Resource allocation method based on massive MIMO NOMA MEC on distribution communication network

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Abstract. The current smart distribution network has problems of slow fault detection and low efficiency. This paper reasonably derives the expression of delay from two aspects of transmission time and calculation time based on technologies such as massive multiple input multiple output, non-orthogonal multiple access, and mobile edge computing (MIMO-NOMA-MEC). In addition, a multi-objective iterative algorithm is designed to minimize the delay by jointly optimizing the transmission power, task allocation coefficient, and the computing resources of the MEC server. Finally, the simulation results show that the processing delay of the system gradually decreases as the number of antennas increases. In addition, the processing delay of the system can still be below 10ms under the extremely bad situation that there are many devices currently requesting services.

1. Introduction
At present, in the power distribution automation system of power grid companies, when the distribution network fails, the distribution automation master station will determine the fault area based on the collected information, automatically isolate the fault area, The main perception layer equipment comes from distribution monitoring terminals, distribution automation terminals, and distribution voltage monitoring terminals. The communication network is a wireless channel such as optical fiber private network or 4G [1]. Facing the current actual situation of the smart grid, first of all, we consider that for some underdeveloped areas, no new cable lines have been built. At the same time, underground pipe gallery resources are in short supply, new channels cannot be built in some areas, and it is difficult to simultaneously lay optical fibers across the entire line. Second, with the development of the distribution network, the amount of data and calculations generated by network edge devices has increased dramatically, bringing more computationally intensive tasks, and posing huge challenges to transmission bandwidth pressure and delay. Therefore, the traditional 4G network can no longer meet the demand well.

With the advent of the 5G era, some advanced technologies such as massive MIMO and NOMA technology can improve spectrum efficiency and can well meet the needs of high-reliability and low-latency services in smart distribution networks [2-3]. In addition, when switching equipment failures, line short circuits, and leapfrog trips occur in the distribution system, the traditional cloud computing mode will cause problems such as long fault location time and slow response to accidents, which affects the reliability of the distribution network. The emergence of mobile edge computing (MEC) has made up for the deficiencies of cloud computing. MEC refers to providing the nearest service on the side close to the physical environment or data source [4], so as to achieve faster network service response and meet the industry's real-time business application requirements. By transferring the collected data to the edge server for calculation, the fault can be quickly located and accurately removed.
At present, some progress has been made in applying MEC to smart grids. Literature [5] analyzed the development status and applicability of edge computing in smart distribution. It also discussed specific application scenarios, including three typical application scenarios: intelligent low-voltage area management, user power management, and distribution network monitoring. Literature [6] proposed the idea of applying edge computing technology to automatic demand response services. Literature [7] proposed an active distribution network PTN physical architecture model based on edge computing. Literature [8] a distributed power distribution fault detection method based on edge computing realized timely perception and real-time response to power distribution network faults.

Although MEC has brought many benefits, it faces the growing number of acquisition equipment, the constant change in the proportion of new energy access, the increasingly complex network topology, and the continuous improvement in the reliability and power quality requirements of electricity, resulting in the edge of MEC. The amount of tasks required to perform calculations has increased sharply, which further increases the spectrum overhead of the network and the calculation overhead of the MEC.

In summary, this article considers the use of massive MIMO technology and NOMA technology to increase the transmission rate, further reduce the delay of transmitting data, and provide support for better realization of rapid fault removal. The collected data can be computed by offloading to MEC server. The massive MIMO-NOMA technology is considered to be applied to MEC to realize the rapid removal of faults in the intelligent distribution network to achieve stable operation.

2. System model
The mobile edge computing network model for fault detection in the distribution network is composed of various electrical equipment of base station (BS) equipped with edge servers. The base station provides wireless access services, and the edge server provides computing services. We assume that \( N \) antennas are deployed on the base station side, and multiple single-antenna devices are grouped into \( M \) clusters, where each cluster contains \( k \) devices.

2.1 Uplink data offloading
We consider performing information statistics every fixed duration \( T \) to realize real-time processing of distribution network data. Multiple smart devices upload the collected and monitored information to the MEC server, and use the power domain multiplexing of NOMA technology to superimpose and encode user information. The reachable rate of the device is expressed as [9].

\[
r_{m,k} = B \log_2 \left( 1 + \frac{P_{m,k} N \hat{\beta}_{m,k}}{P_{m,k} \beta_{m,k} + \sum_{k'=1}^{K-1} P_{m,k'} (N \hat{\beta}_{m,k'} + \hat{\beta}_{m,k'}) + \sum_{m'=1}^{M} \sum_{m''=m}^{M} P_{m',m''} \beta_{m',m''} + \sigma_{m,k}^2} \right)
\]

where, \( \hat{\beta}_{m,k} = \frac{\tau p_s \beta_{m,k}}{\sum_{m=1}^{M} \sum_{k=1}^{K} \tau p_s \beta_{m,k} + 1} \), \( p_s \) represents the transmission power of the device sending pilot. \( \tau \) is the number of pilot symbols. \( \beta_{m,k} \) represents the large-scale fading between the device and the base station. \( P_{m,k} \) is the uplink transmission power, \( \sigma_{m,k}^2 \) is additive white Gaussian noise, \( B \) is the total spectrum bandwidth.

2.2. Local calculation or MEC calculation delay
This article assumes that the total task size for user \( k \) in the \( m \)-th cluster to be uninstalled in MEC is \( D_{m,k} \). These data can be calculated on the local mobile device or MEC server. \( C \) is the number of CPU cycles required to calculate each bit. Next, we define the delay for local calculation or offloading to MEC calculation. \( f_{loc} \) represents the computing power of each user. If the \( k \)-th device
performs its task locally, the local computing time $T_{\text{loc}}$ can be expressed as $T_{\text{loc} m,k} = \frac{D_{m,k} C}{f_{\text{loc}}}$. When using MEC to calculate offload, it mainly includes transmission time and calculation time. The offloading transmission time of the k-th user in the m-th cluster is mainly determined by the amount of offloading tasks and the transmission rate. The transmission time is expressed as $T_{\text{mec} m,k} = \frac{D_{m,k} C}{r_{m,k}}$. The calculation time using the MEC server is expressed as $T_{\text{mec} m,k} = \frac{D_{m,k} C_{\text{mec}}}{f_{\text{mec}}}$. Where, $f_{\text{mec}}$ is the CPU frequency allocated by the computing smart device $SD_{m,k}$, and $C_{\text{mec}}$ is the number of CPU cycles required to calculate an input bit in the MEC server.

We consider that smart devices have certain computing capabilities and can perform partial data calculations. In order to minimize processing delay, we make full use of reasonable computing resources to minimize delay. We assume that the local calculation task amount is $\alpha_{m,k}$. Therefore, the time to perform the task consists of two parts.

$$T_{m,k} = \frac{\alpha_{m,k} D_{m,k} C}{f_{\text{loc}}} + \frac{(1-\alpha_{m,k}) D_{m,k} C_{\text{mec}}}{r_{m,k} f_{\text{mec}}}$$

The shortest time to perform the task is $T_{m,k} = \max \{T_{\text{loc} m,k}, T_{\text{mec} m,k}\}$. We ignore the time required to transmit the calculation results from the MEC to the user.

3. Problem formulation and proposed solution

In order to better meet the needs of users and realize the real-time processing of distribution network services, our aim is to minimize the overall latency consumption among all users by jointly optimizing the users transmit power, computing capacity allocation, and task distribution factor. In order to minimize the total delay of all devices in the system, the optimization problem P1 can be expressed as

$$\min_{P,F,\alpha} \sum_{m=1}^{M} \sum_{k=1}^{K} T_{m,k}$$

C1: $P_{m,k} \leq P_{\text{max}}$ C2: $\alpha_{m,k} \in (0,1)$ C3: $\sum_{m=1}^{M} \sum_{k=1}^{K} f_{m,k} \leq F$

We noticed that problem is non-convex, and the non-convexity is determined by the non-convexity of $r_{m,k}$. In order to facilitate the solution and decouple the problem into the following two sub-problems, first we give the transmission power $P$ and the allocated CPU frequency $F$, the expression of the optimal allocation coefficient is obtained, and then a multi-objective iterative algorithm is designed to jointly optimize $P$ and $F$ to minimize the total delay.

3.1. optimize the user's task allocation coefficient

Given the user's transmission power $P$, assign to $F$, the task allocation coefficient $\alpha$ , can be optimized by solving the following problems.

$$\min_{\alpha} \sum_{m=1}^{M} \sum_{k=1}^{K} T_{m,k}$$

C2: $\alpha_{m,k} \in (0,1)$

Since this problem is a convex problem, and due to the linearity of the objective function and all constraints, in order to make full use of local and MEC resources to achieve minimization, it is obvious that the optimal solution is when the local calculation time is equal to the offload calculation time.

$T_{m,k}^{\text{loc}} = T_{m,k}^{\text{mec}}$.
The optimal task assignment that can be solved is

$$\alpha_{m,k} D_{m,k} C = \frac{(1 - \alpha_{m,k}) D_{m,k}}{r_{m,k}} + \frac{(1 - \alpha_{m,k}) D_{m,k} C_{mec}}{f_{mec}}$$

(3)

The optimal task assignment that can be solved is

$$\alpha_{m,k} = \frac{(f_{mec} + r_{m,k} C_{mec}) f_{loc}}{(f_{mec} + r_{m,k} C_{mec}) f_{loc} + C r_{m,k} f_{mec}}$$

(4)

From the above formula, the optimal task allocation coefficient has nothing to do with the small amount of tasks, but only with the allocated CPU frequency and transmission rate.

3.2. multi-objective iterative algorithm

Based on expression (3), we can transform problem P1(2) into the following

$$\min \sum_{m=1}^{M} \sum_{k=1}^{K} T_{loc}^{m,k}$$

$$C1: P_{n,k} \leq P_{max} \quad C3: \sum_{m=1}^{M} \sum_{k=1}^{K} f_{mec}^{n,k} \leq F \quad C4: \alpha_{m,k} = \frac{(f_{mec} + r_{m,k} C_{mec}) f_{loc}}{(f_{mec} + r_{m,k} C_{mec}) f_{loc} + C r_{m,k} f_{mec}}$$

(5)

It can be seen from formula (3) that when the time delay is optimal, the time to calculate unloading is the same as the local calculation time, so the $T_{m,k}$ in question (2) can be replaced by $T_{loc}^{m,k}$ or $T_{mec}^{m,k}$. In this paper, $T_{mec}^{m,k}$ is selected for the convenience of calculation. Due to the mutual coupling between the three variables of this problem, we propose to use a multi-objective iterative algorithm to solve the problem. In order to realize the fair allocation of resources by MEC, this article assumes $f_{mec}^{n} = F / M \times K$.

Algorithm1 Joint optimization of transmission power, CPU frequency, task allocation coefficient based on multi-objective iterative algorithm

1. Initialize tolerant thresholds $\delta_k = 1$, a group of $P^n$, and the number of iterations $n = 0.2$. While $\delta_k \geq 0.01$, Do $n = n + 1$; 4. Bring $P^n$ into (5) to find the corresponding $R^n$; 5. Obtain the optimal task allocation coefficient according to formula (4); 6. If $P_{n,k} \geq P_{max}$, break; else calculation formula (5) end

7. calculation $\delta_k = \max_n \left| \frac{P_k^n - P_k^{n-1}}{P_k^{n-1}} \right|$. 8. Calculate the optimal $R^n$, and $T$.

4. Simulation results

In this section, we use MALAB to perform numerical simulation. The specific simulation parameters are set as follows: The number of antennas currently deployed in the base station is $N=128$, the number of CPU cycles of MEC is $C_{mec} = 500$ cycles/bit, the number of CPU cycles of a smart device is $C=1000$ cycles/bit. The CPU cycle frequency of the smart terminal device is 0.4GHz, the number of CPU cycles per MEC $500$ cycles/bit, the CPU cycle frequency of the MEC server is $f_{mec}^{mec} = 3.4GHz$.

Figure 1 shows the relationship between the number of antennas using massive MIMO technology and the minimum delay of each device. It can be seen from the figure that as the number of antennas increases, the average minimum delay of each device continues to decrease. This is mainly because The increase in the number of antennas can be seen from formulas (8) and (9) that the uplink reachable rate is greatly increased, which indirectly reduces the transmission delay when offloading tasks, making more tasks offloaded to the MEC server for calculation and reducing the system The total delay of the service.

Figure 2 shows the relationship between the number of devices and the average minimum delay, and it can be seen from the figure that as the current requesting devices increase, the system response delay continues to increase. It is not difficult to understand that the average distribution of MEC computing resources used in this article In this way, the more devices there are, the more computing resources allocated to each device will decrease. Therefore, the calculation time on the MEC server is increased. Nevertheless, the massive MIMO-NOMA solution designed in this article can also reduce the
processing task delay to less than 10ms, making the entire fault handling system safer, more reliable and efficient.

![Figure 1 Number of antennas vs average minimum delay](image1)

![Figure 2 Number of devices and average minimum delay](image2)

5. Conclusion
This article considers the use of massive MIMO technology and NOMA technology to increase the transmission rate, further reduce the delay of transmitting data, and provide support for better realization of rapid fault removal. The collected data can be computed by offloading to MEC server. The massive MIMO-NOMA technology is considered to be applied to MEC to realize the rapid removal of faults in the intelligent distribution network to achieve stable operation.

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