An Efficient Power Allocation Algorithm for Improved System Performance in MIMO Two-Relay Wireless IoT Networks: A Heuristic Approach

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***Abstract*—In this paper, we propose an efficient algorithm to solve the energy allocation problem for the MIMO two-relay system, we exploit the advantages of energy distribution over space and the advantages of scattering to solve this problem and to maximize the data rate over parallel channels for MIMO two-relay system. Our proposed technique can be used to improve the performance of existing wireless networks and systems that use relays. When using a point to point connection, the water-filling algorithm was previously employed for parallel independent channels. Because the gains of channels are possible to be ordered just in one dimension, this approach clearly ends with the most efficient solution. The water-filling algorithm does not work in the MIMO two-relay system because the gains of channels correspond to separate paths. The performance of our proposed protocol is evaluated through simulations. Compared to the uniform energy allocation MIMO two-relay-based algorithms and MIMO single-relay algorithms, the results reveal that our proposed algorithm significantly improves system performance.**

***Index Terms*—IoT, Relay Node, MIMO, Water-filling Algorithm, Energy Allocation Problem.**

I. Introduction

Internet-of-Things (IoT) technologies have attracted much attention in various areas [1]–[3]. Despite the fact that smart connected items deployment has become a reality in our everyday lives, the following important issues have been raised [4], [5]. Over 60% of IoT applications must simultaneously accomplish wide wireless coverage, best battery life, high-speed wireless data, and low energy consumption [6]–[8]. Although some of the aforementioned needs may be met by the recently announced LoRa and NB-IoT protocols, the low-speed wireless data (about 50-250 kbps) represents a major barrier, preventing widespread adoption in many applications [4]. The low power aspect of several IoT technologies (e.g., 802.15.4/ZigBee and Bluetooth Low Energy) restricts the communication range, making them unsuitable for industrial applications like sensing of the environment and monitoring of machine weakness [4]. With its benefits in wide wireless coverage, high interference mitigation capabilities, and energy efficiency, cooperative communication is an excellent choice for addressing the aforementioned difficulties [4]. To relay data to far-off aggregation points in a multi-hop fashion, the authors of [9] use cooperative communications in a smart metering system. It is also used in cluster-based industrial IoT networks to improve quality of service and energy efficiency [10]–[12]. Blind cooperative transmission combined with multihop networking is used by the authors of [13] to reduce underlying protocol overhead and hence allow for scalability in the context of large-scale IoT.

Wireless relaying techniques are still an active area of research. Relaying techniques have recently attracted a lot of study attention because they can improve the communication range and coverage by supporting shadowed areas. MIMO relaying techniques are a key component of next-generation wireless networks because of these advantages [14], [15]. MIMO relays will be used in current and future generations of commercial wireless systems to provide enhanced coverage for high data rate services. An important problem in this domain is how the energy is allocated to maximize the aggregate data rate over parallel channels. In particular, how much energy should be allocated to each space channel in order to improve the throughput performance [16]. An effective algorithm for finding an efficient energy allocation for wireless channels is the water-filling algorithm [17]. With the water-filling energy allocation, more energy is allocated to better quality channels such that the achievable data rate of a communication system is maximized [18]. The water-filling algorithm applied on a single-link, because the values of channel gains can be set in one dimension, this algorithm provides an efficient solution. Because there are various channel gains for different paths in a MIMO relay system, the water-filling algorithm does not work. In [19], the authors provided strategies for resolving the problem of energy allocation in MIMO single relay systems. In this paper, we propose an efficient technique that takes advantage of the benefits of two-relay nodes to find the maximum aggregate data rate for MIMO two-relay system.

The organization of this paper is as follows: In Section II, we describe the system model. In Section III, we focus on energy allocation problem and how we solve this problem using our proposed algorithm. In Section IV, we present our simulation results. In Section V, we conclude this work and outline some possible future directions.

II. System Model

The MIMO two-relay system consists of a single transmitter i, two relay nodes (r_1,r_2), and a single receiver j, where

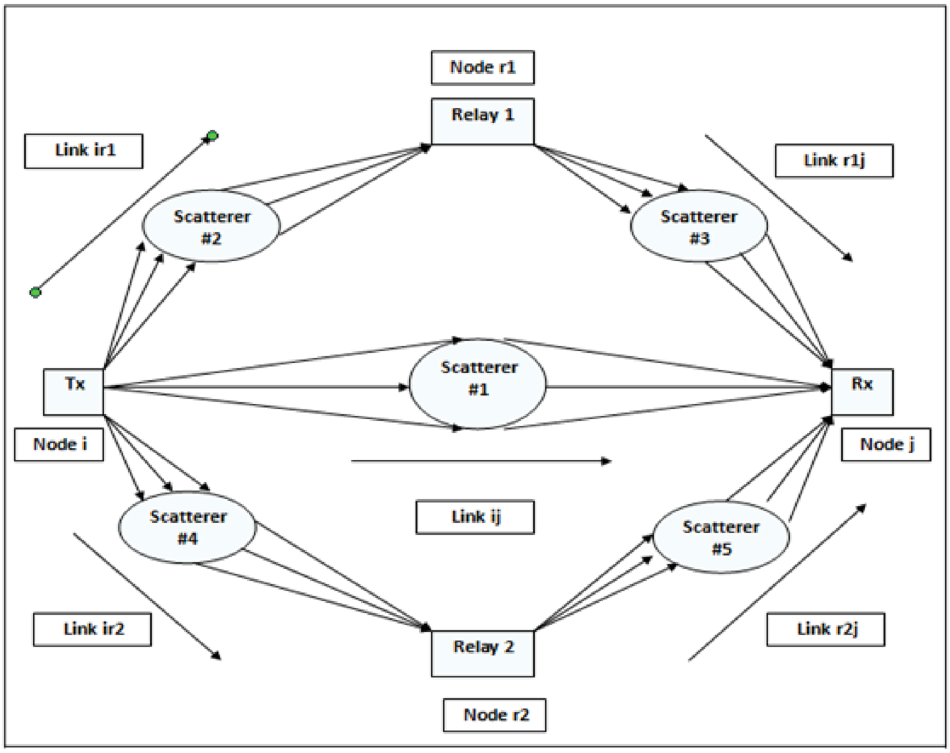

Fig. 1: An illustrative network model for a MIMO two-relay wireless system.

each node within the system equipped with MIMO antenna to utilize the space dimensions, and the location of each node depends on path loss and scattering as shown in Figure 1. The number of independent space channels on a single link is determined by the antenna array geometry and the scattering intensity of physical environments and given by [20]–[23]:

$$N = \frac{1}{\lambda^2} min\{A_i\Phi_i, A_j\Phi_j\} \tag{1}$$

Where N is the number of parallel spatial channels, λ is the wavelength of carrier, (Φ_i, Φ_j) are the scatterers' subtended solid angles, and (A_i, A_j) are the areas of antenna array of the transmitter and the receiver respectively [19]. In our work, we suppose that each of the transmitter, relay node and receiver has eight space dimensions on each link. In order to study the impact of signal scattering and path loss, we assume that each channel is static and each scatterer is lossless similar to [19].

We describe the control channels using the following protocol: First, transmitter node i receives CSI feedback from receiver node j, first relay node r_1 and second relay node r_2 as shown in Figure 1. Second, based on a total energy, the transmitter will solve the energy allocation problem, using our proposed heuristic algorithm. In addition to this, the transmitter matching the transfer data rates between data links (transmitter-first relay node) link and (first relay node-receiver) link and matching the transfer data rates between data links (transmitter-second relay node) link and (second relay node-receiver) link. Then, transmitter node sends the energy vectors allocated to first relay node and second relay node on a control channels. Finally, relay nodes will use the energy vectors to transmit data streams to the receiver.

We describe the data channels using the following protocol: First, transmitter sends parallel data streams on the three independent links (transmitter-first relay node) link, (transmitter-receiver) link and (transmitter-second relay node) link utilizing each link's energy vector. Then, on the (relay-receiver) link, each relay decodes the data received from the transmitter, re-encodes, and transmits the decoded data utilizing link's energy vector obtained from transmitter on the control channel. Finally, the receiver receives data from the transmitter, first relay, and second relay nodes at the same time.

III. ENERGY ALLOCATION PROBLEM AND A HEURISTIC ALGORITHM

We now investigate the problem of allocating energy that transmitter node i tries to solve. Let N_{lm} is the number of parallel spatial channels, $g_{lm}^{(n)}$ is the channel gain and $E_{lm}^{(n)}$ is the energy allocated to link lm on channel n where l can be transmitter i or relay node and m can be relay or receiver node j.

The transmitter node i should attempt at maximizing the aggregate data rate R, through exploiting the benefits of two-relay nodes r_1 and r_2. The optimization problem is given by:

$$\max \ R = \sum_{n=1}^{N_{ij}} log_2(1 + g_{ij}^{(n)} E_{ij}^{(n)}) + \sum_{n=1}^{N_{r_1 j}} log_2(1 + g_{r_1 j}^{(n)} E_{r_1 j}^{(n)}) + \sum_{n=1}^{N_{r_2 j}} log_2(1 + g_{r_2 j}^{(n)} E_{r_2 j}^{(n)})$$

$$subject \ to$$

$$\sum_{n=1}^{N_{ij}} E_{ij}^{(n)} + \sum_{n=1}^{N_{ir_1}} E_{ir_1}^{(n)} + \sum_{n=1}^{N_{r_1 j}} E_{r_1 j}^{(n)} + \sum_{n=1}^{N_{ir_2}} E_{ir_2}^{(n)} + \sum_{n=1}^{N_{r_2 j}} E_{r_2 j}^{(n)} \leq E_{total}$$

$$\sum_{n=1}^{N_{ir_1}} log_2(1 + g_{ir_1}^{(n)} E_{ir_1}^{(n)}) = \sum_{n=1}^{N_{r_1 j}} log_2(1 + g_{r_1 j}^{(n)} E_{r_1 j}^{(n)})$$

$$\sum_{n=1}^{N_{ir_2}} log_2(1 + g_{ir_2}^{(n)} E_{ir_2}^{(n)}) = \sum_{n=1}^{N_{r_2 j}} log_2(1 + g_{r_2 j}^{(n)} E_{r_2 j}^{(n)}) \quad (2)$$

The achieved data rate R is equal to the sum of direct and relay node data rates. The first constrain reflect the fact that the sum of total energy at the transmitter node, first relay node and second relay node must be less than or equal to the parameter E_{total}. The second and third constraints set ensure that the incoming and outgoing data rates links to be equal.

In our work, we proposed an efficient algorithm based on the work in [19] to solve our optimization problem for MIMO two-relay system using the following steps:

1) Before we run our algorithm, the values of channel gains in each link will be sorted in ascending order.
2) If the channel is used we assign label (1) otherwise (0).
3) We set all channels ones, then the constraints in (2) are solved.
4) If the proposed solution doesn't satisfy the constraints in (2), then the algorithm suggests 5 possibilities to solve the problem: In each of these proposed solutions, on only one of the links, the energy of the smallest channel gain value is equal zero, and the problem will be resolved again.
5) If a feasible solution is found, then the algorithm stops.
6) If a feasible solution not found, then the algorithm suggests five possibilities to solve the problem. In the remaining set of channels for each link, the energy of the smallest channel gain value is set to zero.
7) When the heuristic algorithm stops, we compared the different feasible solutions and the best solution is selected as shown in Figure 2.

The proposed heuristic algorithm solves our optimization problem with reasonable amount of computation time for high values of total energy and suffers a long computing time for small values of energies due to the quinary branching at each level. However, the complexity of our algorithm is a function of the number of spatial channels and total energy, Figure 3 shows the flow chart of the heuristic algorithm.

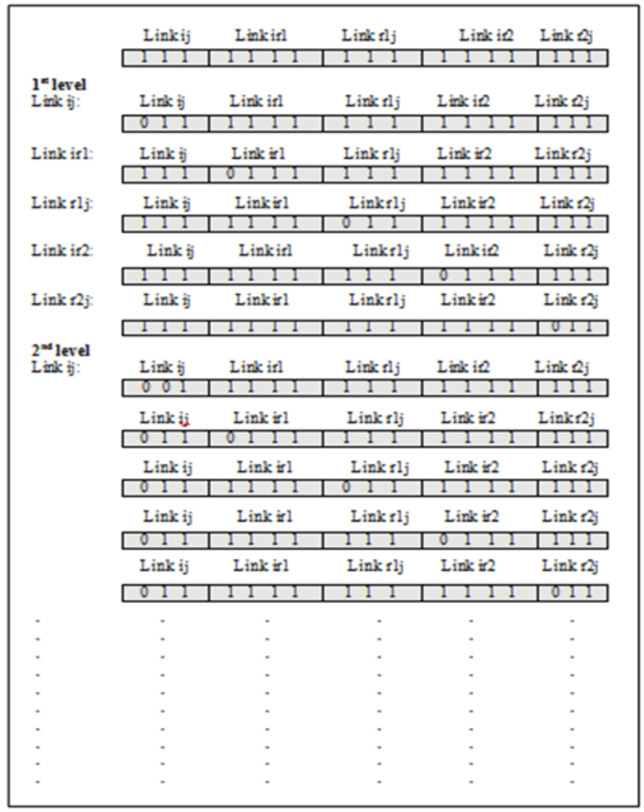

Fig. 2: Sample operation of the proposed heuristic algorithm.

IV. NUMERICAL RESULTS

In this section, we present our numerical results. First, we suppose that the noise energy at each node is approximately the same and each node in our system has eight space dimensions in each link, then we set the coordinate of transmitter node at (0, 0), receiver node at (2.5, 0), first relay node at (1.25, 1.25), and second relay node at (1.25, -1.25) on the xy plane as shown in Figure 4. The 8×8 channel gain matrix is assumed to be $L^{-n}M$ for each link where L is the distance between the transmitter node and receiver node, n is the path-loss exponent, and M is a matrix each of whose elements is a complex-GRV with variance 1.

Performance comparisons are made between our proposed algorithm and uniform energy allocations, and the performance of a single-link system and a system that uses relay nodes as shown in Figure 5, Figure 6 and Figure 7. Simulations show that significant improvements can be realized through the use of heuristic algorithm with relay nodes compared to direct transmissions without relay node(s) and without heuristic algorithm. In Figure 5, the energy allocated uniformly among channels. The relay nodes improve the aggregate data rate by shortening the distance between transmitter node and receiver node and by increasing the number of space independent channels in the system. In Figure 6, the heuristic algorithm allocates energy for the channels of the MIMO system in such a way that more energy is delivered to stronger channels and

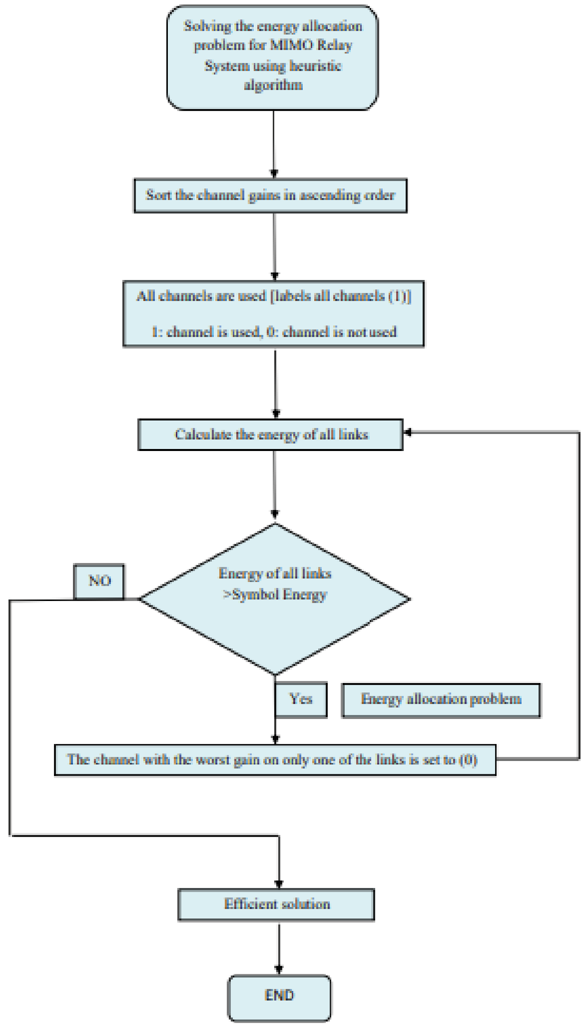

Fig. 3: Flow chart of the proposed heuristic algorithm.

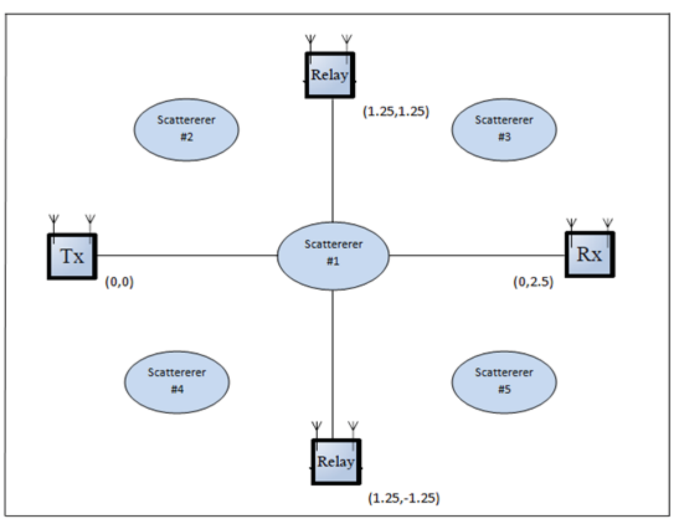

Fig. 4: Network Topology used in the Simulations.

less or no energy to the weaker channels then we can achieve a higher channel capacity and we observe that selecting two relays yields the highest capacity and the increase in capacity is smaller as more relays are included in the communication; this is due to the presence of the energy constraint for the relay nodes imposed in the system model. In Figure 7, we compare between our proposed algorithm with uniform energy allocation. In uniform energy allocation, the $(0.7E_{total})$ is allocated to transmitter i, the $(0.15E_{total})$ is allocated to r_1, and the $(0.15E_{total})$ is allocated to r_2; however, instead of heuristic energy allocation, an equal-energy allocation is utilized by relay node r_1 on the 8 spatial channels to receiver j, relay node r_2 on its 8 channels to receiver j, and by transmitter i on its total of 24 spatial channels to r_1, r_2 and j.

V. CONCLUSION

In this work, we proposed an efficient algorithm for MIMO two-relay system, this algorithm allocates more energy on the stronger channels and less or no energy to the weaker channels. Relay nodes also improve the aggregate data rate by shortening the distance between transmitter node and receiver node and by increasing the number of space independent channels in the system. We compared the performance of our algorithm with heuristic algorithm for the MIMO single relay channel and we showed that our algorithm achieves up to 35% increase in data rate over heuristic algorithm for the MIMO single relay channel. The heuristic algorithm in this work opens the way to develop practically efficient algorithms that use additional number of relay nodes in Wireless networks (i.e., IoT networks, Wireless LAN, etc.), But the generalization of our algorithm to systems that have a high number of nodes need to use better physical model for scatterer and to study the network cost of using relay nodes with MIMO antennas.

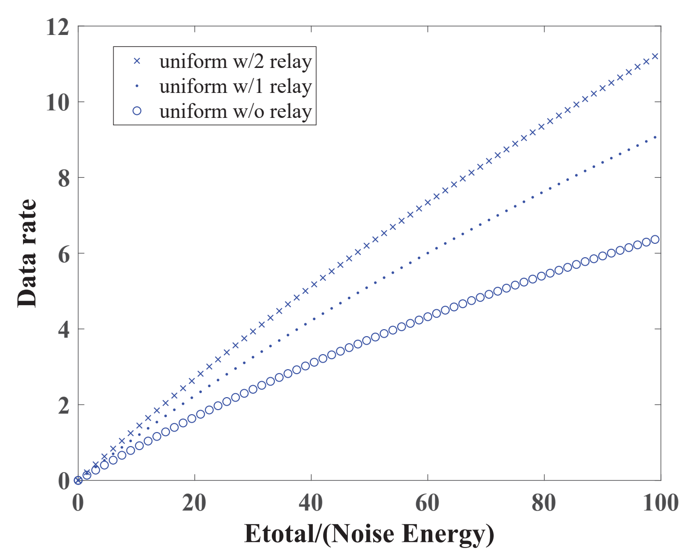

Fig. 5: Performance comparison for uniform energy allocation.

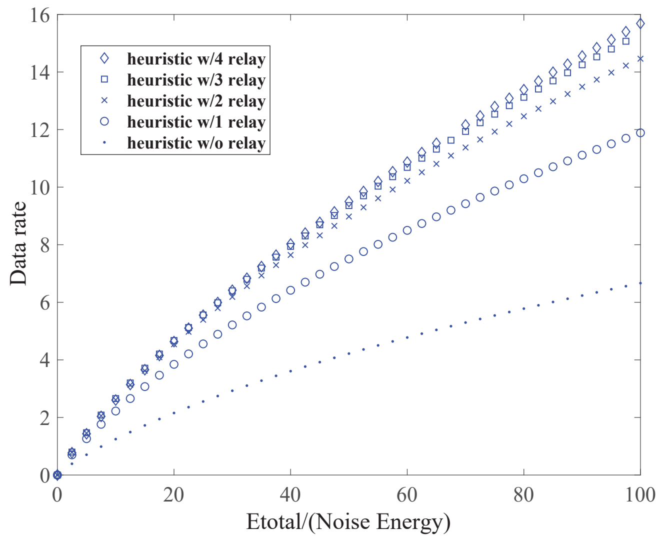

Fig. 6: Performance comparison for heuristic energy allocation.

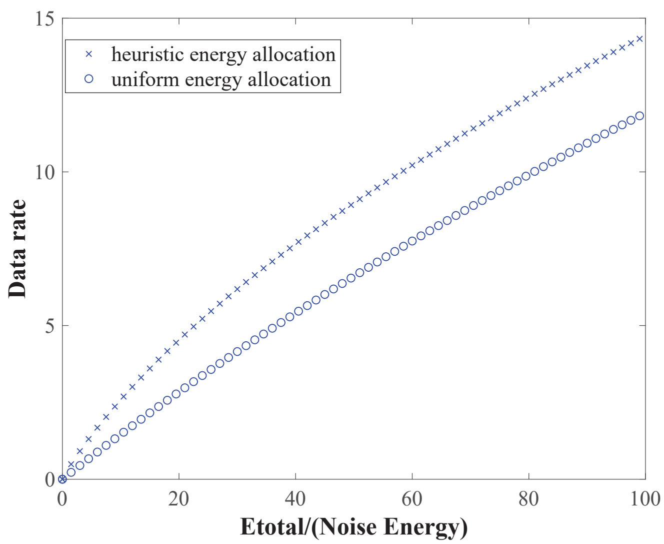

Fig. 7: Data rate for MIMO two-relay system (Heuristic vs. Uniform).

References

[1] H. B. Salameh, M. B. Irshaid, A. A. Ajlouni, and M. Aloqaily, "Energy-efficient cross-layer spectrum sharing in cr green iot networks," *IEEE Transactions on Green Communications and Networking*, pp. 1–1, 2021.

[2] Y. Shim, H. Park, and W. Shin, "Joint time allocation for wireless energy harvesting decode-and-forward relay-based iot networks with rechargeable and nonrechargeable batteries," *IEEE Internet of Things Journal*, vol. 8, no. 4, pp. 2792–2801, 2020.

[3] H. B. Salameh, S. Otoum, M. Aloqaily, R. Derbas, I. A. Ridhawi, and Y. Jararweh, "Intelligent jamming-aware routing in multi-hop iot-based opportunistic cognitive radio networks," *Ad Hoc Networks*, vol. 98, p. 102035, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1570870519306365

[4] X. Zhang, P. Huang, L. Guo, and M. Sha, "Incentivizing relay participation for securing iot communication," in *IEEE INFOCOM 2019-IEEE Conference on Computer Communications*. IEEE, 2019, pp. 1504–1512.

[5] H. Bany Salameh, S. Shtyyat, and Y. Jararweh, "Adaptive variable-size virtual clustering for control channel assignment in dynamic access networks: Design and simulations," *Simulation Modelling Practice and Theory*, vol. 106, p. 102197, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1569190X20301362

[6] Y. Li, K. Chi, H. Chen, Z. Wang, and Y. Zhu, "Narrowband internet of things systems with opportunistic d2d communication," *IEEE Internet of Things Journal*, vol. 5, no. 3, pp. 1474–1484, 2017.

[7] S. Almajali, H. B. Salameh, M. Ayyash, and H. Elgala, "A framework for efficient and secured mobility of iot devices in mobile edge computing," in *2018 Third International Conference on Fog and Mobile Edge Computing (FMEC)*, 2018, pp. 58–62.

[8] H. A. B. Salameh, S. Al-Masri, E. Benkhelifa, and J. Lloret, "Spectrum assignment in hardware-constrained cognitive radio iot networks under varying channel-quality conditions," *IEEE Access*, vol. 7, pp. 42 816–42 825, 2019.

[9] M. S. Omar, S. A. R. Naqvi, S. H. Kabir, and S. A. Hassan, "An experimental evaluation of a cooperative communication-based smart metering data acquisition system," *IEEE Transactions on Industrial Informatics*, vol. 13, no. 1, pp. 399–408, 2016.

[10] H. Bany Salameh, R. Tashtoush, H. Al-Obiedollah, A. Alajlouni, and Y. Jararweh, "Power allocation technique with soft performance guarantees in hybrid ofdma–noma cognitive radio systems: Modeling and simulation," *Simulation Modelling Practice and Theory*, vol. 112, p. 102370, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1569190X21000800

[11] L. Song, K. K. Chai, Y. Chen, J. Schormans, J. Loo, and A. Vinel, "Qos-aware energy-efficient cooperative scheme for cluster-based iot systems," *IEEE Systems Journal*, vol. 11, no. 3, pp. 1447–1455, 2017.

[12] L. Song, K. K. Chai, Y. Chen, J. Loo, and J. Schormans, "Cooperative coalition selection for quality of service optimization in cluster-based capillary networks," *IEEE Systems Journal*, vol. 12, no. 2, pp. 1700–1708, 2016.

[13] A. Bader and M.-S. Alouini, "Localized power control for multihop large-scale internet of things," *IEEE Internet of Things Journal*, vol. 3, no. 4, pp. 503–510, 2015.

[14] M. Asshad, S. A. Khan, A. Kavak, K. Küçük, and D. L. Msongaleli, "Cooperative communications using relay nodes for next-generation wireless networks with optimal selection techniques: A review," *IEEJ Transactions on Electrical and Electronic Engineering*, vol. 14, no. 5, pp. 658–669, 2019.

[15] S. S. . A. A. Bany Salameh, H., "Joint channel assignment and adaptive mode selection in MIMO-based cognitive radio networks," *Arab J Sci Eng*, vol. 45, p. 10233–10244, 2020.

[16] C. She, C. Yang, and L. Liu, "Energy-efficient resource allocation for MIMO-OFDM systems serving random sources with statistical qos requirement," *IEEE Transactions on Communications*, vol. 63, no. 11, pp. 4125–4141, 2015.

[17] C. K. Ho and R. Zhang, "Optimal energy allocation for wireless communications with energy harvesting constraints," *IEEE Transactions on Signal Processing*, vol. 60, no. 9, pp. 4808–4818, 2012.

[18] P. S. Bharathi, M. Balasaraswathi, M. Jayekumar, and S. Padmapriya, "Resource allocation based on hybrid water filling algorithm for energy efficiency enhancement in cognitive radio networks," in *2019 IEEE International Conference on System, Computation, Automation and Networking (ICSCAN)*. IEEE, 2019, pp. 1–8.

[19] T. Kang and V. Rodoplu, "Algorithms for the MIMO single relay channel," *IEEE transactions on wireless communications*, vol. 6, no. 5, pp. 1596–1600, 2007.

[20] G. J. Foschini and M. J. Gans, "On limits of wireless communications in a fading environment when using multiple antennas," *Wireless personal communications*, vol. 6, no. 3, pp. 311–335, 1998.

[21] S. Poon, R. W. Brodersen, and N. Tse, "The signal dimensions in multiple-antenna channels," in *GLOBECOM'03. IEEE Global Telecommunications Conference (IEEE Cat. No. 03CH37489)*, vol. 3. IEEE, 2003, pp. 1247–1251.

[22] V. Rodoplu and T. H. Meng, "Minimum energy mobile wireless networks," *IEEE Journal on selected areas in communications*, vol. 17, no. 8, pp. 1333–1344, 1999.

[23] ——, "Bits-per-joule capacity of energy-limited wireless ad hoc networks," in *Global Telecommunications Conference, 2002. GLOBECOM'02. IEEE*, vol. 1. IEEE, 2002, pp. 16–20.