Proceedings of APCC2015 copyright © 2015 IEICE 14 SB 0087

Frequency Offset Transmitter Diversity for M2M Access System

Seiji Ohmori, Akihiro Yamagishi, Hajime Katsuda, Nobuaki Mochizuki, Mitsuru Harada, and Shuichi Yoshino
NTT Network Innovation Laboratories, NTT
1-1 Hikari-no-oka, Yokosuka City, Kanagawa, 239-0847 JAPAN
Email: ohmori.seiji@lab.ntt.co.jp

***Abstract*—This paper applies a frequency offset transmitter diversity method for Machine-to-Machine (M2M) communication systems. Wireless terminals based on ZigBee and Wi-SUN offer long term usage and low cost. Frequency offset transmitter diversity is useful for these M2M applications because all it needs are additional access point antennas and an error correction function. Conventionally, the error correction function must employ hard decision to support various modulation/demodulation schemes. This paper proposes a Viterbi algorithm with soft decision that uses received signal strength metric calculated by an external circuit.**

Keywords—Frequency offset transmitter diversity; Viterbi algorithm; Soft decision; M2M.

I. INTRODUCTION

The rapid adoption of Machine-to-Machine (M2M) communication systems such as smart wearables and smart sensors is expected in the fields of industry, agriculture, environment and so on [1], [2]. Accordingly, an effective and efficient wireless access system is essential. Many countries (the U.S., China, South Korea, Australia) assign the 920 MHz frequency band for sensor networks, while the 925 - 928 MHz band has been available since 2012 in Japan (ARIB-STD108 [3]).

ZigBee [4] and Wi-SUN [5] are extensively used as M2M wireless access systems in the 920 MHz band. These schemes target sensor networks and/or smart meter systems, so the terminals are fixed and the environment is Non-Line-of-Sight (NLOS). Propagation takes place in quasi-static flat fading environments. In these environments, automatic repeat-request (ARQ) [6] is ineffective because the propagation channel is not time-varying and no time diversity effect can be expected.

To secure time diversity gain in quasi-static flat fading environments, we proposed frequency offset transmitter diversity [7]. This technique is suitable for M2M wireless access systems because it alter the wireless terminal's (WT's) antenna. The WTs of M2M wireless access systems must offer long term usage and low cost [4], [5]. The communication module of low-cost WTs consists of the bare minmum necessary for connecting to the access point (AP). Actually, IEEE802.15.4-2003 [8] specifies ZigBee's PHY layer, while IEEE802.15.4g [9] employs Wi-SUN's PHY layer, and neither specifies error correction. The frequency offset transmitter diversity technique secures time diversity gain in quasi-static flat fading environments but it needs an error correction function. Therefore, it is desirable that the structure of the frequency offset transmitter diversity be unrelated to the PHY layer specification.

To tackle these problems, we define the demodulator's output data type as being binary. We propose a frequency offset transmitter diversity method with a Viterbi algorithm [6] that applies soft decision based on the received signal strength indicator (RSSI). The RSSI is calculated by an external circuit.

The remainder of this paper is organized as follow: Section II explains conventional frequency offset transmitter diversity. Section III explains the proposed soft decision method for frequency offset diversity, Section IV details the improvement in diversity gain compared to conventional methods, and Section V concludes this paper.

II. FREQUENCY OFFSET TRANSMITTER DIVERSITY

In most M2M use cases, WT location is fixed [1], [2], for instance, the WT of electricity or gas meter systems and sensor network systems for environmental monitoring. In these locations, these propagation environments are quasi-static flat fading environments. Thus, if the RSSI of the WT becomes inadequate, the WT disconnects from the AP, and does not reconnect. To secure reconnection, the WT must be moved to another location.

Frequency offset transmitter diversity avoids continuous disconnection in quasi-static flat fading environments [7], [10]. Fig. 1 shows the structure of frequency offset transmitter diversity. Each antenna transmits encoded and interleaved data using unique frequency offset, Δf_d. These offsets yield frequency beating at the received point where the amplitude of the received signal varies in a regular manner. In the receiver, the signal after demodulation is subjected to soft decision or hard decision. As a result, some coding gain is expected. Furthermore, this gain increases with the number of the AP's antennas (branches), because the degree of the amplitude variation is determined by the number of branches, see Fig. 2. Table I lists the simulation parameters. Baud rate and Modulation/Detection follow either IEEE802.15.4-2003 [8] i.e. ZigBee's PHY layer, or IEEE802.15.4g [9], Wi-SUN's PHY layer. The diversity gain is defined the difference for the required CNR of PER 10^{-2}. The figure compares hard decision to soft decision with Viterbi algorithm. This graph confirms that diversity gain increases with the number of transmitter branches, and that soft decision offers greater gain than hard decision.

Soft decision with Viterbi algorithm [6] requires the likelihood of the demodulated bits. In general, the likelihood ratio is calculated according to the amplitude of the baseband. In the M2M wireless access system, however, we assume that the WT's demodulator outputs binary data, "1" or "0," thus the direct application of soft decision with Viterbi algorithm is not possible.

GFSK is suitable for low cost terminals as most of the detection circuit performs only frequency detection via a frequency discriminator. Frequency detection is an inherently non-linear process, thus the LLR for a linear system like BPSK is not suitable [12]. GFSK is mostly employed in Wi-SUN's PHY layer. Thereby, to achieve M2M wireless access with wide coverage, we need frequency offset transmitter diversity with soft decision that supports GFSK.

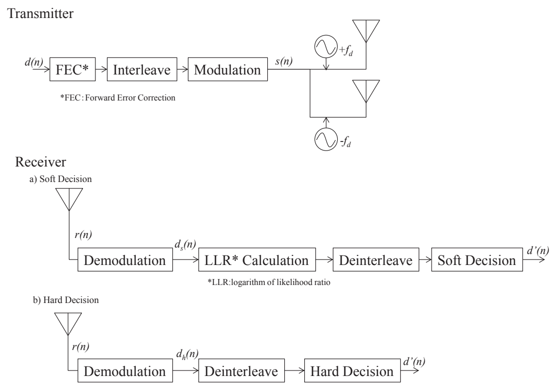

Fig. 1. Structure of the frequency offset transmitter diversity

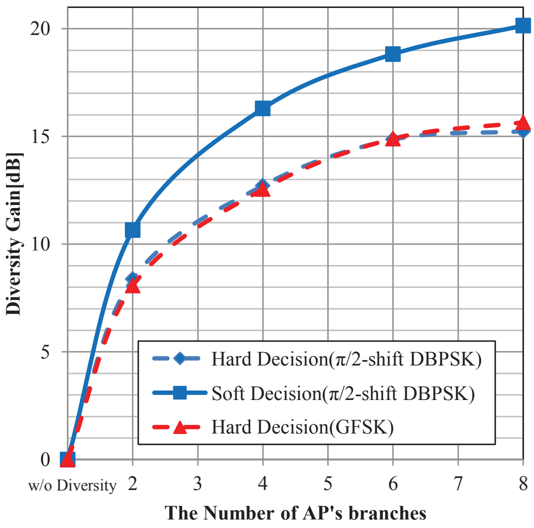

Fig. 2. Gain of Frequency offset transmitter diversity

TABLE I. SIMULATION PARAMETER

Parameter	**Value**
Baud rate	20 kbaud
Modulation/Demodulation	$\pi/2$-shift DBPSK/Differential Detection
	GFSK/Frequency Detection
Data Length	16 byte
Interleave/Deinterleave	Matrix Interleaving (Number of rows: 12 bits)
Frequency offset cycle	64 symbols
Error Correction	Convolutional code (Rate: 1/2 Constraint length: 7)
Propagation Channel	Quasi-static flat fading

III. SOFT DECISION PROPOSAL WITH VITERBI ALGORITHM

Fig. 3 describes the structure of our soft decision proposal. Demodulation data $d_h(n)$ is binary, "1" or "-1," and the RSSI calculation data, $R(n)$, is the amplitude of received signal $r(n)$. Data $d_h(n)$ and $R(n)$ must be synchronized, because the demodulation circuit and the RSSI calculation circuit are independent thus yielding asynchronous outputs. The synchronization method is as

$$P\left(\frac{k}{N_{OS}}\right) = \sum_{n=k}^{N+k} R\left(\frac{n}{N_{OS}}\right) \tag{1}$$

$$(k = \ldots, -2, -1, 0, 1, 2, \ldots)$$

$$\Delta t = \text{maxID}\left(P\left(\frac{k}{N_{OS}}\right)\right) - \frac{L}{2}. \tag{2}$$

Function $\text{maxID}(x(n))$ chooses the sample position of the maximum in sequence $x(n)$, constant L is data length of $d_h(n)$, and constant N_{OS} is the oversampling number. Δt means the time offset of data $d_h(n)$ and $R(n)$.

The logarithm of likelihood ratio (LLR) is calculated using synchronized data $d_h(n)$ and $R(n)$, as

$$B(n) = d_h(n)\frac{R(n)}{\text{mean}\left(\{\mathbf{R}\}\right)} \tag{3}$$

$$\{\mathbf{R}\} = R(1), R(2), R(3), \ldots, R(N). \tag{4}$$

Function $\text{mean}(\{\mathbf{x}\})$ defines the average of sequence $x(n)$. Conventional methods calculate LLR using $B(n)$ as the amplitude of the baseband signal.

The proposal soft decision method imposes a delay due to the synchronization of data $d_h(n)$ and $R(n)$. This delay is, however, not a problem because the frequency offset cycle of frequency offset transmitter diversity is longer than several dozen samples, thus several of the prior or next samples' RSSI values are not varying intensely. That means that when the synchronization delay occurs, the RSSI value of the sample point is close to adjacent samples' RSSI values, which well reflect the likelihood of the demodulated bits.

IV. SIMULATION

This section details simulation results. We start with synchronization error of data $d_h(n)$ and $R(n)$, then turn to the gain yielded by frequency offset transmitter diversity.

We evaluate two modulation/demodulation methods; $\pi/2$-shift DBPSK/Differential Detection and GFSK/Frequency detection, to confirm that the proposal supports various modulation/demodulation methods. Parameters other than modulation/detection are the same as listed in Table I.

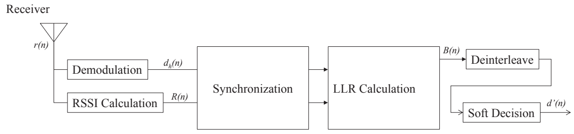

Fig. 3. Structure of the frequency offset transmitter diversity

A. Synchronization delay

Fig. 4 and 5 show the synchronization delay of the proposal synchronization method. The former is for $\pi/2$-shift DBPSK, and the latter for GFSK. Oversampling number N_{OS} is 8.

These graphs show that the synchronization delay decreases as the number of transmitter branches increases, because the channel power increases with the number of transmitter branches. Additionally, GFSK has lower synchronization delay than $\pi/2$-shift DBPSK. Fig. 6 describes the structure of $\pi/2$-shift DBPSK modulation and GFSK modulation. In the former, baseband signal $s_{BPSK}(n)$ passes through a root raised-cosine filter. Therefore, in the time domain, the amplitude of $t_{BPSK}(n)$ is suppressed; the square sum of the root raised-cosine filter's impulse response is 1. In the latter, on the other hand, Gaussian filtered signal $s_{GFSK}(n)$ passes through the filter before frequency modulation. Therefore, the amplitude of $t_{GFSK}(n)$ is constant in the time domain. For this reason, the proposed synchronization method with RSSI detection achieves shorter synchronization delay with GFSK than $\pi/2$-shift DBPSK.

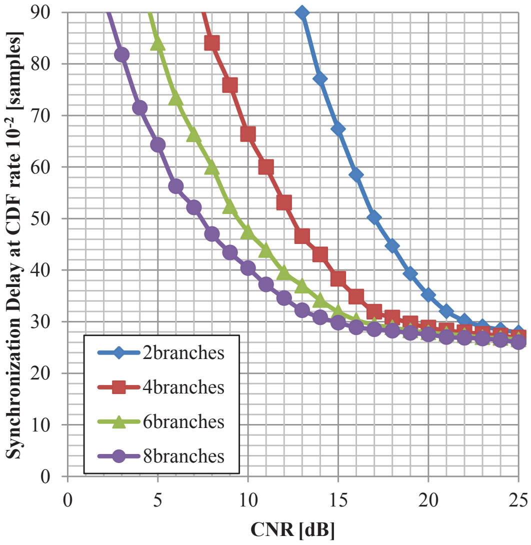

Fig. 4. Synchronization delay of $\pi/2$-shift DBPSK

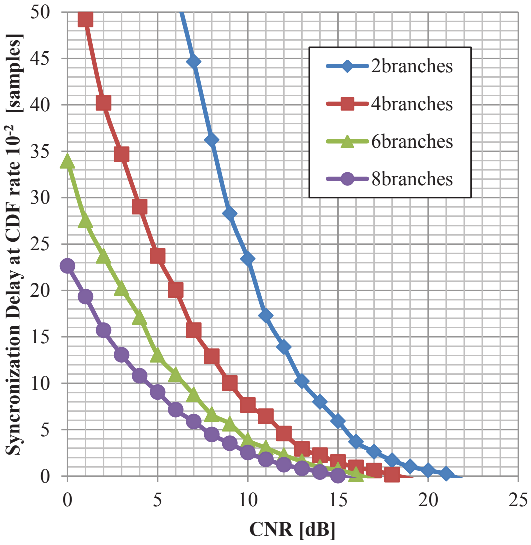

Fig. 5. Synchronization delay of GFSK

B. Gain of the proposed frequency offset transmitter diversity

Fig. 7 and 8 show the gain of the proposal frequency offset transmitter diversity with/without synchronization delay. For comparison, hard decision is shown with conventional soft decision. In GFSK, however, frequency detection is an inherently non-linear process, thus the LLR for a linear system like BPSK is not suitable [12].

These graphs show that the soft decision proposal with LLR based on RSSI is superior to hard decision for either $\pi/2$-shift DBPSK or GFSK. Furthermore, the soft decision proposal is tolerant of the synchronization delay, because the RSSI values of adjacent samples well reflect the likelihood of the demodulated bits.

In particular, the proposed soft decision method is effective for non-linear systems like GFSK, which can not use the LLR of a linear system. In frequency offset transmitter diversity, the amplitude variation created by the frequency offset has a much greater impact than the noise, thus our proposal, LLR based on RSSI, is superior to hard decision.

Furthermore, $\pi/2$-shift DBPSK's and GFSK's PER degradation in flat fading channels is about 15 dB larger than that

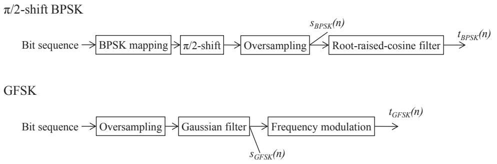

Fig. 6. Structure of modulation

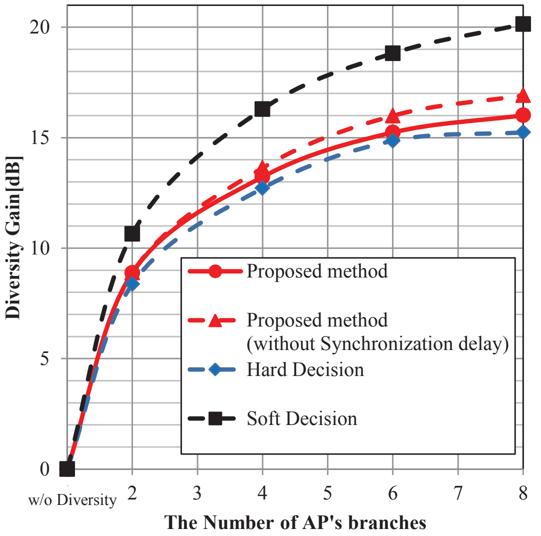

Fig. 7. Frequency offset transmitter diversity gain of $\pi/2$-shift DBPSK

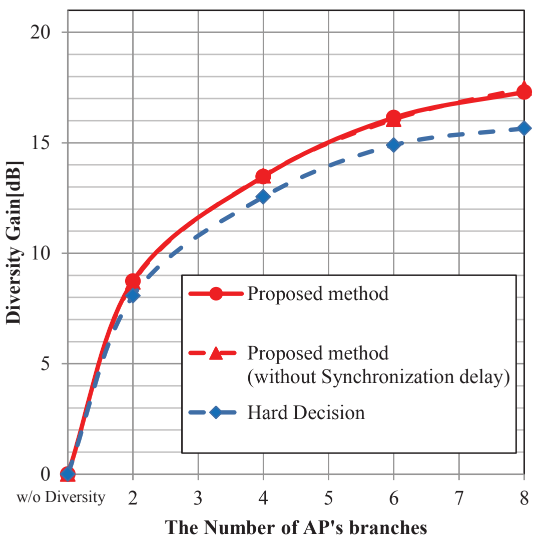

Fig. 8. Frequency offset transmitter diversity gain of GFSK

in AWGN channels [6], [11], [13], Fig. 7 and 8 show that the proposed method offers diversity gain of more than 15 dB with 6 branches, and so can effectively compensate fading degradation.

V. CONCLUSION

In this paper, we proposed a frequency offset transmitter diversity method with Viterbi algorithm that applies soft decision using RSSI that is calculated by an external circuit. Simulations showed the time synchronization delay and the gain of the frequency offset diversity. The proposed method supports various modulation and demodulation methods since $\pi/2$-shift DBPSK and GFSK yielded the same diversity gain. In particular, the proposal can improve the diversity gain even if detection does not apply the soft decision algorithm because of the non-linear circuit like frequency detection of GFSK. Simulations indicated the gain of the proposal even when synchronization delay is considered.

REFERENCES

[1] NGMN Alliance, “NGMN 5G White Paper,” February 2015.

[2] 3GPP, [Online]. Available: http://www.3gpp.org/

[3] The Association of Radio Industries and Businesses (ARIB), “920MHz-BAND TELEMETER, TELECONTROL AND DATA TRANSMISSION RADIO EQUIPMENT,” ARIB STD-T108, February 2012.

[4] Zigbee Alliance, [Online]. Available: http://www.zigbee.org/

[5] Wi-SUN Alliance, [Online]. Available: http://www.wi-sun.org/

[6] Y. Akaiwa. “Introduction to Digital Mobile Communication,” Wiley-Interscience, January 1997.

[7] Y. Fujino, S. Kuwano, S Ohmori, T Fujita, and S. Yoshino, “Cell Range Extension Techniques for Wide-Area Ubiquitous Network,” ISADS2011, March 2011, pp. 35–40.

[8] IEEE 802.15.4-2003, “Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs),” October 2003.

[9] IEEE 802.15.4g, “Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs) Amendment 3: Physical Layer (PHY) Specifications for Low-Data-Rate, Wireless, Smart Metering Utility Networks,” April 2012.

[10] S. Ogose, K. Murota, K. Hirade, “A Transmitter Diversity for MSK with Two-Bit Differential Detection,” IEEE Transactions on Vehicular Technology, vol. VT–33, No. 1, February 1984, pp. 37–43.

[11] B. P. Lathi, “Modern Digital and Analog Communications Systems,” Oxford Univ Pr (Sd), March 1998.

[12] D. Nojima, Y. Nagao, M. Kurosaki, H. Ochi, A. Ishikawa, S. Fukagawa, and A. Tahira, “Soft Decision Viterbi Decoder for FSK Demodulation Under Fast Fading Channel,” ICCE2010, August 2010, pp. 222–227.

[13] J. G. Proakis, “Digital communications,” McGraw-Hill Science/Engineering/Math, August 2000.