Measurement and Parameter Description of Time-varying Ultra-wideband Infostation Channel

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Abstract— In this article, we present the measurement and description of channel parameters for the time-varying Infostation UWB channel. We also consider how such parameters can be used to improve system performance in terms of optimally combating inter-symbol interference (ISI) and inter-channel interference (ICI) in the case of multiband OFDM.

1. INTRODUCTION

The concept of infostation [1–3] presents a new way to look at the problem of providing high data rate wireless access. It is an isolated pocket area with small coverage (hundreds of meters) of high bandwidth connectivity that collects information requests from mobile users and delivers data while users are going through the coverage area. Infostations can be located in heavily populated areas such as airports, shops, pubs, hotels, and along highways. One of the technologies that have the potential to deliver the envisaged high-data rate infostation services is the UWB signaling [3]. The UWB has the basic attributes of extremely low transmission power, operating at unlicensed frequency, high data rate, multipath immunity and low cost. Existing channel characterization and measurement for the UWB channel have been limited to the case where the channel is assumed to be stationary over the transmission duration. However, for many infostation scenarios, time variation is expected due to the mobility of one of the communication terminals/scatterers. Hence, the existing channel models cannot be used to describe this new target scenario where terminal mobility is expected.

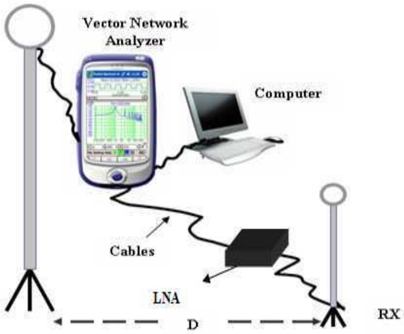
Time-varying channels are often modeled as stationary random processes using the concept of the wide-sense stationary uncorrelated scattering (WSSUS) assumption [4]. Unfortunately, in time-varying UWB channel, the WSSUS assumption is invalid. The nature of the time-varying channel is such that the spatial structures of the multipath components, i.e., their number, time-of-arrivals (TOA), angle-of-arrivals (AOA) and magnitudes, change with time and location, leading to nonstationary statistics. Hence, non-WSSUS characterization [5, 6] of the channel is required. For the UWB channel, the fine time resolution implies narrow delay bins which enable paths to move fast from one tap to another [7]. Hence, the time evolution of the UWB channel cannot be decomposed into the time evolution of the individual taps, but of the individual paths.

In this article, we present the measurement and the descriptions of channel parameters for the time-varying Infostation UWB channel. We also consider how such parameters can be used to improve system performance in terms of combating ICI in the case of multiband OFDM and mismatch in channel estimation.

The rest of this paper is organized as follows. In Section 2, the basic system model is specified. The Infostation UWB channel measurement setup is presented in Section 3. Section 4 is devoted to describing the post processing of the measurement data and the description of the how the channel parameters can be used to improve system performance in terms of optimally combating ISI and ICI in the case of multiband OFDM.

2. SYSTEM MODEL

Channels can be characterized by their response function in time and/or frequency domain say $\mathcal{P}(t, f)$. The variation among the statistics of the measured channel responses taken over a given appreciable interval is assumed to be insignificant (stationary) in the WSSUS case. Unfortunately, in time-varying UWB channel this is not the case as the channel is non-WSSUS. In essence, non-WSSUS scattering function can be viewed as a set of evolutionary functions that are more or less the instantaneous responses $\mathcal{P}(t, f)_i,\ i = 1, 2, 3, \ldots, I$ of the channel to an input. Although the coherence parameters of these instantaneous channel realizations vary from one to another, for practical rationality we consider channel coherency only with respect to the reference channels response regard as being WSSUS say $\mathcal{P}(t, f)_1$. The coherency of $\mathcal{P}(t, f)_1$ is ensured by restricting



(a)

(b)

Figure 1: (a) Illustration of measurement setup. (b) Real measurement setup.

the measurement sampling time J_v at $J_v = \lambda/2$. All other sets of $\Psi = \{\mathcal{P}(\tau, s)_i : \{i \neq 1\} \in Z\}$ are defined only by stationarity the parameters. Hence, the non-WSSUS channel is completely characterized by the coherence time T_c and bandwidth B_c [8], and the stationarity time T_s and bandwidth B_s [5].

3. INFOSTATION UWB CHANNEL MEASUREMENT

The complex channel response is measured with a vector analyzer (VNA) R&S®ZVL13. Measurements were carried out at various locations along a path way within the vicinity of Wireless Communication Centre (WCC) complex Universiti Teknologi Malaysia, as shown in Fig. 1 for the frequency range 3.1–3.628 GHz. The speed of the mobile is about 2 m/s, and measurements were taken at each location marked $A_1 - A_8$. At each location, the measurement is repeated 50 times. The VNA records the variation of 1001 complex tones within the band. This recording is done by sweeping the spectrum in about $20 \times J_v$ time interval. Apart from the mobile antenna, all the objects (potential scatterers) are kept stationary throughout the duration of the measurement. The antennas (monopoles) are of the same height, 1.5 m and the transmit power is -42 dB for all measurements. The signal from the receiving antenna is passed through a low noise amplifier (LNA) with a gain of 24 dB. The distances between the locations are, $A_1 - A_2 = 40$ cm, $A_2 - A_3 = 40$ cm, $A_3 - A_4 = 40$ cm, $A_4 - A_5 = 40$ cm, $A_5 - A_6 = 40$ cm, $A_6 - A_7 = 40$ cm and $A_7 - A_8 = 40$ cm.

4. MEASUREMENT DATA PROCESSING AND PARAMETER DESCRIPTION

The description of the post processing and parameter description for the channel measurement data is given in this section. Since the velocity of the mobile is constant throughout the measurement run, and LOS propagation exists for all measurements, the coherence time for all measurement is approximately constant. Hence, the values of T_s/T_c at A_1, A_2, A_3, A_4, A_5, A_6, A_7 and A_8 are infinity as long as constant velocity is maintained and LOS propagation exists.

The VNA effectively receives a channel output $Y(t)$. In order to obtain the statistical model of the time-variant response from the measured complex channel responses, we apply the autoregressive (AR) model proposed in [9]. Let $Y(f_p, t; A)$ be the time-varying complex received sign measured at a location A and time t. Then the first and second order statistics of the measured channel are captured by the model: $Y(f_p, t; A) = \sum_{n=1}^{N} a_n\, Y(f_{p-n}, t; A) + V(f_p)$, where $V(f_p)$ is a complex white noise process and a_n is the function representing the nth time-varying AR coefficient. We take the inverse fast Fourier transform (IFFT) of $Y(t)$ to arrive at the passband time domain response of the system. We choose 2^{15} — point IFFT which ensures an oversampled period T of 6.1035 ps, which is many times oversampled compared to the Nyquist rate. This oversampling is critical to our analyses as it allows us to accurately approximate the delay version of the received signal as a delay of indices in its sampled version. At a threshold of -10 dB, the measured responses are sampled at the interval of $1/(2BT)$, where $B = 528$ MHz is the bandwidth of the system. The normalized PDP for the positions A_1, A_2, A_3, A_4, A_5, A_6, A_7 and A_8 are shown in Fig. 2.

From Fig. 2, the coherence bandwidth value of 7.56 MHz is computed by assuming that the response at the reference position A_1 upholds the WSSUS assumption. The computed B_s for the

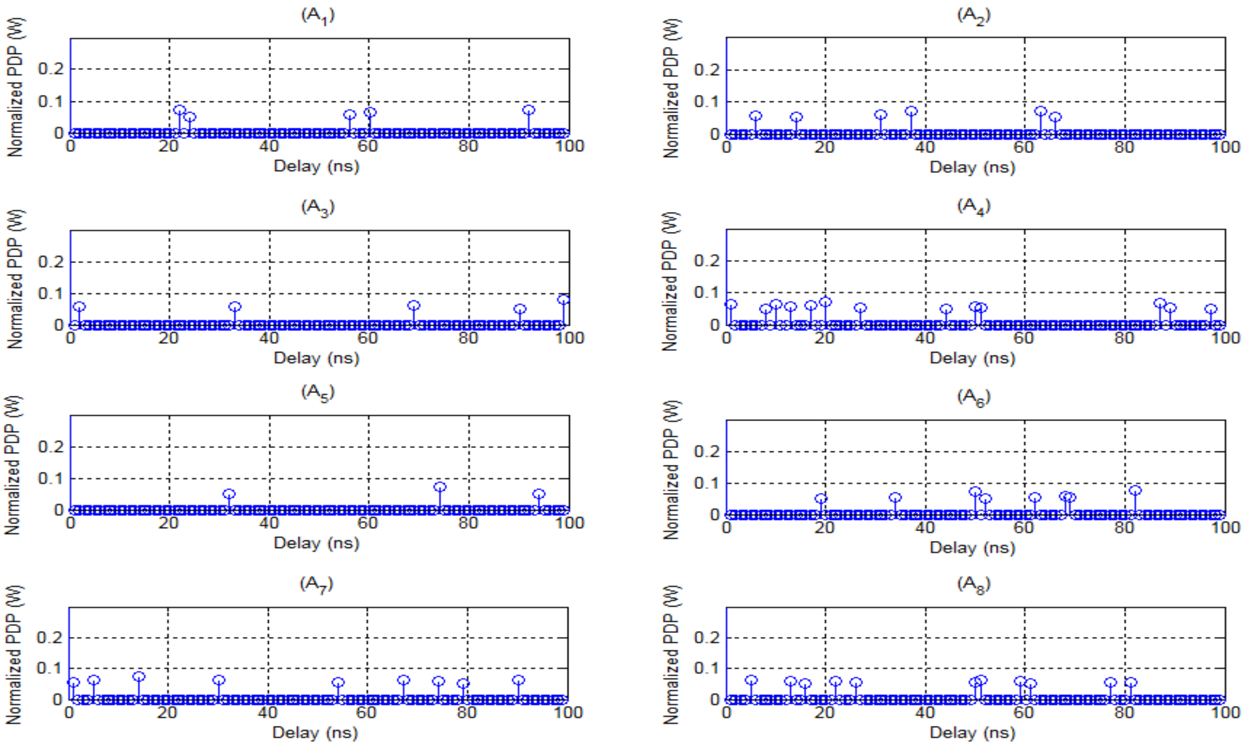


Figure 2: Normalized PDP (in watts) for positions A_1, A_2, A_3, A_4, A_5, A_6, A_7 and A_8.

positions A_2, A_3, A_4, A_5, A_6, A_7 and A_8 (non-WSSUS) are approximately 33.47 MHz, 36.6 MHz, 91.7 MHz, 1711.33 MHz, 114.6 MHz, 76.88 MHz and 306.22 MHz, respectively. These B_s values are computed at -10 dB threshold. The implication of the ratio B_s/B_c can be observed in the case of multiband orthogonal frequency division multiplex (MB-OFDM) UWB. Let us consider the MB-OFDM system designed with Ns number of subcarriers and subcarrier spacing of Fs MHz. In order to combat fading in MB-OFDM, the bandwidths of the subcarriers should be equal or less than the B_c to avoid ISI. However, the choice of small value for Fs implies that the system will be more susceptible to ICI. Hence, the choice of the value of Fs should be optimal between combating frequency selective fading and ICI. If we consider a total bandwidth of 528 MHz, the value of Fs for 128, 64 32 and 16 subcarriers are 4.125 MHz, 8.25 MHz, 16.5 MHz and 33 MHz, respectively. Hence, the choice of 128 subcarrier ensures good ISI performance but with increased error due to ICI, and the choice of 16 subcarriers ensures good ICI performance but with increased susceptibility to ICI. The optimal choice will be to choose the number of subcarriers such that $kFs = B_c$, where the value of k should be chosen to take care of the time-varying nature of B_c. Conventionally, k is chosen to be fixed and of low value, which implies a fixed number of subcarriers. The SNR degradation caused by ICI is given by [10]:

$$D \cong \frac{10}{\ln 10}\frac{1}{3}\left(\frac{\pi f_e}{Fs}\right)^2\left(1+\frac{E_s}{N_0}\right) \tag{1}$$

where f_e is the frequency offset. If we consider the above channel measurement, then the SNR degradations for 128, 64, 32 and 22 subcarriers are shown in Fig. 3.

Figure 3 shows that the SNR degradation for 22 subcarriers ($k = 1$) is better than the performance at $k < 1$ (128, 64 and 32 subcarriers). However, when k is greater than unity, ISI degradation sets in. This implies that instead of a fixed value for k, some form of adaptive subcarrier bandwidth can be employed. The value of stationarity bandwidth can provide information that can be used to adjust k for optimal performance. The values of B_s/B_c at A_1, A_2, A_3, A_4, A_5, A_6, A_7 and A_8 are approximately, ∞, 4.4, 4.8, 12.13, 226.5, 15.2, 10.2, 40.5, respectively. We can define the bandwidth utilization parameter U by: $U \cong -B_{co}^{-1}\left(((\Im B_{co})/\Im - 1) - B_{co}\right)$, where, $\Im = B_s/B_c$ and B_{co} is the reference coherence bandwidth. Hence, the values of U at A_1, A_2, A_3, A_4, A_5, A_6, A_7 and A_8 are approximately, -18.42%, 26.02%, 8.98%, 0.44%, 7.06%, 10.90% and 2.41%, respectively. The negative sign in U indicates that k is greater than 1 by the given percentage and the positive

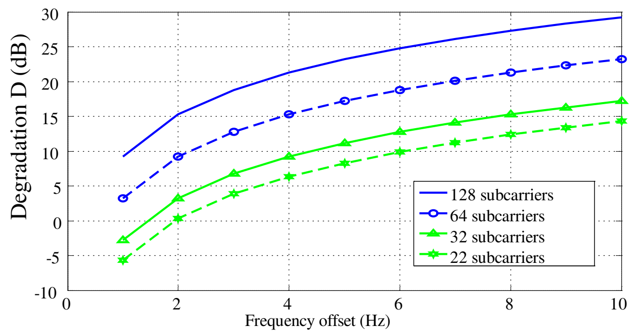


Figure 3: SNR degradation as a function of subcarrier spacing.

sign in U indicates that k is less than 1 by the given percentage. Therefore, this nonstationarity information can be employed to adjust the values of k in order to optimize the system performance at any time instant.

5. CONCLUSION

The measurement and parameter description for the time-varying UWB Infostation channel is presented. The analysis emphasized on the nonstationary properties of the UWB due to the movement of the mobile terminal. Coherence and stationarity parameters were obtained and used to analyze the performance of the measured channel with respect to ICI and ISI in MB-OFDM. From results it implies that some form of adaptive technique using the joint knowledge of the coherence and stationarity parameters will greatly improve the performance of the Infostation channel in terms of combating ICI and ISI.

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