A Modified Recursive Method to Compute the Multipath Impulse Response of the Indoor Wireless Infrared Channel

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Abstract. **The desire for an inexpensive and high-speed links has encouraged current research towards infrared frequency as a medium for indoor wireless communication. This paper presents a modified recursive algorithm to characterize the infrared propagation channel on multipath impulse response for indoor wireless communication. The mathematical model for the source, the receiver and the propagation channel were described. The results obtained were discussed and compared with other researchers.**

I. INTRODUCTION

In the recent years, there are number of potential candidates for indoor wireless local area network, namely radio frequency, microwave, millimetre wave and infrared frequency. Compared to its counterpart, the infrared radiation offers numerous advantages as a medium for short range, indoor communication. Firstly, infrared spectral region offers an unlimited bandwidth, which is unregulated worldwide. Since the infrared medium doesn't penetrate through any opaque barriers, it provides a secured transmission and minimizes the risk of the third party eavesdropping, whereas its wireless counterparts are highly exposed to this problem. Thirdly, the infrared frequency would be the most viable wireless system to be implemented in an environment with severe electromagnetic interference, such as factories or nuclear power plants.

Typically, there are two kinds of infrared links categorized according to the degree of directionality of the transmitter and receiver. High bit rates and efficient power consumption could be achieved through directed line of sight (LOS) link. However, it requires an uninterrupted LOS transmission, stationary transceiver and it suffers from shadowing. On the other hand, the non-LOS channel or diffuse links, which relies on the diffusely reflected light from ceiling and wall, is tolerant to shadowing, needs a poor orientation of transmitter and receiver and allows user mobility. Thus, a diffuse link is not without drawbacks. A diffuse link i severely impaired by multipath induced tempora dispersion, which causes pulse broadening an intersymbol interference (ISI). As a result, it limit the data rate of the infrared transmission system. T overcome this limitation, a high transmit power i required, which can be hazardous to eye safety if i exceeds the limit.

Commonly, an infrared transmission syster employs intensity modulation and direct detection, a it is the most feasible choice in today's technologic trend. In an intensity modulation, the optical sourc converts the electrical signal to optical intensity an transmits into the channel. At the receiver, th transmitted signal, which propagated along variou path with some additive noise component, will b collected by a photodetector.

As the rate of change of the channel slower than the bit rate, the channel is assumed to b a linear time invariant (LTI) system for a determine transmitter and receiver location. Therefore, a infrared channel can be completely characterized b its impulse response, h(t), which is a function physical parameters and transceiver location.

In this paper, we present a new simulatio package to compute the impulse response, h(t), of th indoor infrared channels. The most important conce of the developed simulation package is based on th prior research reported in [1]. The simulation mod was implemented using an interpreted languag Matlab on the PC based. The usage of an interprete language allows the user to enter and change th parameters conveniently through an user friendl graphical user interface (GUI) designed in th package. Comparison with the standard algorithm made in order to distinguish the features of th modified recursive method.

In the following section, we describe th mathematical model for the source, the receiver an the propagation of the infrared ray in the channel well as the algorithm of the computation. A extensive simulation result obtained from th computation is presented in Section 3 and final followed by conclusion.

II. PROPAGATION MODEL OF AN INFRARED CHANNEL

In an infrared propagation model (as illustrated in Figure 1[1], the three main components are: the infrared emitting diode (LED or Laser Diode) as the source, the photodetector (PIN diode or APD) as the receiver and the reflector which can be represented by painted wall, mirrored wall, tiled wall, carpeted floor or linoleum floor, to name a few. Each of these reflectors may contain both specular and diffusive components or either one of it. In order to simplify the assumption, the reflector is modeled as purely diffusive, ideal Lambertian, based on some supporting experimental results [2]. This means that the reflected signal is independent from the incident signal.

The emitter source is modeled using generalized Lambertian radiation pattern. The angular distribution of the emitter radiation intensity is given by:

$$R(\phi) = \frac{n+1}{2\pi} P_s \cos^n(\phi) \tag{1}$$

where ϕ is the angle normal to the emitter surface, P_s is the total emitted power and n is the mode number of the radiation pattern. The receiver is characterized by its field of view (FOV).

The rooms are assumed to be unfurnished, empty and neither border effect nor the diffraction had been considered. The configuration of the rooms are as in Table 1.

The impulse response for line-of-sight without considering any reflection is described by:

$$h(t) = \frac{n+1}{2} \cos^n(\phi) \cos(\theta) \frac{A_R}{R^2} \delta\left(t - \frac{R}{c}\right) \tag{2}$$

for received irradiance within FOV. Here, A_R is the receiver's surface area, R is the distance between the transmitter and the receiver and c is the speed of light. The received signal can be completely characterized as a scaled and delayed Dirac delta function. However, the impulse response for any number of reflection, can be summed up to infinite as below:

$$h(t) = \sum_{k=0}^{\alpha} h^k(t) \tag{3}$$

where k is the number of reflection.

For bounces more than one reflection, the impulse response can be approximated by using a recursive method proposed by Barry *et al.* [1] is given by:

$$h^k(t) = \frac{n+1}{2\pi} \sum_{i=1}^{N} \frac{\rho_i \cos^n(\phi) \cos(\theta)}{R^2} (dA)\left(h^{(k-1)}(t)\right) \tag{4}$$

where N is the total number of reflecting cell (reflectors subdivided into small elements with each area of dA), and ρ_i is the reflectivity coefficient of the reflecting cell.

The computation would be performed numerous times for reflections $k > 1$, on the total number of reflecting cells which is given by:

$$N = 2\left(N_x.N_y + N_x.N_z + N_y.N_z\right) \tag{5}$$

where N_x, N_y and N_z is the number of reflecting cells in their respective planes as indicated by the subscript.

In our analysis, significant advantage can be obtained if we limit the total number of reflecting cell in the computation, without reducing its spatial resolution (in other words, the size of the cell). For instant, consider some of the common transmitter arrangements, currently used in the infrared wireless local area network as illustrated in Fig. 2.

Before that, we equate north with $\hat{x}$, west with $\hat{y}$, and ceiling with $\hat{z}$. Transmitter A is placed on y=0 plane (wall) with $\hat{y}$ orientation, transmitter B at z=h plane (ceiling), where h is the height of the room, with $-\hat{z}$ orientation and transmitter C and D with $\hat{z}$ orientation. The main difference between transmitter C and D is; the location of the transmitter D at the height of l from the floor, usually on the table, on top of the PC and etc., in practical aspect. These arrangements are widely used by commercially available infrared products manufactured by Spectrix Corp.[3] and IRLAN [4], to name a few.

As we had highlighted earlier, the transmitter is modelled as lambertian source and its illumination will be in the range of $-\frac{\pi}{2}$ to $\frac{\pi}{2}$; in other words:

$$\phi \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right] \tag{6}$$

This means the infrared ray produced by the transmitters, as in Fig. 2, will not illuminate on the surface where it was originated for the first reflection from the source to the receiver. As an example, consider transmitter A; the first reflection (k=1) can happen on room surfaces in the north, west, south, ceiling and floor. For the second reflection (k=2), assume the ray had travelled from source (transmitter A) to a reflecting cell in any one of the walls, let say north. Now, the reflecting cell will behave as a source and again, the first reflection from the new source (reflecting cell in the north) occurs only on room surfaces in the east, west, south, top and bottom. Since a particular surface in a room is eliminated from the computation each time, equation (5) have been modified and a sophisticated algorithm of computation have been designed. The algorithm consist of four main functions*; (i) to compute the LOS response, (ii) to compute the k=1 response, (iii) to compute the k=2 response, and (iv) to sum all the impulse responses mentioned above. Function (i) is given by (2), while a general function for higher order terms (k>0) can be calculated using (4), which can be briefly described by the flow chart in Fig. 3.

The algorithm was used to simulate the multipath impulse response for room configurations listed in Table 1. The number of cells in each plane, according to the number of reflections, can be obtained through the information provided at the bottom of the table. Considering a room topology as in configuration A, the source is residing on the ceiling. By neglecting the calculation on the ceiling, the impulse response for k=1 needs only 8500 loops to be calculated using (4). For k=2, the size of the cell had been increased in order to achieve a shorter duration of computation. Due to recursion, the proposed algorithm needs 633825 loops to be generated. Here, we can be easily conclude that the amount of loops will increase exponentially if higher order terms are computed.

III. SIMULATION RESULT

Three different scenarios have been considered to outline the reception of infrared power at the receiver for a particular transceiver arrangement. In this simulation, the source is assumed to emit a 1 Watt power. The designed simulation package reads various specifications from the user, such as the length of the room, coordinates and characteristics of the transceiver, and the number of division on each axis, as the input parameters of the model.

The first configuration, configuration A, is a type of LOS system as well as configuration B. But here (in configuration B) the room is somewhat larger and its walls are with lower reflectivity, which is very close to a real room. The similarities in both configurations are the orientation of the transmitter, pointing straight down, and the receiver, pointing straight up, with a mode of n=1 (ideal Lambertian). In configuration C, the case is totally different where the transmitter is pointing straight up as well as the receiver, which represents a diffuse system. Here, the transmitter is still assumed to be ideal Lambertian. Power histogram over time have been plotted for k=1 response, k=2 response and the total sum of impulse response are clearly depicted in figures 4, 5 and 6 with respect to configuration A,B and C. The time origin for configuration A and B have been adjusted according to the arrival of line-of-sight impulse.

* Due to the limitation imposed by the duration of the computation, only reflections up to 2, had been taken into account.

IV. CONCLUSION

The use of the modified recursive algorithm can reduce the duration of impulse response up to a satisfying level. Moreover, the usage of a low-end system for computation produced a good match between the proposed algorithm and the standard algorithm. Although the simulation was only conducted on two types of infrared channels, it had never failed from providing accurate analysis on other types of infrared links defined by the user, which are commonly used in indoor wireless infrared communication system. However, some statistical approaches are capable of increasing the speed of the impulse response computation. Detailed studies on the statistical algorithms should be done in the future.

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[1] J.R. Barry, J.M. Kahn, W.J. Krause, E.A. Lee, D.G. Messerschmitt "Simulation of multipath impulse response for indoor wireless optical channels" *IEEE J. on selected areas on communications*. Vol. 11, No. 3, pp. 367-379, Apr. 1993.

[2] F.R. Gfeller and U.H Bapst, "Wireless In-House Data Communication via Diffuse Infrared Radiation, " *Proceedings of the IEEE*, Vol. 67, No. 11, pp. 1474-1486 (November 1979).

[3] Web page: www.spectrixcorp.com

[4] Web page: www.irlan.com

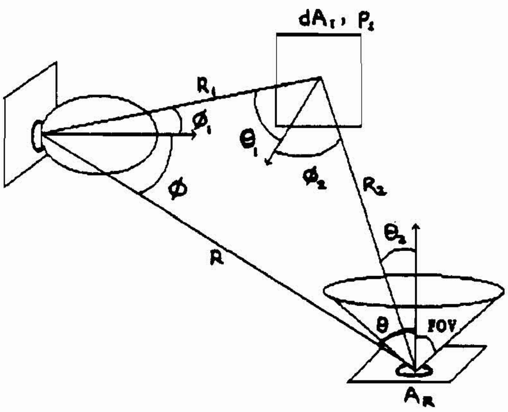

Figure 1: The propagation model of an infrared channel

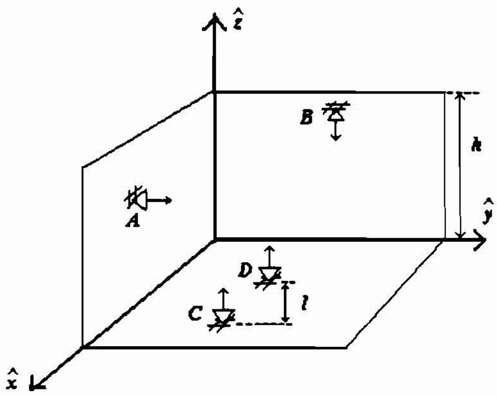

Figure 2: Common Transmitter arrangements

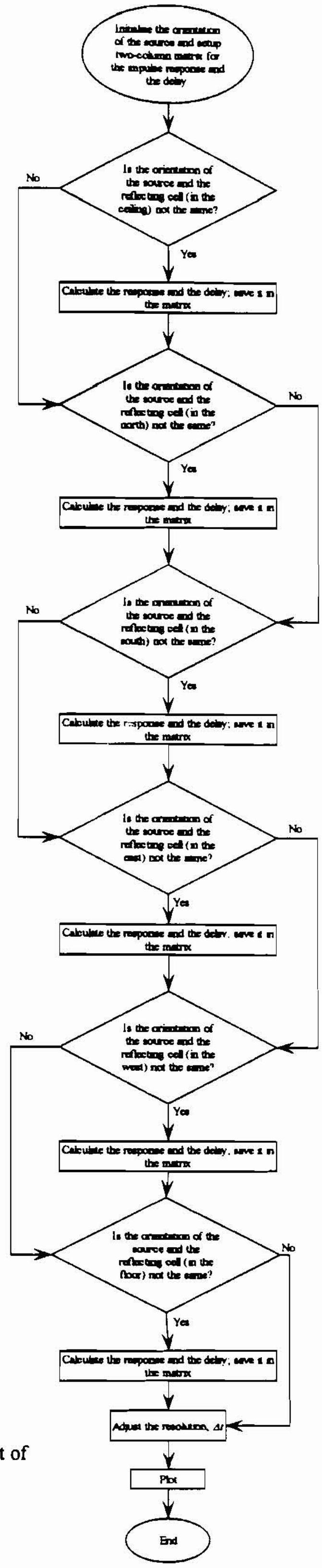

Figure 3: Flow chart of the algorithm

Table 1: Parameters for the simulation

Parameter \ Configuration		A		B		C	
ROOM	length(x)	5 m		7.5 m		7.5 m	
	width(y)	5 m		5.5 m		5.5 m	
	height(z)	3 m		3.5 m		3.5 m	
	ρ_{NORTH}	0.8		0.3		0.58	
	ρ_{SOUTH}	0.8		0.56		0.56	
	ρ_{EAST}	0.8		0.3		0.3	
	ρ_{WEST}	0.8		0.12		0.12	
	$\rho_{CEILING}$	0.8		0.69		0.69	
	ρ_{FLOOR}	0.3		0.09		0.09	
EMITTER	mode	1		1		1	
	x	2.5		2.0		3.75	
	y	2.5		4.0		2.75	
	z	3		3.3		1.0	
	elevation	-90°		-90°		+90°	
	azimuth	0°		0°		0°	
RECEIVER	area	1 cm^2		1 cm^2		1 cm^2	
	FOV	85°		70°		70°	
	x	0.5 m		6.6 m		6.0 m	
	y	1.0 m		2.8 m		0.8 m	
	z	0 m		0.8 m		0.8 m	
	elevation	90°		90°		90°	
	azimuth	0°		0°		0°	
RESOLUTION	Δt	0.2ns		0.2ns		0.2ns	
	no. of reflection	1	2	1	2	1	2
	N_x	50	15	150	18.75	150	18.75
	N_y	50	15	110	13.75	110	13.75
	N_z	30	9	70	8.75	70	8.75

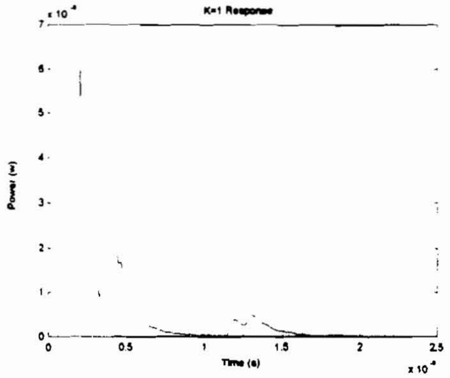

Figure 4 (a) : Configuration A: K=1 Response

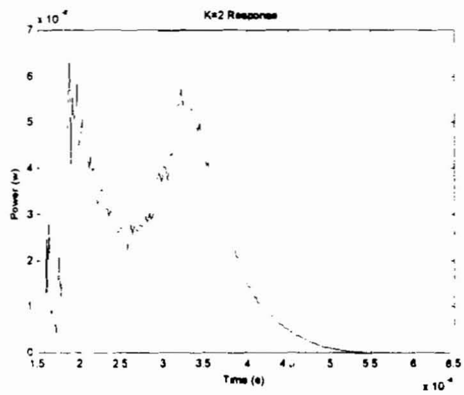

Figure 4 (b) : Configuration A: K=2 Response

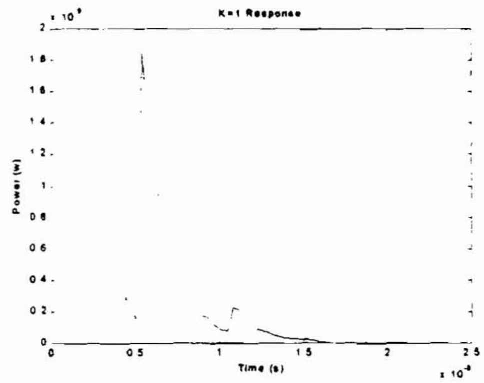

Figure 5 (a) : Configuration B: K=1 Response

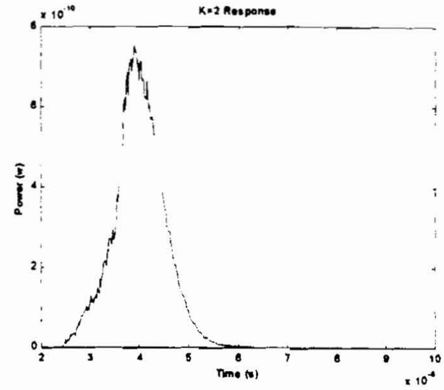

Figure 5 (b) : Configuration B: K=2 Response

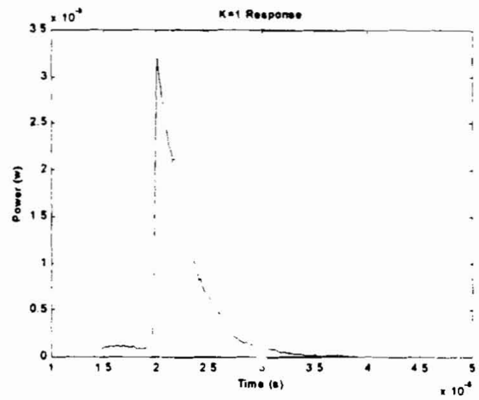

Figure 6 (a) : Configuration C: K=1 Response

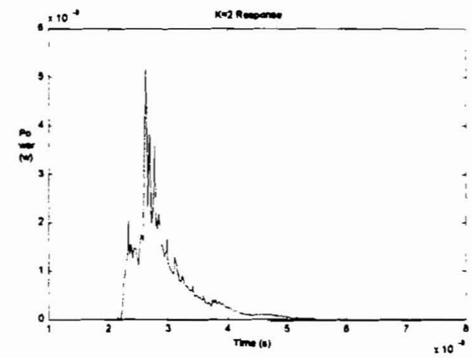

Figure 6 (b) : Configuration C: K=2 Response

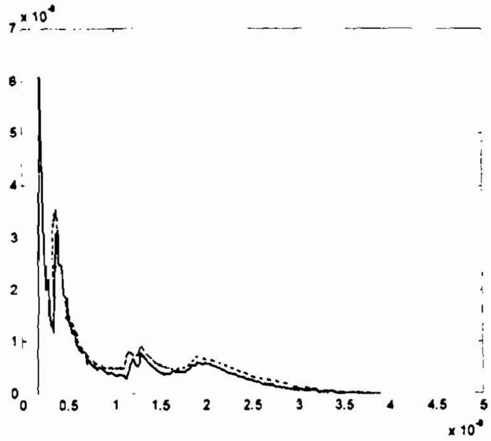

Figure 4(c): Configuration A

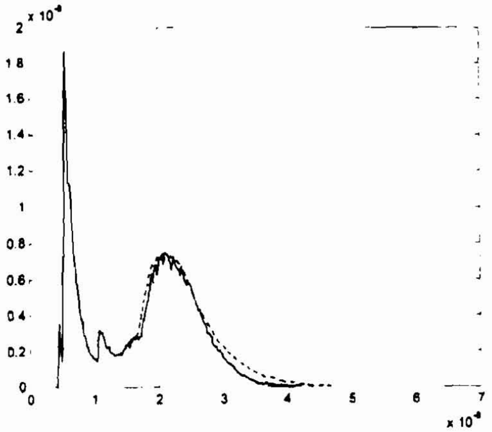

Figure 5(c): Configuration B

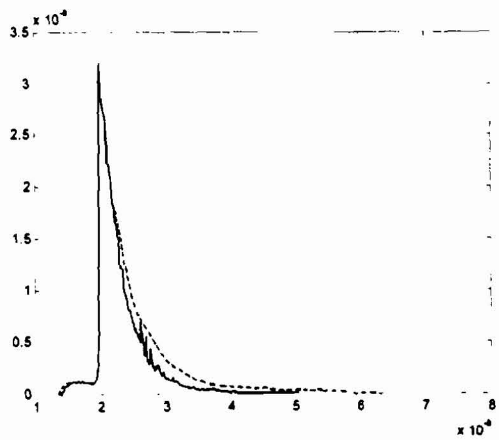

Figure 6(c): Configuration C

Figure 4(c) ,5(c) and 6 (c): Comparison of total impulse response obtained using the standard algorithm and the modified recursive algorithm.

Standard Algorithm
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Modified Recursive Algorithm
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