A data transmission method of digital oilfield monitoring system based on Internet of Things

Jingyi Wang, Xuhua Sun, Hongbo Bu and Xu Fu
School of Computer Science, Xi’an Shiyou University, Xi’an 710065, China
jywang@xsyu.edu.cn

Abstract. To combat the effects that artificial patrols oilfield, artificial inputs production data and the accident is not handed in time, a novel data transmission method is proposed for digital oilfield to make data safe and reliable. Firstly, an oilfield monitoring system based on the Internet of Thing is introduced. Then the proposed method introduces a threshold and only forwards those data which meet the requirements. Furthermore, the proposed data transmission strategy is discussed in detail. It is shown in simulation that the gap between the gain performance of the proposed strategy with the optimal threshold and error-free relay station is only 0.01 dB at $BER = 10^{-n}$.

1. Introduction
It is well-known that Internet of Things (IoT) has gained enough attention from different researchers in industry. IoT communication mainly deals with the exchange of information between objects, people and objects and people. The IoT technology integrates Radio-Frequency, sensor, and nanotechnology, which will be an important technology to change people’s life and lifestyle[1].

With the continuous development of computer technology and information technology, the concept of digital oilfield construction will be a kind of highly efficient and refined oilfield construction management mode gradually. The established oilfield based on the IoT realizes the interconnection between objects and the Internet, and the real-time communication and information transmission between proprietary equipment. The monitoring centre can complete the management, statistics and monitoring of relevant data by the collected production data quickly and efficiently. Yang Yubin[2] has proposed a remote monitoring system of pumping unit based on the IoT, which can monitor the operation of pumping unit in real time and not optimize problems such as packet loss and accuracy during the transmission process of specific data. Yang Lei[3] has constructed an overall hardware framework of the well site security IoT system and studied the security information acquisition and transmission subsystem and the three-layer architecture of security monitoring centre, but did not study the accuracy transmission process of data. Khan et al.[4] has proposed a new architecture-based IoT for the oil and gas industry, which makes the data simple, safe, reliable, fast and collected by smart devices, but did not give a specific framework. Gharibi et al.[5] has proposed a reliable, safe and scalable sensor system that can monitor oil and gas equipment, and specific performance is not given.

In order to ensure unmanned operation of equipment with low signal-to-noise ratio and reliable coordination and communication of remote data, this paper establishes a remote transmission monitoring system for oilfield based on the new Internet of Things technology. The established system is characterized by flexible network formation, low cost, high efficiency, safety and reliability, and
convenient maintenance. The main thing is that a wireless data transmission scheme is proposed in
digital oilfield based on the Internet of Things.

2. System Description
In this section, a novel smart monitoring system of digital oilfield based on IoT is given and then a
multi-well cascade data transmission method is presented.

2.1. A novel smart monitoring system of digital oilfield based on IoT
This system consists of smart sensor object, smart gateway and data processing centre (see Fig.1). Each
part is responsible for its own specific function in order to improve the ability of the entire monitoring
system between interconnected oil wells.

![Fig.1 A smart monitoring system of digital oilfield based on IoT](image)

Each smart sensor object is a transmitting equipment, which is used to measure and gather data
(electricity, load etc.) and send data to the data processing centre. It can independently make data
decisions without human intervention. Once the smart sensor object has collected the data, it will send
useful information to the data processing centre in time. It can prevent abnormal situations from
occurring on emergency. If the equipment on the wellheads needs to be repaired or maintained, the
smart sensor object can inform the data processing centre.

The smart gateway is a translator that acts as a relay between the smart sensor object and the data
processing centre. If the channel between the smart sensor object and the data processing centre is
unusable, the smart gateway will be able to send information that transmitted by the smart sensor object.

The data processing centre is a terminal equipment, which collects and analyses the data from the
source equipment. It also extracts useful information from the received data based on different data
analysis methods, and then analyses problems and takes effective measures against emergencies.

These three components interrelate with each other in a transmission process to ensure the whole
system safe and reliable.

2.2. System model of data transmission
According to the system structure, a multi-well collective relay communication mode is proposed. Its
topological structure was shown in Fig.2.

The WHC receives the collected data from each wireless instrument, processes the data and then
sends it to the data processing centre. At the same time, the WHC receives the command from the
centre and controls the normal operation of various devices in the whole system.

Wireless ZigBee instrument equipment can be used to collect current, temperature, pressure, load,
displacement and other data. After that, the data information is sent to the WHC.
Relay stations are mainly to process and forward data information to the data processing centre, so as to expand the transmission distance of network.

Fig. 2 The topological structure of the process of transmitting data

Fig. 2 can be modelled as the network model shown in Fig. 3. The transmission process of the whole network is composed of two stages as follows:

In the first stage, $M$ WHCs broadcast their collected data $X'_i$ ($i = 1, 2, \ldots, M$) to the $N$ relay stations and the data processing centre $D$, where the superscript $t$ represents time throughout this paper. Then we have

$$Y'_{i,D} = h'_{i,D}X'_i + N'_{i,D} \quad (1)$$

$$Y'_{i,j} = h'_{i,j}X'_i + N'_{i,j} \quad (2)$$

where $Y'_{i,D}$ and $Y'_{i,j}$ are the corresponding data information received by the relay station $R_j$ and the data processing centre $D$ respectively, $N'_{i,D}$ and $N'_{i,j}$ are the noise random variables.

In the second stage, the relay station $R_j$ processes the data sent from all the WHCs. If the data information does not meet the requirements of the system, the relay station $R_j$ blocks the data information and does not forward it to the data processing centre. After this process, the relay station
re-processes the data and forwards the selected data sequence to the data processing centre. Let \( X_j' \) be the data transmitted by the relay station \( R_j \). The received data at the data processing centre is

\[
Y_{j,D}' = h_{j,D}X_j' + N_{j,D}'
\]

where \( Y_{j,D}' \) is the received data information at the data processing centre \( D \) from the relay station \( R_j \), \( N_{j,D}' \) is a noise random variable.

3. Transmission Strategy

In this section, a transmission strategy is deduced based on the research results in the paper [6]. If the bit log-likelihood ratio (LLR) of the received data is below the predetermined threshold, the relay station keeps still and does not send any information. Otherwise, the selected data are sent. We obtain optimum threshold by minimizing error bit probability.

3.1. Description of Threshold

Let \( \Lambda_i' \) represents the bit LLR of the data of the \( i \)-th WHC at the \( R_j \). We obtain

\[
\Lambda_i' = \ln \frac{p(x_i = 1|y_{i,j}, h_{i,j})}{p(x_i = -1|y_{i,j}, h_{i,j})} = \ln \frac{p(y_{i,j}|x_i = 1, h_{i,j})}{p(y_{i,j}|x_i = -1, h_{i,j})} = 2y_{i,j}h_{i,j}/\sigma_{i,j}^2
\]

where \( p(\cdot) \) denote the conditional probability density function. Assuming that \( N_{i,j}' \) is the zero-mean additive Gaussian random variable with variance \( \sigma_{i,j}^2 \). And apparently, the magnitude of \( \Lambda_i' \) is a reliable standard of the accurate data. The data of the WHC is estimated by \( R_j \) as

\[
\hat{x}_i' = \text{sign}(\Lambda_i')
\]

where \( \text{sign}() \) is the signum function. The instantaneous error bit probability of \( \Lambda_i' \) at the relay station \( R_j \) can be expressed by

\[
P_{ij} = \frac{1}{1 + e^{\Lambda_i'}}
\]

Let \( P_{e,T} \) be the predetermined threshold, which means that the relay station transmits the estimated data \( \hat{x}_i' \) to the data processing centre in case of \( P_{ij} \leq P_{e,T} \). According to (6), we obtain

\[
P_{ij} = \frac{1}{1 + e^{\Lambda_i'}} \leq P_{e,T}
\]

or

\[
|\Lambda_i'| \geq \ln\left(\frac{1}{P_{e,T}} - 1\right) = \Lambda_0
\]

From equations (4)-(7), \( \Lambda_i' \) can provide the effective information of the maximum a-posteriori probability decision, which can minimize the error bit probability.

3.2. Optimization of Threshold

The relay station \( R_j \) estimates the value of the received data from each WHC. If the data bit LLR exceeds the predetermined threshold, the relay station operates and transmits the restored data to the data processing centre \( D \). Otherwise, it keeps steady in the second stage. The transmitted data can be expressed as
\[
X_j = \sum_{i=1}^{N} g_{i,j} \hat{X}_{i,j}
\]

where \( g_{i,j} = 0 \) if \( |A_i| < \Lambda_{\theta} \), and \( g_{i,j} = 1 \) if \( |A_i| \geq \Lambda_{\theta} \), \( \Lambda_{\theta} \) is the threshold of set \( S_i \).

Let \( P_i \) be the average error bit probability at the data processing centre. The optimal threshold \( \Lambda_{\theta}^{opt} \) will be determined by minimizing \( P_i \). So we have

\[
\min_{\Lambda_{\theta}} P_i \quad \text{s.t.} \quad \Lambda_{\theta} > 0
\]

Therefore, equation (9) is a linear programming problem. Then, we can use the following probability distribution expression to solve the optimal threshold \( \Lambda_{\theta}^{opt} \).

At the data processing centre \( D \), two factors contribute to error information. One is that the relay station keeps steady and error data occurred in the direct link between WHC and data processing centre. The other one is that the relay station transmits the data information to the data processing centre and error data still occurred. Since these two factors are independent of each other, \( P_i \) can be expressed as

\[
P_i = P_i^1 + P_i^2
\]

where \( P_i^1 \) and \( P_i^2 \) are the error data probabilities corresponding to the first and second factor, respectively. These two parts can be expressed

\[
P_i^1 = P_i^{w(d)} \cdot \Pr[|A_i| < \Lambda_{\theta}]
\]

\[
P_i^2 = P_i^{M\text{AC}} \cdot (1 - P_i^e) + P_i^{(X)} \cdot P_i^e
\]

where \( P_i^{w(d)} \) is the error data probability that error data occurred in the WHC-data processing centre link. When the information is correct at the relay station \( R_j \), \( P_i^{M\text{AC}} \) is the error data probability that error occurred at the data processing centre by using the data information from both \( W_i-D \) link and \( R_j-D \) link. When the information is error at the relay station \( R_j \), \( P_i^{(X)} \) is the error data probability that error occurred at the data processing centre by using the data information from both \( W_i-D \) link and \( R_j-D \) link. \( P_i^e \) is the error data probability that the relay station \( R_j \) operates the data information from the WHC by mistake. The expression of \( \Pr[|A_i| < \Lambda_{\theta}] \) and \( P_i^e \) are shown in [7].

Based on equations (10)-(12), we can easily solve the optimum threshold by minimizing the error data probability. And apparently, the optimal threshold \( \Lambda_{\theta}^{opt} \) can be expressed

\[
\Lambda_{\theta}^{opt} = \log\left(\frac{P_i^{(X)}}{P_i^{w(d)}}\right) - 1
\]

4. Simulation Results

We use a specific example with four WHCs, four relay stations, one data processing centre, and AWGN orthogonal channel with \( SNR_{W_i} = SNR_{R_j} \) and \( N_{f,D} = 0.3 \). Assuming that each WHC transmits the coded data by using a (3824, 1912) irregular LDPC code with degree distribution \( \lambda(x) = 0.21606x + 0.1576x^2 + 0.154x^3 + 0.01848x^4 + 0.04312x^5 + 0.41074x^6 + 0.41074x^7 \), \( \rho(x) = x^8 \). At the relay stations, we operate data by using the RS code coefficients in the finite field \( GF(2^8) \), which is constructed based on the minimal polynomial \( \rho(X) = 1 + X^2 + X^3 + X^4 + X^8 \). The simulated results with all the threshold types including without any threshold, the preset threshold, the optimal threshold.
In this paper, an oilfield monitoring system based on the Internet of Things is established. And then, a data transmission strategy with a threshold in digital oilfield is proposed. The novel strategy has been adopted in the linear programming problem to derive the instantaneous error data probability. The optimal threshold for the proposed strategy is obtained with respect to the minimized instantaneous error data probability. It is shown in simulation that the proposed strategy has significant effect on gain performance. In other word, it can make data of digital oilfield safe and reliable.

**Figure 4** BER performance over AWGN channel

### 5. Conclusion

In this paper, an oilfield monitoring system based on the Internet of Things is established. And then, a data transmission strategy with a threshold in digital oilfield is proposed. The novel strategy has been adopted in the linear programming problem to derive the instantaneous error data probability. The optimal threshold for the proposed strategy is obtained with respect to the minimized instantaneous error data probability. It is shown in simulation that the proposed strategy has significant effect on gain performance. In other word, it can make data of digital oilfield safe and reliable.

### Acknowledgments

This work was financially supported by Innovation and Entrepreneurship Training program for college student of Shaanxi Province (201819040) and Special Scientific Research project of education department of Shaanxi Province (18JK0626).

### References

[1] Atzori L., Iera A., et al. The internet of things: A survey[J]. Computer networks, 2010, 54(15):2787-2805.

[2] Chen Honglong. An experimental platform for remote monitoring of pumoing unit group based on Internet of Things[J]. 2016,33(2):114-116(in Chinese).

[3] Yang Lei. Research on Safety Monitoring System for Oilfield Well Sites Based on Internet of Things[D]. Xi’an: Xi’an Shiyou University,2016:13-25(in Chinese).

[4] W. Z. Khan, M Y Aalsalem., et al. M S Hossian and M Atiquzzaman. A reliable Internet of Things based architecture for oil and gas industry[C]. 2017 19th International Conference on Advanced Communication Technology(ICACT), Bongpyeong, 2017:705-710.

[5] Gharibi W, Aalsalem M, et al. Monitoring gas and oil fields with reliable wireless sensing and Internet of Things[C]. International Conference on Radar, Antenna, Microwave, Electronics, and Telecommunications. 2017:188-191.

[6] H. V. Khuong and H. Y. Kong, LLR-based decode-and-forward protocol for relay networks and closed-form ber expressions[J]. IEICE Trans. Fundamentals. 2006,E89A:1832-1841.

[7] Wang Jingyi. Study on Channel Codes in Wireless Relay Systems[D]. Xi’an: Xidian University,2016:47-60(in Chinese).