MORE PRECISE CHANNEL MODELS, INTERFERENCE PROBLEMS AND THEIR MITIGATION, AND DETECTION OF UWB SIGNALS FOR SPECTRUM MONITORING

Michael Sablatash, CRC, Ottawa, Canada

1. A PROPOSED METHOD FOR MODELING UWB CHANNELS MORE ACCURATELY

- How can a model for mobile fading channels by Turin and Jana[1], who assumed that the accuracy of the model is more important than its complexity, be adapted to model UWB channels so as to get more precise UWB channel models?

- Discrete State Hidden Markov Models (DSHMMs) are more suitable than Finite State Markov Channels (FSMCs) for modeling quantized fading because, in general, they have infinite memory.

- Special case of Continuous State HMMs (CSHMMs), Hidden Gauss-Markov Models (HGMMs) are more popular in applications because the corresponding integrals contain Gaussian probability density functions (PDFs) that can often be evaluated in closed form.

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[1] W. Turin and R. Jana, "Continuous State HMM Modeling of Flat Fading Channels," in *Proc. of 61st IEEE VTC Conference*, Stockholm, Sweden, May 30-June 1, 2005.

- Since fading is a zero-mean Gaussian process it is completely defined by its autocorrelataion function and, therefore, the HGMM autocorrelation function should approximate that of the fading.

- In digital communications the sampled output of the coherent demodulator followed by the receiver matched filter can be approximated by $y_k = c_k x_k + n_k$ where x_k is a sample of the transmitted signal, n_k is a sample of the filtered Gaussian noise and c_k is sample of the fading process.

- The general HMM is defined as a partially observable Markov process whose state $\zeta_k = (c_k, s_k)$ consists of two components, the hidden component s_k, called the hidden state and the observable component c_k called the observation, a sample of the channel process, such as a fading process.

- The HMM is described by the hidden state initial PDF $p_0(s_0)$ and the state transition PDF which has a special form $p_k(c_k, s_k | c_{k-1}, s_{k-1}) = p_k(c_k, s_k | s_{k-1})$. By quantizing the CSHMM the DSHMM is obtained as its “skeleton”.

- For the homogeneous DSHMM the probability of the observation sequence $\mathbf{c}_1^T = (c_1, c_2, ..., c_T)$ is given by

$$Pr(C_1^T) = \mathbf{p}_0 \mathbf{P}(c_1) \mathbf{P}(c_2) \cdots \mathbf{P}(c_T) \mathbf{1} \qquad (1)$$

where $\mathbf{p}_0$ is a row vector of the hidden state initial probabilities, $\mathbf{P}(c_k)$ is the matrix probability of the observations c_k which is a matrix whose *ij*-th element is $p(c_k, s_k = j | s_{k-1} = i)$, and **1** is a column vector of ones.

- Since (1) is valid for both DSHMM and CSHMM, all methods of matrix probability theory can be formally applied for computing for computing various characteristics of the CSHMM.

- Using these methods we compute the autocorrelations of the HGMM of fading described by the state-space model,

$$\begin{aligned} s_{t+1} &= \boldsymbol{F_t} s_t + w_t \\ y_t &= \boldsymbol{H}_t s_t + v_t \end{aligned} \qquad (2)$$

where $t = 0,1,...., w_t$ and v_t are random sequences and the initial state s_0 PDF is $p_0(s_0)$.

- If $u_t = (w_t, v_t) \sim N(u_t, \mathbf{S}_t)$ is a sequence of independent zero mean Gaussian variables with the covariance matrix $\mathbf{S}_t$ and the initial state $s_0 \sim N(s_0 - \mu_0, \Sigma_{ss,0})$ is also Gaussian, then $\varsigma_t = (s_t, c_t)$, where $c_t = y_{t-1}$, is a Hidden Gauss-Markov Model (HGMM).

- We consider only the homogeneous HMMs for which $\mathbf{F}_t = \mathbf{F}$, $\mathbf{H}_t = \mathbf{H}$, and $\mathbf{S}_t = \mathbf{S}$ are real constant matrices. For the HGMM the forward algorithm for computing the observation sequence PDF in (1) can be realized using the Kalman filter.

- Using experimental data an accurate ARMA model (which is a special case of the state-space process) has been obtained, defined by $c_k = \sum_{i=1}^{p} f_i c_{k-i} + v_k$ where $v_k = \sum_{i=0}^{q} d_i n_{k-i}$ and $n_i \sim N(n_i, 2\sigma^2)$ are independent identically distributed Gaussian variables.

2. INTERFERENCE PROBLEMS AND THEIR MITIGATION

- Until about 2002, for mitigating interference by UWB signals into other communication systems, choices of pulse shapes, modulation, representation of a bit by many pulses of very low amplitude, randomization using PN sequences, and related sequences, PSD shaping and whitening, choice of design parameters such as pulse repetition frequency, to move discrete spectral components of UWB into positions where they cause minimum interference, were the main methods.

- For mitigating interference into UWB signals, choice of pulse shapes, modulation methods and a wavelet-based method for decomposing an UWB signal into its subband components, eliminating those subbands that are located where there are interferers from other communication systems, are the main methods advanced so far.

- Multipath interference mitigated using RAKE receivers.

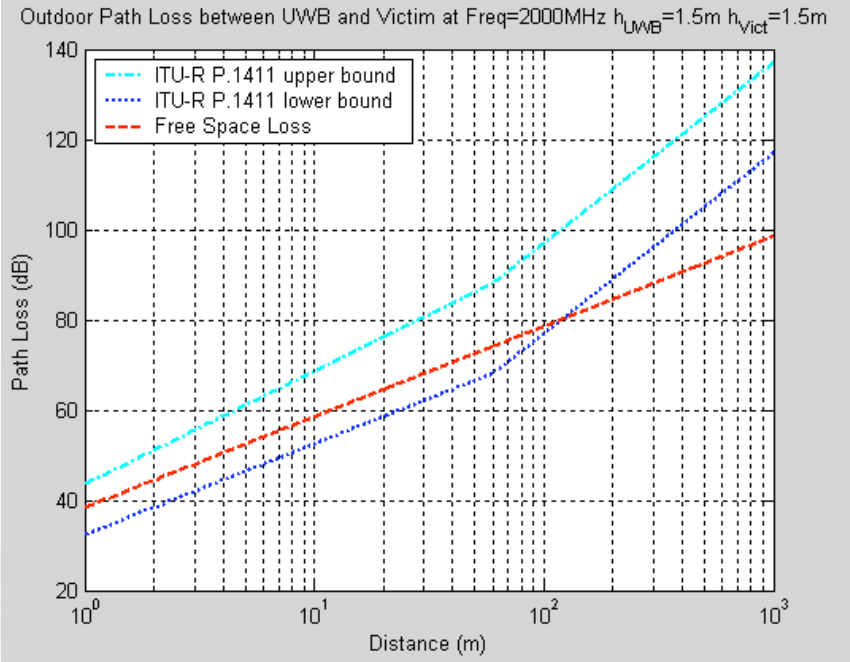
- Using multi-band instead of single band UWB systems as a way to avoid spectrum bands where interference into other communications is most intense is still being debated.

- Recently avoidance methods have been proposed

- How can placement and widths of bands in multi-band systems and interference avoidance methods be made adaptive so as to avoid interference into bands of the spectrum where UWB signals can potentially cause most unwanted interference, or other communication signals can cause the most interference into UWB signals? What is the tradeoff of the possible benefits of adaptive methods with limits on complexity of receivers?

- Given aggregate interference considerations to what extent can the satellite and television, as well as other communication services be guaranteed freedom from interference from UWB signals?

- Have measurement campaigns been sufficient to enable models of interference by UWB signals into satellite, television and other services to be used to predict these interferences with confidence? Are more measurement campaigns needed, or can we rely on known theoretically derived models together with measurement campaigns already conducted to make these predictions?



3. Narrowband and UWB Minimum Detectable Signal Levels

- In the Spectrum Engineering Branch of Industry Canada there is an interest in monitoring the presence of UWB signals. What seems to be known about the possibility of detection of these LPD signals is the following[2].

- The output SNR for a narrowband detection system with a input signal with average available sinusoidal signal power S_s is given by

$$\frac{S_o}{N_o} = \frac{1}{F_{ave}} \frac{S_s}{kT_o B_N} \qquad (3)$$

where

S_o = output signal power for single frequency sinusoid

N_o = output noise power present over the detection system bandwidth

S_s = average available sinusoidal signal power at the input

T_o = 290 degrees Kelvin

F_{ave} = average noise figure

k = Boltzmann's constant=1.38 (10^{-23}) W/Hz/deg K

B_N = noise bandwidth, related to the detection system transfer function $H(f)$.

For some desired SNR the minimum detectable power signal level is $S_a = M_{nbp}$, and $S_o / N_o = D_{nb}$. Rewriting (3) gives

$$M_{nbp} = F_{ave} k T_o B_N D_{nb} \text{ (watts).} \qquad (4)$$

A narrowband (sinusoid) circuit noise bandwidth B_N is approximated by the 3 dB BW. When the input signal is a non-sinusoidal transient, the circuit impulse bandwidth, B_I, is approximated by a 6 dB BW. For UWB impulse-like signals the minimum detectable (UWB) signal is

$$M_{uwbp} = F_{ave} k T_o B_N / B_I^2 \, D_{uwb} \quad \text{(watts/Hz}^2\text{)}. \qquad (5)$$

The detection criterion D_{nb} is average output power/average output noise power, and D_{nwb} is peak instantaneous output signal power /average output noise power for minimum detection. Because impulse noise BW B_I is always greater than narrowband noise bandwidth B_N, let $B_I = KB_N$, where $K > 1$. Equation (5) can then be rewritten as:

$$M_{uwbp} = F_{ave} k T_o \left\{K^2 B_N\right\}^{-1} D_{uwb} \quad \text{(watts/Hz}^2\text{)}. \qquad (6)$$

From (6), as noise BW (or system 3 dB BW) increases, the minimum detectable UWB impulse-like signal level decreases, i.e., sensitivity improves. The wider the collection BW the lower the minimum detectable UWB transient signal. This is in contrast to the behavior of (5) for narrowband minimum detectable signals. For sinusoidal signals, as B_N increases M_{nbp} also increases and the system becomes less sensitive. The above is a summary of the state of the art[2].

- What has been done on this problem of detection of UWB signals, important for monitoring and defense, since 1992?

[2] Elizabeth C. Kisenwether, "Ultrawideband (UWB) impulse signal detection and processing issues," in *Proc. Tactical Communications Conference*, vol. 1, Fort Wayne, IN, vol. 1, 28-30 April 1992, pp. 87-93.

- Can correlation methods such as those used at MIT in the late 1950's, and shown in Y.W. Lee's text (*circa* 1960) be used? Any other methods?
- Several techniques exist for detection of narrow time domain signals. One of these is singularity detection using the "zooming-in" property of wavelets, originated by S. Mallat in the early 1990's. Other time-frequency methods related to wavelet theory have appeared in the literature for about the last 17 years. Can these be used for UWB signal detection?
- How is the presence of UWB signals to be monitored?

4. MIMO UWB Systems

- Results of preliminary investigations[3] indicate considerable promise for MIMO UWB systems, a promise that will probably be the subject of many future investigations.
- Characteristics of the channel dramatically influence the diversity gain, & led to poor results due to time and angular dispersion, due to deficiency of the synchronization scheme.
- Beam switching worked fairly well.
- What are the issues regarding performance of broadband antenna arrays for MIMO? Dispersionless antennas are very difficult to design for UWB.

[3] Alain Sibille, "MIMO diversity for ultra wide band communications," ENSTA, Paris, France, submitted to COST 273 TD(03) 071, Jan.15-17, 2003 16 pp.