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Introducing the Harris-Lucent Compromise Proposal for TGb

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Abstract

HARRIS and LUCENT enthusiastically introduce a compromise proposal which is a modification-and-merger of ideas presented in their earlier independent proposals. HARRIS and LUCENT both feel a signalling scheme based-upon QPSK chips at 11 Mcps provides the smoothest upgrade to high-data-rate/high-performance WLAN systems for the 2.4 GHz PHY. Given this common viewpoint, HARRIS and LUCENT united to perform a comprehensive codeword study which jointly optimises the receiver performance against the codeword structure. One surprise output from the study was a new codeword scheme labelled CCK-16. A second surprise output from the study was a new architecture which combines a RAKE receiver with a symbol-based equalizer. This novel receiver architecture coupled with the complementary codeword structure opens the door to a new level of WLAN performance while minimising complexity. This submission introduces the key characteristics of CCK-16 along with the associated receiver features. HARRIS and LUCENT feel the fruits from this effort represent a significant step forward for TGb.

1. INTRODUCTION

This memo introduces the compromise proposal jointly developed by HARRIS and LUCENT. This proposal combines the best ideas from the earlier independent HARRIS and LUCENT proposals and adds several new features to create a potent TGb compromise. For reader convenience, only the highlights are presented in this submission. Balancing details are found in the comparison matrix. Future submissions will go into greater depth.

2. KEY FEATURES

The new compromise modulation is a variation on HARRIS's MBOK and QMBOK modulation, yet possesses the nice autocorrelation properties as demonstrated by LUCENT's BCPM. The new modified modulation is now distinctively called CCK-16. This is an acronym for *complementary-code-keying with 16 chips*. At the highest data rate, the data is no longer encoded on the I channel and Q channel independently. Instead, the data is encoded serially onto complex chips, eliminating the cross-coupled I/Q-channel corruption induced by multipath distortion. Now the receiver is no longer burdened with uncoupling the I-cross-Q channel distortion.

The modulation codewords now possess an underlying structure which is potently exploited by a symbol-decision-based equalizer. This allows the equalizer to operate at low SNR conditions, yet avoid an associated increase in complexity. The equalizer processing is dominated by simple add/subtract operations in feedback multipath-tail cancelling. The RAKE front-end minimizes the need for heavy-precursor equalization. A channel matched filter boosts the SNR as part of the natural RAKE mechanics.

Harmony exists in the receiver architecture across the data rates. The same basic architecture is used for all data rates from 1 Mbps up to the 10 Mbps rates. A channel matched filter provides channel finger combining. A codeword correlator provides coherent combining of the codeword chips. An optional ISI equalizer stage subtracts intersymbol interference from the preceding symbol decision. An optional ICI equalizer stage subtracts interchip interference from the current-symbol's chips. The equalizer stages are unnecessary to achieve high performance at the fallback rates.

The key features provided by the compromise proposal are summarized in the following table.

TRANSMIT MODULATION	1. Retains QPSK chips at 11 Mcps for interoperability. 2. Extends codewords to 16 chips. 3. Constructs codewords from complementary codes. 4. Serial complex-chip encoding used to enable high performance/complexity ratio. 5. Symbol's phase is differentially encoded to enable receiver PLL simplification. 6. Many data-rates capable with highest rate 10.3 Mbps.
	1. Multiple performance/complexity architectures possible

RECEIVE ARCHITECTURE	• RAKE • RAKE with ISI Equalizer • RAKE with ISI/ICI Equalizer 2. Equalizer is symbol-decision-based not chip-decision-based. 3. Equalization not needed at fallback rates. 4. Differentially-coherent-phase symbol reception minimizes acquisition time. 5. Optimal reduced-complexity codeword correlation demonstrated. 6. Reception is possible using a limited receiver, but the highest data rates are degraded beyond that acceptable for commercial and factory environments.
PACKET ERROR PERFORMANCE	1. Good SOHO, commercial and factory performance. 2. Tolerates high multipath spreads. 3. Tolerates low SNR. 4. Six-finger channel matched filter used. 5. RAKE (64 byte packets at 10.3 Mbps) • Noise—*5.5 dB* • MP—*90 nsec* • Noise plus MP—*15 dB* 6. RAKE-ISI Equalizer (64 byte packets at 10.3 Mbps) • Noise—*5.5 dB* • MP—*144 nsec* • Noise plus MP—*TBD* 7. RAKE-ISI/ICI Equalizer (64 byte packets at 10.3 Mbps) • Noise—*5.5 dB* • MP—*333 nsec* • Noise plus MP—*15.5*

3. CCK-16 CODEWORD DESCRIPTION

This section introduces the high-performing CCK-16 codeword. CCK-16 is short for complementary code keying with 16 chips. We hope the reader becomes as excited as HARRIS/LUCENT once the properties of this new coding structure are understood.

CODEWORD STUDY

HARRIS and LUCENT performed a comprehensive codeword study where 8 chip, 11 chip and 16 chip codes were examined. Various techniques such as Walsh coding, cover codes, cyclic shifting, codeword extension and real versus complex chips were examined. The inherent minimum-distance properties of the codes were analyzed using the matched-filter-bound to evaluate codeword performance without actually performing packet-error-rate tests. This greatly increased the code search/analysis speed. The matched-filter-bound is a theoretical upper-bound on a communication system's performance. HARRIS and LUCENT found a way to theoretically compute the matched-filter-bound under Rayleigh-fading exponential-decaying multipath channel conditions. This measured the theoretical robustness of codewords under severe indoor multipath conditions. Packet error testing was only taken as a follow-up verification step to confirm the results obtained with matched-filter-bound testing.

An addition analysis step examined the RAKE and equalizer. It was found that CCK-16 could be constructed in a way which optimised the merger of RAKE and equalizer. The result was a practical equalizer which uses symbol-based decisions. This invented architecture was previously unknown to the researchers.

After extensive testing, it was found that 16 chip complementary-code-keying gave the overall best results.

This is a different conclusion than that reached by MICRILOR. HARRIS/LUCENT identified the difference as due to the chip modulation scheme difference: MSK versus QPSK chips. CCK-16 has been optimised for QPSK chip signalling. MICRILOR's Walsh coding was optimised for MSK. In addition, HARRIS/LUCENT have crafted CCK-16 to enable fluid equalizer implementation.

The main problem of previous proposals using QPSK chips was caused by the fact that they used independent codes on the in-phase and quadrature signals, which created a significant amount of cross-rail interference in the presence of multipath. To avoid this in our new modulation, we concluded one should ideally transmit only symbols for which processing can be done on I and Q simultaneously, and use code words that all have good autocorrelation properties, such that there is minimal inter-symbol and inter-chip interference. This codeword-encoding feature actually exists in the form of the so-called complementary codes.

COMPLEMENTARY CODE EXAMPLE

An example is given for a code length of 8 chips, where 256 possible sequences *c* can be constructed as follows, using 4 QPSK phases φ_1 to φ_4:

$$c = \{e^{j(\varphi_1+\varphi_2+\varphi_3+\varphi_4)}, e^{j(\varphi_1+\varphi_3+\varphi_4)}, e^{j(\varphi_1+\varphi_2+\varphi_4)},$$
$$-e^{j(\varphi_1+\varphi_4)}, e^{j(\varphi_1+\varphi_2+\varphi_3)}, e^{j(\varphi_1+\varphi_3)}, -e^{j(\varphi_1+\varphi_2)}, e^{j\varphi_1}\}$$

Note, φ_1 is present in all 8 chips, so it simply rotates the entire code word. Hence, to decode these code set, one would need 64 correlators plus an additional phase estimation of the code that gave the largest correlation output. The correlation can be significantly simplified by using techniques like the fast Walsh transform. In fact, when the 4 input phases φ_1 to φ_4 are binary, then the complementary code set reduces to a modified Walsh code set, similar to the one used in HARRIS's original proposal.

For the fallback rates, φ_1 to φ_4 can be set to binary phases, mathematically similar to HARRIS's fallback MBOK.

Note that the information is encoded directly onto complex chips which cannot be cross-coupled corrupted by multipath since each channel finger has an $Ae^{j\theta}$ distortion. A single channel finger gain-scales and phase-rotates the signal. A gain scale and phase rotation of a complex still maintains I/Q orthogonality. This superior encoding technique avoids the corruption resulting from encoding half the information on the I-channel and the other half on the Q-channel, which easily cross-couple corrupts with the multipath finger's $Ae^{j\theta}$ phase rotation.

CODESET EXTENSION

It is common to create larger codesets from lower codesets. Usually the larger codeset is constructed from smaller codesets which possess good autocorrelation/crosscorrelation properties. In this way, using the high-performance foundation, larger codesets can be created with minor degradation in the properties.

Many extension schemes exisits. GOLDEN BRIDGE extended the single code 11-chip Barker code to 11 codewords by cyclically shifting the Barker code 11 times and appending a parity bit. The 11 codewords were all orthogonal.

Another example extension technique is to replicate codes and append bits. An 8-ary Walsh codeset is shown in Fig. 3.1. Three information bits can select one of the 8 codewords.

$$\begin{matrix}
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\
1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\
1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\
1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\
1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\
1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\
1 & -1 & -1 & 1 & -1 & 1 & 1 & -1
\end{matrix}$$

Figure 3.1 8-ary Walsh codes.

In Fig. 3.2 this set is extended to 16 11-chip codewords. The 8-ary Walsh codes of Fig. 3.1 are duplicated once. They show-up in the first 8 chips of the top 8 codewords and again in the bottom 8 codewords. Three bits are appended to make them distinct. A question rises concerning the location of the information. In this case, the first 3 bit select the first 8 chips, while the 4th bit selects the last 3 chips. Is this an 11 chip codeword or an 8 chip codeword followed by a 3 bit codeword? The receiver could detect the first 3 bits by detecting only the first 8 chips and the last bit by detecting the last 3 chips. Also, an adaptive equalizer could process the first 8 chips separate from the last 3 chips.

1	1	1	1	1	1	1	1	1	-1	1
1	-1	1	-1	1	-1	1	-1	1	-1	1
1	1	-1	-1	1	1	-1	-1	1	-1	1
1	-1	-1	1	1	-1	-1	1	1	-1	1
1	1	1	1	-1	-1	-1	-1	1	-1	1
1	-1	1	-1	-1	1	-1	1	1	-1	1
1	1	-1	-1	-1	-1	1	1	1	-1	1
1	-1	-1	1	-1	1	1	-1	1	-1	1
1	1	1	1	1	1	1	1	1	1	-1
1	-1	1	-1	1	-1	1	-1	1	1	-1
1	1	-1	-1	1	1	-1	-1	1	1	-1
1	-1	-1	1	1	-1	-1	1	1	1	-1
1	1	1	1	-1	-1	-1	-1	1	1	-1
1	-1	1	-1	-1	1	-1	1	1	1	-1
1	1	-1	-1	-1	-1	1	1	1	1	-1
1	-1	-1	1	-1	1	1	-1	1	1	-1

Figure 3.2 Extended 8-ary codewords to 16-ary codewords.

The above codeset would not have very good cross-correlation properties because the codewords are merely replicated. The set of Fig. 3.2 is repeated in Fig. 3.3. Now the 4th and 7th chip is inverted for the first 8 codewords, and the 4th and 6th chip is inverted for the last 8 codewords. This improves the cross-correlation performance. However, an receiver (and equalizer) could still make a suboptimal decision on only the first 8 chips followed by the last 3 chips.

1	1	1	-1	1	1	-1	1	1	-1	1
1	-1	1	1	1	-1	-1	-1	1	-1	1
1	1	-1	1	1	1	1	-1	1	-1	1
1	-1	-1	-1	1	-1	1	1	1	-1	1
1	1	1	-1	-1	-1	1	-1	1	-1	1
1	-1	1	1	-1	1	1	1	1	-1	1
1	1	-1	1	-1	-1	-1	1	1	-1	1
1	-1	-1	-1	-1	1	-1	-1	1	-1	1
1	1	1	-1	1	-1	1	1	1	1	-1
1	-1	1	1	1	1	1	-1	1	1	-1
1	1	-1	1	1	-1	-1	-1	1	1	-1
1	-1	-1	-1	1	1	-1	1	1	1	-1
1	1	1	-1	-1	1	-1	-1	1	1	-1
1	-1	1	1	-1	-1	-1	1	1	1	-1
1	1	-1	1	-1	1	1	1	1	1	-1
1	-1	-1	-1	-1	-1	1	-1	1	1	-1

Figure 3.3 Selective chip inversion for the set of Fig. 3.2.

CONCATENATED EXTENSION

HARRIS and LUCENT extended the 8 chip complementary code set in a novel fashion to 16 chips, creating CCK-16. CCK-16 is not a pure 16 chip complementary code, but rather an 8 chip complementary code extended.

The HARRIS/LUCENT extension technique is similar to the Walsh replication above, only the replicates are appended. An 8-chip complementary is appended end-to-end to form a 16 chip codeword. Two different cover codes could have been used, but were not. Using two different cover codes for the first-half/second-half is an option that may be desirable, but insufficient time was available to explore the issue properly.

To avoid the 8 chip (3 info bits) followed by 3 chips (1 info bit) problem raised above, HARRIS/LUCENT firmly binds the two 8 chip halves into a 16 chip whole through a simple encoding scheme. In this case the receiver must observe all 16 chips in order to make an optimal 16 chip codeword decision.

In general, there would be a multiplicative complexity increase for codeword correlation with this scheme. However, HARRIS/LUCENT found a way to make only an additive complexity increase.

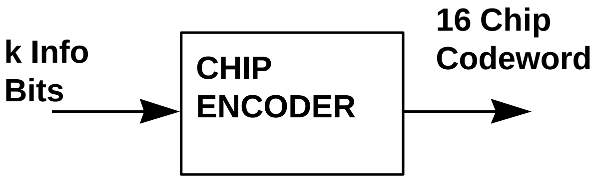

Figure 3.4 The basic encoder block.

INHERENT DATA-RATE SPAN

The inherent data-rate capability of this coding scheme is listed in the Table 3.1. A symbol is 16 chips, and a segment is 8 chips.

As a caveat, HARRIS and LUCENT feel that confusion may exist in the marketplace if all these rates are provided. Consequently, analysis has only been carried out for the nearly 10 Mbps and nearly 5 Mbps rates.

Table 3.1 Bit allocation.

# Info Bits Per Symbol	# of Code Word Bits	# Bits per Segment	# Sign Bits for Segment	# of Codeword Select Bits for Segment	Rate Mbps
15	16	8	2	6	10.3125
13	14	7	2	5	8.9375
11	12	6	2	4	7.5625
9	10	5	2	3	6.1875
7	8	4	2	2	4.8125
5	6	3	2	1	3.4375

4. BRIEF RECEIVER DESCRIPTION

SYMBOL-DECISION EQUALIZATION

Earlier submissions by HARRIS have shown that large multipath delay spreads can be mitigated through the use of an adaptive equalizer. The HARRIS suggested equalizer was low complexity because it minimized the number of feedforward taps. Most of the impulse response energy was pushed into the feedback taps. A drawback with this approach was marginal performance at low SNR's.

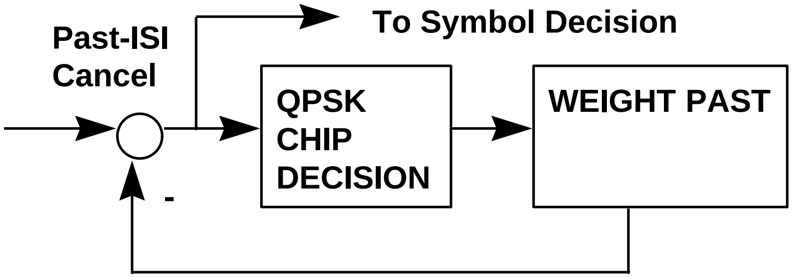

Figure 4.1 Chip-based equalization.

The marginal performance at low SNR's can be directly attributed to the QPSK chip decision shown in Fig. 4.1. The detection SNR of a chip exists in the spread chip-rate bandwidth. The detection SNR of a symbol is in the much-smaller symbol-rate bandwidth. Consequently, with 8 to 11 chips per symbol, the SNR of a chip is degraded. Whenever a chip-decision-error occurs, the multipath is no longer subtracted properly by the feedback taps. Consequently, a chip-decision-error usually leads to a symbol-decision-error.

To mitigate this problem, HARRIS/LUCENT have switched to the architecture shown in Fig. 4.2. Here the equalizer makes a decision using all the symbol's chips. A noise-spike on a single chip no longer forces a symbol error. The combining-gain across the symbol's chips averages-out the noise-spike.

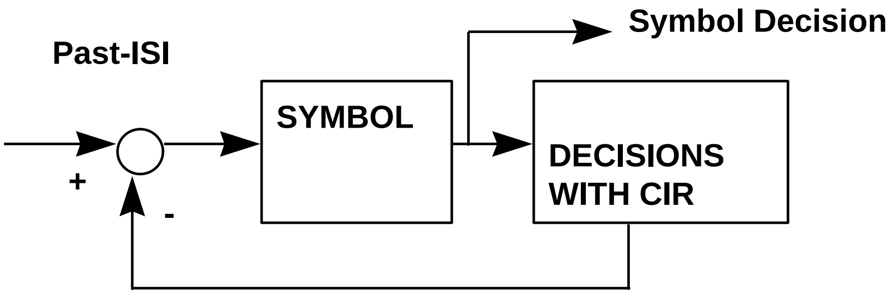

Figure 4.2 equalization.

Unfortunately, a 16 chip symbol is often too complex for the minimize complexity yet retain performance, the recommending CCK-16 encoding scheme described in this submission opens the door to reduced-complexity equalizer architectures which retain robust low-SNR performance. Here the equalizer can make sub-symbol tentative decisions to perform simpler ISI and ICI mitigation which is low-SNR robust.

RAKE-ISI Equalizer and RAKE-ICI/ISI Equalizer

This section identifies 3 possible architectures which can be used to receive the recommended modulation. Other variations are possible, but this section identifies three canonical forms. Each new canonical form subsumes the preceding, to provide a convenient, uncomplicated path to realise increases in performance, merely by building upon previous built foundations.

The first architecture is shown in Fig. 4.4 This is the conventional RAKE receiver, which is well understood and popular.

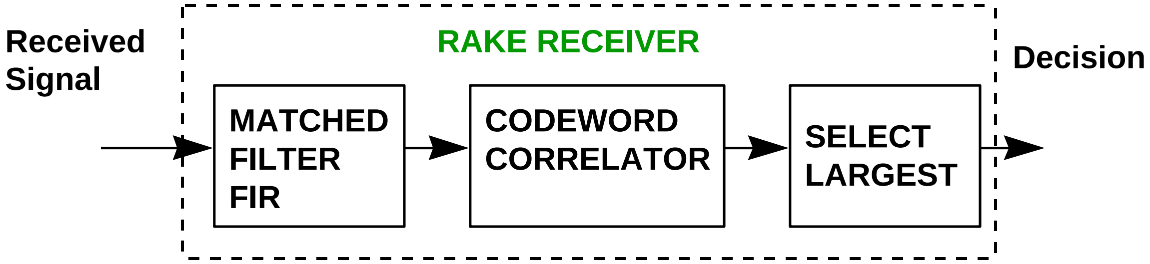

Figure 4.4 Conventional RAKE receiver.

The second architecture is shown in Fig. 4.5. Here a ISI cancelling equalizer is added to the RAKE receiver of Fig. 4.4. The intersymbol interference from the previous symbol is cancelled from the current symbol-under-detection. This is a powerful addition since indoor multipath is dominated by postcursor distortion. While more than one past symbol-decision can be used to cancel symbol-under-detection ISI, the HARRIS/LUCENT simulations have only used the preceding adjacent symbol decision.

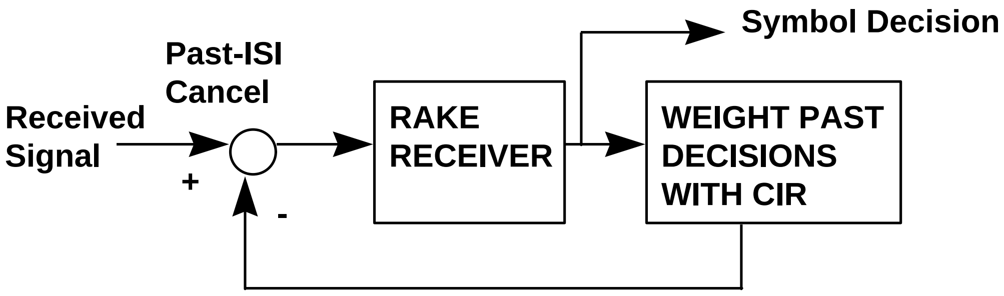

Figure 4.5 RAKE with ISI equalizer.

The third architecture is shown in Fig. 4.6. Here a ICI cancelling equalizer is added to the RAKE with ISI equalizer of Fig. 4.5. The interchip interference which exists on the symbol-under-detection is cancelled as part of the codeword correlator. This is a powerful addition since ICI decreases the distance between codewords.

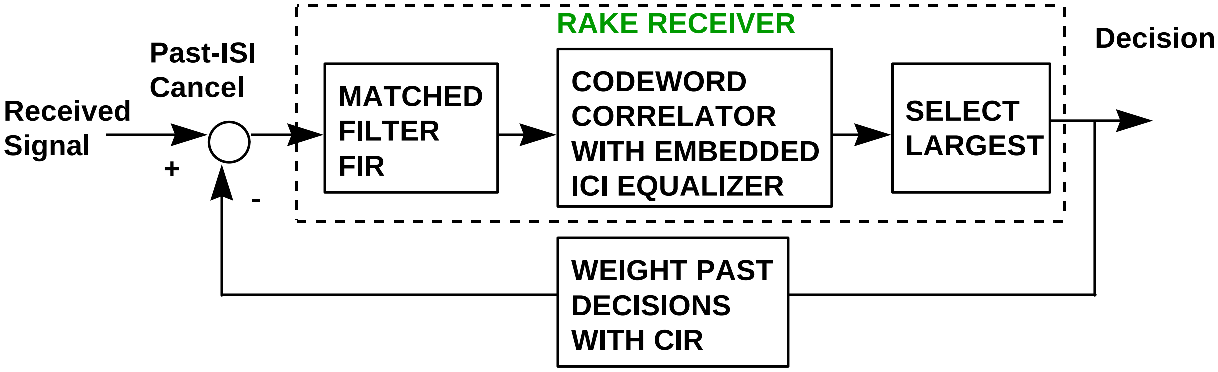

Figure 4.6 RAKE with ISI/ICI

5. CONCLUSION

hope the reader is as excited about the presented innovations as we are. The advances introduced by this submission would not have been possible without the united efforts of HARRIS

are optimistic that others will now join with us in this advance for TGb.