

## Research Article

# Adaptive Opportunistic Cooperative Control Mechanism Based on Combination Forecasting and Multilevel Sensing Technology of Sensors for Mobile Internet of Things

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In mobile Internet of Things, there are many challenges, including sensing technology of sensors, how and when to join cooperative transmission, and how to select the cooperative sensors. To address these problems, we studied the combination forecasting based on the multilevel sensing technology of sensors, building upon which we proposed the adaptive opportunistic cooperative control mechanism based on the threshold values such as activity probability, distance, transmitting power, and number of relay sensors, in consideration of signal to noise ratio and outage probability. More importantly, the relay sensors would do self-test real time in order to judge whether to join the cooperative transmission, for maintaining the optimal cooperative transmission state with high performance. The mathematical analyses results show that the proposed adaptive opportunistic cooperative control approach could perform better in terms of throughput ratio, packet error rate and delay, and energy efficiency, compared with the direct transmission and opportunistic cooperative approaches.

## 1. Introduction

In mobile Internet of Things, the sensing, collection, processing of wireless data, and so forth are relying on the high-density deployment sensors. However, due to the constraints and challenges of sensors [1, 2], for example, dynamic wireless link, limited bandwidth, susceptible to interference channel, limited energy and computation capability, and limited storage, it is difficult to guarantee the quality of service (QoS) for mobile Internet of Things application (MIOT).

The random variation [3, 4] of sensors and Internet of Things (IOT) seriously especially affect the system performance such as mobility, activity probability, and channel quality. There is one key issue in data transmission over MIOT, when and how to build the optimal cooperative data communication on the basis of the sensors and network state.

In this paper, we investigate how and when to choose the optimal sensors with some threshold values based on forecasting, to build the reliable, real time, high resources efficiency and effective data transmission control progress, and to satisfy the diversity requirements of MIOT services.

The rest of the paper is organized as follows. The related work and our work object are elaborated in Section 2. Section 3 describes the randomness verification of data control events sequences. In Section 4, we design a combination forecasting approach based on multilevel sensing technology of sensors in MIOT and give the analysis foundation to obtain the threshold. The proposed scheme of opportunistic cooperative control approach is used to guarantee the real time, high efficient, and reliable data transmission in MIOT, which is shown in Section 5. Section 5 also proposes the adaptive opportunistic cooperative control mechanism based on combination forecasting, including the details of implementation. Mathematics results are given in Section 6. Finally, we conclude the paper in Section 7.

## 2. Related Work

Internet of Things relies on collaboration between the high-density data-sensing deployment sensors, to implement the collection and processing [5, 6]; however sensors in IOT

are self-limiting size, energy, data storage, processing power, and wireless bandwidth, so the cooperative data transmission progress has to consider these factors.

On the one hand, it is well known that sensors could effectively improve the utilization of system resources and network performance. However, there are some key problems of cooperative communication over MIOT [7, 8], including when to start cooperative communication, which sensors to join the cooperative process, and how to establish cooperative transmission control mechanisms. Christophe proposed the approach of such vision based on a federated network comprised of sensors [9]. In view of cluster and multichannel media access control (MAC) schemes, Jonghun Kim and Lee overcome interference with group mobility for reliable wireless communication services over IOT [10].

On the other hand, the status of sensors, which would be affected by transmitting power, channel quality, distance, or activity probability, could influence directly the performance of cooperative communication. So the cooperative transmission process should be rebuilt adaptively and promptly. In [11], authors divided the wireless channels according to implicit ACK and proposed the protocol, which is able to select the routing path in accordance with the link quality. The simple and robust ZigBee transceiver [12] was designed, which is able to support transmission distance of 1.2 km and moving speed of 60 km/h. In the study of article [13], the energy consumption of multi-path-optimized link state routing and dynamic MANET on demand were compared and analyzed.

Particularly, in the progress of opportunistic cooperation, how to effectively reduce energy consumption in the Internet of Things for sensors is one key problem, which is used to improve system throughput, transmission delay, and reliability. Since our previous research introduced the Markov chain model based on Automatic Repeat reQuest (ARQ) and hybrid ARQ to study the characteristics of quality of service and designed the quality of service supported strategy with dynamic priority [14], energy-efficiency-aware adaptive relay selection algorithm based on signal to noise ratio (SNR) was presented to achieve higher system throughput and lower delay [15]. The author of [16] characterized the bidirectional effects between human and opportunistic IOT and discussed the technical challenges and then proposed the reference architecture for developing opportunistic IOT systems. Ros aria et al. proposed the link quality and geographical beaconless OR protocol for efficient video dissemination for mobile multimedia Internet of Things [17]. Gregory Katsaros et al. defined one new collaboration domain and presented the framework through which opportunistic collaboration services can be provisioned.

In a word, because of the special physical and electrical properties of sensors and dynamic Internet of Things topology, especially the diversity of application service in complex environments, it is difficult to meet the needs of practical application and diversity to guarantee quality of service by using direct transmission or fixed cooperative transmission control method. Therefore, it is necessary and important to consider and research the adaptive opportunistic multilevel sensing prediction method, which can not only predict the

TABLE 1: Results of randomness verification.

$m$	$\partial$							
	0.01	0.02	0.05	0.1	0.2	0.3	0.4	0.5
4	<b>T</b>	<b>T</b>	<b>T</b>	F	F	F	F	F
5	<b>T</b>	<b>T</b>	<b>T</b>	<i>T</i>	F	F	F	F
6	<b>T</b>	<b>T</b>	<b>T</b>	<i>T</i>	<i>T</i>	F	F	F
7	<b>T</b>	<b>T</b>	<b>T</b>	<i>T</i>	<i>T</i>	F	F	F
8	<b>T</b>	<b>T</b>	<b>T</b>	<i>T</i>	<i>T</i>	F	F	F

Here, T denotes the characteristic of event sequence randomness. F denotes that the event sequence does not have the random nature. Bold zone represents the sequence which has the random nature when  $m$  is from 4 to 8 and  $\partial$  is from 0.01 to 0.05. Italic zone represents the sequence which has the random nature when  $m$  is from 5 to 8 and  $\partial$  is 0.1. Bold italic zone represents the sequence which has the random nature when  $m$  is from 6 to 8 and  $\partial$  is 0.2.

future trend of Internet of Things, but also establish the best opportunistic cooperation transmission.

### 3. Randomness Verification of Events Sequences

In IOT, data is transmitted in a certain time interval, the event control process in accordance with the arrangement order of events sequence. The dynamic features of the collected event sequence could be analyzed by the correlation coefficients  $m$  with significance level  $\partial$ , which is used to judge whether the sequence satisfies the random characteristic for data transmission control event prediction.

Let  $X$  denote the collected data sequence; the correlation coefficients could be obtained by

$$m = \frac{\sum_{t=1}^{N-k} (x_t - \bar{x})(x_{t+k} - \bar{x})}{\sum_{t=1}^N (x_t - \bar{x})^2}. \quad (1)$$

Here,  $\bar{x} = (1/N) \sum_{t=1}^N x_t$ .

If  $m$  satisfies the following inequality, the events sequence should have characteristics of randomness:

$$|m| \leq \frac{T_a}{\sqrt{N}}. \quad (2)$$

Here,  $T_a$  denotes the weight coefficient according to the significance level  $\partial$ .

In order to analyze the dynamic characteristics of  $m$  and  $\partial$  with the events sequences,  $m$  is set from 4 to 8; the step is 1.  $\partial$  is set to one of the matrices [0.01, 0.02, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5]. The results are shown in Table 1.

The following conclusions could be obtained from Table 1.

- (1) The event sequence has the random nature when  $\partial$  is less than or equal to 0.05.
- (2) The event sequence has the random nature when  $m$  is greater than or equal to 5 and  $\partial$  is 0.1.
- (3) The event sequence has the random nature when  $m$  is greater than or equal to 6 and  $\partial$  is 0.2.
- (4) The event sequence does not have the random nature when  $\partial$  is greater than or equal to 0.3.

#### 4. Multilevel Combination Forecasting Approach Based on Sensing

When data communications of IOT were affected by cyclical movements, dynamic topology, and random interference, it is difficult to predict wireless transmission events. So, the weighted moving average method could be used to eliminate these confounding factors, in order to clear the transmission control event trend for effective forecasting.

The  $n$  statistical packet loss time from the IOT as the base for the actual communication process was used to predict the next packet loss time. Event prediction value could be calculated by the weighted moving average prediction value events according to

$$\text{WMA}_{t+1} = \frac{1}{n} \sum_{i=t+1-n}^t w_{i-t+n} x_i. \quad (3)$$

Here,  $\text{WMA}_{t+1}$  denotes the weighted moving average after  $t$  cyclical movements.  $w$  denotes weighted weights.

Then, the  $n + 1$  and  $n + 2$  packet loss time would be predicted according to  $n$  statistical values, which is used to evaluate the reliability and real time performance of this approach. Here,  $n$  is set from 6 to 10.  $w$  is set to the following three sets of data: (1)  $w_1 = [0.05, 0.1, 0.5, 1.0, 1.5]$ , (2)  $w_2 = [0.5, 1.0, 1.5, 2.0, 2.5]$ , and (3)  $w_3 = [0.05, 0.1, 0.5, 1.0]$ . The prediction results are shown as in Figure 1 and Table 2.

The real time performance analysis of weighted moving average method was summarized in Table 2 and Figure 1 as follows.

- (1) The blue area represents the predicted time for different parameter settings.
- (2) Light green represents the 11th actual statistics; wine red represents the 12th actual statistics.
- (3) The real time performance was better when  $n$  is smaller. That means that the prediction value is closer to the actual predictive value.

Meanwhile, the reliability analysis is shown in Figure 2, and the conclusions are as follows.

- (1) When  $n$  is small the weighted weights must be not too small; otherwise error would be too large.
- (2) When  $n$  is greater and the error is fewer, the reliability is higher.
- (3) The appropriate weighted weights should be selected based on the forecast demand.
- (4) Increasing the length of the array could reduce the prediction error and improve reliability when each element of weighted weight array is equal.

Diversity sensing weighted moving average method is able to choose the best predictive parameter setting to analyze  $n$  and  $w$  for prediction with high reliability and real time performance, but it must have  $n$ , the past actual statistics. It is difficult to meet this condition especially at the early time of Internet of Things, which has to store large amounts of data and would increase the burden on the system.

TABLE 2: Comparative analysis weighted moving average forecast.

Parameter settings	Actual value	Predictive value	Error
$(n_1 = 6, w_1)$	39	43.5282	0.1492
$(n_1 = 6, w_2)$	39	46.7233	0.2866
$(n_1 = 6, w_3)$	39	45.1210	0.1676
$(n_2 = 10, w_1)$	48.5	50.7251	0.1014
$(n_2 = 10, w_2)$	48.5	52.1369	0.1573
$(n_2 = 10, w_3)$	48.5	52.1320	0.1060

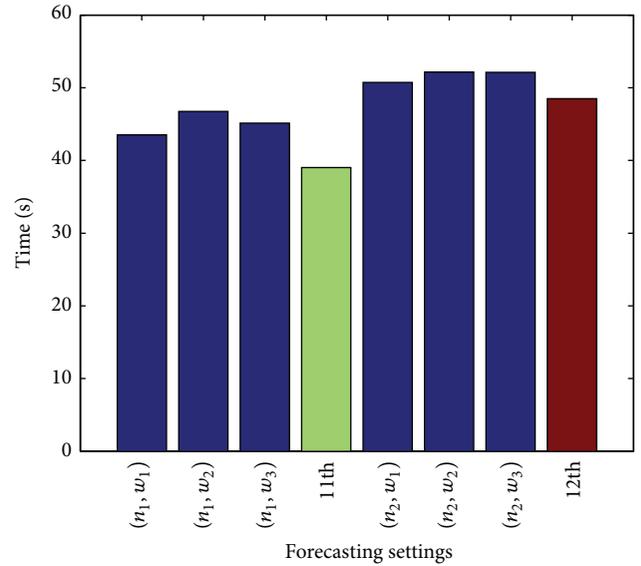


FIGURE 1: Real time performance of weighted moving average method with different parameters.

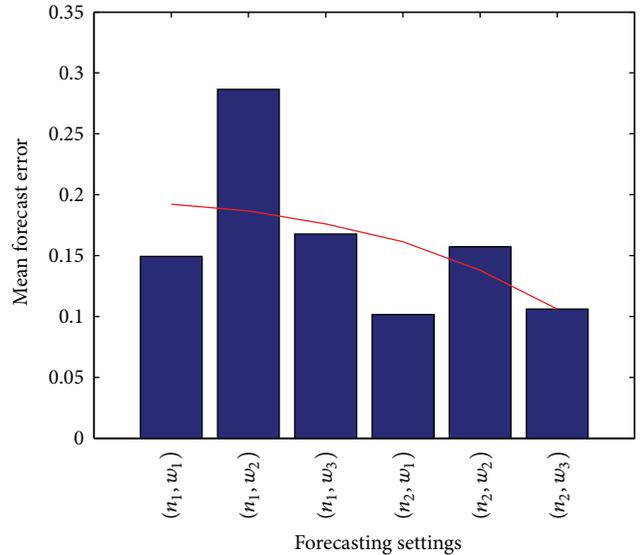


FIGURE 2: Reliability of weighted moving average.

Exponential smoothing forecasting method requires only two values: the latest one on measured and predicted values. Prediction of events is as follows:

$$\text{ES}_{t+1} = S_w x_t + (1 - S_w) \text{ES}_t. \quad (4)$$

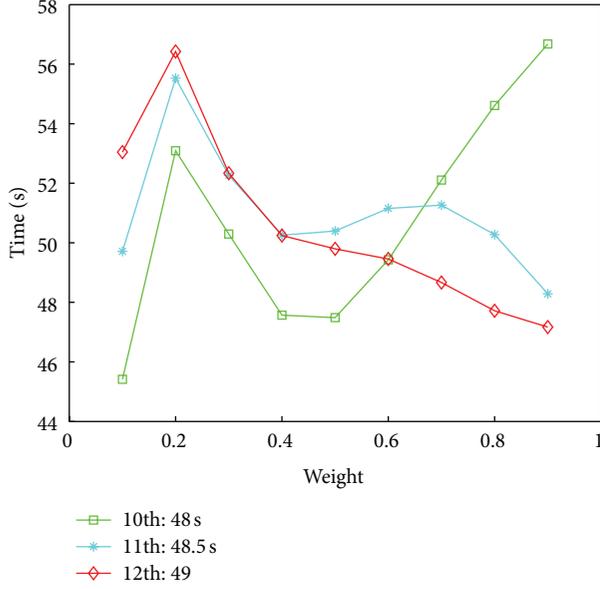


FIGURE 3: Analyses of reliability and real time with exponential smoothing prediction.

Here,  $ES_{t+1}$  denotes the predicting value after  $t$  cyclical movements and  $S_w$  denotes smooth weights.

Then, the  $n + 1$  and  $n + 2$  packet loss time would be predicted according to  $n$  statistical values, which is used to evaluate the reliability and real time performance of this approach.  $S_w$  is set from 0.1 to 1. The results are shown as in Figure 3.

From Figure 3, the following was found.

- (1)  $S_w$  should be less than 0.5 when the 10th was predicted based on 9 actual values, and there is an optimal value.
- (2) When the 11th and 12th time were predicted,  $S_w$  should be greater than 0.5, and there is an optimal value.
- (3) In the later events, the best  $S_w$  should be closer to 1.

In summary, weighted moving average method could choose the best  $n$  and  $w$  based on the prediction request, but there are the past statistics and enough storage space. Exponential smoothing prediction could predict the event trend considering and sensing the reliability and timeliness without past statistics. However, prediction accuracy of weighted moving average is better than the other. Since multilevel sensing combination prediction method based on supporting diversity forecast request was proposed, its workflow is given in Figure 4.

## 5. Adaptive Opportunistic Cooperative Control Mechanism

In IOT, sending sensor transports data to receiving sensor. Assuming that there are  $M-1$  neighbor sensors, which may

join the cooperative transmission, the SNR of receiving sensor could be calculated by

$$\text{SNR} = \frac{E}{\sigma^2} \sum_{i=1}^M \text{AP}_i \text{TP}^i |h_i|^2 \times \left( 10^{\text{TP}^0 - \text{TP}(d_0) + 10\beta \log_{10} d_0 - \text{TP}_n - (2R_{\text{radio}} \ln_2 P_b / B_N)} \right)^{-1}. \quad (5)$$

Here,  $E$  denotes the energy consumption of sending data at sending sensor,  $\sigma^2$  denotes Gaussian white noise variance,  $\text{AP}$  is the activity probability of sensors, which is set from 0 to 1,  $\text{TP}$  is the transmitting power of sensors,  $h_i$  represents the channel quality between sensor  $i$  and receiving sensor,  $d_0$  denotes near-earth reference distance of sensors,  $R_{\text{radio}}$  denotes transmitted signal speed of sending sensor,  $P_b$  is bit error rate, and  $B_N$  denotes noise bandwidth. The outage probability  $P_{\text{out}}$  could be calculated by

$$P_{\text{out}} = \begin{cases} 0, & \text{SNR} \geq \text{TH}_{\text{SNR}}, \\ 1 - \frac{\text{SNR}}{\text{TH}_{\text{SNR}}}, & \text{SNR} < \text{TH}_{\text{SNR}}. \end{cases} \quad (6)$$

Here,  $\text{TH}_{\text{SNR}}$  represents the threshold of SNR.

According to formulas (5) and (6), Figure 5 gives the analysis results of SNR and  $P_{\text{out}}$  with  $M$ ,  $\text{AP}$ ,  $d$ , and  $\text{TP}$ , the threshold values of which could be obtained and are given as follows.

- (1) Threshold of  $\text{AP}$  and  $M$ : ( $\text{AP} = 1, M = 2$ ), ( $\text{AP} = 0.8, M = 3$ ), ( $\text{AP} = 0.6, M = 4$ ), and ( $\text{AP} = 0.4, M = 5$ ).
- (2) Threshold of  $d$  and  $M$ : ( $M = 5, d \geq 10$ ), ( $M = 4, d \leq 8$ ), ( $M = 3, d \leq 6$ ), and ( $M = 2, d \leq 4$ ).
- (3) Threshold of  $\text{TP}$  and  $M$ : ( $M = 5, \text{TP} = 3$ ), ( $M = 4, \text{TP} = 5$ ), ( $M = 3, \text{TP} = 7$ ), and ( $M = 2, \text{TP} = 10$ ).

Therefore, the adaptive opportunistic cooperative transmission control mechanism (CF-OCT) was proposed, which is based on the multilevel sensing combination prediction approach and thresholds. The system architecture is illustrated in Figure 6.

Afterwards, the basic idea of the CF-OCT is presented and its implementation at sending sensor and relay sensors is illustrated as follows in detail.

*Sending Sensor.* (1) The values of  $E$ ,  $d_0$ , and  $R_{\text{radio}}$  could be obtained with the physical and electrical properties of sensors.  $P_b$ ,  $B_N$ , and  $\sigma^2$  could be obtained by actual measurement or statistics.

(2) Network state is defined as  $\langle \text{APs}, \text{Ds}, \text{TPs}, \text{Ms} \rangle$ . Here,  $\text{APs}$  denote the array of  $\text{AP}$ . Similarly,  $\text{Ds}$ ,  $\text{TPs}$ , and  $\text{Ms}$  denote array of them, respectively. Then the channel state signal sequences are sent.

(3) Initialization of level I sensing decision: let  $\text{AP}$  be the control event sequence  $X$ . Steps from (4) to (7) will be executed.

(4)  $\text{Randomness\_Test}(X)$  is called, which is used to test whether the even sequence  $X$  has the randomness and the best

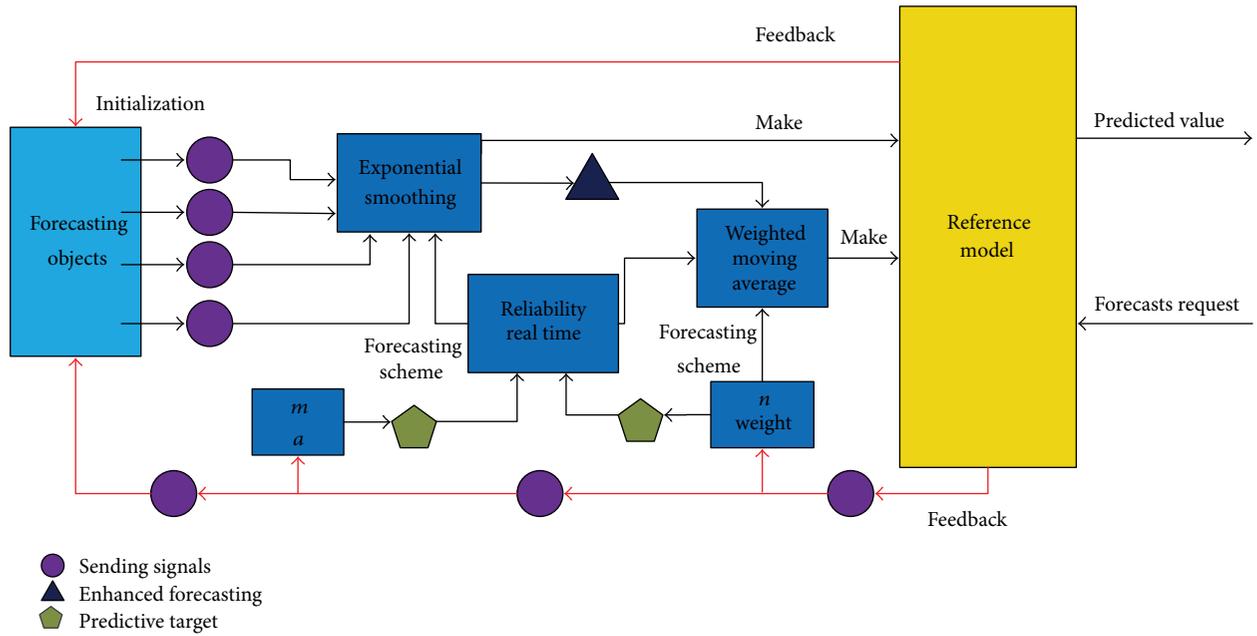


FIGURE 4: Workflow of the multilevel sensing combination forecasting method.

value of  $m$  and  $\partial$ . Here,  $\text{Randomness\_Test}(X)$  is the function of dynamic characteristics of the events sequence detection method.

(5) Detecting whether the statistics are stored in the past: if there are these data, the step (6) will be executed. Otherwise, detecting whether there are enough storage space, the step (7) will be executed when there is not enough space. If it satisfies the condition, the step (6) will be executed.

(6) The  $\text{WeightedMA}(X)$  will be called, which is used to predict the event trend by the weighted moving average method with the best  $n$  and  $w$  based on sensing the prediction requirements. Here,  $\text{WeightedMA}(X)$  is the function of weighted moving average method.

(7) The  $\text{ExponentialS}(X)$  will be called, which is used to predict the event trend by the exponential smoothing with the best obtained  $S_w$  by multilevel sensing approach. Here,  $\text{ExponentialS}(X)$  is the function of exponential smoothing method.

(8) The  $\text{THA}(AP)$  will be called, which is used to calculate the activity probability threshold  $AP_j$  ( $1 < j > N$ ). Similarly, the  $\text{THA}(M)$  will be called for obtaining the cooperative sensor number threshold  $M_j$  ( $1 < j > N$ ). Here,  $\text{THA}(Y)$  is the function of calculating the threshold value of  $Y$ , which could be  $AP$ ,  $M$ ,  $D$ , or  $TP$ .

(9) Carry out level I perceive decisions. The opportunistic cooperative transmission control scheme will be created based on selecting the  $M$  sensors,  $AP$  of which is larger than  $AP$  threshold.

(10) If data sending sensor receives the feedback of system or cooperative sensors, level II decision is perceived. The step (11) will be executed.

(11) Initialization of level II sending decision: let  $D$  be the control event sequence  $X$ . The steps from (4) to (7) will be executed.

(12) The  $\text{THA}(D)$  will be called which is used to calculate the distance threshold  $D_j$  ( $1 < j > N$ ). Obtain the cooperative sensor number threshold  $M_j$  ( $1 < j > N$ ) by calling  $\text{THA}(M)$ .

(13) Carry out level II sensing decisions. The opportunistic cooperative transmission control scheme will be created based on selecting the  $M$  sensors,  $D$  of which is larger than  $D$  threshold.

(14) If data sending sensor receives the feedback of system or cooperative sensors, level III sensing decision is perceived. The step (15) will be executed.

(15) Initialization of level III sending decision: let  $TP$  be the control event sequence  $X$ . The steps from (4) to (7) will be executed.

(16) The  $\text{THA}(TP)$  will be called which is used to calculate the transmitting power threshold  $TP_j$  ( $1 < j > N$ ). Obtain the cooperative sensor number threshold  $M_j$  ( $1 < j > N$ ) by calling  $\text{THA}(M)$ .

(17) Go in level III sensing decisions. The opportunistic cooperative transmission control scheme will be created based on selecting the  $M$  sensors,  $TP$  of which is larger than  $TP$  threshold.

*Cooperative Sensors.* (18) Network state is defined at cooperative sensors as  $\langle APs, Ds, TPs, Ms \rangle$ . Then the channel state signal sequences are sent.

(19) If this sensor has been selected by level I sensing decision, the step (20) will be executed. If it has been selected by level II sensing decision, the step (21) will be executed. Otherwise, the step (22) will be executed.

(20) Send the feedback to sending sensor when its  $AP$  is smaller than  $AP$  threshold.

(21) Send the feedback to sending sensor when its  $D$  is smaller than  $D$  threshold.

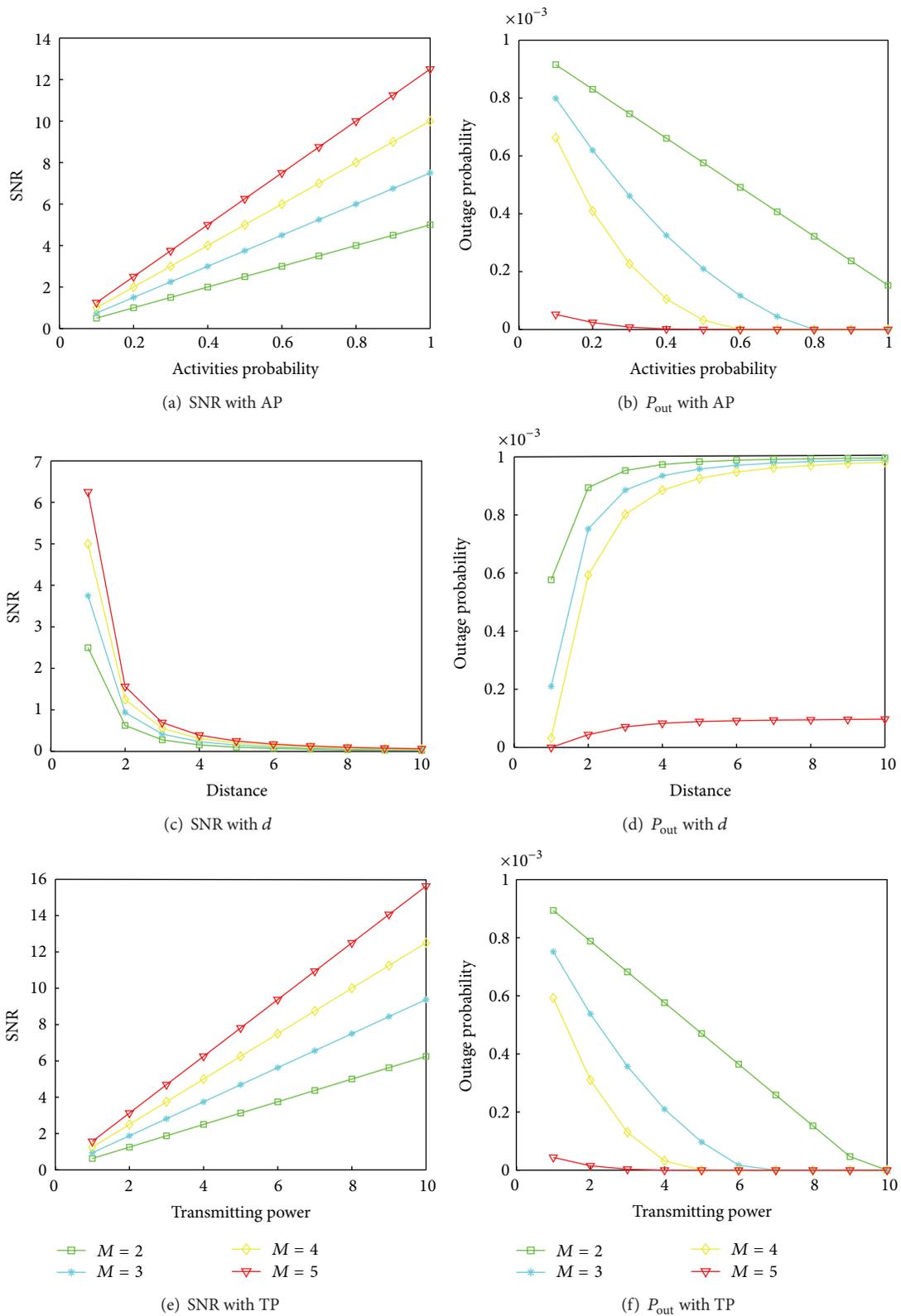


FIGURE 5: Performance analysis with SNR and  $P_{out}$ .

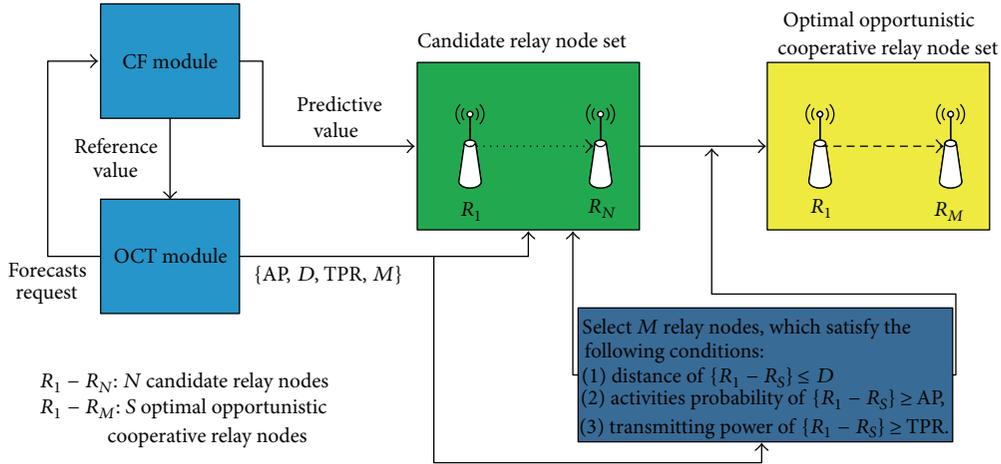


FIGURE 6: CF-OCT in IOT.

(22) Send the feedback to sending sensor when its TP is smaller than TP threshold.

## 6. Performance Evaluation

In this work, we simulate, analyze, and evaluate the performance of direct transmission (DT), opportunistic cooperative transmission (OCT), and the proposed CF-OCT based on activity probability. The parameter settings and environment condition are shown as in Table 3.

The main metrics for performance evaluation for supporting the application services of mobile Internet of Things are listed as follows.

- (1) Delay: the end to end delay between sending sensor and receiving sensor will be calculated merely.
- (2) Throughput: statistics of data packets size received successfully at receiving sensor.
- (3) Energy efficiency: ratio of energy of received data successfully to total energy consumption.

Figure 7 shows four performance metrics as a function of activity probability. The result indicates that activity probability and sensing approach have significant impact on quality of data transmission in mobile Internet of Things. We can observe tremendous improvement of performance using CF-OCT, as compared with DT and OCT. Even at a lower activity of sensors or channel quality of the mobile Internet of Things channel, the performance of CF-OCT always keeps good condition, while the delay and packet error rate with DT and OCT reduce and are almost close to zero. The throughput and energy efficiency of them continue to increase and be close to 1 gradually. The reasons are that not only could the combination forecast method predict the event control trend based on multilevel sensing to minimize the end to end delay, but also the adaptive opportunistic cooperative control strategy improves the energy efficiency, which could create the optimal transmission control scheme; as a result, the system throughput utilization increased and the reliability improved.

TABLE 3: Parameter settings.

Parameters	Value
$B_N$	30 kHz
$T$	1 s
Moving speed	From 0 m/s to 10 m/s
$R_{\text{radio}}$	38.4 kBaud
Mobility model	Random waypoint model
$d_0$	From 15 m to 30 m

## 7. Conclusions

There is great potential for data transmission control event prediction and opportunistic cooperative control to improve the performance of mobile Internet of Things diversity services. The target of this research work is to overcome all kinds of limitations of sensors in mobile Internet of Things; we propose the adaptive opportunistic cooperative transmission control mechanism based on multilevel sensing combination prediction approach.

The main contributions in this work are as follows. First, considering the characteristics of different forecasting methods, we introduce the combination prediction approach based on multilevel sensing of sensors in mobile Internet of Things. Second, the opportunistic cooperative control strategy with diversity threshold values is designed to ensure that data packets have the optimal transmission path and control progress. Finally, we present the adaptive opportunistic cooperative mechanism, working together with above combination prediction approach, in order to improve the communication performance and guarantee the quality of services in mobile Internet of Things.

The mathematics results demonstrate that, compared with the existing typical direct transmission and opportunistic cooperation, the proposed mechanism greatly improves the data transmission quality and achieves significant gains in terms of real time performance, reliability, throughput, and energy efficiency. As a result, the proposed mechanism

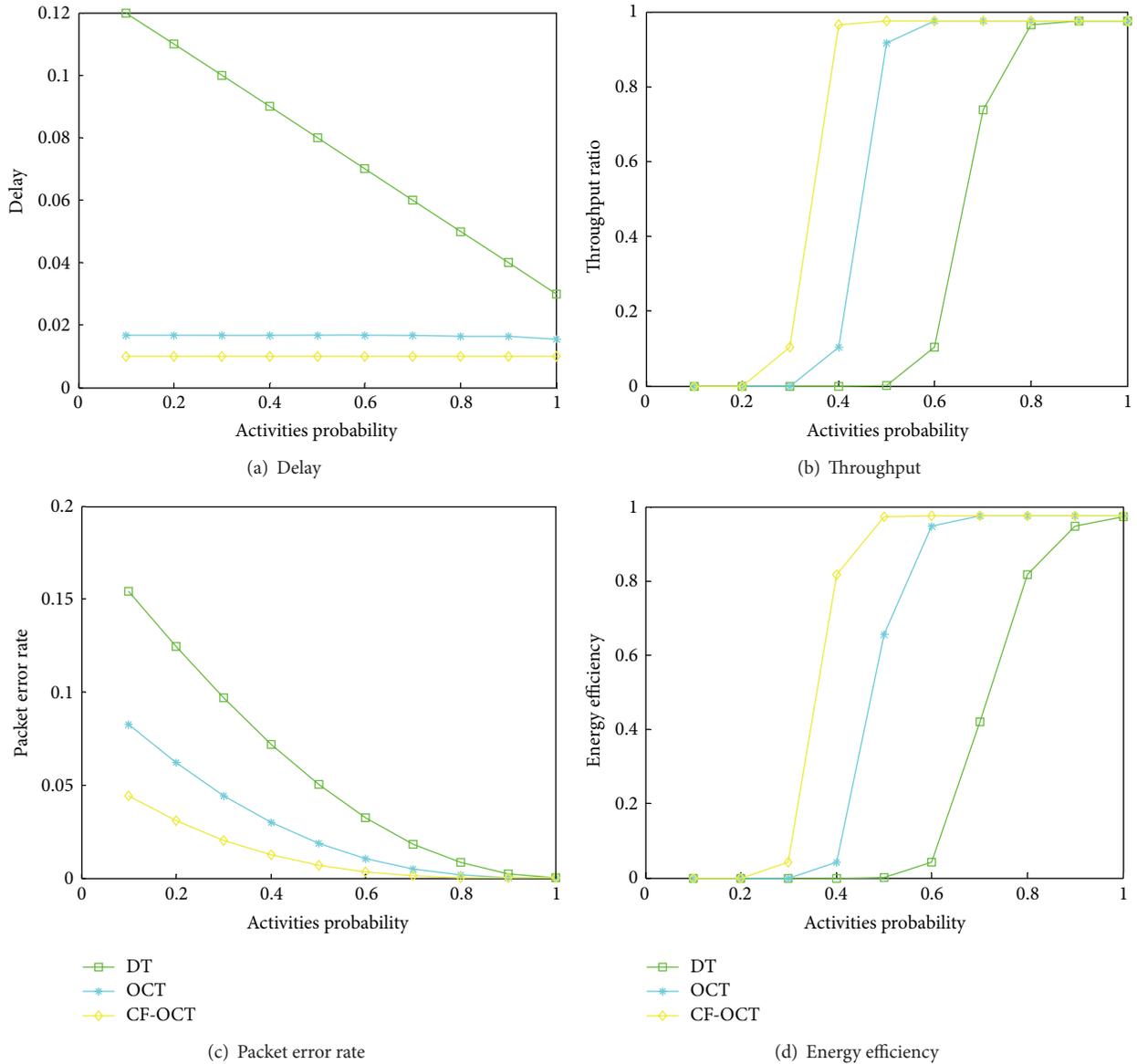


FIGURE 7: Performance with DT, OCT, and CF-OCT.

was determined to be effective and feasible for data diversity communication in mobile Internet of Things.

### Conflict of Interests

The authors declare that they have no financial and personal relationships with other people or organizations that can inappropriately influence their work; there is 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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