A new signaling system for high bit rate wireless LANs is made possible by a novel class of signaling pulses called OWSS pulses, which are generated through a combination of OWDM and spread spectrum concepts.

**Abstract**

Wireless local area networks have emerged as one of today’s driving technologies, delivering high data rates on unlicensed spectrum. This article provides an overview of a new signaling system for high-bit-rate wireless LANs, made possible by a novel class of signaling pulses. Called OWSS pulses, they are generated through a combination of orthogonal wavelength-division multiplexing and spread-spectrum concepts. The system offers several advantages including intrinsic robustness to frequency-selective fading, effective equalization due, in part, to the wide spectrum and wide time-support of the pulses used, high data rate, and flexibility in carving different rates vs. multiple access schedules at the physical layer.

**Introduction**

The importance of wireless networking is clearly evidenced by the widespread deployment of both enterprise and retail products based on the IEEE 802.11 standard. The importance of wireless networking is clearly evidenced by the widespread deployment of both enterprise and retail products based on the IEEE 802.11 standard. The importance of wireless networking is clearly evidenced by the widespread deployment of both enterprise and retail products based on the IEEE 802.11 standard. The importance of wireless networking is clearly evidenced by the widespread deployment of both enterprise and retail products based on the IEEE 802.11 standard. The importance of wireless networking is clearly evidenced by the widespread deployment of both enterprise and retail products based on the IEEE 802.11 standard.
OWSS pulses, and illustrate the benefit of their inherent frequency diversity. The multiple access capability option at the physical layer is discussed next. As stated therein, this can be augmented or supplanted by multiple access at the MAC layer. We describe adaptive equalization for rates up to 108 Mb/s and the passband spectrum studies. The last section briefly points to OWSS-SC, the union of OWSS with STC. Using two transmit antennas and a single receive antenna enables twofold space diversity, and thereby a bit rate of 150 Mb/s over a 25 MHz bandwidth.

**Orthogonal Wavelength Division Multiplexing**

**Background on Orthogonal Multipulse Signaling** — Consider that the pulses \( \phi_m(t), m = 0, 1, \ldots, M - 1 \) form an orthonormal set over a certain interval of time. Then orthogonal multipulse signaling uses a composite pulse over each block signaling interval \( T = MT_s \) formed as [5]

\[
s_0(t) = \sum_{m=0}^{M-1} a_m \phi_m(t),
\]

where \( T_s \) is the basic symbol interval. Each basis pulse \( \phi_m(t) \) serves to create a “virtual” channel over which the symbol \( a_m \) is carried. We will call the vector of symbols \( \mathbf{a} = [a_0, a_1, \ldots, a_{M-1}]^T \) a supersymbol, and the interval \( T \) the supersymbol interval or block interval. As an example, consider OFDM signaling for the case \( M = 8 \) wherein

\[
s_0(t) = a_0 + a_1 e^{j(\Delta \omega t)} + a_2 e^{j(2\Delta \omega t)} + \ldots a_7 e^{j(7\Delta \omega t)},
\]

with \( \Delta \omega = 2\pi/T_s \), where \( T \) denotes the supersymbol interval. The coefficients \( a_0, a_1, a_2, \ldots, a_7 \) represent the information symbols which, in general, are complex. It can easily be shown that the basis pulses \( 1, e^{j(\Delta \omega t)}, e^{j(2\Delta \omega t)}, \ldots, e^{j(7\Delta \omega t)} \) are pairwise orthogonal over the interval \([0, T]\). By multiplying these basis pulses with \( \sqrt{1/T} \), the set becomes orthonormal, that is,

\[
\begin{align*}
&< \sqrt{1/T} e^{j(k\Delta \omega t)}, \sqrt{1/T} e^{j(l\Delta \omega t)} > \\
&= \sum_0^1 e^{j(k\Delta \omega t)} e^{-j(l\Delta \omega t)} dt = \delta_{k,l}, \text{for } 0 \leq k, l \leq 7.
\end{align*}
\]

Here \( \delta_{k,l} \) represents the familiar Kronecker delta, which equals 0 if \( i \neq k, \) and 1 if \( i = k. \)

However, the signal \( s_0(t) \) above represents only one supersymbol, while in point of fact a stream of supersymbols is usually transmitted. For this realistic case the baseband transmitted signal becomes

\[
s(t) = \sum_{n=-\infty}^{\infty} \sum_{m=0}^{M-1} a_{n,m} \phi_m(t - nT) = \sum_{n=-\infty}^{\infty} \mathbf{A}_n^T \mathbf{g}(t - nT).
\]

The double subscript on the symbol \( a_{n,m} \) has the following meaning: the first subscript \( n \) signifies that it is a member of the \( n \)th supersymbol (in the stream of supersymbols), and the second subscript \( m \) proclaims that it is the \( m \)th member of that particular supersymbol.

At the receiver, symbol and block timing extraction is performed, and the received signal is correlated with \( \phi(t - nT) \) to detect the \( n \)th supersymbol at time \( nT \) (actually at time \( nT + \tau \), where \( \tau \) denotes the optimum timing phase [5]). Since very large-scale integrated (VLSI) implementation is often more economical digitally, we will hereafter use discrete time pulses. Furthermore, for convenience, we will use the variable \( t \) to denote both the continuous time variable as well as the signal sample index. Also, \( M \) and \( T \) will be used interchangeably to denote the block length. We note in passing that the actual OFDM implementation employs the inverse fast Fourier transform (IFFT) and FFT algorithms, with the concomitant necessity of the addition of the prefix at the transmitter and its removal at the receiver.

**OWDM Pulses from Full-Tree Wavelet Filters**

Analysis of signals using transforms through the use of a set of basis functions is as least as old as the Fourier transform. In the Fourier transform the basis set consists of all complex sinusoids of the form \( e^{j\omega t} \) where \( \omega \) can take on any real value — positive, negative, or zero. In recent years attention has been focused on basis sets generated from wavelets [6]. A wavelet is a small wave (i.e., it has compact support with an integral, or sum in the case of a discrete wavelet, equal to zero), and has the following wonderful property: All OWDM basis functions can be generated through the process of scaling or shifts from a single function, called the mother wavelet. Appropriately, then, the basis functions are indexed by two indices, one signifying scale, and the other shift. Thus, if \( \psi(t) \) is the mother wavelet, the basis functions are of the form [6]

\[
\psi_{m,n} \triangleq 2^{-m/2} \psi(2^{-m} t - n).
\]

The scale index \( m \) and shift index \( n \) are both integers. Note that a positive \( m \) leads to expansion and a negative value in shrinkage of the waveform, while completely preserving the original shape. Although we have carried out the above discussion in terms of continuous time, a somewhat similar discussion holds for discrete time wavelets and their basis functions. As an example, the two-point sequence \( \psi = [1 \quad -1]/\sqrt{2} \) constitutes the well-known Haar wavelet. A close cousin of the wavelet is the scaling function [6], and for the Haar case it is \( \phi = [1 \quad 1]/\sqrt{2} \). Either the scaling function or the mother wavelet, or both, can be used to create the basis set over the interval of interest. In terms of hardware or software implementation this is frequently done through a tree structure [8]. To illustrate, let us define \( g_0 = [1 \quad 1] \) and \( g_1 = [1 \quad -1] \). Note that these are identical to \( \phi \) and \( \psi \) above, except for a normalization factor. Then we show in Fig. 1 three full trees, more specifically synthesis full trees, which can generate basis functions over support intervals of 2, 4, and 8 points, respectively. Note also that a circle with an up arrow denotes an
Figure 1. Synthesis trees: one-stage, two-stage, and three-stage trees.

upsampling device, and the digit 2 therein signifies that the upsampling ratio is two. Clearly the sampling frequency after each such upsampler doubles.

Indeed, we see in the figure several different sampling frequencies, $F_s$, $2F_s$, $4F_s$, and $8F_s$. As is customary in the communications literature, the $z$-transforms of $g_0$ and $g_1$, $G_0(z)$ and $G_1(z)$, are shown as the filter transfer functions. In each of the three cases shown in this figure, a member of the basis set is generated by applying a unit pulse at any one, and only one, input node while all other nodes receive a zero input. Thus, for example, in Fig. 1b, if input node 2 is driven by a unit pulse, and all other input nodes are held at zero, the output turns out to be $h_2 = [1 -1 1 -1]$. Similarly, in Fig. 1c, if input node 5 is driven by a unit pulse, and all other input nodes are held at zero, the output turns out to be $h_5 = [1 -1 1 -1 -1 1 -1 1]$. Here is a general formula: consider an arbitrary leaf node, say node $n = [i j k]$ (binary address). Then the transfer function from this node to the output node is $P_{ijk} = P_i(z)P_j(z^2)P_k(z^4)$, where for node 5, $P_5(z) = G_1(z)$, $P_4(z) = G_0(z)$, and $P_3(z) = G_1(z)$ from Fig. 1c. The extension to trees with other than three stages is obvious. Through a slight abuse of nomenclature, we will call the set of these output pulses wavelet pulses. It can be shown that the pulses in this set are orthogonal, and in fact had we not ignored the normalization factor $1/\sqrt{2}$, these pulses would be orthonormal. Hereafter we will include the normalization factor so that the set of wavelet pulses $\{h_0, h_1, \ldots, h_{M-1}\}$ will be orthonormal.

Although we have focused on the Haar wavelet above, the structure shown can be used for other wavelets as well. Thus, the tree of Fig. 1c can generate eight Daubechies wavelet pulses $h_i(t)$, $i = 0, \ldots, 7$ if the Daubechies scaling function [6] and the corresponding mother wavelet [6] are used as the filters $g_0$ and $g_1$. For a full tree, such as those shown in Fig. 1, the general rule that relates the number of wavelet pulses to the number of stages is $M = 2^p$ where $p$ denotes the number of stages. As stated earlier, the $i$th wavelet pulse is obtained at the output, when the stimulus at the $i$th input node of the tree is a unit pulse while all other inputs are zero. Extension to higher numbers of stages is self-evident. Actually, the tree structure shown can be used to generate the transmitted signal $s(t)$ of the previous subsection. By applying the $n$th supersymbol
\[ A_n = [a_{n0} \ a_{n1} \ldots \ a_{nM-1}]^T \] at instant \( nM \), and of course repeating this process for all \( n \), it is easily seen using superposition that the output signal from the synthesis tree is of the form

\[
s(t) = \sum_{n=0}^{\infty} \sum_{m=0}^{M-1} a_{n,m} h_m(t-nM) = \sum_{n=-\infty}^{\infty} A_n^T h(t-nM).
\]

It is useful to remark that the synthesis tree is a multirate multi-input/single-output linear filter. Architectures for its efficient implementation are available in the literature. Note that \( M \) also serves as the supersymbol interval, or block interval, which was denoted \( T \) in the continuous time case.

**Double Orthogonality of OWDM Pulses**

Referring to Fig. 1, denote the impulse response from the \( i \)th input node to the output node as

\[ h_i(t), \ i = 0, 1, \ldots, M-1. \]

The lowpass filter \( G_0 \) and the corresponding highpass filter \( G_1 \) can be Daubechies filters (scaling and mother wavelet) [6], Jain filters [7], or some other [6]. Then the family of OWDM pulses \( \{\phi(t)\} \) can be shown to be doubly orthonormal. That is,

\[
< h_i(t), h_k(t) > = \delta_{i,k}, \ i, k = 0, 1, \ldots, M-1
\]

\[
< h_i(t), h_i(t-nM) > = \delta_n, \ \text{for all} \ n.
\]

In the rest of the article we use Daubechies filters to generate the wavelet pulses \( h_i(t) \).

**OWDM Receiver** — Clearly the signal \( s(t) \) can modulate a carrier and then be transmitted over a channel. At the receiver, the signal can be downconverted from radio frequency (RF) to baseband, and then an equalizer, correlator (or matched filter), and detector can be used to retrieve the information symbols. However, OWDM pulses are not broadband and are susceptible to channel fades, just as are the OFDM pulses. The details are not presented in this article; they can be found in [7]. In the present context the significance of the OWDM pulses arises from the fact that they form the foundation for OWSS pulses, as discussed next.

**OWSS Pulses and Signaling System**

An overview of the OWDM spread-spectrum (OWSS) scheme is given in Fig. 2a. Not shown is the training phase, during which a set of known samples \( s(t) \), prestored at the receiver and produced by a set of known transmitted symbols, is used to initially train the equalizer. The details of the transmitter block and the correlator and summer block at the receiver are given in Fig. 2b. Here \( \phi(t) \) is the set of orthogonal wavelet pulses assembled in the form of a vector. Philosophically, the setup is somewhat similar to multicarrier CDMA (MC-CDMA) [8].

**Ideal Receiver Analysis** — Referring to Figs. 2a and 2b, the transmitted signal for the \( i \)th user is

\[
s_i(t) = \sum_{n=0}^{M-1} a_{n,i} \sum_{m=0}^{M-1} c_{n,m}^{(i)} \phi_m(t-nT) = \sum_{n=0}^{M-1} a_{n,i} \psi_i(t-nT),
\]

where \( \psi_i(t) \) is the new broadband pulse for the \( i \)th user. That is,

\[
\psi_i(t) = \sum_{m=0}^{M-1} c_{m}^{(i)} \phi_m(t).
\]

We use Walsh-Hadamard codes, which are orthogonal. As a consequence, it can readily be shown that the OWSS pulses \( \psi_i(t) \), \( i = 0, \ldots, M - 1 \) obey double orthogonality similar to that observed for OWDM pulses in the previous section.

The received signal equals the sum of the signals received from all transmitters. For the rather basic discussion here, we will ignore channel attenuation and multipath effects [9]. Thus, at the \( k \)th receiver the received signal is

\[
r(t) = \sum_{i=1}^{U} r_i(t) = \sum_{i=1}^{U} a_{n,i} \psi_i(t-nT-\tau_i)
\]

Assuming perfect timing [5] (with respect to the \( k \)th user), the output of the \( k \)th receiver correlator can be shown to be

\[
z_n^{(k)} \triangleq a_n^{(k)} + \left( I_{S_n^{(k)}} + I_{C_n^{(k)}} \right) + N_n^{(k)}.
\]

The intersymbol interference term \( I_{S_n^{(k)}} \) is zero due to the impulsive autocorrelation of the OWSS pulses (see the next section). In the remainder of this section we focus on the downlink case for which all \( \tau_i \) are equal so that the interchannel interference term \( I_{C_n^{(k)}} \) is also zero. Thus,

\[
z_n^{(k)} \triangleq a_n^{(k)} + N_n^{(k)}.
\]

The probability of symbol error is then the same as for a single-user additive white Gaussian noise (AWGN) case.

**Simplified Implementation** — Although Figs. 2a and 2b provide a detailed structural realization of the transmitter and receiver, the above discussion clearly points to a simpler realization. Specifically, the second line in the equation for \( s_0(t) \) leads to the transmitter-receiver diagram of Fig. 2c. This is a ROM-based design where the PN code has already been absorbed into the transmit pulse \( \psi_0(t) \) for the \( i \)th transmitter-receiver pair. For simplicity, the serial-to-parallel and parallel-to-serial conversions are not shown. Also, we have added a DFE. Referring to the equation for the transmitted signal, it is important to note that the wavelet pulse set \( \{\phi_i(t)\}_{i=0}^{M-1} \) is common to all users. It is only the PN codes that are different for each user pair, as signified by the superscript \( i \) in that equation.

**Symbol and Bit Error Probabilities**

The input to the decision device is given by the equation for \( z_n^{(k)} \) above. Clearly, the matched filter (or correlation receiver) results available in the literature are applicable to the situation at

At the receiver, the signal can be down-converted from RF to baseband, and then an equalizer, correlator (or matched filter), and detector can be used to retrieve the information symbols. However, the OWDM pulses are not broadband and are susceptible to channel fades, just as are the OFDM pulses.
hand. Bit error probability formulas for several cases are given in [1]. Here, we only present the 64-QAM case.

**OWSS/64QAM**

Denote the constellation points \( \{i \times c\} \pm j \{k \times c\} \), where \( i, k \in \{\pm 1, \pm 3, \pm 5, \pm 7\} \)

\[
|c| = \sqrt{\frac{E_s,av}{42}} = \sqrt{\frac{E_b,av}{7}}.
\]

Then the probability of symbol error and the corresponding probability of bit error can be shown to be given by

\[
P_{e,\text{symb}} = \frac{7}{12} \left( \frac{E_s,av}{21N_0} \right)
\]

\[
P_{e,\text{bit}} = \frac{7}{12} \left( \frac{E_s,av}{21N_0} \right)
\]

A graphical display for the probability of bit error can be found in [1].

**Properties of the Broadband Broad-Time OWSS Pulses**

We now present a study of the new broadband broad-time pulses \( \psi^{(k)}(t) \). Figure 3a shows the pulse \( \psi^{(0)}(t) \) generated by the OWDM-CDMA method [1]. A three-stage tree, together with an 8-point Daubechies wavelet, is used. Walsh-Hadamard codes are used for wavelet domain spreading. In the interest of space, the other seven pulses are not displayed, but have somewhat similar time and spectral behavior. The blockwise autocorrelation for a typical pulse (actually pulse 0) is shown in Fig. 3b, using a rectangular sample transmit pulse. The cross-correlation map of all eight member pulses is shown...
in Fig. 3c on a logarithmic intensity scale. The actual matrix of cross-correlations is an 8 × 8 identity matrix.

Discussion — It is therefore concluded that the eight OWSS pulses ψ(0)(i), i = 0, ..., 7 have the following properties:

• The pulses are broadband as seen from their spectrum.
• The pulses are broad-time, since their time support is long.
• Each pulse has excellent autocorrelation behavior.
• The pulses are mutually orthogonal to support multi-user operation even at the physical layer.

Inherent Frequency Diversity of OWSS Pulses — Equalization can to a large extent overcome the ill effects of multipath fading. However, when a deep fade occurs, for the traditional signaling approaches (TDMA, OFDM, and even OWDM) the equalizer typically behaves in the following way:

• If the equalizer is based on the zero-forcing approach, it amplifies the noise excessively.
• In a minimum mean square approach, it is unable to provide adequate equalization to the underlying signal due to the constraint on noise amplification.

Through a simple experiment it has been shown in [1] that the OWSS pulses can withstand deep fades. Specifically, this is demonstrated by filtering the pulses by a notch filter, and then showing that all of the properties stated in the discussion above are, to a large extent, unaffected.

FLEXIBILITY:

SINGLE TO LARGE MULTI-USER SCENARIOS

The OWSS scheme can be used for multiple access, from a high single-user data rate to various shades of multi-user and correspondingly reduced data rates. Denote the overall system bit rate R. Then any of the combinations, U = 1, U = 2, U = 4, ..., U = M can be incorporated as shown in Table 1. For example, if the number of users is U = 8, the bit rate for each would be R/8 and the number of codes allocated to each M/8; needless to say, M should be chosen to be greater than or equal to 8 (e.g., 16). It is useful to remark that in the single user case, random access sharing of the channel could well be done using CSMA/CA [10]. Thus, the term single user must be interpreted carefully. It simply means that only a single user can access the bandwidth at a time (whereas with U = 8, up to eight users can access the channel simultaneously).

It thus offers the potential for architecting the bandwidth at the physical layer, dynamically if desired. Due to a lack of space, only one scenario is presented as an example. Consider M = 16 (OWSS channels) and a gross bit rate R = 108 Mb/s, so that R_{peri-channel} = 6.75 Mb/s. Then we could provide for a random access channel with 12 codes assigned, 1–12, so the
The bit rate at the PHY layer would be 81 Mb/s; assuming a throughput of 60 percent, a net data bit rate of 48.6 Mb/s could be achieved at the MAC layer. Three quality of service (QoS) reservation channels may be provided with corresponding codes 13–15, one for each 6.75 Mb/s channel; the overall QoS data bit rate would then be 20.25 Mb/s. Finally, one control channel may be provided, 0, with a bit rate of 6.75 Mb/s; its purpose might be manifold, say, QoS reservation, maintenance of the equalizer at all channels, frequency offset estimation, test, reconfiguration, alarm, and emergency recovery.

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**Table 1. Single- and multi-user scenarios.**

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**OWSS Decision Feedback Equalizer**

The baseband part of an OWSS receiver is shown in Fig. 4. It deploys an FE and a DFE, both of finite impulse response (FIR) form [3]. Not shown is the adaptation mechanism, which will not be discussed here but can be found in [3]. The receiver also uses a correlator, a decision device, and an upsampler. Indeed, the output of the equalizer is correlated with an OWSS pulse, which is specific to the user, thus despreading it for detection. Note also that the correlator generates its output every $M$th sample. Therefore, the decision device and error computations operate at a lower rate than does the equalizer. Since the DFE operates at the same speed as the FE, an upsampler is needed, as shown in the figure. Initially, the coefficients of the FE and DFE are obtained through a training phase (using a prestored sequence of symbols and the LMS algorithm for update). Subsequently, the receiver goes into maintenance mode. Of course, the equalizer coefficients are updated in this mode as well. The training phase begins with an arbitrary set of equalizer weights. These weights tend to converge to minimize the MSE. The final weights obtained at the end of the training are then used to initialize the maintenance phase.

As stated earlier, the theory of the adaptive equalizer, in particular the adaptation mechanism, will not be discussed here. However, the results of a simulation experiment are presented.

**Computer Simulation — Experiment 1:** Results of a 64-QAM 108 Mb/s OWSS system over an indoor multipath channel, with a maximum Doppler frequency of 5 Hz, are shown in Fig. 5a [3]. The channel model is a 14-tap complex system.
model with a delay spread of 100 ns and an exponential power delay profile [9]. The OWSS pulse is a four-sample pulse derived from a single-stage full tree [7] deploying a 4-tap Daubechies filter [6] to generate the OWDM pulses. Specifically, it is pulse 1. The FE has 15 taps, the DFE 10 taps. Rate control parameters were $\mu = 10^{-4}$ and $\lambda = 2(10^{-5})$. The additive noise level was taken to be 20 dB. The sequence of events for this simulation is the following:

- Starting with arbitrary equalizer weights, a no-noise LMS training with binary phase shift keying (BPSK) alphabet is performed for 3000 symbols.
- Next, no-noise training without weight update is performed for 1000 64-QAM symbols.
- Finally, maintenance with additive noise and equalizer weight update is done for 9000 64-QAM symbols.

The squared error (SE) variation during LMS training are plotted in the left plot; the right plot shows the SE variation during maintenance. The average SE during the maintenance mode is 0.01839. Note that the 64-QAM symbols are of the form $\{i \times c\} \pm \{j \times c\}$, where $i, k \in \{\pm 1, \pm 3, \pm 5, \pm 7\}$. Since the above SE appears to be surprisingly low, we performed a theoretical cross-check, as discussed in [3]. The theoretical analysis indeed reinforces the effectiveness of the adaptive equalizer.

**Experiment 2: Simulation Results on Symbol Error Probability** — The simulation results on symbol error probability vs. $E_b/N_0$ are shown in Fig. 5b. As can be seen, the probability of symbol error is quite low for practical values of $E_b/N_0$ as shown in Fig. 5b. As can be seen, the probability of symbol error is quite low for practical values of, say, 20–25 dB in a wireless environment. It is on the order of 2 x 10^-4 without the use of coding. Note that these results are obtained for the same setting as in experiment 1.

**OWSS Transmitted Signal Spectrum**

Using the complex envelope $s(t)$, the actual OWSS transmitted signal can be written as

$$s_{RF}(t) = \text{Re} \left( \sum_{i=0}^{M-1} s^{(i)}(t) e^{j\omega_0 t} \right)$$

Naturally, this RF signal is an analog signal and is produced through a modulation process. Prior to modulation, a D/A conversion of the discrete time baseband signal is necessary. To simulate this A/D conversion the discrete time baseband signal is upsampled by a factor of 5, and then LP filtered. For the LP filter, a fifth-order 10-tap Chebyshev filter is utilized with a cutoff to sampling frequency ratio of 0.1 and a ripple of 1 dB. The output of the Chebyshev filter was used to compute the sample spectrum, which was appropriately smoothed and shifted to the RF carrier frequency. The resulting OWSS passband spectrum, modulated with a 5.785 GHz carrier, is found to be compact. Not shown here, it can be found in [3].

**Space-Time Coding for OWSS**

Although the details are not presented, in this section we give a glimpse of our efforts to extend the bit rate using a combination of OWSS and STC [4, 5]. Called OWSS-STC, the new system is targeted at 150 Mb/s over a bandwidth of 25 MHz in the 5.7 GHz band. It employs two transmit antennas and a single receive antenna, and codes blocks of 64-QAM symbols to achieve a twofold diversity. Each transmit antenna transmits symbols at a 25 Msymbols/s rate, and due to the 1/2 rate coding the overall rate achieved is $2 \times 25 \times (1/2) = 25$ Msymbols/s/150 Msymbols/s. The benefits of OWSS are preserved in the OWSS-STC system, except that a continuously pipelined operation is no longer possible. However, a twofold space diversity is achieved, which enhances the performance. It can be shown that after the inverse STC operation, there are two decoupled branches, each with its own equalizer-correlator-detector operating at 75 Mb/s, for an overall bit rate of 150 Mb/s.
The benefits of OWSS are preserved in the OWSS-STC system, except that a continuously pipelined operation is no longer possible. However, a two-fold space diversity is achieved, which enhances the performance.

**Conclusions**

This article describes a new signaling scheme, OWSS, for high-data-rate signaling in WLAN environments. It uses a family of pulses that have both wide time support and wide frequency support. Among the advantages are:

- Single- or multi-user capability
- Inherent frequency diversity for overcoming frequency selective fading
- Continuously pipelined operation (in contrast to OFDM)
- High bandwidth efficiency, which is about twice that for DS-CDMA (assuming rectangular chips for DS-CDMA)

It also has the potential for multiplexing and architecting the bandwidth at the physical layer. Lastly, the article hinted at a combination of OWSS with space-time coding, thereby attaining a space diversity of two and accordingly higher rates. OWSS and OWSS-STC thus appear to be good candidates for 4G wireless LANs for bit rates at 100–150 Mbps and beyond.

**References**


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