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(54) Title: METHOD AND APPARATUS FOR TRANSCEIVERS IN WIRELESS COMMUNICATIONS USING OFDM
SPREAD SPECTRUM

(57) Abstract: This invention is about a method and apparatus for wireless transceiver to send and receive data packets with high data rate. The apparatus may include a base-band processor using OFDM (Orthogonal Frequency Division Multiplexing). The orthogonal nature of the OFDM sub-channels allows them to be overlapped, there by increasing the spectral efficiency. In other words, as orthogonality is maintained, there will be no inter-channel interference in an OFDM system. In any real implementation, however, frequency offset tracking and recovery, phase error estimation and compensation etc.; several factors will cause a certain loss in orthogonality. Designing a system that will minimize these losses therefore becomes a major technical focus. In this invention, synchronization, channel estimation and FEC techniques are suggested to have better performance in the radio channel environment. The algorithm and method for coarse and fine frequency offset compensation, and symbol timing synchronization in the synchroniza-
tion part of OFDM receiver are included. The apparatus may include channel estimation method with LS (Least Square) algorithm and channel decoder with CSI (Channel State Information).



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FIELD OF THE INVENTION

This invention relates to data packet transmission in wireless communications, and particularly between fixed and portable transmitter and receivers.

BACKGROUND AND SUMMARY OF THE INVENTION

OFDM efficiently squeezes multiple modulated carriers tightly together reducing the required bandwidth but keeping the modulated signals orthogonal so they do not interfere with each other. Any digital modulation technique can be used on each carrier and different modulation techniques can be used on separate carriers. The outputs of the modulated carriers are added together before transmission. At the receiver, the modulated carriers must be separated before demodulation. The traditional method of separating the bands is to use filters, which is simply frequency division multiplexing.

The orthogonal nature of the OFDM sub-channels allows them to be overlapped, thereby increasing the spectral efficiency. In other words, as orthogonality is maintained, there will be no inter-channel interference in an OFDM system. In any real implementation, however, frequency offset tracking and recovery, phase error estimation and compensation etc.; several factors will cause a certain loss in orthogonality. Designing a system that will minimize these

losses therefore becomes a major technical focus.

In this invention, synchronization, channel estimation and FEC techniques are suggested to have better performance in the radio channel environment. The algorithm and method for coarse and fine frequency offset compensation, and symbol timing synchronization in the synchronization part of OFDM receiver are included. The apparatus may include channel estimation method with LS (Least Square) algorithm and channel decoder with CSI (Channel State Information).

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of the OFDM Transmitter

FIG. 2 is a block diagram of the OFDM Receiver.

FIG. 3 is a detailed block diagram of the Synchronization part module.

FIGS. 4a and 4b are flow charts of synchronization algorithm and timing interval for synchronization procedure respectively.

FIG. 5 is a detailed block diagram of Equalizer with channel estimation

FIG. 6 is a detailed block diagram of Viterbi decoder with CSI (Channel State Information)

FIG. 7 is a detailed application of OFDM with CDMA baseband modem

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Introduction

This document is about a method and apparatus for wireless transceiver to send and receive data packets with high data rate. The apparatus may include a base-band processor using OFDM (Orthogonal Frequency Division Multiplexing). The orthogonal nature of the OFDM sub-channels allows them to be overlapped, thereby increasing the spectral efficiency. In other words, as orthogonality is maintained, there will be no inter-channel interference in an OFDM system. In any real implementation, however, frequency offset tracking and recovery, phase error estimation and compensation etc.; several factors will cause a certain loss in orthogonality. Designing a system that will minimize these losses therefore becomes a major technical focus.

OFDM Transmitter

FIG. 1 shows the baseband signal transmission from data generation to D/A converter. The input data field generated from MAC (Medium Access Control), passes the Scrambler 110, which is to prohibit the data received from MAC. And then scrambled data passes Channel Encoder 112, and convolution encoded with generating formula. The output data of channel

encoder passes **Interleaver 114** in order to random error from burst error occurrence. And then, data is mapped in **Mapper 116**, into BPSK (Binary Phase Shift Keying), QPSK (Quadrature Phase Shift Keying), 16QAM (Quadrature Amplitude Modulation) according to transmit data rate. **Preamble Generator 118** generates training sequence for initial acquisition and frequency tracking in the receiver. The preamble or data is converted serial to parallel conversion in **S/P 120**. This mapped data is allocated to **IFFT 122**. The sub-carrier frequency, and 7th, 21st, -7th and -21st sub-carrier frequency is reserved for the pilot signals. 64 inphase and quadrature components comes from IFFT processed data of which last 16 values among those 64 are copied in front and become transmitted to RF through D/A converter after protection field inserted.

OFDM Receiver

FIG. 2 shows the baseband signal transmission from data generation to D/A converter. The receiver passes the data from RF after getting it through A/D converter before synchronization of the reception signal and demodulation. First of all, in the **SYNC 130**, it sets frequency offset compensation and symbol timing at synchronization part, carrying reception RSSI and preamble. The frequency offset compensation processes during the time of preamble short symbol, and this is because, in its estimation of channel using preamble long symbol, the equalizer can catch the correct frequency only when frequency offset is compensated before long symbol. So, frequency offset

compensated processes FFT 150 removing protection fields from FFT 150. Equalizer 160 detects the channels applicable to each sub-carrier frequency. Using these detected channel values channel compensation becomes available by multiplying it to equalizer input signal. Equalizer 160 processed data undergo parallel to serial conversion in the P/S 180. And then de-map procedure in the Demapper 182. De-mapped data goes through Deinterleaver 186, the opposite procedure of transmitter, then Decoder 190. Demodulated data is transmitted to PIBB serially in accordance with the control message. The decoded data is descrambled in the Descrambler 210 with reverse procedure of transmitter.

Synchronization

FIG. 3 shows the detailed synchronization procedure of SYNC 130. Synchronizations that is required by OFDM system; *sampling timing synchronization* that is to catch the initial synchronization through sampling after A/D, *symbol timing synchronization* that is to decide FFT signal input area, and *frequency offset compensation* that is to estimate and compensate the frequency offset deviation between transmission and reception.

Synchronization scenario in general is as follows.

- I. Adjust sampling timing. Random sampling is applied because it's

asynchronous.

- II. Receiving block can track the coarse frequency offset since transmitting block sends consecutive training sequence.
- III. Symbol timing synchronization through matched filter can be performed before frequency offset compensation, but it more accurate to do after coarse frequency offset compensation.
- IV. Perform fine frequency offset correction.
- V. Compensate at Equalizer block after channel estimation

Quantization error is to be considered during synchronization algorithm simulation since it is related to A/D converter functionality. Most of current communications are conducted based on asynchronous method, and with the fact, signal have to be sampled before input data to baseband modem under unknown signal status. Resolution, inevitably, becomes differentiated according to sampling frequency, and synchronization error is to be happened according to sampling timing. Sampling timing brings different signal amplitude. However, OFDM, as this is the type that various frequency signals are overlapped orthogonal, is not heavily affected by the sampling and its phenomena differs.

Reception of RSSI 134 is estimated received signal strength. If reception level is higher than certain sensitivity after checking average RSSI in every 16 sample that is short sequence symbol (for example, -82 dBm for 6Mbps). If the current receiving antenna is the input signal from the antenna #0, in next interval it choose appropriate selection after changing to antenna#1 and measuring and comparing of the average RSSI value from the antenna#1, for

antenna diversity. It controls A/D converter input voltage based on RSSI input signal value. So, full synchronization starts with the input signals fluxing into AGC 132.

Symbol unit for OFDM indicates the signal unit that input to IFFT/FFT instead of QPSK, QAM symbols. That is, if FFT input samples are 64 (wireless LAN N=64), it means that 64 samples combine to form one OFDM symbol. Tuning the symbol timing synchronization means to input 0~63 to the Receiver during the transmission without any deviance in their sequence among 0 to 63. In case that received signal guard interval is not removed and correct FFT window is not found Signal orthogonality is lost and ISI appears. ISI takes place and original signal (Y)'s position rotates. Now the rotation rate reaches 360° for the sub-carrier with the highest frequency when 1 sample go crisscross. (Refer to underlined part)

$$\begin{aligned}
 Y &= FFT(y) = \sum_{n=0}^N y(n-p) e^{-j2\pi n/N} + W, \quad m = n - p \\
 &= \sum_{m=-p}^{N-p} y(m) e^{-j2\pi(m+p)/N} + W = \left[\sum_{m=-p}^{N-p} y(m) e^{-j2\pi m/N} \right] \cdot e^{-j2\pi p/N} + W \\
 &= \left[\sum_{m=0}^N y(m) e^{-j2\pi m/N} \right] \cdot e^{-j2\pi p/N} + \left[\sum_{m=-p}^{-1} y(m) e^{-j2\pi m/N} - \sum_{m=N-p+1}^N y(m) e^{-j2\pi m/N} \right] \cdot e^{-j2\pi p/N} + W \\
 &= Y \cdot \underline{e^{-j2\pi p/N}} + ISI + W
 \end{aligned}$$

Frequency offset is the discrepancy generated from the difference between transmitter and receiver in local oscillator, and is more sensitive than single carrier system since the receiver inducts sub-channel intervention by doing sub-

carrier frequency alteration.

$$y = \frac{1}{N} \cdot \left[\sum_{k=0}^{N-1} Y e^{j2\pi \epsilon \frac{(k+\epsilon)}{N}} \right] + W$$

$$Y = \frac{1}{N} \cdot \left[\sum_{k=0}^{N-1} y e^{-j2\pi \epsilon \frac{k}{N}} \right] = Y \cdot \frac{\sin \pi \epsilon}{N \cdot \sin(\pi \epsilon / N)} \cdot e^{j\pi \epsilon \frac{(N-1)}{N}} + I + W$$

Y of formula is the signal received with frequency offset; Y of formula is the signal that passed FFT after guard interval is removed. The first column is the desired signal, and there can find attenuation (sinc function) and phase distortion (e-term) as you see. The second column is ICI resulted from Frequency Offset Estimation 136. Average $\pi \epsilon$ is the position that rotates during N window value.

Received OFDM signal has +/- 20ppm deviation because of the independent RF oscillator, and is displayed as frequency offset. So the received OFDM signal carries frequency offset and this should be compensated.

OFDM decoder synchronization has 3 processes: i) OFDM symbol synchronization acquisition process, ii) coarse frequency offset compensation process and iii) accurate frequency offset compensation process.

Frequency offset estimation 136 conjecture frequency offset using two preamble short symbols (t6, t7). Frequency offset average sends frequency average value to NCO 138 (Numerically Controlled Oscillator) by averaging estimated frequency offset. NCO 138 seeks sine and cosine value applicable to the frequency offset average value. By multiplying this sine and cosine value to

received OFDM signal, frequency can be compensated. Correct frequency offset can be put out using two short symbols (t_9 , t_{10}) through frequency offset estimation. The frequency offset average sends frequency average to NCO 138 by averaging the accurate frequency offset.

The output value of Matched Filter 140 is consisted of 16 short symbol complex conjugates. Absolute value should be executed by multiplying received OFDM signal by Matched Filter 140 output value. Doing this generates the biggest value to each 16 short symbols. Ultimate number finder extract this value and send it to OFDM Symbol Timing Synchronization 142. Since single OFDM symbol carries 80 complex conjugates, OFDM symbol synchronization controller controls the growing counter from 1 to 80 referring to the ultimate value that is generated in every 16 complex conjugate, and sends OFDM symbol start indicating signal to OFDM decoder controller.

FIG. 4a and FIG. 4b show the synchronization algorithm procedure and timing relation respectively.

Receiving mode comes in effect when TX_EN signal drops to low, and reception RSSI is estimated. If reception level is higher than certain sensitivity after checking average RSSI in every 16 sample that is short sequence symbol (for example, -82 dBm for 6Mbps), RSSI indication signal is reported to MAC PHY-CCA.indication. If the current receiving antenna is the input signal from the antenna #0, in next interval it choose appropriate selection after changing to antenna#1 and measuring and comparing of the average RSSI value from the antenna#1, for antenna diversity. It controls A/D converter input voltage based on RSSI input signal value. So, full synchronization starts with the input signals

fluxing into AGC. And with 10 recurring short preamble sequence, the approximate frequency offset of the receiving signal generated by multiplying estimated frequency offset by NCO is compensated. Symbol timing is discovered as the ultimate value of matched filter output and long training sequence start point is discovered using GI (Guard Interval). RX_START signal informs the starting of long preamble of received signal. Based on this signal, OFDM symbol synchronization is set. Using long training sequence, frequency offset is estimated, and accurate frequency offset error is compensated. Adding to this, SIG_VAL and DATA_VAL signals, which indicates signal field and data field interval, are sent to MAC.

Compensation circuit scope is limited within ± 90 degree since, in short code, maximum ± 57.6 degree ($= 3.6 \times 16$) error comes to close if frequency offset is not compensated. Short and long code resolution should be designed with the completed decision on how much compensation in each individual step.

For example, if the compensation in short code is down to 1 sample (3.6°) error and the next part is tuned in long code, only with $3.6^\circ \times 16 = 57.6^\circ$ resolution it works. Because short code conducts calculation accumulating 16 samples' frequency offset, however actually higher resolution value is required than this. In this design, 4bit (3.8°) by exponent of 2 was used.

Since the error limit in this case is maximum $(57.6^\circ \pm (3.8^\circ/2))/16$, error limit per 1 sample becomes 0.11875° . $((3.48125 + 3.71875)/2 - 3.48125)$ this is bigger than 0.073125° , which the angle that compensates when that SNRe (according to frequency offset error) reaches 30dB. Accordingly, fine tune is required. During actual implementation, it is required that estimated phase is to

be converted into sin/cos value. (NCO) The important principle is to satisfy $\sin^2\theta + \cos^2\theta = K$ (constant, normally "1"). Because frequency offset compensation should not accompany the magnitude distortion.

Long code starts basically with coarsely tuned errors. The error during 1 symbol, when short code is coarsely set the frequency offset, occurs maximum about 5°. This includes quantization Error through sampling; Frequency offset estimation error, and NCO correction Error.

When SNRe = 30dB, as already pointed out, it becomes 4.68°. (1.48° in case of SNRe = 40 dB). So, fine frequency offset estimation and correction should be followed during long code. Compensation lookup table shows that the figure to input actually estimated value to NCO. The purpose to create LUT of NCO is to find θ against x,y values, and this is same to find arctan value in calculation. When the actual value is sought, circuit table is to be created and stored in memory and then restore the stored value by decoder value. This is the LUT principal. Long code can be easily compensated with $\arctan(y/x) = y/x$ since θ was fully minimized at short code.

Frequency offset error compensation block using short code training sequence of receiver synchronization block. I, Q signals passing through A/D converter is used to match the symbol timing by Matched Filter. And using short training sequence that recurs in every short code symbol, phase estimation is performed. By obtaining average phase error, frequency offset error is compensated by multiplying the phase difference which is out of boundary in accordance with the phase difference lookup table by the input signal that flow in from NCO.

Since OFDM is digital communication, the baseband signal that moved into from mixer should be converted into digital. The indispensable issues that occur are as follows in general.

Channel Estimation

Major benefit of OFDM method lies in its simplicity to actualize the equalizer comparing to other single carrier system in multi-channel environment. That is, frequency selective fading that appears in high-speed data transfer environment can be minimized to frequency non-selective fading at sub-channel viewpoint by dividing wide frequency channel into numerous sub-channels.

FIG. 5 shows the detailed channel estimation procedure of Equalizer 160.

Channel compensation can easily be achieved with one-tap equalizer in frequency area since it is possible to eliminate the conflict between the inter carrier interference (ICI) by inserting cyclic-prefix, which is longer than channel defer-expansion, as protection interval. At here, dividing it by estimated plural decimal channel value can easily actualize one-tap equalizer. D 162 and D 166 represent tap delay line. Calculate energy from I and Q data, and average in Average 168, this energy value means channel state information with used Channel Decoder 190.

Channel estimation is conducted using long preamble symbol period from Long Code Sequence 170. The channel estimation and compensation procedure

operate in Adder 172 and RAM 174. The simplest LS (Least Square) estimator actualized is described as following formula, in this case performance drop as much as 3 dB can be experienced comparing to the perfect channel estimation.

$$\hat{H}_{LS} = \frac{Y}{\hat{X}}$$

In here, X is training symbol, Y is receiving signal at sub-channel, $\hat{H}_{LS}$ is estimated channel value, and $\hat{X}$ is estimate data signal. Since long preamble for channel estimation has real value as 1 or -1, X in the formula becomes value 1 or -1 and channel value can easily be estimated without calculation by changing the signal in accordance with long preamble value transmitted from receiver signal.

After channel estimation, CSI executed, and as transmission signal is long code sequence, need to multiply this and then by acquiring accumulated average, compensation toward the value of low estimation error can be actualized. The big sized frequency offset creates interference between sub-channels by removing direct communication within them. So, this frequency offset can estimates the frequency offset using the phase change between the two recurring symbol at time area before FFT. When the estimation was done, will only have small sized offset values. However, as time goes by this kind of frequency offset accumulates and cause common phase change among all the sub-channels like phase offset influence. If the remained frequency offset is

0.1ppm, it brings phase change of 1.57×10^{-4} rad per one sample, and as a result, cause 0.01rad (0.5°) within one OFDM symbol.

Phase offset in time area is also phase offset in frequency offset, and to compensate this IEEE 802.11 system has 4 pilot signals. So these 4 pilot signals are averaged in their phase distortion to be compensated and the formula for this is as follows.

$$\hat{\phi}_i = \arg\left(\sum_{i \in P} y_{ij} \cdot a_j^*\right), \quad P(\text{the index set of pilot}) = \{7, 21, 43, 57\}$$

Here y_{ij} is the frequency area signal that passed FFT by the signal received through channel and is j -th element of i -th sequence. a_j has 1 or -1 as the known pilot signal. Since the phase error comes as channel distortion, i -th new channel can be found as below through the channel estimated.

$$H_{ij} = H_{i-1,j} \times (\cos \hat{\phi}_i - \sin \hat{\phi}_i)$$

In the formula above, H_{ij} is i -th is the channel estimation value to j -th sub-channel that estimated by OFDM symbol. However, it is required to average the resulted values using the formula above in an OFDM symbol to minimize the effect of noise in AWGN environment. So, the value that weighted-summed of the estimated result value from the formula above and the existing channel value $H_{i-1,j}$ is used. And the formula is like this.

$$H_{ij} = (1 - \mu)H_{i-1,j} + \mu H_{i-1,j} \times (\cos \hat{\phi}_i - \sin \hat{\phi}_i)$$

Weight μ value here is the value between 0 and 1, and easy to track channel that moves as fast as it becomes sizable, but error value by AWGN becomes bigger. In the environment like the above, in case that the phase distortion is not tracked, 30th OFDM symbol appears to be rotated as much as 17 degree, but we can find that there is not much phase distortion in 30th symbol. To conclude, phase error accumulation value by the remained frequency offset is to be found using the averaged value of phase distortion to 4 pilot channels.

The final transferred and received ample rate for OFDM system is 20Mbps D/A converter operates in 20M since it does not use over-sampling. The sampling oscillator has 40ppm error since it uses the master clock like the one of hardband down conversion oscillator. As described before, initial timing clock phase error is estimated in **Phase Error Estimation 144**, and compensated while being included in channel. However, possible problem may caused if one frame is found to be bigger as time passes because of 40ppm sampling clock offset. Clock phase distortion error, however, can be compensated if the pilot normally compensates channel estimator. So, another separate compensation does not seem to be necessary if it is not an excessive error.

Channel Decoding with CSI

FIG. 6 shows the detailed channel estimation procedure of Channel Decoder 190. The Channel Decoder is 190, performs decoding of convolutional encoder with 1/2 signal rate, is applied hard-decision according to Hamming distance, and set decoding depth to 48. TB part was applied with 3 pointer algorithm that uses 6 memory banks to process high-speed data. Each memory has 24 addresses that is the half of the decoding depth, and 64 bits per each address. Since 3 points algorithm is used for reverse track, Trace Back 204 has 3 modules for reverse track among which 2 performs reverse track and 1 performs decoding in turn. As explained above, among the 3 reverse track modules decoding is done by 1 module and this is selected by control signal (dec_read_pointer). Error correction is inevitable block in the wireless channel environment with noise. Block code or decode signal is selected according to system complexity and capacity, and both are used to increase the performance.

- 1) BMC 196 part: seeks the length between input codes and signal languages
- 2) ACS 200 part: renews the accumulated status value and BM value into new status value and makes SM using this. Sends SM to TB part.
- 3) Trace Back 204 part: Performs decoding using SM of ACS part
- 4) LIFO part: Rearranges sequence alteration resulted during TB procedure

Decoding is conducted on the base of those 4 block divided. Viterbi Decoder

has the components as Figure above. In here, CSI indicates the variable that has wireless channel information. This variable carries the effect as soft-decision, and sends data during equalizer. If channel SNR is high, error rate drops for good signal quality. And its function is to give weighting to input code with variable of this value.

BM part is to calculate the length between input code and code words. Currently Viterbi Decoder conducts 3 bits Soft-Decision 192. In addition, as it receives CSI 198 from Equalizer 160, if it is applied, following block comes out. The ACS calculates path metric actually The TB controller has operation that control Path Memory 202. And this result is from trace back operation. That is the error corrected data. The LIFO turns the output sequence of TB block because TB output sequence reverse order of input sequence. So, the LIFO is final out port of Viterbi decoder.

Alternative Embodiments for Application of OFDM

FIG. 7 shows the application example of OFDM with other mobile radio system. This OFDM transceiver is also applicable in the mobile radio system. The CDMA Base Modem 200 includes channel codec, interleaver-deinterleaver and modulation. The encoded serial data is converted to parallel in S/P 310, and then assign subcarrier input of the IFFT 314. Preamble Generation 312 generate

preamble sequence for synchronization of receiver. The output of IFFT 314 passes D/A 316 transmit to RF. The receiver part operates reverse process of transmission. SYNC 318 operates symbol timing synchronization and frequency offset compensation with data from A/D 320. After frequency offset compensation processes FFT 150. Equalizer 324 detects the channels applicable to each sub-carrier frequency. Using these detected channel values channel compensation becomes available by multiplying it to Equalizer 324 input signal. Also, channel state information transmits to modem. The output of Equalizer 324 is converted to serial in the P/S 326, and then demodulate in the CDMA Base Modem 300. The input of A/D 320 and output of D/A 316 have interface with RF module 330 which has variant frequency band, like as GSM, PCS and CDMA etc.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OF PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A transceiver including a transmitter for transmitting electromagnetic signals and a receiver for receiving electromagnetic signals having amplitude and phase differential characteristics, the transmitter and receiver comprising:

A processor having an output for applying a Fourier transform to the multiplexed information to bring the information into the time domain for transmission;

A processor having time acquisition and frequency offset tracking with

received signal;

A channel estimator for estimation of channel status with received signal; and

A decoder for decoding signals from the channel state information from the channel estimator.

2. A method for allowing a number of wireless transceivers to transmit and receive packets of information symbols, the method comprising the steps of:

The received signal gain controlling input voltage of analog digital converter with received signal power level (RSSI) variation;

Processing the antenna selecting with measurement of RSSI level;

Processing of frequency offset estimation and compensation with preamble symbol;

Processing of channel estimation with use of preamble symbol and pilot symbol;

Processing of data decoding with use of channel state information.

3. A transceiver including an orthogonal frequency multiplexing transmitter and receiver interface with a baseband modem, the transceiver comprising:

A baseband modem having PCS, GSM and CDMA with variant frequency band and multiplexing method;

A processor having an output for applying a Fourier transform to the multiplexed information to bring the information into the time domain for transmission;

A processor generating preamble training sequence for synchronization of receiver;

A synchronization processor having time acquisition and frequency offset tracking with received signal;

A channel equalizer having channel estimation of channel status information with received signal;

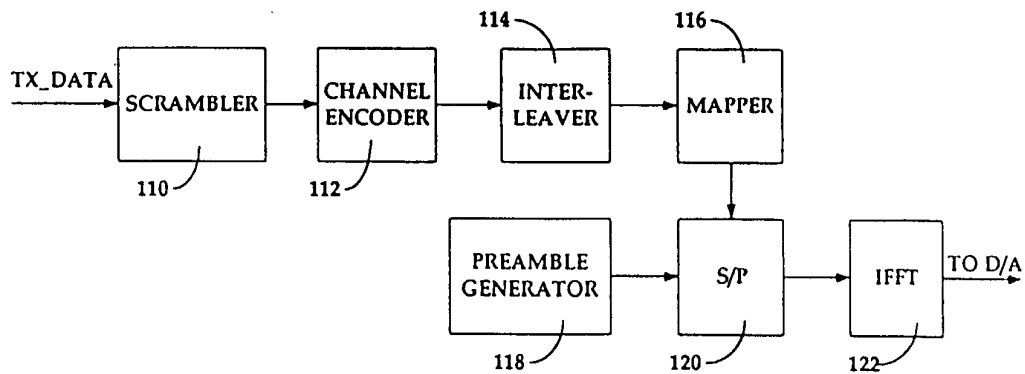


Fig. 1

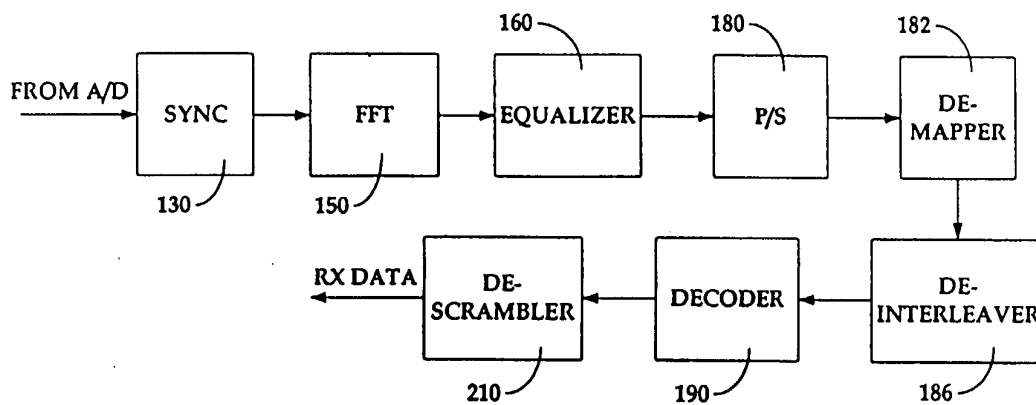


Fig. 2

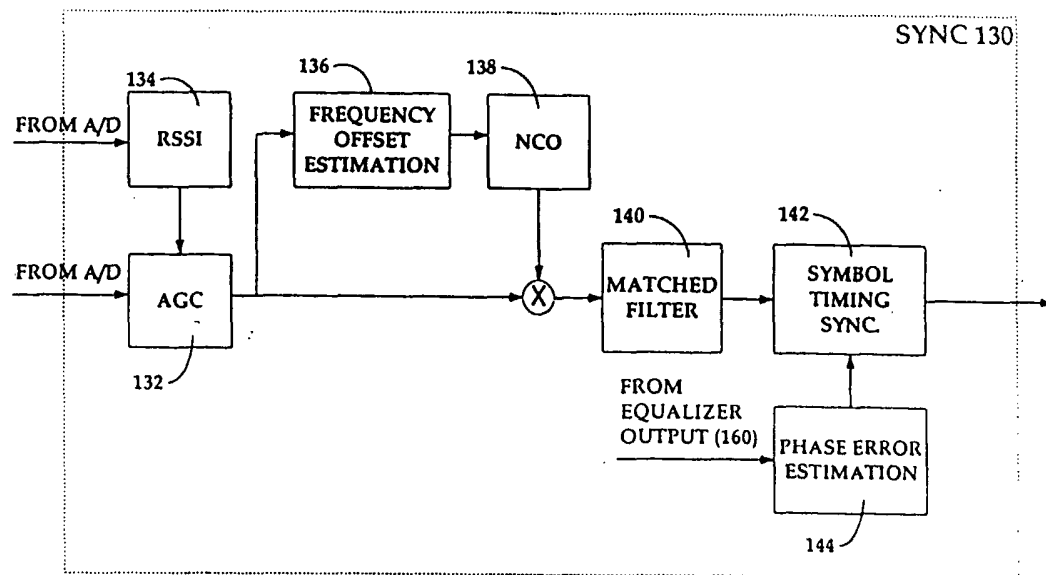


Fig. 3

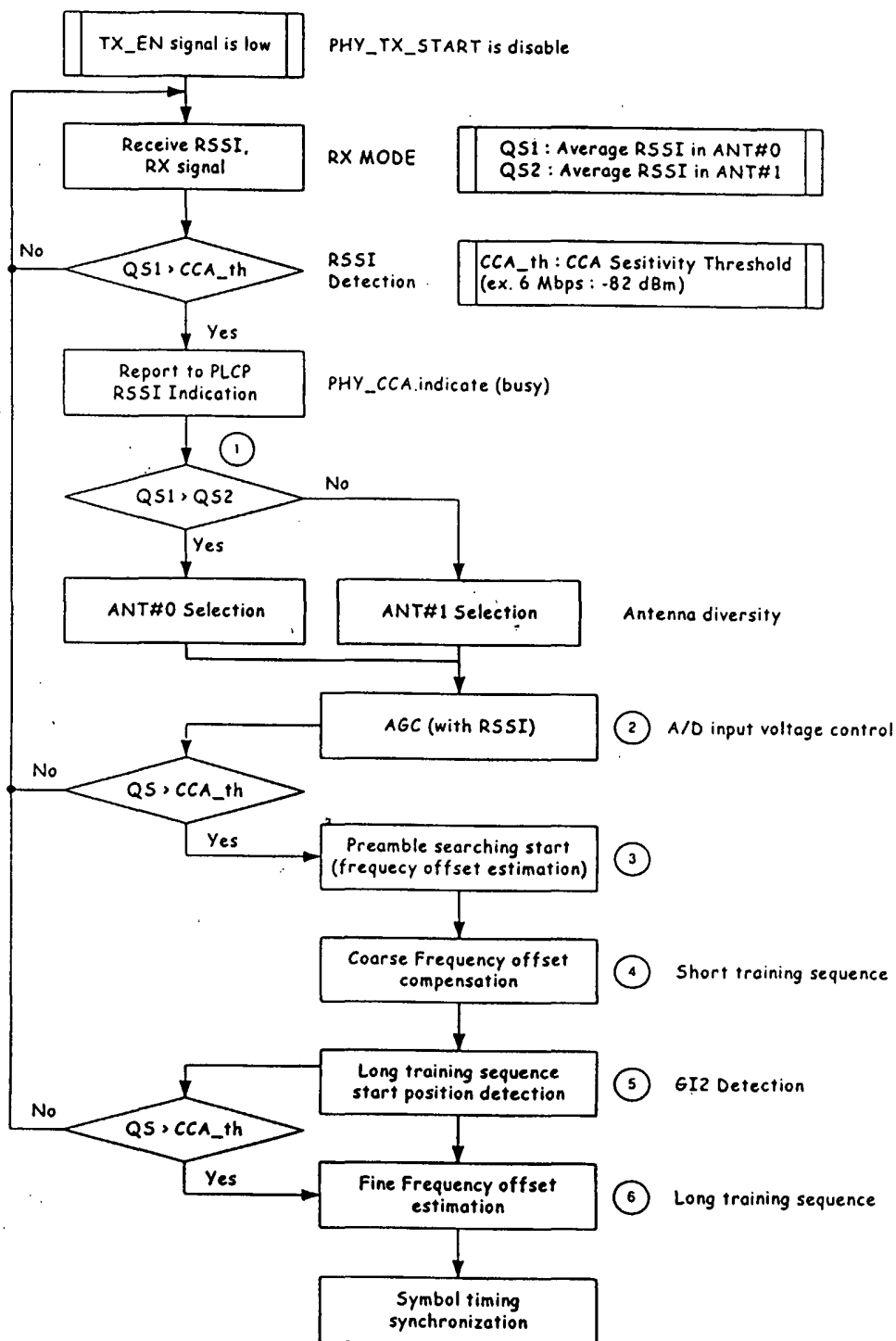
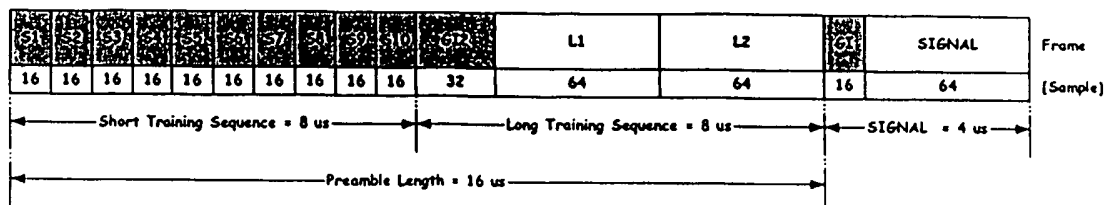


Fig. 4a



- S1 Average RSSI Measurement of Antenna#0
- S2 Average RSSI Measurement of Antenna#1 (1)
- S3 Antenna selection diversity, AGC (2)
- S4 - S7 Calculation of frequency offset estimation (3)
- S8 - S10 Coarse frequency offset timing synchronization (4)
- S11 Long code start detection (5)
- L1 - L2 Fine frequency offset, Symbol timing synchronization (6)



Fig. 4b

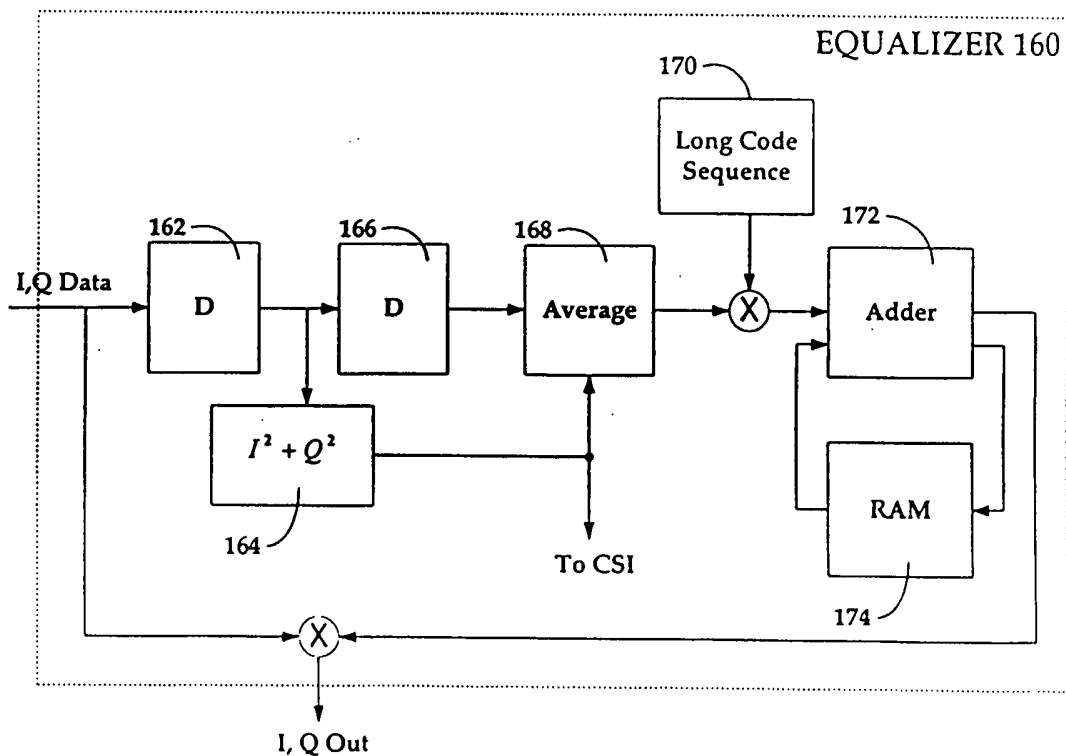


Fig. 5

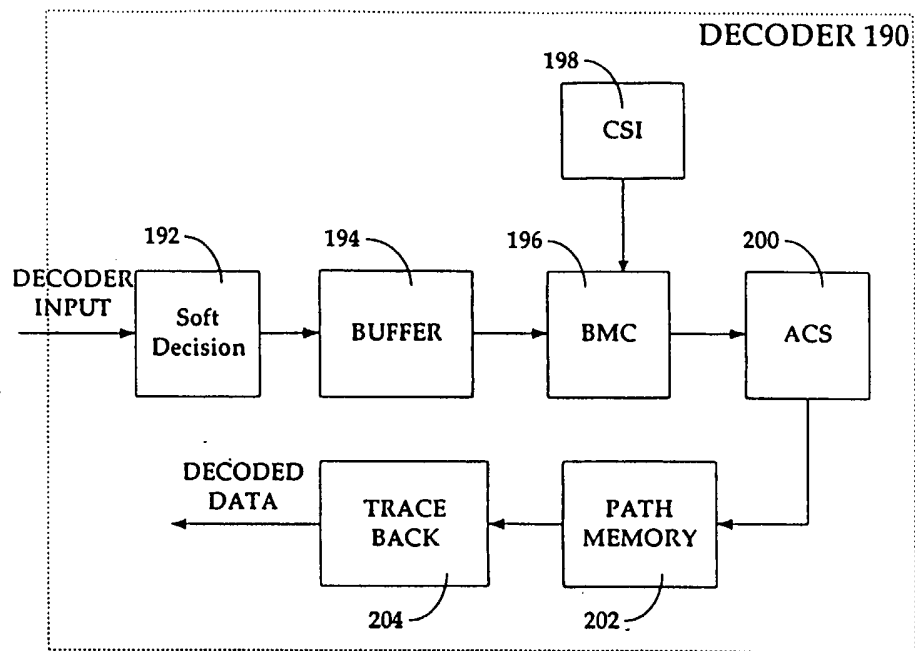


Fig. 6

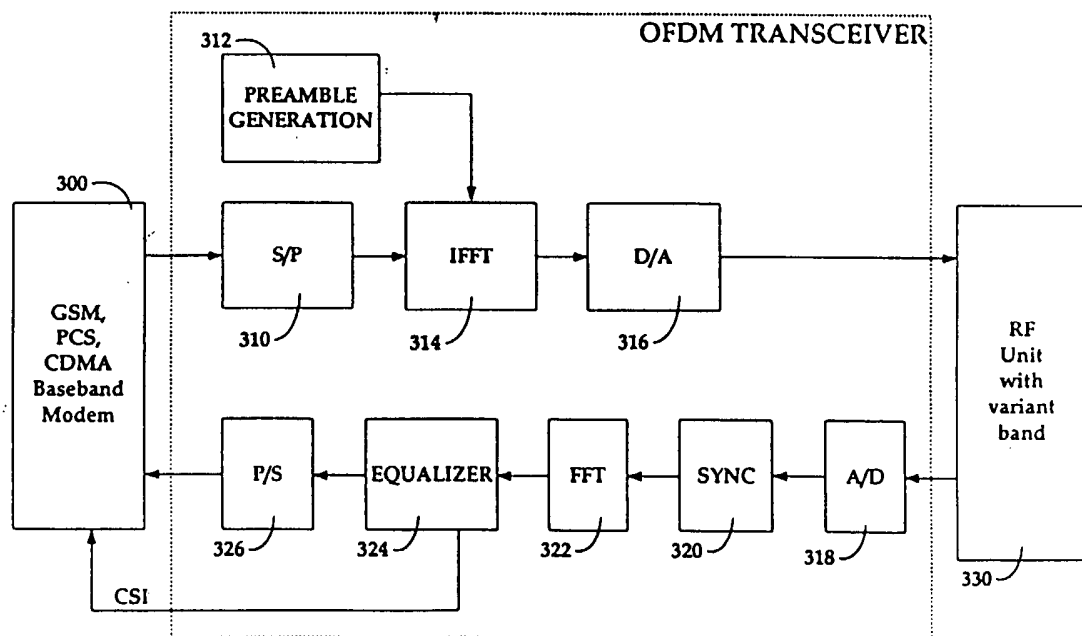


Fig. 7