QoS-aware Opportunistic Cooperative Error Control Mechanism Based on Channel State Sensing for Internet of Things

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Abstract—**It is well known that the performance of Internet of Things application services is easy to be affected by internal noise of sensor, external environment interference and constriction of system resource. In order to solve the above problems, we studied the characteristics of bit error rate, outage ratio, signal to noise, and scale of relay sensors with channel state to choose the optimal transmission control scheme between direct mode and cooperative mode, building upon which we proposed the opportunistic cooperative automatic repeat request (ARQ) mechanism based on the rules and features of throughput ratio, average delay, packet error rate and energy efficiency, in consideration of retransmission time and channel quality. More importantly, the proposed opportunistic cooperative ARQ mechanism could set up the max retransmission time and control the progress of cooperative transmission according to the real-time network and sensor state, as well as Quality of Services (QoS) guarantee requirements of Internet of Things applications. The mathematical analyses and experiment results show that the proposed scheme is superior to the QoS provisioning schemes based on cooperative ARQ alone and direct transmission with channel state alone in terms of reliability, real time performance and life cycle of system, as well as energy efficiency.**

Index Terms—**Internet of Things, Opportunistic Cooperative, Channel state Sensing, Automatic Repeat reQuest (ARQ).**

I. INTRODUCTION

The computation, store, and transportation of several applications of Internet of Things depend on the deployment of high-density sensor networks [1]. However, there are many challenges of Quality of Services (QoS) guarantee of applications [2] because of the impact of external environmental factors and the inherent properties of sensor, as well as the constraint of dynamic topology and bandwidth-constrained of sensor networks.

Recently, some research results [3, 4] solve the above problems through cooperative communication. However, the following issues need to be researched: (1) what factors need to be considered with the cooperative transmission; (2) how to perceive the external interference, channel and sensor state; (3) how to control the progress of cooperative communication; (4) how to combine the error control protocol and cooperative communication for QoS provisioning and so on.

On the one hand, it is well known that channel state has an important impact on system performance. In article [5], the achievable Degrees of Freedom (DoF) was improved by incorporating additional private messages which provided a tight information theoretic DoF outer bound. Quevedo D. E. *et al* [6] defined network state process to describe a finite set of configurations of the radio environment, which illustrated the channel gain distributions of the links between sensors. A distributed protocol for link scheduling was proposed by Saifullah A *et al* [7], which is efficient, scalable, and adaptive to channel condition and network dynamics by creating a conflict-free schedule for transmissions.

On the other hand, the performance and cooperative communication progress may be affected by the status of sensors. For maximizing the throughput of WSNs, Ozlem Durmaz Incela *et al* [8] presented a multi-channel MAC protocol by coordinating transmissions over multiple frequency channels. Iyer V. *et al* [9] proposed a protocol for mitigating the effects of external interference through switching only the directly affected set of sensors onto a new channel. The linear variable differential transformer (LVDT) position sensor was designed by exploiting the finite element method for high rejection to external constant or slowly varying magnetic fields in article [10].

Particularly, the combination of cooperative communication and error control technology is one key problem for guaranteeing the QoS of sensors applications in Internet of Things. According to cross layer design, the truncated cooperative automatic repeat request (C-ARQ) protocol [11] was presented at data link layer based on the adaptive modulation and coding (AMC) at the physical layer for QoS-constrained applications. A novel Medium Access Control (MAC) protocol for ARQ-based [12] was proposed by using network coding techniques for achieving a better network performance in terms of energy efficiency without compromising the offered QoS. A network coding-aided energy efficient MAC protocol [13] was introduced in cooperative ARQ-based wireless networks for increasing the energy efficiency of the network without compromising the system performance in terms of QoS. Jesus Alonso-Zarate *et al* [14] introduced the multi-radio cooperative ARQ schemes by combining long-range and short-range communications, retransmission of which can be requested from the wireless grid surrounding the destination device using the short-range interface instead of the primary cellular link

In addition, our previous research introduced the Markov chain model based on ARQ and HARQ to study the characteristics of QoS and designed the QoS supported strategy with dynamic priority [15]. We proposed the adaptive opportunistic cooperative control mechanism based on the threshold values including the activity probability, distance, transmitting power, and number of relay sensors and so on. [16].

Therefore, it is primary and important to study and analyze the opportunistic cooperative ARQ scheme based on channel state sensing method, which not only could keep the optimal real time performance and energy efficiency of Internet of Things, but also guarantee the reliability and throughput.

In this paper, we research and study the above issues with opportunistic cooperative ARQ based on sensing channel and sensor state, to build the efficient, robust and effective QoS provisioning scheme of sensors in Internet of Things.

II. OPPORTUNISTIC COOPERATIVE CONTROL SCHEME BASED ON CHANNEL STATE

In Internet of Things, the data communication between the sending node and receiving node can be used in two modes:

(1) Direct transmission mode: the receiving node receives only the signal from the sender and abandons signals from other nodes.

(2) Opportunistic cooperative transmission mode: the data stream was transported by the sender and some relay nodes with the opportunity cooperative approach, which would be integrated and transmitted to the upper layer at the receiver.

The network state was defined by {M, SNR, h_i, P_{out}, P_b}. Here, let M denote the number of relay nodes, SNR is the signal to noise ratio, h_i is the channel state, P_{out} is the outage probability and P_b is bit error rate. The state of node was defined by {Sl_i, P_{total}, P_t, P_{ct}}. Here, Sl_i is the active probability of nodes, P_{total} is the total power of system, P_t is signal transmission power and P_{ct} is the circuit processing energy consumption.

Where, the parameters value of network state could be obtained after the system initialization, the node status could be initialized according to the inherent properties of the relay nodes.

The total energy consumption of the communication system includes a transmission power P_t and the circuit processing energy P_{ct}, which can be calculated according to the formula (1).

$$P_{total} = P_t + P_{ct} \tag{1}$$

Let P_{ts} denote the processing circuit power consumption for the transmitting information at the sending node. Let P_{tc} denote the processing circuit power consumption for receiving information at receiving node. Transmit power of sending node or relay nodes could be obtained by formula (2) or (3) respectively.

$$P_{ts} = P_{total} - P_{ct} \tag{2}$$

$$P_{tc} = P_{total} - (2M-1)P_{ct} - P_t \tag{3}$$

On the basis of formula (1), (2) and (3), SNR of the receiver is calculated by formula (4) when the individual channels are independent and Gaussian white noise variance are identical.

$$\begin{cases} SNR = f(|h_i|^2) \\ f(x) = \dfrac{E_0}{N_0 * d_l^q} \sum_{i=1}^{M} Sl_i [P_{total} - (2M-1)P_{ct}] x \end{cases} \tag{4}$$

Here, let N_0 denote Gaussian white noise variance. Let E_0 denote sending signal energy and d_l denote the distance between the sender and the receiver. Let q denote channel fading index.

The outage probability P_{out} is used to evaluate the performance of system at receiving node, which could be calculated by formula (5).

$$P_{out} = P(SNR < \alpha) = 1 - SNR / \alpha \tag{5}$$

Here, α is the wireless link outage threshold value and can be obtained by actual statistics. The bit error rate P_b is the ratio of error bits number to the total number of bits at the receiving node.

$$P_b = \frac{1}{2} e^{f(|h_i|^2)\gamma} \tag{7}$$

Here, γ is the error factor of sensor, determined by the internal noise of sensor and data transmission rate.

Figure 1 shows the variation of M and SNR with different value of the ratio of P_{ct} to P_{total}. We can obtain the following conclusion.

(1) When the ratio of P_{ct} to P_{total} is less than 0.1, the SNR is gradually increasing with the increment of M. The opportunistic cooperative transmission mode can significantly improve the performance of the communication system by increasing the number of relay nodes;

(2) When the ratio of P_{ct} to P_{total} is less than 0.4, the SNR is first gradually increasing and then decreases. The opportunistic cooperative transmission mode should be selected, the optimal transmission effect could be guaranteed only based on the optimal value of M;

(3) When the ratio of P_{ct} to P_{total} is larger than or equal to 0.4, the SNR is reducing with the increment of M. The direct transmission mode must be selected.

In summary, there are two thresholds of the ratio of P_{ct} to P_{total}, which are α_1 (set to 0.4) and β_1 (set to 0.1).

Figure 2 gives the variation of h_i and SNR with different value of the ratio of P_{ct} to P_{total}. We can obtain the following conclusion.

(1) When M and the ratio of P_{ct} to P_{total} are constant, the better channel state the larger SNR;

(2) When M and h_i are constant, the smaller the ratio of P_{ct} to P_{total} the larger SNR;

(3) When h_i is constant and the ratio of P_{ct} to P_{total} is larger than 0.4, the direct transmission mode should be selected for obtaining the large signal gain;

(4) When h_i is constant and the ratio of P_{ct} to P_{total} is smaller than and equal to 0.4, opportunistic cooperative transmission mode should be used.

In summary, the threshold of the ratio of P_{ct} to P_{total} α_2 is set to 0.4. Similarly, on the view of Figure 3 and 4, there are the same variation of P_{out} and P_b with h_i. The threshold of the ratio of P_{ct} to P_{total} α_3 and α_4 are set to 0.4.

Thus, according to the analysis of bit error rate, outage probability, SNR, scale of relay sensors and channel state, we could choose the optimal transmission scheme from direct transmission mode or opportunistic cooperative transmission mode.

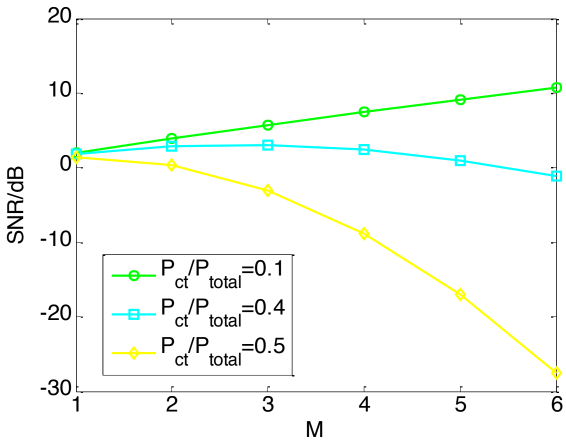


Figure 1 Impact of the number of cooperative nodes on SNR

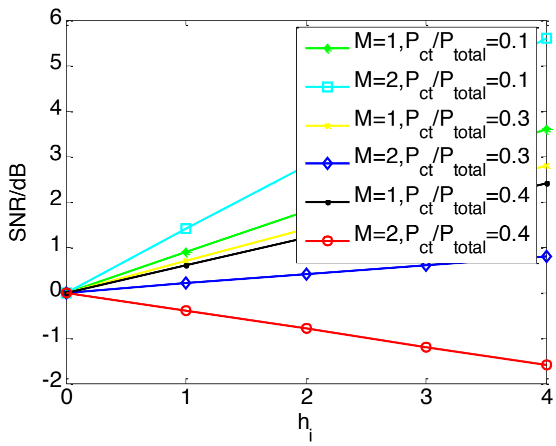


Figure 2 Impact of channel state h_i on SNR

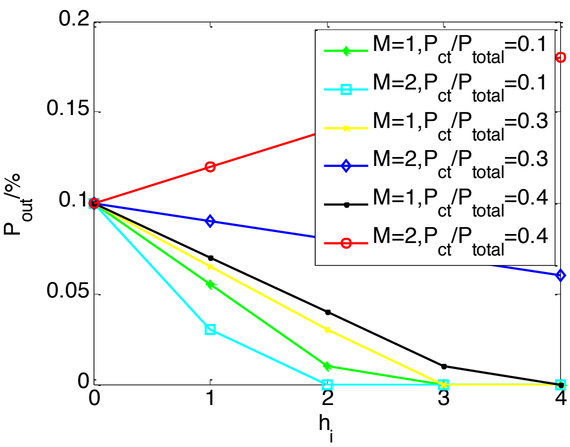


Figure 3 Impact of channel state h_i on outage probability P_{out}

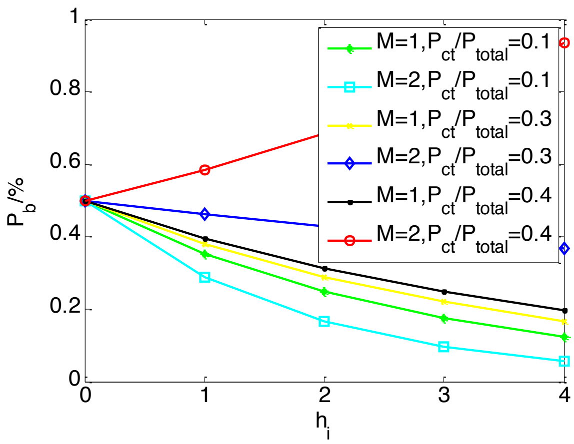


Figure 4 Impact of channel state h_i on bit error rate P_b

III. QOS-AWARE OPPORTUNISTIC COOPERATIVE ARQ MECHANISM

In this section, wireless sensor network model based on Mica2 sensor node is presented, an analytic model based on FEC/ARQ is proposed. The variation characteristics of QoS performance with parameters of the hybrid scheme are summarized by mathematical analyses based on the proposed model.

ARQ mechanism is used at link layer of each sensor. Throughput S_{ARQ} denotes the ratio of the payload packets successfully transmitted to the total transmission of data packets, which could be obtained by formula (7).

$$\begin{cases} S_{ARQ} = \dfrac{l_{payload}}{l_{DATA}+l_{ACK}}\, g(h_i, N_{\max}) \\ g(h_i, N_{\max}) = (1-(1-(1-\dfrac{1}{2}e^{f(|h_i|^2)\frac{B_N}{2R_{radio}}})^{l_{DATA}})^{N_{\max}+1}) \end{cases} \tag{7}$$

Here, N_{max} is the maximum retransmission number. $l_{payload}$ denotes the length of payload. l_{ACK} denotes the length of ACK packet. The value of $l_{payload}$ and l_{ACK} could be obtained according to the inherent properties of the sensor and communication protocol.

Figure (5), (6), (7) and (8) demonstrate the influence of channel state h_i on throughput S_{ARQ} with different N_{max}. We found that the lower P_{ct} the larger S_{ARQ} when M is constant. S_{ARQ} would decrease when P_{ct} is increasing. In addition, the more M the larger S_{ARQ} when P_{ct} is constant. The result of Figure (9) indicates that the influence of system performance by increasing the maximum number of retransmissions depends on the settings of M and the ratio of P_{ct} to P_{total}.

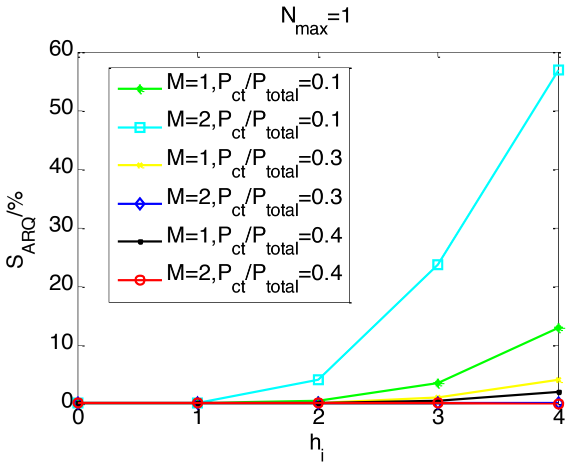


Figure 5 Impact of channel state h_i on throughput S_{ARQ} with $N_{max}=1$

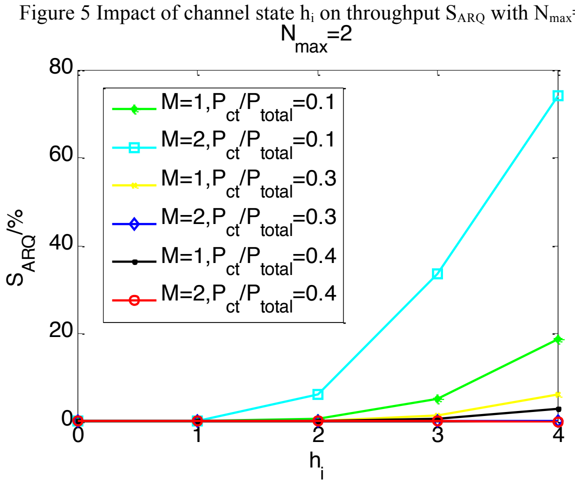


Figure 6 Impact of channel state h_i on throughput S_{ARQ} with $N_{max}=2$

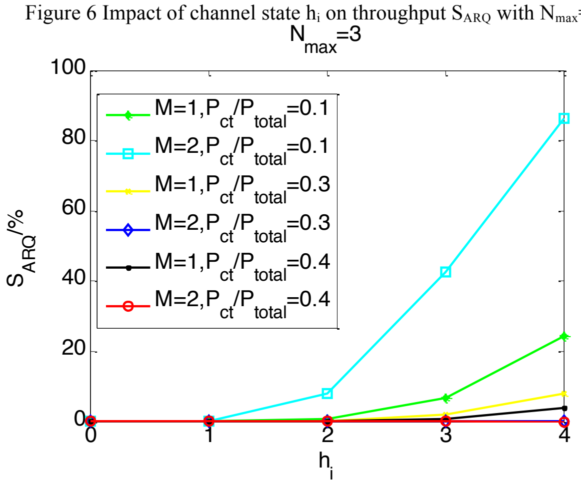


Figure 7 Impact of channel state h_i on throughput S_{ARQ} with $N_{max}=3$

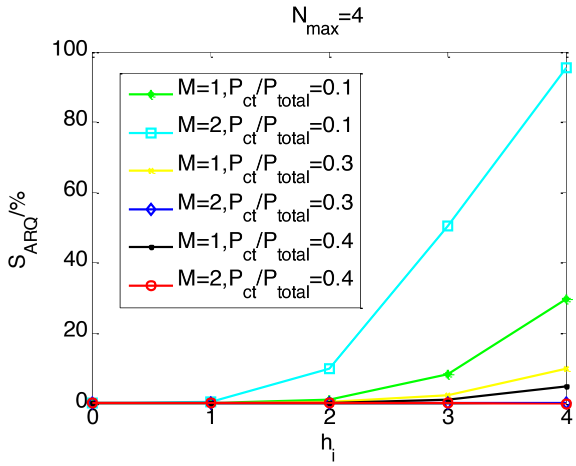


Figure 8 Impact of channel state h_i on throughput S_{ARQ} with $N_{max}=4$

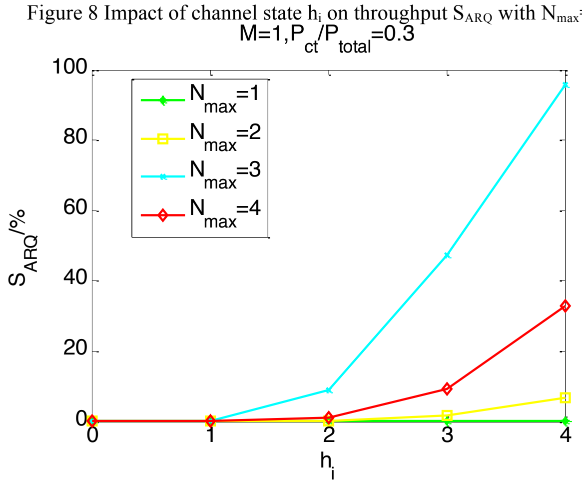


Figure 9 Impact of channel state h_i on throughput S_{ARQ} with constant M and the ratio of P_{ct} to P_{total}

Packet error rate P_{ARQ} means the ratio of the number of error packets to the total packets number within a unit of time of the data communication process, which could be obtained by formula (8).

$$\begin{cases} P_{ARQ} = h(h_i, N_{\max}) \\ h(h_i, N_{\max}) = (1-(1-\frac{1}{2}e^{f(|h_i|^2)\frac{B_N}{2R_{radio}}})^{l_{DATA}})^{N_{\max}+1} \end{cases} \tag{8}$$

Figure (10), (11), (12) and (13) demonstrate the influence of channel state h_i with packet error rate P_{ARQ}. It was found that increasing the retransmission number could significantly decrease the packet error rate when channel state is fine. However, when the channel quality is poor, even if the several retransmission cannot improve the reliability. These conclusions can also be verified from Figure (14). In this case, the receiving node should abandon the package actively.

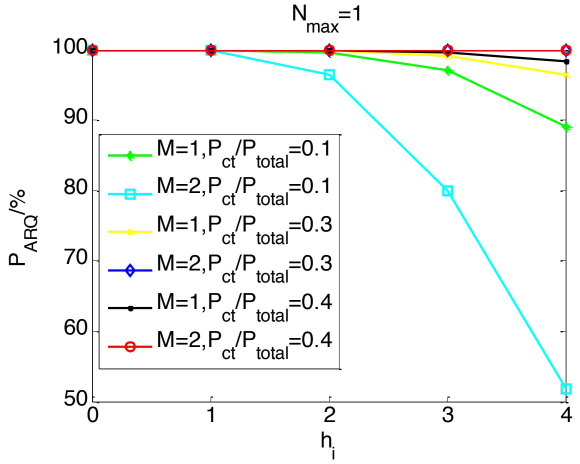


Figure 10 Impact of channel state h_i on packet error rate P_{ARQ} with $N_{max}=1$

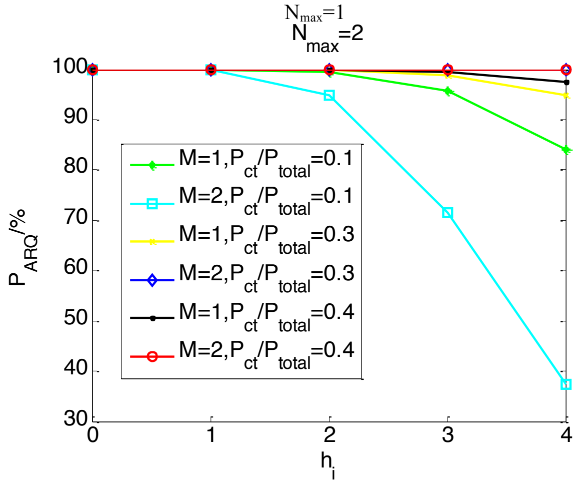


Figure 11 Impact of channel state h_i on packet error rate P_{ARQ} with $N_{max}=2$

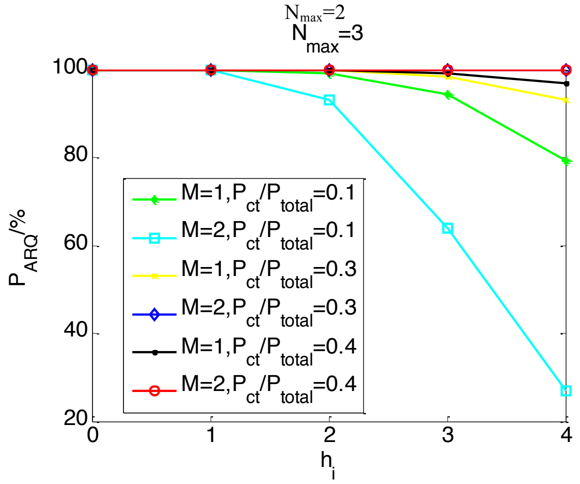


Figure 12 Impact of channel state h_i on packet error rate P_{ARQ} with $N_{max}=3$

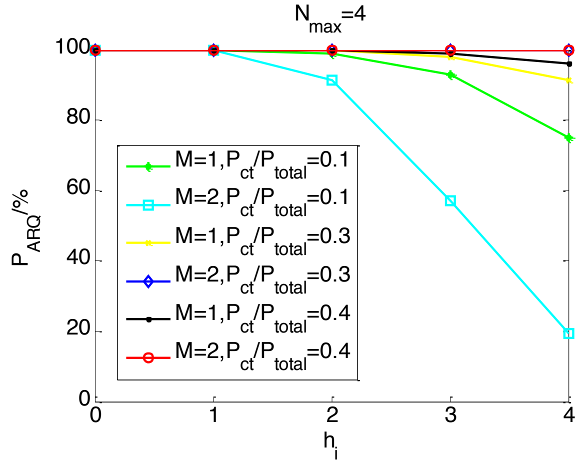


Figure 13 Impact of channel state h_i on packet error rate P_{ARQ} with $N_{max}=4$

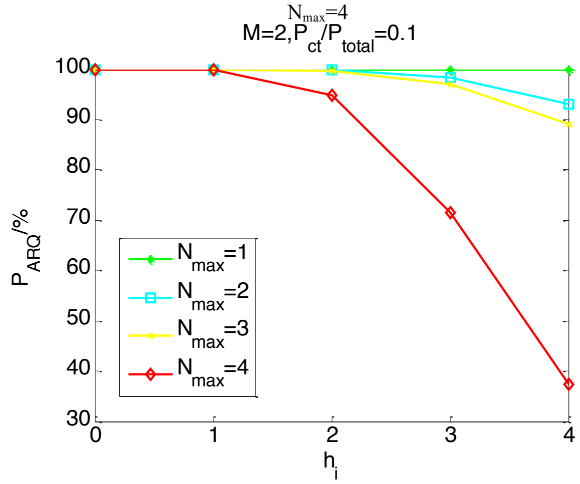


Figure 14 Impact of channel state h_i on packet error rate P_{ARQ} with constant M and the ratio of P_{ct} to P_{total}

Let T_{ARQ} denote the average delay which means the average time between packets sent at the sender and an ACK packet received successfully and could be obtained by formula (9).

$$T_{ARQ} = T\frac{1-h(h_i,N_{max})^{N_{max}+1}}{1-h(h_i,N_{max})} \quad (9)$$

Figure (15), we found that the larger M and the ratio of P_{ct} to P_{total} the larger T_{ARQ} when N_{max} is constant. So, it is effective to improve real time performance by reducing the value of M and the ratio of P_{ct} to P_{total}. Figure (16), (17), (18) and (19) demonstrate the following conclusions:

(1) The larger N_{max} the lager T_{ARQ};

(2) The larger M the larger T_{ARQ} when the ratio of P_{ct} to P_{total} is constant.

(3) The improvement of the channel state can help shorten the delay when the values of M and the ratio of P_{ct} to P_{total} are small. When N_{max} is constant, the delay will be reduced gradually with the improvement of the channel quality, the reducing amplitude decreases with the increase of the value of the ratio of P_{ct} to P_{total}.

(4) T_{ARQ} is insensitive to channel state when the values of M and the ratio of P_{ct} to P_{total} are relatively large. This indicates that T_{ARQ} keeps always maximum even in the high quality of channel state.

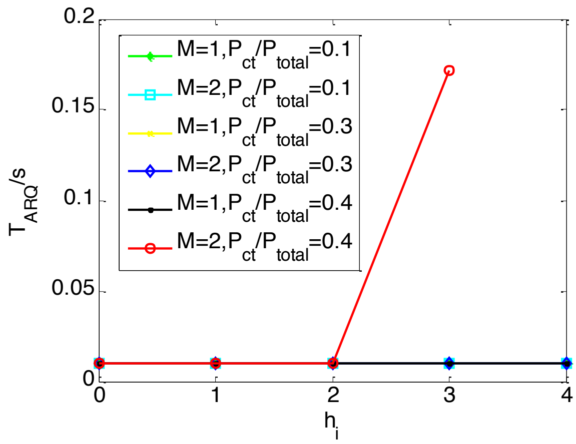


Figure 15 Impact of channel state h_i on average delay T_{ARQ}

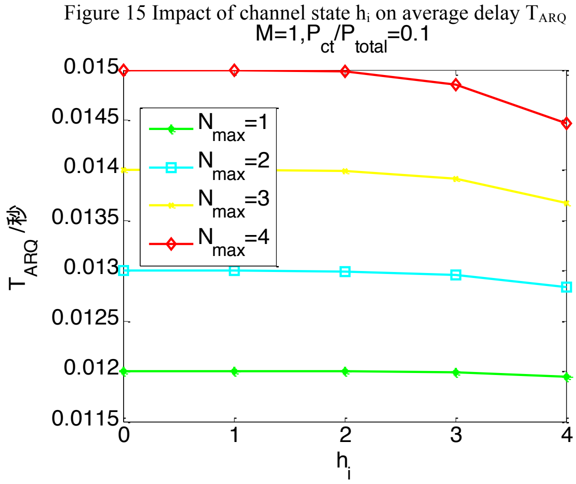


Figure 16 Impact of channel state h_i on average delay T_{ARQ} with M=1 and the ratio of P_{ct} to P_{total} =0.1

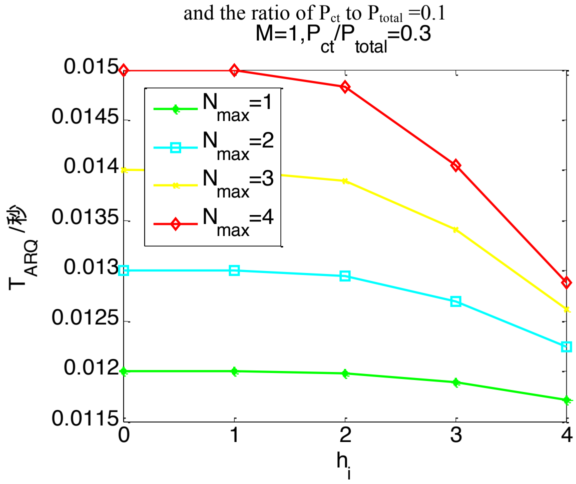


Figure 17 Impact of channel state h_i on average delay T_{ARQ} with M=1 and the ratio of P_{ct} to P_{total} =0.3

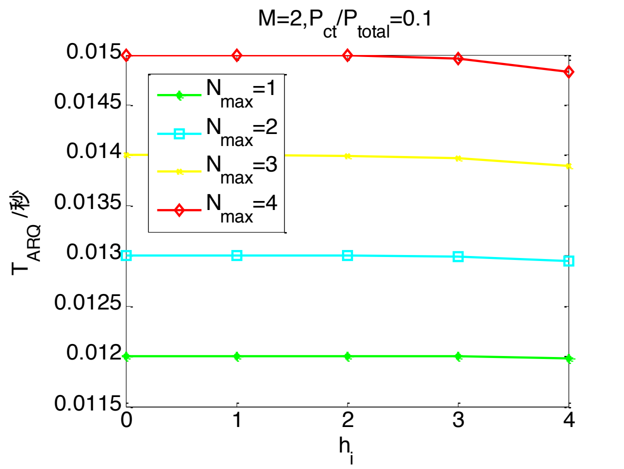


Figure 18 Impact of channel state h_i on average delay T_{ARQ} with M=2 and the ratio of P_{ct} to P_{total} =0.1

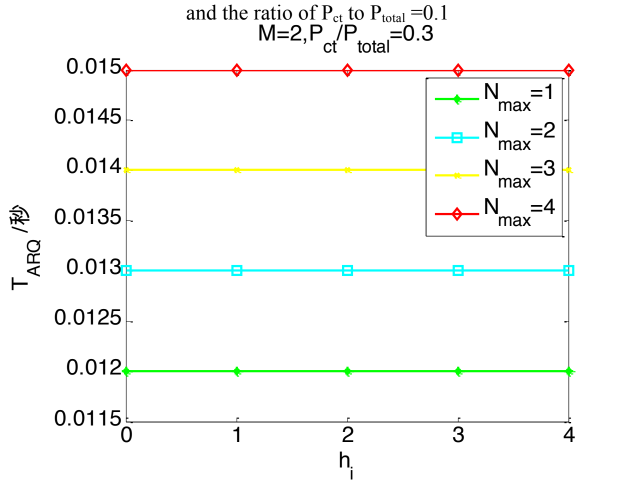


Figure 19 Impact of channel state h_i on average delay T_{ARQ} with M=2 and the ratio of P_{ct} to P_{total} =0.3

System energy efficiency η_{ARQ} could be calculated by formula (10) based on the reliability analysis.

$$\eta_{ARQ} = \frac{l_{payload}}{l_{DATA} + l_{ACK}}(1 - h(h_i, N_{\max})) \qquad (10)$$

From Figure 20, it was found that the lower η_{ARQ} the larger the ratio of P_{ct} to P_{total} when N_{max} is constant. Similarly, the higher η_{ARQ} the lager M when the ratio of P_{ct} to P_{total} is constant. It indicates that it is effective to reduce η_{ARQ} by increasing M or decreasing ratio of P_{ct} to P_{total}. See Figure 21, 22, 23 and 24, we found that η_{ARQ} could be improved by increasing N_{max}.

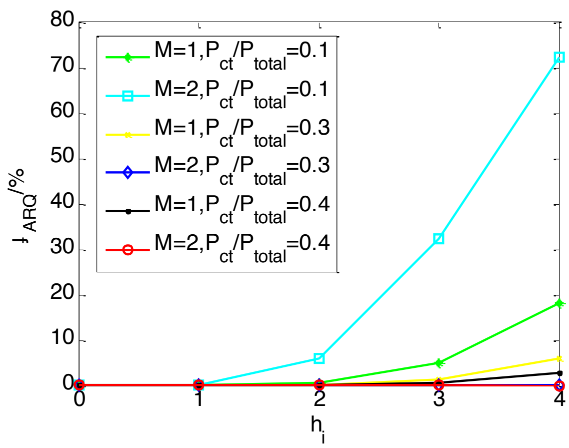


Figure 20 Impact of channel state h_i on energy efficiency η_{ARQ}

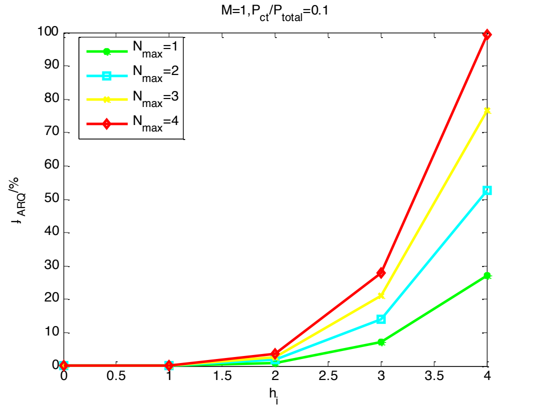


Figure 21 Impact of channel state h_i on average delay T_{ARQ} with M=1 and the ratio of P_{ct} to P_{total} =0.1

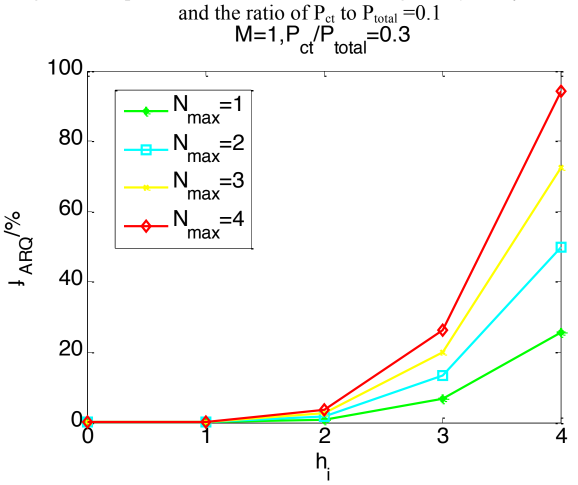


Figure 22 Impact of channel state h_i on average delay T_{ARQ} with M=1 and the ratio of P_{ct} to P_{total} =0.3

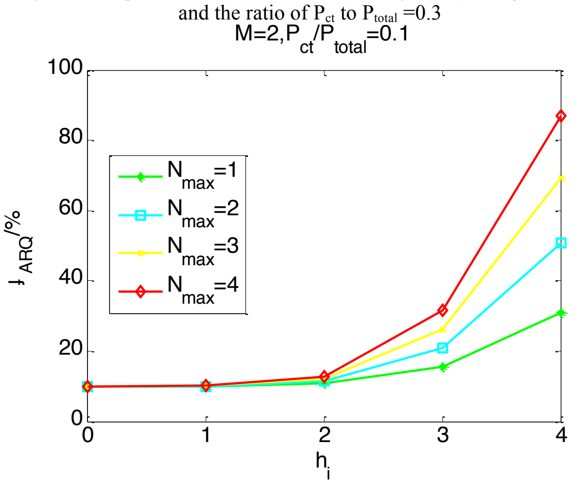


Figure 23 Impact of channel state h_i on average delay T_{ARQ} with M=2 and the ratio of P_{ct} to P_{total} =0.1

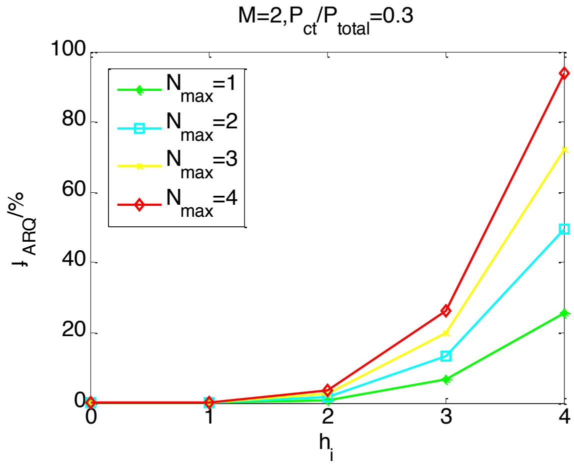


Figure 24 Impact of channel state h_i on average delay T_{ARQ} with M=2 and the ratio of P_{ct} to P_{total} =0.3

In summary, the opportunistic cooperative ARQ scheme with single or multiple performance guarantee could be constructed according to the real time state of h_i, M and the ratio of P_{ct} to P_{total}, combined with the user sensitivity to latency, throughput ratio, energy efficiency and packet error rate.

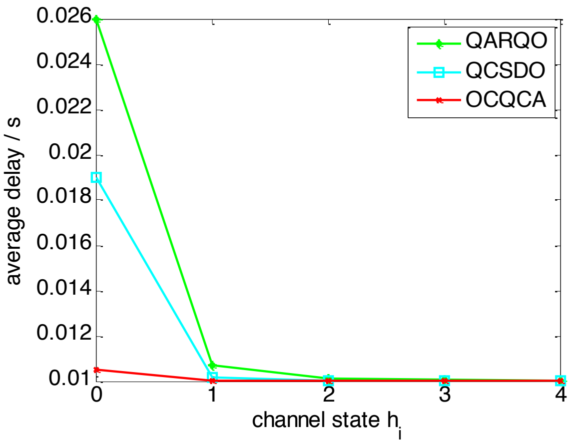
IV. PERFORMANCE EVALUATION

In this section, we present the basic idea of the Channel Aware Cooperative FEC/ARQ (CAC-FEC/ARQ) and its implementation in wireless sensor networks in detail, which is illustrated as follows:

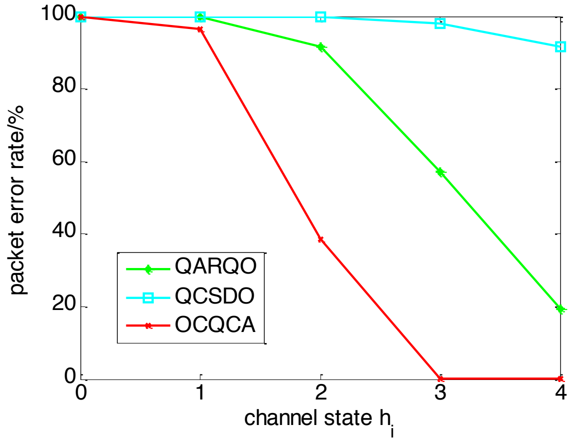
In this work, we simulate, analyze and evaluate the performance of QARQO (QoS provisioning scheme based on cooperative ARQ alone), QCSDO (QoS provisioning scheme based on direct transmission with channel state alone) and the proposed OCQCA in two group experiments.

In group 1 experiment, we compare the above three schemes from delay, packet error rate, energy efficiency and throughput ratio, as shown in Figure 25.

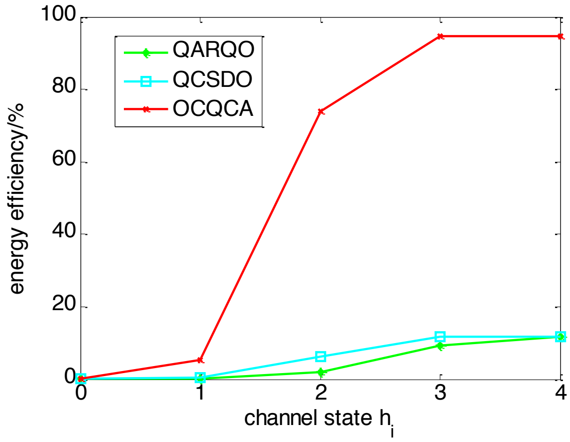
When channel quality is poor (such as $h_i < 1.5$), delay gap of the above three schemes is large. The delay of the proposed scheme is less than one of QARQO and QCSDO shown as Figure 27 (a). However, the packet error rate, energy efficiency and throughput ratio of the proposed scheme are close to one of QARQO and QCSDO as shown in Figure 27 (a), (b) and (c). Of course, QoS provisioning ability of the proposed scheme is better than the other schemes. In order to ensure the overall performance of the system, QARQO and QCSDO have to increase N_{max}, which would be modified according to the network state with opportunistic cooperative communication in the proposed scheme. When channel quality is better (such as $2 < h_i < 3$), the performance of the proposed scheme is superior to one of the other schemes by further optimizing the scale of relay sensors with opportunistic cooperation and ARQ parameters. When channel state is stable and robust (such as $h_i > 3$), the delay and throughput of the proposed scheme is close to the other schemes as shown Figure 27 (a) and (d) because these schemes use the direct communication. However, there are a big gap of packet error rate and energy efficiency as shown Figure 27 (b) and (c). That because the direct communication of the proposed scheme could perceive the channel and sensor state for dynamically setting N_{max} of ARQ.



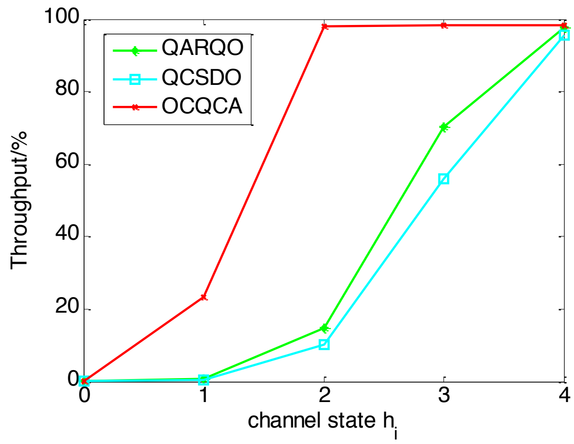
(a) average delay



(b) packet error rate



(c) energy efficiency



(d) Throughput

Figure 25 Performance comparison based on mathematical analysis

In group 2 experiment, we deployed 20 sensors in the 200m * 200m venue zone. We increased the internal noise and external interference in experiment by using the electric circuit given by Figure 26, which are shown in Table I. In addition, the external interference signals would be generated in 20-40 minutes and 50-55 minutes.

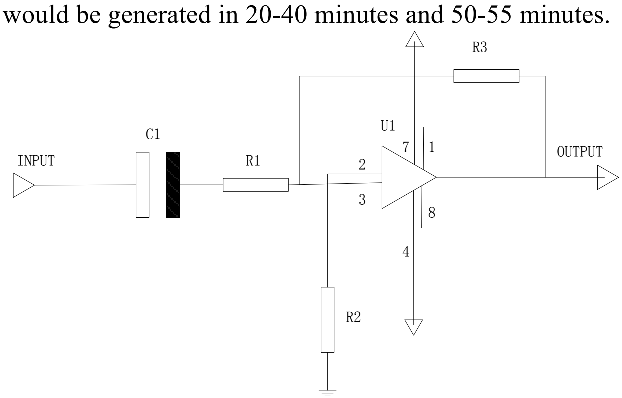
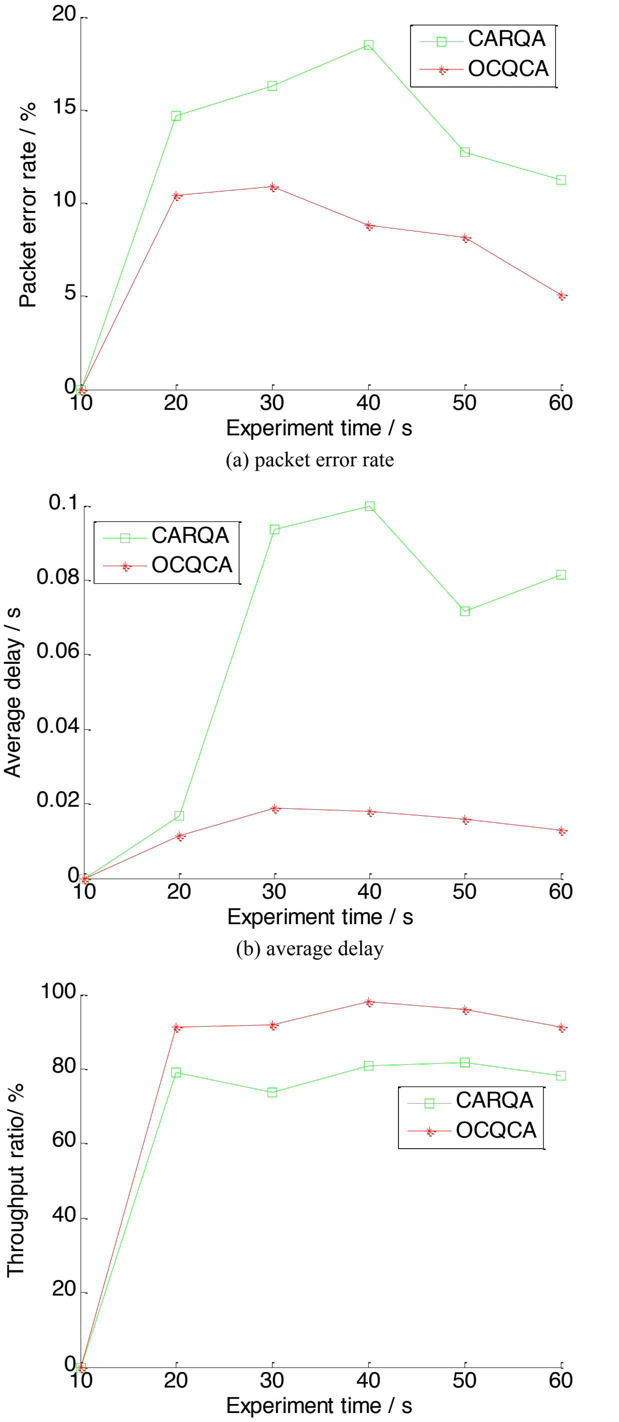


Figure 26 electric circuit for increasing the internal noise and external interference

Table I noise contributions

component	Noise (volts)
Operational Amplifiers OP07	33.5u
External power supply	50.5p
Total output noise	114u
Resistance R1	383k
Resistance R2	402k
Resistance R3	85.7k
Total input noise	1.14M

Figure 27 compare the reliability, real time performance and throughput of CARQA (M=2 and N_{max}=1) and the supposed OCQCA, which are measured once every minute with 60 minutes statistics. The performance gap between the above schems is small in the initial stages of the experiment. There are the great change of CARQA because of the external interference signals between time interval [20, 40] minutes and [50, 55] minutes shown by Figure 27 (a) and (b). However, the proposed scheme has not been much affected by these disturbances. That because the proposed scheme is able to perceive the sensor and channel state. The N_{max} of ARQ would be increased when the network state is poor for guaranteeing the reliability. If the network state keep fine, the retransmission time should be reduced for ensuring the real-time performance. Espesialy, the proposed scheme is able to perceive the ratio of P_{ct} to P_{total} based on channel state and QoS guarantee requirment, the system throughput can always keep the best state, which is not affected by the internal noise outside interference.



(a) packet error rate

(b) average delay

(c) throughput

Figure 27 Performance comparison based on experimental statistics

V. CONCLUSIONS

Opportunistic cooperative ARQ mechanism with channel state sensing is able to satisfy the QoS requirements of Internet of Things applications effectively and reliably. The address of our work is to overcome internal noise of sensors and external interference, as well as limitation of sensor networks and constriction of resources.

The main efforts of our research work are as follows. First, analyzing the characteristics of channel state with signal to noise ratio and energy consumption, we decide how to select transmission mode from direct or opportunistic cooperation in Internet of Things. Second, studying the property of packet error rate, throughput ratio, delay and energy efficiency with channel state, scale of relay sensors and ARQ parameters, opportunistic cooperative ARQ control strategy with diversity support capability is designed to guarantee the Internet of Things applied to a variety of environments. Finally, we proposed the QoS-aware opportunistic cooperative ARQ mechanism.

The mathematics and experiment results demonstrate that the proposed mechanism obviously enhances the transmission performance and obtains significant time and space gains. As a result, the proposed mechanism was indicated that it is more effective and robust for QoS provisioning ability than QoS provisioning scheme based on cooperative ARQ alone or direct transmission with channel state alone in Internet of Things.

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