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RFID Signal Transmission Framework in Software Defined Radio using QAM Scheme

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ABSTRACT

This paper presents the performance evaluation of a RFID signal transmission framework in software defined radio (SDR) using quadrature amplitude modulation (QAM) scheme. The RFID signals within the SDR framework are compared between QAM and phase shift keying (PSK) modulation to check the SDR performance. The SDR system performance is evaluated by comparing bit error rate (BER) versus signal-to-noise ratio (SNR) with satisfactory results.

Key words: RFID, Software Defined Radio, Modulation, Bit error rate, Signal noise ratio.

Introduction

Radio Frequency Identification (RFID) is the hottest technology in wireless applications. To travel the information from one place to another, the use of RFID technology is increasingly in demand. The areas related to RFID hardware devices like tags, readers and their peripheral have mainly dominating the RFID market and research themes (Mohammadi, F.A. and S.R. Ailani, 2007; Han., S. et al., 2007). However, the trend has gradually shifted to the RFID software system. This is due to the necessity for processing huge amount of the data streams delivered by RFID hardware devices gets larger (Han., S. et al., 2007). The focus on hardware is important, but RFID hardware has a minimal value without effective software that can aggregate data from RFID readers and pass it to enterprise applications (Wu, J.D., 2009). A variety of radio frequency techniques are used in RFID soft ware systems (Preradovic, S. et al., 2009; Floerkemeier, C. et al., 2007).

The RFID devices are so inflexible that are generally implemented in hardware. There is a chipset in each device that performs the signal processing to allow the device to communicate with its wireless network. This inflexibility led us to consider alternate software-based designs; called software defined radio (Leong, K.S., 2006; Hannan, M.A. et al., 2010).

Different communication standards and techniques are used among military and public safety agencies make difficulties the necessary interoperability (Zhang, Y. et al., 2007). Constant improvements in techniques applied to different radio communication system stages, including coding, modulation, synchronization and security make any implementation quickly obsolete (Ru. Z. et al., 2009; Islam, M. et al., 2009). These reasons force users to replace equipment frequently, increasing cost and implementation time. Communication link, partially built in software, can solve these problems, making full use of programmable modules (Islam, M. et al., 2010; Islam, M. et al., 2010). Each block has to provide a considerable amount of flexibility while maintaining performance (Bakhraiba, A. et al., 2008). Software Defined Radio (SDR) is an advanced radio technology in which the modulation and demodulation of radio signals is performed exclusively by software. Thus, reduce the peripheral hardware of the RFID communication devices. Communication link of the SDR mainly consists of transmitter, channel and the receiver. The transmitter process an information signal in order to produce a signal most likely to pass reliably and efficiently through the channel to the receiver (Bleich, M.D. et al. 2009; Haghighat, A., 2002).

This paper deals with SDR based digital signal processing technique to process RFID signal and evaluate the performance of the system. The system performance is evaluated by comparing different signal to noise ratio (SNR) versus bit error rate (BER) of the signal using multi-modulation techniques.

SDR Framework:

Realize it or not, RFID is an integral part of our life. RFID is a term coined for short-range radio technology
used to communicate mainly digital information between a stationary location and a movable object or between movable objects. SDR is used to increase productivity and convenience of these RFID communications.

Fig. 1 shows Software defined radio framework, in which the input filter is a band pass filter, which samples the digital signal at a rate of at least twice the received frequency. The sampled digital signals are then converted to analog signal via a wideband DAC and then possibly up-converted from intermediate frequency (IF) to radio frequency (RF). Modulation then changes the RF carrier signals of a tag to convey the information to the receiver through channel. An Additive White Gaussian Noise (AWGN) channel is being chosen for RFID data transmission.

![Fig. 1: SDR framework for RFID signal transmission.](image)

The receiver employs a wideband ADC that captures all of the channels of the software radio node. The receiver then extracts down-converted signals and demodulates the channel waveform using software on a processor. In the receiver, the RF front end translates the received signal from its carrier frequency to an IF signal or to baseband. However, in transmitter, the RF front end translates the transmit signal from IF or baseband to the desired carrier frequency. The output of ADC is sampled at a rate at least twice the bandwidth of the baseband signal. The output filter is a low pass filter, which band limits the baseband signal.

Finally, an estimate of the original signal is produced at the output of the receiver. The receiver’s output signal is then compare to the input signal for evaluation. Several metrics are available to evaluate a communications link performance, as for example the received BER in the case of digital signals.

**Modulation Techniques:**

Modulation can be defined as the process whereby the amplitude, frequency, or phase of the carrier, or a combination of them, is varied in accordance with the digital information to be transmitted. There are numbers of modulation techniques, depends on analog sinusoid features such as amplitude, frequency and phase. The carrier waveform is altered into digital information by amplitude shift keying (ASK), frequency shift keying (FSK), or phase shift keying (PSK) modulation, respectively. In SDR, the modulation techniques provide a considerable amount of flexibility while maintaining performance (Blech, M.D. et al., 2009; Haghighat, A., 2002). The proposed SDR framework is developed using QAM modulation techniques for RFID signal transmission. However, PSK modulation is also used in the SDR to compare the performance evaluation of the system.

**Quadrature Amplitude Modulation:**

QAM is the combination of ASK and PSK modulation in which digital information is carried in both the phase and the amplitude of the carrier signal. QAM is a method for sending two separate channels of information (Simoneau, J.B. and L.W. Pearson, 2009). The carrier is shifted into two carriers namely the sine and cosine versions. The outputs of both modulators are algebraically summed, in which the signal is to be transmitted containing the in-phase, \( I \) and quadrature, \( Q \) information.

Depending on the type of information signal and transmission medium, different modulation techniques are employed (Bin, X. and W. Jiangzhou, 2005). These techniques are used in the transmission from source to sink RFID signal transmission to obtain higher spectral efficiency. In QAM modulation, the information is represented by phase and amplitude variations of the carrier signal (Dinh, A. et al., 2008). The set of possible combinations of amplitude and phase is shown in the constellation diagram of Fig. 2.
The baseband equivalent representation, $u_m(t)$, of the QAM signal can be expressed as:

$$u_m(t) = (A_m^I + jA_m^Q)g(t) \quad m = 1, 2, \ldots, M$$

where $A_m^I, A_m^Q$ is a constant of average transmitted power referred to the in-phase, $I$ and quadrature, $Q$ amplitudes corresponding to the $M$ possible symbols in the two-dimensional space. The function $g(t)$ is a real-valued signal whose shape influences the spectrum of the transmitted signal. The $u_m(t)$, in (1) can also be represented in polar form as follows:

$$u_m(t) = A_m e^{j\theta_m} g(t) \quad m = 1, 2, \ldots, M$$

where, $A_m$ and $\theta_m$ denote the amplitude and phase of the $m^{th}$ symbol and are given as follows:

$$\begin{align*}
A_m &= \sqrt{(A_m^I)^2 + (A_m^Q)^2} \\
\theta_m &= \tan^{-1}\left(\frac{A_m^Q}{A_m^I}\right)
\end{align*}$$

The baseband signal described in (1) can be expressed as a bandpass signal, $s_m(t)$, which is chosen from one of $M$ possible signal waveforms as follows:

$$s_m(t) = A_m g(t) \cos(2\pi f_c t + \theta_m) \quad m = 1, 2, \ldots, M$$

where $f_c$ is the intermediate carrier frequency. Alternatively, the bandpass QAM signal in (4) can be expressed equivalently in terms of its quadrature components as:

$$s_m(t) = A_m g(t)(\cos(2\pi f_c t)\cos(\theta_m) - \sin(2\pi f_c t)\sin(\theta_m))$$

The equation (5) can be written as:

$$s_m(t) = A_m^I \cos(2\pi f_c t) - A_m^Q \sin(2\pi f_c t)$$

Where $A_m^I = A_m g(t) \cos(\theta_m)$ and $A_m^Q = A_m g(t) \sin(\theta_m)$.

QAM is designed to transmit two separate signals independently with the same carrier frequency by using two quadrature carriers $\cos(2\pi f_c)$ and $\sin(2\pi f_c)$. These two separate modulated signals are then added and transmitted. This structure of QAM allows for $M$ discrete amplitude levels (M-QAM) and thus permits a symbol to contain more than one bit of information. The general form a M-QAM signal is given by equation (5), where
g(t) is the signal pulse shape and $A^I_m$ and $A^Q_m$ are the information bearing signal amplitudes of the quadrature carriers.

The above explanation leads to the most common functional representation of the QAM modulator, which is shown in Fig. 3. The input baseband sequence with bit rate $R_b$ bits/second is encoded into two quadrature $M$ level signals, each having a symbol rate of $R=R/K$ symbols/second, where $K=\log_2(M)$. These two components of $I$ and $Q$ are then filtered by pulse-shaping low pass filters (LPF’s) $g(t)$ to limit the transmission bandwidth. Finally, the quadrature signals modulate the $I$ and $Q$ carrier’s for transmission. The transmitted bandpass signal $s_{m}(t)$, which is the summation of all symbols represented by the $M$ possible signaling waveforms for QAM.

![Fig. 3: Typical QAM modulator.](image)

Since the modulator output frequency is often lower than the desired transmission frequency, the modulator frequency must be up-converted to the appropriate radio frequency (RF) for transmission. When the transmitted signal reaches the intended receiver, it undergoes a demodulation process. This step is the opposite of modulation and refers to the process required to extract the original information signal from the modulated signal

**QAM Demodulation:**

The information is carried in the phase and amplitude of the modulated carrier for the QAM signal. The receiver is assumed to be able to generate a reference carrier whose frequency and phase are identical to those of the carrier at the transmitter. When the receiver exploits knowledge of the carrier’s phase to detect the signals, the process is called demodulation (Blech, M.D. et al., 2009). Fig. 4 shows a block diagram of a QAM demodulator.

![Fig. 4. Block diagram of a QAM demodulator.](image)

At the receiver, the received high frequency signal is first down-converted to a lower intermediate frequency (IF) before being further processed. The demodulator performs the majority of its work at an intermediate or baseband frequency. The mixer in the demodulator converts the IF signal to a baseband signal, by multiplying the incoming IF signal with a locally generated carrier reference and the product is passed through a lowpass filter (LPF). The LPF removes the high-frequency components and selects the difference component from the mixer output. These LPFs also perform as matched filters whose impulse responses are matched to the transmitted signal to provide the maximum signal-to-noise ratio (SNR) at their output (Proakis, J.G., 2000).

Assuming that the Gaussian noise is the only channel disturbance, the received signal, $r(t)$, can be expressed as follows.
\( r(t) = s_m(t) + v(t) \)  \( \quad (7) \)

where \( s_m(t) \) denotes the transmitted signal and \( v(t) \) refers to the additive noise. Ignoring the noise, \( r(t) \) is simplified as follows:

\[
\begin{align*}
r(t) &= u_i(t) \cos(2\pi f_c t + \varphi_c) - u_o(t) \sin(2\pi f_c t + \varphi_c) \\
&= u_i(t) \cos(2\pi f_c t) - u_o(t) \sin(2\pi f_c t) \\
&= \cos(\varphi_c) u_i(t) - \sin(\varphi_c) u_o(t)
\end{align*}
\]

where \( u_i(t) \) and \( u_o(t) \) are the \( I \) and \( Q \) amplitudes of the information signal in which \( f_c \) and \( \varphi_c \) are the carrier frequency and phase. This signal is demodulated by two quadrature reference carriers as follows:

\[
\begin{align*}
c_i(t) &= \cos(2\pi f_c t + \varphi_o) \\
c_q(t) &= -\sin(2\pi f_c t + \varphi_o)
\end{align*}
\]

\( \quad (9) \)

Where \( f_c \) and \( \varphi_o \) are the frequency and phase of the locally generated carrier. Multiplication of \( r(t) \) with \( c_i(t) \) followed by low pass filtering, the output in-phase signal with \( I \) component as follows:

\[
\begin{align*}
Y_i(t) = &\frac{1}{2} u_i(t) \cos[2\pi(f_c-f_o)t+(\varphi_c-\varphi_o)] \\
&-\frac{1}{2} u_o(t) \sin[2\pi(f_c-f_o)t+(\varphi_c-\varphi_o)]
\end{align*}
\]

\( \quad (10) \)

Similarly, multiplication of \( r(t) \) by \( c_q(t) \) followed by low pass filtering, the output signal with quadrature component as follows:

\[
\begin{align*}
Y_q(t) = &\frac{1}{2} u_o(t) \cos[2\pi(f_c-f_o)t+(\varphi_c-\varphi_o)] \\
&+\frac{1}{2} u_i(t) \sin[2\pi(f_c-f_o)t+(\varphi_c-\varphi_o)]
\end{align*}
\]

\( \quad (11) \)

We can see from expression (10) and (11) that if \( f_o = f_c \) and \( \varphi_o = \varphi_c \), the output of QAM demodulator is same as the transmitted baseband signal \( u_i(t) \) and \( u_o(t) \). Otherwise, the phase error \( 2\pi(f_c-f_o)t+(\varphi_c-\varphi_o) \) will reduce the signal level in voltage by the factor \( \cos \left[ 2\pi(f_c-f_o)t+(\varphi_c-\varphi_o) \right] \) and in power by a factor \( \cos^2 \left[ 2\pi(f_c-f_o)t+(\varphi_c-\varphi_o) \right] \). Also there is cross-talk interference from the \( I \) and \( Q \) components. Since the average power levels of \( u_i(t) \) and \( u_o(t) \) are similar, a small phase error causes a large degradation in performance. Hence, the phase accuracy requirements for QAM are very high.

**Phase Shift Keying:**

PSK is a modulation technique in which the phase of the carrier wave is modified based on what symbol is being sent (Simoneau, J.B. and L.W. Pearson, 2009). PSK is a method to map data symbol to corresponding phase status. Binary phase shift keying (BPSK) signal is presented in equation (12), when the initial phase is zero.

\[
S_{PSK}(t) = \begin{cases} 
S_1 = A \cos \omega t & 0 \leq t \leq T_b \text{ (for binary 1)} \\
S_2 = -A \cos \omega t & 0 \leq t \leq T_b \text{ (for binary 0)} 
\end{cases}
\]

\( \quad (12) \)

\[
S_{PSK}(t) = \begin{cases} 
S_1 = A \cos \omega t & 0 \leq t \ll T_b \text{ (for binary 1)} \\
S_2 = -A \cos \omega t & 0 \leq t \ll T_b \text{ (for binary 0)} 
\end{cases}
\]

Any number of phases may be used to construct a PSK constellation but 8-PSK is usually the highest order PSK constellation deployed. We simulate it in the RFID environment.

**Results and Discussion**

In this section, we demonstrate the test performances of the proposed SDR system using PSK and QAM modulation scheme. SDR simulations were made by Matlab program to evaluate the RFID signal transmission performances. Transmitted and received signal, modulated and channel signal, BER vs. SNR results of the
proposed system are presented to show the SDR system performances.

Fig. 5 shows the transmitted and received signal using proposed SDR system. It can be seen that the nature and the shape of the transmitted and received signals are same. However, the magnitude of the signals are varied each other due to synchronization noise in the channel and the filter effect. Thus, based on operating principle, it confirmed that the proposed SDR transmitted 100% RFID data to the system.

Fig. 6 shows the comparison between the modulated signal and the channel signal. The channel signal is perturbed slightly due to noise insertion into the channel. This perturbed can be maintaining a sufficient signal-to-noise ratio in the imperfect transmission through electronic circuitry and the propagation medium.

SDR based BER performance of PSK and QAM modulation scheme provides an estimate that exhibits small fluctuations compared to the input value as shown in Fig. 7. The metrics of performance is estimated by plotting BER versus SNR i.e. $E_b/N_0$. It can be seen, due to the influence of the probability error on the detection process, these fluctuations are caused BER degradation as compared to input probability error and reduce the performance. It is also observed that the BER is degrading with the increasing of SNR. In QAM modulation scheme BER degrades almost parallel with the input or ideal degradation curve. However, PSK BER degradation is faster compared to input or ideal BER degradation curve.

![Fig. 5: Transmitted and Received Signals using SDR.](image)

![Fig. 6: Comparison between Modulated and Channel Signals.](image)

The dotted line of QAM modulation shows the BER performance in the proposed SDR system is perfect synchronizations while the PSK modulation show the degraded performance caused by imperfect carrier synchronization and SNR. Therefore, BER degradation in terms of the accuracy can be estimated by the perfect synchronization using SDR program. Thus, SDR exhibits inherent robustness, resulting in high RFID signal transmission efficiency and low circuit complexity is achieved.

The degraded performance of modulation schemes BER and their errors are obtained by varying the SNR from 0 to 25 as shown in Table 1. It is seen that with the increase of SNR, the performance of the system is degrading in terms of BER and synchronizing error of the PSK and QAM modulation, respectively. Table 1 also shows that synchronizing error and BER degradation of QAM scheme are bit better compare to PSK modulation scheme.

<p>| Table 1: Evaluation of PSK and QAM modulations in Terms of BER and SNR. |
|------------------|------------------|------------------|------------------|------------------|------------------|</p>
<table>
<thead>
<tr>
<th>SNR</th>
<th>PSK Error</th>
<th>PSK BER</th>
<th>QAM Error</th>
<th>QAM BER</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>9</td>
<td>0.35</td>
<td>6</td>
<td>0.25</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>0.295</td>
<td>5</td>
<td>0.208333</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>0.2666</td>
<td>4</td>
<td>0.16667</td>
</tr>
<tr>
<td>15</td>
<td>5</td>
<td>0.213</td>
<td>3</td>
<td>0.125</td>
</tr>
</tbody>
</table>
Fig. 7: BER vs. SNR of a RFID system using PSK and QAM modulation.

**Conclusion:**

In this paper, RFID simulation based SDR system is designed for PSK and QAM modulations. This is due to simplicity and reduces the peripheral hardware that is used for RFID devices. The obtained results show that QAM has the best performance in terms of BER versus SNR between PSK and QAM modulations through AWGN channel. It can be seen that the SNR at 6 dB and above, the performance of QAM is better than that of PSK i.e. QAM error probability matched well with the input error probability. Thus, it can be concluded that higher the SNR, higher the BER degradation. As a result, RFID transmission capability is increased.

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