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Research on Interference Elimination-Based Energy Consumption of the Internet of Things

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Abstract

INTRODUCTION: During the uninterrupted operation of the Internet of Things, the continuous activity of a large number of terminal devices not only increases the energy consumption of the nodes, but also causes signal interference between devices, resulting in degraded channel conditions and Quality of Service of the Internet of Things, increased data transmission latency, and a further increase in energy consumption of the Internet of Things.
OBJECTIVES: To mitigate the effects of communication conflict and signal interference on data transmission and reduce the energy consumption of the Internet of Things, an interference elimination-based energy consumption optimization algorithm for the Internet of Things is proposed.
METHODS: According to the model of the Internet of Things, this paper divides the nodes of the Internet of Things into sink nodes and terminal nodes. The sink node dynamically allocates data transmission time-slots based on the Signal-to-Interference plus Noise Ratios of the terminal nodes. Meanwhile, the terminal node adaptively adjusts its power on the basis of its activity status while guaranteeing data transmission performance.
RESULTS: The simulation results showed that the data transmission latency was reduced, signal interference mitigated, channel environments improved, and energy consumption of the Internet of Things lowered.
CONCLUSION: The proposed algorithm can effectively reduce the impact of channel interference on the data transmission of terminal nodes, improve data transmission performance and Quality of Service of the Internet of Things, and reduce energy consumption of the Internet of Things.

Keywords: Internet of Things, energy consumption; signal interference; sink node; terminal node

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1. Introduction

In the construction of intelligent hospitals, the Internet of Things (IoT) technology plays an important supporting role [1,2]. By utilizing the reliable transmission capability of IoT technology, the deep integration of IoT and medical services is achieved, enabling high-quality communication between IoT platform and terminal devices, effective, real-time, and accurate transmission of medical data, and information exchange among patients and medical staff, medical equipment, drugs, etc. [3-5]. The specific application scenarios of IoT technology in intelligent hospitals include intelligent blood management [6,7], intelligent infusion monitoring [8-10], continuous blood glucose monitoring [11,12], etc. However, wireless sensors, wireless RFID readers [13], Bluetooth transmitters, etc. used for data collection and transmission are mostly active devices with limited power. Therefore, reducing the energy consumption of IoT terminal devices while ensuring timely and accurate information transmission is a problem we need to consider [14].

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The major factors affecting the energy consumption of IoT include device type, data transmission, long-term operation, and the design of hardware and software [15,16]. Zhou Xiangjun and Chen Junxiao focus on optimizing the power management system of self-powered IoT nodes, conduct research on key technologies and designs for ultra-low power management, and propose solutions to extend the battery life of terminal devices [17,18]. Liu Kai and Zhao Wen start from optimizing logic and algorithm, through data compression, address the latency problem caused by the large communication data in IoT, thereby reducing data in occupation of processor and memory and lowering energy consumption of devices [19,20]. Multiple inter-protocol communication mechanisms were designed to address the issue of heterogeneous protocol competition in IoT. At the same time, enhancing transmission of weak signals and decoding optimization at the receiving end were explored to reduce the energy consumption of data transmission in IoT [21-23].

Due to the uninterrupted operation of IoT, devices keeping active in a long-term will greatly increase energy consumption. In addition, when a large number of IoT terminal devices remain active concurrently, mutual signal interference among devices can lead to a decrease in Quality of Service (QoS) of IoT, prolonged data transmission time, and increased energy consumption [24,25]. This paper focused on the impact of mutual interference among terminal devices in active state on the energy consumption of IoT, and proposed an interference elimination-based energy consumption optimization algorithm of IoT. In the algorithm, the aggregation device allocates data transmission time-slots based on Signal-to-Interference plus Noise Ratios (SINRs) of the terminal devices. At the same time, the terminal devices adaptively adjust powers according to the activity status. In the monitoring state, the terminal devices lower powers to reduce signal interference among devices, thereby improving QoS of IoT and reducing energy consumption of IoT.

2. System model

Assume that a group devices of IoT using the same wireless network technology for communication includes an aggregation device (sink node) and M terminal devices (terminal nodes), as shown in Figure 1. The group network composed of terminal nodes and sink node is interconnected with the gateway through the sink node, and then connected to the IoT. The receiving signal of the i^{th} terminal node at the sink node, i=1…M, can be modeled as

$$x_i(t) = h_i(t) \cdot s_i(t) + n_i(t) \qquad (1)$$

where $S_i(t)$ is the signal of the i^{th} terminal node, $h_i(t)$ is channel gain of the i^{th} terminal node, and $n_i(t)$ is channel Additive White Gaussian Noise of the ith terminal node.

If the terminal nodes are not effectively managed in an IoT group, multiple terminal nodes may concurrently transmit data on the same channel, resulting in channel blockage and the sink node being unable to receive all data promptly. When the IoT nodes work simultaneously in a small area, they may cause Co-frequency interference and adjacent frequency interference. However, due to the extended distances between inter-group nodes of IoT and the effects of complex and changing propagation environment such as channel multipath and shadow fading, inter-group signal interference is relatively small [26,27]. Therefore, this paper mainly considers intra-group signal interference, dynamically allocating data transmission time-slots based on SINRs of the nodes to avoid concurrent data transmission; meanwhile, adaptively adjusting the powers of terminal nodes according to their current status to ensure effective data transmission in the transmitting and receiving states and minimize signal interference among nodes in the monitoring state.

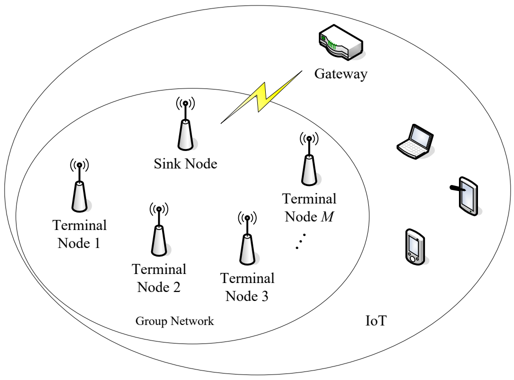

Figure 1. System model

3. Interference elimination-based energy consumption optimization algorithm of IoT

Usually, the size of the data packet transmitted by a group IoT nodes is same. When the SINR of a node is low, its data transmission time increases. The implementation process of interference elimination-based energy consumption optimization algorithm of IoT is divided into the following steps: the sink node dynamically allocates data transmission time-slots for terminal devices within its group per unit transmission time based on SINRs of the nodes, which can effectively avoid communication collisions among the nodes and shorten data transmission latency; the terminal devices lower powers in the monitoring state, which can not only reduce signal interference to other nodes, but also reduce their individual energy consumption, thereby improving QoS of IoT and reducing energy consumption of IoT.

In an IoT group (X group), the SINR of i^{th} terminal node can be written as

$$SINR_i = \frac{S_i}{I_i + N_i} \qquad (2)$$

where S_i is the signal power of i^{th} terminal node, I_i is the power of interfering signal received by i^{th} terminal node, and N_i is the White Gaussian Noise power. The power of interfering signal I_i may be written as

$$I_i = \sum_{j \in \Omega} I_i^j \tag{3}$$

where Ω is the set of nodes that cause signal interference to i^{th} terminal node. In order to facilitate analysis, the signal fading model is defined as [28]

$$S_i = \frac{P_i}{d_i^{\alpha}} \tag{4}$$

where P_i is the transmission power of i^{th} terminal node, d_i is the distance from i^{th} terminal node to the sink node, α represents the signal attenuation index, and its value range is [2, 6].

Assume $SINR_{i,k}$ is the SINR of i^{th} terminal node in k^{th} unit transmission time,the transmission time per unit is T. The SINRs of X group nodes in k^{th} unit transmission time are following as

$$W_k = \left[SINR_{1,k} \quad SINR_{2,k} \quad \cdots \quad SINR_{M,k} \right] \tag{5}$$

Based on the SINRs of the terminal nodes, the data transmission time-slots allocated by the sink node can be written as

$$T_k = \begin{bmatrix} t_{1,k} & 0 & 0 & \cdots & 0 \\ 0 & t_{2,k} & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & 0 & t_{M-1,k} & 0 \\ 0 & \cdots & 0 & 0 & t_{M,k} \end{bmatrix} \tag{6}$$

where $tr(T_k) = \mathrm{T}$, and the transmission time-slot of i^{th} terminal node is obtained by

$$t_{i,k} = \frac{W_k \cdot E - SINR_{i,k}}{W_k \cdot E} \tag{7}$$

where $E = [1 \quad 1 \quad \cdots \quad 1]^{\mathrm{T}}$. There are M elements in matrix E, and all of which are 1.

It can be concluded that the sink node allocates data transmission time-slots for the terminal nodes on the basis of SINRs in k^{th} unit transmission time, which can effectively avoid communication collisions among the nodes. Due to the complex environment of hospitals and the high-density and random distribution of a large number of terminal nodes, shadow fading and multipath effects cause large-scale variations in the interference power and noise power of the terminal nodes. So, the sink node dynamically allocates transmission time-slots based on SINRs of the terminal nodes in different transmission time, which can solve the problems of communication conflict and information transmission latency of IoT nodes.

Based on the channel model of dynamical allocation of transmission time-slots by sink nodes and timely and accurate information transmission of terminal nodes in the transmitting and receiving states, the transmission power can be adaptively adjusted by terminal devices to reduce energy consumption of IoT by lowering power in the monitoring state.

We use $P_{i,k}$ to represent the transmission power of i^{th} terminal node in k^{th} unit transmission time, the transmission power of X group nodes are following as

$$L_k = \left[P_{1,k} \quad P_{2,k} \quad \cdots \quad P_{M,k} \right] \tag{8}$$

If ρ is the strength factor that characterizes the correlation between the transmission power and the power in the monitoring state, $m_{i,k}$ is the the power of i^{th} terminal node in the monitoring state and written as

$$m_{i,k} = \rho P_{i,k} \qquad 0 < \rho < 1 \tag{9}$$

The energy consumption of X group nodes in k^{th} unit transmission time can be obtained by

$$\begin{aligned} E_k &= L_k \cdot T_k \\ &= \left[P_{1,k} \cdot t_{1,k} + \rho \cdot P_{1,k} \cdot \left(\mathrm{T} - t_{1,k} \right) \quad \cdots \quad P_{M,k} \cdot t_{M,k} + \rho \cdot P_{M,k} \cdot \left(\mathrm{T} - t_{M,k} \right) \right] \end{aligned} \tag{10}$$

Of which, the energy consumption of i^{th} terminal node is written as

$$E_{i,k} = P_{i,k} \cdot t_{i,k} + \rho \cdot P_{i,k} \cdot \left(\mathrm{T} - t_{i,k} \right) \tag{11}$$

It is obvious that the energy consumption of IoT is related to the number of terminal nodes and the energy consumption of each node, and the number of terminal nodes is determined by actual application needs. When a group nodes of IoT communicate by the same wireless network technology, the interference elimination-based energy consumption optimization algorithm of IoT can reduce the information transmission latencies of terminal nodes and lower the energy consumption of each node, thereby reducing the energy consumption of IoT.

4. Simulation and analysis

We simulated the interference elimination-based energy consumption optimization algorithm of IoT (IECO) in the scenario of continuous blood glucose monitoring and AWGN channel environment, and compared it with the dynamic power control algorithm based on machine learning (DPCL) and the energy consumption of IoT in conventional working mode (CMEC). In the simulation, one Bluetooth receiver is connected to multiple Bluetooth transmitters simultaneously, the signal of Bluetooth transmitter is a Phase Shift Keying (PSK) signal, the carrier frequency is 10 MHz, the sampling frequency is 100 MHz, the sampling number is 512, the factor ρ representing the power correlation strength of the transmitter is taken as 0.5, the transmission frequency of blood glucose monitoring data is once/30 seconds, the data size is 1000 B, and the channel bandwidth is 1 MHz.

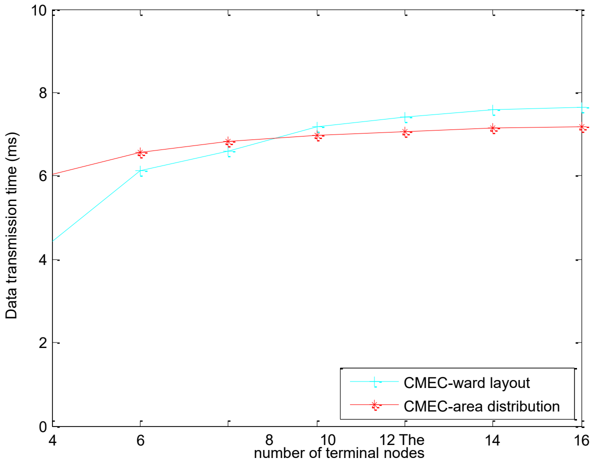

Figure 2. Effect of the distribution of IoT group nodes on the transmission time of CMEC algorithm

In wireless communication system, signal fading is mainly affected by factors such as obstacles, multipath effects, and distance [29,30]. Therefore, the distribution of terminal devices in the IoT group network will affect the received signal of the sink node. Compared with the conventional distribution of IoT grouped nodes, there is more medical equipment in ICU wards, and the distribution of nodes is complex, which greatly increases signal interference and attenuation, resulting in a decrease in channel quality. Due to the fact that one ICU nursing unit cannot exceed 16 beds, in the scenario of continuous blood glucose monitoring, one Bluetooth receiver can be paired with up to 16 Bluetooth transmitters as a group IoT nodes. Figure 2 showed the data transmission time of CMEC algorithm under ward layout and conventional area distribution when signal-to-noise ratio (SNR) is 10 dB. When the number of terminal nodes increases to 10, the signal fading intensifies, the data transmission quality declines, and the data transmission time under ward layout is longer than that under conventional area distribution. Timely and accurate information transmission is an important indicator of QoS in IoT [31]. So in the medical field, we need to consider more on how to improve the QoS of IoT.

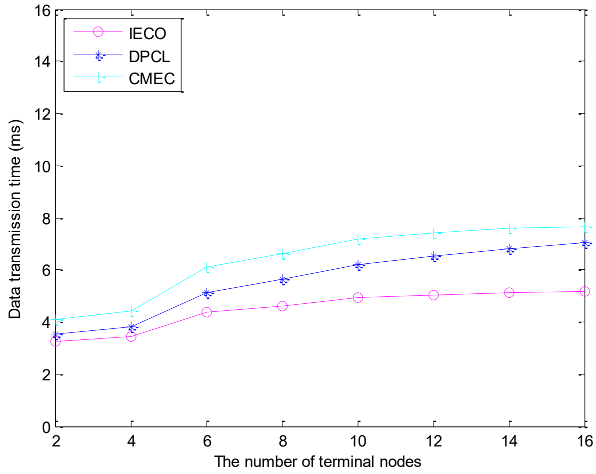

Figure 3. Effect of the number of terminal nodes on the transmission time of IECO, DPCL and CMEC algorithms

Figure 3 showed the data transmission time of IECO, DPCL and CMEC algorithms when SNR is 10 dB, where the terminal devices in IoT group are under ward layout. In the same channel environment, the number of nodes in an IoT group increases from one to multiple, there may occur communication conflicts, causing signal interference among the nodes and leading to a sudden increase in data transmission time; as the number of nodes continues increasing, the transmission time slowly increases.

Table 1 compared the data transmission time of IECO algorithm with CMEC algorithm under conventional area distribution and ward layout. It can be concluded that IECO algorithm can overcome the channel interference experienced by IoT group nodes in ward layout, reduce data transmission time, and improve the effectiveness of data transmission.

Table 1. Data transmission time (ms) of IECO algorithm and CMEC algorithm under conventional area distribution and ward layout

ALGORITHM	NUM=8	NUM=10	NUM=12
CMEC-AREA DISTRIBUTION	6.82	6.97	7.06
CMEC-WARD LAYOUT	6.60	7.18	7.40
IECO	4.61	4.92	5.04

Table 2 showed the data transmission time of the three algorithms in the case of different numbers of terminal nodes. As the number of terminal nodes increases, the transmission time of all algorithms increase, but the transmission time of IECO algorithm remains smallest and relatively stable. Especially when the number of terminal nodes increases to 10, the data transmission time of IECO algorithm is less than 5 ms, while the transmission time of DPCL and CMEC algorithms exceed 6 ms and 7 ms respectively.

Table 2. Data transmission time (ms) of the three algorithms in the case of different numbers of terminal nodes

ALGORITHM	NUM=6	NUM=10	NUM=16
IECO	4.36	4.92	5.17
DPCL	5.14	6.20	7.04
CMEC	6.12	7.18	7.65

Figure 4 showed the data transmission time of the three algorithms in the case of eight terminal nodes. With the increase of SNR, the data transmission time of all algorithms decrease, but IECO algorithm performs clearly superior, its data transmission time reduces rapidly. When the SNR of the terminal node is greater than 10 dB, the channel environment is good, and the transmission time of all algorithms decrease slowly. However, the data transmission time of IECO algorithm remains consistently shorter than that of DPCL and CMEC algorithms. This is because IECO algorithm dynamically allocates transmission time-slots based on the SINRs of terminal nodes, its performance is closely related to the SNRs of nodes. When the SNR of a node increases, the sink node promptly senses and reallocates data transmission time-slots for terminal nodes within its group per unit transmission time, avoiding communication collisions among the nodes and reducing information transmission latency; the terminal nodes lower powers in the monitoring state, reducing signal interference to other nodes, further optimizing channel environment, improving the SINRs of nodes and shortening data transmission time.

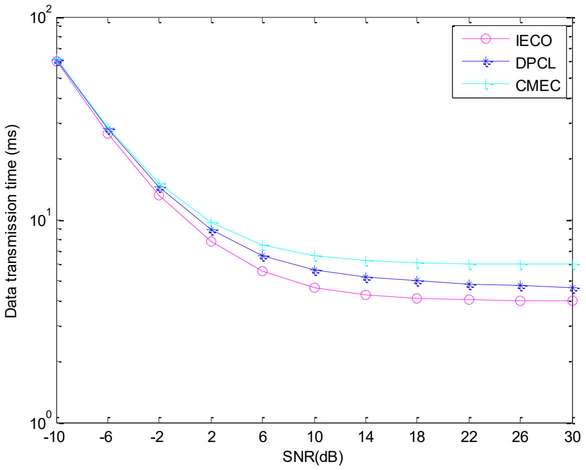

Figure 4. Effect of SNR on the transmission time of IECO, DPCL and CMEC algorithms

In digital communication system, the SNR is generally above 10 dB to function properly, and above 30 dB to ensure the reliability of data transmission. In the scenario of continuous blood glucose monitoring, the transmission power of a terminal device ranges from 0 dB to 30 dB. If the powers of terminal devices are varying, signal interference between nodes increases, channel quality decreases, and the data transmission time of all three algorithms increase, as shown in Figure 5.

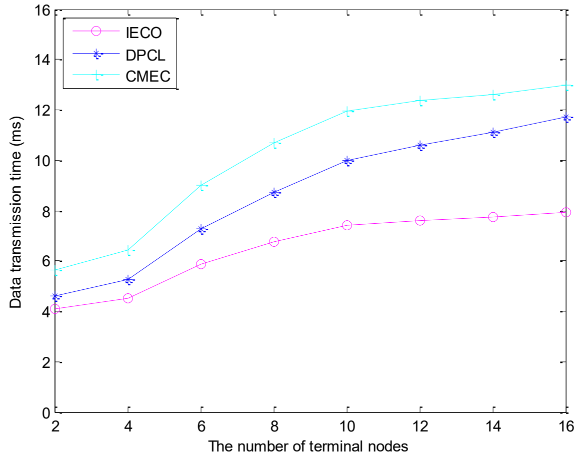

Figure 5. Effect of diverse IoT environments on the transmission time of IECO, DPCL and CMEC algorithms

Table 3 showed the data transmission time of the three algorithms in the case that the powers of terminal devices in an IoT group are varying. When the number of terminal nodes is 10, the data transmission time of IECO, DPCL and CMEC algorithms are 7.4 ms, 10 ms and 12 ms respectively. Compared with Table 2, the data transmission time of DPCL and CMEC algorithms have increased by 60.8% and 66.3% respectively, while IECO algorithm has increased by only 50.4%. In practical applications, an IoT group is usually composed of terminal devices with varying powers. At this point, IECO algorithm can resist signal interference and ensure the effectiveness of data transmission.

Table 3. Data transmission time (ms) of the three algorithms in the case of varying powers of terminal devices in an IoT group

ALGORITHM	NUM=6	NUM=10	NUM=16
IECO	5.89	7.40	7.94
DPCL	7.27	9.97	11.74
CMEC	9.02	11.94	13.00

In hospital environments, mobile medical devices often cause signal fading and interference, leading to a decrease in QoS of IoT. Figure 6 showed the data transmission time of the three algorithms in the case of obstacles in the IoT group network. Due to environmental interference, the data transmission time of all three algorithms increase. When SNR is 10 dB, the data transmission time of IECO algorithm is less than 10 ms, while the transmission time of DPCL and CMEC algorithms exceed 13 ms and 16 ms respectively.

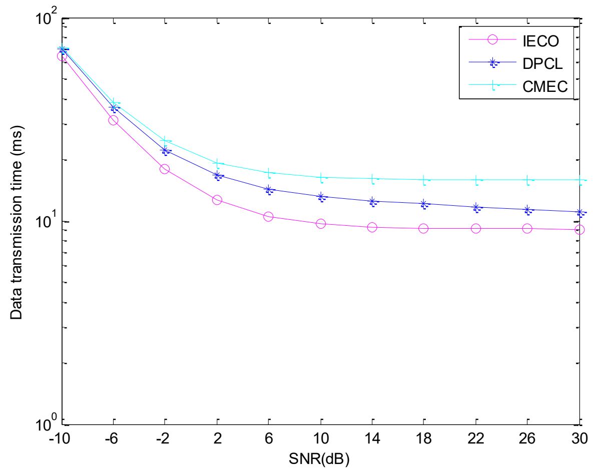

Figure 6. Effect of environmental interference on the transmission time of IECO, DPCL and CMEC algorithms

Table 4 compared the SNRs of the three algorithms in the presence and absence of obstacles when the data transmission time is 10 ms. Due to the influence of obstacles, the signals fade, the SNRs of IECO and DPCL algorithms have increased by 10 dB and 34 dB respectively, while CMEC algorithm cannot meet the data transmission requirement. Obviously, IECO algorithm has better robustness than the other two algorithms.

Table 4. the SNRs (dB) of the three algorithms in the presence and absence of obstacles in the case that the data transmission time is 10 ms

ALGORITHM	IN THE ABSENCE OF OBSTACLES	IN THE PRESENCE OF OBSTACLES
IECO	0	10
DPCL	1	35
CMEC	2	-

Figure 7 presented the effect of SNR and the number of terminal nodes on the energy-saving rate of IECO algorithm. With the increase of SNR, the energy-saving rate gradually improves. In the same channel environment, the more the nodes, the higher the energy-saving rate of terminal device. When SNR is 10 dB, if the number of terminal nodes is 12, the energy-saving rate of terminal device is close to 16%; if the number of nodes is 8, the energy-saving rate is about 15%; if the number of nodes is 4, the energy-saving rate of terminal device is only 11%.

IECO algorithm adaptively adjusts the powers of terminal nodes, reducing signal interference among the nodes and improving the SINRs of nodes. So, in an unit transmission time, the energy consumption of node is reduced. Meanwhile, dynamically allocating data transmission time-slots reduces the probability of node communication conflict, minimizes signal interference among the nodes, and further reduces energy consumption of IoT. Moreover, the more terminal nodes there are, the better IECO algorithm performs in avoiding communication conflict and reducting IoT energy consumption. In the practical application scenarios of IoT, terminal nodes are often densely distributed. On the basis of guaranteeing the QoS of IoT, a sink node is usually grouped with as many terminal nodes as possible. Therefore, the IECO algorithm provides a practical and feasible solution to reduce the energy consumption of IoT.

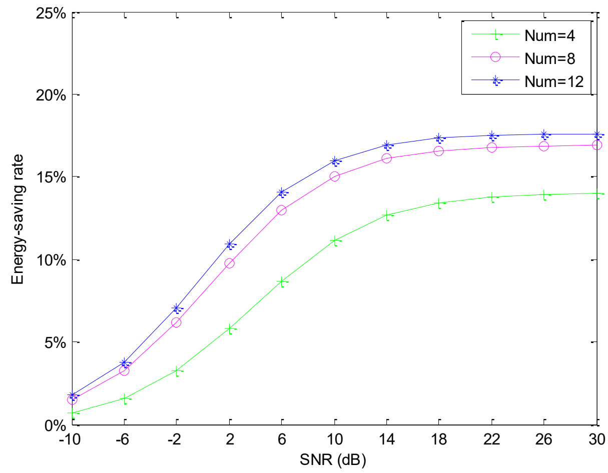

Figure 7. Effect of SNR and the number of terminal nodes on the energy-saving rate of IECO algorithm

5. Conclusions

In order to diminish the effect of communication conflict and signal interference on data transmission of IoT and reduce the energy consumption of IoT, an interference elimination-based energy consumption optimization algorithm of IoT is proposed. In this algorithm, the aggregation device allocates data transmission time-slots for the nodes within its IoT group on the basis of SINRs to avoid communication conflict and reduce information transmission latency. Simultaneously, the terminal devices adaptively adjust power according to activity status, so as to reduce signal interference to other nodes, improve QoS and data transmission performance of IoT, and reduce the energy consumption of IoT nodes. The simulation results showed that the algorithm can effectively reduce the impact of channel interference on the data transmission of terminal devices and lower the energy consumption of IoT.

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