Anti-Jamming, Agile Transceivers
For
Mobile, Ad-Hoc, Wireless Networks

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Abstract

chaotic.com® has invented a series of waveforms and the corresponding receivers that provide significant improvements in wireless channel utilization and throughput. The heart of the technology is our ability to eliminate or greatly reduce the intersymbol interference (ISI) due to multipath propagation and bandwidth-limiting filters in the transmitters. The practical elimination of ISI provides greater spectrum utilization and/or higher absolute data rates. This technology also provides significant reductions in the power requirements and hardware cost.

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The Technology

The burgeoning demand for various forms of wireless connectivity, coupled with fractious international regulatory regimes, creates a complex, constrained optimization problem for the design of deployable, inter-operable, wireless networks. Military systems in particular are facing difficult airwave access issues due to hostile jamming, unintended interference, and complex planning requirements in a radio spectrum allotment crowded with legacy systems. The burden of coexistence and interoperability with legacy systems imposes additional constraints because it is not economically feasible to replace large networks. Agile communication schemes simultaneously address these issues via opportunistic airwave access.

Based on a review of military and other government needs it is clear that reliable urban team communications (UTC) is a pressing need in many operational scenarios. From the streets of Manhattan, and New Orleans to those of Baghdad deployable communications networks are hampered by poor RF propagation, strong interference, and encumbered spectrum allocations. Further, the UTC links are the “First Tactical Kilometer” of larger networking problems within the context of Net-Centric Warfare (systems of systems). In these scenarios the spectrum allotment is captured by many, non-interoperable, legacy communications systems each with its’ own constituency. Agile access can provide a communications backbone for networking the legacy investment, and for rationally modifying or retiring this investment over time.

chaotic.com® is developing agile transceiver (PHY and MAC layer) designs focused on the UTC scenario. The critical, constrained resources are available spectrum and stored energy. To alleviate the spectrum shortage, we first note that the observed utilization of VHF/UHF spectrum in many bands is only about 10% of the available bandwidth. That is, much of the usable spectrum is lying fallow at a given location in space, time, and band. Exploiting this under-used resource is far more complex than simply detecting the unused frequency real estate and temporarily squatting in these bands as a secondary user (e.g. Whitespace Coalition approach). For the UTC scenario, simulations indicate that the observed spectrum occupancy is variable over the nodes of a given agile network. It is the joint spectrum occupancy across nodes that determine the access opportunity and scalability of the network. While there are often uniformly unused bands many of these bands are not available for secondary access due to own forces SIGINT, EMI restrictions, and regulatory compliance issues that are not negotiable on any reasonable time scale. Further, the locally unused bands such as television channels are well known a priori and therefore subject to hostile jamming in military applications.

Joint spectrum structures, nonnegotiable use restrictions, and the potential for jamming imply that secondary spectrum access opportunities will consist of a shifting and noncontiguous set of relatively narrow frequency windows. Interference restrictions with respect to the primary users effectively limit the usefulness of spread spectrum overlays for bands outside those covered under FCC Part 15. This would seem to imply an adaptive multi-carrier approach for secondary access links, but these schemes are highly inefficient users of stored energy. The real advantage of multi-carrier OFDMA schemes such as those proposed for 4G is the ability to overcome the severe inter-symbol interference (ISI) produced by multi-path propagation. This allows OFDMA to trade energy efficiency for high data rates with excellent spectrum efficiency for primary users. In fact, ISI due to both multi-path and bandwidth limiting transmitter filters is recognized as the primary obstacle to achieving reliable power and spectrum efficient performance with single (or switched) carrier modulation schemes.

The conundrum presented by ISI for single-carrier modulation schemes is that lengthening the symbol duration to decrease the resulting irreducible bit error rate (IBER) substantially increases the vulnerability of the link to flat fading, thus severely impacting energy efficiency via the small scale fade margin. The conventional solution is adaptive equalization, relatively short symbols, and partial response signaling with an overhead of known training symbols (e.g. GSM/EDGE). Equalizers are approximate deconvolution operators or maximum likelihood sequence estimators (MLSE via Virterbi algorithm) and robust performance in the presence of additive noise as well as the implementation costs of adaptive equalizers remains fundamental problems.

We have constructed a robust, low cost alternative to deconvolution-based equalizers and MLSE by judiciously matching angle modulation schemes to new receiver designs based on multi-hypothesis decisions (replica basis sets). The result for several of these waveform/receiver combinations is an IBER of zero for maximum delay spreads less than half the symbol duration, and very low IBER for maximum delay spreads less than the full symbol duration. This ability to reliably cope with high levels of ISI can be traded for greater spectrum efficiency via narrower compliance filters and/or higher absolute data rates in multi-path environments at a given bit error rate. The power and cost advantages of single carrier modulation schemes with low PAPR and high ISI immunity are well known.

We have several sets of waveforms, and the corresponding receivers, under development using both single and dual carrier modulation schemes. These schemes are being evaluated to determine what wireless niches they best serve, and they are all suitable for adaptive access control schemes. These schemes are being evaluated using subsets of the 3GPP spatial channel model for rural and urban macro cells (3 km BS to BS) and urban micro cells (1 km BS to BS) and initial indications are significant improvements over GSM/EDGE with respect to bits per second/Hertz/Watt in cellular applications. These schemes can be a highly competitive component for implementation within next generation wireless. Within the UTC scenario, while the advantages appear clear and directly related to cellular models, it is far more difficult to estimate improvements. This is primarily due to a dearth of reliable propagation loss and channel sounding measurements/models for peer-to-peer links in military bands. Further, there are no joint spectrum measurements as a function of environment and node separation in any bands and this prevents a reliable estimate of the advantages of opportunistic access. This said, our approach anticipates and allows for a wide range of possible environments and joint spectrum occupancy states.

Finally, should adaptive access measurements and field tests reveal that significant recovery of locally fallow spectrum is possible then this technology will enable the construction of secondary markets for spectrum access rights that will substantially reduce the inefficiency inherent in centrally planned allocation schemes.