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Time Hopping Versus Frequency Hopping in Ultrawideband Systems

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Abstract

In the last two years, interest in ultrawideband (UWB) systems has exploded. In February 2001, the American FCC (Federal Communications Commission) allowed the use of unlicensed ultra-wideband devices provided their emissions fulfill certain restrictions. Notably the FCC has not mandated any specific spreading or multiple-access (MA) technique. Rather, it is required that the band width of the transmitted signal is at least 500MHz, and that the spectral density of the transmit signal does not exceed 41.3dBm/MHz in a given band. Following the decision of the FCC, the IEEE has formed a standardization group 802.15.3a. This group is currently collecting proposals for a new standard for UWB communications with data rates inexcess of 100Mbit/s over short ranges. The spreading and MA techniques used by the different proposals can be broadly classified into (i) time-domain spreading, which uses the ”time-hopping impulse radio” technique, introduced by Scholtz and Win [1,2], and (ii)frequency hopping schemes. It is thus of high practical, as well as scientific, interest to compare those two schemes. The current paper will provide such a comparison.

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Time hopping versus frequency hopping in ultrawideband systems

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In the last two years, interest in ultrawideband (UWB) systems has exploded. In February 2001, the American FCC (Federal Communications Commission) allowed the use of unlicensed ultrawideband devices provided their emissions fulfill certain restrictions. Notably the FCC has not mandated any specific spreading or multiple-access (MA) technique. Rather, it is required that the bandwidth of the transmitted signal is at least 500MHz, and that the spectral density of the transmit signal does not exceed –41.3 dBm/MHz in a given band.

Following the decision of the FCC, the IEEE has formed a standardization group 802.15.3a. This group is currently collecting proposals for a new standard for UWB communications with data rates in excess of 100Mbit/s over short ranges. The spreading and MA techniques used by the different proposals can be broadly classified into (i) time-domain spreading, which uses the "time-hopping impulse radio" technique introduced by Scholtz and Win [1,2], and (ii) frequency-hopping schemes. It is thus of high practical, as well as scientific, interest to compare those two schemes. The current paper will provide such a comparison.

In an AWGN channel, the two schemes show very strong similarity. Especially, a TH scheme with pulse position modulation, and a frequency-hopping schemes with FSK modulation, are completely dual systems. The only difference lies in their practical implementability: while low-power impulse radios can sometimes directly put the digital output to an antenna, the FSK/FH hopping scheme uses a local oscillator to perform modulation and spreading. For the parameters mandated by the FCC, both of the solutions are not straightforward: for the TH system, it can be difficult to digitally generate output pulses that have no DC components and whose spectrum ranges from 3 to 10GHz. For the FH system, the large relative bandwidth might require multiple local oscillators or frequency multipliers.

The multiple-access performance is theoretically equivalent, as well. Essentially, the allocated spectrum spans an N-dimensional space (where N is the possible spreading factor), into which K vectors (signals) are to be placed (transmitted). It is possible both in the time and the frequency domain to find $K \leq N$ orthogonal vectors that can be transmitted without multiple-access interference.

However, the above consideration is not true anymore when random delays are introduced into the channel – a case that occurs in all currently considered UWB systems. In this case, it is necessary to find TH (or FH) hopping patterns that minimize the MA interference for all possible delays. Recent advances in that area of coding have shown that there exist sequences that lead to at most one collision per hopping cycle, which provides good MA interference rejection for systems with strong spreading. However, we will show in the paper that for very high data rates (480Mbit/s, as required by IEEE), MA interference can lead to significant performance degradation even with those good codes.

It is also noteworthy that FH hopping can deal more easily with narrowband interference than TH. For FH, it is sufficient to exclude the interfered frequency range from the hopping pattern; it is thus sufficient to know the frequency, but not the phase, of the interfering signal. For TH, an interference cancellation scheme first requires an estimation of frequency and phase of the interferer.

Finally, the performance in time-dispersive environments can differ. We will investigate the tradeoff involved in equalization and Rake reception schemes. Furthermore, it is noteworthy that in the FH case, waterfilling, i.e., power control of each subcarrier, can be realized, which increases the theoretical capacity of the system. We will also discuss the peak-to-average ratio (PAR) problem and its differences in TH and FH.

The final paper will describe all those aspects in more detail, and present various solutions for the problems we have identified. A hybrid scheme, which achieves positive aspects of both the TH and the FH system, will be presented and its performance quantified.

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[1] R. A. Scholtz, MILCOM 1993

[2] M. Z. Win and R. A. Scholtz, Trans. Comm.