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Title: Channel estimation for TDD using pilot symbols

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1.0 Introduction

With the WCDMA FDD mode systems, channel estimation is accomplished by averaging pilot symbols that are periodically inserted in the data stream of each user. For the TDD mode systems channel estimation is performed by a cyclic correlation with a specially constructed midamble [1]. The midamble is based upon a sequence with good autocorrelation properties that theoretically should lead to good channel estimates. The midamble codes for all the users are derived from the same basic sequence. However, the use of a midamble derived from a single sequence has four drawbacks.

(1) The maximum number of users times the maximum possible length of the channel impulse response must be less than the length of the basic sequence. Thus the number of users per slot is typically limited to 8, while there are 16 Walsh codes available with a spreading factor of 16. We believe that a hard limit of 8 users should not be adopted but rather that more users be allowed when inter cell interference conditions are favorable.
(2) A second drawback is that channel estimation based on the midamble actually performs worse than simple averaging over pilot symbols. This is shown in simulations presented in this paper.
(3) A third drawback to the use of the midamble is that some network planning must be done to assign the few sequences with good autocorrelation properties to different base stations.
(4) A fourth drawback is that an FFT must be implemented at the receiver to take advantage of the special structure of the midamble. With pilot symbols no FFT is needed. Finally, channel estimation with the midamble is more computationally complex than with pilot symbols, even in the event that multi-user detection is employed at the mobile.

We propose than the midamble be replaced with simple pilot symbols. In the downlink, instead of a 256-chip midamble, 16 pilots with a spreading factor of 16 should be transmitted. This idea was proposed by Panasonic [2] in late 1998, but they did not do simulations to compare the channel estimation performance of the two schemes.

Based upon the raw BER simulations, we find that the E_b/N_0 gain for replacing the midamble with 16 pilot symbols is between 0.2-1.0 dB, depending upon the delay path profile and the Doppler rate. In cases with favorable inter cell interference the capacity can be doubled from 8 to 16 users with the use of pilot symbols. We believe that the use of pilot symbols will allow vendors to implement interference cancellation schemes that can reach the capacity of 16 users for many channel conditions.

2.0 Simulation results

We now do link level simulations to evaluate the performance gains of using simple pilot symbols instead of the specially constructed midamble. The link level simulation parameters used are given in Table 1:

	Vehicular	Indoor-to-outdoor pedestrian
Velocity	120 kmph (Figure 1)	3 kmph (Figure 2)
Spreading gain (SF)	16	16
Number of users	8	8
Midamble parameters	256 chips, basic sequence is 192 chips	256 chips, basic sequence is 192 chips
Midamble channel estimation	Circular convolution performed with FFT, Mult., and IFFT	Circular convolution performed with FFT, Mult., and IFFT
Pilot symbol parameters	16 pilot symbols with spreading factor of 16	16 pilot symbols with spreading factor of 16
Pilot symbol channel estimation	Average over 16 pilot symbols	Average over 16 pilot symbols

Table 1: The simulation parameters used to compare the performance of the midamble versus the performance with pilot symbols.

The performance with the Vehicular B channel is shown in Figure 1. With a spreading factor of 16 and with 8 users, the use of pilot symbols results in a 1.0 dB gain over the use of the midamble at a raw BER of 0.10. This is explained by the fact that the midamble uses a cyclic prefix of 64 chips and a basic sequence of length 192 chips. By discarding the cyclic prefix, the effective number of pilot symbols (with spreading gain of 16) is reduced from 16 to 12.

The performance with the Outdoor-to-Indoor and Pedestrian channel is shown in Figure 2. With a lower Doppler rate, the gain at a raw BER of 0.03 is about 0.2 dB. A lower target BER is used in this case because there is little time diversity at low Doppler to help improve the coded BER, so a lower raw BER is needed. Generally channel estimate performance worsens with higher Doppler rate, and the effect of throwing away pilot symbols is more apparent at higher Doppler rates.

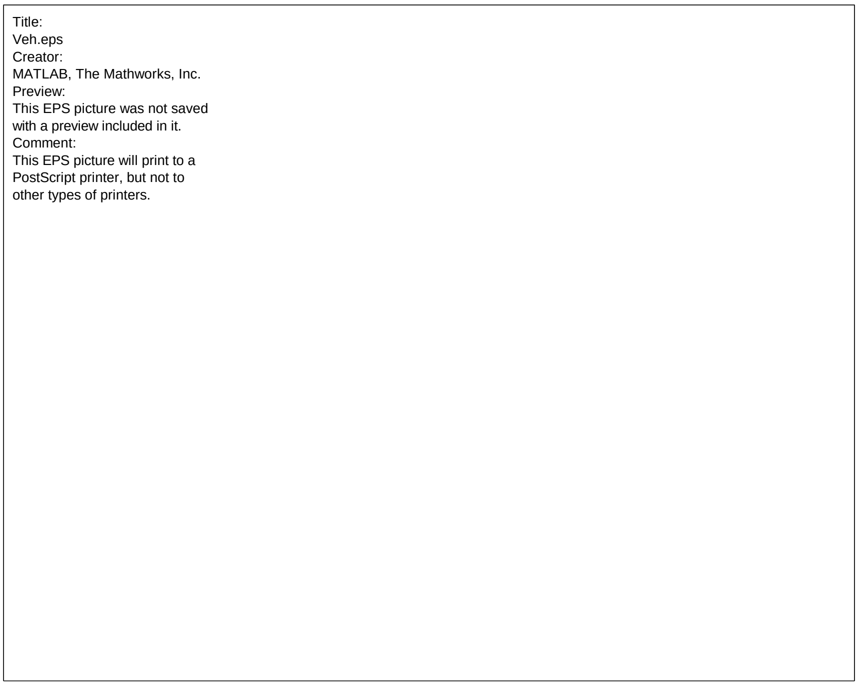

Figure 1: Link level simulations comparing the raw BER performance with the midamble and with pilot symbols for the downlink using the Vehicular B channel model. The spreading gain is 16 and the number of users is 8.

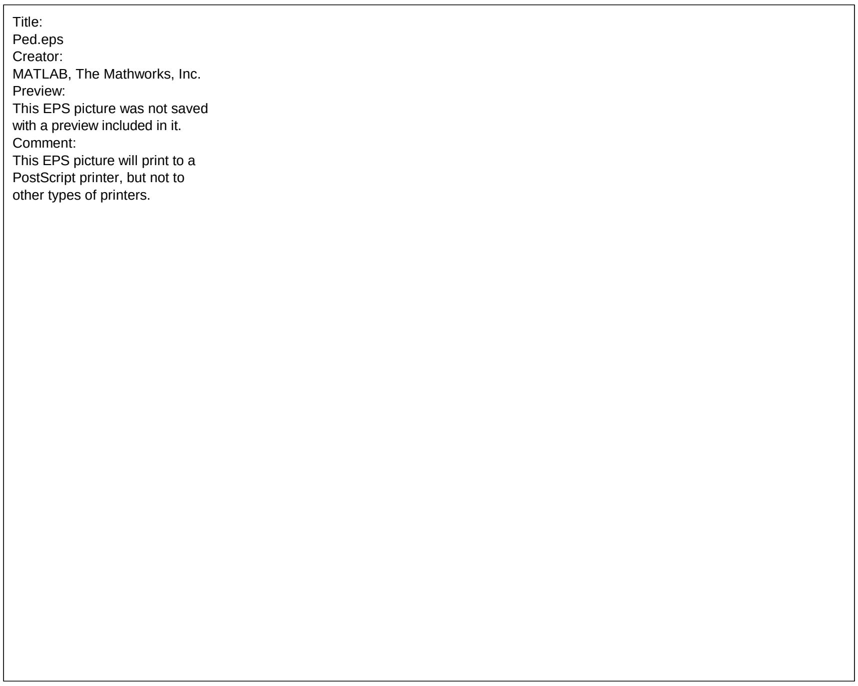

Figure 2: Link level simulations comparing the raw BER performance with the midamble and with pilot symbols for the downlink using the Outdoor-to Indoor and Pedestrian channel model. The spreading gain is 16 and the number of users is 8.

3.0 Complexity Calculations with Multi-User Detection

3.1 Complexity of Channel Estimation with the Midamble

When multi-user detection is used at the mobile, the mobile estimates the channel for all the users in the cell which receive data in the same time slot. With 8 users, 8 separate channel estimates must be made. An analysis of the computational complexity of channel estimation with the midamble is given in [3]. The calculations to determine computational complexity are summarized below. The mobile is assumed to receive information in one time slot per frame, so channel estimations must be made once per frame (100 times per second). Assuming that each complex operation in the FFT requires 4 instructions (4 multiply and accumulates), there are 4 (256) $\log_2(256) = 8192$ operations per FFT. There is both an FFT and IFFT required for the cyclic correlation, so the total number of operations required per second is

(2 FFT's)(100 frames)(8192 instructions) = 1.638 MIPS

The length of the basic sequence is of length 192, so an FFT of length 192 must be computed. A method is presented in [4] in which the 192 length FFT is computed using a method in which the 192 length FFT is broken down into smaller FFT's. Using the fact that 192 = 3*64 and letting X=3 and Y=64, the FFT can be performed with X FFT's of Y points plus Y FFT's of X points. The complexity estimate with this method is given as 1.38 MIPS.

3.2 Complexity of Channel Estimation with Pilot Symbols

Channel estimation with pilot symbols requires despreading the pilot symbols for each user and averaging over the 16 symbols within a time slot. Again, as with the midamble the mobile receives data on one time slot per frame. The Walsh-Hadamard Transform (WHT) can be used to despread all the Walsh codes efficiently. The complexity of the WHT is 16 $\log_2(16)$ complex adds per symbol. There are 16 pilot symbols, so despreading requires (16 symbols)(16)(4)(2) = 2048 instructions per frame. Adding the despread symbols after removing the data modulation requires (8 users)(15 adds)(2 for complex) = 240 instructions per frame. If there are four fingers per user, the total computational complexity is
(100 frames)(4 fingers)(2048+240) = 0.915 MIPS.

Channel estimation with the midamble actually requires 50% more computational complexity than channel estimation with the pilot symbols.

4.0 Conclusions

We have shown that the use of pilot symbols gives a gain of 0.2-1.0 dB in performance versus using the specially constructed midamble. Twice the number of users can be supported for channel estimation. This can result in efficient multi-user detection algorithms being used at the mobile. The computational complexity does not have to be increased 50% to support the midamble approach. FFT's do not have to be built into the mobile if pilot symbols are used. No network planning to assign special midambles to each base station needs to be done if pilot symbols are used.

References

[1] 3GPP RAN WG1, "Transport channels and physical channels description (TDD)", Tdoc 267/99, (S1.21) V1.0.1., March 1999.

[2] Panasonic, "Refinements of TDD and remaining open items", Tdoc 458/98, SMG2 UMTS L1, Stockholm, Sweden, October 1998.

[3] Interdigital Communications Corporation, "Complexity analysis of the multi-user channel estimation in TDD", TSGR1#5(99)579, Cheju, Korea, June 1999.

[4] Motorola, "Complexity of multiple channel estimations and the SU", TSGR1#4(99)389, Yokohama, Japan, April 1999.