SCIENCE CHINA
Information Sciences

• LETTER •

August 2021, Vol. 64 189302:1–189302:2
https://doi.org/10.1007/s11432-020-2968-1

A sparse autoencoder-based approach for cell outage detection in wireless networks

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Received 14 February 2020/Revised 18 April 2020/Accepted 24 June 2020/Published online 2 June 2021

Citation Ma Z A, Pan Z W, Liu N. A sparse autoencoder-based approach for cell outage detection in wireless networks. Sci China Inf Sci, 2021, 64(8): 189302, https://doi.org/10.1007/s11432-020-2968-1

Dear editor,

To meet the requirement of rapid growth in the number of mobile terminals and demand for network service quality from users, wireless networks must implement faster and more intelligent network operation and maintenance functions. One feasible solution is referred to as self-organizing networks (SON) [1]. As a use case of SON, self-healing technology is aimed to detect and diagnose network faults automatically and recover from them.

Cell outage detection is the first step of self-healing in SON and has been widely researched. Xue et al. [2] adopted K-nearest neighbors (KNN) classification algorithm in a two-tier macro-pico cellular network to detect cell outages with users' key performance indicator (KPI). A novel ensemble framework based on support vector machine (SVM) for cell outage detection was proposed in [3]. Back propagation (BP) artificial neural network is employed in [4] to detect cell outages. A cooperative cell outage detection architecture that utilizes spatial correlations among users to decrease communication overhead and improve detection accuracy was proposed in [5]. An improved transductive confidence machine (TCM) learning algorithm-based cell outage detection scheme that performs well in the low user-density case was proposed in [6]. Genetic artificial bee colony (ABC) algorithm is applied in radial basis function (RBF) neural network for optimizing parameters of the neural network to improve cell outage detection accuracy in dense small cell network environment in [7]. Hussain et al. [8] firstly applied deep learning for cell outage detection utilizing deep neural network (DNN).

However, the high cell outage detection performance of the learning algorithms proposed in [1–8] is based on the premise of "large amount of data". Since wireless network cell outages are small-probability events, it is highly difficult to collect sufficient samples with cell outage events. Similar to [6, 7], although the algorithm proposed in [5] is capable of detecting cell outages with low user density, a large amount of users' reference signal received power (RSRP) data still needs to be collected to make predictions, and the high performance obtained using deep learning in [8] is based on the acquisition of huge dataset containing over ten million user logs, which is the main limitation acknowledged by the authors [8]. Generative adversarial network (GAN) is employed in [9] to synthesize more samples with outage events for cell outage detection, but the required sample size is not discussed. Therefore, it is indispensable to improve the performance of cell outage detection under the condition of "small-number samples collected".

Motivated by this, a cell outage detection algorithm based on sparse autoencoder where adopts synthetic minority over-sampling technique (SMOTE) is proposed in this letter. SMOTE is a sampling method that oversamples the minority class which rarely appears. Sparse autoencoder automatically learns features from unlabeled data and obtains an efficient representation from original samples. In the proposed algorithm, firstly, SMOTE is employed to preprocess by oversampling data with cell outage events via interpolation. Predictably, there is still room for improvement since SMOTE does not change the "primitive structure" of sample points. Thus, the sparse autoencoder is used to extract high-level features of original data and obtains an efficient representation of samples that is more effective for learning. Finally, the outputs of the hidden layer in sparse autoencoder are utilized for cell outage detection via Logistic regression (LR).

The main contribution of this letter is that a cell outage detection algorithm based on sparse autoencoder with SMOTE is proposed, which improves the detection rate under the condition of small-number samples collected. Compared to Logistic regression-based cell outage detection, there is up to 30% improvement in detection rate. Compared with existing techniques in cell outage detection, only a small number of samples are needed to guarantee a high detection rate.

System model. Consider a network where base stations are uniformly distributed as given in Appendix A. For each user i, a two-dimensional sample, i.e., reference signal received power (RSRP) and signal to interference plus noise ratio (SINR) is collected. Thus, the dataset collected can be represented as $S = \{(\boldsymbol{x}_1, y_1),$

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$(\boldsymbol{x}_2, y_2), \ldots, (\boldsymbol{x}_i, y_i), \ldots, (\boldsymbol{x}_m, y_m)\}$, where m denotes the total number of the samples collected. $\boldsymbol{x}_i = (\mathrm{RSRP}, \mathrm{SINR})$, y_i which equals 1 or 0 is the label of $\boldsymbol{x}_i$, indicating the status of the associated cell. $y_i = 1$ denotes that the cell is normal, $y_i = 0$ denotes the cell is in outage. All the samples collected are sent to a central network management unit for analysis.

Proposed algorithm. A cell outage detection algorithm based on sparse autoencoder is proposed. After collecting the dataset S in wireless networks, the synthetic minority over-sampling technique (SMOTE) is firstly employed to preprocess the samples in S by oversampling data points with cell outage events. Then the sparse autoencoder is trained to extract high-level features of samples preprocessed by SMOTE, obtaining a high-dimensional representation for more effective learning. In the last step of the proposed algorithm, the outputs of the hidden layer in sparse autoencoder are utilized for cell outage detection via Logistic regression. The proposed algorithm is shown in Appendix B.

Simulation results and analysis. In the simulation, 50 base stations are uniformly distributed within an area of 100 m × 90 m. The transmit power of one randomly chosen base station is set to decrease 25 dBm to simulate the cell outage [2, 5]. The more detailed parameter configuration is given in Appendix C.

Figure 1 illustrates the performance of the proposed algorithm. We can see that the detection rate of all algorithms improves with the increase of the number of collected samples because more information is utilized for detection, and the proposed algorithm shows the best performance and significant performance gain over Logistic regression. More simulation results are presented in Appendix C.

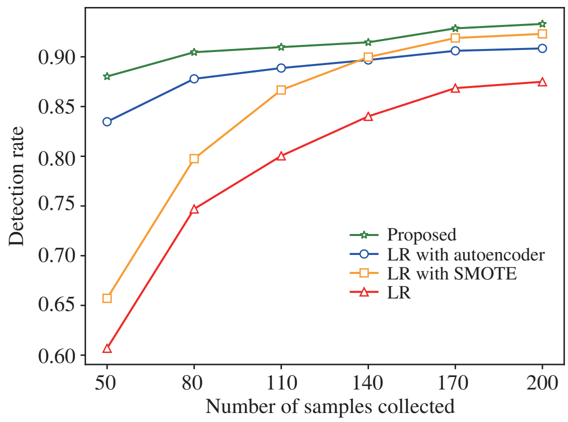

Figure 1 (Color online) Detection rate versus number of samples.

The Logistic regression-based scheme only learns limited information with small-sample size since there is no processing on the collected samples, whose performance is far worse than the proposed algorithm. In the proposed algorithm, SMOTE is firstly employed to interpolate reasonably between samples with outage events, which provides more effective information for cell outage detection, and sparse autoencoder is then utilized to extract advanced hidden features of samples to further improve the detection performance. Therefore, the proposed algorithm with SMOTE and sparse autoencoder performs best.

Conclusion. In this letter, a cell outage detection algorithm based on sparse autoencoder is proposed. SMOTE is firstly employed to preprocess by oversampling data with cell outage events. Then, the sparse autoencoder is used for extracting high-level features of original data, obtaining an efficient representation of samples. Finally, the outputs of the hidden layer in sparse autoencoder are utilized for cell outage detection via Logistic regression. The proposed algorithm shows significant detection rate gain over Logistic regression-based cell outage detection, especially for a small number of samples.

Acknowledgements This work was partially supported by National Key Research and Development Project (Grant No. 2018YFB1802402).

Supporting information Appendixes A–C. The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

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