[0015] Data to be communicated is represented in binary digits. A transmission medium connecting a transmitter and receiver of the system is capable of transporting signals, which can be disturbed by the environment, including signals between other pairs of communicating devices (cross talk). There also may be (regulatory) constraints on the power of the signal inserted in the transmission medium. The transmitter generates a signal, driving the transmission line with a signal equivalent to an encoded input sequence. The receiver receives the signal and converts that signal into an output sequence, which is a copy of the input sequence if no errors occur. The transmitter and receiver devices combined allow for calibration, providing a means for the devices together to compensate for certain types of distortion occurring in the transmission medium. The system must also ensure that the receiver can generate a local clock, appropriate for the reception and conversion of the transmitted signal into the output sequence.

OBJECTS AND SUMMARY OF THE INVENTION

[0016] In view of the foregoing deficiencies, a primary object of the invention is to provide techniques for increasing the effective digital data throughput of a communications link which may include any of a wired transmission medium, a wireless transmission link, a satellite link, and possibly a fiber optic communication network.

[0017] More particularly, an object of this invention is to provide systems and methods in which the effective capacity of a communications link is enhanced.

[0018] A further object of the invention is to provide systems and methods which are more robust against interference on the communications link than current systems and methods.

[0019] Briefly stated, these and other objects of the invention are attained in the form of systems and methods by means of which data throughput is enhanced by transforming an incoming bit stream into one or more Time-and-Frequency-Bounded (TFB) packets that each include a plurality of TFB waveform components. This transformation is accomplished by mapping incoming bits to a set of TFB functions, such that respective TFB functions in the set of functions are awarded a characteristic weighing factor, corresponding to a value or status of corresponding bits. A plurality of weighted TFB functions are combined to generate the TFB packets. These TFB packets are then combined into a TFB information stream that is transmitted over the communications link.

[0020] The Time-and-Frequency-Bounded (TFB) functions are functions that exhibit the following properties:

[0021] each function f in this class is smooth,

[0022] for each function f in this class and for any polynomial p(t), given any $\epsilon>0$, there exists a T such that for $|t|>T$, $|f(t)\ p(t)|<\epsilon$, in other words each function in this class has a limited extent in the time domain beyond which the amplitude of the product of the function and any polynomial is negligible or at least lower than a predetermined threshold value ϵ, and

[0023] for the Fourier transform $F(\omega)$ of the function f, and for any polynomial $p(\omega)$, given an $\epsilon>0$, there exists an Ω such that for $|\omega|>\Omega$, $|F(\omega)\ p(\omega)|<\epsilon$, in other words each function this class has a limited extent in the frequency domain beyond which the amplitude of the product of the function and any polynomial is negligible or at least lower than the predetermined threshold value ϵ.

[0024] This unique and heretofore unexploited property of time and frequency confinement is especially useful in situations where it is desired to provide all or a portion of the communications link using a single transmission medium or channel.

[0025] Illustratively, given a number of optimized TFB waveforms, the width of a frequency band they occupy can be set by scaling their time variables. In this manner a variable number of frequency bands of arbitrary widths can be employed. Optimizing the TFB waveforms for occupying relatively narrow frequency bands, by scaling their time variables accordingly, allows more efficient use of available bandwidth and the effect of an RF interference source is limited to the small frequency band of the interference source, having little effect on the communications link as a whole.

[0026] A particularly suitable sub-class of TFB functions are orthogonal TFB functions. From this sub-class, Hermite-Gauss functions are a preferred embodiment. It is noted that a system using Hermite-Gauss functions per se is known from U.S. Pat. No. 3,384,715.

[0027] Pursuant to a further embodiment of the invention, the incoming bits comprise the digital bit stream (input sequence) carried on one or more incoming channels in the form of binary "on" and "off" bits. Given a collection of preferably linearly independent TFB functions, called base functions, data is encoded by mapping bits from a representation of the data to at least approximations of the base functions. The input sequence is encoded in blocks. In the remainder these will be referred to as TFB blocks The TFB blocks are constructed from N different base functions, N being the number of functions used for encoding (as used herein, N is a positive integer). Illustratively this mapping process is implemented by mapping a first incoming bit to a first TFB function, a second incoming bit to a second TFB function, and so on, until an N^{th} TFB function is reached, whereupon the process cycles back to the first TFB function. Note that the mapping of one bit to one TFB function is descriptive only, and that in practice multiple bits may be mapped onto a single TFB function. Preferably the incoming stream of bits is buffered prior to encoding.

[0028] In a further embodiment the bits are grouped in groups of length M, where M depends on the number of bits needed for error correction; N-M bits are added for this error correction. The first M bits of the not yet encoded input sequence, and N-M error correction bits, are then mapped onto N different base functions. Note that both M and N may be defined dynamically, possibly per block. This encoding can be repeated indefinitely. In case there are insufficient data in the input sequence to fill the block, padding bits are generated preferably.

[0029] Illustratively mapping is achieved by multiplying an i^{th} function from a selected set of TFB functions with a first weighing factor, e.g. −1, if an i^{th} bit=0 or with a second, different, weighing factor, e.g. +1, if the i^{th} bit=1, and subsequently adding all N thus weighted functions to form