Multiple Access Schemes over Multipath Fading Channels

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Abstract — We compare the performance of different accessing schemes for communication over an additive white Gaussian noise multiple access channel with multipath fading. We assume that only the receiver can track the channel variations. We investigate time division, frequency division and code division multiple access schemes and consider the Shannon capacity as well as the probability of outage. Although orthogonal code division multiple access has the same total capacity with frequency and time division, it has better probability of outage. We also provide an extension of our comparison to a CDMA system employing non-orthogonal codes and multiuser detection.

I. SUMMARY

The resources available in a wireless communication system are shared between users according to several accessing schemes such as frequency division, time division or code division. The purpose of this work is to compare these accessing schemes for the multipath fading multiple access channel using different measures of performance. The comparison of the capacity regions for discrete, memoryless and time-invariant multiple access channel can be found in [1].

The mobile communication environment exhibits a randomly time varying channel with memory which results in multiple paths and fading in the amplitude of the signal. We use a multipath fading channel model and assume that the receiver can track the variations in the channel, whereas the transmitters cannot. Thus the transmitters cannot allocate power depending on the channel parameters; they have to use the same strategy independent of the channel variation.

The time division multiple access (TDMA) scheme allocates separate time slots for different users, while the frequency division multiple access (FDMA) scheme allocates different frequency bands. For code division multiple access (CDMA) scheme, we first consider an orthogonal system which can be interpreted as dividing the total degrees of freedom among users [2]. We then extend our results to a general direct sequence spread spectrum system. When joint decoding is used at the receiver, Gallager [3] has shown that CDMA system can support larger rates than FDMA. However, joint decoding requires exponential complexity in the number of users. We investigate schemes requiring reduced complexity. In particular, we focus on a CDMA system where the receiver employs a linear multiuser detector followed by single user decoders.

Our first performance measure is the Shannon capacity. Assuming stationary and ergodic channel variations, the capacity can be found by taking expectation of the “instantaneous” mutual information terms [3]. Shannon capacity gives us long term achievable communication rates, but does not capture the time scale of variations in the channel. Other measures of performance which are better suited for slowly

varying channels with severe delay limitations are the delay limited capacity [4] and the probability of outage [5].

Our results show that orthogonal CDMA has the same total Shannon capacity as TDMA and FDMA. However, the outage performance of CDMA is better than the other orthogonal schemes, due to the fact that CDMA is capable of increasing diversity by “observing” more independent fading channel states than TDMA or FDMA. We also show that CDMA has larger delay limited capacity than TDMA and FDMA. However, when the frequency response $H(f) = 0$ is in the support of the fading process (which is the case for almost all of the practical fading models used), the delay limited capacity is zero for all the accessing schemes. Note that as the transmitters cannot track the channel variations (unlike in [4]), the power cannot be allocated into different fading states to improve the performance.

In general, for a direct sequence spread spectrum system where orthogonality of the codes is not assumed, we consider a linear detector followed by single user decoders. We incorporate the detector in our channel model and solve for the capacity region. When the channel is memoryless and time invariant, we find that spreading sequences that meet Welch’s lower bound [6] maximize the total capacity for equal average power constraints for both the minimum mean squared error (MMSE) detector and the matched filter (MF) detector. The surprising result, though, is that both detectors result in the same total Shannon capacity. A similar observation was made in [7]. We investigate Shannon capacity and probability of outage performances of both MMSE and MF detectors under fading when the above “optimal” spreading sequences are used.

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