Hindawi Publishing Corporation
Journal of Sensors
Volume 2014, Article ID 690521, 10 pages
http://dx.doi.org/10.1155/2014/690521

Research Article

Resource Management Technique Based on Lightweight and Compressed Sensing for Mobile Internet of Things

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Received 18 July 2014; Accepted 29 August 2014; Published 23 December 2014

Academic Editor: Junjie Chen

In mobile Internet of Tings, based on cross-layer design and resource-aware scheduling, the combination of light weight coding and compressed sensing is used to improve the real-time performance of acquisition of system resource and reliability of resource management in this paper. Compressed sensing scheme based on the adaptive frame format definition of lightweight coding is able to set up the parameters such as sample signal, signal and hops. The nonlinear relationship matrixes between resource information of sensors or system and quality of services are built to manage the global or local network resource scheduling. Experimental results show that the proposed scheme is better than the traditional scheme or resource management based on compressed sensing alone scheme, which can make the system be able to achieve optimal resource allocation.

1. Introduction

With the rapid development of Internet of Things applications, types of business are endless and proportion of data services keeps rising [1]. Growth trend of network resource requirements appears explosive [2], which presents more challenges to Mobile Internet of Things (MIOT). Support mobile data services business and big data of the new generation IOT technology have gradually become the mainstream of development of next generation networks [3]. IOT technical standards with large capacity, packet, and intelligent features have been increasingly sophisticated [4]. However, the restricted network performance problems due to capacity constraints of sensor and the other problems caused by limited resources have become increasingly prominent. For MIOT, data transfer instability problems [5] may be caused by resource allocation problems caused by sensor energy capacity constrained and instability of the network topology. The other problem is quality of services (QoS) performance degradation issues of mobile service caused by resource scheduling and resource allocation mechanism [6]. Since, research on energy conservation and resource scheduling intelligence and rationalization became the hot issue in academia and industry.

On the one hand, a model-based approach for the efficient provisioning and management of the communication between heterogeneous resource-constrained devices were proposed in [7], which includes a set of interoperable communication libraries providing an abstract communication layer that can integrate both powerful and resource-constrained devices. Vlacheas et al. [8] proposed a cognitive management framework for IoT, in which dynamically changing real-world objects are represented in a virtualized environment. In this framework, the cognition and proximity are used to select the most relevant objects for the purpose of an application in an intelligent and autonomic way. In [9], the authors presented a trust and reputation model TRM-IoT to enforce the cooperation between things in a network of IoT based on in-depth understanding of trust establishment process and quantitative comparison among trust establishment methods.

On the other hand, a lightweight and density-aware reprogramming protocol was proposed by Dong et al. [10] with XOR, which was used to reduce the communication cost and deliver better performance than the typical reprogramming protocol for sensor networks. Programmable and energy efficient vision sensor node (VSN) architecture was proposed and implemented [11], which has lower energy requirements and reduced design complexity. In this framework, the initial data are implemented on the VSN and the control dominated complex tasks are processed on a server simultaneously. In [12], the authors addressed the issues of timeliness and transmission reliability of existing industrial communication standards and combined a forward error correction coding scheme on the medium access control layer with a lightweight routing protocol.

In particular, Candès et al. [13] studied the recovery of signals from underdamped data in the common situation, where such signals are not sparse in an orthonormal basis or incoherent dictionary, but in a truly redundant dictionary. Laska et al. [14] found the heretofore relatively unexplored property that many compressive sensing measurement systems are democratic. Spectral compressive sensing was introduced by Duarte and Baraniuk [15], which significantly outperforms current state-of-the-art compressed sensing algorithms based on the DFT. Based on the joint use of three essential ingredients, Krzakala et al. [16] proposed the probabilistic approach to signal reconstruction, the message-passing algorithm, and the measurement matrix inspired by the theory of crystal nucleation.

In this paper, we investigate how to select the optimal network resource management scheme to satisfy the diversity and dynamic requirements of application services in MIOT.

The rest of the paper is organized as follows. Section 2 describes the lightweight coding based on network resource management. In Section 3, we design a compressed sensing model for network resource management. The adaptive resource management scheme based on the combination is used to implement reliable and efficient resource allocation and scheduling, which is shown in Section 4. Simulation and mathematics results are shown in Section 5. Finally, we conclude the paper in Section 6.

2. Lightweight Coding and Network Resource Management

Based on the hierarchical model in MIOT, the lightweight coding positioning technology and interactive cross-layer design are shown in Figure 1. Here, the location technology is divided into virtual positioning technology and physical positioning technology.

Virtual Positioning. Orientation of end to end at the network layer or application layer, session as a unit.

Physical Positioning. Orientation of point to point at perception layer, hop as a unit.

The implementation of positioning technology in MIOT is based on information sharing between different layers in order to achieve coding hierarchy. The lightweight encoding positioning architecture is shown in Figure 2.

In particular, Figure 3 gives the defined frame format of lightweight encoding. An increase of 2 bits is used to record the use of virtual positioning or the use of physical positioning. Here, let PHY denote physical layer and let MAC denote the data link layer of sensor network. Depending on the resources demand of lightweight coding and variation, we define the frame formant into 4 different types, which are denoted by LW_i ($i = 1, 2, 3, 4$) and assigned 2 bits. V, P, Se, and Sy are occupied by one bit respectively. V represents the virtual positioning. P represents the physical positioning. Se denotes the content of Info field in the frame, which represents the resource information of sensors. Similarly, Sy denotes that the content of Info field in the frame represents the system resource information. Table 1 gives a definition of the specific circumstances of lightweight coding in MIOT.

Table 1: Lightweight encoding type assignment.

LW_i	V	P	Se	Sy	Info
00/01/10/11	0	1	0	1	$ANBNCN, \ldots, X_N$
00/01/10/11	0	1	1	0	$ANBNCN, \ldots, X_N$
00/01/10/11	1	0	0	1	$ANBNCN, \ldots, X_N$
00/01/10/11	1	0	1	0	$ANBNCN, \ldots, X_N$

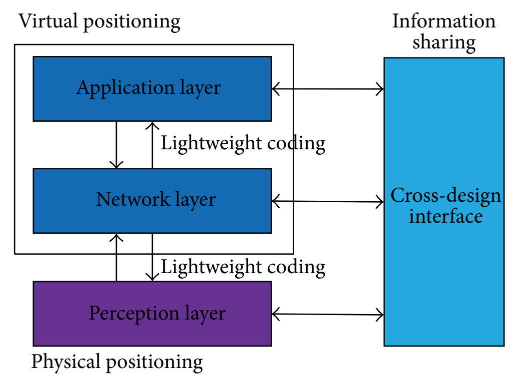

Figure 1: Hierarchical model in MIOT.

In Table 1, in the Info field, let $A, B, C, \ldots, X$ denote the assigned resource and let N denote the number of required resources. Length of this field would be defined according to the specific circumstances adaptively. Since, length of lightweight encoding frame format is variable, IOT positioning based on lightweight coding is described as follows.

(1) Data sender node sends a request of lightweight coding to the network layer.

(2) The network layer protocol analyzes service data request to determine what resources need to be allocated and assign the Info field the value.

(3) Sender node sends resources probe packets to MIOT through flooding.

(4) The sensor node would build a loopback packet and send feedback to the IOT gateway when it receives the MIOT resource probe packets.

(5) The positioning data would be transmitted between sender node and IOT gateway when V is 1 and P is equal to 0.

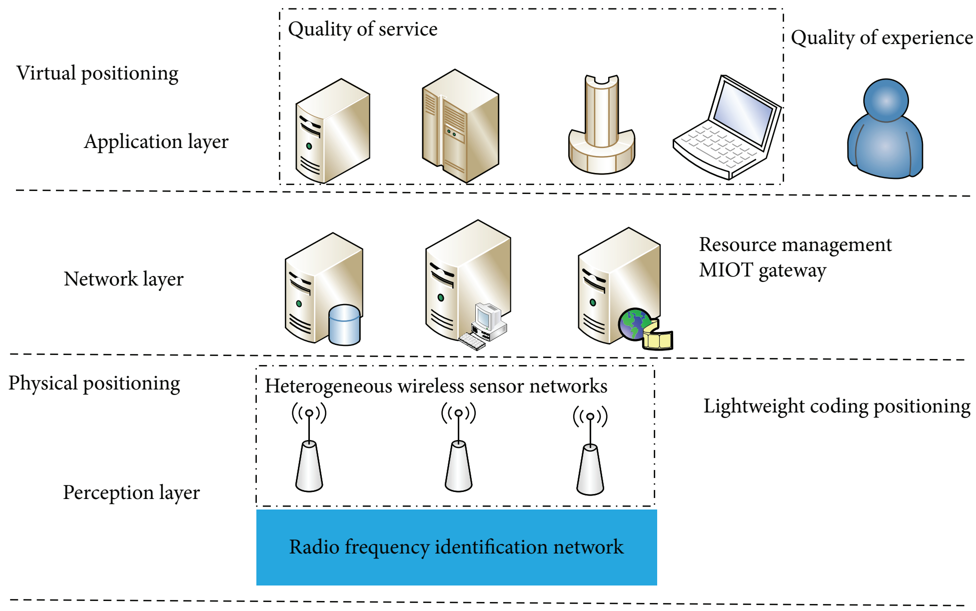

FIGURE 2: MIOT architecture of lightweight encoding positioning.

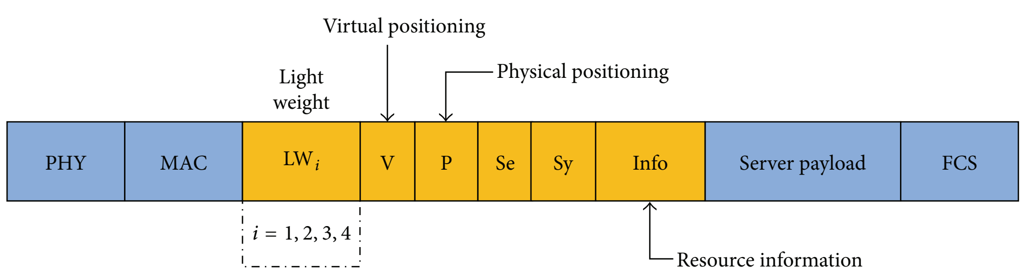

FIGURE 3: Frame definition based on lightweight encoding.

(6) The values of Se and Sy in frame format are modified by IOT gateway and forwarded to sender node.

(7) After sender node receives confirmation packet from the gateway, it would analyze the impact of the number of resources for lightweight encoding according to Info field, thereby selecting the best coding scheme LW_i.

(8) The lightweight encoding frame format based on current resource management would be determined by steps from (1) to (7).

(9) At sender node, the data would be encapsulated according to the determined frame format at step (8) and then sent to the IOT gateway.

(10) Gateway finds the receiver node on basis of the data frame from sender node by virtual positioning.

(11) End to end communication would be established based on resource sharing between the sender and receiver nodes.

(12) Receiver node sends periodically confirmation packet to the gateway. If there is packet loss or other phenomena which cause receiver cannot receive the correct data, the gateway reestablishes end to end connection by completing the steps from (1) to (7) through physical positioning.

3. Compressed Sensing and Network Resource Management

For compressed data of lightweight encoding, compression sensing technology is able to further optimize the signal sampling and data transfer, to facilitate further optimization of resource management. In reality, the number of hops between sensor and sink node is often less than the number of samples M of compression sensing. This leads to that data transmission frequency based on compressed sensing was significantly greater than that of the traditional way. Therefore, the combination of lightweight encoding and compression sensing is used to simultaneously reduce

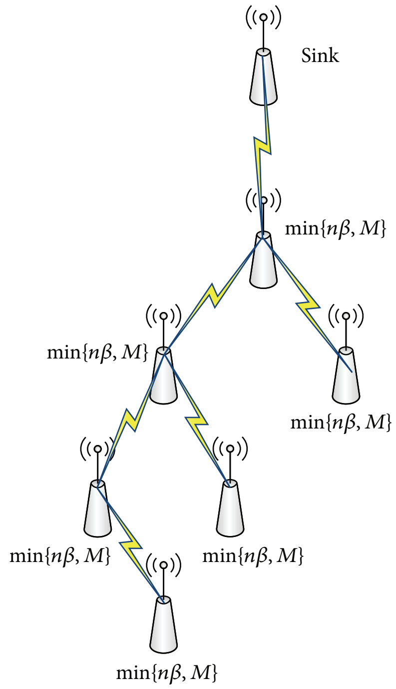

Figure 4: Comparison of the combination scheme and the traditional way.

the number of hops in the compressed data transmission in our work, such as in Figure 4.

Here, let n denote the shortest path length between the current sensor and the sink node. Let β denote the lightweight coding weights and let M denote the number of samples in compressed sensing. The $\min\{n\beta, M\}$ means that data transmission frequency would be assigned by selecting the smallest parameters from the lightweight coding and compressed sensing, which is to ensure that the number of current transfers always keeps the minimum.

MIOT compressed sensing technology consists of three elements which are as follows.

(1) Sparse representation of the signal: the sparsity of the signal is a prerequisite for compressed sensing. MIOT transmission signal should be represented by the suitable sparse basis representation.

(2) Noncorrelation measurements: noncorrelation measurement is the key to compressed sensing, Non correlation measurement is the key of compressed sensing. Then we design the measurement matrix. Note that we need a group of sparse matrixes that is used to measure the sparse signal, which must not be associated with the signal sample.

(3) Signal reconstruction: a way to achieve signal reconstruction is nonlinear optimization.

In our work, the measurement matrix is designed based on resource information η of sensor such as the residual energy, energy efficiency, and bandwidth. Here, η is used to record the ratio of current resource to total resource. So the sampling sparse matrix y is as follows:

$$y = \Phi_{MN} X \eta \begin{cases} 1 & 0 < \eta < a \\ M & a \le \eta < b \\ \min\{M, N\} & b \le \eta < c \\ N & c \le \eta < 1. \end{cases} \quad (1)$$

Here, let Φ_{MN} denote the sampled signal matrix. Let N denote the number of sensors in MIOT. X is used to denote the sample matrix. a, b, and c are used to record the resource allocation thresholds and could be obtained by real measurement, which is to make the decision of the weight of compressed sensing. In particular, sampled signal is divided into 4 groups, which are X_1, X_2, X_3, and X_4. So the data transmission frequency of sampled signal X is as follows:

$$\begin{aligned} X_1 &= \{X, 2X, \ldots, NX\}, \\ X_2 &= \left\{\frac{X_M}{2}, \frac{2X_M}{2}, \ldots, \frac{NX_M}{2}\right\}, \\ X_3 &= \left\{\frac{X_{\min\{M,N\}}}{3}, \frac{2X_{\min\{M,N\}}}{3}, \ldots, \frac{NX_{\min\{M,N\}}}{3}\right\}, \\ X_4 &= \left\{\frac{X_N}{4}, \frac{2X_N}{4}, \ldots, \frac{NX_N}{4}\right\}. \end{aligned} \quad (2)$$

Above all, the sampling sparse matrix y is given by

$$y = \begin{bmatrix} X_1 & & & \\ & X_2 & & \\ & & X_3 & \\ & & & X_4 \end{bmatrix} \begin{bmatrix} & & & \Phi_1 \\ & & \Phi_2 & \\ & \Phi_3 & & \\ \Phi_4 & & & \end{bmatrix}^T. \quad (3)$$

Four different measurements matrixes are designed and given by formula (4). In the actual use of the process, selecting the best measurement matrix is based on system resources:

$$\begin{aligned} H_1 &= \begin{bmatrix} X_1 \\ X_1 \\ \vdots \\ X_1 \end{bmatrix} \begin{bmatrix} 1 \\ 2 \\ \vdots \\ N \end{bmatrix}^T \begin{bmatrix} \varphi_1 & & & \\ & \varphi_1 & & \\ & & \ddots & \\ & & & \varphi_1 \end{bmatrix}, \\ H_2 &= \frac{1}{2} \begin{bmatrix} X_M \\ X_M \\ \vdots \\ X_M \end{bmatrix} \begin{bmatrix} 1 \\ 2 \\ \vdots \\ N \end{bmatrix}^T \begin{bmatrix} \varphi_2 & & & \\ & \varphi_2 & & \\ & & \ddots & \\ & & & \varphi_2 \end{bmatrix}, \\ H_3 &= \frac{1}{3} \begin{bmatrix} X_{\min\{M,N\}} \\ X_{\min\{M,N\}} \\ \vdots \\ X_{\min\{M,N\}} \end{bmatrix} \begin{bmatrix} 1 \\ 2 \\ \vdots \\ N \end{bmatrix}^T \begin{bmatrix} \varphi_3 & & & \\ & \varphi_3 & & \\ & & \ddots & \\ & & & \varphi_3 \end{bmatrix}, \\ H_4 &= \frac{1}{4} \begin{bmatrix} X_{\min\{M,N\}} \\ X_{\min\{M,N\}} \\ \vdots \\ X_{\min\{M,N\}} \end{bmatrix} \begin{bmatrix} 1 \\ 2 \\ \vdots \\ N \end{bmatrix}^T \begin{bmatrix} \varphi_4 & & & \\ & \varphi_4 & & \\ & & \ddots & \\ & & & \varphi_4 \end{bmatrix}. \end{aligned} \quad (4)$$

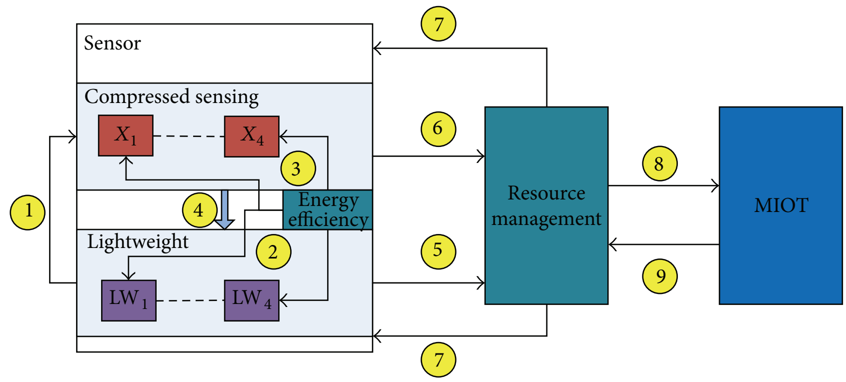

FIGURE 5: Implementation architecture of NRM-LWComSen.

Here, let φ_1, φ_2, φ_3, and φ_4 denote the 4 groups of resource allocation weights of lightweight coding scheme, which could be analyzed with the value of Info field in frame format. As the compressed sensing is used in our work based on the lightweight coding, so the signal reconstruction algorithm is described as follows.

Output. Measurement matrix $H = \{H_1, H_2, H_3, H_4\}$, sampled signal matrix $X = \{X_1, X_2, X_3, X_4\}$, sampling sparse matrix y.

Input. Reconstructed signal $\overline{X} = \{\overline{X}_1, \overline{X}_2, \overline{X}_3, \overline{X}_4\}$.

Parameters. Data transmission frequency $\min\{M, N\}$, sample M, number of sensors N.

(1) All sample signals would be compressed and projected to the corresponding measurement matrix.

(2) Analyze the critical situation and the resources according to the Info field.

(3) Obtain the X and H matrixes after calculating the threshold and developing grouping interval.

(4) Obtain the sampling sparse matrix y and calculate the sparsity and compare with the projection of measurement matrix.

(5) Calculate the reconstructed signal according to the formula $\overline{X} = (y/\Phi_{MN})\min_{l\in[1,4]}\|\eta_l/H_l\|$.

4. Adaptive Network Resource Management Scheme of NRM-LWComSen

In MIOT, based on cross-layer design and resource-aware scheduling policy, the combination of lightweight coding and grouping compressed sensing is able to improve the reliability of resource management and real-time performance of accessing to system resources information.

4.1. Implementation Architecture of NRM-LWComSen. Figure 5 gives the implementation architecture of resource management technique based on lightweight coding and compressed sensing for MIOT denoted by NRM-LWComSen. In Figure 5, sensors have the module of lightweight coding, compressed sensing, and analysis of energy efficiency. Module of analysis of energy efficiency sets up the compressed parameters by ③ and notifies the module of lightweight coding to select the optimal frame format definition by ②. Module of lightweight coding notifies the compressed sensing module to adaptive perception through ①. Then module of compressed sensing provides the resource sharing information by ④. After the above operations, the sensor makes the operations of sample, noncorrelation measurements, and signal reconstruction by ⑥ and implements the real-time position by ⑤. Next, after implementation of resource optimal management and assignment, the resource management module is active, which is used to collect the real time information of MIOT through ⑨ at the same time. Sensor achieves the coordination information through ⑦. In Figure 5, ⑧ will be active when resource allocation scheme has been determined in order to provide the optimal resource management and service scheduling policy.

The proposed scheme could perceive the system situation information and schedule resource adaptively, which is implemented based on the cooperation of compressed sensing and lightweight coding. Figures 6 and 7 show the resource coordination mechanism based on MIOT feedback information and real-time access to system resources information processing flow. Specific processes of the NRM-LWComSen are described as follows.

(1) Module of energy efficiency analysis would set up the parameters through ①.

(2) Lightweight coding frame format is selected by the energy efficiency threshold with ②.

(3) Select the optimal combination from the 16 combinations, such as X_1LW_1, X_1LW_2, X_1LW_3, X_2LW_4, X_2LW_1, X_2LW_2, X_2LW_3, X_2LW_4, X_3LW_1, X_3LW_2, X_3LW_3, X_3LW_4, X_4LW_1, X_4LW_2, X_4LW_3, X_4LW_4, and send it to service scheduling management coordination with ③.

(4) The services are divided into 4 classes based on reliability, energy request, and signal strength, which are denoted by S_1, S_2, S_3, and S_4. Then these services enter the service request queue through ④ and ⑤.

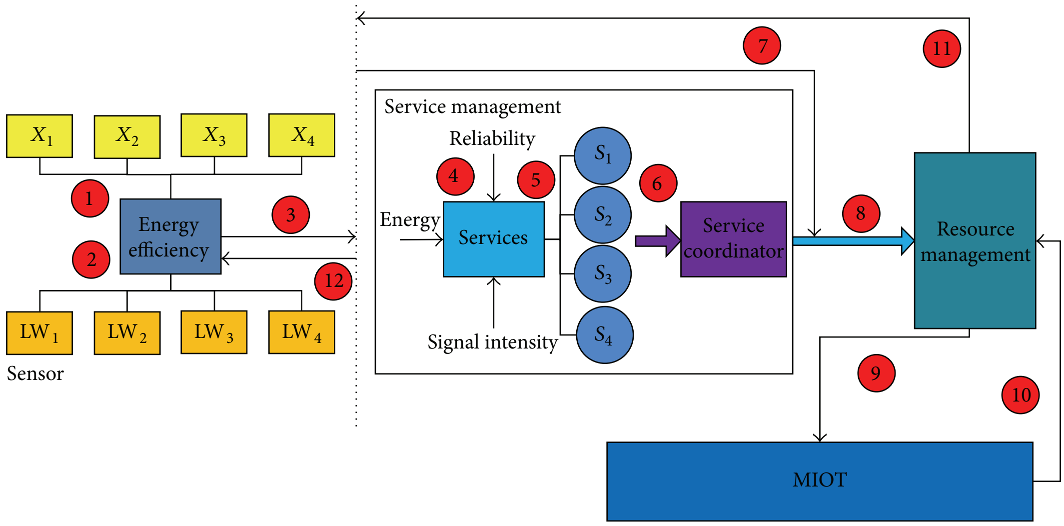

FIGURE 6: Resource coordination mechanism in MIOT.

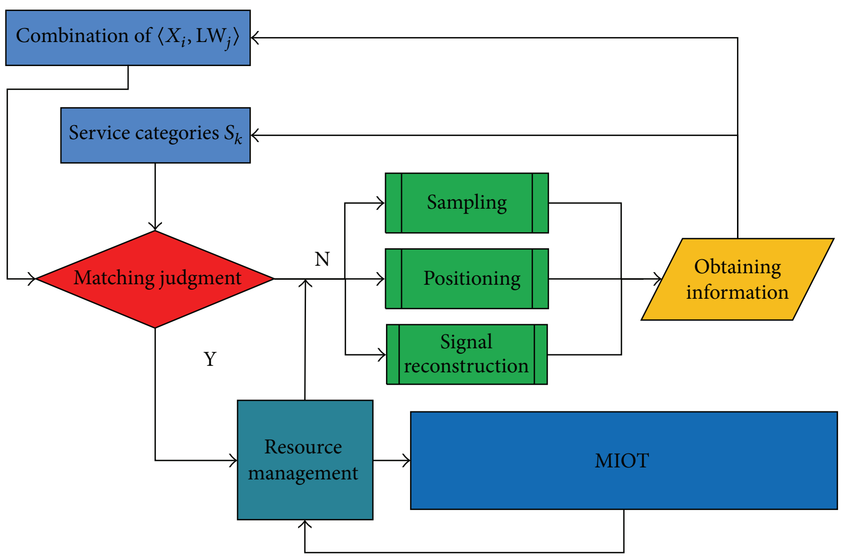

FIGURE 7: Real-time access to system resources information processing flow.

(5) Choose the current service object according to the queue management and service coordinator.

(6) Make the decision of combination of $\langle X_i, LW_j \rangle$ and S_k in module of matching judgment. If it is yes, step (7) is active. If it is no, reconfigure combination and services classified information according to the real-time feedback information from MIOT based on steps from (1) to (6).

(7) According the result of ⑧, resource management and scheduling operation are carried out. Then enter the MIOT through ⑨.

(8) The real-time information is forwarded to resource management module by ⑩ and to sensors by ⑪.

(9) Module of analysis of energy efficiency obtains the real-time information from MIOT through ⑫ and reconstructs the combination scheme of lightweight coding and compressed sensing form the 16 combinations by executing the operation from steps (3) to (8).

4.2. Resource Acquisition and Coordination Methods Based on Positioning of Lightweight Encoding. The basic idea of system information acquisition and coordinated approach based on resource-aware lightweight coding is the implementation of resource classification method. The frame format is classified in accordance with the real-time system and then locate the nodes on the system, the system resources would be scheduled and allocated based on the compressed sensing technology. Lightweight coding method is used to solve some confusion issues of MIOT such as data acquisition of data receiver module at sensor and transmission of service

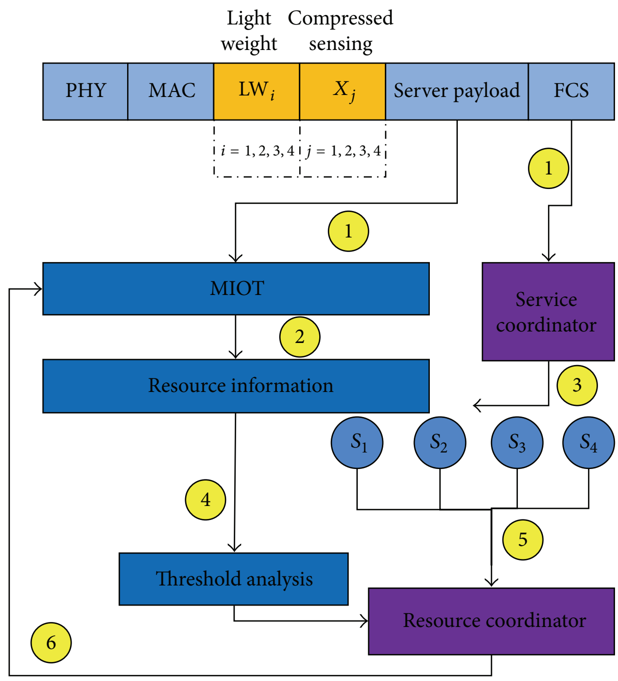

Figure 8: Basic architecture of resource acquisition and coordination method.

request information, as well as queue arrangement. Figure 8 shows the basic architecture of resource acquisition and coordination method.

In Figure 8, ① represents sending the frame into MIOT or service coordination module. ② denotes the acquisition of resource information. ③ indicates selecting the optimal service object from the 4 groups of service queue in service coordination module. Analysis and transmission of threshold are denoted by ④. The development of resource scheduling and allocation scheme is denoted by ⑤. Let ⑥ denote entering of MIOT.

Practical applications of the scheme in Figure 8 require paying attention to the following two points.

(1) Scheduling service S_k belongs to the set of $\{S_1, S_2, S_3, S_4\}$. T is the service scheduling adjustment cycle. R_w is the resource analysis weight. So, the best matching service S could be selected by the following formula according to the adaptive selection and resource status when t is close to T:

$$S \triangleq \lim_{t \to T} \{S_1, S_2, S_3, S_4\} R_w. \quad (5)$$

(2) The threshold analysis could be established based on real-time network status and resources state of MIOT, which is shown in the following formula:

$$\text{Th} = \begin{cases} \text{Th}_1 & \partial_1 \leq \text{Res} < \partial_2 \\ \text{Th}_2 & \partial_2 \leq \text{Res} < \partial_3 \\ \text{Th}_3 & \partial_3 \leq \text{Res} < \partial_4 \\ \text{Th}_4 & \partial_4 \leq \text{Res} < \partial_5. \end{cases} \quad (6)$$

Here, Let Res denote the system resource such as energy and transmit power. Let ∂_1, ∂_2, ∂_3, ∂_4, and ∂_5 denote the five critical values on basis of analysis conclusion of resource threshold.

4.3. MIOT Network Resource Scheduling Based on Compression Sensing. Compressed sensing technology of network resource scheduling is used to make the assignment of encoded sample signal and parameters of resource management, in order to reduce the complexity of resource management and smooth scheduling method. Queue scheduling is based on the user-defined service priorities. According to the actual situation, the flexible adjustment of resource scheduling strategy is used to protect the low priority queue to receive the appropriate service for guaranteeing the fair service of MIOT. The implementation model of the proposed scheme is illustrated by Figure 9.

Sample signal is sent to resource list after compressed sensing by ①. With the help of the operation of service scheduling queue, the sample signal is sent to MIOT through ②. If users define the service priorities and send request by ③, the service scheduling rules would be modified and sent to sensors by ④.

5. Performance Evaluation

In order to analyze and evaluate the performance of the proposed scheme, we designed two groups of experiments. In experiment 1, in order to verify the effectiveness of the scheme and the energy saving effect and sensor of the wireless data transmission, a 10-node network is deployed. The remaining percentage of energy accounts to initialization

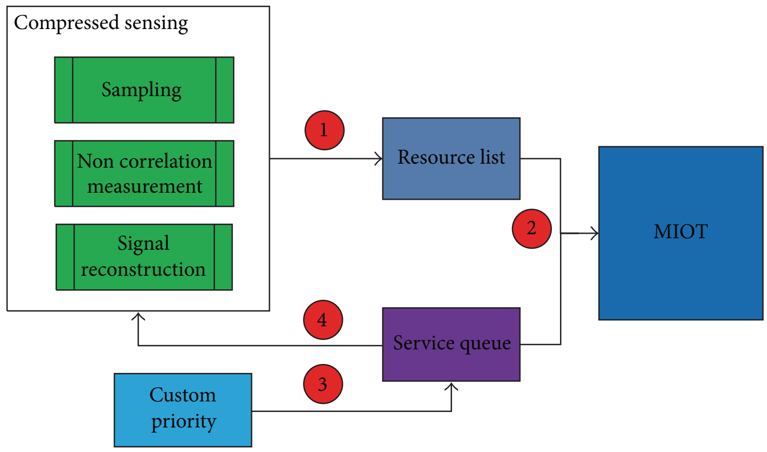

Figure 9: Flow of network resource scheduling based on compression sensing.

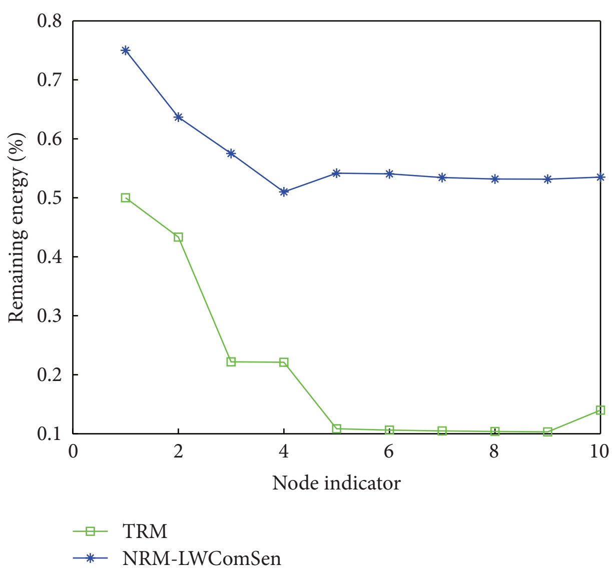

Figure 10: Comparison of energy saving effect.

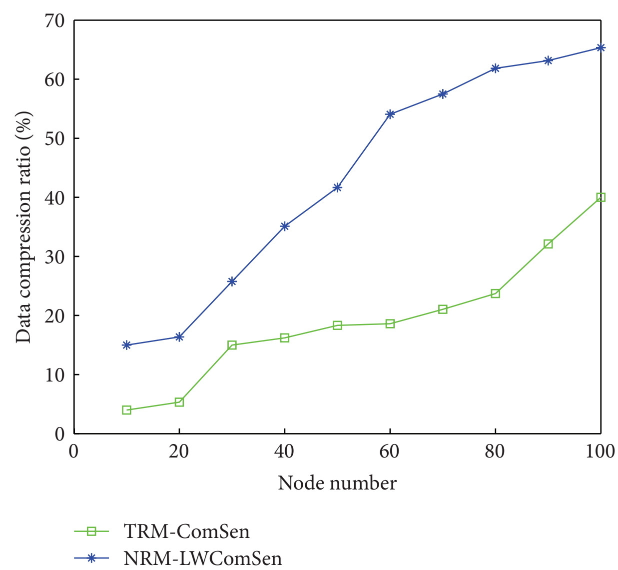

Figure 11: Analysis of data compression ratio.

of traditional resource management (TRM) and the proposed NRM-LWComSen is counted and shown as in Figure 10.

The proposed strategy is superior to the energy saving effect of the TRM in sensors of the various states, which shows that the proposed scheme can be applied to the MIOT composed of heterogeneous sensors.

In experiment 2, sensors of the MIOT are deployed from 10 to 100, in step 10. We study the data compressing ratio, the increase percentage of energy consumption, and data reconstruction error with the sensors number in MIOT between the network management system using compressed sensing technology alone (TRM-ComSen) and the proposed NRM-LWComSen scheme.

(1) Figure 11 gives the comparison result of NRM-LWComSen and TRM-ComSen. We found that the compression ratio increases as the number of nodes increases. However, the performance of NRM-LWComSen is better than that of TRM-ComSen. This is because the compressed sensing is based on the lightweight coding. Sparse sampling matrix is defined by the real-time status of network resources, which is able to maintain a high compression ratio and further optimize resource utilization.

(2) Energy saving effect of the NRM-LWComSen and TRM-ComSen is shown as in Figure 12. We found that the increase percent of energy consumption is lower than that of TRM-ComSen. Because the data compression ratio of the proposed mechanism is large and the less data need to be transmitted, the system energy increases slowly and has the obvious energy saving effect.

(3) The impact of two mechanisms for network data signal reconstruction error is given by Figure 13. It is found that the error increases linearly. However, the slope of the proposed mechanism was significantly lower than that of TRM-ComSen because the definition of frame format based

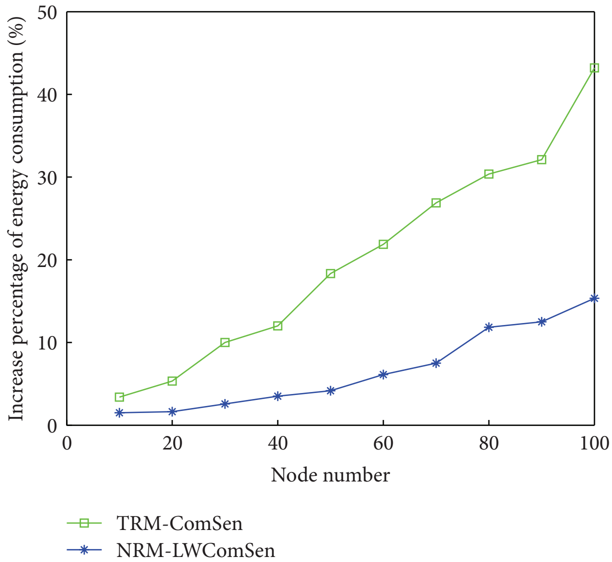

Figure 12: Analysis of energy saving effect.

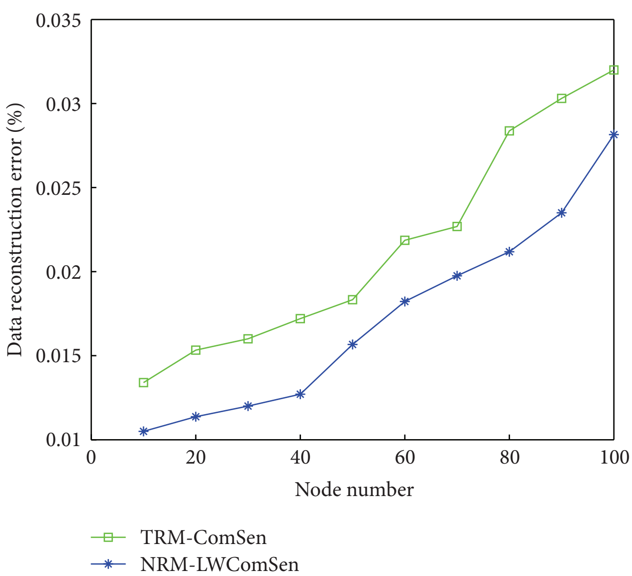

Figure 13: Comparison of data reconstruction error.

on system resource and the real-time performance of parameters setting in compressed sensing, as well as rationality of resource allocation.

6. Conclusion

We studied the definition types of frame format in lightweight coding deployed in MIOT and their impact on the compressed sensing technology. The parameters of compressed sensing, such as number of sample signals and measurement matrix, are selected based on resource information defined in the frame formant. We developed the combination model of the above schemes that can provide estimations for the optimal resource scheduling in the presence of dynamic and variable MIOT environment. This proposed scheme helps us to improve performance of MIOT, prolong system life cycle, and optimize resource utilization. The model was evaluated with two groups of simulation experiments that have shown clear superiority between the mathematical analysis and the simulation results.

Conflict of Interests

The authors declare that they have no financial or personal relationships with other people or organizations that can inappropriately influence their work; there are no professional or other personal interests of any nature or kind in any product, service, and/or company that could be construed as influencing the position presented in or the review of the paper.

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