Channel Estimation Based in Comb-Type Pilots Arrangement for OFDM System over Time Varying Channel

Hala M. Mahmoud
Al-Quds University/ Department of Electronics Engineering, Jerusalem, Palestine
Email: hmahmoud@eng.alquds.edu

Allam S. Mousa
An-Najah-University/ Department of Electrical Engineering, Nablus, Palestine
Email: allam@najah.edu

Rashid Saleem
University of Manchester /School of Electrical and Electronic Engineering, UK
Email: rashid.saleem@postgrad.manchester.ac.uk

***Abstract*----Orthogonal Frequency Division Multiplexing (OFDM) has been recently applied widely in wireless communication systems, due to its high data rate, transmission capability with high bandwidth, efficiency and its robustness to multipath delay .Channel estimation is an essential problem in OFDM system. Pilot-aided channel estimation has been used; a good choice of the pilot pattern should match the channel behavior both in time and frequency domains. We explored comb pilot arrangements. The advantage for comb type pilots arrangement in channel estimation is the ability to track the variation of the channel caused by doppler frequency, it is observed that the doppler effect can be reduced, and so this will increase the system mobility. Kalman and Least Square (LS) estimators have been proposed to estimate the Channel Frequency Response (CFR) at the pilots location, then CFR at data sub channels are obtained by mean of interpolation between estimates at pilot locations. Different types of interpolations have been used such as; low pass interpolation; spline cubic interpolation and linear interpolation. Kalman estimation has better performance than LS estimation. The estimators perform about the same for SNR lower than 10 dB. The performances of all schemes have been compared by finding Bit Error Rate (BER), where BPSK modulation scheme was used.**

Keyword--Channel estimation, OFDM, time-varying channels, Kalman filtering, LS estimation

I. INTRODUCTION

In wireless mobile communications, the channels are time, frequency selectivity. The transmitted signal propagating via multiple paths experiences various delays due to different lengths of the paths. This makes the channel frequency selective and causes inter-symbol interference (ISI). The ISI may distort the received signal so severely that the transmitted symbols cannot be recovered. Multicarrier modulation such as OFDM is a powerful technique to turn the frequency selective wireless channel into a set of frequency flat narrowband channels. This reduces the complexity of the equalization task considerably. Mobility causes the Channel Impulse Response (CIR) to be time-varying. Hence, it needs then to be tracked over time. The knowledge of the CIR is needed at the receiver in order to recover the transmitted data. Typically, no prior knowledge on the channel is available, and it may vary over time. Hence, it needs to be estimated and the estimates updated in a regular basis. In communication systems, channel estimation methods may be classified as blind, semi-blind or pilot-aided. Blind algorithms do not require any training data and exploit statistical or structural properties of communication signals. Pilot-aided methods on the other hand rely on a set of known symbols interleaved with data in order to acquire the channel estimate. Semi-blind methods combine a blind criterion with limited amount of pilot data, which improves both effective data rates and convergence speed. They also benefit from a larger sample support since both pilot and data are used for channel

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estimation.

Pilot-aided methods or non blind channel estimation that can be performed by either inserting pilot tones into all of the sub carriers of OFDM symbols, with a specific period, or inserting pilot tones into each OFDM symbol. The first one, block type pilot channel estimation, has been developed under the assumption of slow fading channel. The estimation of the channel for this block-type pilot arrangement can be based on LS or Minimum Mean-Square Error (MMSE). The later, comb-type pilot channel estimation has been introduced to satisfy the need for estimation when the channel changes even in one OFDM block [2]. The comb-type pilot channel estimation consists of algorithms to estimate the channel at pilot frequencies, and to interpolate the channel coefficients that belong to the pilot sub carriers using low pass interpolation, spline cubic interpolation or linear interpolation [3], to obtain the CFR at the data sub carriers. The channel estimation at the pilots can be based on, LS, MMSE, Least Mean-Square (LMS), Recursive Least Square (RLS); Kalman estimation has been suggested in order to increase the performance of the estimation process.

In this paper, channel estimation is performed in two steps:

- The first step is to estimate the channel frequency coefficients at the pilot symbols positions using LS estimator and Kalman estimator.
- Using the estimates of the channel frequency coefficients we then interpolate over channel frequency coefficients corresponding to the data symbols.

Our approach is to enhance the performance of the estimation process using Kalman estimator to estimate the CFR at the pilots, and comb pilots arrangement to track the time varying channel and so decrease the doppler effects.

II. SYSTEM MODEL

A standard OFDM system is shown in Fig.1. The information symbols are grouped into blocks and Inverse Discrete Fourier Transform (IDFT) is performed on each block then a proper cyclic prefix (CP) extension is added before they are fed into the modulator and transmitted. At the receiver, Discrete Fourier Transform (DFT) is performed on each received OFDM symbol after the CP is removed. The received signal at the input of DFT is given by (1).

$$yk[n]=Hk[n]xk[n]+wk[n]$$

$$k=1,\ldots N \quad -\infty<n<\infty \qquad (1)$$

Where $x_k[n]$ is the k^{th} information symbol of the n^{th} OFDM symbol, $H_k[n]$ is the gain of the k^{th} sub channel during the n^{th} OFDM symbol, $w_k[n]$ is the noise, and N is the total number of sub carriers [4]. A dynamic estimation of channel is necessary before the demodulation of OFDM signals since the radio channel is frequency selective and time-varying for wideband mobile communication systems. The channel estimation can be performed by either Block type pilots channel estimation or Comb type pilots channel estimation. To ease the implementation of the OFDM modulator, the number of available sub carriers K is set to be a power of 2, $k=2^L$. The sub carriers are indexed as k=0,1,..,k-1 while the OFDM symbols are denoted as n=0,1,…,N-1, and L is the total Number of sub carrier (N) divided by the Number of Pilot sub carrier (K_p). Equi-spaced pilot sub carriers in the frequency domain are known to minimize the channel estimation error [5]; accordingly, the numbers of pilot arrangements that constitute possible choices for the transmitter in each OFDM symbol are L+1 which is explained as:

- No pilot sub carriers (Kp = 0): the OFDM symbol contains only data sub carriers.
- $k=2^L$ Equi-spaced pilot sub carriers where k=0, 1… Kp – 1, [6].

The channel is assumed to be Rayleigh fading and, Jakes' model is used for the Doppler Power Spectrum (DPS) of the fading process. Specifically, the correlation of the channel gain $H_k[n]$ is given as by (2).

$$R_{hh}(n)=J_0(2\pi f_{dmax}T_f n) \qquad (2)$$

Where J_0 () is the zero-order Bessel function of the first kind, T_f is the symbol period, and ($f_{dmax}T_f$) denotes the doppler rate [7].

III. CHANNEL ESTIMATION USING LS ESTIMATOR

For comb type pilot subcarrier arrangement, the K_p pilot signals $X_p(m)$, m =0, 1, 2, …, K_p are uniformly inserted into X(k). That is, the total N subcarriers are divided into K_p groups, each with L= N/K_p adjacent subcarriers. In each group, the first subcarrier is used to transmit pilot signal. The OFDM signal modulated on the k^{th} subcarrier as shown in (3) and (4).

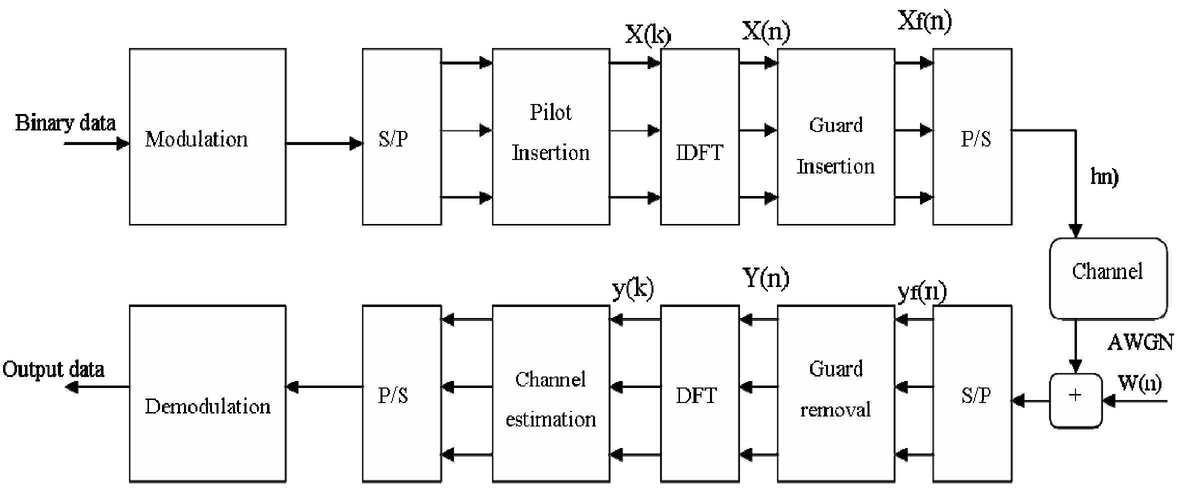

Figure 1. OFDM system model.

$$X(k) = X(mL + l) \tag{3}$$

Where

$$X(k) = \begin{cases} X_p(m) = 0, \text{where} l = 0. \\ \text{inf.Data}, \text{where} l = 1,2,\cdots L-1 \end{cases} \tag{4}$$

$X_p(m)$ is the m[th] pilot carrier value. The received pilot signal vector, $Y_p = [Y_p(0), Y_p(1), \dots Y_p(N_p\text{-}1)]^T$ can be expressed as given by (5) and (6).

$$Y_p = X_p H_p + W_p \tag{5}$$

Where

$$X_p = \begin{bmatrix} x_p & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & x_p(N_p - 1) \end{bmatrix} \tag{6}$$

H_p (k) is the frequency response of the channel at pilot sub-carriers and defined as $H_p = [H_p(0), H_p(1), \dots H_p(N_p\text{-}1)]^T$, and I_p is a vector of Inter-Carrier Interference (ICI) and W_p is the vector of Gaussian noise in pilot subcarriers. The estimation of pilot signals based on LS criterion, is given by (7) and (8) respectively.

$$H_{p,ls} = [H_{p,ls}(0), H_{p,ls}(1), \dots H_{p,ls}(N\text{-}1)]^T \tag{7}$$

$$H_{p,ls} = X_p^{-1} Y_p \tag{8}$$

The LS estimate of Hp is susceptible to Gaussian noise and ICI because the channel responses of data subcarriers are obtained by interpolation [8].

IV. KALMAN ESTIMATOR

An adaptive estimator is an estimator that updates its parameters over time as a consequence of changing channel statistics. Kalman estimator is one of the adaptive estimation algorithms that are used to estimate the fading process in OFDM system. It is an efficient recursive algorithm which estimates the state of a dynamic system from a series of noisy measurements. Kalman filter has been applied in communication systems since 1970s and it could also be applied to track the states of time varying channels, the state variable is defined as the channel states, which can be modeled as AR model, because it reflects the statistics of time varying channel. The noise is Gaussian Wide-Sense Stationary Uncorrelated Scattering one (GWSSUS). A time-varying frequency-selective wireless channel is usually modeled as a Wide-Sense Stationary Uncorrelated Scattering (WSSUS) process. The impulse response of a WSSUS channel is expressed as in (9)

$$H(t, \tau) = \sum_{k=1}^{M} \alpha(t)\delta(t - \tau_k) \tag{9}$$

These describes the propagation of waves through multiple paths of different delays τ_k and attenuation α (t), α (t) are Wide-Sense Stationary (WSS) complex Gaussian processes, and are uncorrelated for different paths. The AR-model that is assumed to model the time-variant channel is given by (10)[5].

$$H(l+1) = FH(l) + w(l) \quad (10)$$

Where H (l) is the frequency response of the channel at the pilot symbols positions with dimension M x 1 and w (l) is the driving noise at the pilot symbols position with dimension Mx1 which is a zero-mean process. Using this AR-model it is possible to construct the Kalman channel estimator as given in (11) to (14), where the gain, innovation process, channels impulse response and error covariance matrix is stated respectively;

$$K(l)=FP(l,l-1)C(l)^H[C(l)P(l,l-1)C(l)^H+\sigma^2 I]^{-1} \quad (11)$$

$$A(l) = Y(l)-C(l)H(l) \quad (12)$$

$$H(l+1) = FH(l) + K(l)\alpha(l) \quad (13)$$

$$P(l+1,l) = F[1-F^{-1}K(l)]P(l,l-1)F^H+V \quad (14)$$

Where C(l) is a M x M diagonal matrix with pilot symbols on its diagonal, M is the number of pilot symbols, σ^2 is the variance of the AWGN, and K(l) is the Kalman gain which is used to update the channel impulse response in order to minimize the error α(l), the correlation of the time-variant channel is modeled as given by (15).

$$E[h(l,i)h^*(l+1),j)] = \begin{cases} p_i j_0(2\Pi f_{dmax} T_f), i = j \\ 0, i \neq j \end{cases} \quad (15)$$

Where P_i = [E h (l, i)], f_{dmax} is the maximum doppler shift, T_f is OFDM symbol time, J_0 () is the bessel function of the first-kind and zero order and i ,j are the frame and subcarrier index respectively. Rewriting H(l) as given by (16)

$$H(l) = Wh(l) \quad (16)$$

Then

$$E[H(l)^H H(l+1)] = J_0(2\pi f_{dmax} T_f) WPW^T \quad (17)$$

Where P is an N x N diagonal matrix with the diagonal elements P_i and W is an M x N partial DFT matrix obtained from a DFT matrix by deleting the rows that does not correspond to pilot symbols. Here M denotes the number of pilot symbols in one OFDM symbol and N is the total number of symbols in one OFDM symbol and F is given in (18), [7], [9].

$$F = (2\pi f_{dmax} T_f) WPW^T \quad (18)$$

The complexity of Kalman estimator can be reduced by factorize P (l,l-1) using Eigen value de-composition which is given in (19).

$$P(l, l-1) = U D(l) U^T \quad (19)$$

Where U is the unitary matrix whose columns is the Eigen vectors and D (l) is a diagonal matrix with the Eigen values on its diagonal

V. CHANNEL INTERPOLATION

Once the CFR estimates have been obtained at the pilot subcarrier frequencies, they are extended to data subcarriers by interpolation. There are two types of interpolators

- One dimensional Interpolator.
- Two dimensional interpolator.

Later on, the theory of two-dimensional sampling was invoked, in an effort to both reduce pilot symbol rates and improve channel estimation performance. When the channel is probed simultaneously in time and frequency domains, the overhead of pilot symbols may be reduced significantly as two-dimensional (2-D) processing captures simultaneously the correlation of the channel transfer function in both time and frequency. Two dimensional interpolators such as wiener filtering method or since interpolator are used instead of using two interpolators in time and frequency. Two-dimensional time-frequency wiener filter, which is the optimal filter in the mean square error sense, this estimator assumes knowledge of the doubly selective channel statistics, a condition which is hard to fulfill in realistic scenarios where the channel is not directly observable [1].

There are different types of one dimensional interpolation schemes such as; linear interpolation, spline-cubic interpolation, low pass interpolation, second order interpolation and time domain When pilot symbols are distributed within the OFDM block using, e.g., comb-type pilot structure, interpolation in the frequency direction is mandatory to obtain the CFR at data subcarriers. Piecewise-linear and piecewise-constant interpolation are among the simplest approaches. Higher-order interpolation such as piecewise second-order polynomial interpolation, low-pass and cubic-spline methods offer improved channel interpolation. The spacing between pilots or the amount of pilots is determined by the frequency selectivity of the channel, which relates to the maximum delay spread of the channel in time domain. With block-type of pilots, interpolation in the time domain is needed instead. Time-selectivity of the channel dictates the rate of retraining. It should be chosen smaller than the coherence time in this work we have viewed three types of Interpolation, linear interpolation, low pass interpolation and spline cubic interpolation:

A. Linear interpolation

The channel estimation at the data subcarrier k where $mL<k<(m+1)L$, using linear interpolation is given in (20) and (21), [10].

$$H(k)=H(mL+l), \quad 0\leq l\leq L \tag{20}$$

$$H(k)=H_p(m+1)-H_p(m)\left(\frac{m}{L}\right)+H_p(m)$$

$$H(k)=H_p(m+1)-H_p(m)\left(\frac{m}{L}\right)+H_p(m) \tag{21}$$

B. Low-Pass Interpolation

The low-pass interpolation method is performed by inserting zeros into the original sequence and then applying a low-pass finite-length impulse response (FIR) filter, which allows the original data to pass through it without any changing. This method also interpolates such that the mean-square error between the interpolated points and their ideal values is minimized [10].

C. Spline Cubic Interpolation

The spline cubic interpolation method produces smooth and continuous polynomial fitted to given data points. The fundamental idea behind spline cubic interpolation is based on draw smooth curves through a number of points [10].

VI. SIMULATION RESULTS

interpolation.

Simulation results have been used to demonstrate the performance of the algorithm discussed above. An OFDM system is considered with the parameters as given in Table1.

The BER of the OFDM system was tested against the SNR using Kalman and LS estimation methods, with different interpolation techniques as shown in Figure 2 and Figure 3. It can be seen that Low Pass Interpolation have better performance than either Spline cubic or Linear interpolation, this is because Low pass interpolation technique does the interpolation such that the mean-square error between the interpolated points and their ideal values is minimized.

TABLE 1
SIMULATION PARAMETERS

Parameter	Specifications
Number of Subcarrier	512
IFFT, FFT Size	512
Modulation Type	BPSK
Pilot Ratio	1/8
Channel Model	Rayleigh Fading
Doppler Frequency	70 Hz
Guard Interval	1/32 from symbol period

The system performance of using comb type pilots arrangement based on Kalman estimation method, has outperformed better than the LS estimation as illustrated in Fig.4. LS estimator is particularly interesting since it is one of the most simple estimation methods. Low pass interpolation method has been used as an interpolation technique, because it has the best performance among the other interpolation methods

One of the parameters that affect Kalman and LS estimation performance is the modulation technique used, where simulation results could show that 2-QAM modulation method has achieved better performance than 4, and 16-QAM as illustrated in Fig.5 and Fig 6. Moreover, BPSK method has given better performance than QPSK, 8-PSK and 16PSK .

One of the advantages for comb type pilots arrangements in channel estimation is the ability to track the variation of the channel caused by Doppler frequency this is because every OFDM symbol has certain amount of pilots. In Fig 7 it is clear that as the Doppler frequency increase the BER remains constant at constant SNR, which mean as the mobility increases the BER will remain constant

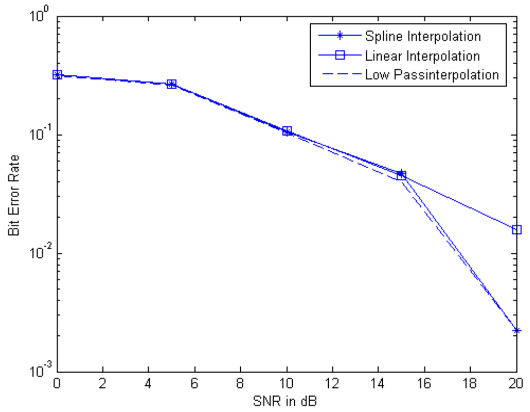

Figure 2. Interpolation methods using Kalman estimator

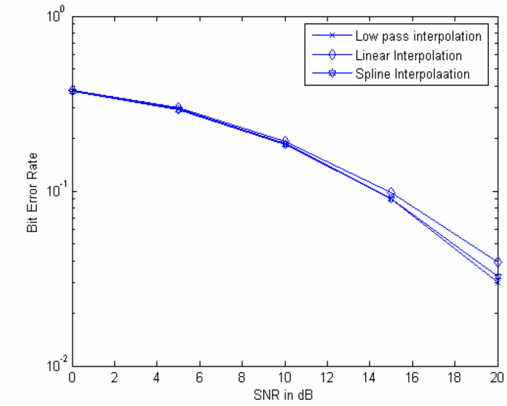

Figure 3 Interpolation methods using LS estimation

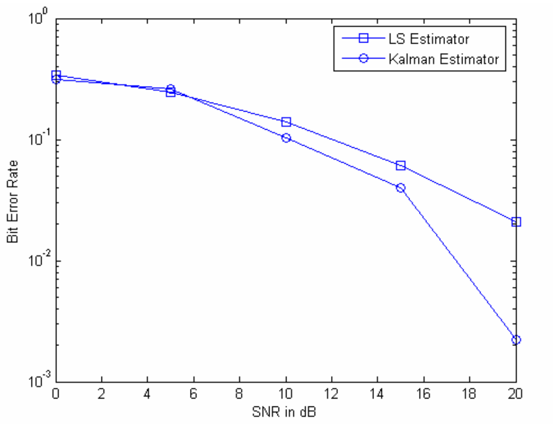

Figure 4 Kalman and Least square estimators performance

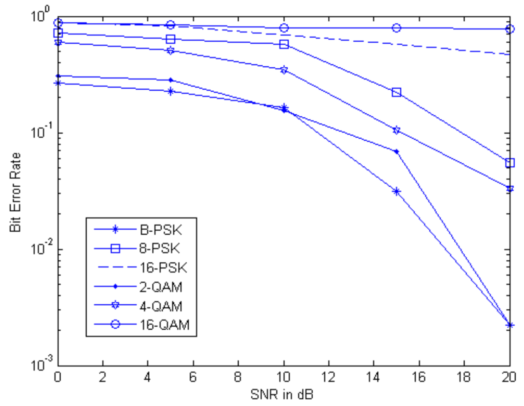

Figure 5. Performance for M-QAM and M-PSK modulation schemes, Kalman Estimator

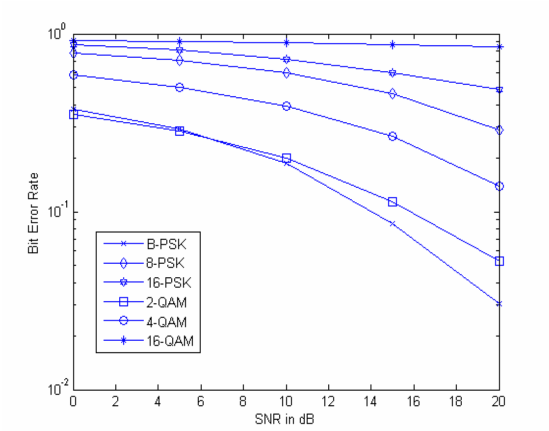

Figure 6. Performance for M-QAM and M-PSK modulation schemes

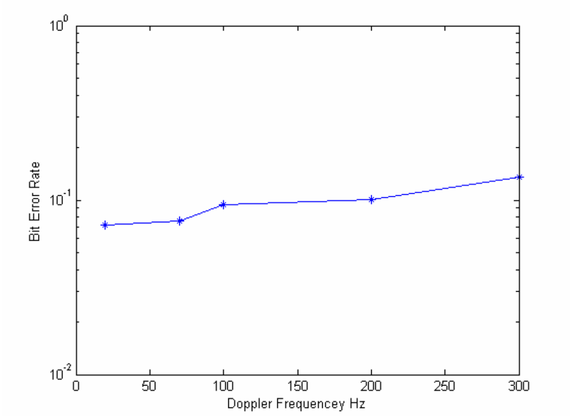

Figure 7. Doppler frequency effect for SNR=15dB,Kalman estimator

VII. CONCLUSION

Channel estimation based on comb type pilot arrangement was presented by giving channel estimation method at pilot frequencies and then by mean of interpolation the CFR at data frequencies are estimated. The advantage of using comb type pilots arrangement is the ability to track the variation of channel in time. Simulation results shows that comb-type pilot based channel estimation with low-pass interpolation performs the best among all other interpolation methods. This expected since low pass interpolation does the interpolation in such a way that mean square error is minimized. Kalman estimation has better performance than LS estimation. The estimators perform about the same for SNR lower than 10 dB. This is an interesting property which means that the choice of channel estimator is not that important in terms of symbol errors for low SNR. When choosing a channel estimating method for low SNR the focus should instead be on how much information the estimating methods needs and also how high its complexity is. Different parameters were considered to see how it affects the BER performance. For Modulation scheme, the 2-QAM and BPSK have the least BER compared to the rest of M-QAM and M-PSK.

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Hala M. Mahmoud she was born in Palestine in 8th of July 1983. Received her M.Sc. program in Computer and Electrical Engineering Department of Al Quds University. She received her B.Sc. Degrees in Electrical Engineering from An Najah National University in December 2006 with a very good rank. Her current research interests include wireless communication with emphasis on WiMAX and OFDM.

Allam S. Mousa received his B.Sc. M.Sc. and PhD. Degrees in Electrical and Electronics Engineering from Eastern Mediterranean University in 1990, 1992 and 1996 respectively. From 1996 to 2000 he worked as an Assistant Professor at Al Quds University, in 1999 he was the chairman of the Electronics Engineering Department at the same university. In 2000 he joint An Najah University, from 2004 until now he is the chairman of the Electrical Engineering Department, he is also an Associate Professor there. His current research interests are OFDM, Digital Signal Processing with emphasis on Image and Audio coding, Coverage and Capacity of mobile communication.