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A Spectral and Energy Efficiency of Adaptive Modulation (AM) with Power Control in Wireless Sensor Network

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***Abstract*— This paper presents a combination of power control and adaptive modulation performance in wireless sensor networks (WSN). WSN comprised numerous smart and small sensor nodes with limited power, memory, and processing. Furthermore, there is an impairment wireless channel between the sensor node and the coordinator node. Energy and spectral efficiency are essential issues in WSN. These two targets can be reached by applying a combination of power control and adaptive modulation. This work proposes a power control system to determine the modulation level through feedback SNR value of instantaneous wireless channel condition. The modulation level continuously changed based on the wireless channel condition. This adaptive modulation increases spectral efficiency. A better channel condition will drive to switch into a higher modulation level and vice versa. The result shows that the existence of power control can increase by about 9% of spectral efficiency than a system without power control. The system without power control just has a 91 % of selection probability, while the system equipped with power control creates a 100 % selection probability at the same of modulation level (16 QAM). Besides, combining power control with adaptive modulation also adjusts transmitting power at sensor nodes so that the effective use of transmitting power at the sensor node can be achieved. Combining power control and adaptive modulation can decrease the power consumption, enlarge the spectral efficiency with specific target bit error rate (BER), reduce the interference level, and significantly improve the WSN system performance.**

***Keywords*— adaptive modulation; power control; wireless sensor network; spectral efficiency; energy efficiency.**

I. INTRODUCTION

Wireless sensor networks (WSN) have attracted research attention. It has become a potential research topic in wireless communication. It was considered as one of the most prominent technologies due to characteristics, fault tolerance, cost-effectiveness, easy deployment, scalability, flexibility, and self-organizing capabilities. WSN are usefully deployed in many different fields such as structural health monitoring, home automation, agricultural monitoring, healthcare monitoring, environmental controlling, intelligent transportation system, etc. They were comprised of numerous intelligent and small sensors node equipped with limited power transmitting, routing capability, and wireless radio communication capabilities. Generally, WSN is deployed in complex environments, which are less human activities. These sensor nodes gather an amount of information about the surrounding environment through wireless transmissions such as temperature, pressure, humidity, images, and noise [1], [2]. A battery with limited capacities powers sensors. Wireless sensor networks applications operate in a long operating lifetime; improving spectral & energy efficiency is an important aspect. The specific character of sensor nodes is severe energy constraints. The limited energy in the sensor node will affect the wireless coverage of sensors, data rate transfer, bit error rate (BER) of wireless communication, and computational capabilities. There is a tradeoff between limited energy-usage and quality of service (QoS) in wireless sensor communication. Reducing power consumption, i.e., transmit power, under spectral & energy constraint, thus poses the main challenge in wireless sensor networks. The low transmitting power sensitively leads to error information in wireless transmission because of attenuation, interference, fading, and noise in the wireless channel. The impairment of wireless channel degrades the reliability and quality link of the network system.

Furthermore, data rate transfer is also reduced by the impairment channel. Limitation of sensor nodes (energy and computational constraints) and impairment of wireless channel drive to develop a technique that counters the effects and improves the bit error rate and data rate transfer level in networks system. Modulation and coding channel techniques are mostly selected to combat the impairment of channel and increase the energy efficiency in sensor nodes. The level modulation and code rate of channel coding adapt to the wireless channel quality changes. It is usually called an adaptive modulation and coding (AMC) system [3]. Level modulation considers many bit per symbol; higher-level modulation can transfer more bits per symbol and vice versa. The level modulation is continuously adapted based on the changing of wireless link quality. Besides, the code rate of channel coding defines an error detection-correction and bandwidth efficiency. Higher code rate means that the channel coding has good bandwidth efficiency and weak error detection-correction. In contrast, lower code rate channel coding produces good error detection-correction and weak bandwidth efficiency.

Various previous studies [4] investigate the power consumption level that is affected by transmitting power allocation, number of sensor nodes in clustered WSN. Some studies explored a cross-layer approach to handle the transmission power consumption and maximizing both symbol error rate and throughput [5], [6]. The system uses adaptive modulation and channel gain estimated in the first layer/physical layer and various time slots in the MAC layer. Combining adaptive modulation and coding (AMC) in the physical layer and finite-length queuing in the data link layer was used to optimize average spectral efficiency, average throughput, and packet loss rate [7]. The improvement of the retransmission algorithm is based on network coding to get optimal retransmission number [8]. The quasi-cyclic FEC for detection and correction of burst errors is proposed to reduce the number of retransmission by knowing minimum distance among linear codes [9]. The performance of adaptive FEC was investigated in [10], it used various metrics such as a non-LOS (NLOS)/line of sight (LOS), signal to noise ratio (SNR) and acknowledgment (ACK)/non-ACK (NACK) to select an optimal FEC. Based on several works aforementioned, the main objectives are solving the effects of impairment channel, increase bit error rate, and data rate transfer rather than to maximize spectral and energy efficiency. Therefore, we propose a combination of adaptive modulation and power control in wireless sensor networks. The power control technique will directly affect to transmit power level to maximize spectral & energy efficiency efficiently. The coordinator node measures the link/channel quality of each sensor node that is expressed in the signal to noise ratio (SNIR. The SNR value represented the link/channel condition. It will be a fundamental parameter to determine the level of transmitting power in sensor nodes[11], [12]. Sensor nodes will transmit adaptively based on their channel condition. Optimal use of transmitting power minimizes interference to enhance capacity and conserves energy to maximize battery life.

II. Materials and Method

A. Adaptive Modulation

This proposed architecture is a hydroponic monitoring wireless sensor network. In this system, the sensor nodes can sense and transmit a vital environment and planting medium information in the greenhouse: e.g., humidity, temperature, pH, electro-conductivity (EC), etc. All information transmitted into the coordinator node as depicted in Fig.1. Considering limited power in the sensor nodes, wireless channel impairment, and error rate, as a consequence, we have to adjust adaptively transmit power in sensor node to increase the spectral & energy efficiency, reduce the interference and improve the bit error rate. Changing of modulation level and adaptive transmitting power are based on the link/channel quality when the link quality is better (high SNR). As a consequence, the transmit power will be reduced, and a higher modulation level is chosen. The lower modulation level and increased transmit power will be chosen when the worse link quality. A higher modulation level generates a higher transmission data rate. Besides, the distance between the coordinator node and the sensor nodes also affects the transmit power and modulation level, longer distance creates higher attenuation and vice versa.

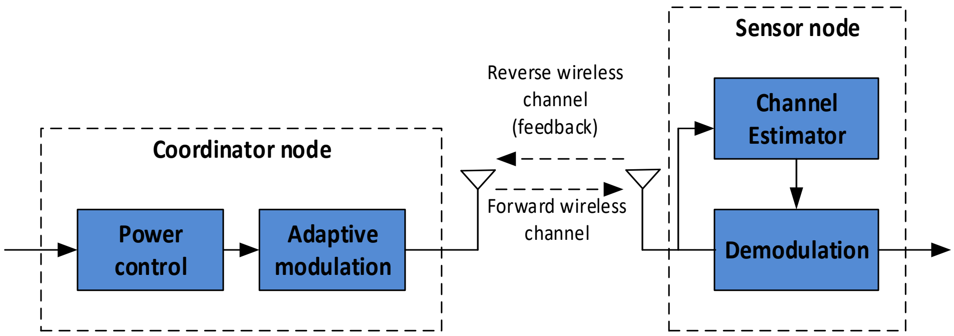

Fig. 1 A system model of combination power control and adaptive modulation

TABLE I
System Parameters

Parameter	Value
Frequency	2.4 GHz
Modulation	BPSK, QPSK, 8 PSK, 16 QAM
Code rate	3/4
Antenna	MIMO 2x2
Channel	Rayleigh fading

Rayleigh variable is generated by two random gaussian variables a_c and a_s with zero mean and σ^2variance, it is detailed in Fig.2 [13].

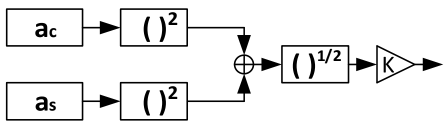

Fig. 2 Rayleigh distributed coefficient generator

The WSN system consists of the AMC and power control at the lowest layer (physical layer), the processing unit at the physical layer is a frame. Consequently, the AMC is adapted to a frame-by-frame unit. We assume there are n modulation/coding schemes (MCSs) provided at the physical layer. The number of MCS levels depend on the type of modulation instantaneous. Each MCS consists of a specific modulation and coding code pair. Some assumptions are used, the feedback channel is error-free, and the CSI using training-based channel estimation is assumed to be perfect. Based on the CSI, which is estimated by the channel estimator at the receiver and transmitted over the feedback channel, the AMC and power controller determines the transmit power and chooses the level of MCS. Then, the transmitter uses the chosen MCS to process the data frame and transmits the frame with the specific transmit power over the fading channel.

B. Signal to Noise Ratio and Bit Error Rate

The signal to noise ratio at the sensor node/receiver is SNR_{rx}, the coordinator node has a transmit power P_{tx}. The relation transmit power (P_{tx}) and signal to noise ratio (SNR) is formulated as follows [14]:

$$SNR_{rx} = \frac{P_{tx}}{N}\ x\ L \tag{1}$$

Where L is an accumulation of the channel attenuation and antenna gain both transmitter and receiver antenna, N is the noise power that is expressed as $N = N_0\ x\ R_{sx}$ with N_0 is the noise power density and R_{sx} is the transmission/transfer symbol rate which is denoted as $R_{sx} = \frac{R}{b}$ where b is modulation constellation level, and R is the transmission/transfer rate. Considering SNR, energy per bit (E_b), and transmission time per bit (T_b) are formulated as follows

$$SNR_{rx} = \frac{E_b}{N_0}\ x\ b \tag{2}$$

$$E_b = P_{tx}\ x\ T_b \text{ and } T_b = \frac{1}{R} \tag{3}$$

Therefore, the effective power transmitted with specific BER can be expressed as

$$\begin{aligned} P_t &= SNR_{rx}\ x\ N\ x\ \frac{1}{L} = SNR_{rx}\ x\ R_{sx}\ x\ \frac{N_0}{L} \\ &= R_s\ x\ b\ x\ \frac{N_0}{L}\ x\ \frac{E_b}{N_0} \end{aligned} \tag{4}$$

The reciprocal relation between bit error rate (BER) and $\frac{E_b}{N_0}$ in for QPSK (quadrature phase-shift keying) is formulated as follows.

$$BER = \frac{1}{2}\ erfc\sqrt{\frac{E_b}{N_0}} \tag{5}$$

$$\frac{E_b}{N_0} = [erfc^{-1}\ (2\ x\ BER)]^2 \tag{6}$$

Hence, the transmit power can be expressed as $P_{tx} = R_s\ x\ b\ \left(\frac{N_0}{L}\right)\ [erfc^{-1}\ (2\ x\ BER)]^2$.

Fig.1 shows a system model of power control and adaptive modulation address to increase data rate and effective transmit power. Adaptive modulation and power control system using the received SNR to adjust the transmission parameter. In this work, we use a specific modulation level, i.e., QPSK, 8PSK, and 16 QAM. Channel state information (CSI) is estimated in a sensor node that is sent back to the coordinator node through a feedback channel. The adaptive modulation controller selected modulation level and transmit power level based on this CSI. Based on [8], $\frac{N_0}{2}$ is the noise density, $\bar{E}$ denotes the transmission power, $\bar{g}$ expresses an average channel gain than assumed $\bar{g}$ = 1, B is signal bandwidth. Instantaneous SNR at the time (t) in a sensor node is $\beta(t) = \frac{\bar{E}g(t)}{N} = \frac{\bar{E}g(t)}{N_0\ B}$ and average SNR is $\bar{\beta} = \frac{\bar{E}}{N_0\ B}$. Furthermore, instantaneous SNR can be expressed in function of power adaptation $E\big(\beta(t)\big)$, $\beta(t)\ \frac{E(\beta(t))}{\bar{E}}$. The probability density function of β is given by $P_\beta(\beta) = \frac{1}{\bar{\beta}} exp\left(-\frac{\beta}{\bar{\beta}}\right)$. Adjusting adaptively transmit power $E(\beta)$ as function of β with the objectives target BER and average power $\bar{E}$, the upper bound of BER in coherent M-QAM is

$$\begin{aligned} BER &\le 2\ exp\left(-\frac{1.5\beta}{M-1}\frac{E(\beta)}{\bar{E}}\right) \\ &= 2\ exp\left(-\frac{1.5\beta}{2^{b_j}-1}\frac{E(\beta)}{\bar{E}}\right) \end{aligned} \tag{7}$$

Modulation constellation level with specific BER can be denoted as

$$M(\beta) = 1 + \beta K\frac{E(\beta)}{\bar{E}}$$
$$\text{with } K = \begin{cases} K_1 = \frac{-1.5}{\ln(0.5BER_0)},\ j = 1 \\ K_2 = \frac{-1.5}{\ln(5BER_0)},\ j = 0,2,3,\dots,N \end{cases} \tag{8}$$

Maximizing spectral efficiency can be reached by optimizing

$$E[log_2 M(\beta)] = \int log_2\left(1 + K\beta\frac{E(\beta)}{\bar{E}}\right)P_\beta(\beta)\ d\beta \tag{9}$$

with the average transmit power constraint

$$\int_0^\infty E(\beta)P_\beta(\beta)d\beta = \bar{E} \tag{10}$$

Using the Lagrange method to find optimal power control that formulates as follows

$$\begin{aligned} J\big(E(\beta)\big) = &\int_0^\infty log_2\left(1 + K\beta\frac{E(\beta)}{\bar{E}}\right)P_\beta(\beta)d\beta \\ &+ \lambda\left(\int_0^\infty E(\beta)\ P_\beta(\beta)d\beta - \bar{E}\right) \end{aligned} \tag{11}$$

$$\frac{\partial J\big(E(\beta)\big)}{\partial E(\beta)} = \left[\left(\frac{1/\ln(2)}{1 + K\beta E(\beta)/\bar{E}}\right)\frac{K\beta}{\bar{E}} + \lambda\right]P_\beta(\beta) = 0 \tag{12}$$

From equation 11 and 12, we get optimal power control :

$$\frac{E(\beta)}{\bar{E}} = \frac{1}{-\lambda\bar{E}\ln(2)} - \frac{1}{\beta K} \tag{13}$$

$$\frac{E(\beta)}{\bar{E}} = \begin{cases} \frac{1}{\beta_0} - \frac{1}{\beta K}, \beta \geq \frac{\beta_0}{K} \\ 0, \quad \beta < \frac{\beta_0}{K} \end{cases}, \text{ with}$$
$$K = \begin{cases} K_1 = \frac{-1.5}{\ln(0.5BER_0)}, \; j = 1 \\ K_2 = \frac{-1.5}{\ln(5BER_0)}, \; j = 2,3, \ldots, N \end{cases} \tag{14}$$

with β_0 is cutoff value, when β is large, means the link/channel quality is good, and consequently, the sensor nodes transmit higher power. Reversely, small β means the link/channel is worse, so the transmit power is reduced. The modulation constellation level also can be determined by received SNR.

$$M(\beta) = \frac{\beta}{\beta_0/K} \tag{15}$$

Received SNR assign the modulation constellation level by adjusting the threshold by the equation :

$$\beta_j = \frac{M_j\beta_0}{K} \text{ ,with } K = \begin{cases} K_1 = \frac{-1.5}{\ln(0.5BER_0)}, \; j = 1 \\ K_2 = \frac{-1.5}{\ln(5BER_0)}, \; j = 2,3, \ldots, N \end{cases} \tag{16}$$

The relationship between power control, transmit power, and modulation constellation level with specific BER can be described as follows:

$$\frac{E_j(\beta)}{\bar{E}} = \begin{cases} (M_j - 1)\frac{1}{\beta K}, & \frac{M_j\beta_0}{K} \leq \beta < \frac{M_{j+1}\beta_0}{K} \\ 0 & M_j = 0 \end{cases} \text{ with } K = \begin{cases} K_1 = \frac{-1.5}{\ln(0.5BER_0)}, \; j = 1 \\ K_2 = \frac{-1.5}{\ln(5BER_0)}, \; j = 2,3, \ldots, N \end{cases} \tag{17}$$

III. Results and Discussion

In this section, we analyze the role of power control to determine adaptively transmit power and adaptive modulation scheme according to the feedback SNR at the receiver (sensor node). This SNR value represents the channel condition. The power control system makes that effective use of transmitting power is achieved and also triggers switching of the threshold of adaptive modulation, which is maximizing spectral efficiency. The optimization of modulation level and transmission power is jointly considered.

A. Cut Off Performance

We can calculate variable β_0 (cut off) as seen in Fig. 3. The switching threshold of modulation level is changing according to SNR varies. The relationship between SNR and modulation level can be described that when the transmitter system (coordinator node) receives good SNR so that the user (sensor node) switches to the higher modulation level. The lower SNR generates a lower modulation system.

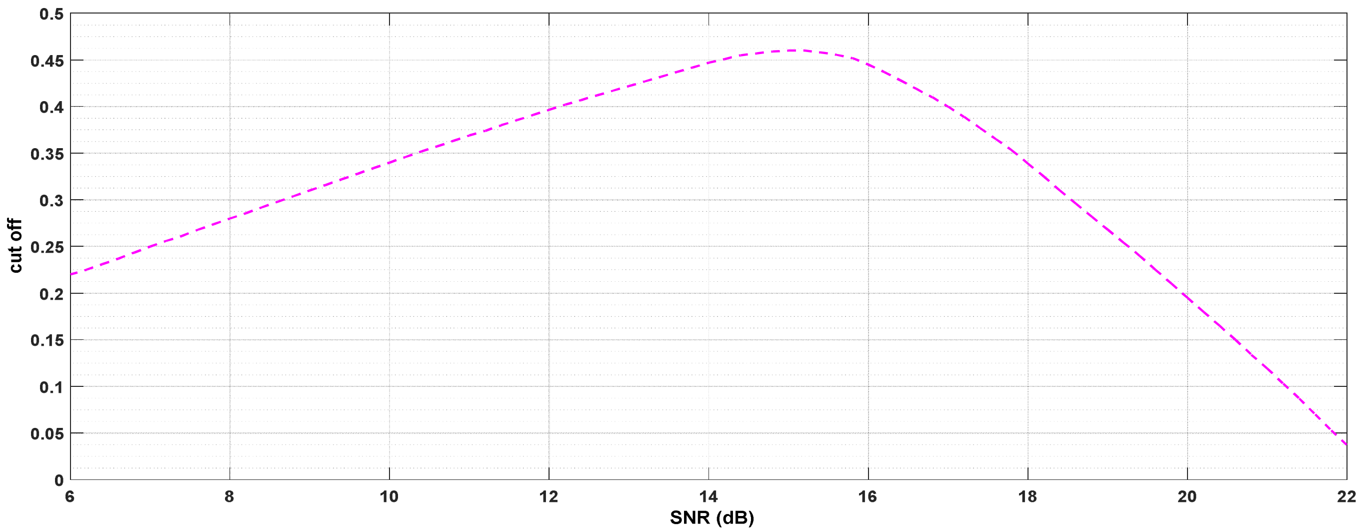

Fig. 3 SNR and cut off (β_0)

B. Adaptive Modulation Threshold and Bit Error Rate

Based on Fig. 4, the results show that the shifting threshold of adaptive modulation without power control is affected by the SNR level. The threshold of modulation BPSK, QPSK, 8PSK, 16QAM are 7.52 dB, 10.31 dB, 18.4 dB, 20.5 dB, respectively. When SNR is higher so that the threshold will be shifted into a higher modulation level and vice versa. Higher modulation level has more bits per symbol, as a consequence that the data rate is faster. Fig. 5 depicts the bit error rate performance based on variation modulation level. Higher modulation level needs more SNR in specific target BER and yields worse BER in specific target SNR. However, a higher modulation level has higher spectral efficiency.

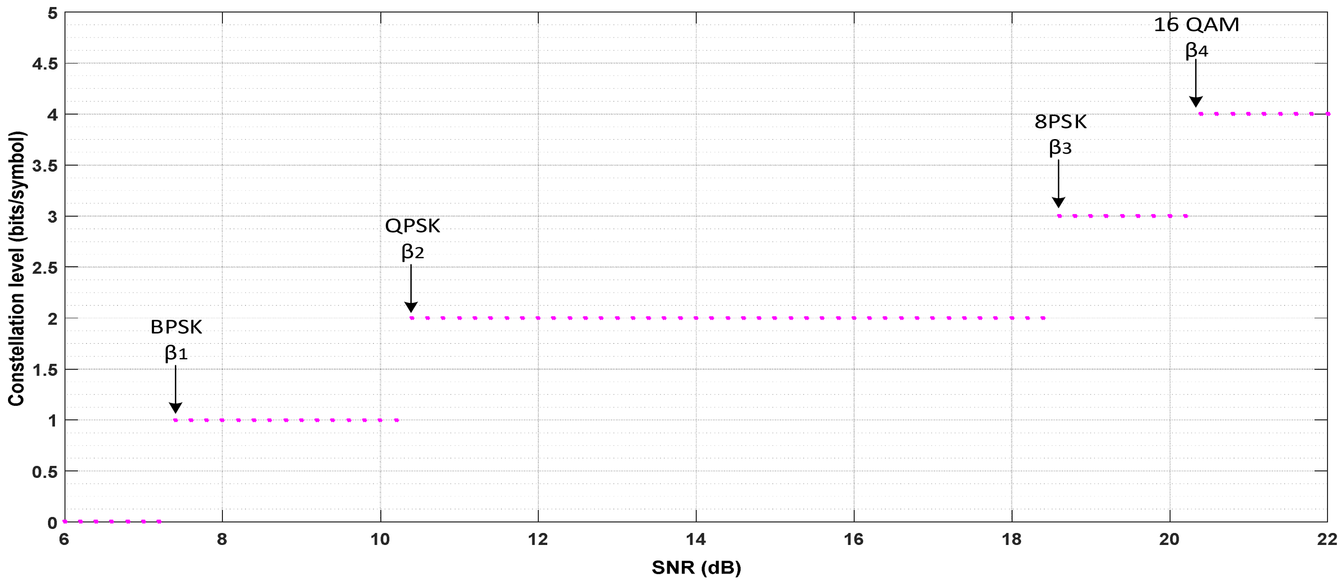

Fig.4 Adaptive modulation threshold without power control in BER 5 x 10^{-3}

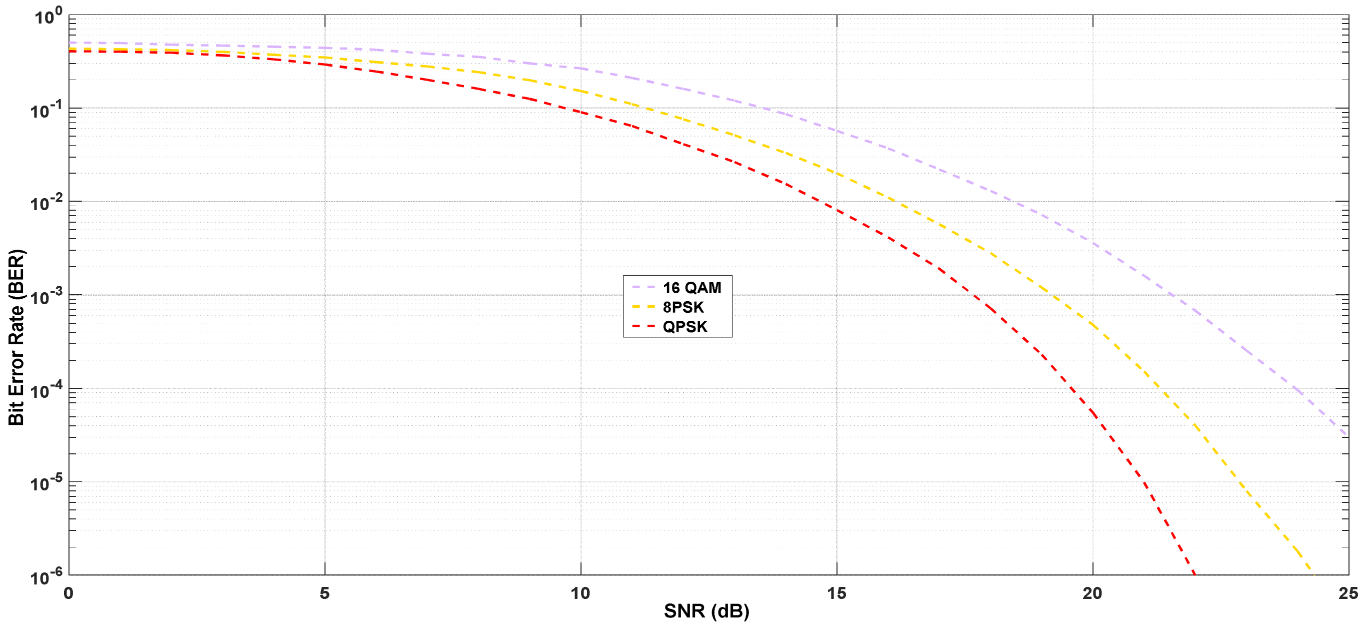

Fig.5 Performance of bit error rate

C. Selection Probability

Fig. 6 and Fig. 7 provide a description of the difference in modulation level selection probability with power control and without power control. Adaptive modulation with control power changes the threshold modulation level and adjusts the transmit power according to the link/channel condition that as expressed in SNR at the receiver. Adjusting the transmit power gives more accurate used power, making lower power consumption, reducing interference, and achieving optimal spectral efficiency. The system will require to reduce the transmit power and switch to lower modulation levels when the instantaneous link/channel condition is bad (lower SNR). Reversely, increasing the transmit power and higher modulation level will be chosen when the link/channel condition is good (high SNR). A higher modulation level that has more bits per symbol in good link/channel condition yields maximal spectral efficiency.

Meanwhile, the power control system will adjust adaptively the transmit power so that the efficient use of power is achieved. Based on the results in Fig. 6 and Fig. 7, we categorize three regions of SNR: low SNR region covers 0 – 6 dB, medium SNR region includes 6 – 12 dB, and high SNR region covers 12 – 18 dB. Low SNR region dominantly occupied by lower modulation level, i.e., QPSK and 8PSK. In the medium SNR region, the selection probability of a lower modulation level is decreased, and a higher modulation level initially rises. Last, the selection probability of higher modulation level (16 QAM) outperforms in the high SNR region. Performance comparison between power control and non-power control system is clearly depicted in Fig. 6 and Fig. 7, particularly at the higher SNR region, there is a significantly changing of

16 QAM performance. When the system without power control with 16 QAM only has about 91% probability of being used at high SNR region while the system using power control that the 16 QAM reaches 100% probability to be selected in the high SNR region. Performance improving from 91 % to be 100% probability means that spectral efficiency is increasing, and maximal capacity is achieved.

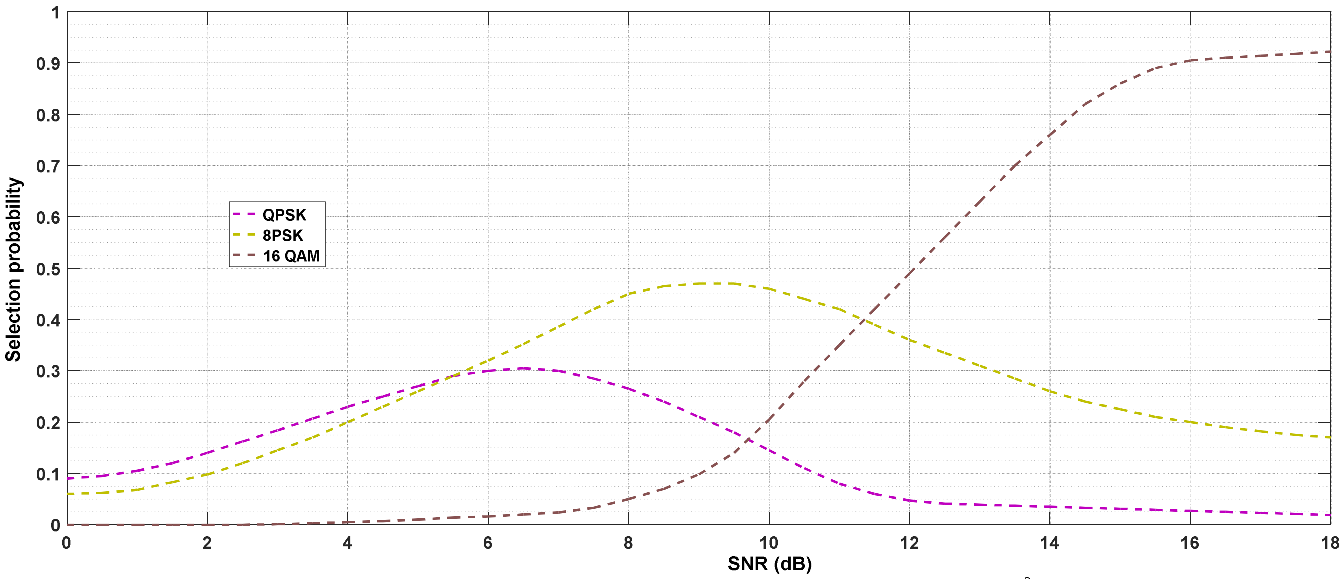

Fig. 6 Selection probability of modulation level without power control (BER 5 x 10^{-3})

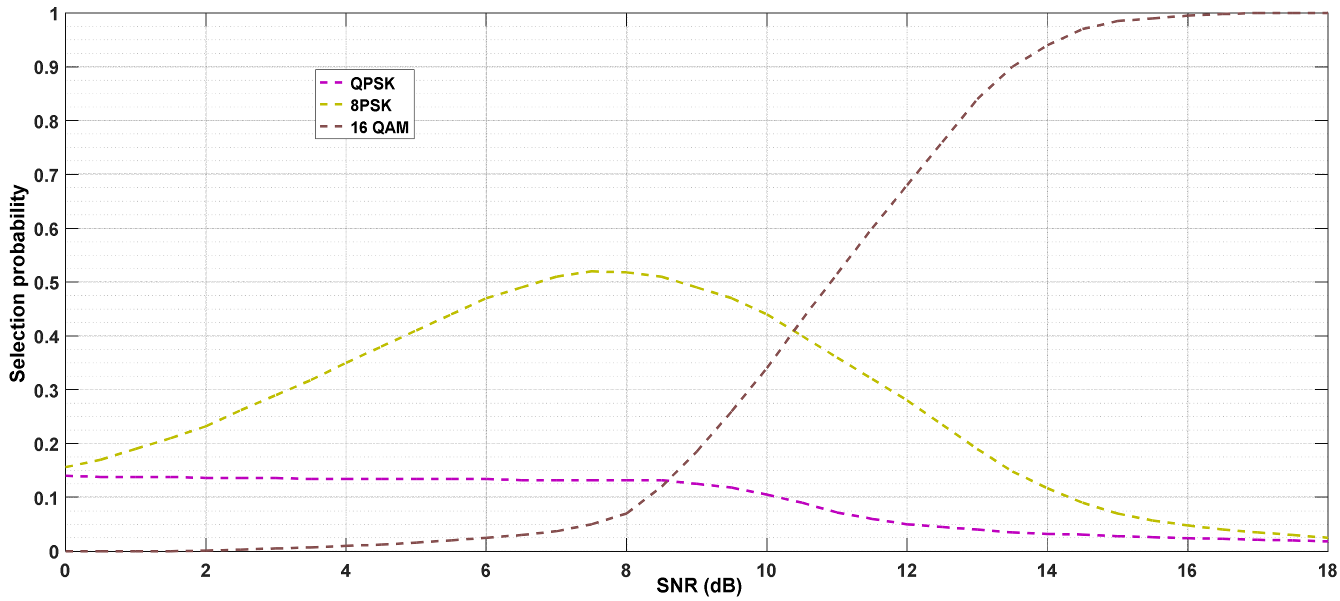

Fig. 7 Selection probability of modulation level with power control (BER 5 x 10^{-3})

D. Utility System

Fig. 8 explains that higher utility needs higher SNR. Besides, in this simulation, we use the multiple-input multiple-output (MIMO) 2 x 2 system (2 transmit antennas and 2 receive antennas). Using MIMO system generates an advantage in terms of spatial multiplexing that will be increasing the data rate transfer [15]. Based on Fig. 8, the higher modulation level (16 QAM) dominantly performs in higher SNR. Conversely, lower modulation level (QPSK) works in lower SNR. Changing the SNR value indicates a wireless channel fluctuation. Higher SNR means better link/channel condition while lower SNR denotes worse link/channel condition. This SNR value will be transformed to be channel state information (CSI) that to be a basic criterion in the power control system. The power control system instructs the user to add or reduce the transmit power through CSI. The user will adjust adaptively their transmit power according to SNR, the transmit power is very efficient and interference limited.

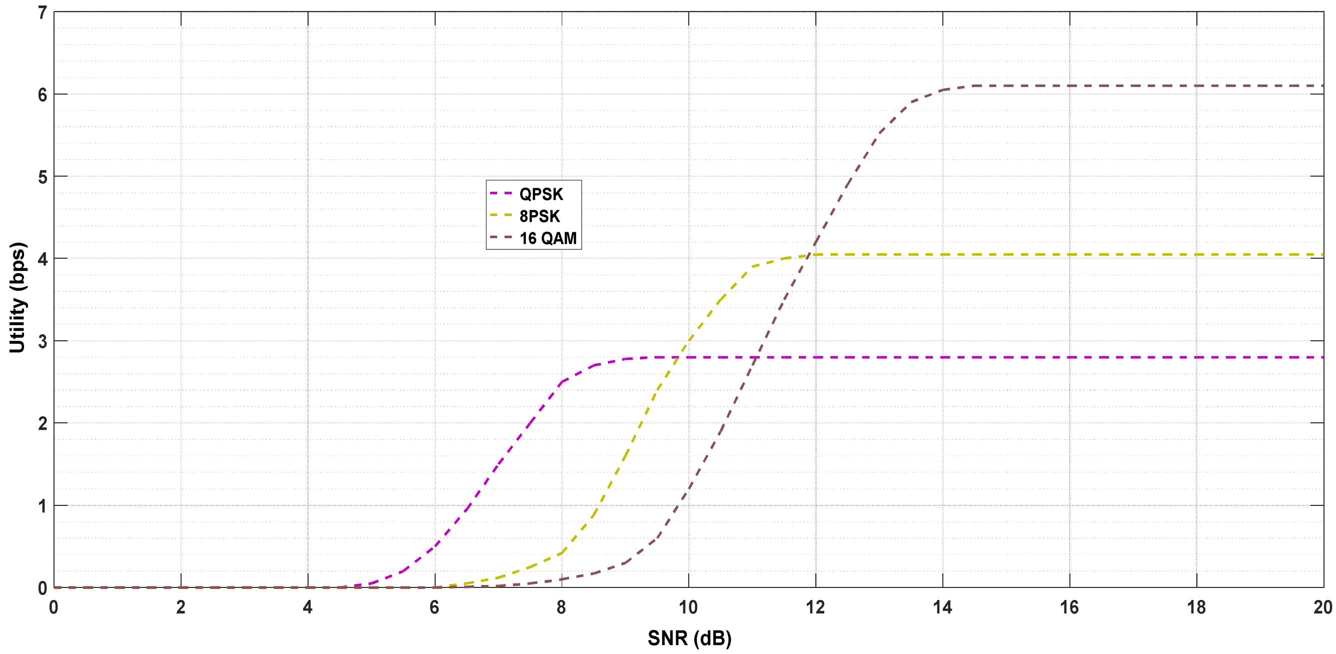

Fig. 8 Utility system with a variety of modulation level in 2x2 MIMO (BER 5 x 10^{-3})

IV. Conclusions

This work focuses on energy and spectral efficiency issues in WSN. The coordinator sensor will accept a channel state information (CSI) that this information to be a base parameter to determine the modulation level and the transmitting power at the sensor node. CSI contains SNR information on the instantaneous wireless channel. Higher SNR means a better wireless channel condition and needs low transmitting power at the sensor node. Conversely, lower SNR means that the sensor node needs a higher transmitting power to compensate for the worse wireless channel condition. Besides, higher SNR drives higher modulation levels which have more spectral efficiency. Based on the result, the existence of power control gives about 9% improvement of spectral efficiency (16 QAM). Power control also helps to increase the utility system; a higher modulation level generates a better utility system. Combining power control and adaptive modulation reduce power consumption, increase spectral efficiency, and extend the lifetime of the sensor node.

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References

[1] H.I. Kobo, A. M. A. Mahfouz, and G. P. Hancke, “A Survey on Software-Defined Wireless Sensor Networks: Challenges and Design Requirements,” *IEEE Access*, vol. 5, pp. 1872-1899, Feb. 2017.

[2] D. S. Kim, B. J. Chung, and S. Y. Son, “Implementation of a Low-Cost Energy and Environment Monitoring System Based on a Hybrid Wireless Sensor Network,” *Journal of Sensors*, vol. 2017, pp. 1-11, Jul. 2017.

[3] R. Zeng, T. Liu, X. T. Yu, and Z. Zhang, “Novel Channel Quality Indicator Prediction Scheme for Adaptive Modulation and Coding in High Mobility Environments,” *IEEE Access*, vol. 7, pp. 11543-11553, Jan. 2019.

[4] J. Zhang and R. Yan, “Centralized Energy-Efficient Clustering Routing Protocol for Mobile Nodes in Wireless Sensor Networks,” *IEEE Communications Letters*, vol. 23, no. 7, pp. 1215-1218, May 2019.

[5] K. Li, W. Ni, L. Duan, M. Abolhasan, and J. Niu, “Wireless Power Transfer and Data Collection in Wireless Sensor Networks,” *IEEE Transactions on Vehicular Technology*, vol. 67, no. 3, pp. 2686-2697, Mar. 2018.

[6] B. Jan, H. Farman, H. Javed, B. Montrucchio, M. Khan and S. Ali, “Energy Efficient Hierarchical Clustering Approaches in Wireless Sensor Networks: A Survey,” *Journal Wireless Communications and Mobile Computing*, vol. 2017, pp.1-14, Oct. 2017.

[7] I. Ez-zazi, M. Arioua, A. El Oualkadi, and P. Lorenz, “On The Performance of Adaptive Coding Schemes for Energy Efficient and Reliable Clustered Wireless Sensor Networks,” *Ad Hoc Networks*, vol. 64, pp. 99-111, Sept. 2017.

[8] M. A. M. Hassanien, P. Loskot, S. M. Al-Shehri, T. Numanoğlu, and M. Mert, “Design and Performance Evaluation of Bitwise Retransmission Schemes in Wireless Sensor Networks,” *Physical Communication*, vol. 37, pp. 1-15, Dec. 2019.

[9] P. Kaythry and K. Rajendiran, “Energy Efficient Quasi Cyclic FEC for Wireless Sensor Networks,” *Applied Mathematics & Information Sciences*, vol. 11, no. 6, pp.1815-1824, Nov. 2017.

[10] M. Kang, D. K. Noh, and I. Yoon, “Energy-Aware Control of Error Correction Rate for Solar-Powered Wireless Sensor Networks,” *Sensors*, vol. 18, no. 8, pp. 1-18, Aug. 2018.

[11] W. Jiao, H. Ding, H. Wu, and G. Yu, “Spectrum Efficiency of Jointing Adaptive Modulation Coding and Truncated ARQ With QoS Constraints,” *IEEE Access*, vol. 6, pp. 46915-46925, Aug. 2018.

[12] H. Teng, X. Liu, A. Liu, H. Shen, C. Huang, and T. Wang, “Adaptive Transmission Power Control for Reliable Data Forwarding in Sensor Based Networks,” *Wireless Communications and Mobile Computing*, vol. 2018, pp.1-22, Mar. 2018.

[13] S. Pramono and Sugihartono, “Three, Four Transmit Antennas Space Time Block Coded MIMO in Rayleigh Fading Channel: Performance Results,” in *Proc.* International Conference on System Engineering and Technology, Sept. 2012, pp.1-4.

[14] S. Ganesh, and R. Amutha, “Efficient and Secure Routing Protocol for Wireless Sensor Networks through Optimal Power Control and Optimal Handoff-Based Recovery Mechanism,” *Journal of Computer Networks and Communications*, vol. 2012, pp.1-8, Aug. 2012.

[15] R. Muthalagu, “Transceiver Design for MIMO Systems with Individual Transmit Power Constraints,” *International Journal of Electrical and Computer Engineering*, vol. 8, no. 3, pp.1583-1595, Jun. 2018.