

A Fast Automatic Gain Control Scheme for Initial Cell Search in 3GPP LTE TDD System

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Abstract— In this paper, we propose a fast automatic gain control (AGC) scheme for initial cell search in long term evolution (LTE) time division duplex (TDD) system. Since the received signal has a large signal power difference between uplink and downlink in TDD systems, conventional AGC scheme leads to increased AGC gain variation and the received signal will be attenuated. In order to overcome this problem, we propose a modified AGC scheme based on the average amplitude ratio calculation which can not only effectively increase convergence speed of the AGC gain but also maintain the stability of AGC operation. Also, it is important for AGC to converge efficiently for the accurate radio frame timing detection during the subsequent initial cell search procedure. Therefore, we also consider the proposed AGC scheme in combination with primary synchronization signal (PSS) detection interface. By using extensive computer simulation in the presence of frequency offset and various channel environments, we show that the proposed method can obtain a good behavior in terms of convergence speed and PSS detection performance in LTE TDD system and verify that it is attractive and suitable for implementation with stable operation.

Keywords— AGC, LTE, FDD, TDD, initial cell search

I. INTRODUCTION

In wireless communication systems such as LTE, the received signal has an unpredictable signal power and varies over a wide dynamic range caused by multi-path fading channel and unwanted signals such as strong interferer signal. Therefore, an AGC is necessary for dynamically adjusting the AGC gain of the incoming signal to prevent the quantization error or saturation at the analog-to-digital converter (ADC). In addition, in order to maintain the average power of the received signal close to a desired level and accurately demodulate a received signal, the AGC should be able to track the signal power and set the gain accordingly [1], [2].

A typical AGC scheme which is continuously operational for the received signal is applied to the receiver regardless of the transmission path in the frequency division duplex (FDD) system. However, in TDD system, it leads to significant performance degradation by applying common AGC scheme due to large AGC gain variation which is caused by signal level difference between downlink and uplink subframe.

Generally, it can be overcome by considering the training symbol or guard period (GP) at the beginning of a downlink transmission in which no information is sent, even though the

transceiver is active [3]. However, it is not appropriate for LTE system in contrast to packet-oriented networks. Moreover, it is an important AGC strategy to converge efficiently for the accurate radio frame timing detection during the subsequent initial cell search procedure which is one of the most critical issues when the LTE system is implemented.

Therefore, we propose a modified AGC scheme based on the average amplitude ratio calculation which can not only effectively increase the convergence speed of the AGC gain but also maintain the stability of AGC operation in LTE TDD system. Also we consider the proposed AGC scheme in combination with PSS detection interface for the first step of initial cell search process in LTE TDD system to obtain both a stable AGC operation and accurate PSS detection performance.

This paper is organized as follows. In Section II, we introduce LTE frame structure for TDD system, and the signal model considered in this paper. A brief description of the conventional AGC method and the problem in LTE TDD system are described in Section III. The proposed AGC scheme and the application considering initial cell search processing are described in Section IV. The results of performance comparison are presented in Section V and a conclusion is drawn in Section VI.

II. LTE FRAME STRUCTURE AND SIGNAL MODEL

A. LTE Frame Structure

Figure 1 describes the LTE frame structure for TDD mode [4]. For TDD, a subframe is either allocated to downlink or uplink transmission. As shown in Figure 1, the total length of downlink pilot time slot (DwPTS), GP, and uplink pilot time slot (UpPTS) fields is equal to 1 ms duration.

B. Signal Model

The n -th time-domain sample of the m -th transmitted symbol can be expressed as

$$\begin{aligned} x\left(m\left(N+N_{cp}\right)T_s+N_{cp}T_s+nT_s\right) &= x_{m,n} \\ &= \frac{1}{N} \sum_{k=-N/2+1}^{N/2} X_{m,k} e^{j2\pi nk/N}, n = -N_{cp}, \dots, N-1 \end{aligned} \quad (1)$$

where T_s is a basic time unit, N is fast Fourier transform (FFT) size, $x(t)$ is the transmitted signal, and $X_{m,k}$ is the k -th complex-value frequency-domain signal of the m -th symbol.

Note that in order to prevent inter symbol interference (ISI), a cyclic prefix (CP) of N_{cp} sample is inserted at the beginning of each symbol. Further assuming that the channel is almost stationary, the received symbol can be expressed as [5].

$$y(m(N + N_{cp})T_s + N_{cp}T_s + nT_s) = y_{m,n} \quad (2)$$

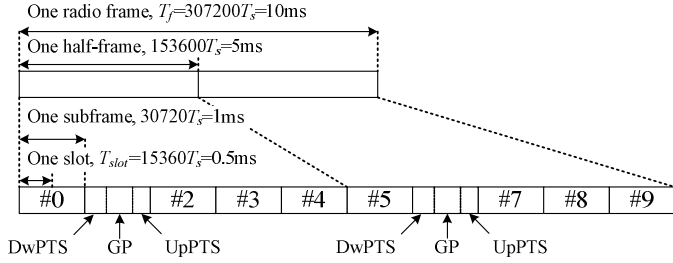


Figure 1. LTE frame structure for TDD mode

III. CONVENTIONAL AGC SCHEME

A. Description of the Conventional AGC Scheme

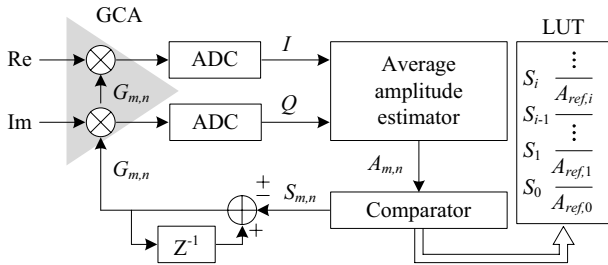


Figure 2. LTE frame structure for TDD mode

Figure 2 shows the functional structure of the digital feedback AGC which is the most commonly used one for wireless communication receiver [6], [7].

1) Average Amplitude Estimator: By defining that $\hat{y}_{m,n}$ is the received sample signal after ADC operation, the average amplitude of $\hat{y}_{m,n}$ is continuously estimated by using (3).

$$A_{m,n} = \alpha |\hat{y}_{m,n}| + (1 - \alpha) \cdot A_{m,n-1}, \text{ where } \alpha = 2^{-L} \quad (3)$$

The average amplitude $A_{m,n}$ determines whether the received signal is within the dynamic range of ADC before adjusting the AGC gain $G_{m,n}$ of gain controlled amplifier (GCA).

2) Comparator: In order to calculate the gain control value $S_{m,n}$ such as the step size S_i , the average amplitude $A_{m,n}$ is compared to the reference amplitude $A_{ref,i}$ corresponding the reference gain $G_{ref,i}$ which is increased by i dB from the primary gain $G_{ref,0}$. The step size S_i which is easily obtained by using a look-up table (LUT) can be described as

$$S_{m,n} = S_i = \arg \min_i |A_{m,n} - A_{ref,i}|, i = 0, 1, \dots \quad (4)$$

3) GCA: The GCA is a linear-in-dB gain control circuitry that adjusts the level of incoming signal with AGC gain $G_{m,n}$. The AGC gain $G_{m,n}$ is determined with the average amplitude $A_{m,n}$ and gain control value $S_{m,n}$, and it can be described as

$$G_{m,n} = \begin{cases} G_{m,n-1} + S_{m,n}, & |A_{m,n} - A_{ref,i}| < 0 \\ G_{m,n-1} - S_{m,n}, & |A_{m,n} - A_{ref,i}| > 0 \end{cases} \quad (5)$$

B. The Problem of Conventional AGC Scheme

The conventional AGC scheme is continuously applied to the receiver regardless of the transmission path in FDD mode, because both downlink and uplink transmission are isolated from each other by different frequency bands and downlink subframe transmission is continuous. However, in TDD mode, where the same frequency band is used for downlink and uplink subframe which are separately transmitted by a time division, applying the conventional AGC scheme may lead to significant performance degradation due to large AGC gain variation which is caused by signal level difference between downlink and uplink subframe as shown in Fig. 3. As shown in Figure 3, in TDD mode, it takes more than one OFDM symbol duration for AGC gain convergence, where as in FDD mode, the AGC gain remains stable.

Reference [8] and [9] give the basic solution to overcome this limitation by using the hybrid gamma parameter. It is well known that large gamma parameter can result in fast convergence and small gamma parameter can reduce the amount of jitter in the gain adjustment process. However, the most serious disadvantages of the design of [8] and [9] are the heuristic parameter-changing-point, the application of optimal parameter according to circumstances, and the need of synchronization signal offered by the subsequent initial cell search procedure and digital decoder. In general, it is difficult to find and employ the factors mentioned above accurately in the TDD mode with large signal power variation and the error of synchronization signal causes serious performance degradation; therefore this scheme will not work in practice.

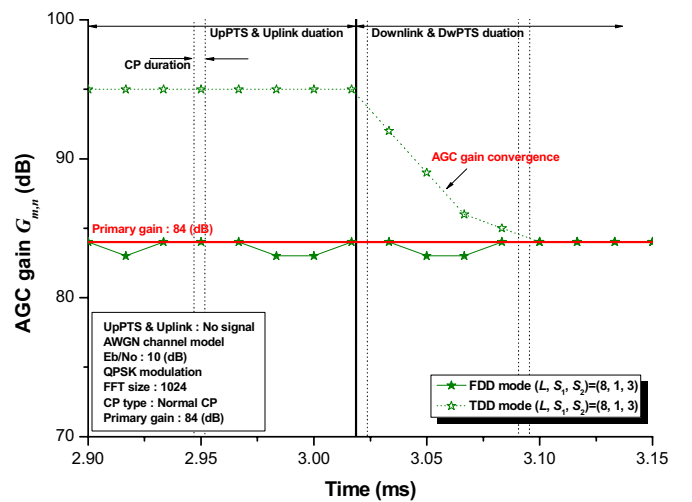


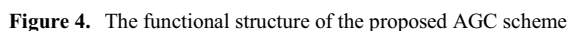
Figure 3. Convergence of AGC gain adjustment for FDD and TDD mode

IV. THE PROPOSED AGC SCHEME

A. Requirement of LTE System for Stable AGC Operation

A. Requirement of LTE System for Stable AGC Operation

B. Description of the proposed AGC scheme



1) Signal Amplitude Ratio Calculator: After ADC operation, the average amplitude ratio of the received sample signal is

$$S_p = \frac{1}{\beta} \sum_{i=1}^{\beta} \left| \frac{\hat{y}_{m,n-\beta-i}}{G_{m,n-\beta-i}} \right| \bigg/ \frac{1}{\beta} \sum_{i=1}^{\beta} \left| \frac{\hat{y}_{m,n-i}}{G_{m,n-i}} \right| \quad (6)$$

$$= \frac{\sum_{i=1}^{\beta} \left| \frac{\hat{y}_{m,n-\beta-i}}{G_{m,n-\beta-i}} \right|}{\sum_{i=1}^{\beta} \left| \frac{\hat{y}_{m,n-i}}{G_{m,n-i}} \right|}, \text{ where } \beta = \alpha^{-1} = 2^L$$

The γ which can adjust and guarantee the AGC quality at any point in time such as the switching point between downlink and uplink transmission is described as

$$\gamma = A_{ref, \max[i]} - A_{ref, 0} \quad (7)$$

The variable AGC gain at the GCA is updated by using the selector output, and it can be described as

$$S_{m,n} = \begin{cases} S_p, & |S_p| > \gamma \\ S_i, & |S_p| < \gamma \end{cases} \quad (8)$$

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C. Application of the Proposed AGC for Initial Cell Search of 3GPP LTE TDD System

During initial cell search in LTE TDD system, the received signal will be attenuated by large AGC gain variation, which can be easily caused by the signal level difference between downlink and uplink subframe as shown in Fig. 3. This effect can induce cell search performance degradation, especially PSS detection because PSS detection performs with time domain received sample signal after AGC/ADC operation [4].

Therefore, we consider the proposed AGC scheme in combination with PSS detection interface to obtain both a stable AGC operation and accurate PSS detection performance.

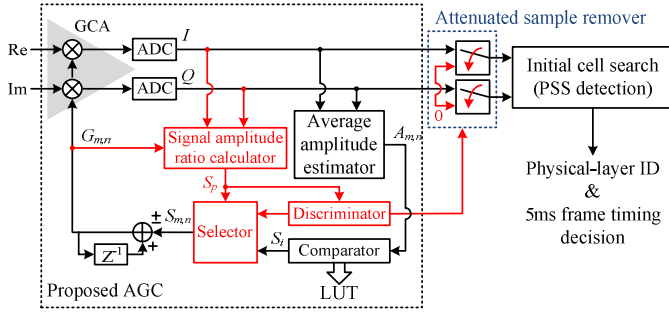


Figure 6. The functional structure of the proposed AGC and initial cell search procedure

Figure 6 shows the functional structure of the PSS detection with proposed AGC scheme for LTE TDD system. As shown in Figure 6, we consider “attenuated sample remover” for interfacing between the proposed AGC scheme and PSS detection to obtain more accurate symbol timing and physical-layer identity (ID) which is detected by PSS. To obtain acceptable PSS detection performance, the attenuated sample due to AGC gain variation should be eliminated by changing the attenuated sample into zero value. This simple interface allows maintaining acceptable PSS detection performance without any influence from the AGC.

V. PERFORMANCE EVALUATION

The simulation parameters based on LTE specifications for the initial cell search are listed in Table 1 [4].

TABLE 1. SIMULATION PARAMETERS

Parameter	Value
Carrier frequency	2.6 GHz
Bandwidth (FFT size N)	10 MHz (1024)
Sampling frequency	15.36 MHz
Uplink-downlink configuration	#0
Special subframe configuration	#3
ADC bit resolution	12 bit
Guard interval type	Normal cyclic prefix
Channel environment	EVA / ETU
Mobile speed	60 km/h
Maximum frequency offset (Normalized frequency offset)	5 ppm (0.866)

For performance evaluation, we set the normalized frequency offset by subcarrier spacing due to the frequency error of the standard oscillator of a UE to be 0.866 in the initial cell search assuming the accuracy of 5 ppm for the local frequency of the UE receiver at a 2.6 GHz carrier frequency. Also, for the multi-path fading environments, both extended vehicular A (EVA) and extended typical urban (ETU) with mobile speed 60 km/h are considered [10].

Figure 7 and Figure 8 show the comparisons for average convergence time and variation of AGC gain between the proposed AGC scheme and the conventional AGC scheme in variable channel environment of LTE TDD system, respectively. Average convergence time is measured from the start of switching point between uplink and downlink transmission to the steady-state of AGC gain, and variation of AGC gain is measured during downlink and DwPTS transmission.

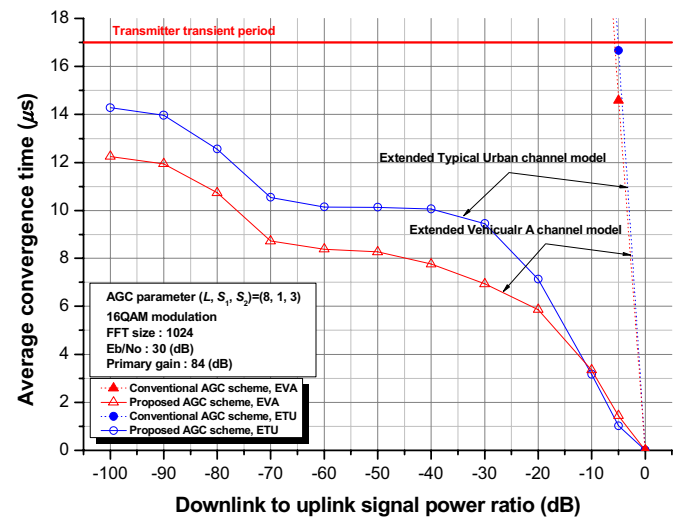


Figure 7. Average convergence time comparisons for various downlink to uplink signal power ratio [Conventional vs. Proposed]

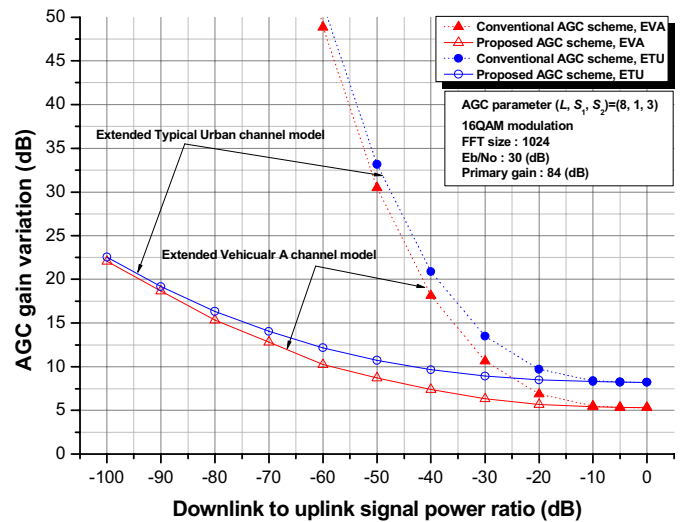
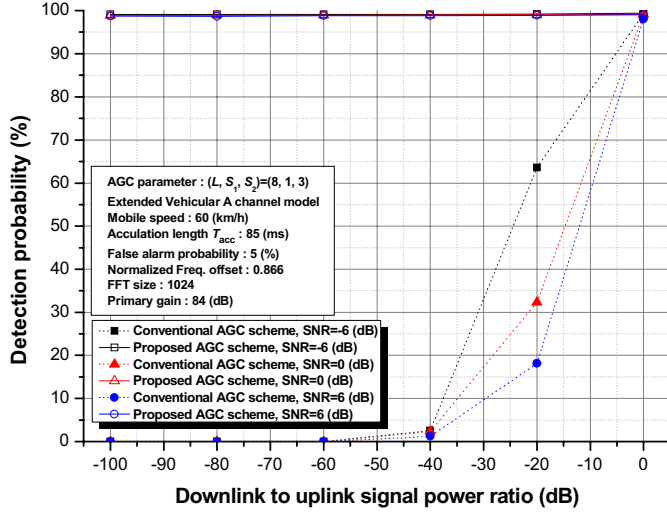
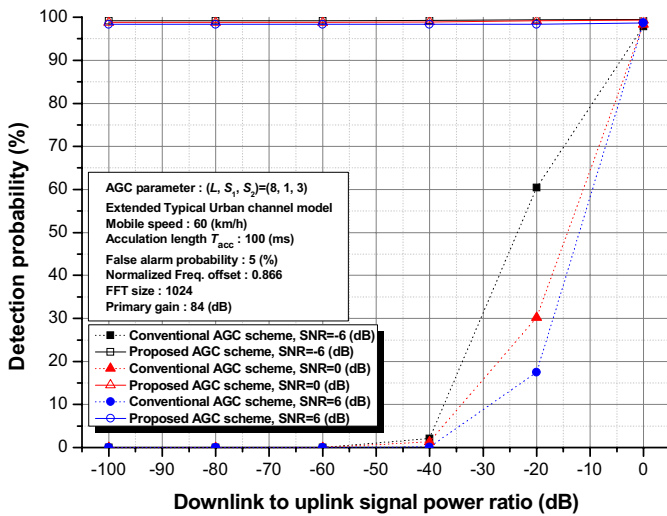


Figure 8. AGC gain variation comparisons for various downlink to uplink signal power ratio [Conventional vs. Proposed]

As shown in Figure 7 and Figure 8, we can see that the proposed AGC scheme using the average amplitude ratio has much faster convergence time than the conventional AGC scheme within the target transient period with small AGC variation, although average transient time is increased due to saturation effect at ADC caused by decreasing downlink to uplink signal power ratio.



(a) EVA channel



(b) ETU channel

Figure 9. PSS detection probability comparisons for different SNR in variable channel environments [Conventional vs. Proposed]

Figure 9 shows the comparisons for detection probabilities of PSS between the proposed AGC scheme and the conventional AGC scheme with different signal to noise ratio (SNR) in variable channel environment in LTE TDD system with partial-correlation method and maximum likelihood (ML) metric to mitigate the frequency offset and deep fading affects, respectively [12], [13]. Also, the accumulation technique is applied in the PSS detection to improve detection

probability at low SNR during T_{acc} time which is given in multiple of 5 ms half-frame period. In this paper, we define the detection probability as the probability when PSS detection is obtained between $\square N_{cp}$ sample duration of on-time. Also, to achieve the 99% detection probability, we assume that the accumulation lengths $T_{acc}=85$ ms and $T_{acc}=100$ ms in EVA, and ETU channel condition, respectively.

As shown in Figure 9, the conventional method causes serious performance degradation, especially the low signal power ratio between downlink and uplink subframe. This performance degradation is caused by slow convergence of AGC gain due to signal power difference between uplink and downlink subframe. However, the proposed method maintains an acceptable PSS detection probability and provides up to 99% detection probability even in LTE TDD mode which has nearly 100 dB difference of the received signal power between downlink and uplink subframe.

From these results, we can verify that the proposed AGC scheme reflects the signal variation quickly and can adjust the received signal power to an optimum level within dynamic range even in LTE TDD system which has nearly 100 dB difference of the received signal power between downlink and uplink subframe.

VI. CONCLUSIONS

In this paper, we proposed a digital AGC scheme based on feedback structure which can not only effectively increase the convergence speed of the AGC gain by using the current signal amplitude ratio adaptively but also maintain the stability of AGC operation. By using extensive computer simulation in various channel environments, we show that the proposed method can obtain a good behavior in terms of convergence speed and PSS detection performance in LTE TDD system. Consequently, the proposed method is attractive and suitable for implementation with stable operation.

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