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科学研究費助成事業　　研究成果報告書

平成　２９　年　　６　月　１３　日現在

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研究種目：　基盤研究(B)（一般）
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課題番号：　２５２８９１１３

研究課題名（和文）STAR-CODE: STAR-struCtured relaying for glObal wireless Data Exchange

研究課題名（英文）STAR-CODE: STAR-struCtured relaying for glObal wireless Data Exchange

研究代表者

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交付決定額（研究期間全体）：（直接経費）　　13,300,000円

研究成果の概要（和文）：STAR-CODEプロジェクトの目標は、ネットワークそのものをコーディングスキームの構造として見ることで、スキームマルチターミナルノード用の効率的なコミュニケーションのテクノロジを作成し、ネットワーク情報理論とコーディング理論の最近の進歩に基づく技術を設計することである。その成果は、新しいアルゴリズム、新しい定理、データスループットを改善し、電力使用を削減することである。

研究成果の概要（英文）：The goal of the STAR-CODE project is to create efficient communication concepts/technologies for multiterminal nodes based on the recent advances in network information theory and coding theory, where the network itself expresses a structure of coding schemes. Example of applications include disaster-area communication systems, universal wireless access in rural areas, sensor networks and vehicle-to-vehicle communications. The outcomes include new algorithms, theorems, coding schemes to improve the data throughput, reduce the power use, and increase the reliability of star-structured network topologies.

In summary, the results are: (1) new wireless network capacity bound for networks with multiple relays and side information, (2) new decoding technique for multiple multiway relay, (3) explicit error-floor analysis for finite-length setting, (4) induced degree distribution due to Rayleigh fading channels, (5) optimal degree distributions.

研究分野：　情報通信工学、情報理論

キーワード：　情報通信工学　情報理論　無線通信　符号理論

１．研究開始当初の背景

Wireless communications have become as important to our lives as house, car, or computer. However, in the future there is a need to limit the energy consumption of the battery-driven devices. Without new approaches for energy savings, there is a significant threat that in the future, users will be searching for power outlets rather than network access. Cooperative communications can improve the performance of wireless networks. Intuitively, if the users cooperate, the communication system can work better, reducing computational complexity, decreasing power consumption and improving data rates.

The theoretical limits of cooperative networks are now being intensely studied; however, many open questions remain, particularly for complex wireless networks. For example, little is known about star-structured networks, where users U1, U2, …, UK exchange information with the help of a relay R as shown in Fig. 1.

This project uses star-structured network as the basic platform, where the networks itself can be seen as the structure of coding scheme. The goal of the STAR-CODE project is to find information-theoretic limits, effective coding and modulation techniques, optimal power and rate allocation for such networks. Furthermore, it will evaluate the performance in low-computational complexity and minimum-transmission phase scenarios. A potential application is cross-country communications, to provide universal access to rural areas, where the relay R is a satellite, as shown in Fig. 2. Another application is disaster-area communications, when infrastructure is unavailable, enabling emergency-response personnel to communicate using a rapidly-deployed relay.

In summary, the contributions of this project are:

(1) new wireless network capacity bound for networks with multiple relays,
(2) new wireless network capacity bound for networks exploiting side information
(3) new decoding technique for multiple multiway relay,
(4) explicit error-floor analysis for finite-length setting for low latency communications,
(5) induced degree distribution due to Rayleigh fading channels,
(6) optimal degree distributions suitable for coded random access with and without multiuser detections (MUD) capability.

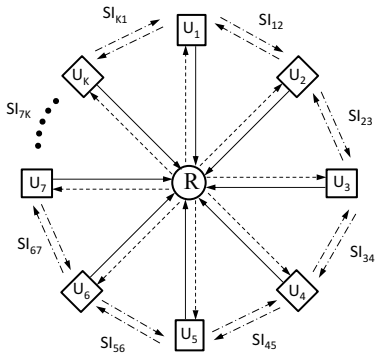

Fig. 1 Star-structured relaying with side information between users. SI_{xy} is side information between nodes x and y.

２．研究の目的

The goal of the STAR-CODE project is to create efficient communication concepts/technologies for multiterminal nodes based on the recent advances in network information theory and coding theory, where the network itself expresses a structure of coding schemes. This project considered star-structured network topologies with a central relay as the platform for full information exchange.

Based on the recent development in coding theory for low density parity check (LDPC) codes e.g., spatial coupling and random access on graph, this project is aiming to solve problems of star-structured network as described in Fig.2.

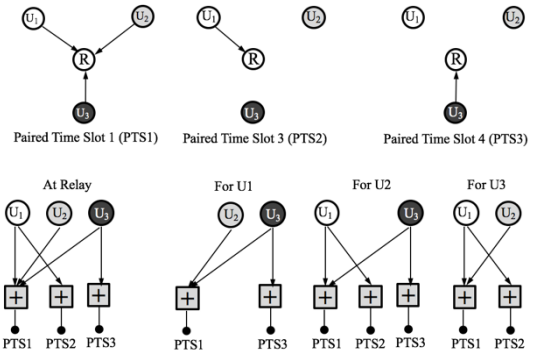

Fig. 2 Multiterminal networks viewed as LDPC codes possible as solution for wireless super-dense networks.

Fig. 2 shows an example of star-structured relaying system with three users. The carefully designed scheduling of transmission (to the relay) can be seen as a spatial coupling of the star-structured network. Many open problems are, e.g. (1) theoretical communications limits, (2) multiple access detection schemes, (3) optimal user power allocation, (4) optimal transmission scheduling.

3．研究の方法

The STAR-CODE project is divided into five work packages (WP) for a total of three years. However, due to publication reasons, the project was extended to 4 years in total. Each WP has its own novelty, expected results, and project workers (PW), where the project outputs are aimed at both academia and industry.

In the first year, the project focuses on correlated sources and joint source and channel coding for application in the network. In the second year, the project investigates graph-based transmission with random access on network, where the devices or users and time-slot can be seen as variable nodes and check nodes of LDPC codes, respectively.

In the final year WP focuses on the global optimizations given the results obtained in the first and second year, especially on the degree distribution, rate and power allocations. Each WP is based on unique theoretical and computer simulation activities which result in unique technologies but under the same umbrella of single relay cooperative communications.

4．研究成果

The project provided significant results contributing to academic and industries to develop multiple access scheme for wireless super-dense networks. Some most important results are as follows:

(1) New wireless network capacity bound for networks with multiple relays [14],[15].

The results revealed the theoretical limit of wireless super-dense networks involving multiple multiway relays as shown by Fig. 3. In Fig. 3, it is shown the increase of theoretical capacity limits to the throughput at around 1.8 packets/slot achieved by average network rate of 0.5. The details can be seen in [14].

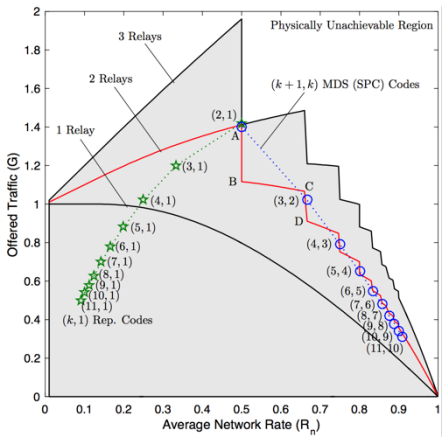

Fig. 3 New theoretical capacity limits for wireless super-dense networks involving multiple multiway relays [14].

(2) New wireless network capacity bound for wireless networks exploiting side information.

Surprisingly, Fig. 4 shows the improvement of networks capacity limit to the value of almost double only by exploiting the side information from the neighboring nodes. The details can be found in [15].

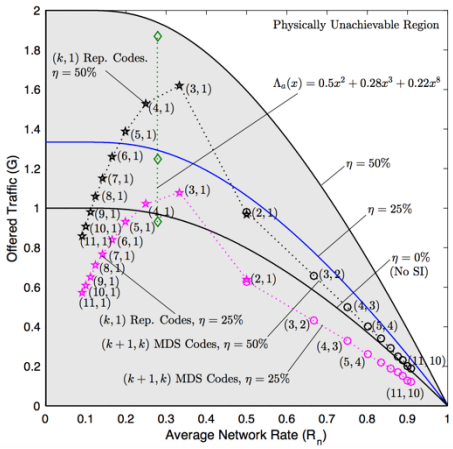

Fig. 4 New theoretical capacity limits for wireless super-dense networks exploiting side information available from neighboring nodes [15].

(3) New decoding technique for multiple multiway relay.
The new decoding schemes are divided into two parts, the complexity of which is similar and low.

① Decoding for multiple multiway relays. This decoding scheme works by exchanging erasure probability between two different factor graphs. One graph from the main relay and another graph from the additional relays as shown in Fig. 5.

② Decoding for networks exploiting side information. Similar to the above description, this decoding also exchanges erasure probability between two graphs. However, we found that the number of connecting edges is maximum half of the total edges, due to in practices, it is rare that all neighbors are connected.

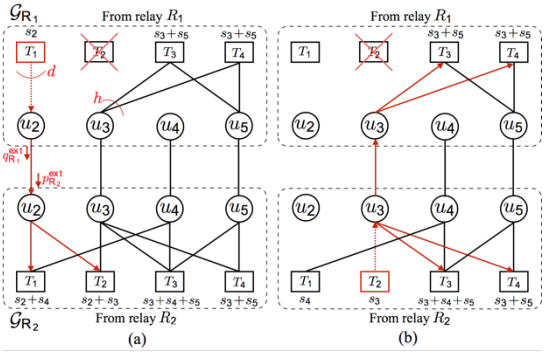

Fig. 5 New decoding technique for wireless networks with multiple multiway relays [14]

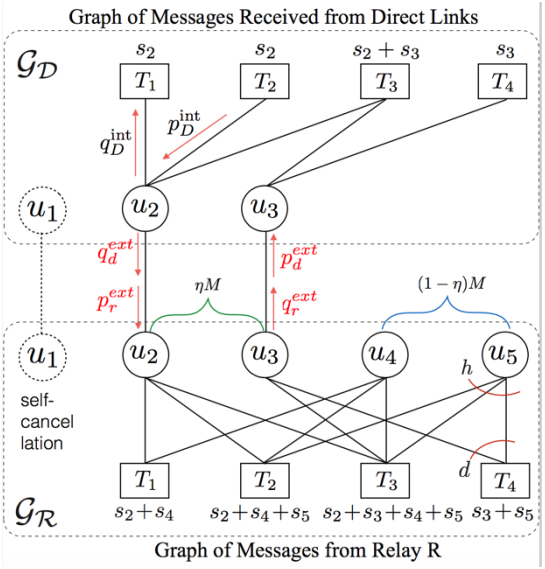

Fig. 6 New decoding technique for wireless networks exploiting side information from neighboring nodes [15].

(4) Explicit error-floor analysis for finite-length setting for low latency communications [17].

(5) Induced degree distribution due to Rayleigh fading channels [13],[17]

(6) Optimal degree distributions suitable for coded random access with and without multiuser detections (MUD) capability [J1].

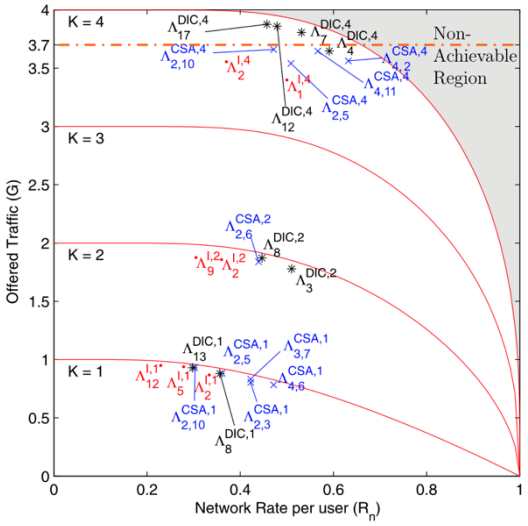

Fig. 7 New network capacity bound [J1].

The network capacity bounds for general multiuser detection (MUD) with capability of K={1, 2, 3, 4} are shown in Fig. 8. This figure confirms the bound and approached coding schemes in practice. It is excellent that the bound can also be approached with several coding schemes in practice with carefully designed degree distributions. The detailed of the design can be found in [J1].

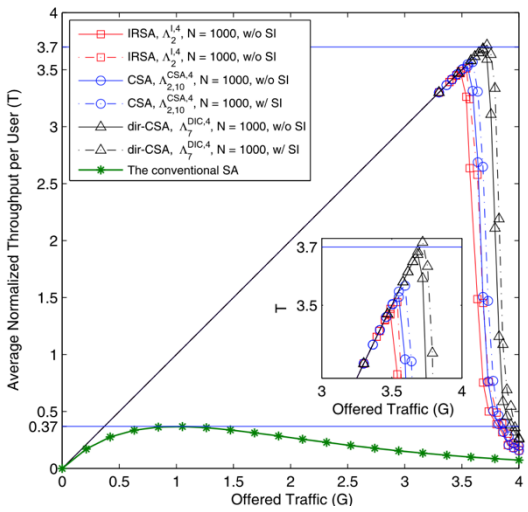

Fig. 8 Increase of network capacity 1000% or 10x compared with the

conventional slotted ALOHA [J1].

In Fig. 9, we confirmed that practically we can achieve 1000% capacity improvement with the optimal degree distributions obtained via EXIT chart analysis.

From the results of this project, we learned and reveals many things including the analysis of super-dense networks are even possible to be analyzed using EXIT chart.

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〔その他〕

1. http://www.jaist.ac.jp/~anwar-k/projects.html
2. http://anwarkhoirul.staff.telkomuniversity.ac.id
3. https://www.ieice.org/cs/ns/jpn/esawards.html

One of our project results is awarded by IEICE General Conference in English Session forwarded to Mr. Mohammad Nur Hasan in NS 研究会 October 2016.

これまでの受賞研究

受賞年・受賞回	受賞研究
2016年 第4回	BS-3-39 「Estimating Source Correlation Online in Massive Multiway Multirelay Networks」 Mohammad Nur Hasan・Anwar Khoirul (JAIST)
	BS-3-42 「A Database-Assisted Collision Aware Data Channel Selection for V2V Communication: Practical Evaluation」 Hitoshi Nakao・Kazuya Tsukamoto・Masato Tsuru・Kazuya Tsukamoto (Kyushu Inst. of Tech.)
	BS-3-44 「Initial Evaluation of Acoustic Vehicle Count System utilizing Dynamic Time Warping」 Song Liu・Shigemi Ishida・Kohei Mimura (Kyushu Univ.)・Shigeaki Tagashira (Kansai Univ.)・Akira Fukuda (Kyushu Univ.)

Fig. 10 Award received by Mr. Mohammad Nur Hasan in Himeji, Japan, Oct. 2016.

６．研究組織

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