A Simple Data Relay Process and Turbo Code Application to Wireless Sensor Networks

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***Abstract*— In this study, we focus on relay process of intermediate node of wireless sensor networks. In conventional wireless sensor networks, the intermediate node performs the regenerative repeating process such that error correction, detection and re-encoding are processed. This is reliable, but it requires a lot of processing effort and may take much energy. To reduce a burden of relay process, we propose to omit error decoding and/or re-encoding process at the intermediate nodes. Further, we propose a method that realizes soft-decision decoding for hard-detected signals. With this method, we can employ Turbo code to wireless sensor networks. As results, we show that though omitting the decoding and re-encoding process at the intermediate node may not affect much to the performance.**

I. INTRODUCTION

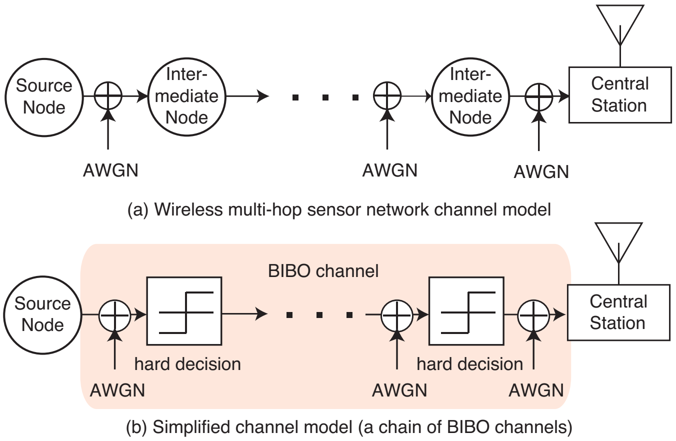
The technology of wireless sensor networks is invaluable in many applications. For example, tiny, inexpensive sensors can be sprayed onto roads, forests or machines to monitor and detect a variety of events such as highway traffic, wildlife habitat condition, manufacturing job flow. Because of this, wireless sensor networks have attracted considerable research attention in the last few years [1].

Sensor nodes are battery driven and hence operate on an extremely frugal energy budget. Because of its spatial coverage and multiplicity in sensing aspects and modality, the raw data are not directly send to a central station but each sensor node locally process simple computation and transmit only the required and partially process data to the nearest node. This means that data are transmitted in multi-hop manner to a central station. Intermediate nodes act as regenerating repeaters.

In multi-hop data transmission, error control coding is applied and transmitted to an intermediate node according to the routing information. At the intermediate node, error correct decoding and/or detection are processed. If no error is detected, the data are sent to next intermediate node. If error is detected, the node requests retransmission. This regenerative repeating process may take processing time and energy.

In this paper, we consider to omit this error correction and/or detection process at intermediate nodes. Only routing is performed and data are relayed without any error correction or detection. Error correction is performed only at the central station (destination).

At an intermediate node, the data are demodulated and hard detected. This is necessary to retrieve routing information. Therefore, only hard decision decoding can be processed at the central station. However, this limits the use of powerful FEC schemes, such as Turbo code.



(a) Wireless multi-hop sensor network channel model

(b) Simplified channel model (a chain of BIBO channels)

Fig. 1. Multi-hop channel model of wireless sensor networks

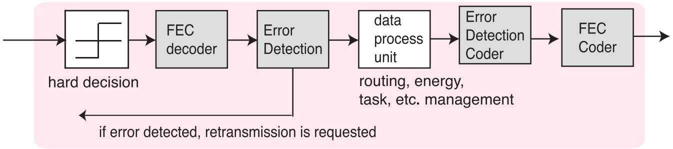
Powerful FEC decoding are based on a set of rules to exchange and combine some sort of soft information with the purpose of providing reliable decisions about the input sequences. The use of the soft-decision and/or channel state information is beneficial for its performance [2]. Since the decoding is based on the iterative manner, the processing time and efforts are much high. Therefore, it is difficult to apply Turbo code and the other powerful to wireless sensor networks.

We solve this problem by a method to realize soft-decision decoding for hard-detected signals [3]. This enables us to use powerful soft-decision decoding algorithms such as Turbo decoding. Since we can employ powerful FEC, omitting the decoding and re-encoding process at the intermediate nodes may not affect much to the overall performance.

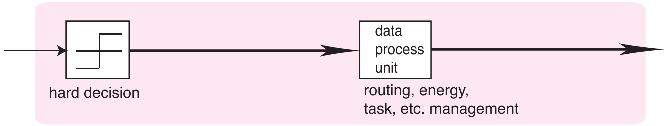
The rest of the summary is as follows. We present system model in next section and describe the concept of how to realize the soft-decision decoding for hard-detected signal. Then, we present the numerical results and conclusion.

II. MULTI-HOP CHANNEL MODEL OF WIRELESS SENSOR NETWORKS

A simplified wireless multi-hop sensor network channel model is shown in Fig.1. The channel can be assumed as a chain of symmetric binary-input and binary-output (BIBO)



(a) Conventional regenerative repeating process



(b) Proposed regenerative repeating process

Fig. 2. Regenerative relay process at an intermediate node

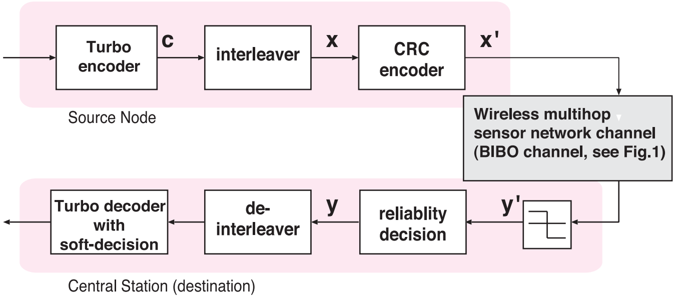


Fig. 3. Simplified system model (proposed system)

channel. The outputs of this BIBO channel are also hard-detected antipodal signals of +1 or -1. Let the number of hops be M and the inter-node bit probability be p_b^m then the bit error probability at the destination node is written as

$$\begin{aligned} p_b^m &= 1 - \prod_{m=1}^{M} (1 - p_b^m) && (1) \\ &\approx \sum_{m=1}^{M} p_b^m, && (2) \end{aligned}$$

where we only consider only the dominant term thus omit the term with power of p_b. If we further assume that p_b^m is the same for all intermediate nodes, then the bit error probability at the destination node is Mp_b. This suggests the linear decrease of bit error probability as the increase of number of hops.

At a source node, transmit data are encoded by a forward error correcting code and error detection code. Then the data are transmitted in a form of a packet with routing information. At an intermediate node, the received signal is demodulated and hard-detected to extract the routing information.

In conventional wireless sensor networks, the intermediate node performs the regenerative repeating process such that error correction, detection and re-encoding are processed as shown in Fig.2 (a). If no error is detected, the data are sent to the next intermediate node. If error is detected, the node requests retransmission. These processes extend latency, however reliable relay transmission can be guaranteed.

We omit this error correction and/or detection process at intermediate nodes as shown in Fig.2 (b). Only routing is performed and data are relayed without any error correction or detection. If necessary, energy, task and the other management process are performed. We note that these processes are mandatory and cannot be neglected. Usually a header contains those information and since lost of the header information vanishes the whole data, we assume that the header information is protected and no error will be occur during the relay process. This assumption is valid as the header information is much smaller than the data, a repetitive configuration is possible for maximize the error protection.

At the central station (destination), a powerful soft-decision decoding (Turbo decoding) is performed for the hard-detected signal. Figure 3 shows the simplified system model of our proposed scheme.

III. REALIZATION OF SOFT-DECISION DECODING FOR HARD-DETECT SIGNALS

As mentioned, the signal is hard-detect and passed to the next intermediate node. The issue that we need to overcome is, therefore, how to overcome the loss due to the hard-detections at the intermediate node. The degradations that the destination node face are 1) one comes from the BIBO channels Mp_b and 2) the loss due that the powerful soft-decision decoding is not possible.

To overcome the issues, we consider the realization of soft-decision decoding for hard detect signals. This enable us to apply a powerful error correcting code, such as Turbo code, that is based on reliable soft-values and iterative decoding process. The key is how to obtain reliable (soft) value from the hard-detect signal. This can be done with an aid of error detection code [3].

As shown in Fig.3, after encoded by a powerful FEC, the output data is interleaved and error detection coding is performed. At an intermediate node, no regenerative repeating process is done. Only routing is performed.

At the central station, received hard-detect signal is first fed into the error detection decoder. The decoder outputs the two states depend upon the reliability of the received codeword; with error or without error. Based on this value, we assign the reliability value to the received signal and then fed into the powerful FEC decoder.

A. *Reliable information by error detection*

In general, there are three states according to the channel errors in error detection scheme. Those cases are 1) the case without error, 2) the case with detectable error and finally 3) the case with error but the error detection scheme cannot detect the error [4]. The cases are depicted in Fig.4.

The probability of undetected error for a binary linear block code may be upper-bounded by a quality of 2^{-r} where r is the number of the parity check bits of an error detecting code. Therefore, fewer than 2^{-r} error bits inside the whole p_b error patterns remain undetected.

Let us define $\epsilon = 2^{-r} p_b$ be an upper-bound of the remaining errors which are not detected. Since the good channel state is

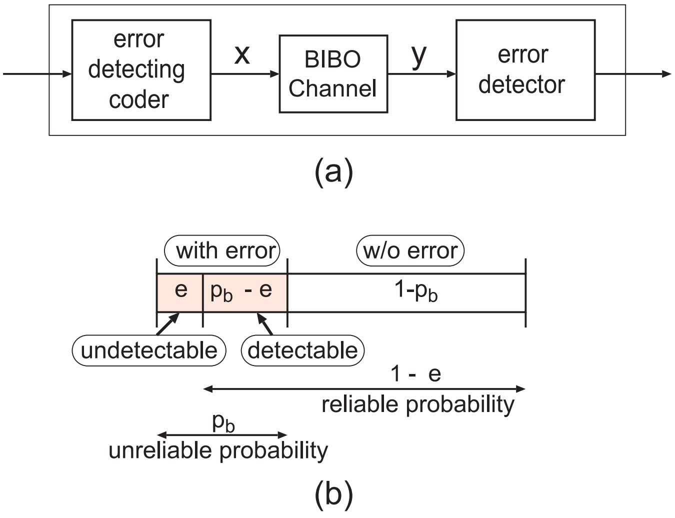


Fig. 4. Reliablity values of error detection scheme for BIBO channel

dependant on the capability of error correcting code, we obtain a good reliability coefficient R^{good} as

$$R^{good} = ln\frac{1-\epsilon}{\epsilon}. \tag{3}$$

Accordingly, the bad channel coefficient is

$$R^{good} = ln\frac{1-p_b}{p_b} \tag{4}$$

IV. SYSTEM MODEL

A. Transmitter

The data is first encoded by a powerful FEC at the source node. Let a block of codeword be

$$\boldsymbol{c} = [c_0, c_1, \cdots, c_{N-1}] \tag{5}$$

where N is the length of codeword. This codeword is interleaved and divided into a sub-block denoted by $\boldsymbol{x}$ as,

$$\begin{aligned} \boldsymbol{x} &= [x_0, x_1, \cdots, x_{L-1}] && (6) \\ x_l &= [x_{l,0}, x_{l,1}, \cdots, x_{l,M-1}] && (7) \end{aligned}$$

where L is the number of sub-block and x_l is the associated elements. The total length of the block is $N = LM$.

Each sub-block is finally encoded by a error detection encoder, such as CRC, and then transmitted.

B. Reciever

The received signal at a destination node is first demodulated and hard detected. We write $\boldsymbol{y}_l$ as a block of hard detected signals as

$$\boldsymbol{y} = [y_0, y_1, \cdots, y_{L-1}], \tag{8}$$

and then each sub-block y_l is then error detection is performed.

After the error detection, each sub-block y_l is de decided as the case without error or with error. The received block with the case without data is considered as ”good” reliability state block and the block with error is considered as ”bad” reliability state block.

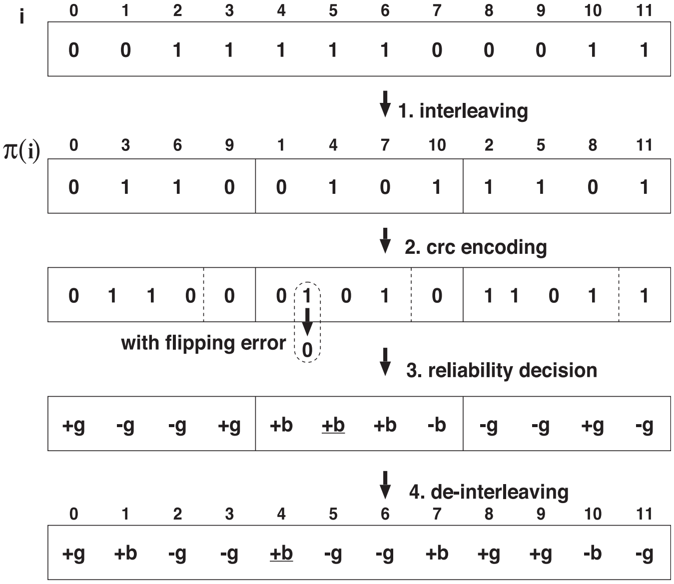


Fig. 5. Example of procedure

The data except the parity bit in good reliability state is multiplied by a ”good” reliability coefficient R^{good} .

$$y_l = [R^{good}y_{l,0}, R^{good}y_{l,1}, \cdots, R^{good}y_{l,M-1}] \tag{9}$$

Accordingly, the bad reliability state block is written as

$$y_l = [R^{bad}y_{l,0}, R^{bad}y_{l,1}, \cdots, R^{bad}y_{l,M-1}]. \tag{10}$$

Finally, the blocks are interleaved and fed into the powerful soft-decision decoder.

C. Example of the procedure

Figure 5 illustrates a simple example of the procedure.

First, a block of 12 bits of FEC outputs is interleaved. Then the interleaved data is divided into sub-blocks.

$$\begin{aligned} \mathbf{x}_0 &= (0,1,1,0), \\ \mathbf{x}_1 &= (0,1,0,1), \\ \mathbf{x}_2 &= (1,1,0,1). \end{aligned}$$

Next, an error detection coding is performed and then the date is transmitted.

At the receiver, the received signals are hard detected. The received sub-blocks including the parity-check bits are:

$$\begin{aligned} \mathbf{y}'_0 &= (0,1,1,0;0), \\ \mathbf{y}'_1 &= (0,0,0,1;0), \\ \mathbf{y}'_2 &= (1,1,0,1;1). \end{aligned}$$

In this example, the first sub-block $\mathbf{y}'_0$ and the third sub-block $\mathbf{y}'_2$, are detected without error. The second sub-block consists of a flipping error in the second bit $y'_{1,1}$.

After the error detection, each sub-block can be decided as without error or with error. In the former case without error, a sub-block are decided with good” reliable decision, while in latter case with error, a sub-block are decided with bad" reliable decision.

The reliability can be set with a value of $R^{good}(= g)$ or $R^{bad}(= b)$. By multiplication of the value to the error detect signals, we obtain (two states) soft values.

$$\begin{aligned}\mathbf{y}_0 &= (+g, -g, -g, +g),\\ \mathbf{y}_1 &= (+b, +b, +b, -b),\\ \mathbf{y}_2 &= (-g, -g, +g, -g).\end{aligned}$$

Finally, the block $\mathbf{y} = [\mathbf{y}_0, \mathbf{y}_1, \mathbf{y}_2]$ is de-interleaved and fed into the soft-decision decoder.

V. NUMERICAL EXAMPLE

The performance bounds are obtained based on simulation. The component codes inside the turbo code are two convolutional codes of rate $5/6$. Both component codes consist of recursive systematic convolutional code with memory 2 of the shift register with generator matrix

$$\mathbf{G}(D) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & \frac{1+D}{1+D+D^2} \\ 0 & 1 & 0 & 0 & 0 & \frac{1+D^2}{1+D+D^2} \\ 0 & 0 & 1 & 0 & 0 & \frac{D+D^2}{1+D+D^2} \\ 0 & 0 & 0 & 1 & 0 & \frac{D}{1+D+D^2} \\ 0 & 0 & 0 & 0 & 1 & \frac{1}{1+D+D^2} \end{bmatrix}.$$

A pseudo-random interleaver is selected between two component codes in the turbo code. The overall code rate of the turbo code is $5/7$. With puncturing procedure, the overall code rate of the turbo code is $5/6$. The puncturing is a periodic procedure such that in each 7 bit codeword (including 5 information bits and 2 parity-check bits for each component code), one bit is punctured. A CRC code of code rate $8/9$ is selected for the simulation. In the simulation, all results are based on 6 iterative decoding stages. The input length of the information bits is 900 bits.

In this work, we consider one hop case for simplicity ($M = 2$) and inter-node bit error probability p_b is the same for all nodes. We also assume that the header information can be retrieved without error.

Figure 6 shows the bit error rate (BER) performance. Three curves are plotted in Fig.6. The turbo decoding scheme using hard-decision from a BIBO channel is denoted as conventional decoding. The turbo decoding scheme using perfect channel information under AWGN channel, such as the original turbo decoding scheme described in [2], is denoted as ideal decoding. The turbo decoding scheme using the error-detected reliability is denoted as proposed decoding.

The conventional turbo decoding scheme with hard-decision shows more than 2.5 dB loss of the coding gain comparing with the ideal turbo decoding scheme with soft-decision. In contrast, the proposed turbo decoding scheme with the error-detected reliability shows slightly better than the conventional turbo decoding scheme with hard-decision in the range of low Eb/No and more than 2.0 dB better in the range of moderate to high Eb/N0. However, the BER performance of the proposed decoding scheme is 1.0 dB worse than the ideal turbo decoding scheme in the range of low Eb/N0. In the range of moderate to high Eb/N0, there is only slight difference between the performance of the proposed decoding scheme and the ideal decoding scheme.

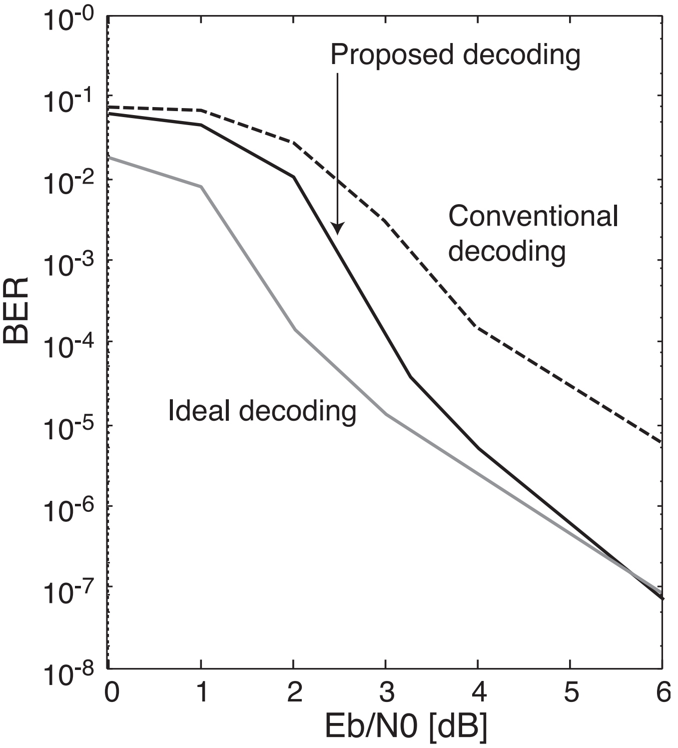


Fig. 6. BER performance

VI. CONCLUSION

In this study, we present a simple data relay process for intermediate nodes of wireless sensor networks. We omit the regenerative repeating process, error correction, detection, and re-encoding process. This reduces a processing effort and energy however the data transmission quality degrades. To overcome this, we propose a method that realizes soft-decision decoding for hard-detected signals. Although data are passed as hard-detected value, the method enables to use the powerful Turbo decoding. As results, good BER performance is confirmed.

Acknowledgement

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