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SPACE-TIME DIVERSITY FOR MULTIMEDIA DELIVERY OVER WIRELESS CHANNELS

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ABSTRACT

A source-channel matched layered space-time diversity technique is presented for reliable delivery of layer coded multimedia data through wireless channels. The transmission system is transformed to multiple subchannels and each associated with different diversity gain, therefore different error performance. Similarly to the parallel transmission proposed for ADSL[9], we develop a parallel transmission scheme to match the source layers to the channel layers. Power control alters the error performance of each channel layer to achieve the optimal performance.

1. INTRODUCTION

Dramatic development in the area of personal communications services allows wireless multimedia services. In the near future, it is expected that millions of users will have access to a wide variety of services that will be made available over national and international communication networks. Mobile uses will be able to access their data and other services such as email, e-news including stock market news, video telephony, yellow pages, map services, electronic banking, etc. while on the move. Real-time multimedia services require high reliability with a low bounded time delay and a reasonably high transmission rate. Wireless channels on the other hand are error-prone, time-varying and band-limited. Automatic repeat request(ARQ) allows retransmission of the corrupted data, but yields long delay. Proper error control can be used to obtain more reliable transmission, and maintain a low delay. However, this causes unnecessary overhead and reduces throughput during periods of good channel status.

The derogatory effects of multipath fading in a wireless communication system can be mitigated by employing antenna diversity. It involves multiple transmit antennas and/or receive antennas to allow multiple signal replica at the receiver. Such advantage makes it to attractive to use for the transmission over band-limited wireless channels[1, 2, 3]. Recently, space-time diversity which achieves both space and time diversity, has raised great interests[4, 5, 6, 7]. Space-time codes which is a joint design of coding, modulation, transmit and receive diversity, has been developed for high data rate wireless communications[8].

The current diversity techniques are all developed for data transmission. In this paper, we consider the problem of reliable multimedia data delivery through wireless channels using multiple transmit/receive antennas. Multimedia input can be represented in terms of a number of layers, each resulting in a distinct data stream representing different perceptually relevant components of source material. Different layers may have distinctly different tolerances to channel errors and the corresponding data streams can then be handled differently by the transmitter[9]. In another word, the source layers receive unequal error protection(UEP). In [9], we proposed a parallel transmission scheme for wireline channels, which transmits layers with higher error performance requirement through subchannels with higher channel gain to noise ratio. In this paper, we apply the parallel transmission scheme to layered space-time diversity technique.

2. LAYERED SPACE-TIME DIVERSITY

We consider the layered space-time architecture proposed in [5, 6]. It utilizes multiple antenna arrays at both transmitter and receiver. The diagonal layered space-time (DLST) code distributes the coded data across diagonals in space-time domain. This structure leads to theoretical rates which increase linearly with the number of antennas at the transmitter and receiver. Horizonal layered space-time(HLST) code distributes the coded data among the rows in space domain, which leads to less complexity compared to DLST. By employing interference suppression and interference cancellation, the coded data layers can be separated and decoded independently. This results in a much lower decoding complexity compared to the trellis space-time

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codes which employ ML decoding, especially for large number of transmit antennas. We consider HLST in the paper, where each antenna is considered as a channel layer or subchannel.

The structure of HLST code is shown in Figure 1, assuming N transmit antennas and M receive antennas. Let $\mathbf{t} = (t_1, t_2, ..., t_N)$ denote the vector of transmitted symbols and $\mathbf{r} = (r_1, r_2, ..., r_M)$ denote the received signal,

$$\mathbf{r} = H\mathbf{t} + \mathbf{v} \tag{1}$$

where $\mathbf{v}$ represents the noisy vector and H represents the channel gain matrix. Assuming perfect H estimation at receiver, the decision variables from each horizontal location can be extracted and decoded. The receiver first picks one layer, e.g. layer $N-1$, and extracts it by making a decision based on the received vector $\mathbf{r}$. Then the factor or contribution of layer $N-1$ to $\mathbf{r}$ is removed based on the decision of layer $N-1$. Therefore, layer $N-2$ can be similarly decoded without the interference of layer $N-1$. Here we refer the layer as channel layer. For layer k, the probability of transmitting $\mathbf{t}$ and decoding $\mathbf{c}$ is[7]

$$\begin{aligned} P(\mathbf{t} \to \mathbf{c}|H) &= Q\Big(\sqrt{\frac{E}{2N_0}\sum_{l=0}^{N-1}|R_l^k|^2|\mathbf{t}-\mathbf{c}|^2}\Big) \\ &\leq exp\Big(-\frac{E}{4N_0}\sum_{l=0}^{N-1}|R_l^k|^2|\mathbf{t}-\mathbf{c}|^2\Big). \end{aligned} \tag{2}$$

And the average error probability of layer k can be approximated as

$$Prob(\mathbf{t} \to \mathbf{c}) \approx \prod_{\mathbf{c},\mathbf{t}}\Big((|\mathbf{c}-\mathbf{t}|^2)^{-(M-k)}\Big)(\frac{E}{N_0})^{\sum_{\mathbf{c},\mathbf{t},\mathbf{c}\neq\mathbf{t}} M-k}. \tag{3}$$

By applying Reed Solomon $(N, N-T+1)$ code, the symbol error probability for layer k is then

$$Pe \approx \Big(\frac{Ed^2}{4N_0}\Big)^{-T(M-k)}, \tag{4}$$

where d^2 is the minimum distance between two neighboring modulation symbols. Therefore, layer k is associated with diversity gain $M-k$ and should have better error performance than layer $N-1, ..k+1$ statistically.

3. POWER CONTROL IN LAYERED SPACE-TIME CODE

HLST code is originally designed for data transmission. In such case, the design criteria is the error performance averaged over all the channel layers. Assuming each channel layer uses the same transmitted power, the average SER of the channel layers can be computed as

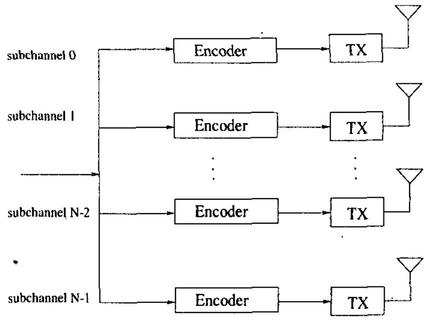

Figure 1: Horizontal Layered Space-Time Code

$$\begin{aligned} Pe(E) &= \frac{1}{N}\sum_{k=0}^{N-1}\Big(\frac{Ed^2}{4N_0}\Big)^{-T(M-k)} \\ &= \frac{1}{N}\Big(\frac{Ed^2}{4N_0}\Big)^{-TM}\frac{\Big(\frac{Ed^2}{4N_0}\Big)^{TN}-1}{\Big(\frac{Ed^2}{4N_0}\Big)^{T}-1}, \end{aligned} \tag{5}$$

where the average power used $E_T = E$.

On the other hand, power allocation can also be applied to equalize the error performance of channel layers. It leads to

$$\begin{aligned} &Pe_k(E_k) = (\frac{E_k d^2}{4N_0})^{-T(M-k)} = (\frac{E_l d^2}{4N_0})^{-T(M-l)} = Pe_l(E_l) \\ &\to E_k = \Big(\frac{E_0 d^2}{4N_0}\Big)^{\frac{M}{M-k}}\frac{4N_0}{d^2} \quad \text{and} \\ &Pe_k = Pe(E_0) = \Big(\frac{E_0 d^2}{4N_0}\Big)^{-TM}, \end{aligned} \tag{6}$$

where E_0 represents the transmitted power for channel layer 0. E_0 is a function of $E_T = \frac{1}{N}\sum_{k=0}^{N-1}E_k$; therefore, the overall error performance can be represented as a function of E_T. However, due to the exponential factor $\frac{M}{M-k}$, such allocation leads to huge variation in the transmitted power assigned to the layers. Figure 4 illustrates the transmitted power for layer $N-1, ..., 0$ assuming $N = M = 7$ and 8PSK modulation $d^2 = 0.7654$, as a function of E_T. As can be seen, the transmitted power assigned to layer 6 increases dramatically as E_T increases. This would yields difficulty in power amplifiers. Therefore, such approach is not feasible for practical applications.

3.1. Optimization for Serial Transmission

To transmit layer coded multimedia data, the source layers can be transmitted consecutively as shown in

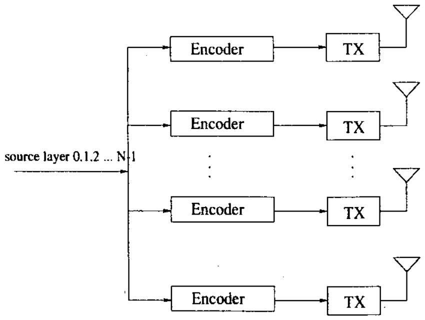

Figure 2: Serial Transmission in HLST

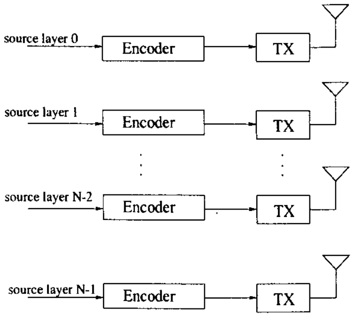

Figure 3: Parallel Transmission in HLST

Figure 2, and the transmitted power can be assigned to minimize the approximated channel distortion

$$\begin{aligned} \min \quad & D_c = \sum_{l=0}^{N_s} W_l Pe(E_T^l) \\ \text{subject to} \quad & \sum_{l=0}^{N_s} S_l E_T^l = E_{budget}, \end{aligned} \tag{7}$$

where N_s is the number of source layers, S_l is the symbol length of layer l. Similar to previous sections, LaGrange multiplier method can be applied to find the optimal solution.

3.2. Optimization for Parallel Transmission

For HLST code, channel layers are associated with different error performance. Rather than equalizing or averaging the error performance among all the channel layers, we propose to transmit different source layers as different channel layers, as shown in Figure 3. We assume $N = N_s$ so that each source layer is mapped to one channel layers. The combined source-channel layer approach can allocate the transmitted power and the error control coding rate to achieve the optimal error performance distribution. The distortion minimization function can be formulated as

$$\begin{aligned} \min \quad & \sum_{k=0}^{N-1} W_k \left(\frac{E_k d^2}{4N_0}\right)^{-T_k(M-k)} \\ \text{subject to} \quad & \sum_{k=0}^{N-1} S_k E_k = E_{budget}. \end{aligned} \tag{8}$$

Here we assume that $S_k = S$, $k = 0 \ldots N-1$. Using LaGrange multiplier, the optimal power distribution satisfies

$$E_k = \frac{4N_0}{d^2}\left(\frac{W_k T(M-k)}{S\lambda}\right)^{\frac{1}{T(M-k)+1}} \tag{9}$$

and λ satisfies

$$\sum_{k=0}^{N-1} S\frac{4N_0}{d^2}\left(\frac{W_k T(M-k)}{S\lambda}\right)^{\frac{1}{T(M-k)+1}} = E_{budget}. \tag{10}$$

Since the left hand side is a monotonic function of λ, the optimal solution can be computed using Newton or bisection methods.

4. SIMULATION RESULT

The transmission system employs 7 transmit antennas and 7 receive antennas. We apply Reed Solomon (7,3) code with 8PSK modulation. Therefore, each diagonal contains 7 8PSK symbols or a RS block. The corresponding parameters are $d^2 = 0.54$ and $T = 7-3+1 = 5$. For simplicity, we assume the source multimedia data are decomposed into 7 equal length source layers, each associated with a weighting factor W_k, $k = 0, \ldots, N-1$. We compare the serial transmission and parallel transmission system in terms of the mean square error of the transmitted and received data, as shown in Figure 5. For serial transmission, equal power distribution in (5) is achieved. Parallel approach outperforms serial approach in low SNR region. As SNR increases, the performances converge. The actual symbol error rate of source layers are also illustrated in Figure 6 and 7. The parallel approach utilizes the property of HLST code and achieves UEP efficiently. The SER performance for the most important source layers causes the performance bottleneck for serial transmission, since huge amount of transmitted power has to be assigned to reduce the noise effect in the channel layer $N-1, N-2, \ldots$.

5. CONCLUSION

By matching the source layers to channel layers of Layered space-time codes, we propose a parallel transmission scheme utilizing the natural UEP in HLST architecture. Power allocation is performed to optimize the error performance according to the importance of the source layers.

However, the space-time codes rely on being able to accurately estimate the fading coefficients which are assumed to vary slowly. Therefore, the need of powerful and yet efficient channel estimation or equalization techniques is very important. In this paper, we assume perfect channel estimation. Future work may incorporate the channel estimation into the system and investigating the overall performance.

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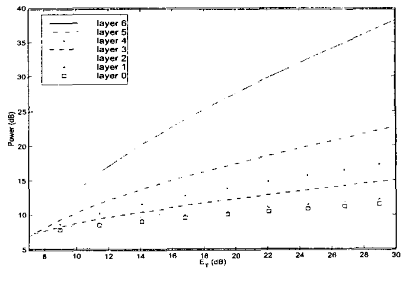

Figure 4: Layer Power Distribution

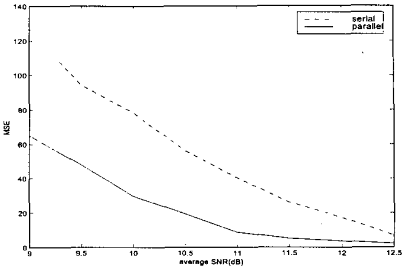

Figure 5: MSE Performance Comparison of serial and Parallel Transmission

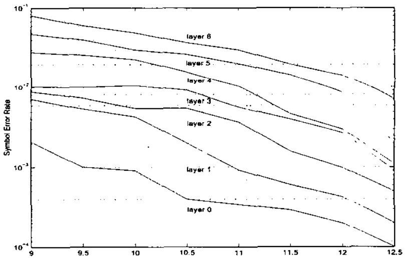

Figure 6: Serial Transmission: Layer Symbol Error Rate Distribution

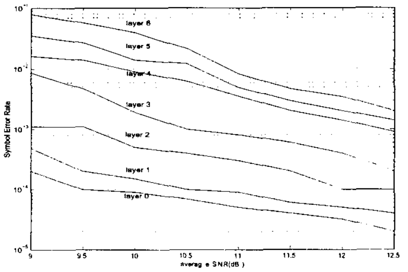

Figure 7: Parallel Transmission: Layer Symbol Error Rate Distribution