Submission to IEEE 802.4.L
Irvine Meeting, March 1990

Approaches to Indoor RADIOLAN which provide Processing Gain and Coding Gain

Prepared By

Larry Van Der Jagt

Knowledge Implementations, Inc.
32 Conklin Road, Warwick, NY 10990
914-986-3492

Introduction and History

Preliminary investigations of the electrical environment done by KII in an Auto Body Assembly Plant, a Retail Store, and an Office environment have served to quantify and corroborate previously available information concerning path loss and delay spread in the electrical environment in which RADIOLAN is expected to operate. In addition, to previously reported information, the techniques which were utilized in these tests provided information regarding the phase characteristics of the propogation environment. These tests also revealed the presence of substantial amounts of impulse noise and the presence of intentional narrowband radiators in the frequency bands of interest. The presence of these types of disturbances is not unexpected given the types of noise generators which are known to exist in the environments of interest, and given the fact that RADIOLAN using spread spectrum techniques does not have primary user status in any of the bands in which it is authorized to operate. The presence of these interferers prompted investigations by the group into the quantitative aspects of interference rejection available through the use of spread spectrum techniques.

During the IEEE 802.4.L meeting which took place at Parsippany, New Jersey in January of 1990 a table was developed which clearly indicates the significant advantages in system margins which can be obtained through the use of higher dimensional spreading codes. Although certain elements of this table may still be incorrect (in our opinion overly pessemistic), the overall picture which emerges from this table points to dramatic improvements to be had with increased spreading factors. At this meeting and in subsequent submissions prepared by Hughes Network Systems opinions were expressed that the use of convolutional or block encoding should be considered as a means of obtaining an additional coding gain above and beyond the processing gain which will result from the use of spread spectrum techniques. Questions and concerns were raised regarding the impact of this additional coding on system complexity and data rate. Proposals were also made at this meeting with respect to methods which might be utilized to recover some of the data rate which seems to be lost as a result of the bandwidth expansion inherent in the spreading process. These proposals raised concerns about the cross-correlation properties of the various sequences which might be utilized in such a system. Some work was done during the meeting indicating that m-sequences might have reasonable cross-correlation properties but additional research on the cross-correlation aspects of various sequences was requested.

This document has been generated in an effort to bring into focus some of the system level considerations which have an impact on the design tradeoffs which are still to be made in our efforts to acheive a standard for RADIOLAN. In light of those system level considerations the Code Division Multiple Access Proposal introduced by KII at the previous meeting is expanded upon. As part of this expansion, information relating to the incorporation of block or convolutional codes into the system is reviewed.

This document will first address some aspects of the headend distribution system which may be used to solve some of the significant problems associated with network synchronization and near-far problems. Next it will turn to the issue of cross-correlation and finally to the issue of techniques for incorporating coding without further bandwidth expansion.

The points we are trying to make in this document can be summarized by three items which are listed here and repeated in the conclusion:

1) We would like the issue of synchronous vs. asynchronous headends addressed as quickly as possible with a resolution to use the synchronous version in our standard being our preferred solution to this issue.

2) We favor the use of a clear channel transmitted reference code which will enable the receivers to quickly and accurately determine the impulse response of the channel and to quickly and accurately synchronize with the headend. We would like a preliminary indication of the position of the group with respect to a transmitted reference code.

3) We favor solutions which increase the spreading factor to obtain the maximum amount of benefit from spreading given the other constraints of the system.

With this as an introduction we offer the following information:

Time Space Characteristics of a Headended System

The operation of the headend system has not been examined in detail by the committee to date. It appears to us at KII that it is important to address the system level operation before the appropriate tradeoffs regarding modulation and coding can be made at the subsystem level. Figure One illustrates two possible headend systems working on fixed length chunks of data.

The diagram on the left is an asynchronous system. Each station transmits to the headend. When the headend receives the entire chunk it immediately turns around and retransmits the chunk for the benefit of the other stations. When the chunk is received in its entirety by the station which originated the chunk it is free to immediately begin transmission of the next chunk of the transmission. At the end of a message, a new station becomes the originator and is free to use the media as soon as it receives the final portion of the message from the previous station. The time space scenario at the end of a message is illustrated in the diagram at the point where Station A begins transmitting to the headend. This type of operation results in a non-constant headend cycle as is illustrated by the inequality of "T1" and "T2" in the diagram.

The diagram on the right illustrates the operation of a system in which the headend cycle time is constant. The headend cycle time is set at twice the length of a message chunk, plus the round trip propogation delay associated with reaching the headend from the farthest station, plus headend turn around time, plus the station turn around time (plus appropriate system margin). This headend cycle time is illustarted by "T4" in the diagram. In this systems all stations can know when a transmission is originating from the headend and direct their attention to only

Knowledge Implementations, Inc.
Fiber Optic and Communications Systems Egineering/Marketing

those messages. The potential blocking interval is illustrated by the heavy polygon which appears in the diagram on the right.

It should be noted that in approximate terms the one way propogation delay of a signal traveling in free space over a distance of 100 meters, is 330 nanoseconds which in a 1 megabit per second system is less than one symbol time or substantially less than 1 octet. Assuming that the message chunks are substantially more than 1 octet in length this indicates that the predominate determining factor of headend cycle time is chunk size, and the additional ineffícencies (beyond the basic factor of 2 resulting from ping-pong operation) are largely determined by chunk size. The reader can also get a general impression of the thruput degradation which may result from a tradeoff towards synchronism in headend operation by looking at the difference between the overall time length of the diagram on the right as compared to the diagram on the left. Of course the impact of this is actually determined by a complex combination of factors including chunk size, network topography, and message traffic patterns.

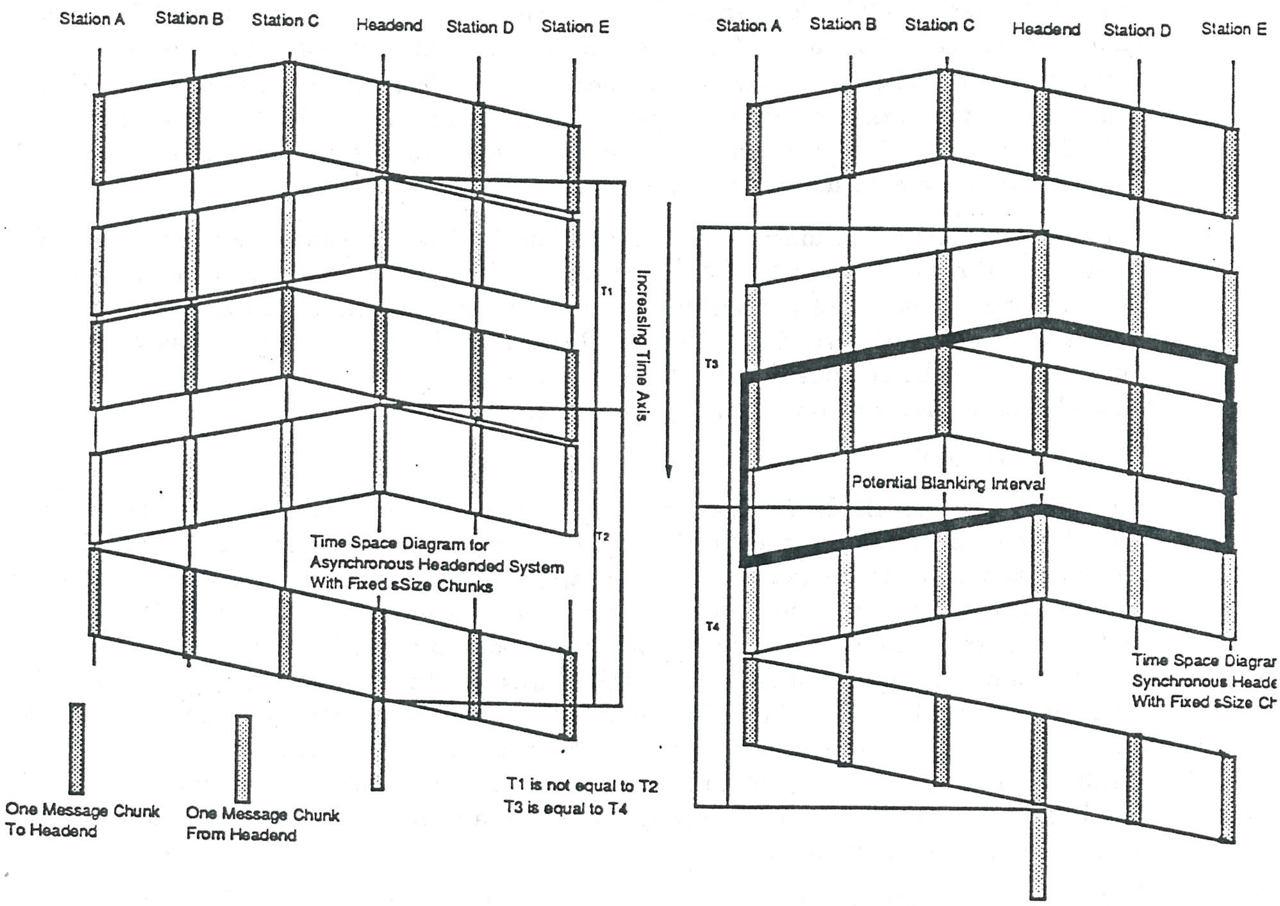

Figure One

In the discussion which follows the assumption will be made that a synchronous headend has been chosen. This choice appears to provide design options which may not be available in other potential systems.

32 Conklin Road, Warwick, NY 10990 Voice 914-986-3492 FAX 914-986-6441

Knowledge Implementations, Inc.
Fiber Optic and Communications Systems Egineering/Marketing

Cross-Correlation of Multiple Codes

A review of the literature on spread spectrum multiple access systems reveals that the issue of cross-correlation has been studied in some depth for the case of asynchronous combinations of codes. This literature develops worst case cross-correlations given the unknown phase characteristics which are inherent in the asynchronous multiple access environment. It is our contention that upper bounds associated with the asynchronous case are also valid for a case in which the codes can be rigidly synchronized. In fact it should be possible to take advantage of this added constraint to select codes and/or code phases which reduce the upper bound. With that in mind, the peak cross-correlation of asynchronous m-sequences has been shown (Sarwate and Pursley, Proc. IEEE vol. 68 pp. 593-619 May 1980) to be .32 and .37 of the peak autocorrelation value for values of m between 5 and 8 (spreading between 31 and 255). It has also been shown that (Gold, IEEE Trans. Inform. Theory, vol. IT-14, pp. 154-156 January 1968) combinations of m-sequences produce better cross correlation results with the peaks being $2^{(m+1)/2}+1$ for m odd. This makes the cross correlation peaks about .13 of the autocorrelation peak in the case of m=7 (spreading to 127). There are 129 Gold Codes of length 127. Further reductions of cross correlation peaks are possible if a sequence of codes derived from m-sequence by means of another simple procedure (called Kasami codes) are used. The cross correlation peaks of these sequences are optimal and of height $2^{m/2}+1$ or .06 of the autocorrelation peak if m=8. There are 16 Kasami codes of length 255. In addition, some work has been done by Geraniotis and Pursley IEEE Trans. on Comm. vol. COM-30, pp 985-995 May 1982 which provides data for various sytems using various spreading codes as a function of number of simultanenous users and E_b/N_0.

It is clear from the preliminary investigations done by Mike Maslied in the previous meeting (and the additional research described briefly above (which indicate that previous investigations may be pessemistic) that CDMA is a viable means for regaining some of the loss in bit/rate which results from increased spreading. This result appears clear even before the as yet unexplored gains which may be possible through the removal of the assumption that the codes being used for multiple access arrive at random phases is taken.

A System Proposal

It is proposed that if the headend is operating in a synchronous manner, and if there are available a number of codes greater than 2 which may be used in a code division multiple access system that the headend can transmit a timing reference during its cycle which can be used by all stations to synchronize their internal transmission and reception process. We are well aware that the transmission of a timing reference is viewed as a potential waste of available transmit power, however, given the burst nature of the transmissions in this system as well as the seemingly unavoidable near-far situation, and the potential for channel time variance, we feel that this use of transmit power is justified. The potential reduction in receiver complexity which results from the transmission of a reference also helps to convince us that the penalty is justified. The Figures Two and Three illustrate systems with a transmitted reference which might be used for the RADIOLAN system.

Figure Two illustrates a case in which the availability of multiple spreading codes can be used as a technique for either increasing information rate or for mitigating the impact of coding on the information rate.

Figure Three illustrates a system in which the bandwidth expansion which has been gained as a result of spreading does double duty as bandwidth expansion to accommodate coding. The fundamental concept which is being presented in this diagram is that if a transmit reference is used to provide accurate timing information for the receiver, the requirement that data be

32 Conklin Road, Warwick, NY 10990 Voice 914-986-3492 FAX 914-986-6441

Knowledge Implementations, Inc.
Fiber Optic and Communications Systems Egineering/Marketing

transmitted as an (n,k) repetition code with n equal to the spreading factor and k = 1 in order to provide the prospect for multipath resolveability and possible compensation is removed. The information which is required to accomplish this task (i.e. the impulse response of the channel) is present in the transmitted reference and does not need to be duplicated for the other channels. This allows the other channels to be encoded to provide additional performance enhancements beyond those available from bandwidth expansion.

For instance, we would expect that in a system utilizing a design like this that k information bits would be encoded either in a block code or a convolutional code into n transmit bits, where n is equal to k * N where N is the spreading factor. This allows us to use a bandwidth of N times the information bandwidth resulting in a processing gain and without further expanding the transmit signal bandwidth to encode the data to obtain additional coding gain. In other words, we have already expanded the bandwidth by a large factor to acheive spreading and this same bandwidth expansion is available for use in encoding so let's use it!

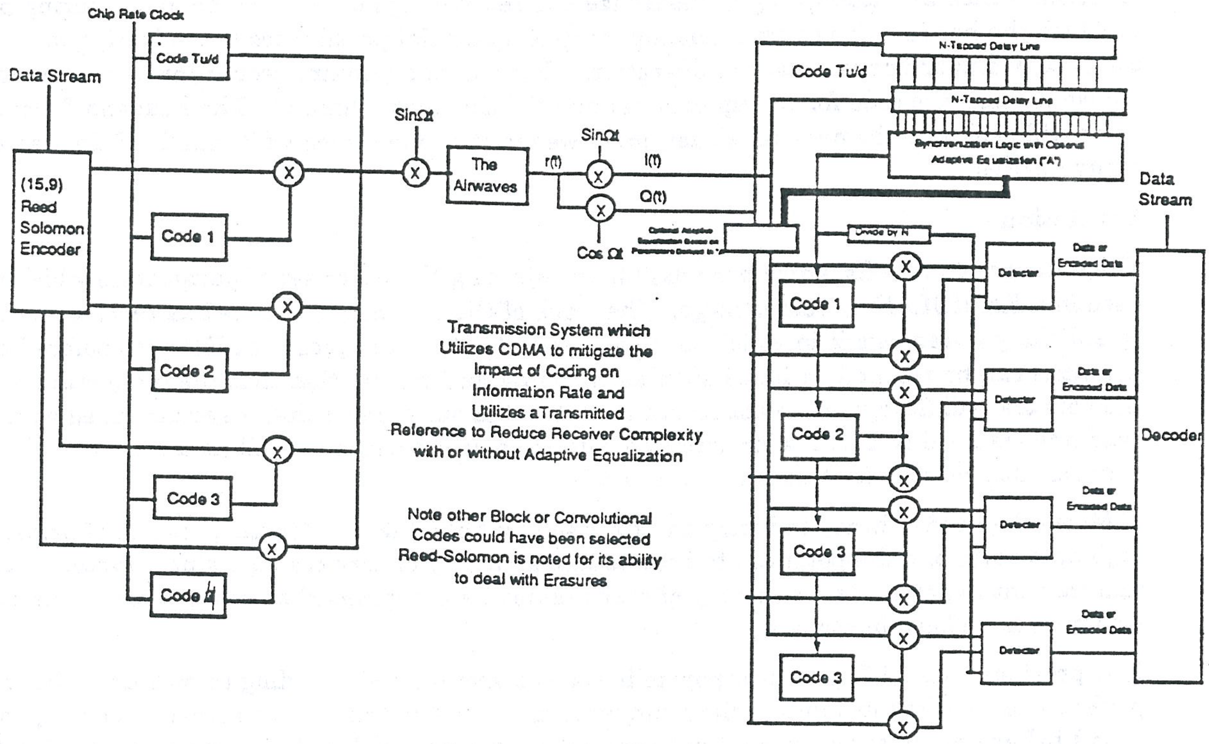

Figure Two

This type of approach is also available in systems which do not use a transmitted reference, however, we feel that with the transmitted reference the possibilities for multipath cancellation beyond that available from simple spreading presents the possibility to acheive substantially higher data rates than currently proposed.

32 Conklin Road, Warwick, NY 10990 Voice 914-986-3492 FAX 914-986-6441

Knowledge Implementations, Inc.

Fiber Optic and Communications Systems Egineering/Marketing

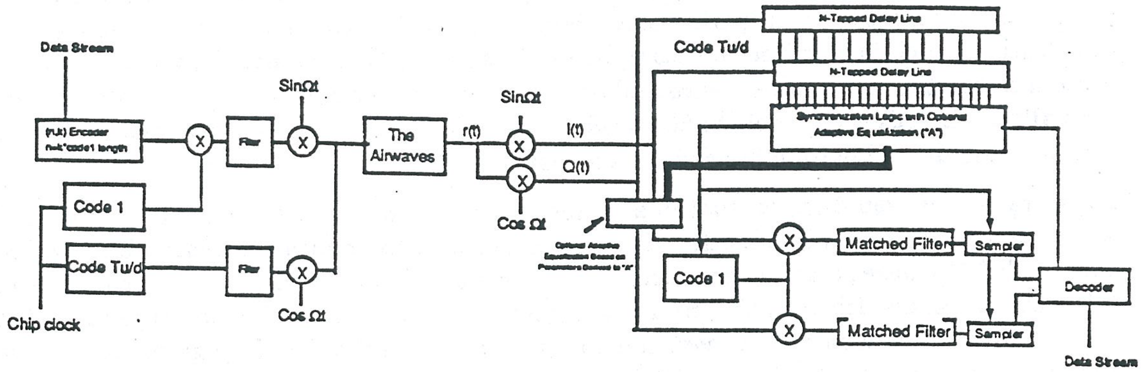

Figure Three

In making a case for a synchronous headend, we believe that the possiblity to disable receiver functions which are attempting to maximize the receive signal from the headend during periods in which the headend is not transmitting offers substantial possibilites for reduction in complexity and/or improvement in operation. Our current thinking would involve a separate transmit reference code for the up channel and for the down channel. The headend function must still deal with the near-far situation, however, it is one device while the DTE devices are many devices.

Conclusion

The number of tradeoffs which are possible in selecting the exact set of parameters which will be used in a RADIOLAN system is large. The work of the committee to date has revolved around establishing a framework in which to move forward. It is our opinion at KII that before final decisions can be reached on items such as encoding and modulation that the big picture of how the network will fit together must be put to rest. It is our opinion that a system based on a synchronous head end with a transmitted reference would serve us well as a model for the big picture. Our reasons for this are as follows:

1) Meets the need of heavy industry as expressed by Mike Maslied for the prospect of providing high data rates and the potential to accomodate a variety of services on a single system. A similar requirement to accomodate a variety of services has been expressed by other potential users with whom we have been in contact.

2) It provides a possibility to incorporate block or convolutional encoding to pick up additional performance without expanding the bandwidth any further than it has already been expanded. This I believe provides the main functional enhancement which is being requested by Hughes Network Systems in their recent proposal. I also believe that with this addition and the appropriate design tradeoffs on modulation and encoding we have the potential to provide a system which is "state-of-the-art" .

3) It provides a degree of spreading which meets the current proposed rules of the FCC regardless of which of the currently known interpretations of those rules ultimately applies.

4) It provides the hooks for existing or new technologies to potentially provide significant enhancements to system operation by incorporating such possible features as adaptive equalization and other possible technologies. Some of these technologies may be particularly necessary in a mobile environment. This meets the needs which have been expressed by General Motors representatives to provide for mobile operation. The enhancements to the probability of error

32 Conklin Road, Warwick, NY 10990 Voice 914-986-3492 FAX 914-986-6441

Knowledge Implementations, Inc.
Fiber Optic and Communications Systems Egineering/Marketing

performance will also serve to reduce antennae spacing and hence lower installation costs in large facilities such as a car body assembly plant.

At this time we are not yet prepared to provide an opinion on what the best choice for coding and modulation would be for the system. One of the major reasons for this is that we believe that there are possibilities to combine the coding, spreading and modulation functions which will result in better utilization of the limited bandwidth we have to work with than the approaches which are currently on the table. The intent of this document is to provide a first input showing that systems which begin the process of better utilizing the bandwidth expansion due to spreading are possible.

This paper has addressed a variety of issues. Lest there be any confusion about what direction we are requesting the group to take based on this submittal we offer the following summary:

1) We would like the issue of synchronous vs. asynchronous headends addressed as quickly as possible with a resolution to use the synchronous version in our standard being our preferred solution to this issue.

2) We favor the use of a clear channel transmitted reference code which will enable the receivers to quickly and accurately determine the impulse response of the channel and to quickly and accurately synchronize with the headend. We would like a preliminary indication of the position of the group with respect to a transmitted reference code.

3) We favor solutions which increase the spreading factor to obtain the maximum amount of benefit from spreading given the other constraints of the system.

It is my sincere hope that this document will be useful in bringing into focus and perhaps resolving some of the issues currently facing the committee. Thank you for taking the time to read it.

32 Conklin Road, Warwick, NY 10990 Voice 914-986-3492 FAX 914-986-6441