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On Suitable Codes For Frame Synchronisation In Packet Radio LANs

I R Johnson, T A Wilkinson,
A E Jones, S K Barton
Department of Electrical Engineering
University of Bradford
Bradford BD7 1DP, U.K.

Mu Li, A Nix,
J Marvill, M Beach
Centre for Communications Research
University of Bristol
Bristol BS8 1TR, U.K.

Abstract: **Standardisation bodies in Europe and North America are currently developing standards for high data rate packet radio LANs. Radio LANs will have two main applications: wired LAN replacement and *ad-hoc* networking. In contrast to wired LAN replacement, ad-hoc networks will operate without control from a central node. As a consequence, no central synchronisation is provided and nodes must have the capability of acquiring all synchronisation from a received packet. This synchronisation can be achieved by matched filtering synchronisation codes inserted into each data packet. This paper discusses these synchronisation requirements and outlines synchronisation sequence selection criteria.**

I. INTRODUCTION

ETSI RES10 are still in the process of defining the HIPERLAN standard which will be the new European standard for HIgh PErformance Radio Local Area Networks. Although this process is not complete, many aspects of the standard are firm, particularly aspects of higher level system design. Generally, for HIPERLAN, communication will be mesh and multiple access will be asynchronous. These communication aspects impact heavily on the design of the physical layer of the system in that packets can arrive at a destination from any source, at any time and over any channel. Within this general framework more structured modes of communication may be possible, such as star communication with synchronous multiple access. However, the physical layer must be designed to support the general case. This is the so-called ad-hoc network, where , for example, a group of users with laptop computers sit around a table and set up a network.

It is the aim of HIPERLAN to provide networking with a user data rate in the range of 10-20 Mbits/s. To achieve this it is likely that RES10 will adopt a constant envelope transmission scheme with an equaliser to overcome the inter-symbol interference caused by dispersion in the multi-path channel. With such a scheme, an adaptive receiver must train its equaliser from scratch every time it receives a packet because every packet could arrive from a different transmitter from the previous one. Furthermore, other operations must be carried out before equaliser training can take place, such as identification of start of packet and, in-turn, start of training sequence in the received packet. This is necessary for synchronisation of the training sequence in the equaliser training. Also, market demands dictate that wireless LAN products must be inexpensive, and hence they will contain low-performance oscillators. The anticipated system will not be fully coherent and consequently there will be frequency offset between the transmitter and receiver local oscillators. This frequency offset must be measured and compensated for in the receiver. All of these synchronisation functions can be performed by using pseudo-random noise sequences (PRNs) inserted into the data packet and matched filtering in the receiver.

This paper describes work which was carried out under ESPRIT project 7359 LAURA (Local Area Network User Radio Access) when investigating the design/selection of suitable sequences for synchronisation in the LAURA proposal for the transmission scheme in the HIPERLAN standard [1]. To a certain extent this work involved re-visiting work which was carried out in the design of training sequences for the GSM system [2]. However, our requirements are sufficiently different, and in a number of ways more severe. Also, we found the published information on the design/selection and performance of the GSM sequences to be sparse. Hence, this paper identifies synchronisation issues and describes the sequence selection procedure for LAURA.

II. CONVENTIONAL SYNCHRONISATION SEQUENCES

Classically, Barker codes [3] have been used for synchronisation in communication systems. These real sequences have ideal auto-correlation functions (ACFs) in that the side-lobes of the even and odd periodic and

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aperiodic ACFs are bounded by ±1. There are no Barker sequences longer than 13. Neglecting their inverses, there are only two Barker sequences of any given length, one of which is the time-reversed version of the other.

It is the aperiodic ACF properties that are of interest when the sequences are used for synchronisation purposes, as the sequence will be surrounded by random data (or noise). When this is the case only the central point of the ACF is guaranteed. The other points depend on the ACF and the surrounding data as described in [3]. To minimise the probability of incorrect synchronisation we must minimise the probability of the combined effect of side-lobes, surrounding random data and noise causing the ACF to exceed a specified threshold and consequently being wrongly identified as a peak.

Of course, in the general case in communications we are dealing with complex signals and hence we require complex sequences for synchronisation. Complex Barker sequences do exist and were reported in [4]. However, like the real Barker sequences there are no complex Barker sequences longer than 13.

III. IMPACT OF MODULATION SCHEME ON SYNCHRONISATION

The use of PRN sequences for synchronisation is straight forward with linear modulation schemes such as phase shift keying but more difficult with nonlinear modulation schemes such as frequency shift keying. The reason for this is that the sequence must be designed so that it has the desired properties in the modulation domain. This is because the sequence must be detected by matched filtering before demodulation as it is required for initialisation of the demodulation process.

A number of modulation schemes have been proposed for the HIPERLAN standard. The LAURA project proposal is Gaussian Minimum Shift Keying (GMSK) with a BT product of 0.5 [1]. Strictly speaking, this is a nonlinear modulation scheme. However it can be linearly approximated because the BT product is large. In other words the signal can be viewed as a form of offset quadrature phase shift keying (OQPSK) with a particular type of pulse shaping. By pre-coding the data before it is passed to the GMSK modulator [1], and thus removing the differential aspect, this modulation scheme can be made exactly equivalent to OQPSK. Synchronisation sequences were required that were compatible with this modulation format.

IV. EFFECT OF LOCAL OSCILLATOR FREQUENCY OFFSET

In the proposed modulation scheme the information is carried in the phase of the signal. With the differential aspect of the modulation removed from the GMSK signal, as described above, the absolute phase of the signal represents the data, not the change in phase. Any frequency offset between the transmitter and receiver will give the effect of rotation of the constellation points. As such, when the constellation has rotated by more than half of the angle between the constellation points, in this case 45°, all subsequent data will be incorrectly detected until the constellation has rotated through another 315°. Any frequency offset between the transmitter and receiver oscillators must thus be measured and compensated for.

The transmission scheme has a transmission rate of 15 Mbit/s. The system will be demonstrated with oscillators in the transmitter and receiver which have a frequency stability of 1.5×10^{-6}. With a carrier frequency of around 5 GHz this stability translates to a worst case frequency error of 7.5kHz, or 0.18°/bit. If it is assumed that the transmitter and receiver both have ±7.5kHz offset which is uniformly distributed, the rms offset will be 6.12kHz, or 0.147°/bit. The phase of the signal must be measured at a rate which satisfies the Nyquist sampling criterion, i.e. the signal must be sampled sufficiently often to ensure that the phase has rotated less than 180°, preferably much less. It has been decided that sequences for measuring the phase of the signal will be inserted every 384 bits throughout the packet. This satisfies the Nyquist criterion at over three times the rms frequency offset.

In the absence of multipath, accurate estimation of carrier phase from the peak of the ACF from a matched filter requires an ACF with zero imaginary part around the peak. This is necessary because it is possible that the peak will be incorrectly detected as a result of noise. A steep gradient in the phase of the ACF would lead to a large error in the phase measurement. The imaginary part of the ACF of the complex Barker sequences proposed in [3] is always zero. This is because these sequences are palindromic, or symmetrical about their centre. This is the condition to guarantee a zero imaginary part of the ACF. It is quite simple to design sequence searches to look only for palindromic sequences. However, there are other properties to consider and, as always, design for perfection in one aspect is at the expense of perfection in another aspect. In fact it is only necessary to have zero imaginary part of the ACF around the peak.

V. SEQUENCE PROPERTIES FOR LAURA

For our application we required the synchronisation sequences to have the following additional properties.

The synchronisation sequences will not only be used to identify the synchronisation of the training sequence but also the channel impulse response. Accurate estimation of the impulse response from the matched filtering process is difficult because auto-correlation side-lobes from a particular component in the impulse response interfere with adjacent components in the impulse response. Hence we need to minimise the side-lobe level to an extent either side of the peak of the ACF in accordance with the expected significant duration of the impulse response. The transmission rate is 15Mbit/s (a bit period of 67ns). The maximum rms delay spread that the system will encounter is around 100ns. An exponential power delay profile of rms delay spread 100ns falls to 10dB after 230ns, or around 3 bit periods. Hence it was decided that the ACF of the synchronisation sequence would have to have low side-lobes for 3 bits either side of the peak.

We can design/select our sequence to have the above aperiodic ACF properties but to guarantee the properties around the peak we must pad the sequence with non-random bits effectively increasing its length, although matched filtering is still only performed over the original length. Hence, it was decided that the sequences would be padded with 3 bits at either end.

It was considered that complex sequences of 26 bits would give sufficient processing gain for synchronisation in the system. With the padding bits this gives a total sequence length of 32 bits. This gives a processing gain greater than that in the GSM system [2]. However, unlike GSM, the system must be designed to cope with "cold start" communication for every packet and for this reason greater processing gain is required to give extra protection against system settling times such as AGC response.

Three sequences were required for the system, each being 26 bits long padded with 3 bits at either end. The three sequences were for the following purposes

1) Start of frame identification and equaliser training
2) Phase measurement
3) End of frame identification

The selected sequences should have minimal cross correlation with one another.

The possibility of using a matched filter to detect the start of frame sequence and then switching its coefficients and using the same filter to detect the end of frame was considered. However, it was decided to search for all of the sequences all of the time, as this would provide collision detection capability.

As described above, the start of frame sequence is incorporated into the equaliser training sequence. Research showed that with the selected equaliser training algorithm, a training sequence of 48 bits is sufficient for an rms delay spread up to 100 ns. The resulting packet structure for the demonstrator is shown in Figure 1.

VI. SEQUENCE SEARCHING

Synchronisation sequences are usually selected by computer search where sequences are tested for fitness. The fitness function is specified according to the sequence correlation function requirements. Sequences that pass the fitness test or are of the highest fitness are selected. If short sequences are required sequential searching is appropriate as long as the fitness tests applied to each sequence are relatively fast. However, for long sequences sequential searching is too time consuming especially if the fitness tests are slow. In searching for long sequences natural algorithms such as simulated annealing can be used. In these algorithms the optimum sequences are effectively evolved. This process consists of testing a sequence, changing it slightly and testing again. The change is accepted if it is good and rejected if it is bad but a bad change can be accepted or a good change rejected with a finite but small probability to avoid local maxima of the fitness function. The control of the acceptance/rejection probabilities and the degree of change should be optimised. Using these techniques good sequences can be obtained very quickly but there is no guarantee that the best sequence is found.

VII. SELECTED SEQUENCES

Three synchronisation sequences were selected for the system using the strategy described above and a fitness function based on the performance requirements discussed.

The real, imaginary and magnitude components of the ACF of sequence 1 are shown in Figure 2. The ACFs are symmetrical and so only half of the function has been shown. The other two sequences had similar ACFs. It can be seen that the ACFs of the sequences have the desired properties.

The cross-correlation functions of each pair of sequences are shown in Figure 3. The cross-correlation functions of such sequences are, in general, not symmetrical. However, in the selected sequences, sequence 2 is the complex conjugate of sequence 1. Thus the cross-correlation of sequence 1 with sequence 2 is symmetrical. It can be seen that the sequence cross-correlation is low.

The above correlation functions were produced using unfiltered data. In practice, the data will be pre-filtered prior to transmission and sequence detection performed at baseband using digital FIR filters. With pre-filtered data and the FIR filter taps set such that they are matched to the transmitted data the resulting function is shown in Figure 4. For GMSK modulation with BT=0.5 the modulation scheme is approximately linear and so the correlation function maintains the form of that produced with infiltered data, Figure 2. As the bandwidth of the signal has been reduced, some of the fine detail of the function has been lost, as expected.

XIII. CONCLUSIONS

The criteria for selecting synchronisation sequences for the LAURA proposal for HIPERLAN have been discussed.The search strategy used has been described and examples of the auto- and cross-correlation functions of the selected sequences have been presented. Currently, we are in the process of examining the system performance, using the selected sequences, by simulation.

IX. ACKNOWLEDGEMENTS

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X. REFERENCES

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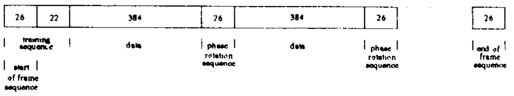

Fig.1. Packet structure

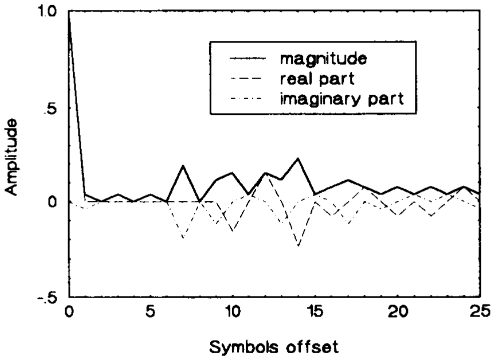

Fig.2. Autocorrelation of sequence 1 using unfiltered data

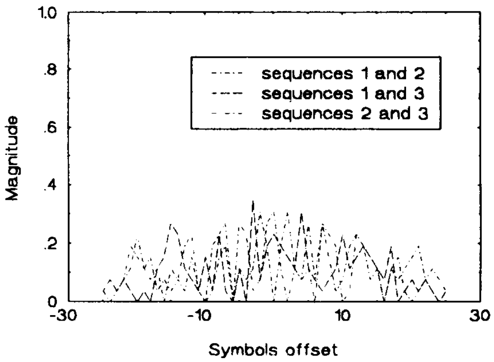

Fig. 3. Cross-correlation of pairs of sequences

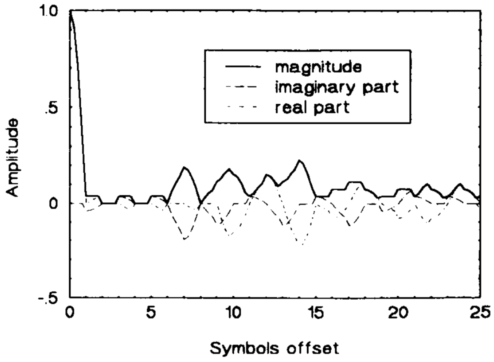

Fig.4. Autocorrelation of sequence 1 using pre-filtered data