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ORIGINAL RESEARCH

Energy efficient indoor localisation for narrowband internet of things

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Abstract

There are an increasing number of Narrow Band IoT devices being manufactured as the technology behind them develops quickly. The high co-channel interference and signal attenuation seen in edge Narrow Band IoT devices make it challenging to guarantee the service quality of these devices. To maximise the data rate fairness of Narrow Band IoT devices, a multi-dimensional indoor localisation model is devised, consisting of transmission power, data scheduling, and time slot scheduling, based on a network model that employs non-orthogonal multiple access via a relay. Based on this network model, the optimisation goal of Narrow Band IoT device data rate ratio fairness is first established by the authors, while taking into account the Narrow Band IoT network: The multi-dimensional indoor localisation optimisation model of equipment tends to minimize data rate, energy constraints and EH relay energy and data buffer constraints, data scheduling and time slot scheduling. As a result, each Narrow Band IoT device's data rate needs are met while the network's overall performance is optimised. We investigate the model's potential for convex optimisation and offer an algorithm for optimising the distribution of multiple resources using the KKT criterion. The current work primarily considers the NOMA Narrow Band IoT network under a single EH relay. However, the growth of Narrow Band IoT devices also leads to a rise in co-channel interference, which impacts NOMA's performance enhancement. Through simulation, the proposed approach is successfully shown. These improvements have boosted the network's energy efficiency by 44.1%, data rate proportional fairness by 11.9%, and spectrum efficiency by 55.4%.

KEYWORDS

artificial inteligence, detection of moving objects, internet of things

1 | INTRODUCTION

With the rapid development of Internet of Things technology in recent years, various Internet of Things applications (such as smart meters, smart manufacturing, smart homes, automatic driving, health monitoring, smart agriculture, and so on) have emerged, ushering in the era of the Internet of Everything [1–5]. IoT technology is the driving force behind enhanced monitoring and efficient control of the electrical network, from intelligent energy metres to the installation of sensors at crucial locations from the manufacturing plants to the distribution points. To meet the performance needs of giant machine-type communications in the Internet of Things and provide a pleasant service experience for Internet of Things users, mobile network ecological structure and resource management must be improved further [4–8]. A 3GPP-compliant cellular

IoT technology, known as NB-IoT, is recognised as being essential for addressing the needs of the Internet of Things [6, 8–10]. With very low bandwidth, Narrow Band IoT is implemented in the cellular networks in-band, guard band, and independent carrier. It therefore has a high degree of versatility and applicability, low power usage, thorough coverage, a variety of connections, and a reasonable price. However, in order to the meet network access needs for Narrow Band IoT, several cellular base stations must be installed. This will surely result in large energy consumption and greenhouse gas emissions [11, 12].

Energy use, particularly the use of fossil fuels, is widely acknowledged as the primary cause of climatic change and greenhouse effect. The negative environmental implications of this type of energy use result from both the energy consumption and the exploitation process. The burning of fossil fuels, which is connected to various economic activities, releases carbon dioxide into the atmosphere, which plays a significant role in climate change. Although rising energy demand encourages economic expansion, it also contributes to greenhouse gas emissions. This research integrates Non-Orthogonal Multiple Access (NOMA) [13], Energy Harvesting (EH) [12, 14–17], and relay technology [18] to accomplish green communication by effectively improving the data rate fairness of Narrow Band IoT devices and taking into account network spectrum efficiency and energy efficiency. The technique of choosing resource-saving communication and networking products and technology is known as 'green communication'. This approach applies to all forms of communication. With a battery life goal of over 10 years, NB-IoT is meant to increase the lifespan of gadgets. For this purpose, it has been determined that a careful design of smart channel coding schemes is a feasible strategy for improving NB-IoT energy efficiency. NOMA employs the Successive Interference Cancellation (SIC) method to allow numerous users to access the same frequency band while always obtaining the best channel capacity in this frequency band in the event of mutual interference. The maximum average mutual information is what is referred to as the channel capacity that can be sent over a discrete memoryless channel in a single instant of a signaling interval, as well as the probabilities of the maximum rate of trustworthy data transmission. A subset of channel capacity is what bandwidth can be viewed as. The maximum amount of information that can be precisely sent in each amount of time is taken into consideration while determining bandwidth. Channel capacity, for instance, can be quite high, but inadequate signal quality would result in limited bandwidth.

The 3GPP, the worldwide standards body in charge of all significant mobile telecommunications standards, produced the NB-IoT wireless telecommunications technology standard. While 4G LTE and other earlier wireless telecommunications protocols used the same sub-6 GHz wireless spectrum, NB-IoT (together with LTE-M) was created with the Internet of Things.

Compared with the traditional orthogonal access method, NOMA increases the system capacity under the same spectrum resource, reduces the user's transmission power under the same target rate, and saves user energy consumption. Orthogonal multiple access (MA) approaches coordinate how many users access the network, avoiding transmission collisions from various users. The three orthogonal multiple access protocols that are most often used are FDMA, TDMA, and OFDMA. In cellular systems, connectivity refers to multiuser access to the radio resources. The good performance of NOMA is suitable for networks with different channel gains between users, but for an industrial Internet of Things scenario where devices are densely distributed through the Narrow Band IoT long-distance connections, the channel gain discrimination between devices is relatively low. It will affect the performance advantages of NOMA. The EH relay technology can effectively improve the network access of long-distance Narrow Band IoT devices while reducing energy consumption. The EH relay uses the energy in the collection environment to supply power to the relay, which can effectively deal with energy consumption. In next-generation wireless communications, NOMA is one of the radio access strategies that shows the most promise. In contrast to orthogonal frequency division multiple access (OFDMA), the current de facto standard orthogonal multiple access (OMA) technique, NOMA offers a number of desirable potential benefits, including improved spectrum efficiency, reduced latency with high reliability, and massive connectivity. The fundamental principle of NOMA is to provide services to many customers at the same time, place, and frequency.

Additionally, during environmental harm and a lack of resources , the EH relay collects energy wirelessly as opposed to the grid's wired power supply, improving the flexibility of the relay's deployment. In addition, as opposed to battery power supplies, it does not require battery replacement or charging, resulting in less difficulty and expense associated with maintenance.

In recent years, research on NOMA, EH and relay technology has attracted much attention. Literature [19] considered a downlink NOMA relay scenario with a direct link, all nodes work in half-duplex mode, and in the case of fixed indoor localisation under the following conditions. In a half-duplex system, both sides can converse with one another, but not concurrently; only one channel of conversation is carried out at once. As an example of a half-duplex device, consider a walkie-talkie or two-way radio with a push-to-talk button. Data can be sent and retrieved one at a time in half-duplex mode. It is a multiple conversation, although taking place one at a time. The benefit of half-duplex mode is that both devices can transmit and receive data in this mode, and they can also use the entire capacity of the communication channel while sending data. Liu et al. studied the outage probability and average throughput of different relay strategies. Literature [18] designed a relay-assisted downlink NOMA framework, which uses two time slots to complete a transmission from the base station to the user, through the power spectrum efficiency is optimised by allocation. Literature [20] aimed at a downlink NOMA heterogeneous network with end-user energy collection, considering the uncertainty of channel parameters, and proposed an indoor localisation algorithm based on robustness to maximise energy efficiency. In the algorithm, different single variables are solved using the Lagrangian duality principle and the monotonicity principle, respectively. The variables based on the duality principle are iterated using the method of updating multipliers in the outer layer and updating variables in the inner layer, and on this basis, the combination of multiple variables is iterated until convergence. Authors suggest an optimisation approach combining coordinate gradient descent and CVX and employs the pre-existing, non-optimised SIC and non-linear EH models as a foundation. The multi-dimensional indoor localisation optimisation model of the equipment tends to minimize data rate, energy restrictions, EH relay energy and data buffer restrictions, data scheduling, and time slot scheduling. As a result, the network's overall performance is optimised while each Narrow Band IoT device's data rate requirements are met. We look at the model's potential for convex optimisation and present a method for KKT-optimised distribution of numerous resources. The IoT technology is the driving force behind improved electrical network monitoring and control, including the installation of sensors at strategic locations from production facilities to distribution terminals and intelligent energy meters. To deliver a positive customer experience while meeting the performance requirements of communications across massive machines in the Internet of Things.

The literature [21, 22] applied NOMA to the Narrow Band IoT network, and the simulation results show that compared with the non-orthogonal multiple access Narrow Band IoT network, the throughput and the number of user access of the NOMA Narrow Band IoT network have been greatly improved. In literature [23], in an EH relay NOMA downlink with two users, the system throughput is maximised by optimising the power split factor. The above literatures adopt their respective indoor localisation schemes, mainly considering the outage probability, throughput, network performance in terms of energy efficiency, power consumption etc., does not take into account the fairness among users and other performances. For different network structures, indoor localisation algorithms are still of great research significance. Similar to GPS location services, indoor location monitoring is used in enclosed spaces. Using cellphones, tracking tags, mobile devices, and other devices that provide indoor location tracking services, users can locate persons and property inside a building.

Through the application of EH and relay technology, the performance advantages of NOMA can be guaranteed. On the other hand, since the channel gain difference between Narrow Band IoT devices is retained, how to optimise the network performance while ensuring the quality of service of each Narrow Band IoT device becomes very important. The NB-IoT is a special narrowband radio technology made specifically for IoT with the purpose of reducing implementation costs. It may be quickly integrated in GSM or LTE networks. The Internet of Things can be implemented, nevertheless, thanks to certain other wireless communication technologies. Today, the Internet is widely used. It has an impact on practically every region of the world and on several facets of human life. In the case of given indoor localisation, NOMA continuously eliminates the interference of the decoded center Narrow Band IoT device (Narrow Band IoT device with the largest channel gain) signal from the superimposed signal through the continuous interference elimination mechanism during decoding, reducing the interference of the edge Narrow Band IoT device. In the upcoming years, it is projected that Internet of Things (IoT) growth would quicken. The ever-expanding IoT applications, however, cannot be supported by the available wireless spectrum. Concurrent wireless communications are allowed, and decoding the overlaid signal is a possible approach. A viable approach to improving spectrum efficiency in the face of intense competition for resources is to permit concurrent wireless transmissions and carefully decode the superimposed signals. PNC calls for a relay node as a helper, which is incompatible with the usual situation that calls for the overlaid signal to be directly decoded at the receiver.

NB-IoT is built on the LTE design, with some changes made to meet the mMTC standards. Numerous IoT use cases, such as smart wearables, smart cities, and smart homes, are projected to be addressed by massive connectivity. Lag devices can be installed in hard-to-reach areas because these activities don't require high throughput or frequent reporting.

The interference received by devices (Narrow Band IoT devices with the smallest channel gain) improves the performance of edge Narrow Band IoT devices, promotes fairness among Narrow Band IoT devices, and improves network performance. In indoor localisation management, if only network performance is considered, and ignoring the performance of a single Narrow Band IoT device, then the central Narrow Band IoT device will get the best resources, while the edge Narrow Band IoT devices will get the worst resources, that is, Narrow Band IoT devices with smaller channel gain will not get good services [24]. Concurrent wireless communications are permitted, and one method is to decode the signal that is being superimposed. In the face of fierce competition for resources, allowing concurrent wireless transmissions and carefully decoding the superimposed signals is a possible strategy for increasing spectrum efficiency. PNC specifies a relay node as a helper, which conflicts with the typical scenario, which specifies that the overlay signal be decoded directly at the receiver. NB-IoT is based on the LTE architecture, with minor modifications needed to comply with mMTC requirements. Massive connectivity is expected to be used to handle several IoT use cases, including smart wearables, smart cities, and smart homes. Due to the fact that these activities don't require high throughput or frequent reporting, lag devices can be positioned in difficult-to-reach places. Therefore, indoor localisation is considered from the perspective of maximising the fairness of the data rate ratio of Narrow Band IoT devices, so as to achieve the optimisation of system performance while satisfying the fairness between Narrow Band IoT devices. The most recent technology, NB-IoT, was discovered and standardised in a short period of time in response to consumer demand. NBIoT can effectively support the M-IoT application industry. This is a separate radio interface that is closely linked to LTE, as seen by its inclusion in the most recent LTE specifications [25, 26].

Narrowband transmission offers coverage and capacity expansion, which is a benefit [27]. The NB-IoT design heavily borrows from legacy LTE. The NB-IoT technology is suitable for users sending small amounts of sparsely spaced, delay-tolerant data. The deployment of NB-IoT has also been facilitated and accelerated by the ubiquitous coverage, scalability, and cohabitation with LTE network. Additionally, as NB-IoT runs in regulated channels, interference take advantage of the advancements made possible by the RIS technology, which enables software-defined control of the electromagnetic properties of the wireless medium [28, 29]. In accordance with the suggested solution, the positioning of the target is accomplished by one initial signal transmitted by one base station (BS) and three additional signals reflected by three RISs (selected from a set of available RISs), thereby requiring significantly less infrastructure and lowering implementation costs.

The main contributions of this paper are as follows:

(1) For the uplink EH relay NOMA Narrow Band IoT network model, with the proportional fairness of Narrow Band IoT equipment data rate as the optimisation goal, considering the minimum data rate requirements of Narrow Band IoT equipment, taking into account the energy of Narrow Band IoT equipment, EH relay energy and data cache constraints, the establishment of a multi-dimensional indoor localisation problem model that combines power allocation, data scheduling (bit scheduling) and time slot scheduling. The problem model is a non-convex optimisation problem, and it is difficult to obtain an analytical solution directly.
(2) In view of the non-convex optimisation characteristics of the optimisation problem, the convex optimisation characteristics of the optimisation problem are discovered through variable substitution and logarithmisation. Based on the Lagrangian function and KKT conditions, a combination of gradient descent and sub-gradient descent is proposed using the multi-dimensional resource optimisation allocation algorithm.
(3) Through simulation experiments, the effectiveness of the proposed algorithm is verified. Compared with the traditional orthogonal multiple access Narrow Band IoT network, the proposed EH relay NOMA Narrow Band IoT network based on multi-dimensional resource optimisation allocation can effectively guarantee the edge Narrow Band IoT. The quality of service of the equipment improves the performance of the network and with the increase in the number of Narrow Band IoT devices connected to the network and the energy collected on the EH relay, the network performance is further improved.

The multi-dimensional indoor localisation optimisation model of equipment tends to minimize data rate, energy constraints and EH relay energy and data buffer constraints, data scheduling and time slot scheduling.

Section 1 provides the global overview of Narrow Band Internet of things; Section 2 covers the system model and problem modeling; Section 3 presents the algorithm design, Section 4 presents simulation experiment and analysis. The major conclusions drawn from the study in the Section 5.

2 | SYSTEM MODEL AND PROBLEM MODELING

Due to the existence of co-channel interference, the optimisation problem (1–3) is non-convex, but it can be transformed into an equivalent convex optimisation problem through a series of transformations and substitutions.

Introduce a new variable X_{d_n}, its expression is given below:

$$X_{d_n} = \frac{h_{d_n} p_{d_n}}{\sum_{j=n+1}^{N} h_{d_j} p_{d_j} + N_r}, \forall n \in N \tag{1}$$

Given X_{d_n}, the value of p_{d_n} can be calculated as follows:

$$p_{d_n} = \frac{x_{d_n} N_r}{h_{d_n}} \prod_{j=n+1}^{N} \left(x_{d_j} + 1 \right), \forall n \in N \tag{2}$$

At this time, the constraint condition Equation (4) can be rewritten as follows:

$$\frac{\tau x_{d_n} N_r}{h_{d_n}} \prod_{j=n+1}^{N} \left(x_{d_j} + 1 \right) \le \frac{E_{d_n}}{T} - \tau P_N, \forall n \in N \tag{3}$$

Introduce new variables s_{d_n} and $\overline{\tau}$, let $s_{d_n} = Q_{d_n} + \tau TRd_n$, $\overline{\tau} = 1 - \tau$, at this time, the constraints Equations (5) and (8) can be transformed into the following equivalent forms as given below:

$$Q_{d_n} \le s_{d_n} \le Q_{max}, \forall n \in N \tag{4}$$

$$\alpha_{d_n}^{-1} s_{d_n}^{-1} \le \frac{1}{TR_{min}}, \forall n \in N \tag{5}$$

When $\overline{\tau}$ is fixed, the amount of data sent by the EH relay node ($\overline{\tau} TR_r$) increases with the increase of the transmission power of the EH relay node. According to the causal relationship between B_{d_n} and R_r, the decisive role of p_r on R_r and pr is limited by the energy of E_r, substituting s_{d_n} into the expression Equation (2) of B_{d_n}, combined with the expression Equation (3) of R_r, without losing the optimality, the constraint conditions Equations (6) and (7) can be expressed as into the following equivalent form as given below:

$$\sum_{n=1}^{N} \alpha_{d_n} s_{d_n} \le \overline{\tau} T W_r \log \left(1 - \frac{h_r P_R}{N_s} + \frac{h_r E_r}{\overline{\tau} T N_s} \right) \tag{6}$$

Restriction Equation (6) works when $p_r = \frac{E_r}{\overline{\tau} T} - P_R$. Similarly, the restriction condition $s_{d_n} = Q_{d_n} + \tau TR_{d_n}$ can be equivalently transformed as follows:

$$s_{d_n} \le Q_{d_n} + \tau T W_s \log\left(1 + x_{d_n}\right), \forall n \in N \tag{7}$$

So far, through variable substitution, the optimisation problem Equation (3) is equivalently transformed into the following form as given below:

$$\begin{aligned} &\text{P2}: \min_{x,\alpha,s,\tau,\bar{\tau}} \prod_{n=1}^{N} \alpha_{d_n}^{-1} s_{d_n}^{-1} \\ &\text{s. t.} \quad \text{constraints (12)} \end{aligned} \tag{8}$$

$$0 \leqslant \tau + \bar{\tau} \leqslant 1$$

$$0 \leqslant \alpha_{d_n} \leqslant 1, \forall n \in \mathcal{N}, x_{d_n} \geqslant 0, \forall n \in \mathcal{N} \tag{9}$$

Among them, x, α and s are the vectors of $x_{d_n}{}'s, \alpha_{d_n}{}'s$ *and* $s_{d_n}{}'s$, respectively. From the optimal solution $x_{d_n}^*{}'s, x_{d_n}^*{}'s, x_{d_n}^*{}'s$ *and* τ^* of the optimisation problem Equation (17), the optimal solutions $p_{d_n}^*$ *and* pr^* can be further obtained as follows:

$$p_{d_n}^* = \frac{x_{d_n}^* N_r}{h_{d_n}} \prod_{j=n+1}^{N} \left(x_{d_j}^* + 1\right), \forall n \in \mathcal{N} \tag{10}$$

$$p_r^* = \frac{N_s}{h_r} \left(\exp\left(\frac{\sum_{n=1}^{N} \alpha_{d_n}^* s_{d_n}^*}{\bar{\tau}^* T W_r} \right) - 1 \right) \tag{11}$$

At this time, the restrictive conditions Equations (4) and (5) are in effect. According to Equations (6)–(8), the optimal solution of the problem Equation (3) can be obtained by solving the problem Equation (6). For the optimisation problem Equation (6), the following Theorem 1 holds.

Theorem 1 *Through one-to-one logarithmic domain transformation, the optimisation Equation (6) can be transformed into a convex optimisation problem.*

Proof Through logarithmic domain transformation, the objective function of problem Equation (6) can be written as $\sum_{n=1}^{N} - \left(\tilde{\alpha} d_n + \tilde{s} d_n\right)$, where $\tilde{\alpha}\, d_n$ and $\tilde{s}\, d_n$ represent logαdn and logsdn, respectively. Obviously $\sum_{n=1}^{N} - \left(\tilde{\alpha}\, d_n + \tilde{s}\, d_n\right)$ is convex, and it is proved that the objective function in the logarithmic domain is convex. The following proves that in the logarithmic domain, all constraints can be transformed into convex. Let $\tilde{\tau} = \log \tau$ *and* $\tilde{x}\, d_n = \log x d_n$, in the logarithmic domain the constraint condition Equation (2) can be written as follows:

$$\begin{aligned} &\tilde{\tau} + \tilde{x}_{d_n} + \sum_{j=n+1}^{N} \log\left(\exp(\tilde{x}_{d_j}) + 1 \right) \leqslant \\ &\log\left(\frac{E_{d_n}}{T} - \exp(\tilde{\tau}) P_N \right) + \log \frac{h_{d_n}}{N_r}, \forall n \in \mathcal{N} \end{aligned} \tag{12}$$

Since the original constraint Equation (2) is a monomial upper bound inequality constraint, its logarithmic form (i.e. constraint Equation (20)) is convex. The logarithmic constraints of Equations (3) and (4) are also convex. Through the logarithmic domain transformation, the constraints Equations (5) and (6) can be rewritten as follows:

$$\begin{aligned} &\log\left(\sum_{n=1}^{N} \exp\left(\tilde{\alpha}_{d_n} + \tilde{s}_{d_n} \right) \right) \leqslant \tilde{\bar{\tau}} + \log(T W_r) \\ &+ \log\log\left(1 - \frac{h_r P_R}{N_s} + \frac{\exp(-\tilde{\bar{\tau}}) h_r E_r}{T N_s} \right) \end{aligned} \tag{13}$$

$$\tilde{s}_{d_n} \leqslant \log\left(Q_{d_n} + \exp(\tilde{\tau}) T W_s \log\left(1 + \exp\left(\tilde{x}_{d_n} \right) \right) \right) \tag{14}$$

Because $1 - \frac{h_r P_R}{N_s} \le 1$, the Hessian matrix of the function on the right side of Equation (12) is a negative definite matrix, so the function is concave. At the same time, the left side of the inequality $\log\left(\sum_{n=1}^{N} \exp\left(\tilde{\alpha}_{d_n} + \tilde{s}_{d_n} \right) \right)$ is convex Therefore; the inequality constraint Equation (12) is convex. The logarithmic form of the remaining three constraints in the optimisation problem Equation (6) is obviously convex. Through the variable substitution in the logarithmic form, and the objective function and constraints one-to-one logarithmic field transformation, the optimisation problem Equation (6) is transformed into a convex optimisation problem. Theorem 1 is established, and the proof is completed.

3 | ALGORITHM DESIGN

The initial non-convex optimisation issue is transformed into a convex optimisation problem through variable substitution and logarithmisation, opening up the possibility of designing an algorithm based on KKT conditions. Additionally, KKT conditions can provide global optimality, providing a low-complexity algorithm for subsequent design and a baseline for performance evaluation. Next, figuring out the convex optimisation problem's ideal solution is begun. Based on the convexity of the optimisation problem, the optimal solution of the problem can be calculated using the KKT condition [30]. In the case of the specified indoor localisation, NOMA continuously reduces the interference of the edge Narrow Band IoT device by continuously removing the interference of the decoded center Narrow Band IoT device (Narrow Band IoT device with the largest channel gain) signal from the superimposed signal during decoding. Allowing concurrent wireless transmissions and carefully decoding the superimposed signals is one proposed tactic for boosting spectrum efficiency in the face of strong resource rivalry. Contrary to the normal case, which calls for the overlay signal to be directly decoded at the receiver, PNC provides a relay node as an assistance. With a few minor adjustments required to meet mMTC specifications, NB-IoT is based on the LTE architecture. Specifically, the Lagrangian function of the problem is given below:

$$
\begin{aligned}
&L(\tilde{\boldsymbol{x}}, \tilde{\boldsymbol{\alpha}}, \tilde{\boldsymbol{s}}, \tilde{\tau}, \tilde{\bar{\tau}}, \lambda, \boldsymbol{\mu}, \boldsymbol{v}, \xi, \sigma, \phi) \\
&= \sum_{n=1}^{N} -\left(\tilde{\alpha}_{d_n} + \tilde{s}_{d_n}\right) + \sigma\left(\exp(\tilde{\tau}) + \exp(\tilde{\bar{\tau}}) - 1\right) \\
&\quad + \sum_{n=1}^{N} \lambda_{d_n}\left(\tilde{\tau} + \tilde{x}_{d_n} + \sum_{j=n+1}^{N} \log\left(\exp(\tilde{x}_{d_j}) + 1\right)\right) \\
&\quad - \log\left(\frac{E_{d_n}}{T} - \exp(\tilde{\tau})P_N\right) - \log\frac{h_{d_n}}{N_r} + \sum_{n=1}^{N} \mu_{d_n}\left(\tilde{s}_{d_n} - \log\left(Q_{d_n}\right.\right. \\
&\quad \left.\left. + \exp(\tilde{\tau})TW_s \log\left(1 + \exp(\tilde{x}_{d_n})\right)\right)\right) \\
&\quad + \sum_{n=1}^{N} \nu_{d_n}\left(\log(TR_{min}) - \tilde{\alpha}_{d_n} - \tilde{s}_{d_n}\right. \\
&\quad + \xi\left(\log\left(\sum_{n=1}^{N} \exp\left(\tilde{\alpha}_{d_n} + \tilde{s}_{d_n}\right)\right)\right) = \tilde{\bar{\tau}} - \log(TW_r) \\
&\quad - \log\log\left(1 + \frac{h_r E_r \exp(-\tilde{\bar{\tau}})}{N_s T} - \frac{h_r P_R}{N_s}\right) \\
&\quad + \sum_{n=1}^{N} \phi_{d_n}\left(\tilde{s}_{d_n} - \log(Q_{max})\right)
\end{aligned} \tag{15}
$$

Among them, $\boldsymbol{\lambda}$, $\boldsymbol{\mu}$, $\boldsymbol{\nu}$ and $\boldsymbol{\phi}$ represent the vectors of $\lambda_{d_n}'\text{s}, \mu_{d_n}'\text{s}, \text{v}_{d_n}'\text{s}, \text{and} \varnothing\ \text{d}_n'\text{s},$ respectively. $\lambda d_n \geq 0, \mu d_n \geq 0, \nu d_n \geq 0, \xi \geq 0, \sigma \geq 0$ *and* $\varphi d_n \geq 0$ are the constraint conditions Equation (20), Equation (22), $\tilde{\alpha}_{d_n} + \tilde{s}_{d_n} \geq log(TR_{min})$, Equation (21), $exp(\tilde{\tau}) + exp(\overline{\tau}) \leq 1$ and $\tilde{s}_{d_n} \leq log(Q_{max})$ corresponds to the Lagrangian multiplier. The boundary inequality constraints $\tilde{s}_{d_n} \geq log(Qd_n)$ and $\tilde{\alpha}_{d_n} \leq 0$ can be restricted under the KKT condition.

After getting the Lagrangian function Equation (14), analyse the multi-objective and multi-dimensional optimisation characteristics of variables in the current problem. The method of updating multipliers in the outer layer and updating variables in the inner layer is used to iterate the variables based on the duality principle, and on this foundation, the combination of multiple variables is iterated until convergence. The pre-existing, non-optimised SIC and nonlinear EH models are used as a foundation for the authors' proposed optimisation strategy, which combines coordinate gradient descent with CVX. The variables in the current problem have multi-objective and multi-dimensional optimisation features.

If you want to calculate each variable and Lagrangian separately through direct one-to-one stability analysis for the optimal solution of multipliers, it is necessary to consider the characteristics of each variable and Lagrange multiplier relatively independently, and then use different sub-algorithms to solve according to the characteristics of each variable and Lagrange multiplier, and then combine these sub-algorithms to get the optimal solution of the problem, but this algorithm has a certain complexity. In addition, the algorithm highly related to each variable and Lagrange multiplier characteristics has certain limitations. From the perspective of practice and application, when the solution of the optimisation problem changes slightly, the original algorithm is likely to fail, which is not conducive to subsequent maintenance. Thanks to the transformation of the convex optimisation problem and the guarantee of the global optimality of the KKT condition, this paper designs a low-complexity algorithm. By minimising Lagrangian function Equation (14) and maximising the Lagrangian dual function $\boldsymbol{g}(\boldsymbol{\lambda}, \boldsymbol{\mu}, \boldsymbol{\nu}, \boldsymbol{\xi}, \boldsymbol{\sigma}, \boldsymbol{\phi})$ get the optimal solution to the indoor localisation problem, namely

$$
\begin{aligned}
g(\boldsymbol{\lambda}, \boldsymbol{\mu}, \boldsymbol{v}, \xi, \sigma, \boldsymbol{\phi}) = \underset{\tilde{\boldsymbol{x}}, \tilde{\boldsymbol{\alpha}}, \tilde{s}, \tilde{\tau}, \tilde{\tau}}{min}\ L\left(\tilde{\boldsymbol{x}}, \tilde{\boldsymbol{\alpha}}, \tilde{\boldsymbol{s}}, \tilde{\tau}, \tilde{\bar{\tau}}, \boldsymbol{\lambda}, \boldsymbol{\mu}, \boldsymbol{v}, \xi, \sigma, \phi\right) \\
\text{s. t. } \tilde{s}_{d_n} \geqslant \log\left(Q_{d_n}\right), \forall n \in \mathcal{N}\ \tilde{\alpha}_{d_n} \leqslant 0, \forall n \in \mathcal{N}
\end{aligned} \tag{16}
$$

$$
\begin{aligned}
&\underset{\lambda, \boldsymbol{\mu}, \boldsymbol{v}, \xi, \sigma, \boldsymbol{\phi}}{max}\ g(\boldsymbol{\lambda}, \boldsymbol{\mu}, \boldsymbol{v}, \xi, \sigma, \boldsymbol{\phi}) \\
&\text{s. t. } \forall\ \lambda_{d_n}, \forall \mu_{d_n}, \forall \nu_{d_n}, \xi, \sigma, \forall \phi_{d_n} \geqslant 0
\end{aligned} \tag{17}
$$

This paper proposes an optimal indoor localisation algorithm using the joint gradient descent method and sub-gradient descent method to solve Equations (14) and (15).

First, for the Lagrangian function L (•) carry out derivatives with respect to $\tilde{x}_{d_n}, \tilde{\alpha}_{d_n}, \tilde{s}_{d_n}, \tau \sim$ *and* $\overline{\tau}$, respectively, and get the below equations:

$$
\frac{\partial L(\cdot)}{\partial \tilde{x}_{d_n}} = \lambda_{d_n} + \frac{\exp(\tilde{x}_{d_n})}{\exp(\tilde{x}_{d_n}) + 1} \sum_{n'=1}^{n-1} \lambda_{d_n} - \mu_{d_n} \frac{TW_s \exp(\tilde{\tau}) \dfrac{\exp \tilde{x}_{d_n}}{(1 + \exp(\tilde{x}_{d_n}))\log 2}}{Q_{d_n} + TW_s \exp(\tilde{\tau}) \log_2(1 + \exp(\tilde{x}_{d_n}))} \tag{18}
$$

$$
\frac{\partial L(\cdot)}{\partial \tilde{\alpha}_{d_n}} = -1 - \nu_{d_n} + \xi \frac{\exp(\tilde{\alpha}_{d_n} + \tilde{s}_{d_n})}{\sum_{n=1}^{N} \exp(\tilde{\alpha}_{d_n} + \tilde{s}_{d_n})} \tag{19}
$$

$$
\frac{\partial L(\cdot)}{\partial \tilde{s}_{d_n}} = -1 + \mu_{d_n} - \nu_{d_n} + \xi \frac{\exp\left(\tilde{\alpha}_{d_n} + \tilde{s}_{d_n}\right)}{\sum_{n=1}^{N} \exp\left(\tilde{\alpha}_{d_n} + \tilde{s}_{d_n}\right)} + \phi_{d_n} \tag{20}
$$

$$
\frac{\partial L(\cdot *)}{\partial \tilde{\tau}} = \sum_{n=1}^{N} \lambda_{d_n} \frac{E_{d_n}}{E_{d_n} - TP_N \exp(\tilde{\tau})} + \sigma \exp(\tilde{\tau}) - \sum_{n=1}^{N} \left(\mu_{d_n} \times \frac{TW_s \log_2(1 + \exp(\tilde{x}_{d_n})) \exp(\tilde{\tau}^2)}{Q_{d_n} + \exp(\tilde{\tau}) TW_s \log_2(1 + \exp(\tilde{x}_{d_n}))}\right) \tag{21}
$$

$$\frac{\partial L(\cdot)}{\partial \bar{\tilde{\tau}}} = \sigma \exp(\bar{\tilde{\tau}}) - \xi + \frac{\frac{h_r E_r \exp(-\bar{\tilde{\tau}})}{N_s T + h_r E_r \exp(-\bar{\tilde{\tau}}) - h_r P_R T}}{\log\left(1 + \frac{h_r E_r \exp(-\bar{\tilde{\tau}})}{N_s T} - \frac{h_r P_R}{N_s}\right)} \tag{22}$$

Let $\left[\tilde{x}^{(k-1)}, \tilde{a}^{(k-1)}, \tilde{s}^{(k-1)}, \tilde{\tau}^{(k-1)}, \bar{\tilde{\tau}}^{(k-1)}\right]$ be the $(k-1)$ th Variables obtained by iterative update, $\left[\lambda^{(k-1)}, \mu^{(k-1)}, \nu^{(k-1)}, \xi^{(k-1)}, \sigma^{(k-1)}, \phi^{(k-1)}\right]$ is the Lagrangian multiplier obtained by the $(k-1)$ th iteration update, then the gradient descent direction of the variable can be expressed as follows:

$$\Delta_{\tilde{x}_{d_n}}^{(k)} = -\frac{\partial L(\cdot)}{\partial \tilde{x}_{d_n}}\bigg|_{\tilde{x}_{d_n}^{(k-1)}, \tau^{(k-1)}, \lambda^{(k-1)}, \mu_{d_n}^{(k-1)}} \tag{23}$$

$$\Delta_{\tilde{\alpha}_{d_n}}^{(k)} = -\frac{\partial L(\cdot)}{\partial \tilde{\alpha}_{d_n}}\bigg|_{\tilde{a}^{(k-1)}, \tilde{s}^{(k-1)}, v_{d_n}^{(k-1)}, \xi^{(k-1)}} \tag{24}$$

$$\Delta_{\tilde{s}_{d_n}}^{(k)} = -\frac{\partial L(\cdot)}{\partial \tilde{s}_{d_n}}\bigg|_{\tilde{a}^{(k-1)}, \tilde{s}^{(k-1)}, \mu_{d_n}^{(k-1)}, v_{d_n}^{(k-1)}, \tilde{\varepsilon}^{(k-1)}, \phi_{d_n}^{(k-1)}} \tag{25}$$

$$\Delta_{\tilde{\tau}}^{(k)} = -\frac{\partial L(\cdot)}{\partial \tilde{\tau}}\bigg|_{\tilde{x}_{d_n}^{(k-1)}, \tilde{\tau}^{(k-1)}, \lambda^{(k-1)}, \mu^{(k-1)}, \sigma^{(k-1)}} \tag{26}$$

$$\Delta_{\bar{\tilde{\tau}}}^{(k)} = -\frac{\partial L(\cdot)}{\partial \bar{\tilde{\tau}}}\bigg|_{\bar{\tilde{\tau}}^{(k-1)}, \xi^{(k-1)}, \sigma^{(k-1)}} \tag{27}$$

Secondly, the variables $\left[\tilde{x}^{(k)}, \tilde{a}^{(k)}, \tilde{s}^{(k)}, \tilde{\tau}^{(k)}, \bar{\tilde{\tau}}^{(k)}\right]$ in the Lagrangian function Equation (24) are updated by linear search. Specifically, get the following equations:

$$\tilde{x}_{d_n}^{(k)} = \tilde{x}_{d_n}^{(k-1)} + \kappa^{(k)} \Delta_{\tilde{x}_{d_n}}{}^{(k)} \tag{28}$$

$$\tilde{\alpha}_{d_n}^{(k)} = \left[\tilde{\alpha}_{d_n}^{(k-1)} + \kappa^{(k)} \Delta_{\tilde{\alpha}_{d_n}}{}^{(k)}\right]^{0} \tag{29}$$

$$\tilde{s}_{d_n}^{(k)} = \left[\tilde{s}_{d_n}^{(k-1)} + \kappa^{(k)} \Delta_{\tilde{s}_{d_n}}{}^{(k)}\right]_{\log\left(Q_{d_n}\right)} \tag{30}$$

$$\tilde{\tau}^{(k)} = \tilde{\tau}^{(k-1)} + \kappa^{(k)} \Delta_{\tilde{\tau}}{}^{(k)} \tag{31}$$

$$\tilde{\tau}^{(k)} = \tilde{\tau}^{(k-1)} + \kappa^{(k)} \Delta_{\bar{\tilde{\tau}}}^{(k)} \tag{32}$$

Among them, $[y]_a^b$ represents $max\{a, min\{y, b\}\}$. $\kappa^{(k)}$ represents the step size of the kth iteration. When updating variables $\tilde{x}^{(k)}, \tilde{a}^{(k)}, \tilde{s}^{(k)}, \tilde{\tau}^{(k)}, and\ \bar{\tilde{\tau}}^{(k)}$, the step size of each iteration can be different.

Then, update the Lagrangian multipliers $\left[\lambda^{(k)}, \mu^{(k)}, \nu^{(k)}, \xi^{(k)}, \sigma^{(k)}, \phi^{(k)}\right]$ with the subgradient descent method, the expression is as follows:

$$\lambda_{d_n}^{(k)} = \left[\lambda_{d_n}^{(k-1)} + \imath^{(k)}\left(\tilde{\tau}^{(k)} + \tilde{x}_{d_n}^{(k)} + \sum_{j=n+1}^{N} \log\left(\exp\left(\tilde{x}_{d_j}^{(k)}\right) + 1\right) - \log\left(\frac{E_{d_n}}{T} - \exp\left(\tilde{\tau}^{(k)}\right) P_N\right) - \log\frac{h_{d_n}}{N_r}\right)\right]_0 \tag{33}$$

$$\mu_{d_n}^{(k)} = \left[\mu_{d_n}^{(k-1)} + \imath^{(k)}\left(\tilde{s}_{d_n}^{(k)} - \log\left(Q_{d_n} + \exp\left(\tilde{\tau}^{(k)}\right) TW_s \log\left(1 + \exp\left(\tilde{x}_{d_n}^{(k)}\right)\right)\right)\right)\right]_0 \tag{34}$$

$$\nu_{d_n}^{(k)} = \left[\nu_{d_n}^{(k-1)} + \imath^{(k)}\left(\log(TR_{min}) - \tilde{\alpha}_{d_n}^{(k)} - \tilde{s}_{d_n}^{(k)}\right)\right]_0 \tag{35}$$

$$\xi^{(k)} = \left[\xi^{(k-1)} + \imath^{(k)}\left(\log\left(\sum_{n=1}^{N} \exp\left(\tilde{\alpha}_{d_n}^{(k)} + \tilde{s}_{d_n}^{(k)}\right)\right) - \tilde{\tau}^{(k)} - \log(TW_r) - \log\log\left(1 + \frac{h_r E_r \exp\left(-\tilde{\tau}^{(k)}\right)}{N_s T} - \frac{h_r P_R}{N_s}\right)\right)\right]_0 \tag{36}$$

$$\sigma^{(k)} = \left[\sigma^{(k-1)} + i^{(k)}\left(\exp\left(\tilde{\tau}^{(k)}\right) + \exp\left(\bar{\tilde{\tau}}^{(k)}\right) - 1\right)\right]_0 \tag{37}$$

$$\phi_{d_n}^{(k)} = \left[\phi_{d_n}^{(k-1)} + \epsilon^{(k)}\left(\tilde{s}_{d_n}^{(k)} - \log(Q_{max})\right)\right]_0 \tag{38}$$

Among them, ı(k) represents the step size of the kth iteration. Update the Lagrangian multipliers $\lambda^{(k)}, \mu^{(k)}, \nu^{(k)}, \xi^{(k)}, \sigma^{(k)}, and\ \phi^{(k)}$, the step size of each iteration can be different.

Repeat the above process until the cut-off condition is established. The cut-off condition is defined as follows: ε Here, ε is a small enough positive number, and $\Delta_{\tilde{x}}{}^{(k)}, \Delta_{\tilde{a}}{}^{(k)}, d\ \Delta_{\tilde{s}}{}^{(k)}, \Delta_{\tilde{\tau}}{}^{(k)}\ and\ \Delta_{\bar{\tilde{\tau}}}{}^{(k)}$ are the vector, the detailed steps of the optimal indoor localisation algorithm are shown in Figure 1. Commercial developers and researchers are interested in indoor localisation. In fact, the accessibility of localisation schemes, methods, and algorithms enables the addition of position data to already-existing communication applications

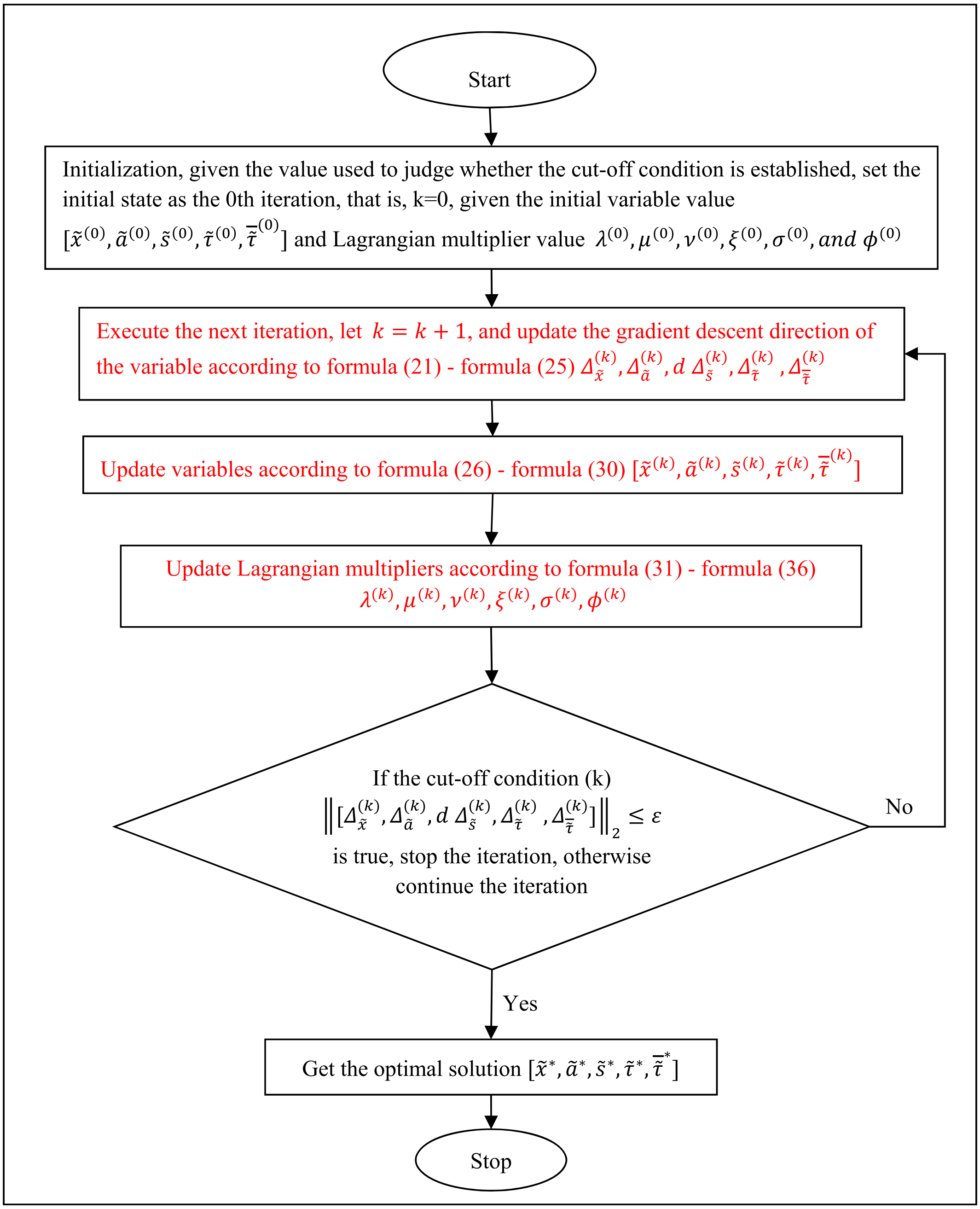


FIGURE 1 Flow chart of optimal indoor localisation algorithm.

and services. It is not simple to construct utilising short-range radio technology for localisation. In actuality, a number of factors, including building materials, nearby objects, the presence of humans etc., affect radio signal transmission inside structures.

3.1 | Theoretical analysis

The production of Narrow Band IoT devices is increasing as the technology for these devices develops quickly. However, because of significant co-channel interference and signal attenuation, it is still challenging to guarantee the service quality of edge Narrow Band IoT devices. The 3GPP-compliant cellular IoT technology known as NB-IoT is acknowledged as being essential for addressing the needs of the Internet of Things. Research on NOMA, EH, and relay technologies has gotten a lot of attention recently. Although NOMA performs well in networks with disparate channel gains across users, the channel gain discrimination between devices in an industrial Internet of Things scenario, where devices are dispersed widely over long-distance Narrow Band IoT connections, is quite low. The market is moving toward using the NB-IoT technology among all LPWA technologies.

Since NB-IoT is an open 3GPP standard, it offers flexible deployment options as well as broader market acceptance. It can coexist peacefully with current cellular technology. As a result of its commercial success, it has drawn countless businesses and numerous scholars from all over the world.

4 | SIMULATION EXPERIMENT AND ANALYSIS

4.1 | Parameter setting

The algorithm's performance is examined through simulation, and the simulation's setting parameters are as follows. Think about an uplink Narrow Band IoT network where the EH relay node and sink node are separated by 2000 m. The EH relay node's bandwidth in the fan-shaped region is set at 0.1 MHz, and the equipment sharing bandwidth is 180 kHz. (38 + 30log10 (d))dB (d is in m) [30–33] and (128.1 + 37.6log10 (d))dB (d is in km) [34] are the settings for the interior and outdoor channel fading models, respectively; 2GHz is the carrier frequency; the noise's power spectral density is configured to be −174dBm/Hz [35, 36]; the barebones data rate the demand is set to 64 kbps, the time slot length is set to 1 s, the energy collected on the EH relay is 2 J, the size of the data queue allotted by the EH relay to each Narrow Band IoT device is 1 Mbits. The battery energy in each Narrow Band IoT device is evenly distributed between 0.1 and 0.2 J.

4.2 | Performance analysis

The transmission method suggested in this study is compared with the conventional transmission scheme, and the transmission performance of FDMA is further investigated, in order to further examine the performance of the NOMA EH relay transmission scheme. In the FDMA transmission method, each Narrow Band IoT device receives an average distribution of the bandwidth that is shared by Narrow Band IoT devices in NOMA. In addition to examining whether the data rate ratio is fair, each scheme's network performance is also thoroughly examined by looking at its spectrum and energy usage.

4.2.1 | The impact of the number of narrow band IoT devices on performance

We discovered that when the number of Narrow Band IoT devices in the network grows, the fairness of the data rate ratio also grows, but the data rate attained by the Narrow Band IoT devices in the network falls. This is how we validated the algorithm's efficacy. By increasing the number of Narrow Band IoT devices from 2 to 16, the influence of the number of Narrow Band IoT devices on network performance is examined in order to better balance the network. The outcomes are displayed in Figure 2. Figure 2a,b depict how many Narrow Band IoT devices there are. The fairness of the network data rate ratio and spectrum efficiency continuously improve as the number of Narrow Band IoT devices grows. Figure 2c demonstrates how network energy efficiency declines as the number of Narrow Band IoT devices rises [37, 38]. This is primarily due to the fact that as the number of Narrow Band IoT devices rises, spectral efficiency rises, the bearing pressure on the EH relay rises, limited by the energy it harvests, the bearing support it offers to a single Narrow Band IoT device decreases, and the data rate obtained by a single Narrow Band IoT device decreases, all of which led to a decrease in energy efficiency and a decrease in network energy efficiency. Figure 2a–c, show the performance of NOMA and FDMA in comparison, and it is clear that NOMA consistently outperforms FDMA in terms of network performance. The data rate ratio of NOMA is reasonable when compared to that of FDMA with an increase of 11.9% on average, a rise in spectral efficiency of 55.4%, and an average rise in network energy efficiency of 44.1%.

4.2.2 | Influence of transmission distance from EH relay node to sink node on performance

The performance study of varying the transmission distance between the EH relay node and the sink node is shown in Figure 3. Transmission range shifts from 400 to 3200 m Figure 3 shows that as the transmission distance between the EH relay node and the sink node increases, the proportionate fairness of data rate, spectrum efficiency, and energy efficiency of NOMA steadily decline with increasing distance [39]. This is because longer transmission distances decrease the network's performance by reducing the channel gain from the EH relay node to the sink node and the data rate of the EH relay node. Similar results can be seen when comparing the performance of NOMA and FDMA in Figure 3a,c, where it is evident that NOMA performs better than FDMA in terms of spectrum efficiency, network energy efficiency, and data rate proportional fairness, increasing each by an average of 50.7%, 7.9%, and 7.9%, respectively.

4.2.3 | Impact of EH Relay Energy Harvesting on performance

Figure 4 shows the performance analysis in the case of changing the energy collected by the EH relay, and the energy collected by the EH relay changes from 0.5 to 4J.

Figure 4a,b show that the EH relay's data rate increases with the amount of energy it collects, the fairness of the data rate ratio increases, and the network's spectral efficiency increases. Using Figure 4b the rise in energy gathered by the EH relay cannot linearly improve the network throughput, as can also be observed from the fact that the spectral efficiency

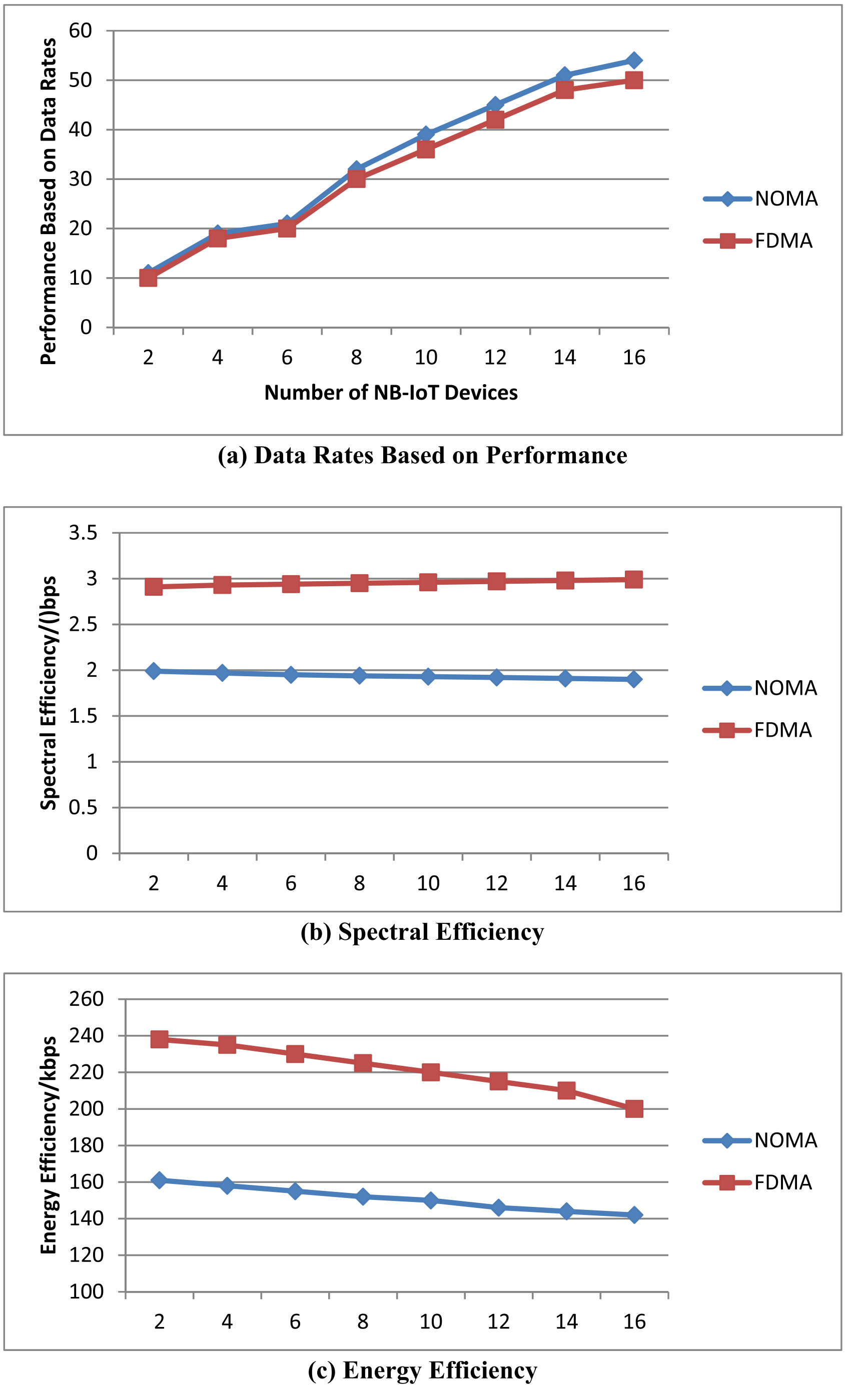
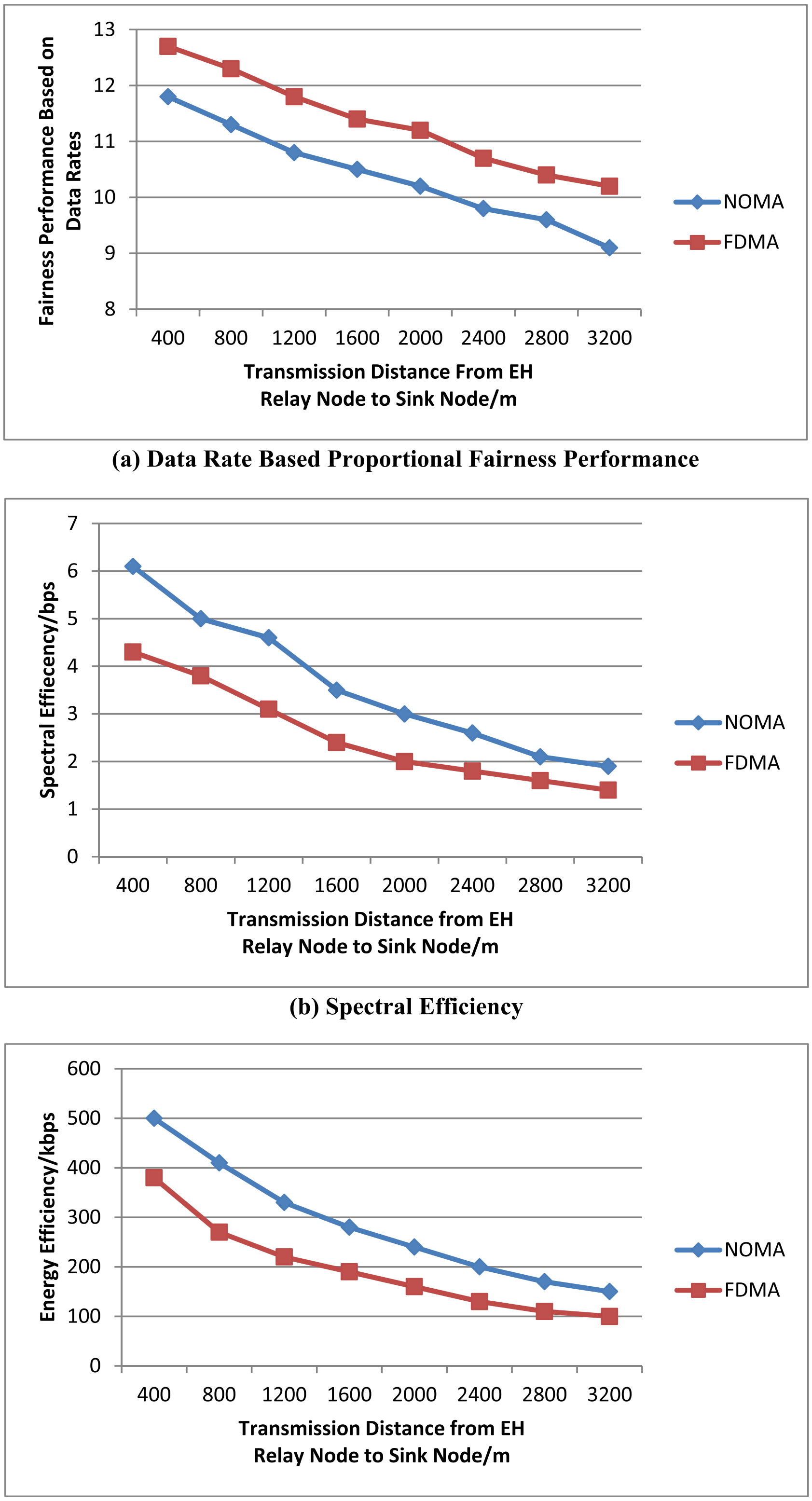


FIGURE 2 Performance analysis under the condition of changing the number of narrow band IoT devices. (a) Data rates based on performance. (b) Spectral efficiency. (c) Energy efficiency.

increases logarithmically about the increase in energy collected by the EH relay. As illustrated in Figure 4c, as the energy gathered by the EH relay increases, the energy efficiency of the network decreases. This is also evident from the data rate equation, which states that the data rate increases logarithmically with power. By boosting the energy gathered by the EH relay while not adding to the burden, we may rely on this advantage to improve the network's spectrum efficiency and data rate proportional fairness. Therefore, it is better than the conventional energy supply method. The performance of NOMA and FDMA may also be compared in Figure 4, which shows that NOMA performs better than FDMA on average in terms of data rate proportional fairness, spectrum efficiency, and network energy efficiency by 7%, 50.7%, and 42.8%, respectively.

In order to properly balance the network, the impact of the number of Narrow Band IoT devices on network performance is investigated by increasing the number from 2 to 16. The transmission performance of FDM as well as the standard transmission scheme are compared with the transmission method proposed in this work. This is mainly because as the quantity of Narrow Band IoT devices increases, spectral



(a) Data Rate Based Proportional Fairness Performance

(b) Spectral Efficiency

(c) Energy Efficiency

FIGURE 3 Performance analysis of changing the transmission distance from EH relay node to sink node. (a) Data rate based proportional fairness performance. (b) Spectral efficiency. (c) Energy efficiency.

efficiency increases, bearing pressure on the EH relay increases, limited by the energy it harvests, bearing support it provides to a single Narrow Band IoT device decreases, and the data rate attained by a single Narrow Band IoT device decreases, all of which result in a decrease in energy efficiency.

5 | CONCLUSION

This paper studies the application of NOMA and EH relay in Narrow Band IoT network, and proposes NOMA EH relay Narrow Band IoT network. Based on this network model, this

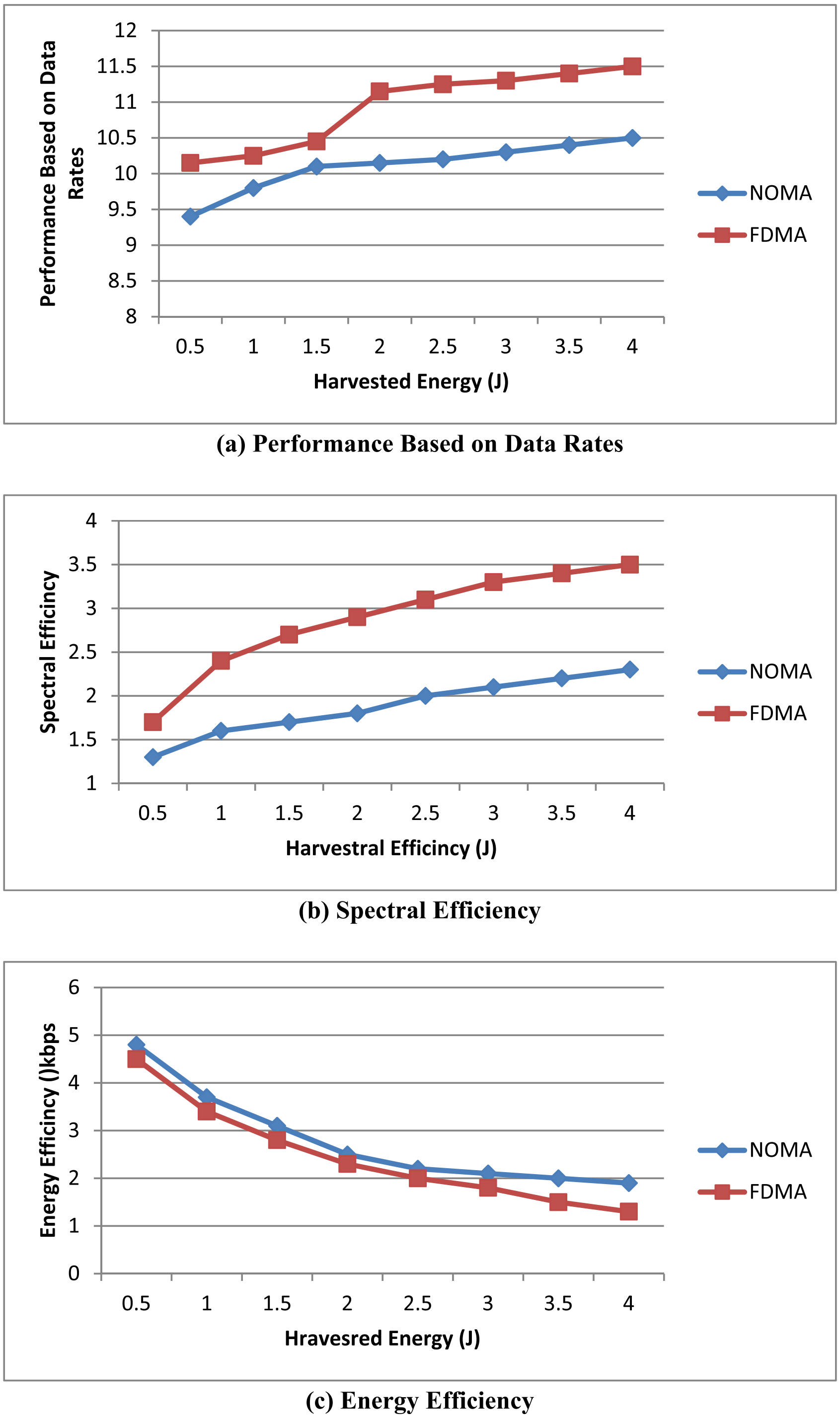


FIGURE 4 Performance analysis in the case of changing EH relay energy Harvesting. (a) Performance based on data rates. (b) Spectral efficiency. (c) Energy efficiency

paper first establishes the optimisation goal of Narrow Band IoT device data rate ratio fairness, while taking into account the Narrow Band IoT network. The multi-dimensional indoor localisation optimisation model of equipment tends to minimize data rate, energy constraints and EH relay energy and data buffer constraints, data scheduling and time slot scheduling. Variable conversion converts the non-convex optimisation issue into a convex optimisation problem. The best strategy for indoor localisation is suggested based on the Lagrange function and KKT conditions. The simulation results demonstrate the algorithm's effectiveness in obtaining the ideal indoor localisation strategy, and performance analysis reveals how it differs from the conventional average algorithm. As a result, NO-MA can significantly enhance the EH relay Narrow Band IoT network's performance compared to cross-multiple access. The current work primarily considers the NOMA Narrow Band IoT network under a single EH relay. However, the growth of Narrow Band IoT devices also leads to a rise in co-channel interference, which impacts NOMA's performance enhancement. Therefore, to ensure the high performance of the NOMA Narrow Band IoT network, we will investigate the multi-EH relay NOMA Narrow Band IoT network, optimise the transmission power and time slot scheduling, and jointly optimise the device grouping.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

1. Gerasimenko, M., et al.: Cooperative radio resource management in heterogeneous cloud radio access networks. In: IEEE Access, vol. 3, pp. 397–406 (2015). https://doi.org/10.1109/ACCESS.2015.2422266
2. Papanikolaou, V.K., et al.: Hierarchical multiple access (HiMA) for fog-RAN: protocol design and indoor localisation. In: IEEE Transactions on Wireless Communications, vol. 21, pp. 960–975 (2022). https://doi.org/10.1109/TWC.2021.3100538
3. Korrai, P., et al.: A RAN resource slicing mechanism for multiplexing of eMBB and URLLC services in OFDMA based 5G wireless networks. In: IEEE Access, vol. 8, pp. 45674–45688 (2020). https://doi.org/10.1109/ACCESS.2020.2977773
4. Liu, B., et al.: Indoor localisation for non-orthogonal multiple access-enabled fog radio access networks. In: IEEE Transactions on Wireless Communications, vol. 19, pp. 3867–3878 (2020). https://doi.org/10.1109/TWC.2020.2978843
5. Zhai, D., et al.: Energy-saving resource management for D2D and cellular coexisting networks enhanced by hybrid multiple access technologies. In: IEEE Transactions on Wireless Communications, vol. 16, pp. 2678–2692 (2017). https://doi.org/10.1109/TWC.2017.2671863
6. Li, Y., et al.: Joint indoor localisation and trajectory optimisation with QoS in UAV-based NOMA wireless networks. In: IEEE Transactions on Wireless Communications, vol. 20, pp. 6343–6355 (2021). https://doi.org/10.1109/TWC.2021.3073570
7. Tong, X., Li, X., Liu, Y.: Research on resource efficiency optimisation model of TDMA-based distributed wireless ad hoc networks. In: IEEE Access, vol. 8, pp. 96249–96260 (2020). https://doi.org/10.1109/ACCESS.2020.2993339
8. Zhang, Y., et al.: Indoor localisation in terrestrial-satellite-based next generation multiple access networks with interference cooperation. IEEE J. Sel. Area. Commun. 40(4), 1210–1221 (2022). https://doi.org/10.1109/JSAC.2022.3145810
9. Rahimi, P., et al.: Joint radio indoor localisation and beamforming optimisation for industrial internet of things in software-defined networking-based virtual fog-radio access network 5G-and-Beyond wireless environments. In: IEEE Transactions on Industrial Informatics, vol. 18, pp. 4198–4209 (2022). https://doi.org/10.1109/TII.2021.3126813
10. Li, N., et al.: Cooperative optimisation for OFDMA indoor localisation in multi-RRH millimeter-wave CRAN. In: IEEE Access, vol. 8, pp. 164035–164044 (2020). https://doi.org/10.1109/ACCESS.2020.3022363
11. Liao, Y., Yang, G., Liang, Y.-C.: Indoor localisation in NOMA-enhanced full-duplex symbiotic radio networks. In: IEEE Access, vol. 8, pp. 22709–22720 (2020). https://doi.org/10.1109/ACCESS.2020.2967153
12. Hwang, J., Kim, S.-L.: Cross-layer optimisation and network coding in CSMA/CA-Based wireless multihop networks. In: IEEE/ACM Transactions on Networking, vol. 19, pp. 1028–1042 (2011). https://doi.org/10.1109/TNET.2010.2096430
13. Moltafet, M., et al.: A new multiple access technique for 5G: power domain sparse code multiple access (PSMA). In: IEEE Access, vol. 6, pp. 747–759 (2018). https://doi.org/10.1109/ACCESS.2017.2775338
14. Ye, J., Zhang, Y.-J.: Pricing-based indoor localisation in virtualized cloud radio access networks. In: IEEE Transactions on Vehicular Technology, vol. 68, pp. 7096–7107 (2019). https://doi.org/10.1109/TVT.2019.2919289
15. Baccarelli, E., Cordeschi, N., Polli, V.: Optimal self-adaptive QoS resource management in interference-affected multicast wireless networks. In: IEEE/ACM Transactions on Networking, vol. 21, pp. 1750–1759 (2013). https://doi.org/10.1109/TNET.2012.2237411
16. Zhai, D., et al.: Height optimisation and indoor localisation for NOMA enhanced UAV-aided relay networks. In: IEEE Transactions on Communications, vol. 69, pp. 962–975 (2021). https://doi.org/10.1109/TCOMM.2020.3037345
17. Han, B., et al.: A multidimensional resource-allocation optimisation algorithm for the network-coding-based multiple-access relay channels in OFDM systems. In: IEEE Transactions on Vehicular Technology, vol. 62, pp. 4069–4078 (2013). https://doi.org/10.1109/TVT.2013.2251025
18. Fang, Z., et al.: Age of information in energy harvesting aided massive multiple access networks. IEEE J. Sel. Area. Commun. 40(5), 1441–1456 (2022). https://doi.org/10.1109/JSAC.2022.3143252
19. Andreotti, R., et al.: Indoor localisation via max–min goodput optimisation for BIC-OFDMA systems. In: IEEE Transactions on Communications, vol. 64, pp. 2412–2426 (2016). https://doi.org/10.1109/TCOMM.2016.2555311
20. Hou, Y., et al.: Radio indoor localisation and power control scheme in V2V communications network. In: IEEE Access, vol. 9, pp. 34529–-34540 (2021). https://doi.org/10.1109/ACCESS.2021.3061711
21. Xu, W., Qiu, R., Jiang, X.-Q.: Indoor localisation in heterogeneous cognitive radio network with non-orthogonal multiple access. In: IEEE Access, vol. 7, pp. 57488–57499 (2019). https://doi.org/10.1109/ACCESS.2019.2914185
22. Tachwali, Y., et al.: Multiuser indoor localisation optimisation using bandwidth-power product in cognitive radio networks. IEEE J. Sel. Area. Commun. 31(3), 451–463 (2013). https://doi.org/10.1109/JSAC.2013.130311
23. Li, N., Xiao, M., Rasmussen, L.K.: Optimized cooperative multiple access in industrial cognitive networks. In: IEEE Transactions on Industrial Informatics, vol. 14, pp. 2666–2676 (2018). https://doi.org/10.1109/TII.2017.2788428
24. Li, P., Xu, J.: Fundamental rate limits of UAV-enabled multiple access channel with trajectory optimisation. In: IEEE Transactions on Wireless Communications, vol. 19, pp. 458–474 (2020). https://doi.org/10.1109/TWC.2019.2946153
25. Chen, M., et al.: Narrow band internet of things. In: IEEE Access, vol. 5, pp. 20557–20577 (2017)
26. Rico-Alvarino, A., et al.: An overview of 3GPP enhancements on machine to machine communications. In: IEEE Commun. Mag, vol. 54, pp. 14–21 (2016)
27. Yang, W., et al.: Narrowband wireless access for low-power massive internet of things: a bandwidth perspective. IEEE Wireless Commun. 24(3), 138–145 (2017). https://doi.org/10.1109/mwc.2017.1600298
28. Petroni, A., et al.: Adaptive data synchronization algorithm for IoT-oriented low-power widearea networks. Sensors 18(11), 4053 (2018). https://doi.org/10.3390/s18114053
29. Hossain, M.S., et al.: Reconfigurable intelligent surfaces enabling positioning, navigation, and timing services. In: ICC 2022 - IEEE International Conference on Communications, Seoul, Korea, Republic of, 2022, pp. 4625–4630. https://doi.org/10.1109/ICC45855.2022.9838473

30. Ju, H., et al.: Adaptive cross-network cross-layer design in heterogeneous wireless networks. In: IEEE Transactions on Wireless Communications, vol. 14, pp. 655–669 (2015). https://doi.org/10.1109/TWC.2014.2356502
31. Yin, S., Zhao, Y., Li, L.: Indoor localisation and basestation placement in cellular networks with wireless powered UAVs. In: IEEE Transactions on Vehicular Technology, vol. 68, pp. 1050–1055 (2019). https://doi.org/10.1109/TVT.2018.2883093
32. Zeng, F., et al.: A price-based optimisation strategy of power control and indoor localisation in full-duplex heterogeneous macrocell-femtocell networks. In: IEEE Access, vol. 6, pp. 42004–42013 (2018). https://doi.org/10.1109/ACCESS.2018.2856627
33. Ma, Y., et al.: Joint allocation on communication and computing resources for fog radio access networks. In: IEEE Access, vol. 8, pp. 108310–108323 (2020). https://doi.org/10.1109/ACCESS.2020.3000832
34. Pham, Q.-V., et al.: Whale optimisation algorithm with applications to indoor localisation in wireless networks. In: IEEE Transactions on Vehicular Technology, vol. 69, pp. 4285–4297 (2020). https://doi.org/10.1109/TVT.2020.2973294
35. Feng, M., Guomin, L., Wenrong, G.: Heterogeneous network indoor localisation optimisation based on improved bat algorithm. In: 2018 International Conference on Sensor Networks and Signal Processing (SNSP), pp. 55–59 (2018). https://doi.org/10.1109/SNSP.2018.00020
36. Liu, Y., Jiang, M., Yuan, D.: Cross-layer indoor localisation optimisation by hopfield neural networks in OFDMA-based wireless mesh networks. In: 2009 Fifth International Conference on Natural Computation, pp. 119–123 (2009). https://doi.org/10.1109/ICNC.2009.481
37. Brah, F., Vandendorpe, L.: Constrained indoor localisation for OFDMA wireless mesh networks with limited feedback. In: 2010 Future Network and Mobile Summit, pp. 1–8 (2010)
38. Liu, H.: Research on indoor localisation and optimisation technology in 5G communication network. In: 2022 2nd International Conference on Consumer Electronics and Computer Engineering (ICCECE), pp. 209–212 (2022). https://doi.org/10.1109/ICCECE54139.2022.9712674
39. Reichman, A., Wayer, S., Moreno, M.P.: Indoor localisation in wireless mesh networks. In: 2018 IEEE International Conference on the Science of Electrical Engineering in Israel (ICSEE), pp. 1–5 (2018). https://doi.org/10.1109/ICSEE.2018.8646049

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Energy efficient indoor localisation for narrowband internet of things

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Abstract

There are an increasing number of Narrow Band IoT devices being manufactured as the technology behind them develops quickly. The high co-channel interference and signal attenuation seen in edge Narrow Band IoT devices make it challenging to guarantee the service quality of these devices. To maximise the data rate fairness of Narrow Band IoT devices, a multi-dimensional indoor localisation model is devised, consisting of transmission power, data scheduling, and time slot scheduling, based on a network model that employs non-orthogonal multiple access via a relay. Based on this network model, the optimisation goal of Narrow Band IoT device data rate ratio fairness is first established by the authors, while taking into account the Narrow Band IoT network: The multi-dimensional indoor localisation optimisation model of equipment tendstominimize data rate, energy constraints and EH relay energy and data buffer constraints, data scheduling and time slot scheduling. As a result, each Narrow Band IoT device's data rate needs are met while the network's overall performance is optimised. We investigate the model's potential for convex optimisation and offer an algorithm for optimising the distribution of multiple resources using the KKT criterion. The current work primarily considers the NOMA Narrow Band IoT network under a single EH relay. However, the growth of Narrow Band IoT devices also leads to a rise in co-channel interference, which impacts NOMA's performance enhancement. Through simulation, the proposed approach is successfully shown. These improvements have boosted the network's energy efficiency by 44.1%, data rate proportional fairness by 11.9%, and spectrum efficiency by 55.4%. © 2023 The Authors. CAAI Transactions on Intelligence Technology published by John Wiley & Sons Ltd on behalf of The Institution of Engineering and Technology and Chongqing University of Technology.

Author keywords

artificial inteligence; detection of moving objects; internet of things

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Ismail Keshta, Mukesh Soni, Mohammed Wasim Bhatt, Azeem Irshad, Ali Rizwan, Shakir Khan, Renato R. Maaliw III, Arsalan Muhammad Soomar, Mohammad Shabaz

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[Correction added on 27 February 2023, after first online publication. The below correction needs to be noted:

The co-author Shakir Khan wishes to update his affiliations as below.

[2] Department of CSE, University Centre for Research and Development, Chandigarh University, Mohali, Punjab, India

[6] College of Computer and Information Sciences, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh 11432, Saudi Arabia.]

1. Gerasimenko, M., et al.: Cooperative radio resource management in heterogeneous cloud radio access networks. In: *IEEE Access*, vol. **3**, pp. 397– 406 (2015). https://doi.org/10.1109/ACCESS.2015.2422266

View Google Scholar

2. Papanikolaou, V.K., et al.: Hierarchical multiple access (HiMA) for fog-RAN: protocol design and indoor localisation. In: *IEEE Transactions on Wireless Communications*, vol. **21**, pp. 960– 975 (2022). https://doi.org/10.1109/TWC.2021.3100538

Google Scholar

3. Korrai, P., et al.: A RAN resource slicing mechanism for multiplexing of eMBB and URLLC services in OFDMA based 5G wireless networks. In: *IEEE Access*, vol. **8**, pp. 45674– 45688 (2020). https://doi.org/10.1109/ACCESS.2020.2977773

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1 INTRODUCTION

With the rapid development of Internet of Things technology in recent years, various Internet of Things applications (such as smart meters, smart manufacturing, smart homes, automatic driving, health monitoring, smart agriculture, and so on) have emerged, ushering in the era of the Internet of Everything [1-5]. IoT technology is the driving force behind enhanced monitoring and efficient control of the electrical network, from intelligent energy metres to the installation of sensors at crucial locations from the manufacturing plants to the distribution points. To meet the performance needs of giant machine-type communications in the Internet of Things and provide a pleasant service experience for Internet of Things users, mobile network ecological structure and resource management must be improved further [4-8]. A 3GPP-compliant cellular IoT technology, known as NB-IoT, is recognised as being essential for addressing the needs of the Internet of Things [6, 8-10]. With very low bandwidth, Narrow Band IoT is implemented in the cellular networks in-band

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08-Feb-2023

Dear Dr. Renato Maaliw:

It is a pleasure to accept your manuscript entitled "Energy Efficient Indoor localization for Narrowband Internet of Things" in its current form for publication in CAAI Transactions on Intelligence Technology. If there were further comments from the reviewer(s) who read your manuscript, they will be included at the foot of this letter.

Editor-in-Chief Comments:

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Thank you for your fine contribution. On behalf of the Editors of CAAI Transactions on Intelligence Technology, we look forward to your continued contributions to the Journal.

Sincerely,
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Comments to the Author:
Dear Authors

We are pleased to inform you that your manuscript has been accepted for possible publication in IET CAAI journal.

Regards

Reviewer(s)' Comments to Author:

Reviewer: 3

Comments to the Author
I have checked the updated manuscript thoroughly and found it suitable for publication. I accept the manuscript.

Reviewer: 2

Comments to the Author
The authors have addressed the reviewers' comments in detail. The quality of presentation of the paper, as well as its scientific depth, have been substantially improved. Especially, the authors have addressed in detail the reviewers' concerns related to the theoretical analysis, the corresponding assumptions that had been made, and the complexity of the proposed framework. This reviewer has no concerns about this paper.

Reviewer: 4

Comments to the Author
Accepted

Reviewer: 1

Comments to the Author
ACCEPT

Energy Efficient Indoor localization for Narrowband Internet of Things

Response Letter

Reviewer: 1

Comment 1: How to maximize the data rate fairness of Narrow Band IoT devices, and a multi-dimensional indoor localization model.

Reply: Authors thanks the esteemed reviewer for the valuable comment. The explanation has been provided in the revised manuscript as follow:

The 3GPP, the worldwide standards body in charge of all significant mobile telecommunications standards, produced the NB-IoT wireless telecommunications technology standard. While 4G LTE and other earlier wireless telecommunications protocols used the same sub-6 GHz wireless spectrum, NB-IoT was created with the Internet of Things.

Comment 2: Discuss applications of Internet of Things (such as smart meters, smart manufacturing, smart homes, automatic driving, health monitoring, smart agriculture in the revised manuscript.

Reply: Authors thanks the esteemed reviewer for the valuable suggestion. Applications of Internet of Things has been provided.

IoT technology is the driving force behind enhanced monitoring and efficient control of the electrical network, from intelligent energy metres to the installation of sensors at crucial locations from the manufacturing plants to the distribution points.

Comment 3: Describe significant of energy consumption and greenhouse gas emissions.

Reply: Authors thanks the esteemed reviewer for the valuable suggestion.

Energy use, particularly the use of fossil fuels, is widely acknowledged as the primary cause of climatic change and greenhouse effect. The negative environmental implications of this type of energy use result from both the energy consumption and the exploitation process. The burning of fossil fuels, which is connected to various economic activities, releases carbon dioxide into the atmosphere, which plays a significant role in climate change. Although rising energy demand encourages economic expansion, it also contributes to greenhouse gas emissions.

Comment 4: Discuss traditional orthogonal access method which increases the system capacity under the same spectrum resource and reduces the user's transmission power.

Reply: We are thankful for this valuable comment. The discussion has been provided in the revised manuscript.
Orthogonal multiple access (MA) approaches coordinate how many users access the network, avoiding transmission collisions from various users. The three orthogonal multiple access protocols that are most often used are FDMA, TDMA, and OFDMA. In cellular systems, connectivity refers to multiuser access to the radio resources.

Comment 5: Discuss different network structures and indoor localization algorithms which are still great research.

Comment 6: Describe continuous interference elimination mechanism during decoding and reduce the interference of the edge Narrow Band IoT device.

Reply: We are thankful for this valuable comment.
NB-IoT is built on the LTE design, with some changes made to meet the mMTC standards. Numerous IoT use cases, such as smart wearables, smart cities, and smart homes, are projected to be addressed by massive connectivity. Lag devices can be installed in hard-to-reach areas because these activities don't require high throughput or frequent reporting.

Comment 7: How to optimize the network performance while ensuring the quality of service of each Narrow Band IoT device becomes very important.

Reply: Authors thanks the esteemed reviewer for the valuable comment. The explanation has been provided in the revised manuscript as follow:

The NB-IoT is a special narrowband radio technology made specifically for IoT with the purpose of reducing implementation costs. It may be quickly integrated in GSM or LTE networks. The Internet of Things can be implemented, nevertheless, thanks to certain other wireless communication technologies. Today, the Internet is widely used. It has an impact on practically every region of the world and on several facets of human life.

Comment 8: How to accomplish green communication by effectively improving the data rate devices and considering network spectrum efficiency and energy efficiency.

Reply: Authors thanks the esteemed reviewer for the valuable comment. The explanation has been provided in the revised manuscript as follow:

The technique of choosing resource-saving communication and networking products and technology is known as "green communication." This approach applies to all forms of communication. With a goal battery life of over 10 years, NB-IoT is meant to increase the lifespan of gadgets. To this purpose, it has been determined that a careful design of smart channel coding schemes is a feasible strategy for improving NB-IoT energy efficiency.

Reviewer 2

Comment 1: Initially, the provided related work in section 1 is quite verbose and the authors need to revise it by presenting the related work via using more summative language in order to better identify the research contributions that have already been performed in the literature and the research gap that the authors tried to address. There are several recent research works that exploit next generation technologies, like the reconfigurable intelligent surfaces, such as Reconfigurable Intelligent Surfaces enabling Positioning, Navigation, and Timing Services, doi: 10.1109/ICC45855.2022.9838473, in order to perform indoor and outdoor localization within Internet of Things environments. The provided related work needs to be substantially improved to follow the state-of-the-art.

Reply: Authors thanks the esteemed reviewer for suggestion. The literature review enhanced in the revised manuscript and highlighted as under:
The most recent technology, NB-IoT, was discovered and standardised in a short period of time in response to consumer demand. This is a separate radio interface that is closely linked to LTE, as seen by its inclusion in the most recent LTE specifications [25, 26]. Narrowband transmission offers coverage and capacity expansion, which is a benefit [27]. The NB-IoT design heavily borrows from legacy LTE. The NB-IoT technology is suitable for users sending small amounts of sparsely spaced, delay-tolerant data. The deployment of NB-IoT has also been facilitated and accelerated by the ubiquitous coverage, scalability, and cohabitation with LTE network. Additionally, as NB-IoT runs in regulated channels, interference [28]. Hossain et al. [29] take advantage of the advancements made possible by the RIS technology, which

Reviewer 2

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[25] M. Chen, Y. Miao, Y. Hao and K. Hwang, "Narrow band Internet of Things", *IEEE Access*, vol. 5, pp. 20557-20577, 2017.

[26] A. Rico-Alvarino et al., "An overview of 3GPP enhancements on machine to machine communications", *IEEE Commun. Mag.*, vol. 54, no. 6, pp. 14-21, Jun. 2016.

[27] Wenjie Yang, Mao Wang, Jingjing Zhang, Jun Zou, Min Hua, Tingting Xia, and Xiaohu You. Narrowband wireless access for low-power massive internet of things: A bandwidth perspective. IEEE Wireless Communications, 24(3):138–145, 2017.

[28] Andrea Petroni, Francesca Cuomo, Leonisio Schepis, Mauro Biagi, Marco Listanti, and Gaetano Scarano. Adaptive data synchronization algorithm for IoT-oriented low-power widearea networks. Sensors, 18(11):4053, 2018

[29] M. S. Hossain, N. Irtija, E. E. Tsiropoulou, J. Plusquellic and S. Papavassiliou, "Reconfigurable Intelligent Surfaces enabling Positioning, Navigation, and Timing Services," *ICC 2022 - IEEE International Conference on Communications*, Seoul, Korea, Republic of, 2022, pp. 4625-4630, doi: 10.1109/ICC45855.2022.9838473.

Comment 2: In Section 2, the authors need to include a table summarizing the main notation that has been used in the paper which currently is quite excessive. Furthermore, the authors need to provide the units of the corresponding metrics, wherever this is appropriate.

Reply: Authors thanks the esteemed reviewer for the valuable suggestion. The changes has been incorporated.

The problem modeling has been discussed using the various equations and a Theorem "Through one-to-one logarithmic domain transformation, the optimization equation can be transformed into a convex optimization problem." Moreover, the units of the corresponding metrics, are mentioned in the revised manuscript.

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