Reliable Transmission Control Scheme Based on FEC Sensing and Adaptive MIMO for Mobile Internet of Things

Yong Jin[1], Feng Li[1], Ya Fan[1], Ruigang Li[2], and Huan Dai[1]
[1] School of Computer Science & Engineering, Changshu Institute of Technology, Changshu 215500, China
[2] Changshu Museum, Jiangsu, Changshu, 215500, China
Email: jinyong@cslg.cn; {csefengli, rgangli, daihuanjob}@163.com; 2643753061@qq.com

Abstract —In mobile Internet of Things, it is one key issue how to provide the reliable guarantee of transmission over sensors in connection with the services diversity, dynamic topology and various unknown interference. To solve these problems, we analyzed the Forward Error Control (FEC) sensing technology based on Cyclic Redundancy Check (CRC) and adaptive Multiple Input Multiple Output (MIMO) approach, building upon which we proposed the reliable transmission control scheme, in order to guarantee the Quality of Services. The mathematical analyses and NS simulation results show that the proposed transmission control scheme maintain the better performance such as throughput, reliability, real time performance and energy efficiency, than the FEC alone and MIMO alone approaches.

Index Terms—Mobile internet of tings, FEC sensing, adaptive multiple-input multiple-output, reliable transmission

I. Introduction

Perception of the physical world and process of change, a lot of objects should be detected [1], [2], including temperature, pressure, humidity, strain, so the miniaturization and low-power sensors for applications is important and significant. There are some challenging issues of design, communication and transmission over sensors in Mobile Internet of Things (MIOT).

Wireless communication environment of MIOT is dynamic and harsh, which have various interferences. Transmission and communication over this channel is susceptible to such distortions as finite bandwidth, resources, mobility, application service diversity, etc [3], [4]. These restrictions, combined with the characteristics of sensor networks [5] such as limited computation ability, storage and self-organization, make it difficult to guarantee Quality of Services (QoS) over MIOT.

Manuscript received September 10, 2014; revised December 30, 2014.

This work is supported in part by National Natural Science Foundation of China grant No. 61300186, Project of Jiangsu Province University Natural Science gran No. 13KJB510001, science and technology development project of Changshu (Social Development category) grant No.CS201413, project of Teaching Reform of Education College of computer science and Engineering of Changshu Institute of Technology under grant No. JGJSJ201307 and University Students' innovative undertaking training program of Changshu Institute of Technology, grant No.2014.

Corresponding author email: jinyong@cslg.cn.

doi:10.12720/jcm.9.12.954-961

In this paper, based on cross layer design, we focus on how to provide the reliable and effective quality provision and satisfy the requirements of application services with Forward Error Control (FEC), Cyclic Redundancy Check (CRC), Multiple Input Multiple Output (MIMO), sensing technology and so on over sensors in MIOT.

The rest of the paper is organized as follows. The related work is elaborated in Section II. Section III describes the FEC sensing scheme at data link layer based on CRC at physical layer. In Section IV we design the adaptive MIMO approach at physical layer of sensors on the basis of the FEC sensing in MIOT. The proposed reliable transmission control scheme is used to guarantee the reliable, efficient and effective wireless communication, which is shown in Section V. Simulation and mathematics results are given in Section VI. Finally, we conclude the paper in Section VII.

II. Related Work

Many studies have been made about reliable transmission in MIOT, but there are still some deficiencies to be addressed.

On the one hand, S. Tozlu *et al* applied Wi-Fi into IP connectivity on basis of low power feasibility on battery powered devices, and analyzed the interference and range performance based on three different services [5]. Dahai Han *et al* researched the concept of information aggregation layer based on the bottleneck between mass sensors and electric power communication transmission network [6]. Then they used the sensor information processing and data fusion at aggregation layer, which had been taken on the embedded smart gateway, as well as provided front-end processing and analysis of sensor information to implement in varied intelligent power grids scenario. Z. F. Song *et al* [7] proposed the reliable transmission scheme for security and protection system for IOT and designed the cooperative transmission scheme for enhancing the quality of data services. In our previous research results [8] and [9], based on a Markov chain model for FEC and deriving the expressions for QoS, an adaptive cooperative forward error correction based on energy efficiency was proposed, as well as the reliable adaptive relay selection approach and adaptive QoS supported algorithm. However, the above research ignore the impact of the encoding technique such as CRC approach at the physical layer.

On the other hand, based on DRX (Discontinuous Reception)/DTX (Discontinuous Transmission) optimization and QoS guarantee technology IoT applications, the authors [10] optimized DRX/DTX parameters and scheduled devices' packets with the base station by balancing the impacts between QoS parameters and DRX/DTX configurations. The article [11] reviewed current standards and research activities in both industry and academia of the research community to contribute to the IoT field, authors of which considered the calculation of mathematical functions at the time of wireless superimposition of data sequences. S. Sigg *et al* [12] proposed the communication scheme in view of mathematical computations of wireless transmission, which is able to execute the complex computations at cooperating sensor with low computational complexity. Based on cross-layer module for IoT, Chong Han *et al* [13] accurately captured both the high heterogeneity of the IoT and impact of the Internet. Especially, they developed the fundamental part of the module to study the optimal routing paths and the communication parameters among different layer functionalities. The implementation of two-way relay network on the basis of physical-layer network coding principle was proposed by Lu Lua *et al* [14] which was simple to implement and amplify the noise along with the signal before forwarding the signal. However, there is not further in-depth study of the error control mechanism in IOT.

In addition, R. Morelos-Zaragoza *et al* [15] examined the error performance of the tag-to-reader link of a passive UHF (Ultra High Frequency) RFID (Radio Frequency Identification) system and proposed the correction technique of single errors in the received EPC with a look-up table. A simplified air interface protocol and a simultaneous access channel for uplink communication was proposed by C. S. Bontu *et al* [16], which can be considered either as an enhancement or an overlay to the existing cellular systems. E. Ustunel *et al* [17] studied the CRC coding performance on basis of a cross layer performance criterion, which considered the CRC generator polynomial, message length, and Signal-to-Noise Ratio (SNR). An adaptive Successive Cancellation-List decoder with CRC was proposed in article [18], which is able to increase the list and reduce significant complexity. The above findings have not done extensive research on the combined error control and sensing technology.

Specially, the specialized delivery scheme in the context of IOT, was proposed by H. Sharma *et al* [19] based on usage of byte-level error-correction codes, which is used to improve relevant delivery parameters. In article [20], the author considered error correction codes with simple block code, which is used to improve the transmission performance of molecular communications. In the study of article [21], an error-correction algorithm was presented, which aims at emulating the notion of error correction algorithm. Then, authors also illustrated some probabilistic measures to make the algorithm more efficient without sacrificing its effectiveness. Authors of article [22] demonstrated the massive MIMO concept and contemporary research, including the challenge of making many low-cost low-precision components, acquisition and synchronization for newly-joined terminals and so on. Based on the equivalent circuit models, article [24] investigated the capacity of near field magnetically coupled communication systems, which is coupled single-input-single-output (SISO) and multiple-input-single-output (MISO). A comprehensive review of the current and rapidly emerging ecosystem of IOT was studied by Melanie Swan [24]. Chien-Liang Fok *et al* [25] provided a mechanism of a general QoS function, which distilled the multi-dimensional QoS specifications. However, the in-depth study of performance effect of encoding technology to the MIMO technology is ignored in the above research results.

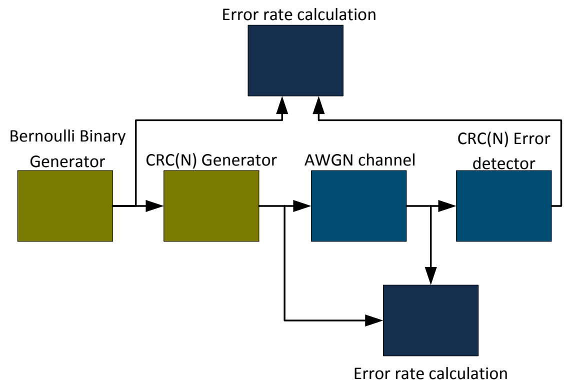


Fig. 1. Communication model of sensors with CRC coding.

III. FEC Sensing Scheme based on CRC

In this section, we design the communication model of sensors with CRC coding in IOT, which is shown as Fig 1. Here, signal resource is the Bernoulli binary generator, output of which is the binary data based on frame format. CRC coder and decoder select the CRC-16 scheme. The channel is set to Additive White Gaussian Noise (AWGN) channel. The bit error rate is added up by the Error Rate Calculation module. Let S_{EF} denote the error frame number checked by CRC decoder, then the frame error rate P_{EF} could be calculated by formula (1).

$$P_{EF} = (S_{ef} \times T_{sam} \times F_{sam}) / T \tag{1}$$

Here, T is the communication time, which is set to 0.1s. T_{sam} represents the sampling time. F_{sam} denotes the number of samples in each frame.

After that, the FEC coding model based on CRC coding scheme is designed and shown as Fig. 2, dataflow of which is shown as Fig. 3. And the proposed FEC sensing algorithm is described as follows:

1) The data packets are sent by sending sensor after CRC coding.

2) From FEC coding module to Decode module through AWGN channel.

3) At receiving sensor, CRC decoding after FEC decoding.

4) Bit error rate is counted at error rate calculation model and send the data packets to the upper layer.

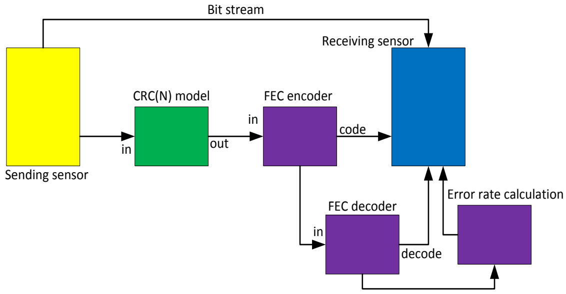


Fig. 2. FEC coding model based on CRC coding

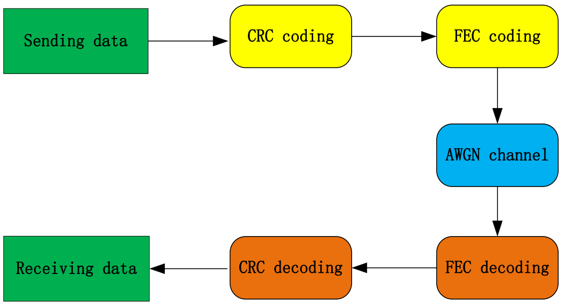


Fig. 3. Dataflow of FEC model based on CRC

Immediately, we analyze and evaluate the performance of five different FEC sensing scheme with SNR, including FEC(15,5), FEC(15,7), FEC(15,9), FEC(15,11), FEC(15,13). SNR is set from 0dB to 10dB. The bit error rate and frame error rate are given by Fig. 4 and 5. We could found that the performance of FEC sensing scheme based on CRC is better than one of without using the proposed scheme in terms of bit error rate and frame error rate. We get the following conclusions:

1) FEC (15, 5) can guarantee error-free transmission when SNR is larger than 4 dB.

2) FEC (15, 13) may guarantee error-free transmission only when SNR is larger than 8 dB.

3) Particularly, any FEC sensing scheme could guarantee error-free transmission when SNR is larger than 8 dB.

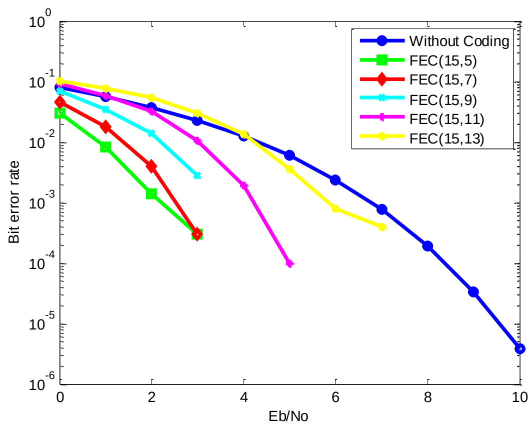


Fig. 4. Bit error rate

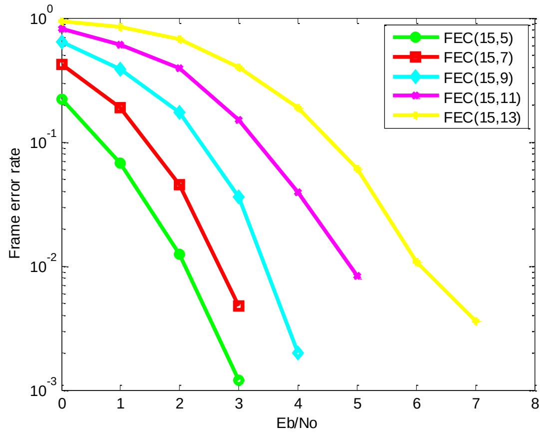


Fig. 5. Frame error rate

So we should select the FEC sensing scheme with high coding efficiency, which is illustrated by Fig. 6.

In a word, there are the optimal SNR threshold for different FEC sensing scheme, which could guarantee error-free transmission when SNR is larger than the threshold and given by Table I and II.

So, we study the relationship between coding efficiency, energy consumption and frame length.

TABLE I: SNR THRESHOLD WHEN BIT ERROR RATE IS 0.

FEC scheme	FEC(15,5)	FEC(15,7)	FEC(15,9)	FEC(15,11)	FEC(15,13)
SNR Threshold	4 dB	4 dB	4 dB	6 dB	8 dB

TABLE II: SNR THRESHOLD WHEN FRAME ERROR RATE IS 0.

FEC scheme	FEC(15,5)	FEC(15,7)	FEC(15,9)	FEC(15,11)	FEC(15,13)
SNR Threshold	3 dB	4 dB	5 dB	6 dB	8 dB

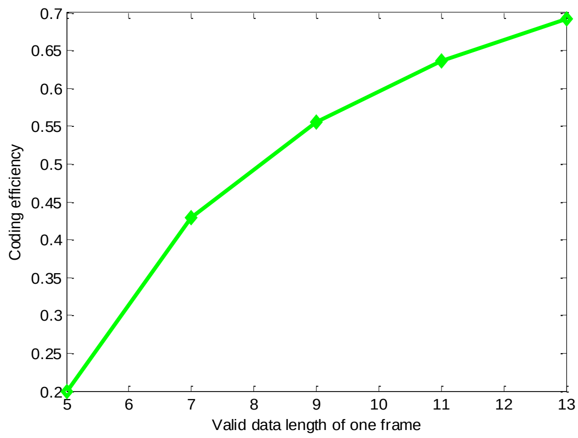


Fig. 6. Coding efficiency

Let α_{code} denote the coding efficiency and T_b denote the data length. Let T_F be the data frame length and k be the energy consumption coefficient. η represents the total energy consumption, which could be calculate by formula (2).

$$\eta = k \frac{T_b}{\alpha_{code} T_F} \tag{2}$$

We found that α_{code} and η are inversely. With Fig. 6, we also found the coding efficiency would be increasing with the increase of valid data length of one frame. The higher the coding efficiency is, the less the number of data frames is, which indicate that the longer the length of the valid data of each frame, the less the energy consumed.

Similarly, FEC (15, 5), FEC (15, 7) and FEC (15, 9) scheme could make the bit error rate zero when SNR is equal to 5 dB illustrated from Fig. 6. From the aspect of reducing energy consumption, the longer valid information for each frame, the less the total number of frames, so in this case the use of FEC (15, 9) can get the maximum network performance.

Summary, from FEC(15,5), FEC(15,7), FEC(15,9), FEC(15,11) to FEC(15,13) scheme, the code efficiency is from low to high, energy consumption is from high to low, and there is the unique SNR threshold, an optimal FEC sensing scheme based on the CRC should be selected to maintain the reliable transmission status depending on the channel state, which works as follows and the flowchart of the proposed adaptive FEC sensing mechanism based on CRC is given by Fig. 7:

1) Sensors of IOT could select the FEC (15, 13) scheme without CRC coding when SNR is larger than 7 dB to obtain the best communication performance and energy efficiency.

2) Sensors of IOT could select the FEC (15, 11) scheme without CRC coding when SNR is less than or equal 7 dB and larger than 5 dB.

3) Sensors of IOT could select the FEC (15, 9) scheme without CRC coding when SNR is less than or equal 5 dB and larger than 4 dB.

4) Sensors of IOT could select the FEC (15, 7) scheme with CRC coding when SNR is Less than or equal 4 dB.

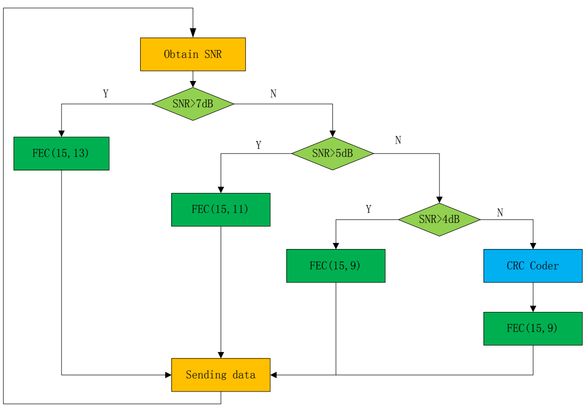


Fig. 7. Flowchart of adaptive FEC sensing mechanism based on CRC

IV. ADAPTIVE MIMO BASED ON FEC

In order to simultaneously achieve multiple transmitting antenna of sensors in IOT, we use MIMO technology for receiving diversity. Assuming that the receiving signal at t time slot at the n receiving antenna is denoted by $y_n(t)$, here t is set 1 or 2, as well as n is one of the array [1, 2, 3, …… , N_r].

Let $h_{m,n}$ denote the channel factor between the m transmitting antenna and the n receiving antenna. So the receiving signal of the first time slot is given by formula (3).

$$y_n(1) = (h_{1,n}a_1 + h_{2,n}a_2)n_n(1) \tag{3}$$

Likewise, the receiving signal of second time slot is given by formula (4).

$$y_n(2) = (h_{1,n}a_1^* + h_{2,n}a_2^*)n_n(2) \tag{4}$$

where, let n_n(t) denote the AWGN weight of the t time slot in the n receiving antenna. On the foundation of linear combination of all the receiving antenna, we can obtain the optimal sufficient statistics at receiver, which is given by formula (5) and (6).

$$y_n(1) = \sqrt{|h_{1,n}|^2 + |h_{2,n}|^2}\, a_1 + n_n^{''}(1) \tag{5}$$

$$y_n(2) = \sqrt{|h_{1,n}|^2 + |h_{2,n}|^2}\, a_2 + n_n^{''}(2) \tag{6}$$

The decision variables of transmitted symbols would be obtained by using maximum ratio combining algorithm as a symbol for the judgment launch of optimal solution, as shown in formula (7).

$$y(t) = \sum_{n=1}^{N_r} \sqrt{|h_{1,n}|^2 + |h_{2,n}|^2}\, y_n(t), t = 1,2 \tag{7}$$

On the basis of the decision variables, it is the best static when Euclidean distance y(t) is least, as shown formula (8) and (9).

$$\hat{a}_1 = \arg\min_{a1} \left| \sum_{n=1}^{N_r} h_{1,n}^* y_n(1) + h_{2,n} y_n^*(2) - (|h_{1,n}|^2 + |h_{2,n}|^2) a_1 \right| \tag{8}$$

$$\hat{a}_2 = \arg\min_{a1} \left| \sum_{n=1}^{N_r} h_{2,n}^* y_n(1) - h_{1,n} y_n^*(2) - (|h_{1,n}|^2 + |h_{2,n}|^2) a_2 \right| \tag{9}$$

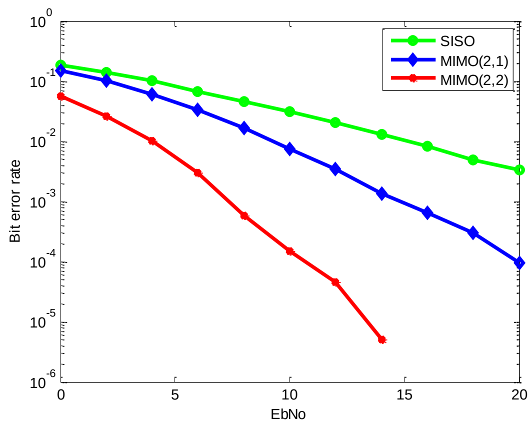


Fig. 8. Reliability evaluation of three antenna scheme with SNR

Then Fig. 8 illustrates the reliability analysis with SNR denoted by EbN0. We found that the bit error rate of SISO, MIMO (2, 1) and MIMO (2, 2) are all decreasing with the increase of SNR. Especially, the performance of

MIMO (2, 2) is superior to MIMO (2, 1), one of which is superior to SISO. In a word, MIMO technology could improve reliability with expanding the diversity by increasing the number of receiving and transmitting antennas.

Simultaneously, the bit error rate would be decreasing with the increase of data packet length, which is shown in Fig. 9. So the *n* value should be increasing for improving the performance, but it could not be excessive increase in the number of redundant.

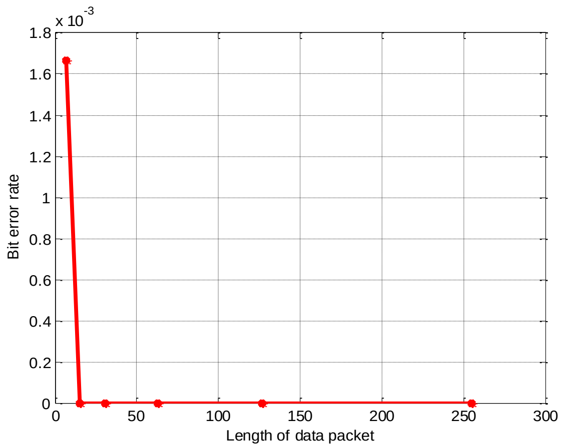


Fig. 9. Reliability evaluation with data packet length.

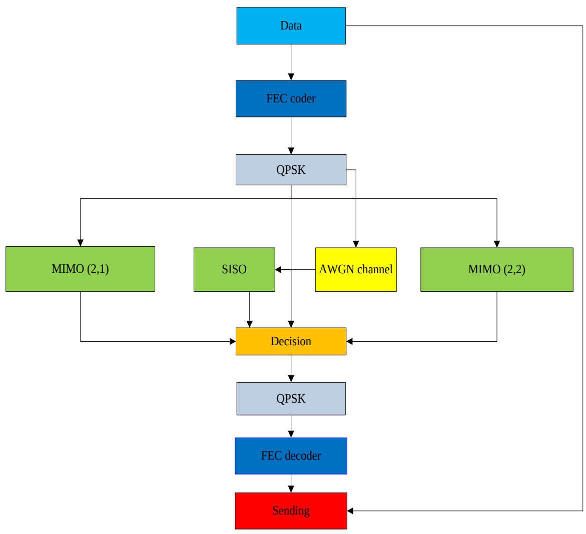


Fig. 10. Flowchart of selecting the antenna scheme between SISO, MIMO (2, 1) and MIMO (2, 2)

Then, the Fig. 10 shows the workflow of the selection progress with FEC sensing, as follows:

1) The signal source was encoded by FEC coder and QPSK modulation encoding.

2) To choose the best encoded solution for the signal source from step (1).

3) Through the QPSK demodulation and error rate statistics by FEC decoding.

4) The optimal FEC scheme would be selected based on CRC at physical layer, as well as optimal antenna solution selected from SISO, MIMO (2,1) and MIMO (2,2).

Based on the foregoing analysis, we combine MIMO technology and FEC sensing to propose the adaptive MIMO technology for IOT, the workflow of which is illustrated by Fig. 10.

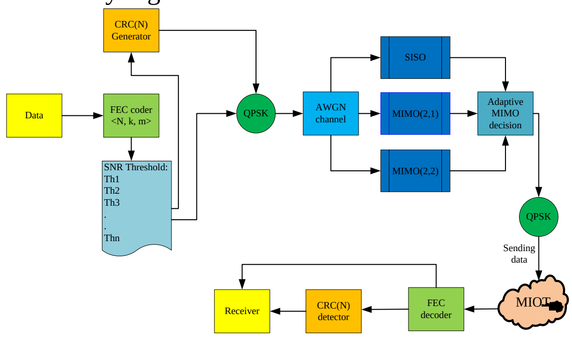


Fig. 11. Work processes of the proposed reliable transmission control scheme

V. Reliable Transmission Control Scheme

In this section, we propose the reliable transmission control scheme based on the FEC sensing scheme in section 3 and adaptive MIMO technology in section 4, which is shown as Fig. 11.

In the actual work process of the proposed scheme in MIOT, there are some aspects need to pay attention.

(1) After the desired signal source QPSK modulation only when the signal source must be the random matrix composed of four numbers 0, 1, 2, 3.

(2) The signal source would go through FEC encoder only when which is the random matrix composed by 0, 1,2,3,4,5,6,7.

Therefore, the signal source must be generated by the random matrices within the matrix elements composed by [0, 2m-1] at first. Secondly, the signal could be encoded by FEC sensing scheme.

VI. Performance Evaluation

In this work, we simulate, analyze and evaluate the performance of the proposed scheme denoted by FMATTC, compared with traditional transmission with the FEC alone and MIMO alone through three group experiments. The experimental data is the average value after 100 time simulation or mathematical analysis

A. *Experimental Results with Channel State.*

Fig. 12 shows two performance metrics as a function of EbN0 in experiment 1. The result of bit error rate and frame error rate indicate that the channel state of sensors in MIOT have important implication on communication and transmission of wireless data. It is clear that there is significant improvement of performance with FMATTC, as compared with the FEC alone and MIMO alone mechanisms. Even if the channel quality is poor, the proposed strategy can still maintain a high reliability. For example, the bit error rate and frame error rate are close to zero when SNR is equal to 5dB, which of the FEC alone and MIMO alone are close to 10^{-3} and 0.05 respectively.

The reasons are that not only the CRC-aware FEC sensing scheme could set up the optimal FEC and CRC coding scheme based on channel state, but also the adaptive MIMO strategy obtains the optimal antenna gain; as a result, the network reliability strengthened.

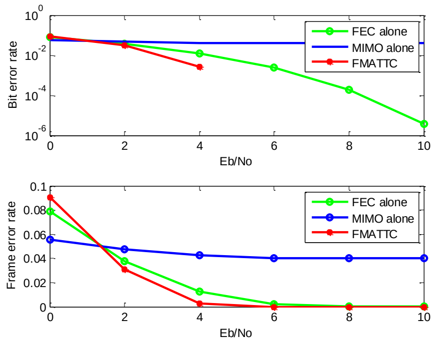


Fig. 12. Reliability analysis with SNR.

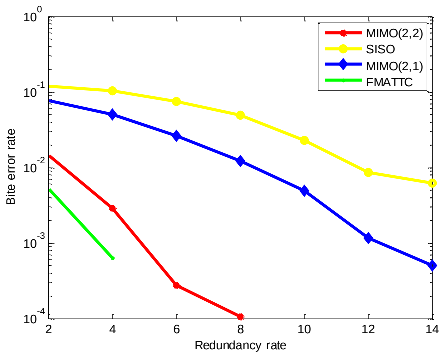


Fig. 13. Reliability an redundancy rate.

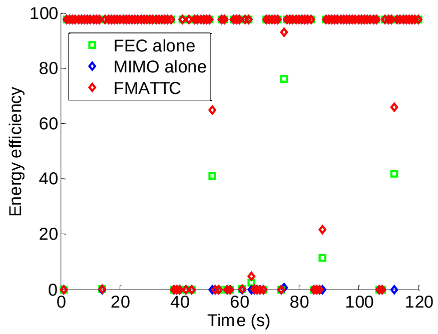
B. *Experimental Results with Redundancy Rate.*

Fig. 13 shows the bit error rate as a function of four different schemes such as SISO, MIMO (2, 1), MIMO (2, 2) and FMATTC with redundancy rate in experiment 2. We found that the bit error rate of four schemes is in the fall as the increase of redundancy rate. The FMATTC has the maximum amplitude and can significantly improve the reliability with low redundancy rate, indicating that the proposed strategy is the most effective in four kinds of policies. For example, the bit error rate of FMATTC is close to zero when redundancy rate is larger than 4. However, the bit error rate of MIMO (2, 2) is close to zero only when redundancy rate is larger than 8, one of the other schemes have to be larger than 14.

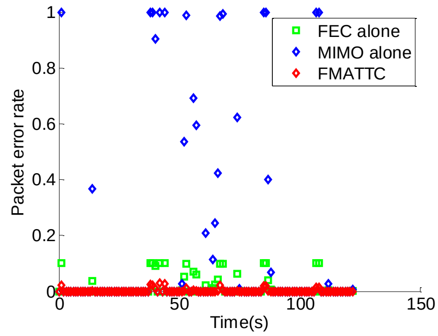
C. *Experimental Results with QoS Supported Capacity.*

Fig. 14 shows the four performance metrics as a function of the FEC alone, MIMO alone and FMATTC schemes in experiment 3.

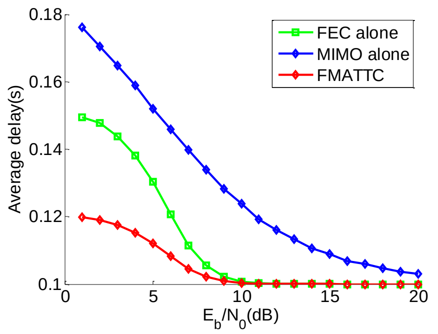
Fig. 14 (a) and (b) illustrate the energy efficiency and packet error rate using NS-2 simulation. The simulation time is 120 seconds. The experimental data is the average value after 100 time simulation. The proposed FMATTC is not only able to achieve higher energy efficiency, but also improve the reliability of transmission in MIOT. The enhancement of FEC sensing technology and adaptive MIMO control scheme can significantly decrease the energy consumption for sensors in MIOT. Comparing with the traditional the FEC alone and MIMO alone schemes, FMATTC is able to achieve obvious enhancement in energy utilization and reliability.



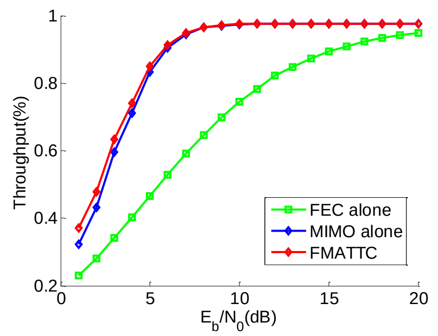
(a) Energy efficiency with simulatin time.



(b) Packet error rate with simulation time.



(c) Delay with SNR.



(d) Throughput with SNR.

Fig. 14 Performance evaluation of end to end QoS.

The analysis of average delay is shown in Fig. 14 (c), one of FMATTC can achieve the evident reinforcement. The main reason is that the error control aware adaptive MIMO based on FEC sensing enhances the space and spectral gain, as well as antenna diversity gain. As shown in Fig. 14 (d), the FMATTC always performs better than the traditional the FEC alone and MIMO alone mechanisms. The improvement of throughput is benefited from the adaptive CRC and FEC sensing of sensors in MIOT, which are able to make full use of system resources.

VII. Conclusions and Future Work

Purpose of our work is to resolve the bottlenecks of sensors in MIOT; we propose the reliable transmission control scheme based on FEC sensing and adaptive MIMO technology denoted by FMATTC.

The main contributions in our work are as follows. First, considering the characteristics of CRC and FEC schemes, we introduce the FEC sensing scheme based on CRC to study the characteristics of reliability with channel state. Second, the adaptive MIMO technology with FEC sensing is designed to ensure the rational and effective use of antenna and spectrum. Finally, we present the reliable transmission control scheme based on cross layer design, working together with the above two mechanisms, to improve resource utilization and reliability, as well as to extend the MIOT system life.

The mathematics and simulation results demonstrate that, compared with the existing traditional mechanisms, FMATTC greatly guarantees the QoS of MIOT application services and obtains the obvious system gains in terms of reliability, real time performance, and throughput, as well energy efficiency. As a result, it is determined that the proposed scheme is effective, efficient and robust for transmission control and QoS guarantee in MIOT.

In our future work, we will research and study one approach used to switch the SISO and MIMO. Simultaneously, we would activate the antenna by trigger signal according to settings of our proposed scheme to switch them.

Acknowledgment

This work is supported in part by National Natural Science Foundation of China grant No. 61300186, Project of Jiangsu Province University Natural Science gran No. 13KJB510001, science and technology development project of Changshu (Social Development category) grant No.CS201413, project of Teaching Reform of Education College of computer science and Engineering of Changshu Institute of Technology under grant No. JGJSJ201307 and University Students' innovative undertaking training program of Changshu Institute of Technology, grant No.2014.

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Yong Jin was born in Shanxi Province, China, in 1981. He received the M.S. degree from the Nanjing University of Technology of China (NJUT), Nanjing, in 2009, in computer application technology. He is currently working as lecture in Changshu Institute of Technology. His research interests include wireless sensor networks, error control, and performance evaluation, etc.

Feng Li and **Ya Fan** are undergraduate students in Changshu Institute of Technology. Their research interests include wireless sensor networks, Internet of Things.

Ruigang Li is the deputy Director of Changshu Museum. His research interests include Heritage conservation and wisdom Museum with Internet of Things.

Huan Dai received the PhD degree from the Jiang Nan University in 2012. He is currently working as lecture in Changshu Institute of Technology. His research interests include wireless sensor networks, pattern recognition, artificial intelligence, etc.