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Article / Book Information

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論 文 要 旨

THESIS SUMMARY

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学生氏名： Student's Name	白木 善史	指導教員（主）： Academic Advisor(main)	樺島 祥介　教授
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

In this study, we developed guidelines for designing long-lifetime sensor networks, in which many sensors gather information and send it to a fusion center, in most cases, via wireless communications. In the last two decades, sensor networks have attracted a great deal attention for monitoring the environment, infrastructure, and temperature on farms as well as for other engineering applications. One important issue in sensor network technology is how to prolong network lifetime, and much effort has been made to fabricate low-cost and high-capacity batteries and low-power-consumption sensors and develop energy-efficient network operating protocols. Here, we report two results as guidelines for designing long-lifetime sensor networks, which we obtained using statistical mechanics methods. One concerns the robustness of random networks, which can be used to estimate the lifetime and coverage of sensor networks with respect to sensor failures and other defects. The other reveals the typical reconstruction performance of distributed compressed sensing (DCS), which can compress data with low computational cost and reduce communication traffic and thereby contribute to realizing long-lifetime sensor networks.

To evaluate the robustness of random networks, we developed a scheme for evaluating the size of the largest connected subnetwork (giant component) in random networks when sites (nodes) or bonds (edges) are removed from the networks. For this purpose, we employed the cavity method from statistical mechanics of disordered systems. A random network is fairly regarded as a model of sensor networks, and the removal of sites and bonds corresponds to run out of batteries in sensor nodes and blocks of communications between sensor nodes, respectively. An advantage of our scheme is the capability of handling targeted attacks on sites/bonds in the presence of degree correlations beyond naive analyses on random failures (crashes) in networks without degree correlations. We apply our scheme particularly to random networks of bimodal degree distribution (two-peak networks), which have been proposed in earlier studies as networks robust against random failures of sites and targeted (random degree-dependent) attacks on them. Our analysis indicates that the correlations among degrees affect a network's robustness against targeted attacks on sites or bonds nontrivially depending on the details of network configurations. In addition, the size of the giant component and the percolation threshold, which means such a critical ratio of failures that the size of the giant component vanishes as $N \to \infty$, do not have the same tendency, especially when we consider the influences of bond attacks with various degree correlations.

To investigate how we can reduce communication traffic in sensor networks, we study the DCS problem with a noiseless measurement. The DCS framework provides an efficient and low-computational-cost compression scheme for multichannel signals that are sparse and highly correlated with one another. A signal model called the joint sparse model 2 (JSM-2) or multiple measurement vector problem, in which all sparse signals share their support, is especially important for dealing with practical problems such as arrayed acoustic sensors, magnetic resonance imaging, and magnetoencephalography. We here investigate typical reconstruction performance of two representative signal reconstruction schemes for JSM-2 problems. One is $\ell 2,1$-norm minimization reconstruction and the other is Bayesian optimal reconstruction. Employing the replica method of statistical mechanics, we show that the reconstruction performance of both schemes, which exploit the knowledge of the sharing of the signal support, overcomes that of the corresponding approaches for the single-channel compressed sensing problem. To validate our theoretical prediction, we also developed a computationally feasible approximate algorithm for performing the Bayes optimal based on the belief propagation (BP) framework scheme. Our replica-based analysis numerically indicates that a fundamental reconstruction limit can be achieved by the BP-based approximate algorithm in a practical time when the number of channels is sufficiently large, for example 10. The results of numerical experiments for both reconstruction schemes excellently agree with the theoretical evaluation.

To reveal the reconstruction performance of the DCS problem in a more realistic situation, we also investigated the JSM-2 problem with noisy measurements for $\ell 2,1$-norm regularized least square and the

Bayesian optimal reconstruction scheme in terms of mean square error. Employing the replica method, we show that the performance of the schemes, which exploit the knowledge of the sharing of the signal support, overcomes that of the corresponding methods for the single-channel compressed sensing problem. The results of numerical experiments with the computationally feasible approximation algorithm we developed for this study agree with the theoretical prediction.

In conclusion, we revealed the robustness of random networks and the reconstruction performance of the DCS problem, which can serve as guidelines for designing long-lifetime sensor networks. We showed that the degree correlations in random networks significantly contribute to their robustness when they suffer from random failures and removal of important components, which correspond to hub sensor nodes and their communication paths in sensor networks. In addition, we clarified that increasing the number of channels (sensors) contributes to enhancing the reconstruction performance of DCS problems in both noiseless and noisy scenarios. By combining these two results, we can design energy-efficient scheduling of activating sensor nodes.