Energy Efficient Layered Broadcast/Multicast Mechanism in Green 4G wireless networks

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***Abstract*—Layered broadcast/multicast mechanism is a promising method to provide energy efficient and reliable services for users with diverse fading channels in Green 4G wireless networks, however, there is a great challenge to determine the optimal modulation parameters in applications due to the varying wireless environment and the technique characteristics. In this work, an Energy efficient Layered Broadcast/Multicast (ELBM) mechanism is proposed to solve this problem in a Nakagami-m fading channel. With consideration of both the efficiency and reliability, an energy efficiency evaluation function is formulated, and to facilitate the decision process of optimal modulation parameters, a modulation solution set is defined, which consists of limited number of optional modulation solutions and would be proved valid for achieving the optimal performance. Based on the modulation solution set, a layered modulation solution selection algorithm is illustrated to determine the optimal modulation parameters effectively. Numeric analysis is conducted to verify the proposed mechanism with comparing to conventional scheme, and the results demonstrate that ELBM mechanism could yield higher energy efficiency under different bit error rate (BER) targets and channel fading conditions.**

***Index Terms*—energy efficient, layered broadcast/multicast, green 4G wireless network**

I. Introduction

With the increasing demand for wireless communication services, the Information and Communication Technology (ICT) industry will produce more Green House Gas (GHG) emission than before, and this could comprises the great efforts committed by the entire society to mitigate the climate change globally. To alleviate the negative impact on GHG footprint of ICT sector, green 4G wireless networks needs to provide energy efficient and reliable transmission for all users [1].

Layered broadcast/multicast mechanism is a promising method to facilitate such a task. In layered broadcast/multicast mechanism, the data would be modulated into multiple layers[2], and the reliability and energy efficiency of the system would be improved with proper modulation parameters, namely the users with severe channel conditions could receive the lower layer(s) to maintain a reliable service, and the upper layer(s) would transmit extra information to users with better channel conditions to achieve higher energy efficiency. Moreover, layered broadcast/multicast mechanism could be directly implemented in green 4G wireless networks, and don't need other facilities such as relay nodes [3][4].

However, since the transmit power of upper layers will bring in a self-interference to lower layers, the power allocation plan would also impact on decoding the signal. Therefore, the calculation of optimal modulation parameters of layered broadcast/multicast mechanism is much more complicated than the non-layered modulation scheme, especially in multi-user scenario. Many related researches have been conducted on this issue. The optimal power allocation is investigated in [5] in single user case, and the minimum expected distortion will be achieved for a M-layer application in a M-state fading channel based on a recursive power allocation mechanism. In [6], a layered transmission approach is proposed in fading wiretap channels for single user, in which the information is encoded into multiple layers by employing superposition coding. Based on a proposed utility function, the focus in [7] is on optimizing the power allocation for layered transmission of broadcast service over Rayleigh fading channel. However, in these studies, the upper layers are assumed to be correctly received at fixed channel SNR thresholds, and the influence of power allocation is not considered. It should be mentioned that in [8] the relation between power allocation plans and corresponding channel SNR thresholds are considered, however, the power allocation scheme and channel SNR threshold are not solved simultaneously, and the discussion is only conducted in a single user situation. Moreover, in all these previous notions the transmission rate is evaluated theoretically based on Shannon theory, and the modulation schemes practically supported in applications are not discussed.

To provide layered broadcast/multicast services for multiple users in green 4G wireless networks, a practical method that could effectively determine the modulation parameters (or referred to as modulation solution), namely the modulation schemes supported in applications and corresponding power allocation plans for each layer, is very important and has not been illustrated yet to the best of our survey. Motivated by this, a practical Energy efficient Layered Broadcast/Multicast (ELBM) mechanism is proposed in this work. Firstly, after introducing the channel model, the energy efficiency evaluation function is defined with consideration of both the reliability and efficiency. Then, a modulation solution set is proposed, which contains limited number of optional modulation solutions, and it would be further proved valid for achieving the highest energy efficiency. After that, an effective layered modulation solution selection algorithm is illustrated to determine the optimal modulation parameters based on Markov decision process, and the numeric results prove that ELBM could yield superior performance than conventional mechanism under diverse Bit Error Rate (BER) targets and

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channel fading conditions.

The rest of the article is as organized as follows: section II introduces the channel fading channel characterized by Finite State Markov Channel (FSMC) model; section III illustrates the framework of the proposed Energy efficient Layered Broadcast/Multicast mechanism, and formulas the evaluation function of energy efficiency; section IV defines the modulation solution set, and proves it is valid to achieve the highest energy efficiency; section V illustrates a layered modulation solution selection algorithm based on Markov decision process to effectively determine the optimal modulation parameters; Numeric results is presented in section VI and the superior performance of the proposed ELBM is demonstrated and discussed; finally, section VII concludes the contribution of this work.

II. Channel Model

In this work, a common frame structure shown in Fig.1 is adopted, which contains N_{ts} time-slots and each time-slot consists of N_s modulated symbols. Usually the channel state information is available at the transmitter after one/multiple time-slot(s) in application, therefore, to capture the time variations in wireless channel between two adjacent modulated symbols, a Finite State Markov Channel (FSMC) model is utilized, as shown in Fig.2.

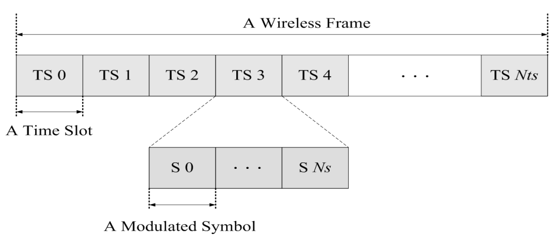

Fig. 1. Frame Structure

Let $S = \{s_0, s_1, ..., s_K\}$ denote the state space, corresponding to the boundary vector $[\gamma_0, \gamma_1, ..., \gamma_K, \gamma_{K+1}]$, and state s_j represents that receiver SNR is located in the range $[\gamma_j, \gamma_{j+1})$, $0 \leq j \leq K$. For the most conservative performance evaluation, state s_j would actually be assigned to γ_j in this work.

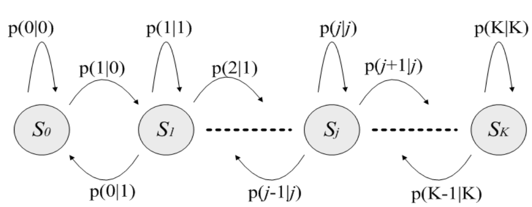

Fig. 2. Markov chain

Consider the same channel model as in [2], the steady-state probability of state s_j in a Nakagami-m fading channel could be calculated by [9]

$$p(s_j) = \frac{\Gamma(m, m\gamma_j/\bar{\gamma}) - \Gamma(m, m\gamma_{j+1}/\bar{\gamma})}{\Gamma(m)}, \tag{1}$$

where $\Gamma(m) = \int_0^\infty e^{-t} t^{m-1} dt$ is the gamma function, and $\Gamma(m, \alpha) = \int_0^\alpha e^{-t} t^{m-1} dt$ is the incomplete gamma function.

The level crossing rate of state s_j, which represents the expected number of times per second the received signal SNR γ passes across the given SNR γ_j in a positive (or negative) direction, could be expressed by [9]

$$N(s_j) = \sqrt{\frac{2\pi m \gamma_j}{\bar{\gamma}}} \frac{f_m}{\Gamma(m)} \left(\frac{m\gamma_j}{\bar{\gamma}}\right)^{m-1} \exp(-\frac{m\gamma_j}{\bar{\gamma}}) \tag{2}$$

where $f_m = v/\lambda_c$ is the maximum Doppler frequency for a receiver at speed v and wavelength λ_c.

Specifically assume the transitions only happen between adjacent states during the transmission of a symbol, and the state transition probability $P(s_j|s_i)$ could be approximated by

$$\begin{cases} p(s_{i+1}|s_i) = \dfrac{N(s_{j+1})T_s}{p(s_i)} \ , \quad p(s_{i-1}|s_i) = \dfrac{N(s_i)T_s}{p(s_i)} \ , \\ p(s_i|s_i) = 1 - p(s_{i+1}|s_i) - p(s_{i-1}|s_i) \ , \\ p(s_j|s_i) = 0 \ , \quad if |i-j| > 1 \end{cases} \tag{3}$$

where T_s is the time duration of a modulated symbol.

III. Proposed Layered Broadcast/Multicast Mechanism

A. Layered Broadcast/Modulation Mechanism

Layered broadcast/multicast mechanism is a promising method to provide energy efficient and reliable services for users with diverse fading channels in Green 4G wireless networks. At the transmitter, the input data will be divided into multiple layers and layered modulated based on the parameters provided by the ELBM algorithm; correspondingly, the receivers will decode the layered modulated symbols and try to recover as many layers of data as possible according to corresponding channel conditions, and the related channel state information would be estimated and feedback to transmitter for next time-slot.

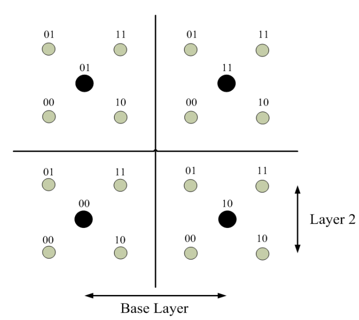

Fig. 3. Generalized 4/16-QAM constellation

As an example, a generalized layered 4/16-QAM constellation with Grey mapping is shown in Fig.3. The larger black circles stands for a fictitious 4-QAM constellation, represents the information of the layer 1 (or referred to as base layer), and the actual 16-QAM constellation denoted by gray symbols stands for the layer 2 (or referred to as upper layer).

To simplify the discussion, a two-layer ELBM mechansim is investigated in the following sections, however, the related conclusions could be also adapted to multiple-layer scenarios.

B. Definition of Modulation Solution

Assume X modulation schemes are supported in applications, and the transmit power could be freely allocated to each layer as needed with an overall power limit P_t. Let modulation-id set $A(m_1, m_2)$ stand for modulation-id m_1 and m_2, $m_1, m_2 \in [1, X]$, are adopted for layer 1 and layer 2, respectively.

Moreover, with specified power allocation plan, a modulation solution $M(m_1, m_2, P_1, P_2)$ could be defined, where P_1 and P_2 are the transmit power for layer 1 and layer 2, and it is obviously

$$P_t = P_1 + P_2 \tag{4}$$

It should be noticed that by setting $\{m_2 = 0, P_2 = 0\}$, the modulation solution $M(m_1, m_2, P_1, P_2)$ could also represents the non-layered modulation applications.

C. Evaluation function of Energy Efficiency

In non-layered modulation scenario, the receiver SNR at channel state s_k could be expressed by

$$\gamma_{s_k} = \frac{h_k^2 Pt}{N_0} \tag{5}$$

where h_k^2 is the channel power gain of s_k, and N_0 is the additive Gaussian white noise.

However, considering the self-interference of upper layer, the SINR of both layers of the received signal could be calculated by [5]

$$\gamma_{s_k}^1 = \frac{h_k^2 P_1}{h_k^2 P_2 + N_0}\ ,\quad \gamma_{s_k}^2 = \frac{h_k^2 P_2}{N_0} \tag{6}$$

To guarantee the reliability of wireless transmission, Bit Error Rate (BER) is widely recognized as an important QoS (Quality of Service) merit. Let ξ_l denote the BER target assigned for layer l, and the information of layer l would be identified as correctly received only if its BER target has been fulfilled. Moreover, because the upper layer signal would be decoded after canceling the transmit power of lower layer according to Eq.(6), a necessary condition for decoding upper layer is that the base layer is correctly received.

Therefore, if a modulation solution $M_s = M(m_1, m_2, P_1, P_2)$ is adopted at state s_k, the corresponding transmission rate, denoted by $R(M_s, s_k)$ (bits/second), could be calculated by

$$R(M_s, s_k) = \frac{1}{T_s} \sum_{l=1}^{2} r(m_l)(1 - f_e(m_l, \gamma_{s_k}^l))\Phi(l) \tag{7}$$

where T_s is the duration of a symbol, $f_e(m_l, \gamma_{s_k}^l)$ is the bit error rate of layer l with given modulation-id m_l and corresponding SINR $\gamma_{s_k}^l$ [2][10], $r(m_l)$ is the number of bits of a symbol of modulation-id m_l, $\Phi(l)$ represents if layer l, $l \in [1, 2]$, satisfies the BER constraints and it could be expressed by

$$\Phi(l) = \begin{cases} 1 * \prod_{j=1}^{l-1} \Phi(j), & if\ f_e(m_l, \gamma_{s_k}^l) \le \xi_l \\ 0, & if\ else \end{cases} \tag{8}$$

Since BER target is usually assigned strictly in applications (such as 10^{-3} or 10^{-6}), Eq.(7) could be approximated by

$$R(M_s, s_k) \approx \frac{1}{T_s} \sum_{l=1}^{2} r(m_l)\Phi(l) \tag{9}$$

Assume the adoption of ideal Nyquist signal pulses with a fixed symbol period $T_s = 1/B$ [11], the average spectral efficiency of M_s could be evaluated by Eq.(10). Moreover, to ensure the reliability of layered broadcast/multicast services for users with severe fading channel, a punishment gain P_g will be considered if a user failed to decode the base layer.

$$\begin{aligned} \eta(M_s, s_k) &= \frac{R(M_s, s_k)}{B} \\ &= \begin{cases} \sum_{l=1}^{2} r(m_l)\Phi(l), & if\ f_e(m_1, \gamma_{s_k}^l) \le \xi_1 \\ -P_g, & if\ else \end{cases} \end{aligned} \tag{10}$$

Therefore, the energy efficiency evaluation function (bits/J) of modulation solution M_s could be expressed by

$$\Lambda(M_s) = \frac{E(\eta(M_s))B_o}{P_t} \tag{11}$$

where B_o is the bandwidth utilized in transmission, $E(\eta(M_s))$ is the expectation of average spectral efficiency of all U users during all N_s symbols, and it could be calculated by

$$E(\eta(M_s)) = \sum_{u=1}^{U} \sum_{n=1}^{N_s} \frac{1}{UN_s} \eta(M_s, s_{u,n}) \tag{12}$$

where $s_{u,n}$ is the channel state of the u^{th} user during the n^{th} symbol.

IV. Proposed Modulation Solution Set

A. Enhanced Modulation Solution

For a specified modulation-id set $A_s = A(m_1, m_2)$, $m_1, m_2 \in [1, X]$, the channel SNR threshold of receiving both layer is impacted by the power allocation plan according to Eq.(6). In this case, denote the lowest channel SNR required to decode both layers by $\gamma^e(A_s)$, and define the corresponding modulation solution as the Enhanced Modulation Solution, denoted by $M_s^e(A_s) = M(m_1, m_2, P_1^e(A_s), P_2^e(A_s))$, which satisfies

$$\begin{cases} \gamma_{\gamma^e}^1(A_s) = \dfrac{P_1^e(A_s)}{P_2^e(A_s) + \frac{P_t}{\gamma^e(A_s)}}\ , & \gamma_{\gamma^e}^2(A_s) = P_2^e(A_s)\ \dfrac{\gamma_e(A_s)}{P_t} \\ \xi_1 = f_e(m_1, \gamma_{\gamma^e}^1(A_s))\ , & \xi_2 = f_e(m_2, \gamma_{\gamma^e}^2(A_s)) \\ P_t = P_1^e(A_s) + P_2^e(A_s) \end{cases} \tag{13}$$

where $\gamma_{\gamma^e}^1(A_s)$ and $\gamma_{\gamma^e}^2(A_s)$ are the SINR of layer 1 and layer 2 at channel SNR $\gamma_e(A_s)$, respectively.

By solving Eq.(13), the close-form equations of $\gamma^e(A_s)$ and power allocation plan $\{P_1^e(A_s), P_2^e(A_s)\}$ could be derived as

$$\begin{cases} P_1^e(A_s) = \dfrac{P_t g_e(\xi_1, m_1)}{1 + g_e(\xi_1, m_1)}(1 + \dfrac{1}{\gamma^e(A_s)}) \\ P_2^e(A_s) = \dfrac{P_t g_e(\xi_2, m_2)}{\gamma^e(A_s)} \\ \gamma^e(A_s) = g_e(\xi_1, m_1)(1 + g_e(\xi_2, m_2)) + g_e(\xi_2, m_2) \end{cases} \tag{14}$$

where $g_e(\xi_l, m_l)$ is the inverse function of $f_e(\bullet)$ to calculate the SINR of layer l when its BER is ξ_l and modulation-id is m_l.

B. Primary Modulation Solution

However, for state $s_k \le \gamma^e(A_s)$, it is obviously the user(s) might not be able to successfully receive both layers. In this case, to increase the chance of correctly decoding upper layer while ensure receiving the base layer, a Primary Modulation Solution $M_s^p(A_s, s_k) = M(m_1, m_2, P_1^p(A_s, s_k), P_2^p(A_s, s_k))$ is defined, which satisfies

$$\begin{cases} \gamma_{s_k}^1 = \dfrac{P_1^p(A_s, s_k) h_k^2}{P_2^p(A_s, s_k) h_k^2 + N_0}, \qquad f_e(m_1, \gamma_{s_k}^1) = \xi_1 \\ P_t = P_1^p(A_s, s_k) + P_2^p(A_s, s_k) \end{cases} \tag{15}$$

By solving Eq.(15), the close-form of corresponding parameters could be derived as

$$\begin{cases} P_1^p(A_s, s_k) = \dfrac{P_t g_e(\xi_1, m_1)}{1 + g_e(\xi_1, m_1)}(1 + \dfrac{1}{s_k}), \ iff_e(m_1, \gamma_{s_k}) \le \xi_1 \\ P_2^p(A_s, s_k) = P_t - P_1^p(A_s, s_k) \end{cases} \tag{16}$$

It should be noticed that when $s_k = \gamma^e(A_s)$, the Primary Modulation Solution $M_s^p(A_s, s_k)$ will be exactly the same with the Enhanced Modulation Solution $M_s^e(A_s)$; therefore, the Enhanced Modulation Solution could be considered as a special case of Primary Modulation Solution.

C. Modulation Solution Set

To facilitate the decision process of optimal modulation parameters, a modulation solution set M^o is defined in this work. The Modulation Solution Set consists of limited number of optional modulation solutions, and it could be determined according to the following procedure.

For each state s_k, $k \in [1, K]$, and each modulation-id set $A_s = A(m_1, m_2)$, $m_1, m_2 \in [1, X]$:

(1) if the Enhanced Modulation Solution $M_s^e(A_s)$ could be satisfied, namely $\gamma^e(A_s) \le s_k$, $M_s^e(A_s)$ would be added into M^o if it is not included yet;
(2) otherwise, the Primary Modulation Solution $M_s^p(A_s, s_k)$ would be added in to M^o if it is not included yet.

There are two important merits for the Primary Modulation Solutions of a modulation-id set $A_s = A(m_1, m_2)$, $\forall m_1, m_2 \in [1, X]$, as will be discussed in the following Lemmas.

Lemma 1: For any Primary Modulation Solutions $M_s^p(A_s, s_k)$ and $M_s^p(A_s, s_j)$, if $s_k \le s_j$, then $P_1^p(A_s, s_k) \ge P_1^p(A_s, s_j)$.

Proof: If $s_k \le s_j$, according to Eq.(5), we have

$$h_k^2 \le h_j^2 \tag{17}$$

where h_k^2 and h_j^2 are the channel power gain of state s_k and s_j, respectively.

Considering the definition of Primary Modulation Solution, the SNR thresholds for decoding layer 1 of $M_s^p(A_s, s_k)$ and $M_s^p(A_s, s_j)$ are s_k and s_j, respectively, namely

$$f_e(m_1, \gamma_{s_k}^1) = f_e(m_1, \gamma_{s_j}^1) = \xi_1 \tag{18}$$

Based on Eq.(6), it is obviously

$$\frac{h_k^2 P_1^p(A_s, s_k)}{h_k^2(P_t - P_1^p(A_s, s_k)) + N_0} = \frac{h_j^2 P_1^p(A_s, s_j)}{h_j^2(P_t - P_1^p(A_s, s_j)) + N_0} \tag{19}$$

Therefore, the *Lemma* 1 could be proved, since

$$P_1^p(A_s, s_k) = \frac{h_k^2 h_j^2 P_t + h_j^2 N_0}{h_k^2 h_j^2 P_t + h_k^2 N_0} P_1^p(A_s, s_j) \ge P_1^p(A_s, s_j) \tag{20}$$

Lemma 2: For any Primary Modulation Solutions $M_s^p(A_s, s_k)$ and $M_s^p(A_s, s_j)$, if $P_1^p(A_s, s_k) \le P_1^p(A_s, s_j)$, then $\Gamma_a \le \Gamma_b$, where Γ_a and Γ_b are the channel SNR threshold of decoding both layers of $M_s^p(A_s, s_k)$ and $M_s^p(A_s, s_j)$, respectively.

Proof: If $P_1^p(A_s, s_k) \le P_1^p(A_s, s_j)$, then

$$\begin{aligned} P_2^p(A_s, s_k) &= P_t - P_1^p(A_s, s_k) \\ &\ge P_t - P_1^p(A_s, s_j) = P_2^p(A_s, s_j) \end{aligned} \tag{21}$$

Considering the definition of Primary Modulation Solution, it is obviously

$$\begin{cases} f_e(m_1, \gamma_{\Gamma_a}^1) \le \xi_1 \\ f_e(m_1, \gamma_{\Gamma_b}^1) \le \xi_1 \end{cases} \tag{22}$$

$$f_e(m_2, \gamma_{\Gamma_a}^2) = f_e(m_2, \gamma_{\Gamma_b}^2) = \xi_2 \tag{23}$$

Based on Eq.(6) and Eq.(23), we have

$$\frac{h_a^2 P_2^p(A_s, s_k)}{N_0} = \frac{h_b^2 P_2^p(A_s, s_j)}{N_0} \tag{24}$$

where h_a^2 and h_b^2 are the channel power gain of channel SNR Γ_a and Γ_b, respectively.

By solving Eq.(24), h_a^2 could be expressed by

$$h_a^2 = \frac{P_2^p(A_s, s_j)}{P_2^p(A_s, s_k)} h_b^2 \le h_b^2 \tag{25}$$

Therefore, the *Lemma* 2 could proved, since

$$\Gamma_a = \frac{h_a^2 P_t}{N_0} \le \frac{h_b^2 P_t}{N_0} = \Gamma_b \tag{26}$$

Theorem: In a network provides layered broadcast/multicast services for U users and each time-slot contains N_s symbols, the modulation solution set M^o would be valid for achieving the highest energy efficiency, namely there will be at least one modulation solution $M_s \in M^o$ that could achieve the energy efficiency higher than or equal to any other modulation solutions (which might not be included in M^o).

Proof: Assume the modulation solution that could yield the highest energy efficiency is $M_s^\alpha = M(m_1, m_2, P_1^\alpha, P_2^\alpha)$, therefore the energy efficiency of adopting M_s^α could be expressed by

$$\Lambda(M_s^\alpha) = \frac{1}{P_t} \sum_{u=1}^{U} \sum_{n=1}^{N} \frac{1}{U N_s} \eta(M_s^\alpha, s_{u,n}) B_o \tag{27}$$

Denote the channel SNR threshold for decoding layer 1 and layer 2 of M_s^{α} by Γ_1^{α} and Γ_2^{α}, respectively, and it is obviously

$$\Gamma_1^{\alpha} \leq \Gamma_2^{\alpha} \tag{28}$$

Considering the definition of Primary Modulation Solution, M_s^{α} would be exactly the same with $M_s^p(A_s, \Gamma_1^{\alpha}) = M(A_s, P_1^p(A_s, \Gamma_1^{\alpha}), P_2^p(A_s, \Gamma_1^{\alpha}))$. Without loss of generality, assume $\Gamma_1^{\alpha} \in [s_{i-1}, s_i)$, and M_s^{α} would not be included in Modulation Solution Set M^o unless Γ_1^{α} equals to s_{i-1}.

In this case, select $M_s^{\beta} = M(m_1, m_2, P_1^p(A_s, s_i), P_1^p(A_s, s_i))$ from M^o, and denote the channel SNR threshold of decoding layer 2 of M_s^{β} by Γ_2^{β}. The energy efficiency of adopting M_s^{β} could be expressed by

$$\Lambda(M_s^{\beta}) = \frac{1}{P_t}\sum_{u=1}^{U}\sum_{n=1}^{N_s}\frac{1}{UN_s}\eta(M_s^{\beta}, s_{u,n})B_o \tag{29}$$

According to *Lemma* 1, if $\Gamma_1^{\alpha} \leq s_i$, then $P_1^{\alpha} \geq P_1^p(A_s, s_i)$, and according to *Lemma* 2, if $P_1^p(A_s, s_i) \leq P_1^{\alpha}$, then $\Gamma_2^{\beta} \leq \Gamma_2^{\alpha}$; therefore, the theorem, namely $\Lambda(M_s^{\beta}) \leq \Lambda(M_s^{\alpha})$, could be proved since

$$\begin{cases} \eta(M_s^{\beta}, s_{u,n}) = \sum_{l=1}^{2} r(m_l) \geq \eta(M^{\alpha}, s_{u,n}) & , if\, s_{u,n} \geq \Gamma_2^{\beta} \\ \eta(M_s^{\beta}, s_{u,n}) = r(m_1) = \eta(M^{\alpha}, s_{u,n}) & , if\, s_{u,n} \in [s_i, \Gamma_2^{\beta}) \\ \eta(M_s^{\beta}, s_{u,n}) = -Pg = \eta(M^{\alpha}, s_{u,n}) & , if\, s_{u,n} \leq s_{i-1} \end{cases} \tag{30}$$

V. Layered Modulation Solution Selection Algorithm

To determine the optimal modulation solution in a precise and efficient approach, a Layered Modulation Solution Selection Algorithm is proposed in this section based on Markov decision process. The modulation solution set M^o is adopted as the action set. Given the initial channel state vector $S^i = \{s_{1,1}, ..., s_{U,1}\}$ for all users, and let $\upsilon(s_{u,1})$ and $\Upsilon(S^i)$ denote the expected total reward of the u^{th} and all U user(s) during all N_s symbols, respectively, therefore the optimality equations could be expressed by [12]

$$\begin{cases} \Upsilon(S^i) = \max_{M_s \in M}\{\frac{1}{P_t}\sum_{u=1}^{U}\frac{1}{UN_s}\upsilon(s_{u,1})\} \\ \upsilon(s_{u,1}) = \eta(M_s, s_{u,1}) + \sum_{s_j \in S}\lambda p(s_j|s_{u,1})\upsilon(s_j) \end{cases} \tag{31}$$

where λ is the discount factor, and $\lambda \in [0, 1)$.

To solve Eq.(31), the value iteration algorithm (VIA) from [12] is adopted to determine the stationary deterministic optimal policy $\delta(S^i)$, which indicates the modulation solution to choose with specified S^i. The algorithm is described as follows

1. Select $\Upsilon^0(S^i) = 0$, and $\upsilon^0(s_{u,1})$, $\forall s_{u,1} \in S^i$. Specify $\varepsilon > 0$ and set $k = 0$.

2. For each $s_{u,1} \in S^i$, compute $\Upsilon^{k+1}(S^i)$ and $\upsilon^{k+1}(s_{u,1})$ by

$$\begin{cases} \Upsilon^{k+1}(S^i) = \sum_{u=1}^{U}\frac{1}{UN_s}\upsilon^{k+1}(s_{u,1}) \\ \upsilon^{k+1}(s_{u,1}) = \eta(M_s, s_{u,1}) + \lambda\sum_{s_j \in S} p(s_j|s_{u,1})\upsilon^k(s_j) \end{cases} \tag{32}$$

3. If $\|\Upsilon^{k+1}(S^i) - \Upsilon^k(S^i)\| < \varepsilon(1-\lambda)/2\lambda$, go to step 4. Otherwise, increment k by 1 and return to step 2.

4. Determine the stationary optimal policy

$$\delta(S^i) = arg\max_{M_s \in M^o}\sum_{u=1}^{U}\frac{1}{UN_s}\upsilon^{k+1}(s_{u,1}) \tag{33}$$

and stop.

VI. Numerical Results

In this section, the performance of the proposed Energy efficient Layered Broadcast/Multicast(ELBM) mechanism is evaluated and analyzed under different BER targets and channel fading conditions in Matlab environment. The numeric results is discussed with comparison to a conventional non-layered broadcast/multicast mechanism.

The transmit power P_t of base station is 43dBm, the bandwidth B is 20MHz, and the power spectral density of additive Gaussian White Noise is -174dBm/Hz, which are practical parameters in LTE networks. Without loss of generality, the same BER target ξ is set for both layers. Three representative wireless fading channels, namely fast fading channel(m = 0.5), medium fading channel(m = 0.7) and rayleigh fading channel(m = 1), are investigated in the analysis. The modulation schemes are selected from LTE standard, and there are 100 users in the system.

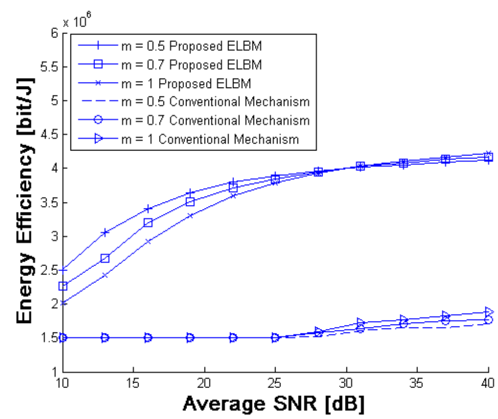

Fig. 4. Energy Efficiency at $\xi = 10^{-3}$

Comparing Fig.4 - Fig.7, it is obviously that the proposed work could achieve a general superior performance than non-layered broadcast/multicast mechanism under diverse BER targets. With stricter BER constraints, the system profits of both mechanisms are compromised because the network would select a more conservative modulation solution to ensure the reliability of the layered broadcast/multicast service provided. Especially, since more transmit power would be allocated to layer 1 to mitigate the self-interference of layer 2 in this situation, the proposed ELBM will suffer more impacts from the variation of BER target.

The influence of channel fading to the proposed ELBM is also evaluated in Fig.4 - Fig.7. The proposed ELBM would yield much higher performance than conventional mechanism

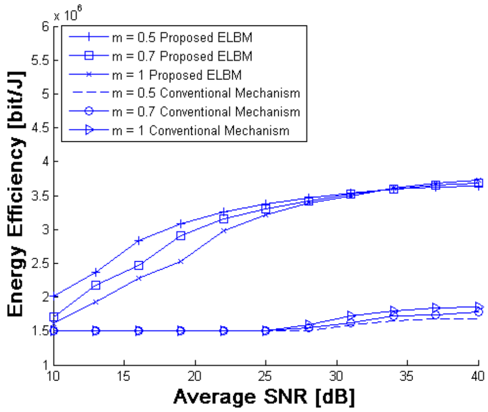

Fig. 5. Energy Efficiency at $\xi = 10^{-4}$

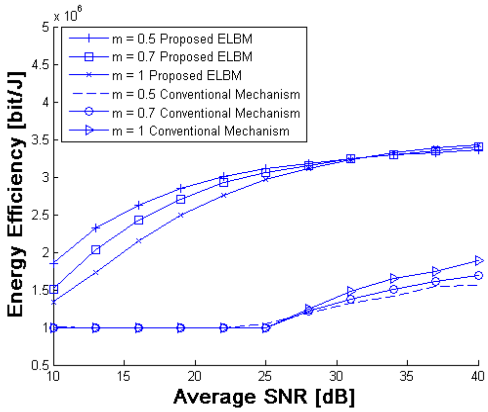

Fig. 6. Energy Efficiency at $\xi = 10^{-5}$

under various average channel SNR and channel fading parameter m, because the upper layer could be provide higher rates for users with good channel condition, while the base layer maintains a reliable transmission for users with severe fading channels. It is very interesting to notice that higher energy efficiency would be achieved when fading is faster (namely m is smaller) in the low average SNR regime, while the situation is quite the opposite when average SNR increases. Comparing with Rayleigh fading channel, the fast fading channels usually represent more dramatic channel SNR fluctuations, which will increase the probability of good channel condition when average SNR is low, and vice versa.

VII. Conclusion

In this work, a practical Energy efficient layered Broadcast/Multicast scheme is proposed for Green 4G wireless networks. First, an evaluation function of energy efficiency is defined with consideration of both the reliability and efficiency; then as a main contribution of this work, a modulation solution set is calculated, which contains limited number of modulation solutions and is proved valid for achieving the highest system performance; based on the modulation solution set, a layered modulation solution selection algorithm is illustrated to determine the optimal modulation parameters effectively. Numeric

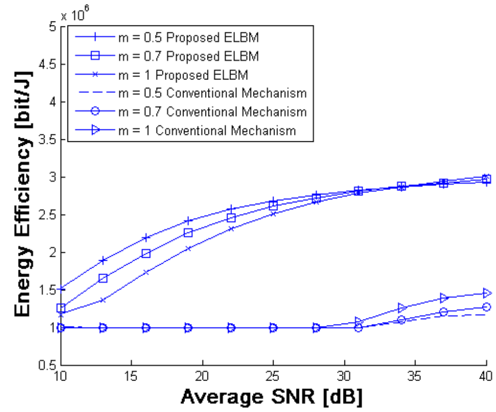

Fig. 7. Energy Efficiency at $\xi = 10^{-6}$

results prove that the proposed ELBM could achieve higher energy efficiency than conventional mechanism under diverse BER targets and channel fading conditions.

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