

UWB OPPORTUNITIES FOR SMART HOME APPLICATIONS

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ABSTRACT: This paper focuses on those features of impulse radio (IR) technology that makes it attractive for smart home applications. Firstly, a highly flexible air interface definition is presented that allows for the production of low cost IR transmitters, still able to support a wide range of applications. Secondly, the robustness of IR communication against small and large scale fading is shown based on office environment radio channel measurements. To conclude, some straightforward link-budget and throughput analysis are presented, which highlight the potential of IR technology.

KEYWORDS: UWB, Impulse Radio, Smart Home Applications

1. INTRODUCTION

Almost all communication systems in use today deploy a sinusoid as an elementary waveform, on which information is mapped via some sort of modulation. The result is that signal energy is concentrated in a well defined frequency band, which makes noise and interference suppression relatively easy, e.g. by means of band-pass filtering. Unfortunately, such narrow band systems are inherently sensitive to fading. To obtain a robust wireless communication system, a relatively large fading margin has to be respected resulting in a reduced system capacity.

In the last ten years the interest in ultra wide band (UWB) technology has grown [1], [2] and [3]. Following the FCC proposal ([4]) a UWB system has a minimum fractional bandwidth of 0.2 or , alternatively, occupies more than 500 MHz. One of the most promising UWB technologies is Impulse Radio (IR) [3], where ultra-short pulses, called monocycles, are transmitted with a duration of less than a nanosecond and a duty cycle typically below 1 %. This in combination with a low transmit power results in a signal with a low power spectral density, which allows for the coexistence of IR systems and narrowband systems and enables the re-use of spectrum. In addition, it is well known that a large signal bandwidth makes systems inherently resilient against fading. In opposite to narrowband systems, the system bandwidth is a property of the IR monocycle shape itself and hence independent of the transmitted data rate. Consequently, even low data rate services profit from the fading immunity of IR technology.

The air interface of IR transmitters can be

designed to be extremely flexible allowing the support of a wide range of applications/services. Different user data rates and BERs can be realized by an appropriate combination of the pulse repetition rate and the modulation scheme. Furthermore, the generation of IR signals requires a low complexity, e.g. [5], which enables the production of small size, low cost transmitters. Applications for IR devices could be high data rate WLANs, wireless video surveillance or audio data transmissions. Additionally, IR is well suited for low rate and/or unidirectional sensor data applications. Further applications are expected to emerge that exploit the highly precise localization and tracking capabilities inherent to IR technology, e.g. location based services.

As almost any application is supported by the IR air interface, a single IR receiver is able to communicate with the different devices intended for different applications introducing a new dimension of interoperability between these systems. Hence, IR is expected to open up a wide field of opportunities for smart home applications.

In the following, an IR based air interface is presented, able to support a wide range of applications. Subsequently, an analysis on the robustness of wireless IR communication is presented, to illustrate its potential for the support of QoS, followed by a straightforward link-budget and throughput analysis.

2. FLEXIBLE SIGNAL DEFINITION

This section describes the definition of a flexible transmit signal format that allows for a low-cost transmitter. Assuming that the UWB system will

contain a traditional OSI-ISO layering, the data link layer should be able to control a set of parameters, such that the physical layer is matched to the needs of the applications in terms of e.g. bit rate, bit error rate. An IR signal (e.g. [3]) is composed of a sequence of very short pulses, which occur pseudo-randomly in time, where the pseudo-randomness is generated by a time hopping (TH) code. The signals can be modulated in several ways, including pulse amplitude modulation (PAM) and pulse position modulation (PPM). To ensure low-cost UWB devices, all pulses shall have the same shape. The pulses are produced by a pulse generator which is triggered by digital logic. The digital logic unleashes the pulses at a discrete time grid with interval duration T_c , the so-called chip rate. In practice, only one of N_h chips actually contains a pulse resulting in a duty cycle of $1/N_h$. The exact position of a pulse depends on a) the PPM shift and b) the TH code. The function of the TH code is to randomize the transmit signal for the benefit of user separation and spectral shaping and to avoid eavesdropping. By taking all previous considerations and pouring them into a mathematical form, we obtain

$$s(t) = \sum_k a_k w(t - T_c(p_k + c_k + kN_h)), \quad (1)$$

where $w(t)$, a_k , p_k and c_k are respectively the pulse shape, the amplitude of the k -th pulse, the PPM shift of the k -th pulse and the TH code shift of the k -th pulse. This definition is unlike the definition in [3], where N_s pulses have the same amplitude and PPM shift. In essence, this is a form of forward error control, specifically a rate $1/N_s$ repetition code. Therefore, it is omitted in the transmit signal format presented here.

Furthermore, the elementary PPM modulation shift in [3] is independent of the chip duration. However, an elementary pulse shift equal to the chip duration enables the logic to control the TH code and PPM over a single interface, resulting in a simplified implementation. Note that the PPM shift and TH code should be designed such that two adjacent symbols are not placed in the same chip-slot.

3. ROBUSTNESS OF UWB SIGNALS

Many applications require a communication link with a stable quality level. Typically, the wireless indoor radio channel is composed out of a large amount of multipath components and thus a high number of copies of the transmit pulse arrive at the receiver. Therefore, the received energy in narrowband systems varies extensively and rapidly in space or time due to alternately

constructive and destructive overlapping of echoes. The large signal bandwidth of IR systems results in a frequency diversity such that the variations of the received energy decrease. In this section, the robustness of IR communication and its dependency on the signal bandwidth is investigated.

3.1 The measurements

The basis for the analysis is a propagation measurement campaign performed at the IMST premises as described in [6]. The analyzed measurements were conducted at three different locations within a single room, where at each location the transmitter remained at a fixed position and the receiver position was moved over a 31×151 grid with a 1 cm spacing. The locations were selected such that one location contains only NLOS channel responses, another one contains a transition from LOS to NLOS and the third location has only LOS channel responses. At each position in the grid the attenuation and the phase of the channel response is measured from 1 to 11 GHz with a 6.25MHz frequency spacing.

3.2 Small scale fading analysis

Similar to [7], a signal is considered to be robust against small scale fading, if the signal quality varies little when the receiver position is varied over a small area. The quality of a signal received at position i,j is expressed by the mean power gain of the channel response

$$G_{i,j}(f_L, B) = \frac{1}{B} \int_{f_L}^{f_L+B} |H_{i,j}(f)|^2 df \quad (2)$$

where $H_{i,j}(f)$ is the complex transfer function of the channel including the transmit and receive antennas, and f_L and B are the lower frequency and bandwidth, respectively. The distribution function of the signal quality and its dependency on the signal bandwidth is determined. To ensure that the distribution is dominated by small scale effects only measurements within a 31×31 grid have been included in the analysis. The Nakagami m -distribution is often deployed to model statistically the intensity of small scale fading, see e.g. [8]. The comprehensive model holds that the rms amplitude of n i.i.d. Rayleigh fading channels has a Nakagami distribution with shape factor m equal to n . Using the estimation principle of [9], the m -factor has been estimated over the square root of the mean power gain. Fig.1 and Fig.2 present the cumulative distribution function (CDF) of the signal quality for the LOS and the NLOS scenario, while the legend contains the estimation for the m -value for each bandwidth.

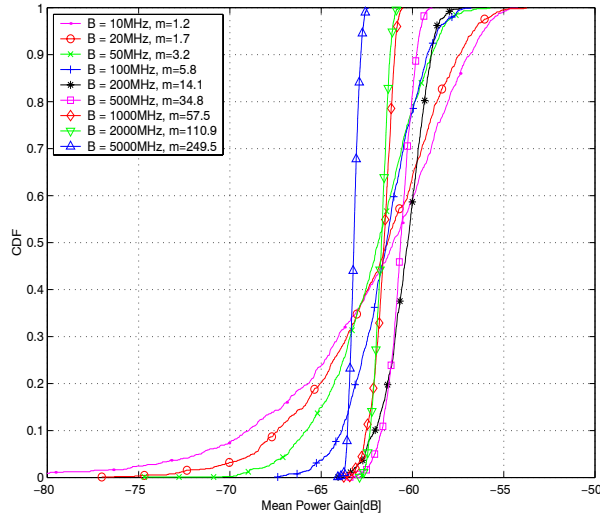


Fig.1:The CDF of the mean power gain of a LOS channel with f_L equal to 3.1 GHz.

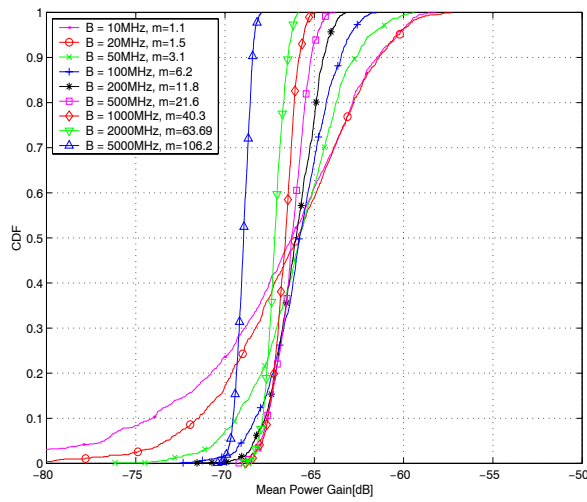


Fig.2:The CDF of the mean power gain of a NLOS channel with f_L equal to 3.1 GHz.

Both figures show that the signals with a larger bandwidth are more robust against small scale fading, since a higher robustness is indicated by a higher m -value and a steeper signal quality CDF. Even for the LOS scenario, the large signal quality variations are observed for small bandwidth signals. Analysis of the LOS channel responses revealed that the multipath gain is in the same order as the LOS gain, such that deep fades occur. Consequently, an increased signal bandwidth can significantly improve the robustness of the signal quality even for LOS scenarios.

3.3 Large scale fading analysis

The local average mean power gain depends on the environment and the position of both the transmitter and the receiver in the environment. Potentially, an extensive variation in the mean power gain could occur over a short distance due

to large scale fading, e.g. by a sudden obstruction of the LOS component. Therefore, the mean power gain has been analyzed over the measurement grid, where the LOS path was obstructed by a metal cabinet for all position higher as 90 centimeter. To ensure that the signal quality variations are dominated by large scale fading effect, the B and F_L where fixed to 5 GHz and 3.1 GHz respectively. The signal quality as function of the grid position is shown in Fig 3 from a side perspective.

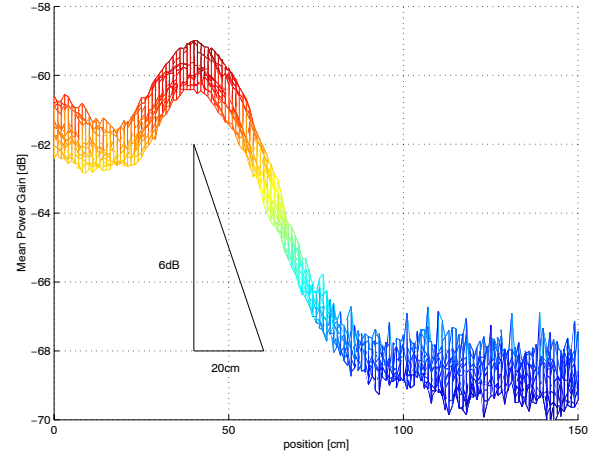


Fig.3:The mean power gain as function of the position in the measurement grid.

At the LOS section of the grid the signal quality has a sinusoidal behavior with a increasing amplitude toward the LOS-NLOS border which smoothly goes into an exponential decay for the NLOS section. The signal quality decay on the edge of both sections is approximately 6dB/20 cm with a total energy loss of approximately 8-10dB. The 6dB/20cm signal quality decay in the IR system is small compared to the typical small scale fading value of around 30dB within a few centimeters observed for narrowband systems, see e.g. [10]. Under the assumption of walking speed in an indoor environment, the large scale fading in IR systems can be compensated, e.g. by power control. Therefore, IR systems are expected to outperform conventional systems in terms of robustness and power efficiency.

4. THE POTENTIAL OF IMPULSE RADIO

To illustrate the potential of UWB technology, the measurement results have been used for a straightforward link-budget computation. In accordance with FCC regulation, the transmit power P_t is chosen such that spectral limitation of -71,25 dBW/MHz is respected. The channel loss is defined as

$$G_c(f_L, B) = E_{i,j} [G_{i,j}(f_L, B)], \quad (3)$$

where $E[\cdot]$ denotes an expectation and the fading margin is defined as

$$M_f(f_L, B) = T - G_c(f_L, B) \quad [dBW] \quad (4)$$

where T is defined such that

$$E[G_{i,j}(f_L, B) < T] = 10^{-2}. \quad (5)$$

The received signal power $P_r(f_L, B)$ is equal to

$$P_t(f_L, B) + G_c(f_L, B) + M_f(f_L, B) \quad [dBW] \quad (6)$$

Under the assumption that the communication is only disturbed by thermal noise, the maximum achievable bit-rate

$$R_b(f_L, B) = \frac{P_r(f_L, B)}{N_0} \left(\frac{E_b}{N_0} \right)^{-1} \quad [bits/s], \quad (7)$$

where E_b is the energy per bit and $N_0 = kT$ with k equal to the constant of Boltzmann and T is the noise temperature in Kelvin. Based on the channel measurements, the values of P_t , G_c , M_f , P_r and R_b have been determined for the case that $E_b/N_0 = 10$ [dB] and $T = 300$ [K]. Table 1 and Table 2 contain the results for respectively the LOS measurements and NLOS measurements.

Table 1: Link budget results for the LOS case

B [MHz]	P_t [dBW]	G_c [dB]	M_f [dB]	P_r [dBW]	R_b [Mb/s]
10	-61,30	-62,20	-17,70	-141,00	0,18
20	-58,20	-61,90	-11,10	-131,00	1,82
50	-54,30	-62,20	-7,12	-124,00	10,66
100	-51,30	-61,50	-4,72	-117,00	43,18
200	-48,20	-60,40	-3,04	-112,00	164,26
500	-44,30	-60,70	-2,09	-107,00	476,53
1.000	-41,30	-61,60	-1,56	-104,00	864,98
2.000	-38,20	-61,70	-0,97	-101,00	1.940,85
5.000	-34,30	-63,20	-0,56	-98,00	3.805,14

Table 2: Link budget results for the NLOS case

B [MHz]	P_t [dBW]	G_c [dB]	M_f [dB]	P_r [dBW]	R_b [Mb/s]
10	-61,30	-67,20	-18,60	-147,00	0,05
20	-58,20	-66,30	-11,50	-136,00	0,60
50	-54,30	-65,90	-7,23	-127,00	4,38
100	-51,30	-65,90	-4,74	-122,00	15,76
200	-48,20	-66,10	-3,19	-118,00	42,81
500	-44,30	-66,30	-2,33	-113,00	123,78
1.000	-41,30	-66,70	-1,80	-110,00	256,64
2.000	-38,20	-67,20	-1,28	-107,00	512,70
5.000	-34,30	-69,00	-1,03	-104,00	902,14

Both tables reveal an increase of the maximum bit rate if the bandwidth is increased. This is caused by a) an increased bandwidth allows for an increased transmit power and b) an increased bandwidth allows for a smaller fading margin. At the lower bandwidths, the throughput improvement is dominated by the decrease in fading margin and at the larger bandwidths, it is dominated by the increase in transmit power. Furthermore, the mean channel gain declines with

an increasing signal bandwidth, due to the constant aperture measurement antennas. Clearly, the achievable throughputs are optimistic and only achievable for the scenarios limited only by thermal noise. Therefore, the results should not be taken as an absolute reference, but as an indication for the potential of IR systems operating in an office environment within FCC regulation.

5. FUTURE WORK

The commercial success of IR systems depends, at least partly, on the IR receiver architectures. On one hand, these receivers should be able to exploit the inherent capabilities of IR and on the other hand they should be simple and low cost. Therefore, receiver architectures are a key activity within our research program. Preliminary conclusions reveal that a receiver architecture based on the delay hopped transmit reference (DHTR) principle ([11]) seems to fit these requirements.

6. ACKNOWLEDGEMENTS

The authors wish to thank J. Pamp and J. Kunisch for the access to the pool of measurement data. This work was supported by the EU under project number: IST 2000-25197-whyless.com

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