ANN based demodulator for UMTS signal measurements

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Abstract: The paper proposes the use of the Artificial Neural Network (ANN) to design a new demodulator of the telecommunication signals. This demodulator is candidate to be employed into the measurement instrument of the third generation mobile telecommunications UMTS Terrestrial Radio Access. It is developed on the basis of the multiplayer perceptron ANN and it permits to perform in one shot both the descrambling and the despreading operations. Numerical tests performed by using signals according to the UMTS standard show that the ANN demodulator can guaranty greater accuracy than the traditional one in the case the modulated signal is affected by high level of both noise and distortion.

Keywords: UMTS, Demodulator, Descrambling, Despreading, Artificial Neural Network.

I. Introduction

The advantageous use of the Artificial Neural Networks (ANNs) in measurement instrumentation and, in particular, to process the modulated signals for telecommunication has been shown in previous papers [1]-[2]. In [1] the ANN based decoder for Dual Tone Multi Frequency signals was presented, and the results of tests performed on the DSP implementation are shown. The comparison with the traditional ones permits to highlight the advantageous performances of the ANN based demodulator beyond the limits given by the international recommendations. In [2] the ANN based demodulator for signals of the GSM standard was designed, discussed and metrological characterised. Numerical tests confirm that the use of this demodulator permits to reduce the carrier frequency error measurement in the case of both static and dynamic propagation of the signals.
These results confirm that the ANNs show interesting properties to efficiently process the input signals affected by high level of both noise and distortion characterising the telecommunication networks. Moreover, the parallel architecture of the ANNs permits to process the signals in very fast way. Therefore, the ANNs are an useful tool that permits to overcome the limits of the traditional approach to the signal processing.
The ANN based demodulator to be taken into account in the paper is part of the input block of the non-intrusive instrument designed for measurements on signals of the third generation mobile telecommunications UMTS Terrestrial Radio Access (UTRA). Important aspect taken into account in developing the ANN based demodulator is that the UMTS standard imposes (i) the scrambling code in order to realize the transmission with frame Wide-band Code Division Multiple Access (W-CDMA), and (ii) the spreading code in order to realize the multi-user transmission. Therefore, beside to be able to operate in substitution of the traditional demodulator block, others assigned functions to the proposed demodulator regard to both the descrambling and the despreading operations of the input signal. Than, the operations that the ANN are required to perform in one shot are: (i) the descrambling of the input signal, previously down converted in base band, according with the used code by the transmitter, (ii) the despreading in order to recovery the transmitted symbols, and (iii) the symbol extraction. Fig.1 shows the block schemes of both the traditional and the ANN based demodulator in the case four output channels are considered. In both the schemes (i) the input signal is down converted in base band, (ii) the two components, the phase signal component I and the quadrature component Q, are extracted, (iii) the symbols are recovered, and (iv) the symbols are reconstructed for each channel. Nevertheless, the two schemes of Fig.1 differ because the ANN based demodulator works so as to perform in parallel way (i) the descrambling, (ii) the despreading, and (iii) the symbol extraction operations of the traditional demodulator. The pre-processing block, before the ANN block, operates to adapt the signal to the requirements of the successive block. The proposed demodulator is constituted by two ANNs, one trained for the phase signal component I and another for the quadrature component Q. The ANN architecture showing the best performances and, consequently, used in the proposed demodulator is the multiplayer perceptron.
In the following, both the design and the training phase of the ANN based demodulator are presented in the case of the Frequency Division Duplex (FDD) functioning modes. Successively, the preliminary results of the numerical tests on the third generation modulated signals, generated according to the international recommendations [3]-[8], are given and compared with that of the traditional demodulator.

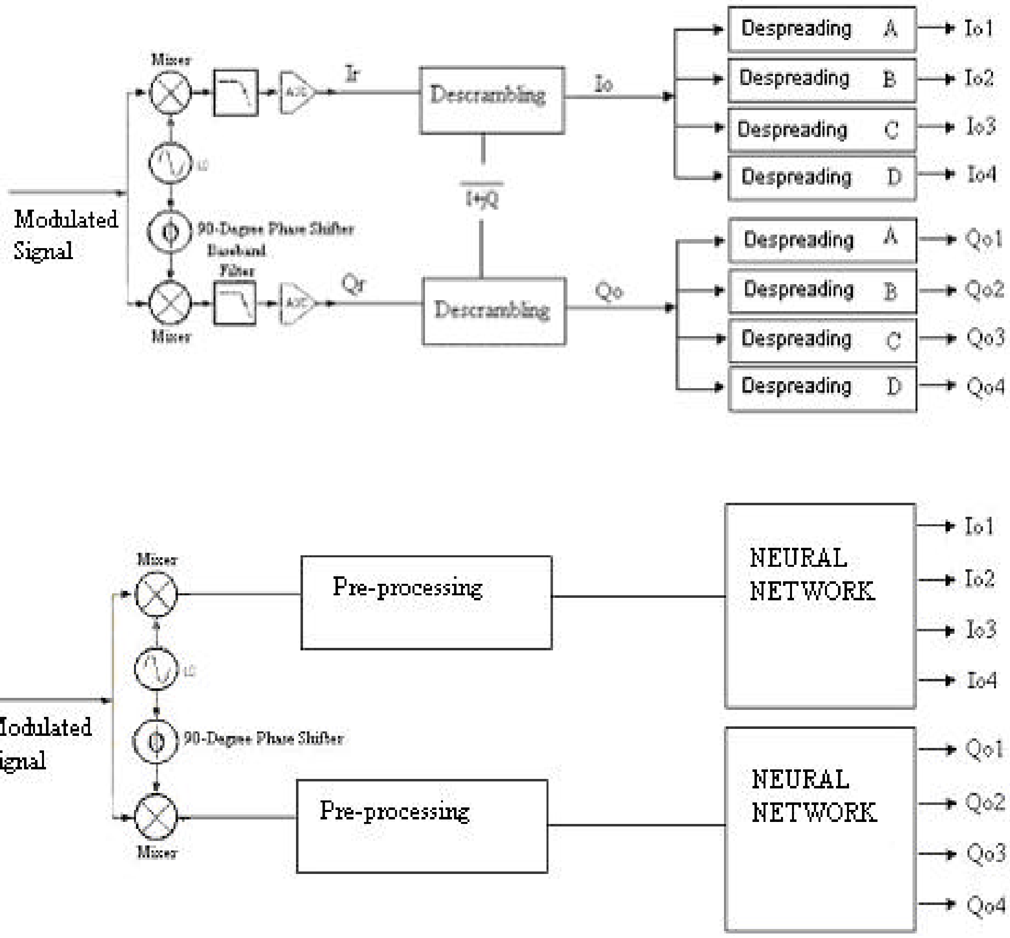

Figure1 Block schemes of the traditional receiver (up) and of the ANN based receiver (down).

II. ANN based demodulator

In order to recovery the transmitted symbol, the two ANNs are trained according to the following relations for the I and the Q components, respectively:

$$\mathrm{Symb}(n)=\frac{\sum_{i=(n-1)SF+1}^{nSF}((I_r(i)\cdot I_s(i)+Q_r(i)\cdot Q_s(i))\cdot(-C(i)))}{2\cdot SF} \tag{1}$$

$$\mathrm{Symb}(n)=\frac{\sum_{i=(n-1)SF+1}^{nSF}((Q_r(i)\cdot I_s(i)-I_r(i)\cdot Q_s(i))\cdot(-C(i)))}{2\cdot SF} \tag{2}$$

where: $I_r(i)$ and $Q_r(i)$ are the phase and quadrature components, respectively, of the modulated signal after the filtering and sampling process, $I_s(i)$ and $Q_s(i)$ are the phase and quadrature components of the scrambling code, respectively, C(i) is the spreading code of the selected channel, SF is the spreading factor identifying the selected channel.

In order to reduce the computational complexity, the trained ANN refers to four channels, only. Therefore, the input vector is constituted by 20 components, four for each of $I_r(i)$, $Q_r(i)$, $I_s(i)$, $Q_s(i)$ and C(i). After numerous tests, the best configuration of the ANN based demodulator consists of the multiplayer perceptron architecture with 20 neurons in the input layer, 210 neurons in the hidden and 2 neurons in the output layer. The ANN is trained by using modulated signals generated according to the UMTS standard [3], [5] and [7] in the following operating conditions: (i) assigned scrambling code, and (ii) assigned channel set [0, 1, 5, 7]. Therefore, the trained ANN can be used in the following

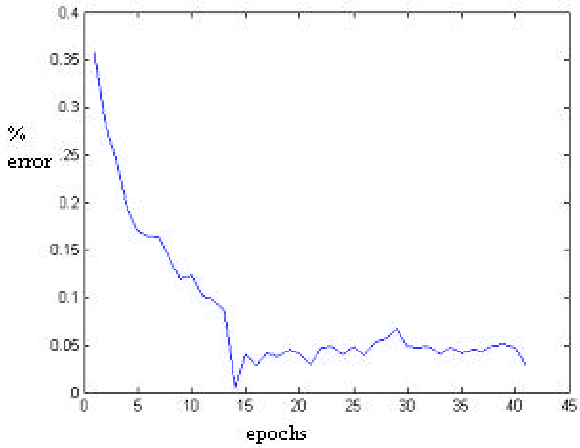

Figure 2 Trend of the percentage error during the training phase of the multiplayer perceptron ANN.

operating conditions: (i) channels included in the standard, and (ii) signals with scrambling code corresponding to that used in the training phase. Other characteristic of the training phase are: (i) sigmoid transfer function of each neuron, (ii) resilient back-propagation algorithm in order to reduce the convergence problems, and (iii) output signal constituted by sequences of the discrete values [-1, 1].
The trend of the percentage error, defined as difference between the assigned symbol and the detected one, is shown in Fig.2 versus the epochs of the training phase. The considered ANN architecture is particularly robust. Indeed, tested by signals not included in the training set, the minimum error is 8.4% after 41 epochs, only.

III. Numerical tests of the ANN based demodulator

Numerical tests are performed to assess the errors of the ANN based demodulator in the following actual operating conditions: (i) signal affected by clipping, (ii) carrier frequency error, (iii) carrier phase error, (iv) burst synchronisation error, (v) transmission noise, and (v) signal affected by multi-path interferences. The modulated signals occurring in these operating conditions are degraded and they can differ from the theoretical ones on the basis of the different causes. Therefore, the numerical generation of these degraded signals is performed in accordance (i) to the limit conditions given in the ETSI recommendations [5]-[8], and (ii) to both the rules and the simulation models presented in literature [9]-[12]. In the previously considered operating conditions, the ANN based demodulator is compared with the traditional one in order to highlight (i) the advantages, (ii) the disadvantages, and (iii) to detect the limit operating conditions. The parameter used in the comparison is the Bit Error Rate (BER) according to the ETSI recommendation [4], [5]. In the following the comparison between the neural modulator and the tradition one is shown by examining each of the actual operating conditions taken into account.

A. Signal affected by clipping

The clipping occurs when the signal amplitude overcomes the dynamical range of the integrated components. The consequent signal degradation causes (i) the frequency distortion out the assigned band, and (ii) the Error Vector Magnitude variation. The clipping level, defined as the ratio between the clipped signal and the original one, in the UMTS system can rice the value of 64%. Fig.3a) shows that the ANN based demodulator is characterised by BER values lower than the traditional demodulator for clipping level greater than the value of 14 dB, corresponding to the values of the clipping level of the usual functioning conditions of the UMTS system.

B. Carrier frequency error

The carrier frequency error occurs as consequence of the non correct down conversion of the modulated signal. Fig.3b) shows that the ANN based demodulator is characterised by BER values lower than the traditional demodulator for frequency error greater than 100 Hz, corresponding to 1% of the carrier frequency.

C. Carrier phase error

The carrier phase error occurs as consequence of the non correct synchronization during the demodulation. Fig.3c) shows that the ANN based demodulator is characterised by BER values lower than the traditional demodulator for phase error greater than 5 rad.

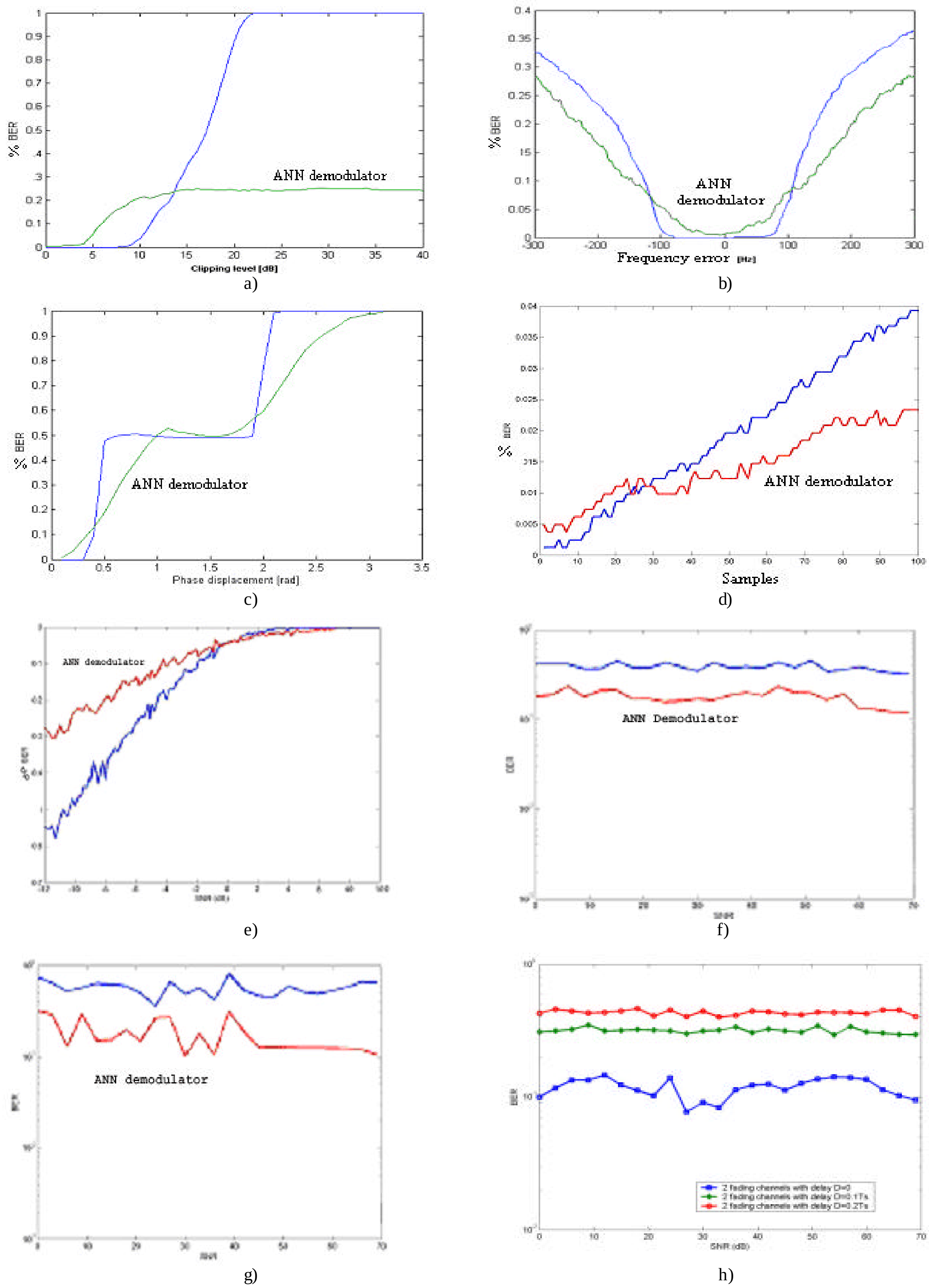

Figure 3 BER evaluated in the case of traditional and ANN based demodulator in the operating conditions characterised by: a) signal affected by clipping, b) carrier frequency error, c) carrier phase error, d) burst synchronisation error, e) transmission noise, f) one channel with signal affected by multipath interferences and speed 90 km/h, g) one channel with signal affected by multipath interferences and speed 5 km/h, h) two channels with signal affected by fade interferences with delay 0, 0.1 Ts and 0.2 Ts (Ts chip time).

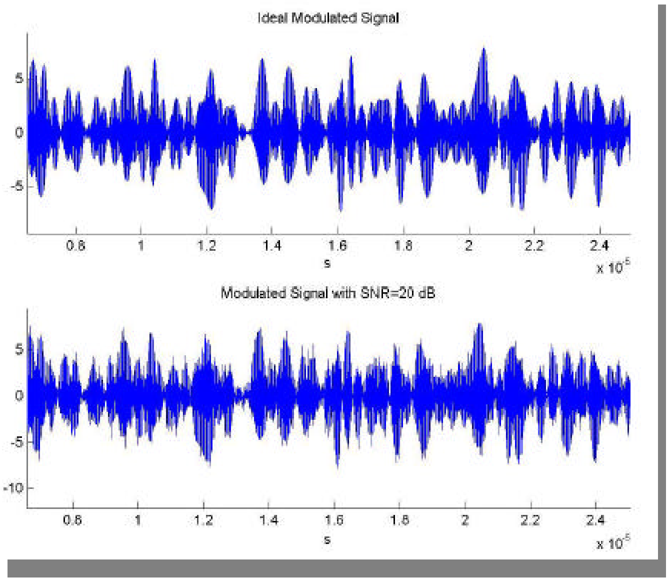

Figure 4 Modulated signal affected by AWGN: the original signal(upper), the modulated signal with SNR equal to 20dB (down).

D. Burst synchronisation error

In the case the burst synchronisation error occurs, Fig.3d) shows that the ANN based demodulator is characterised by BER values lower than the traditional demodulator for synchronisation error greater than 30 samples.

E. Transmission noise

The noise superimposed to the modulated signal is the Average White Gaussian Noise (AWGN). Fig.4 shows the original signal and the corrupted one characterised by SNR=20dB. It can be noted as the original signal is deteriorated and the corrupted one has shape almost different from the original signal. Fig.3e) shows that the ANN based demodulator is characterised by BER lower than the traditional demodulator for SNR greater than 0 dB.

F. Signal affected by multi-path interferences

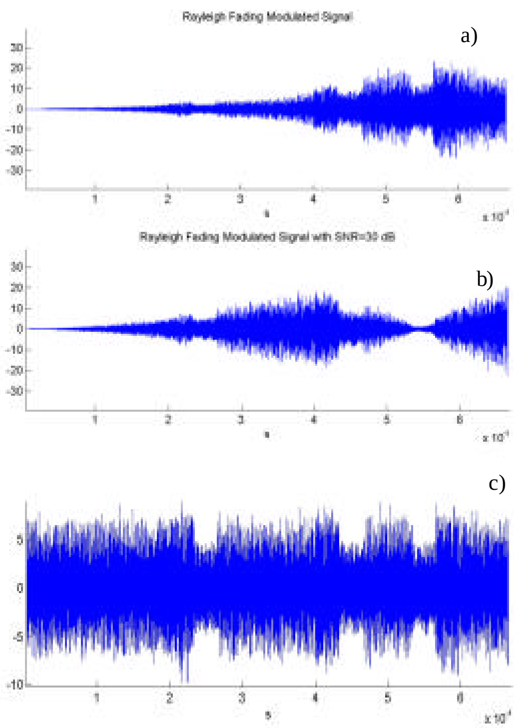

Figure 5 Rayleigh fading modulated signal (a), Rayleigh fading modulated signal and noise (b), original modulated signal (c).

The multi-path propagation is produced by reflection of the transmitted signal from obstacles and, consequently, a lot of signals, instead of only one, with different time delay and attenuation are received. Moreover, the variety of paths causes, also, the phase changes, which are frequency dependent. In addition, the speed of the mobile station causes Doppler effect on the received signal. All these effects are very difficult to model. The method presented in [12] permits to adequate modelling the multipath fading for mobile radio. This model is based on the assumption that the amplitude of the complex envelope of the received signal at the antenna is characterised by Rayleigh distribution.

Fig.5 shows the modulated signal and the corresponding signal affected by multi-path interferences simulated according to the model given in [12]. It can be noted as the signal affected by multi-path interferences is substantially degraded and the waveform shape is far different from that of the original modulated signal. Therefore, both the ANN based and the traditional demodulators work in very cumbersome operating conditions.

In the case only one channel is taken into account and the signal is affected by multipath interferences, Fig.3f), and g) show that the ANN based demodulator is characterized by BER lower than the traditional demodulator. Moreover, Fig.3h) shows the trend of the BER evaluated for the ANN based demodulator, in the case that two channels are contemporary working and the signal is affected by fade interferences with delay equal to 0, 0.1 Ts and 0.2 Ts, where Ts is the chip time defined in the UMTS system. Also in this working condition the values of the BER are low.

IV. Conclusions

The paper proposes the use of the Artificial Neural Network (ANN) to point out the new demodulator of the telecommunication signals. This demodulator is designed to be employed into the measurement instrument of signals of the third generation mobile telecommunication systems.

The operating characteristics of the ANN based demodulator were evaluated in the following conditions: (i) input signal affected by clipping, (ii) carrier frequency error, (iii) carrier phase error, (iv) burst synchronisation error, (v) transmission noise, and (v) input signal affected by multi-path interferences.

The numerical investigation has pointed out that the ANN based demodulator is more robust than the traditional demodulator and it candidates to be used in the measurement instruments. Indeed, the ANN demodulator can guaranty greater accuracy in the case the modulated signal is affected by high level of both noise and distortion.

The ongoing activity is mainly oriented to overcome the limit imposed by the ANN trained consisting in the need to operate with only one scrambling code.

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