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Design Simulation of Multiple Differential Transceiver at 2.0 GHz for Third Generation Mobile Communication System

[1]M. S. Johal, [1]M. K. Suaidi, [1]A. R. Othman, [1]H. Mohd. Dom

[1]Faculty of Electronics and Computer Engineering
Universiti Teknikal Malaysia Melaka
Locked Bag 1200, 75450 Ayer Keroh, Melaka.
Email: syahrir@utem.edu.my, kadim@utem.edu.my, rani@utem.edu.my, hairulisam@utem.edu.my

Abstract – **Third generation mobile communication system is widely used nowadays. One of its parameter standard, which is QPSK modulation has been adopted by International Telecommunication Union (ITU) to be used in IMT-2000. However, due to amplitude variations introduced in QPSK, a rather robust and reliable data modulation technique, namely the π/4-shift Differential QPSK is proposed. For detection purposes, two types of detectors are evaluated for their performance in AWGN and Rayleigh fading channels. A differential detection technique called multiple differential detection technique which uses maximum-likelihood sequence estimation (MLSE) of the transmitted phases is compared with conventional differential detection which uses symbol-by-symbol detection. By using some of the IMT-2000 standard parameters, the simulation results show that multiple differential detection scheme performs much better than conventional differential detection scheme.**

Keywords: π/4-shift Differential QPSK, multiple differential detection, square root raised cosine Nyquist filter, multipath, intersymbol interference

1. INTRODUCTION

In the wireless world, the demand for advanced information services is growing. Voice and low-rate data services are insufficient in a world where high-speed Internet access is taken for granted. The trend is toward global information networks that offer flexible multimedia information services to users on demand, anywhere, anytime. The need to support bandwidth-intensive multimedia services places new and challenging demands on cellular systems and networks. The current generation of mobile communication systems, which utilizes digital technology to provide voice and data services must provide high quality signal and data reproduction [1], [2]. International Mobile Telecommunication-2000 (IMT-2000), formerly known as Future Public Land Mobile Telecommunication System (FPLMTS), currently operating in the 2 GHz band on a worldwide basis for the satellite and terrestrial components is capable of offering a wider range of services including multimedia services, with the same quality obtained from the fixed telecommunication networks in many different radio environments [3]. However, these objectives are not easily met because it is well known to all mobile communication engineers and users that two of the major disturbances in the transmission of digital information over land-mobile link are the presence of fading and thermal-electric noise. In order to reduce this problem, a more reliable data encoding method is necessary.

Several techniques have been proposed to reduce the effect of multipath fading channel. A differential detection technique for MPSK called multiple symbol differential detection has been proposed, which uses maximum-likelihood sequence estimation (MLSE) of the transmitted phases rather than symbol-by-symbol detection as in conventional differential detection [4]. It has been shown in [4] that for binary DPSK, extending the observation interval from N = 2 (for conventional differential detection) to N = 3 recovers more than half of the E_b / N_o loss of differential detection versus coherent detection with differential encoding. Whereas for QPSK (M = 4), the improvement of E_b / N_o performance of observation interval N = 3 relative to N = 2 is more than 1 dB.

In [5], Abrardo et al. have presented the application of the differential detection algorithm proposed in [4] to the demodulation of a GMSK signal. This algorithm presents quite an attractive performance both in an AWGN and in a multipath channel as compared to coherent detection algorithm.

So far, no literature on performance evaluation on IMT-2000 or sometimes it is known as third generation mobile communication system employing multiple differential detection algorithm has been studied. Currently, the IMT-2000 has adopted QPSK modulation scheme to be used in time division duplex (TDD) mode for Wideband Code Division Multiple Access (W_CDMA) system. However, with QPSK, when the phase changes from 0^0 to 180^0, the signal amplitude must pass through zero, so there is an amplitude component in the transmitted signal [9]. The amplitude is constant at the sampling intervals but varies during the phase transitions. Therefore, in this report, a more reliable QPSK modulation scheme with differential encoding (also known as π/4-DQPSK) is proposed. As mentioned earlier, two major disturbances introduced in the land-mobile link are the presence of fading and thermal-electric noise. As a result, an effective way to recover the original information is of an even greater importance. A promising solution to reproducing the sent information is through the usage of a multiple differential decoder.

The main objective of this research is to design and implement a comprehensive communication system using MATLAB software which simulates a real life communication system so that practical observations can be made with thorough understanding of the system's behaviour. The simulation results between single differential detection and multiple differential detection methods will be compared and analyzed. The differential detection scheme performs multiplication between a signal sample and the complex conjugate of another sample received by progressively increasing multiples of delays before. The difference in phases between the samples is then used to decode the signal to its original information bits. Because of the large number of detectors used in the system, this approach has been named multiple differential detection.

2. SYSTEM MODEL

W-CDMA is the currently most important mode of the third generation cellular standard IMT-2000 [11][12]. Third generation mobile wireless systems are often referred to as Universal Mobile Terrestrial Telecommunication Systems (UMTS). The UMTS system intends to integrate all forms of mobile communications including terrestrial, satellite and indoor communications.

Objectives of third generation systems include providing the user with higher data rates and seamlessly integrating data and voice services. To achieve these objectives, the data rate are spread over a much wider frequency range. The third generation systems is implemented in the PCS bands from 1800 MHz to 2000 MHz [13].

One of the most commonly used bandwidth efficient techniques for transmission of digital signals is the Phase Shift Keying (PSK) techniques. A particularly important class of MPSK signaling is the M=4 case, referred to as QPSK, in which they correspond to 4 phasors, spaced every 90^0 in $[0,2\pi]$. Another family of QPSK type signals, namely the $\pi/4$-shift DQPSK has been chosen as the standard modulation technique for the Japanese and North American digital cellular radio system[10]. However, only $\pi/4$-shift DQPSK baseband signal is considered for application due to the size of this project. Figure 1 shows the signal constellation of QPSK and $\pi/4$-shift DQPSK type signals.

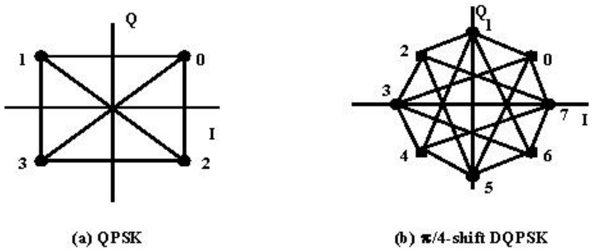

Figure 1: The signal space of (a) QPSK versus the signal space of (b) π/4-shift DQPSK

From Figure 1, the transmitted carrier phase is differentially encoded by a pair of input bits, so that the carrier phase angle at the ith symbol interval is dictated by

$$\theta_i = \theta_{i-1} + \Delta\theta_i$$

where $\Delta\theta_i$ is the differential phase, taking values from { $\pi/4$, $3\pi/4$, $5\pi/4$, $7\pi/4$ }. The main advantage of using $\pi/4$-shift DQPSK type signaling, as compared to QPSK, is its higher spectral efficiency in the presence of non-linearities due to its reduced envelope fluctuation, making it less sensitive to distortion imposed by non-linear power amplifier stages.

It is necessary to understand the details of the structure of an entire communication system in order to produce the algorithm for the differential detection scheme. Figure 2 shows the $\pi/4$-DQPSK transmitter model [6].

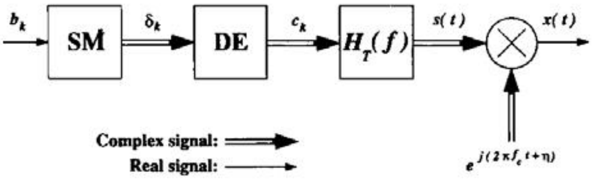

Figure 2: Block diagram of transmitter model

From the block diagram, the $\pi/4$-DQPSK baseband generator is represented in its equivalent form as the combination of a signal mapper, a differential encoder and a Nyquist filter. The input signal, b_k, is an information word which consists a sequence of bits, values of 0's and 1's. The signal mapper takes readings at every two bits and maps the value onto the QPSK signal space in a straightforward manner.

$$\{00, 01, 10, 11\} \rightarrow \{0, 1, 2, 3\}$$

Now, the representation of the signal from the signal mapper is $\delta_k = \gamma_k e^{j\Omega_k}$, where γ_k and Ω_k represent the envelope and the phase, respectively. For all PSK signals, the envelope can be considered to be equal to 1 since it is constant. So the signal from the signal mapper is simply denoted as

$\delta_k = \gamma_k e^{j\Omega_k}$, with $\Omega_k = \{\pm\pi/4, \pm 3\pi/4\}$ (1)

Differential encoding of the sequence of δ_k 's yields the sequence of differentially encoded symbols c_k. For example, PSK signals are differentially encoded as

$$c_k = \delta_k \frac{c_{k-1}}{\gamma_{k-1}} = \exp[j(\phi_{k-1} \oplus \Omega_k)] \quad (2)$$

with ϕ_k denoting the phase of c_k and $\oplus$ modulo-2π addition. The differential encoder simply converts the 2-bit symbols of the QPSK signal into 3-bit symbols of the $\pi/4$-shift DQPSK signal. The computation for this task is achieved by analyzing the transition of one QPSK point to the next. Hence, the signal leaving the differential encoder is denoted as

$c_k = e^{j\theta_k}$, with $\theta_k = \{0, \pm\pi/4, \pm 2\pi/4, \pm 3\pi/4, \pi\}$ (3)

After passing through the premodulation filter, the signal can then be represented as

$$s(t) = \sum_{k=0}^{L} c_k h_T(t - kT). \quad (4)$$

In (4), T is the symbol duration, L is the number of symbols transmitted, and $h_T(t)$ is the impulse response corresponding to $H_T(f)$ which is a well-known square root α, $\sqrt{\alpha}$ raised cosine filter [7]. The signal is now represented in two complex components. The values of the signal's complex components are still in digital form at this stage but each complex component is now an 8-bit symbol.

Before reaching the modulator, digital-to-analog (D/A) conversion must take place first. So, the 8-bit digital values become analog values. When the signal is modulated by the carrier frequency, it becomes

$$x(t) = \mathrm{Re}\{s(t)e^{j(2\pi f_c t + \rho)}\} \quad (5)$$

where f_c is the carrier frequency and ρ is the initial phase of the modulator.

In the propagation channel, x(t) is assumed to be corrupted by a mixture of multiplicative, non-selective fading, f(t) and AWGN, n(t) which introduces a one-sided power spectral density, N_o [7].

At the receiver, realization is achieved by the block diagram in Figure 3 [7].

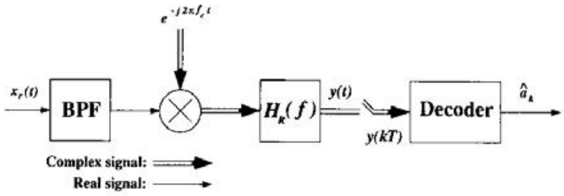

Figure 3: Block diagram of receiver model

The received signal is first passed through a wideband bandpass filter (BPF) to limit the Gaussian noise without distorting the information carrying signal. The signal is represented by

$$x_r(t) = x(t)f(t) + n(t) \quad (6)$$

It can be seen from the block diagram that the demodulator is composed of both a carrier down-converter and pre-detection filter. After undergoing the down-conversion process and filtering to remove the excess spectrum in the higher frequencies, the received signal is expressed as

$$\begin{aligned} y(t) &= s(t)f(t)e^{j\rho} + n(t)e^{-j(2\pi f_c t + \rho)} \\ &= f(t)e^{j\rho}\sum_{k=0}^{L} c_k h(t - kT) + n_I(t) - jn_Q(t) \end{aligned} \quad (7)$$

where $n_I(t)$ and $n_Q(t)$ are the in-phase and quadrature baseband components of the narrowband Gaussian noise, respectively. The new impulse response, h(t) , is corresponded to the product of $H_T(f) \bullet H_R(f)$. The predetection filter, $H_R(f)$ is chosen to match the Nyquist filter, $H_T(f)$ in the transmitter such that h(t) satisfies Nyquist's first criterion of preventing intersymbol interference (ISI). So, the criterion for the impulse response upon sampling would have to meet the following condition:

$$h(t) = \begin{cases} 1 & \text{for } k = 0 \\ 0 & \text{elsewhere} \end{cases} \quad (8)$$

Therefore, the sampling by the decoder of the signal y(t) at t = kT would yield $y_k = y(kT)$, which is denoted by

$$y_k = (f_I(kT) + jf_Q(kT))c_k e^{j\rho} + n_I(kT) - jn_Q(kT). \quad (9)$$

If we assume the decoder acts as a conventional differential decoder then it computes the phase change between symbols by operating on samples from the in-phase and quadrature components of the signal received from the demodulator. The signal, y_k , from the demodulator can be generalized into the following forms for the in-phase and the quadrature of its complex components as shown below:

$$I_k = \cos(\theta_k + \varphi) \tag{10}$$

and

$$Q_k = \sin(\theta_k + \varphi). \tag{11}$$

The element θ_k represents the points on the $\pi/4$-shift DQPSK signal space and the φ represents the distortion caused by the fading, noise and the carrier's phase lag. Now, the phase change between two symbols can be calculated by the following two formulae:

$$d_k[I] = I_k I_{k-1} + Q_k Q_{k-1}$$

$$= \cos(\theta_k + \varphi)\cos(\theta_{k-1} + \varphi) + \sin(\theta_k + \varphi)\sin(\theta_{k-1} + \varphi)$$
$$= 0.5\cos(\theta_k - \theta_{k-1}) + 0.5\cos(\theta_k + \theta_{k-1} + \varphi)$$

$$+ 0.5\cos(\theta_k - \theta_{k-1}) - 0.5\cos(\theta_k + \theta_{k-1} + \varphi)$$
$$= \cos(\theta_k - \theta_{k-1}) \tag{12}$$

$$d_k[Q] = Q_k I_{k-1} + I_k Q_{k-1}$$
$$= \sin(\theta_k + \varphi)\cos(\theta_{k-1} + \varphi) - \cos(\theta_k + \varphi)\sin(\theta_{k-1} + \varphi)$$
$$= 0.5\sin(\theta_k - \theta_{k-1}) + 0.5\sin(\theta_k + \theta_{k-1} + \varphi)$$
$$- 0.5\sin(\theta_k - \theta_{k-1}) - 0.5\sin(\theta_k + \theta_{k-1} + \varphi)$$

$$= \sin(\theta_k - \theta_{k-1}) \tag{13}$$

where $d_k[I]$ and $d_k[Q]$ are the changes in magnitude of the in-phase and the quadrature components. Notice that each component changes with respect to the phase difference between the two symbols. Using this knowledge, a decision on the output of the 2-bit symbols can be made based on the technique demonstrated by Table 1.

The multiple differential decoder is an elaboration on the conventional differential decoder. Generally, as in [8], the term "multiple differential detectors" refers to differential detectors which decode the receiver signal over a multi-symbol interval. The multiple order of the detector corresponds to the prediction order of the detector [6]. If the prediction order of the multiple differential detector is set to 1, then the current multiple differential detector is just a normal conventional differential detector. Then, torealize a multiple differential detection scheme, a predetermined number of memory latches is chosen to store the phase change values. Then, a decision-maker would process the output 2-bit signal based on the pattern of the phase changes. The block diagram in Figure 4 illustrates the general format of the multiple differential detection scheme.

Table 1: Output references of the conventional differential decoder

θ_k - θ_{k-1}	cos()	sin()		Outputs	I	Q
$\pi/4$	$1/\sqrt{2}$	$1/\sqrt{2}$	⇔	00	>0	>0
$-\pi/4$	$1/\sqrt{2}$	$-1/\sqrt{2}$		10	>0	<0
$3\pi/4$	$-1/\sqrt{2}$	$1/\sqrt{2}$		01	<0	>0
$-3\pi/4$	$-1/\sqrt{2}$	$-1/\sqrt{2}$		11	<0	<0

Prior to generating the 2-bit output, the decision-maker computes the pattern of one phase change value to the next. Such phase changing patterns would correspond to the values of the points on the $\pi/4$-shift DQPSK signal space. This recognition of phase changing pattern can be achieved by referring to a look-up table and the signal space maps of both QPSK and $\pi/4$-shift DQPSK which are stored in permanent memory areas. Table 2 shows how the processor computes the pattern of phase changes.

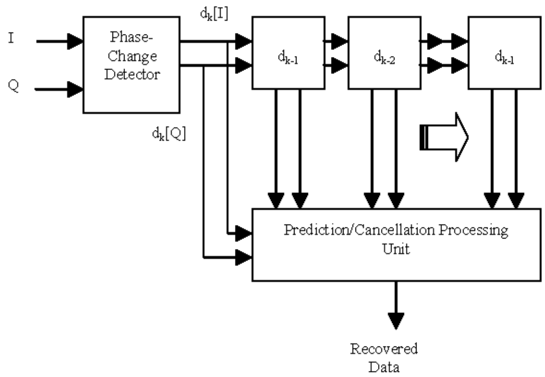

Figure 4: Block diagram of multiple differential detection scheme

Table 2: Mapping for pattern in phase changes

	Points on π/4-shift DQPSK Signal Space									
	0	1	2	3	4	5	6	7		
	000	001	010	011	100	101	110	111	**Additive Constants**	**Outputs**
Next Signals	001	010	011	100	101	110	111	000	001	00
	011	100	101	110	111	000	001	010	011	01
	101	110	111	000	001	010	011	100	101	11
	111	000	001	010	011	100	101	110	111	10

From the mapping table, the processor initially maps the first few signals onto the points of $\pi/4$-shift DQPSK signal space. Then, as subsequent signals arrive, each one would be mapped according to what point the previous signal is located. For example, the previous signal is mapped at point 3 in column 4, then the next incoming signal can only be mapped with values which fall in column 4. Each incoming signal is also converted to its equivalent value as a constant. This is accomplished simply by subtracting, circular shifting method, the value of the current signal by that of the previous signal. A 2-bit decoded output symbol is then produced by logical derivation from the constant.

3. SIMULATION RESULTS AND DISCUSSION

Simulation results are presented for the proposed scheme whereby the simulation methodology for the bit error rate uses the well-known Monte Carlo simulation techniques. The simulation begins with comparing the error rate performance of the proposed system with conventional differential detection scheme in two different environments. Since the overall transceiver system under investigation is meant for IMT-2000, then some standard parameter specifications for third generation mobile communication system will be used in the simulation. For simplicity, a maximum data rate of 2 Mbps, root raised cosine Nyquist filter, α = 0.22 and operating frequency of 2 GHz are chosen as common parameter for comparison purposes.

The MATLAB simulation results for this section can be seen in Figure 5, Figure 6, Figure 7 and Figure 8.

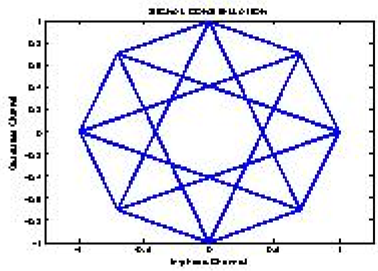

Figure 5: Unfiltered π/4-shift DQPSK signal constellation

Figure 5 shows the unfiltered π/4-shift DQPSK signal constellation. Clearly, one can see that the phase transitions can only take place in either ± 45° or ± 135°. This is the advantage of employing π/4-shift DQPSK as compared to QPSK modulation because the signal will never have amplitude variations close to the zero value (the origin). As for Figure 6, it is assumed that the transmitted signal is filtered using Butterworth filter with the order of 5 to produce some amplitude variations in order to see the effect on the signal. Again, the result proves itself that even in the case of heavy amplitude variations imposed on the signal, it will never reaches the zero value.

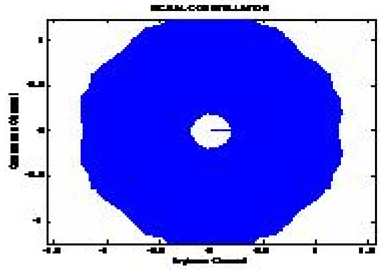

Figure 6: Filtered π/4-shift DQPSK signal constellation

The corresponding in-phase and quadrature transmitted signal components can be observed in Figure 7 for unfiltered components and also Figure 8 for filtered components. The results are normalized in time in order to obtain the general idea of the transmitted signal components. Based on the results from the signal constellations above, it is understandable that the unfiltered transmitted signal components produce better pulse-like amplitude than that of the filtered transmitted signal components. The third graphs for both Figure 7 and 8 are the combination of both in-phase and quadrature signal components. It is observed that both graphs are the same as their respected in-phase components because MATLAB ignores the plot for imaginary components.

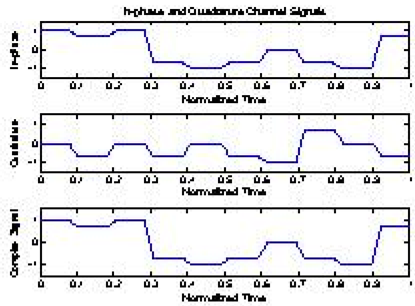

Figure 7: Unfiltered in-phase and quadrature channel signals

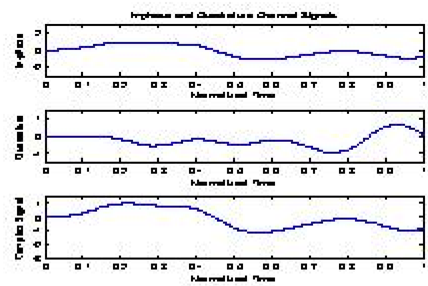

Figure 8: Filtered in-phase and quadrature channel signals

Case 1: Performance comparison of conventional differential detection scheme and multiple differential detection scheme in AWGN channel

Figure 9 shows that the performance of $\pi/4$-DQPSK system with multiple differential detection is slightly better than conventional differential detection scheme. For example, at a bit error rate, BER = 10^{-3}, multiple differential detector performs slightly better by 0.2 dB than its conventional differential detector. This simulation is used as a reference for the second investigation.

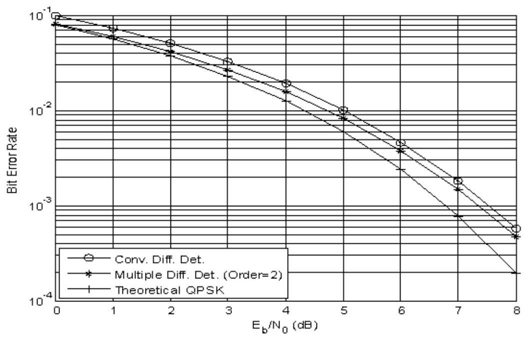

Figure 9: Performance comparison of conventional and multiple differential detection schemes in AWGN channel

Case 2: Performance comparison of conventional differential detection scheme and multiple differential detection scheme in AWGN and Rayleigh fading channel

In this simulation, the fading factor of the overall communication system needs to be determined. The fading factor refers to how much of the original signal is affected by fading. This value is calculated by dividing the bandwidth value of the channel by the data rate of the signal. Knowing that the operating frequency is at 2 GHz and the symbol rate is set at 1 Mbps, then the fading factor, B_FT is calculated to be 0.000185. As well known, the B_FT product is an important parameter when evaluating the performance of digital modulation schemes transmitted over a fading channel. Normalizing B_F to the symbol rate $1/T_s$, the higher the B_FT product, the faster the fading interference changes with respect to the symbol duration.

As expected, the bit error rate for both schemes will deteriorate in the Rayleigh fading channel from Figure 10. However, the performance of multiple differential detection scheme improves by gaining about 1 dB at BER = 10^{-2}. This clearly shows that the proposed multiple differential scheme performs better than conventional differential detection scheme for $\pi/4$-DQPSK signaling in IMT-2000.

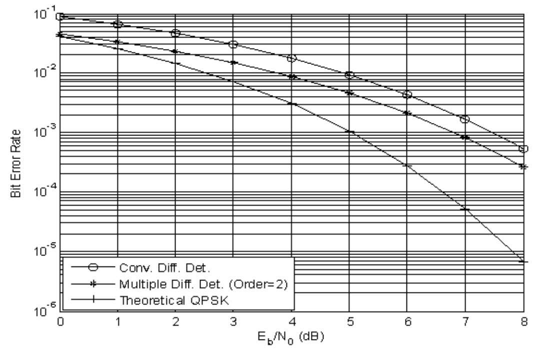

Figure 10: Performance comparison of conventional and multiple differential detection schemes in AWGN and Rayleigh fading channel

4. CONCLUSION

This project studies the performance of $\pi/4$-DQPSK signaling employing either multiple differential detection scheme or conventional differential detection scheme in AWGN and Rayleigh fading channels. The differential encoding of QPSK modulation was intended to provide a more reliable data encoding technique by reducing the amplitude variation problem in conventional QPSK. Furthermore, by implementing the multiple differential detection scheme the performance of overall transceiver is much better than conventional differential detection scheme in both channels. In fact, the objective of this project has been achieved by conducting design simulations on the performance comparison of multiple differential detection scheme and single or conventional differential detection scheme for third generation mobile communication system. As a conclusion, the proposed detection system is feasible and can be applied in current third generation mobile communication system.

5. REFERENCES

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