

User grouping for NOMA-based sensor nodes for improved outage probability and throughput

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Abstract

In this study, relays are used to combine users grouped from two clusters of wireless sensor nodes. The relay is an amplifier and a forward node. The network consists of clusters of sensor nodes; the near and far cluster selects one of the users and pair them for signal transmission; and these nodes select a relay for transmission to sink. The sensors use non-orthogonal multiple access (NOMA) for multiuser uplink for the purpose of transmission and detection of signal. Outage probability and throughput of the sensor nodes for different combinations of power are compared over Rayleigh fading, and for the effectiveness of the work, Monte Carlo simulations are used. This study uses a hybrid approach that combines LoRa and NOMA nodes to achieve effective communication by utilizing both technologies.

Keywords

OMA, NOMA, WSN, User Grouping, relay, SIC, SINR

1. Introduction

Over the recent years, the utilization of wireless sensor networks (WSNs) in many fields is gaining attention for a variety of uses, e.g., monitoring, measuring, sensing, etc. in agriculture, industry, smart cities, medical care, etc. [1–3]. The inclusion of WSN has an advantage of adapting to the existing architecture that can be utilized without requiring additional costs of equipment and wiring (WSNs operate on radio except the backbone network), and they have additional advantage of fast connection and cloud. The WSN suffers from the data transmission problems when the larger number of devices generates massive amount of data [4]. The non-orthogonal multiple access (NOMA) technique is considered as an option that address this issue of massive amount of data and connectivity requirement in both downlink and uplink transmissions [5–7]. Multiple users can be supported while using the same time and frequency resources. This study focuses on creating a ground-based LoRa network that will eventually connect to

a satellite [8]. However, LoRaWAN networks have a problem with collisions when there are many devices trying to send data at once. This is especially problematic in crowded areas like cities. To fix this, we suggest a new method called Energy efficiency (EE)-LoRa. EE-LoRa helps LoRaWAN networks use less energy by choosing the right spreading factor and controlling the power of the gateways [9].

When a sensor node communicates with its relay or sink [10], it consumes maximum power at that time while operating in WSNs. The coverage area of sensor nodes is limited to adjacent nodes in WSNs; therefore, they rely on relay(s) to transfer information to sink node(s), which are located at farther distance. The WSNs when used for agriculture purpose are divided into different clusters in a way to cover the whole farm and reduce complexity, which makes the sensor nodes to connect with nodes in their own cluster only. Furthermore, in order to reduce consumption of energy consumption, the sensor nodes can be synchronized to transmit data at a predefined interval of time [10, 11]. NOMA is one of the key techniques for

5G and beyond next generation due to its capability to meet the demand of high rate and massive connectivity in both downlink and uplinks transmissions [12–16]. As compared to traditional orthogonal multiple access (OMA), it can provide support to more users while using the same time and frequency elements. The support to relaying provided by NOMA makes it more suitable candidate for WSNs. NOMA utilizes amplify-and-forward (AF) and decode-and-forward (DF) relaying system transmissions for cooperative communication, which can achieve astounding gain in the ergodic sum rate [17, 18].

The problems in WSNs can be used with the transition techniques combined with NOMA. Gomez et al. [19] used the uplink NOMA model with two users while using the DF relay for communication with base station. This study gives an in-depth system analysis by providing the formulas on throughput and system probability while adjusting SNR and transmitted power.

The remainder of this study is as follows. System model is given in Section 2.

II. System Model

In this model, a relaying system is used for uplink of the WSN as shown in Figure 1. The system consists of M sensor clusters, consists of N sensor nodes,

and has R relay nodes and a sink. Consider a sensor cluster is denoted by $m_i, 1 \leq i \leq M$, a sensor node in a cluster i is denoted by $n_{ij}, 1 \leq j \leq N$, and a relay used by j^{th} sensor node in i^{th} cluster is denoted by $r_k, 1 \leq k \leq K$. Two sensor nodes from two nearby clusters will do user grouping depending on their channel quality, and the relays are simple AF relays that forward it to the sink node. The sensor nodes in each cluster, relay, and sink can work only in half duplex mode.

The signals from paired sensor nodes n_{ij} and $n_{i+1,j+1}$ utilize the superposition principle of NOMA as follows:

Phase 1: Sensor nodes n_{ij} and $n_{i+1,j+1}$ send signals x_{ij} and $x_{i+1,j+1}$ to the selected relay r_k in the first half of

transmission block time (T) i.e. $\left(\frac{T}{2}\right)$.

Phase 2: In the second half $\left(\frac{T}{2}\right)$ of the period,

the selected relay receives the superimposed signal, amplifies it, and forward it to the sink. The sink then uses successive interference cancellation (SIC) to detect the individual signals x_{ij} and $x_{i+1,j+1}$ from nodes n_{ij} and $n_{i+1,j+1}$, respectively.

Mathematically,

In phase 1

The superposition signal received at selected r_k will be

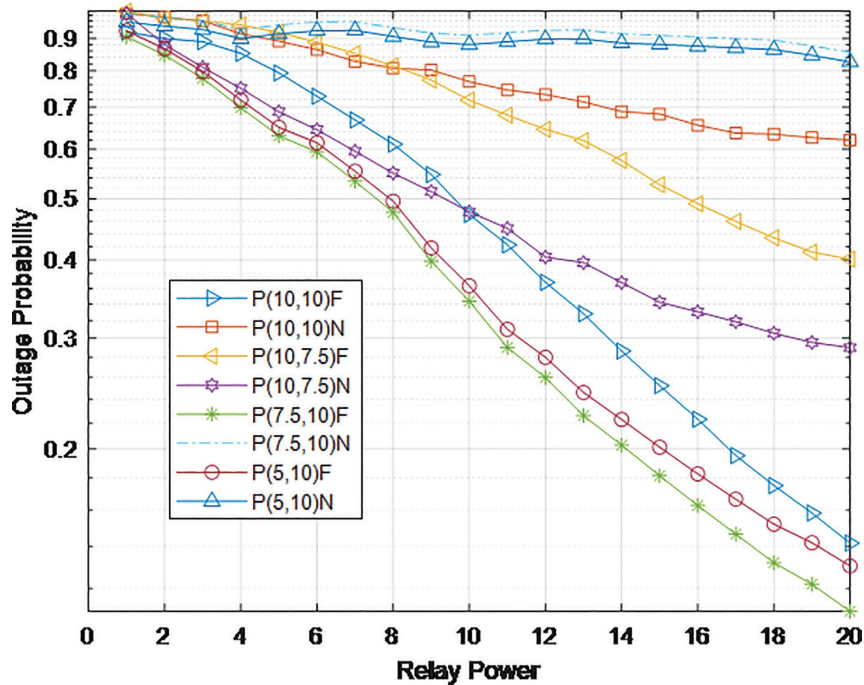


Figure 1: Outage probability compared with the relay power for varying power levels of near and far users.

$$y_k^{\text{rec}} = \sqrt{(\alpha_{i,j} P_{i,j})} h_{i,j}^k x_{i,j} + \sqrt{(\alpha_{i+1,j+1} P_{i+1,j+1})} h_{i+1,j+1}^k x_{i+1,j+1} + n_k \quad (1)$$

where $\alpha_{i,j} + \alpha_{i+1,j+1} = 1$, $\alpha_{i,j}$, $\alpha_{i+1,j+1}$ denotes the power coefficients of sensor nodes, $h_{i,j}^k, h_{i+1,j+1}^k$ denotes the Rayleigh fading channel coefficient of links between sensor nodes and relays, and n_k denotes AWGN noise with mean equals to zero and variance of σ^2 . The Rayleigh fading is used as it is a reasonable model to consider the ionospheric and tropospheric signal propagation while including effect of buildings and objects in the urban environment.

In Phase 2: By employing AF at relay r_k , the transmitted signal will be

$$y_k^{\text{trans}} = G_k y_k^{\text{rec}} \quad (2)$$

$$\text{where } G_k = \frac{P_k}{\sqrt{\alpha_{i,j} P_{i,j} (h_{i,j}^k)^2 + \alpha_{i+1,j+1} P_{i+1,j+1} (h_{i+1,j+1}^k)^2 + \sigma^2}},$$

and P_k is transmission power of relay r_k .

The received signal at sink will be

$$y_s = \frac{G_k y_k^{\text{trans}} h_s}{\sqrt{d}} + n_s \quad (3)$$

where h_s denotes the Rayleigh fading channel coefficient of links between the relay and the sink, d is the Euclidean distance between the relay and the sink, and n_k denotes AWGN noise with mean equals to zero and variance of σ^2 .

SIC can be applied to a user pair effectively when one user is the near user and another is the far user, assuming that n_{ij} is the near user and $n_{i+1,j+1}$ is the far user. Using SIC, the n_{ij} signal will be detected first due to better channel conditions, and its signal will be subtracted from the overall signal to detect the $n_{i+1,j+1}$ signal. The instantaneous SINR for the detection of signal $x_{i,j}$ is

$$\text{SINR}_{x_{i,j}} = \frac{\alpha_{i,j} P_{i,j} G_k^2 (h_{i,j}^k)^2 (h_s)^2}{\left(G_k^2 (\alpha_{i+1,j+1} P_{i+1,j+1}) (h_{i+1,j+1}^k)^2 + \sigma^2 \right) (h_s)^2 + \sigma^2 d} \quad (4)$$

$$\text{SINR}_{x_{i+1,j+1}} = \frac{\alpha_{i+1,j+1} P_{i+1,j+1} P_k (h_{i+1,j+1}^k)^2 (h_s)^2}{d (\alpha_{i,j} P_{i,j}) (h_{i,j}^k)^2 + d (\alpha_{i+1,j+1} P_{i+1,j+1}) (h_{i+1,j+1}^k)^2 + P_k (h_{i,j}^k)^2 + \sigma^2 d} \quad (5)$$

For any variable Z_i for exponent distribution, the probability density function (PDF) and cumulative distribution function (CDF) are calculated as follows:

$$f_{Z_i}(z) = \frac{1}{\mu} e^{-\frac{z}{\mu}} \quad (6)$$

Here, $\frac{1}{\mu}$ denotes the decay parameter.

$$F_{Z_i}(z) = 1 - e^{-\frac{z}{\mu}} \quad (7)$$

The outage probability for the detection of signals n_{ij} and $n_{i+1,j+1}$ is calculated using [20, 21].

III. Numerical Results and Discussion

For the simulation purpose, Monte Carlo simulation is used to evidence the parameters impact on transmitted power, number of sensor nodes, etc. [20, 21]. The simulation parameters are given.

The outage probability and throughput of the network are compared for different power levels of near and far users, P(10dBm, 10 dBm), P(7.5 dBm, 10 dBm), and P(5 dBm, 10 dBm); the 1st power denotes the power of the near user, and the 2nd power denotes the power of the far user. In Figure 1, the outage probability of near and far users is compared for different power combinations with varying relay powers. The outage probability depends on the SNR ratio of the signal, and from simulations, it is clear that when the relay power increases, the outage probability of both near and far users decreases. Also, when the power of users is high, the outage probability of user signals increases. Even when the near user power is 5 dB, it follows the same trend.

In Figure 2, the throughput of both near and far users is compared for different power combinations explained earlier, and when the power level of near and far users decreases, the throughput of the corresponding user decreases. The throughput compared here is the final throughput at the sink, and the intermediate throughput at the relay is not compared. Decreasing the power of users leads to the decrease in the throughput. When the near user power is 5 dB, the throughput decreases for the near user and increases for the far user.

In Figures 3 and 4, the outage probability and throughput of the network are compared when the number of nodes increases for increasing the relay power. When the number of nodes increases, interference in a cluster increases due to simultaneous

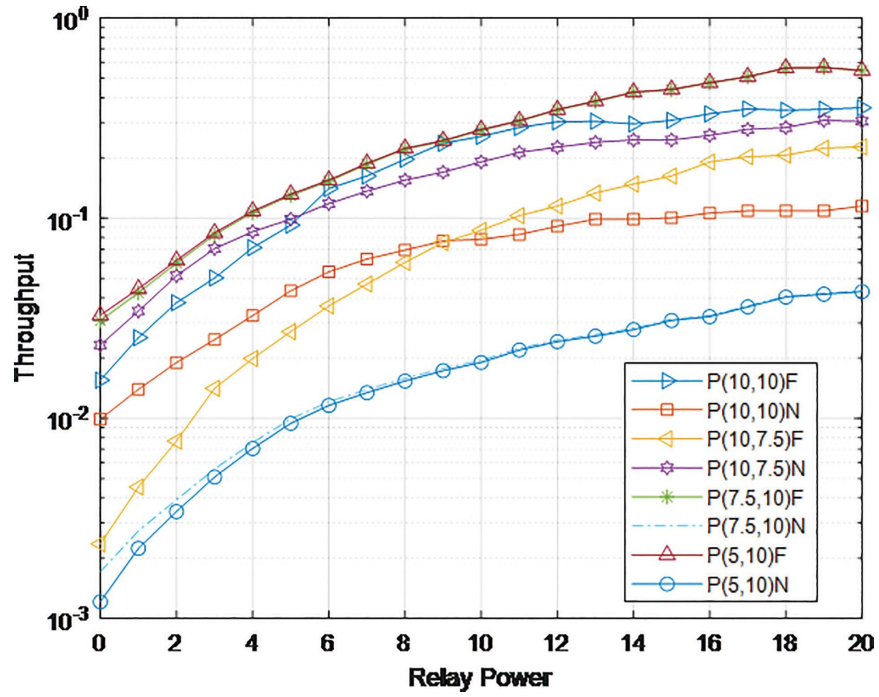


Figure 2: Throughput compared with the relay power for varying power levels of near and far users.

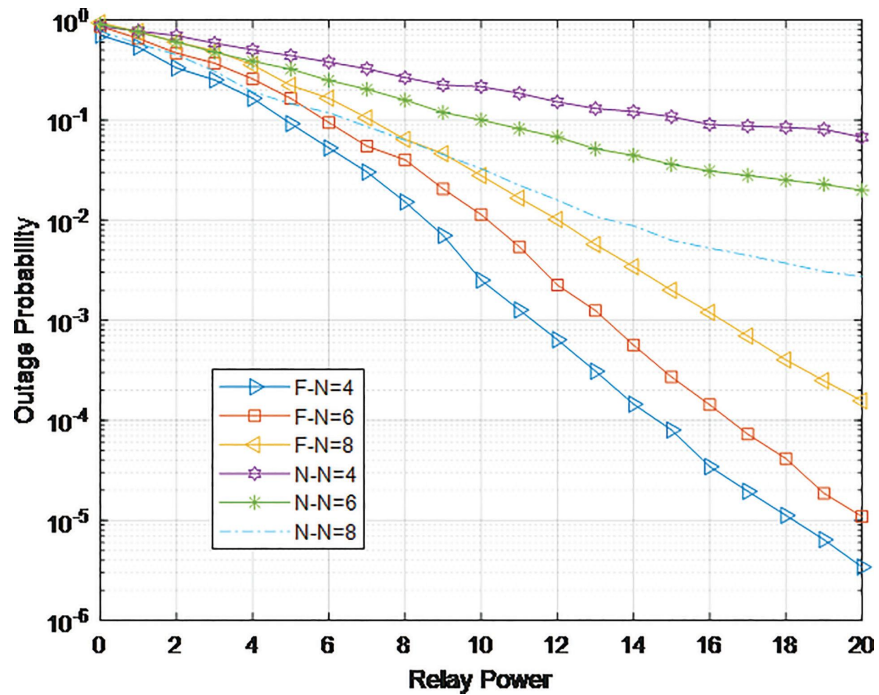


Figure 3: Outage probability compared with the relay power for different number of nodes in a cluster.

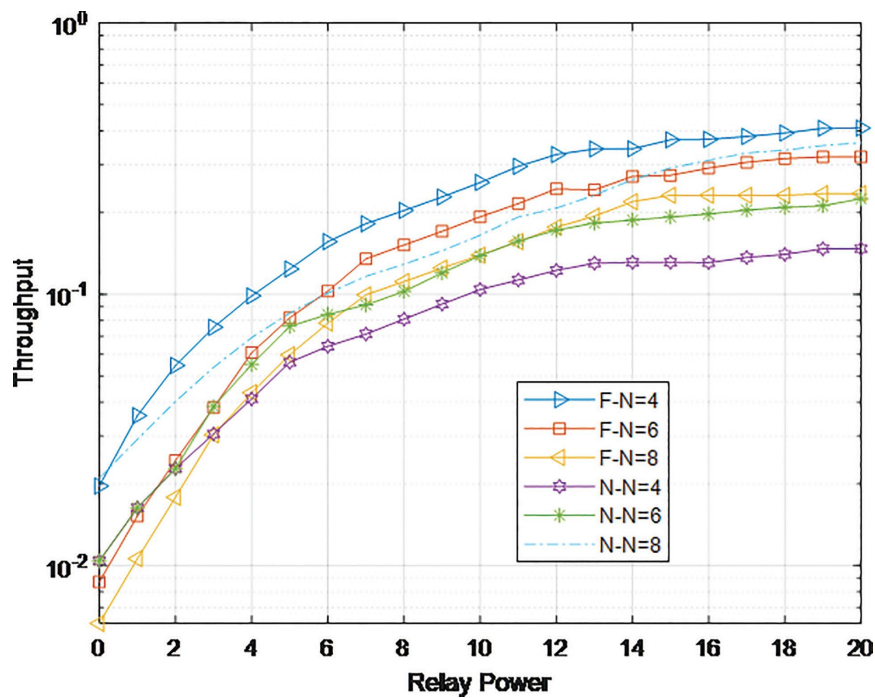


Figure 4: Outage probability compared with the relay power for different number of nodes in a cluster.

transmission of other users. When the number of near and far users are 4, the outage probability is minimum for both clusters, and when the number of users are 8, the outage probability is higher for near and far users. However, the outage probability decreases for both clusters when the relay power increases from 0 dBm to 20 dBm.

In results of Figure 4, the throughput of both clusters decreases with an increase in the number of nodes.

IV. Conclusion

In this study, the clustered sensor nodes utilize NOMA for the purpose of transmission to the sink node. The LoRa nodes operate mostly in the unlicensed spectrum, and employment of the larger number of LoRa nodes will create scarcity in the number of resources, due to which NOMA is used in this study that allows multiple transmissions in uplink by differentiating them based on their power levels. Due to the limitation of the coverage area of sensor nodes, the cluster's near and far nodes use relays, and the relay node uses AF on the received signal and transmits it to the sink. The outage probability and the throughput of the network are investigated while varying the transmitted power of the relay and powers of near and far nodes with a

variation in the number of nodes in a cluster. When the number of nodes is less, the throughput is higher and the outage probability is less.

References

- [1] M. M. Alam and E. Ben Hamida, "Wearable wireless sensor networks: Applications, standards, and research trends," in *Emerging Communication Technologies Based on Wireless Sensor Networks: Current Research and Future Applications*, 2016. doi: 10.1201/b20085-6.
- [2] S. Kurt, H. U. Yildiz, M. Yigit, B. Tavli, and V. C. Gungor, "Packet Size Optimization in Wireless Sensor Networks for Smart Grid Applications," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 3, 2017, doi: 10.1109/TIE.2016.2619319.
- [3] A. B. Noel, A. Abdaoui, T. Elfouly, M. H. Ahmed, A. Badawy, and M. S. Shehata, "Structural Health Monitoring Using Wireless Sensor Networks: A Comprehensive Survey," *IEEE Communications Surveys and Tutorials*, vol. 19, no. 3, 2017, doi: 10.1109/COMST.2017.2691551.
- [4] H. Harb, A. K. Idrees, A. Jaber, A. Makhoul, O. Zahwe, and M. A. Taam, "Wireless Sensor Networks:

A Big Data Source in Internet of Things,” *International Journal of Sensors, Wireless Communications and Control*, vol. 7, no. 2, 2017, doi: 10.2174/2210327907666170906144926.

[5] Z. Zhang, H. Sun, and R. Q. Hu, “Downlink and uplink non-orthogonal multiple access in a dense wireless network,” *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 12, 2017, doi: 10.1109/JSAC.2017.2724646.

[6] L. Dai, B. Wang, Y. Yuan, S. Han, C. L. I, and Z. Wang, “Non-orthogonal multiple access for 5G: Solutions, challenges, opportunities, and future research trends,” *IEEE Communications Magazine*, vol. 53, no. 9, 2015, doi: 10.1109/MCOM.2015.7263349.

[7] Z. Ding, M. Peng, and H. V. Poor, “Cooperative Non-Orthogonal Multiple Access in 5G Systems,” *IEEE Communications Letters*, vol. 19, no. 8, 2015, doi: 10.1109/LCOMM.2015.2441064.

[8] G. Gupta, R. Van Zyl, and V. Balyan, “Evaluation of LoRa nodes for long-range communication,” *Nonlinear Engineering*, vol. 11, no. 1, 2022, doi: 10.1515/nleng-2022-0236.

[9] A. Loubany, S. Lahoud, A. E. Samhat, and M. El Helou, “Improving Energy Efficiency in LoRaWAN Networks with Multiple Gateways,” *Sensors*, vol. 23, no. 11, 2023, doi: 10.3390/s23115315.

[10] H. Sahota, R. Kumar, and A. Kamal, “A wireless sensor network for precision agriculture and its performance,” in *Wireless Communications and Mobile Computing*, 2011. doi: 10.1002/wcm.1229.

[11] I. Khan, F. Belqasmi, R. Glitho, N. Crespi, M. Morrow, and P. Polakos, “Wireless sensor network virtualization: A survey,” 2016. doi: 10.1109/COMST.2015.2412971.

[12] Z. Ding, R. Schober, and H. V. Poor, “A General MIMO Framework for NOMA Downlink and Uplink Transmission Based on Signal Alignment,” *IEEE Trans Wirel Commun*, vol. 15, no. 6, 2016, doi: 10.1109/TWC.2016.2542066.

[13] Y. Liu, Z. Ding, M. Eikashlan, and H. V. Poor, “Cooperative non-orthogonal multiple access

in 5G systems with SWIPT,” in *2015 23rd European Signal Processing Conference, EUSIPCO 2015*, 2015. doi: 10.1109/EUSIPCO.2015.7362734.

[14] J. Zeng et al., “Investigation on Evolving Single-Carrier NOMA into Multi-Carrier NOMA in 5G,” *IEEE Access*, vol. 6, 2018, doi: 10.1109/ACCESS.2018.2868093.

[15] D. Wan, M. Wen, F. Ji, H. Yu, and F. Chen, “On the achievable sum-rate of NOMA-based diamond relay networks,” *IEEE Trans Veh Technol*, vol. 68, no. 2, 2019, doi: 10.1109/TVT.2018.2886845.

[16] D. Wan, M. Wen, F. Ji, H. Yu, and F. Chen, “Non-orthogonal multiple access for cooperative communications: Challenges, opportunities, and trends,” *IEEE Wirel Commun*, vol. 25, no. 2, 2018, doi: 10.1109/MWC.2018.1700134.

[17] W. Duan, X. Q. Jiang, M. Wen, J. Wang, and G. Zhang, “Two-Stage superposed transmission for cooperative NOMA systems,” *IEEE Access*, vol. 6, 2018, doi: 10.1109/ACCESS.2017.2789193.

[18] M. Xu, F. Ji, M. Wen, and W. Duan, “Novel Receiver Design for the Cooperative Relaying System with Non-Orthogonal Multiple Access,” *IEEE Communications Letters*, vol. 20, no. 8, 2016, doi: 10.1109/LCOMM.2016.2575011.

[19] G. Gomez, F. J. Martin-Vega, F. Javier Lopez-Martinez, Y. Liu, and M. El Kashlan, “Physical Layer Security in Uplink NOMA Multi-Antenna Systems with Randomly Distributed Eavesdroppers,” *IEEE Access*, vol. 7, 2019, doi: 10.1109/ACCESS.2019.2920578.

[20] V. Balyan, “Outage probability of cognitive radio network utilizing non orthogonal multiple access,” in *2020 7th International Conference on Signal Processing and Integrated Networks, SPIN 2020*, 2020. doi: 10.1109/SPIN48934.2020.9071401.

[21] V. Balyan and R. Daniels, “Resource allocation for NOMA based networks using relays: cell centre and cell edge users,” *International Journal on Smart Sensing and Intelligent Systems*, vol. 13, no. 1, 2020, doi: 10.21307/ijssis-2020-031.