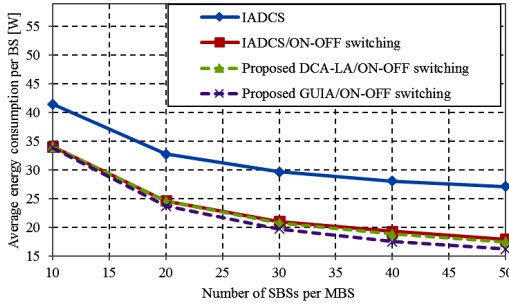


Fig. 1: Average energy consumption per BS versus the number of SBSs, given 60 UEs.

Fig. 1 shows the average energy consumption per BS as the number of SBSs varies for 60 active UEs. When the number of SBSs in the network increases, the path loss between the BS and the UE degrades. Thus, it induces a decrease in the required transmit power to provide the certain received power at the UE's receiver. From Fig. 1, we can observe that with increasing the number of SBSs, the average energy consumption per BS decreases. At the number of SBSs = 50, the reduction of average energy consumption per BS in IADCS/ON-OFF switching,

DCA-LA/ON-OFF switching, and proposed GUIA/ON-OFF switching compared to IADCS approach are 33.8%, 35.6%, and 40.3%, respectively. Moreover, for a given number of SBSs, proposed GUIA/ON-OFF switching mechanism consumes less energy compared to the other approaches. However, it has almost the same performance compared to the approaches based on ON-OFF switching. The main reason is that the DCA-LA/ON-OFF switching and IADCS/ON-OFF switching utilize the ON-OFF switching mechanism for unnecessary BSs, whereas in IADCS algorithm, each BS transmits with its maximum power. On the other hand, in GUIA/ON-OFF switching, the BS selects the better downlink channel, in terms of CCI, compared to the other mechanisms based on the ON-OFF switching. This is due to receiving the reports from its associated UEs. Therefore, the interference over the selected channel using GUIA/ON-OFF switching mechanism is less than the other mechanisms. This leads to a decrease in the required transmit power to guarantee the same received power at the UE's receiver.

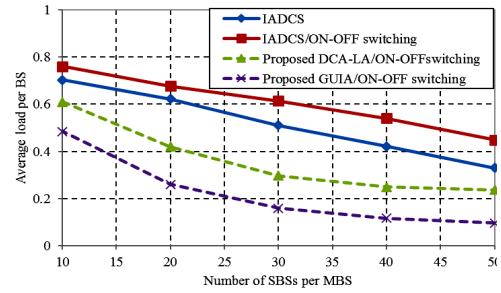


Fig. 3: Average utility per BS versus the number of UEs, given 5 SBSs.

Fig. 2 shows the average load per BS for 60 active UEs. As the number of SBSs increases, average load per BS decreases through offloading UEs associated with highly loaded BSs to lightly loaded BSs. Since GUIA/ON-OFF switching mechanism assigns the resources in the efficient manner, it can reduce interference on downlink channel at the UE's receiver. As a result, it improves the achievable transmission rate of the UE, and thus, it reduces the BS's load. From Fig. 2, it can be seen that the proposed GUIA/ON-OFF switching method balances the load among BSs, and yields 78.3%, 70.6%, and 59.2% average load reduction per BS compared to IADCS/ON-OFF switching, IADCS, and DCA-LA/ON-OFF switching approaches, respectively.

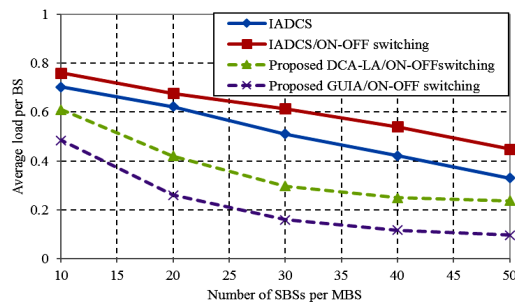


Fig. 2: Average load per BS versus the number of SBSs, given 60 UEs.

Fig. 3 shows the average utility per BS versus the number of UEs for 5 SBSs. As the number of UEs increases, more BSs are working in active mode, and less BSs choose OFF mode. Therefore, the BS's load and energy consumption increase, and thus, the utility of the BS decreases. Since GUIA/ON-OFF switching balances load, and saves more energy compared to the other mechanisms, it improves the BS's utility. However, for high number of UEs, the behavior of mechanisms based on the ON-OFF switching method becomes closer to each other. This is mainly due to the fact that, the load of BSs increases, and approaches to the maximum BS's load. On the other hand, the average energy consumed by BSs in the mechanisms based on the ON-OFF switching method is almost same. Fig. 3 shows that the average utility of the proposed GUIA/ON-OFF switching yields, respectively, 17.8%, 34%, and 63.9% improvement over DCA-LA/ON-OFF switching, IADCS/ON-OFF switching, and IADCS approaches for 20 UEs.

5. 主な発表論文等

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6. 研究組織

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