Time-Varying UWB Channel Measurement and Data Transfer Analysis for Multiuser MB-OFDM-Based Infostation Network*

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Abstract

This paper presents the path loss and time dispersion parameters results obtained from a set of channel measurements conducted in various outdoor environments that are typical of multiuser Infostation application scenarios. The measurement procedure takes into account the practical scenarios typical of the positions and movements of the users in the particular Infostation network. A data transfer analysis for multiband orthogonal frequency division multiplexing is also presented. As expected, the rough estimate of simultaneous data transfer in a multiuser Infostation scenario indicates dependency of the download percentage on the data size, number and speed of the users, and the elapse time.

Keywords: Ultra-WideBand (UWB), Infostation, Path Loss, Time Dispersion Analysis, Data Transfer Analysis

1 Introduction

By the traditional definition, Infostation is a wireless communication system characterized by sequential user access with discontinuous coverage areas and high data rate transmissions (Cavalcanti *et al.*, 2002; Frenkiel *et al.*, 2000; Galluccio *et al.*, 2008; Iacono and Rose, 2002; Rajappan *et al.*, 2006). However, inspired by the inherent high data rate of Ultra-WideBand (UWB) technology, and the various multiple access schemes and their performance that have been reported (Foerster, 2002; Win and Scholtz, 2000), multiuser Infostation, in which simultaneous user-access is possible, deserves consideration. The concept of Infostation 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 (few hundreds of meters) of high speed connectivity.

The Infostation network can be located in diverse areas, and in different user-defined scenarios such as sit-through, walk-through and drive-through scenarios. The *drive-through* scenario corresponds to high-speed users that pass through the coverage area in seconds, as in a roadway and railway. The *walk-through* scenario is characterized by slow moving users, such as in airports, sidewalks or malls. Finally, we have the *sit-through* scenario where stationary users, such as those in a classroom/recreational park (Cavalcanti *et al.*, 2002).

In some of these scenarios, services will include large-size data transfers. Such services demand technologies that can handle high data rate information transfer. Since, the Infostation technology is designed for small area of coverage, and will coexist with conventional networks, technologies with low transmission power are good candidates. The potential of using UWB technologies in Infostation is mentioned in (Chude-Okonkwo *et al.*, 2012; Lakkundi, 2006). UWB systems have the basic attributes of extremely low transmission power, operating at unlicensed frequency, high data rate, multipath immunity and low cost.

Like in any communication system, the performance of the UWB system depends heavily on the environment in which it will be deployed. Hence, system design is often preceded by channel measurement and modelling. The various scenarios highlighted above can primarily be categorized into indoor and outdoor. A large literature base on UWB indoor measurements is available some of which can be found in (Cramer *et al.*, 2002; Donlan *et al.*, 2006; Irahhauten *et al.*, 2006; Lee, 2010; Molisch, 2009; Nkakanou *et al.*, 2011; Noori *et al.*, 2009; Rissafi *et al.*, 2012; Win *et al.*, 1997; Yu *et al.*, 2004). However, to the best of our knowledge, the number of outdoor measurement campaigns presented in the literature are limited. Some of the existing works on outdoor measurement campaigns can be found in (Anderson *et al.*, 2013; Di Francesco *et al.*, 2005; Kim *et al.*, 2005; Lee, 2010; Niu *et al.*, 2008; Richardson *et al.*, 2006; Santos *et al.*, 2010; Souza and Bello, 2008; Win *et al.*, 1997). And as far as we know, apart from the outdoor measurement in a gas-station and drive-by restaurant (Rissafi *et al.*, 2012), roadway and parking lot (Lee, 2010), no other literature on the UWB measurement in Infostation scenario is available. This paper aims to provide

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measurements to fill in the gap. Particularly, we describe two Infostation service scenarios, and conduct channel measurements in the related environments. The scenarios are the Infostation network in an outdoor recreation park and Infostation network along a roadway/sidewalk. The detail description of these scenarios will be provided in the next section.

Some of the measurement procedures used in this paper differs from those in existing literature in that, our procedure mimics the typical user position and mobility with respect to a given Infostation Access Point (AP).

Our main contributions in this paper are as follows:

(i) We describe two dissimilar multiuser Infostation scenarios, and highlight on some of their enabling technologies.

(ii) We provide the result of the Path Loss Exponent (PLE) and time dispersion parameters obtained from the measurement campaign conducted.

(iii) We present a comparative analysis of our results with what has been presented in literature and deduce the similarities and deviations in them and discuss the reasons for such.

(iv) The “manytime-manywhere” concept of the Infostation may not be feasible in the case where the information to be accessed is not available ‘manywhere’. And with the small coverage area of the Infostation, to cater for delay sensitive information, simple raw data rate analysis of a typical MultiBand Orthogonal Frequency Multiplexing (MB-OFDM) transceiver deployed in such scenarios is presented. The data rate analysis provides one with a rough estimate of how much data can be downloaded over a given time and mobile speed.

The rest of the paper is organized as follows. Section 2 describes the two Infostation service scenarios that we consider in this paper. The description of the measurement setup, environments and procedure are given in Section 3. Section 4 considers the measurement results in terms of path loss, time dispersion analysis, and a rough analysis of data transfer rates for the two scenarios.

2 Resources and Methods Used

2.1 Description of the Multiuser Infostation Service Scenarios and Their Enabling Technologies

The respective deliverable services described in this work employ the Infostation concepts and the UWB technology. The enabling technologies for this application includes UWB-Radio-Over-Fiber (UWB-RoF) (Yu *et al.*, 2008). Typically, it is envisaged that if the server(s) is/are located away from the Infostation, the large data transfer meant for users can be handled by a fiber optic backbone. The fiber can be connected to the internet or other networks.

2.1.1 High-Speed Multiuser Data Access in Recreation Park

A typical scenario that can benefit from this Infostation setting is where users can simultaneously download/upload high quality videos/images/data that have very large data size in a matter of seconds while siting/walking around a recreation park. The challenge here is that given the small coverage areas of the Infostation network, and the “manytime-manywhere” concept not being feasible, users have to be able to download/upload the data before exiting the coverage perimeter. And being a public area, the number of potential users per cell and the signal scattering by vegetation as well as structures, has to be taken into consideration. More also, users accessing a particular Infostation may experience different channel conditions due to their different positions.

2.1.2 Roadside Multiuser Infostation Access

In this scenario, drive-through and walk-through users can simultaneously access/upload information from/to an Infostation located along the way. Such information may, for example, be high-definition movies. The speed of the user and the mobility of object/persons inside the propagation environment have significant impact on the performance of the system. Owing to the inherent small coverage area, the speed of the user will determine how much data is accessed over a given time. The UWB-RoF is one of the enabling technologies. We note that related forms of this scenario has been introduced in (Domazetovic *et al.*, 2002), but not in the context of UWB and multiuser scenario.

2.2 Measurement Setup, Environments, and Procedure

The goal of the measurements is to investigate the statistical characteristics of the two Infostation scenarios described above. Typical environments that match the two Infostation scenarios are considered. These environments are located inside the Universiti Teknologi Malaysia, Skudai. All measurements were carried out at the early hours of the morning to reduce the influence of mobile scatterers.

2.2.1 Measurement Setup

The measurement for obtaining the channel response is carried out in the time domain. The sounding system includes a pair of PulsON® 410 transceivers manufactured by the Time Domain Corporation. The system uses coherent transmissions to maintain the phase information of each pulse. This enables the capture of the received waveform without a wired connection between the transmitting and receiving sides. Each transceiver has a vertically polarized omnidirectional wideband (3.1-10.6 GHz) dipole antenna mounted on it. In all the measurement scenarios, the transmitting antenna, which serves as the AP, is located 2.5 m above the ground. The pulse bandwidth is 2.2 GHz over the frequency range of 3.1-5.3 GHz. A step size of 32 is used, which allows for one measurement every 61 ps.

2.2.2 Measurement Environments

The measurements performed are classified into three channel modes as follows:

(i) CH1 – outdoor roadway (nearside)/80 m;
(ii) CH2 – outdoor roadway (far-side)/80 m; and
(iii) CH3 – outdoor recreational park.

CH1 and CH2 channel measurements are taken along a campus driveway located at the front of Block P16 building complex in the university as shown in Fig. 1, with a dark arrow pointing to the AP location. Fig. 2 also shows a sketch of the setup. On either side of the driveway is the building complex and vegetation on a slope. CH3, on the other hand, is a section of the recreation park beside a lake and situated inside the university campus as shown in Fig. 3. Fig. 4 shows a sketch of the setup for the CH3 measurements.

Fig. 1 Roadway Measurement Environment

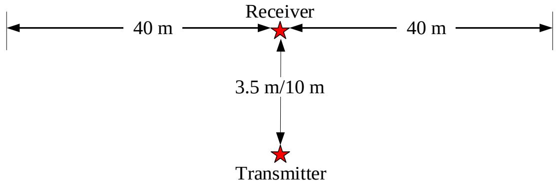

Fig. 2 Sketch of the Setup for collecting RF Propagating Data at Roadway

2.2.3 Measurement Procedures

This subsection discusses the measurement procedures employed in the Infostation scenarios described.

Roadway Scenario

In the roadway scenario, the receiver is placed at the edge of the roadway. Measurements were taken under two separate mobile scenarios: first at a speed of 0.8 m/s and 1.2 m/s in the second instance. The transmitter is held at a height of 1 m from the ground as it is moved along a defined straight path along the roadway. Let us fit in a virtual straight line that cuts through the transmitter location. This virtual straight line is equidistance to the measurement routes for CH1 and CH2 with separation distance of 3.5 m and 10 m separation distances, respectively. We moved a distance of 80 m along the CH1 and CH2 routes. An average of 235 samples of the Channel Impulse Response (CIR) were taken at 0.8 m/s and 135 samples at 1.2 m/s.

The choice of continuous movement for the measurement is informed by the typical situation whereby a person moves within an Infostation network. In addition, the 80-m long measurement route is chosen to indicate a challenging coverage radius of 40 m.

Recreational Park Scenario

The measurement procedure used in the case of the recreational park scenario depicts a typical scenario in the park where people sit at different locations and download/upload information from the same AP in an Infostation network. Five different areas in the park, are considered. We designate these five areas as G_1, G_2, G_3, G_4 and G_5. In each location, measurements are taken at random positions within a circular area of radius 1 m. The centers of the circular areas that enclose G_1, G_2, G_3, G_4 and G_5 are about 12 m, 29 m, 25 m, 10 m and 29 m, respectively, from the transmitter (akin to the AP) as shown in Fig. 4. Note that the location of the transmitter is close to the red sign board in the photos (see Fig. 3) and the sitting positions of the users are indicated by the dark arrows. In all cases, the receiver is located 1 m above the ground, which depicts the typical scenario where the user is sitting on a bench. Area G_2 is situated on a platform somewhere close to the middle of the lake in the park, while the rest of the areas are situated off the lake shore. Average of 50 CIR were recorded at random positions at each location.

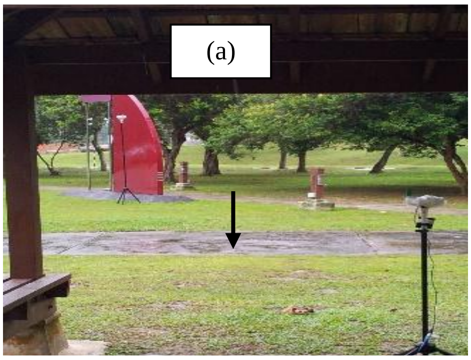

Fig. 3 Recreation Park Environment Measurements for (a) G_1 (b) G_2 (c) G_3 (d) G_4 and (e) G_5

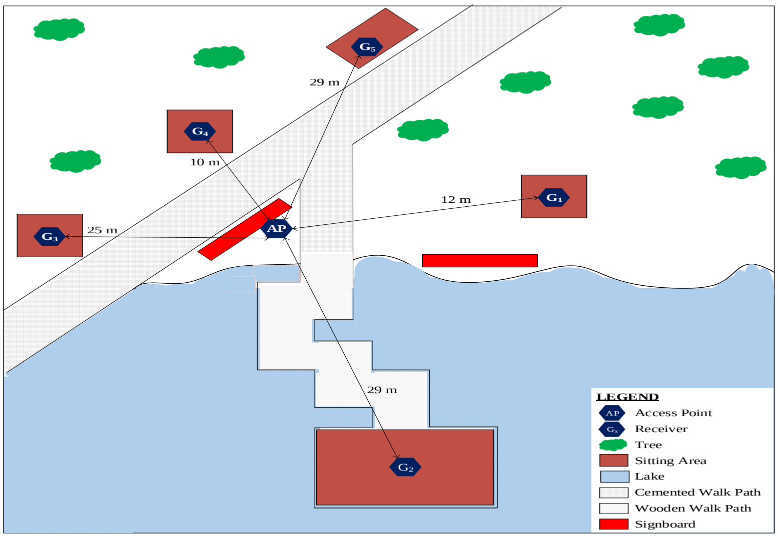

Fig. 4 Layout of the Recreational Park Measurement Environment

3 Results and Discussion

3.1 Measurement Results

The CIR at each measurement location is obtained. The CIRs are obtained by deconvolving the template waveform from the recorded (received) signal using the CLEAN algorithm at 25 dB threshold. Typically, the channel characteristics are captured by path loss exponents, and the time dispersion parameters viz. RMS delay spread τ_{rms}, mean excess delay $\tau_{m,mean}$, maximum Doppler spread C, coherence bandwidth B_C, and coherence time T_C (Molisch, 2011).

3.1.1 Path Loss Analysis

For UWB systems, it is a well-known fact that Path Loss (PL) is a function of both frequency and distance (Karedal *et al.*, 2007; Molisch *et al.*, 2006). This can be simplified by assuming that frequency dependence and distance can be treated independently of each other as (Chehri *et al.*, 2008):

$$P(f,d) = PL(f) \cdot PL(d) \tag{1}$$

In this paper, we focus our analysis on path loss dependence on distance. The choice of distance is because the UWB channel exhibits little or no impact on frequency (El Din *et al.*, 2010). A general model for path loss in decibels at distance d, i.e. PL(d), is given as (Chehri *et al.*, 2008; Lee, 2010; Muqaibel *et al.*, 2006):

$$PL(d) = PL_0 + 10 n_{PL} \log\left(\frac{d}{d_0}\right) + X_{PL}, \quad d \geq d_0 \tag{2}$$

where n_{PL} is the path loss exponent, X_{PL} is a random variable that is often modeled as a zero-mean Gaussian with standard deviation σ_{PL}, and the constant PL_0 is the path loss at a reference distance d_0 = 1 m.

Path Loss Exponent Analysis

Fig. 5 shows the scatter plots of the path loss for CH1 and CH2, which are obtained by computing the total received power of each measured signal relative to the received power at d_0 given in (2), with distance. It is observed that path loss and distance are inversely proportional. Thus, the path loss generally decreases as the receiver approaches the transmitter and vice versa. The experimental value of n_{PL}, taken as the slope of the regression line, is given in Table 1 for CH1 and CH2. Observe that n_{PL} generally decreases with increase in speed in all cases, with only the results for the left direction of CH1 being an exception. Note that in Table 1, 'Left' direction represents the distance 0-40 m and 'Right' also represents the distance 40-80 m of our measurement.

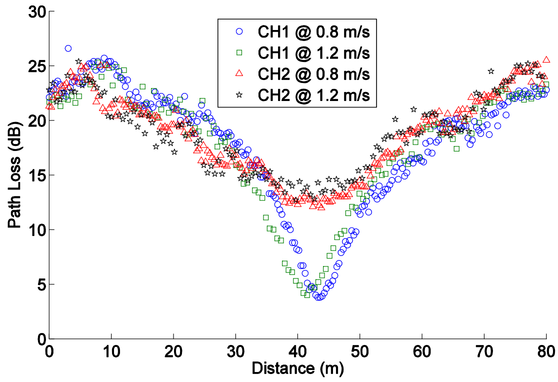

Fig. 5. Scatter Plots of the Path Loss versus Distance for Channels CH1 and CH2

Table 1 Path Loss Exponent Values for CH1 and CH2

Channel	Speed (m/s)	Direction	n_{PL}
CH1	0.8	Left	0.3534
		Right	0.4949
	1.2	Left	0.4083
		Right	0.4552
CH2	0.8	Left	0.2826
		Right	0.3518
	1.2	Left	0.2653
		Right	0.3132

Comparison with Other Outdoor UWB Path Loss Models

The path loss exponent for different outdoor UWB scenarios has been reported in literature. The IEEE 802.15.4a standardization group has proposed UWB channel models for various settings which includes a farm area (outdoor). This outdoor farm area channel model is based on ray-tracing simulation (Molisch *et al.*, 2006). The results reported in this paper is based on measurements which differs from that reported in (Molisch *et al.*, 2006). Other path loss exponent values have been reported for outdoor suburban (Di Francesco *et al.*, 2005), outdoor roadway (Lee, 2010) and forest (Renzo *et al.*, 2006) settings, which are all based on measurements.

Table 2 shows a comparison of the path loss exponent and other channel parameters. The values of the path loss exponents reported in (Di Francesco *et al.*, 2005; Renzo *et al.*, 2006) and (Lee, 2010; Molisch *et al.*, 2006) have approximately equal values. These path loss exponent values are notably higher compared to our results in Table 1. This may be as a result of the combination of line-of-sight (LOS) and non-LOS in (Di Francesco *et al.*, 2005) and environments with several multipath components whereas our reported environment had only one building with minimal vegetation as described in Section 2.2.2.

Table 2 Comparison of Channel and Path Loss Parameter Values

Source	Setting	Range (m)	Freq. range (GHz)	Meas. D^2	n_{PL}
Di Francesco *et al.* (2005)	Outdoor suburban	–	–	–	2.66
Molisch *et al.* (2006)	Farm	10-51	–	–	1.58
Lee (2010)	Outdoor roadway	2.5-20	3.1-6.3	Time	1.6
		30-80			1.6
(Renzo *et al.*, 2006)	Forest	1-25	–	Time	2.5-2.6

3.1.2 Time Dispersion Analysis

Time dispersion is a characteristic of multipath channel that extends the signal in time so that the duration of the received signal is greater than the transmitted signal. This effect is usually captured by parameters such as maximum excess delay τ_m, τ_{rms}, and B_C. The τ_{rms} is the square root of the second central moment of the Power Delay Profile (PDP). The maximum excess delay (X dB) of the PDP is defined as the time delay during which the multipath energy falls to X dB below the maximum value. If we represent the PDP at the kth delay as $P(\tau_k)$, then τ_{rms} is expressed with respect to the second-order moment as (Rappaport, 2002):

$$\tau_{rms} = \sqrt{\overline{\tau^2} - (\tau_m)^2} \tag{3}$$

with

$$\tau_m = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)} \tag{4}$$

and

$$\overline{\tau^2} = \frac{\sum_k P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)} \tag{5}$$

The B_C and T_C over which the channel can be considered statistically invariant are given at 50 % correlation by (Rappaport, 2002):

$$B_C = \frac{1}{5\tau_{rms}} \tag{6}$$

and

$$T_C = \frac{1}{5\upsilon_{\max}} \tag{7}$$

where $\upsilon_{\max}$ is the maximum Doppler shift experienced by the transmit signal.

RMS Delay Spread and Mean Excess Delay

Fig. 6 shows the Cumulative Distribution Function (CDF) of the variations in τ_{rms} and the maximum and minimum variation are also provided in Table 3 for CH1 and CH2. The behavior of the CDF for $\tau_{m,mean}$ also indicates a slight deviation in relation to that of τ_{rms}. Fig. 7 shows the CDF of the mean excess delay.

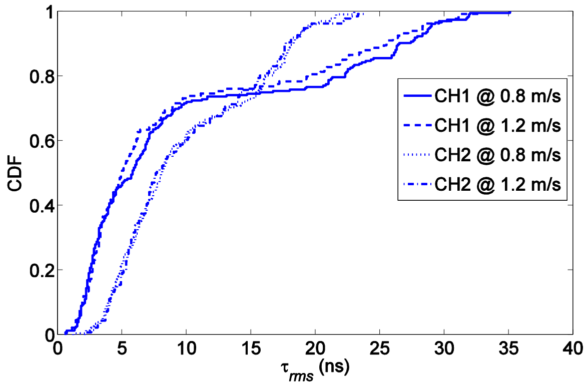

Fig. 6 Cumulative distribution function versus RMS delay spread for CH1 and CH2

Table 3 RMS Delay Spread and Mean Excess Delay Values for CH1 and CH2

Channel	Speed (m/s)	τ_{rms} (ns) Min.	τ_{rms} (ns) Max.	$\tau_{m,mean}$ (ns) Min.	$\tau_{m,mean}$ (ns) Max.
CH1	0.8	0.6	35.1	0.3	37.4
	1.2	0.6	32.7	0.3	36.9
CH2	0.8	1.2	23.0	0.4	33.9
	1.2	2.1	23.8	0.6	30.7

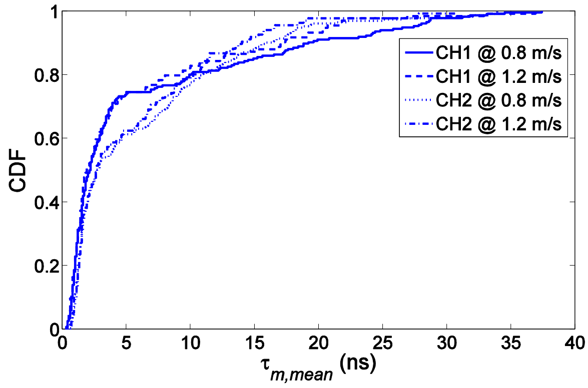

Fig. 7 Cumulative Distribution Function versus Mean Excess Delay Spread for CH1 and CH2

Variation of RMS Delay Spread

The dependence of τ_{rms} on the separation distance between the transmitter and receiver is an important result which can influence system design. The τ_{rms} values of our measurements are plotted versus separation distance in Fig. 8. The significant difference in τ_{rms} values at the extreme ends of the transmitter may be as a results of the different scatterers at both places. The correlation coefficient result between τ_{rms} and distance for CH1 and CH2 are also shown in Table 4. The results for CH1 indicate a strong downhill linear relationship when the speed of movement is 0.8 m/s and a moderate downhill relationship when the speed of movement is 1.2 m/s. In the case of CH2, the results indicate a moderate downhill relationship in both cases.

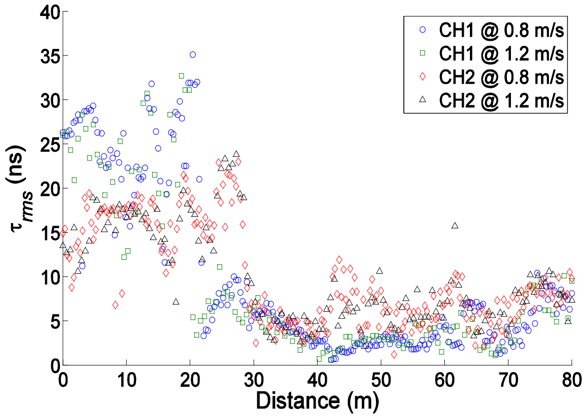

Fig. 8 RMS Delay Spread Versus Distance for Ch1 and Ch2

The τ_{rms} values are again plotted versus the corresponding τ_m values in Fig. 9. The correlation coefficient result between τ_{rms} and τ_m for CH1 and CH2 are also shown in Table 4. The results for CH1 indicate a strong uphill relationship in both speed scenarios but in the case of CH2, the 0.8 m/s speed scenario shows a moderate uphill relationship whereas the 1.2 m/s speed scenario indicates a weak uphill relationship.

Table 4 Correlation between RMS Delay Spread and Distance and RMS Delay Spread and Maximum Excess Delay for Ch1 and Ch2

Channel	Speed (m/s)	Correlation Coefficient	
		τ_{rms} and distance	τ_{rms} and τ_m
CH1	0.8	-0.7258	0.7356
	1.2	-0.6946	0.7042
CH2	0.8	-0.6551	0.3928
	1.2	-0.6278	0.2837

Comparison with Other Outdoor UWB Time Dispersion Parameters

The τ_{rms} values reflect the complexity of the multipath structure. Table 5 shows a comparison of time dispersion and other channel parameters. The range of values reported in Table 3 reflect the low complexity of our measurement environment as was discussed earlier in Section 2.2.2.

Table 5 Comparison of Channel and Time Dispersion Parameter Values

Source	Setting	Range (m)	Freq. (GHz)	Mea. D[2]	τ_{rms} (ns)	τ_m (ns)
Lee (2010)	Outdoor Roadway	2.5-20	3.1-6.3	Time	2.7	–
		30-80			6.5	–
Kim *et al.* (2005)	Outdoor Office	7-14	3-6	Freq.	55.1	24.1
Molisch *et al.* (2006)	Farm	10-51	–	–	21.0	–
Santos *et al.* (2010)	Outdoor Petrol Station	–	3.1-10.6	Freq.	–	–
Renzo *et al.* (2006)	Forest	1-25	–	Time	5-11	1-4.5

3.2 Data Transfer Analysis

In this section we run a simple analysis of the rate at which data can be accessed by users in a typical Infostation scenario. Particularly, we analyze the possibility of a user downloading data within the short coverage range of the Infostation network. Our approach to this respect is to compute the data size of a typical application, compute the raw data rate of the UWB transceiver (in this case the MB-OFDM transceiver) and calculate the data access within a given distance and time. For the MB-OFDM, the raw data rate D_R can be expressed as:

$$D_R = \left(c\log_2 M \times \frac{N_{data}}{N_{total}} \right) \left(\frac{1}{1+\Delta f T_g} \right) \qquad (8)$$

where c is the code rate, B is the bandwidth of the system and M is the modulation level. The number of data subcarriers and the total subcarrier are denoted as N_{data} and N_{total}, respectively. The term Δf is the subcarrier spacing, and T_g is the guard interval.

The values of all the symbols in (8), except for T_g, are obtained from (Batra *et al.*, 2004; Munier and Eriksson, 2006) and listed in Table 6. The value of T_g is chosen according to the thumb rule $T_g \geq 10\tau_{rms}$. The value of D_R using the parameters in (Batra *et al.*, 2004; Munier and Eriksson, 2006) given in Table 6 is 396.99 Mbps. Table 7 shows the values of D_R for different values of T_g. The values of the τ_{rms} used to compute the T_g are the mean values measured at the three different scenarios. The maximum τ_{rms} values given in Table 3 indicate the highest values recorded.

Table 6 MB-OFDM Parameter Values Used For Analysis

c	B (MHz)	M	N_{total}	N_{data}	T_g (ns)	Δf (MHz)
1/2	528	4	128	100	9.47	4.125

Table 7 Data Rate Values Obtained for the Three Scenarios

Scenario	Max τ_{rms} (ns)	Mean τ_{rms} (ns)	Min T_g (ns)	Data Rate (Mbps)
CH1 @ 0.8 m/s	35.1	9.902	99.02	292.87
CH1 @ 1.2 m/s	32.7	9.181	91.81	299.19
CH2 @ 0.8 m/s	23.0	9.953	99.53	292.44
CH2 @ 1.2 m/s	23.8	9.905	99.05	292.85
CH3	28.5	7.577	75.77	314.27

A close look at Table 7 shows that the conventional T_g value given in Table 6 is less the maximum τ_{rms} values measured at all the scenarios. Thus, this T_g value may lead to increase in error due to inter symbol interference (ISI).

Let us consider typical settings for data access in the Park and Roadway Infostation scenarios presented in Section 2. In both scenarios, we consider a situation where users desire to download high quality movies from an Infostation located in the vicinity. Such movies can be accessed from the internet or located in a local server.

In our data transfer analysis, we consider MP4 videos with the following properties; video and audio bitrates of 1.4 Mbps and 192 kbps, respectively. The D_R values in Table 7 set the upper limit for the achievable data rate in a single-user application. If we consider a multiuser scenario, the number of users for a given data rate, R_s, and the signal-to-noise ratio (SNR) can be calculated using the expression (Somayazulu, 2002):

$$N_{u,\max} = \frac{1}{C \cdot R_s \cdot SNR} + 1 \qquad (9)$$

where C =164.5 ps.

For various number of users and SNR value of 10 dB, the percentage of download for a given data size and transit time is shown in Table 8 for different scenarios. By the transit time or the worst-case elapse time, T_L, we mean the time it takes a user to move beyond the coverage area. We assume that for the Roadway and the Park scenario, the coverage range is at the maximum distance of measurement, which are 30 m and 29 m respectively.

From Table 8, it can be observed that the download percentage decreases with increase in the number of users and data size. If we consider a single user scenario, then the data rate computed in Table 7 can be used, and 100 % data download will be achieved in all scenarios within 10 s.

Table 8 Percentage of Download for A Given Data Size and Transit Time

Scenario	Video Length (min)	Data Size (MB)	$N_{u,max}$	R_s (Mbps)	v_m (m/s)	T_L (s)	%
Roadway	60	700	20	32.0	0.8	100	100
			50	12.41	1.2	66.7	100
			50	12.41	2.0	40.0	70.9
	120	1400	10	67.55	0.8	100	100
			20	32.0	1.2	66.7	100
			20	32.0	2.0	40.0	91.4
Park	120	1400	25	25.33	-	60.0	100
	120	1400	50	12.41	-	60.0	53.2

4 Conclusion

We presented the time dispersion results of measurement campaign conducted for two separate Infostation applications scenarios. The data transfer analysis of these scenarios were provided. For simultaneous data transfer in a multiuser application, the data size, the number of user, the speed of the user and the elapse time, determines the percentage of download. As future work, we will consider a more elaborate data transfer analysis as well as a detailed analysis of channel estimator performance in the measured channel. The implementation of various Infostation communication scenarios on a software-defined platform will be considered.

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