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MIMO UWB-IR Noncoherent Transceiver with Poisson Wireless Models

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***Abstract* — Multi-antenna-based multi-input multi-output (MIMO) communications becomes the next revolution in wireless data communications. MIMO has gone through the adoption curve for commercial wireless systems to the point that today, all high throughput commercial standards, i.e. WiMax, Wi-Fi, cellular, etc., have adopted MIMO as part of the optional. This paper is to present our investigations of the behaviors of the MIMO Ultra-Wide-Band-Impulse Radio (UWB-IR) systems, which will contribute to optimal designs for the low-power high-speed data communication over unlicensed bandwidth spanning several GHz, such as IEEE 802.15 families. Our investigations are based on that without requiring any channel estimation procedure we develop and analyze three no coherent transceiver channels based on Poisson model. The simulations for our investigations show that the Poisson distribution of the path arriving will affect the signal-noise ratio (SNR) and that for the Nakagami distributed multipath fading channel the "*m*" factor, together with receiver number will impact on the SNR on the MIMO UWB-IR systems.**

***Keywords* — MIMO, IEEE 802.15, UWB-IR, Nakagami distribution, Poisson distribution, wireless communications**

I. Introduction

Multi-antenna-based multi-input multi-output (MIMO) communications first occurred in the mid-1990s when researchers at Bell Labs and Stanford were looking for ways to increase system throughput without increasing bandwidth. After that thousands of research papers have been written on the topic dealing with both physical layer and network layer ramifications of the technology. In fact all high throughput commercial standards, such as WiMax, Wi-Fi, cellular, etc., have adopted MIMO as part of the optional. The adoption of MIMO into military wireless communications systems has to some extent lagged its adoption in the commercial arena.

Ultra Wide Band Impulse Radio (UWB-IR) is an emerging wireless technology, proposed for low power high speed data communication over unlicensed bandwidth. This technology has been drawing great attentions from the researchers [1-9]. The currently the transceiver architectures have been showing the tendency of extending this technology to next generation WLAN compliant operating scenarios. Therefore, exploiting both spatial and temporal diversity and combing the MIMO technology with the UWB-IR become inevitable, which is our current paper contributes to.

The design of a MIMO communication system depends on the degree of knowledge of the channel state information (CSI), which is normally very expensive. As normal way did it is based on the UWB-IR statistical channel models we take the noncoherent transceiver [7, 16-18] and focus on wireless three models, namely Gaussian, Nakagami and log-normal distribution channels. In particular we extended previous research results [13-15] to investigate how the Nakagami m factor affects the signal to noise ratio (S/N) in the statistical channel model.

Our simulations presented the following suggestions: (a) if we take so called single-cluster Poisson model [7], namely the random integer valued number, then the mean of this random integer valued number will impact on the MIMO S/N regardless which of three models (Gaussian, Nakagami and log-normal distribution channels) and (b) for the Nakagami distribution channel, as we expected that the "*m*" factor will impact on the MIMO S/N.

II. MIMO UWB-IR Statistical Channel Models

The baseband point to point (P2P), shown in Figure 1, is composed by N_t transmit and Nr receive antennas working on an UWB-IR MIMO channel.

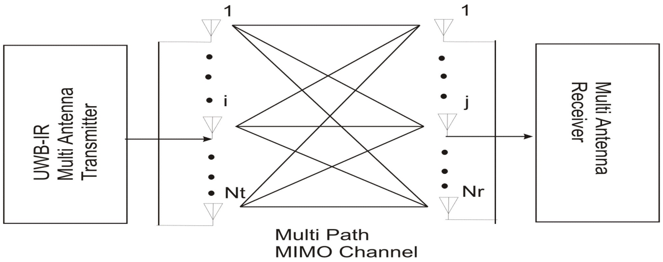

Figure 1: The MIMO point to point UWB-IR system with N_t transmit and N_r receive antennas. The MIMO UWB-IR channel is affected by multipath fading that is described by $N_t \times N_r$ baseband impulse channel responses.

At the signaling period T_s second the source of Figure 1 generates an L-ary ($L \geq 2$) information symbol b, i.e. $b \in \{0, 1, \ldots, L-1\}$. The multi-antenna transmitter maps b onto N_t M-ary baseband signals of time duration limited by T_s. It is noted that the USB baseband pulse is limited to pulse time, T_p, and repeated N_f times over each signaling period, T_s, here N_f is the number of frames and the time for frames of duration denoted by T_f. In order to avoid inter-frame interference (IFI), we must have $T_f > T_\mu$, where T_μ is the UWB channel delay spread time. From [2], we have single input single output (SISO) UWB-IR channel by IEEE 802.14. if we take the impulse channel responses in Figure 1 as $h_{ji}(t)$, $0 \leq j \leq N_t$, $0 \leq j \leq N_r$), we may collect these impulse responses into the corresponding ($N_t \times N_r$) matrix $\mathbf{H}(t)$. Therefore, as IEEE 802.15 recommend that each SISO impulse response $h_{ji}(t)$ in Figure 1 is modeled as the superposition of several path clusters, with both inter-cluster and intra-cluster inter-arrival times being exponentially distributed. From [1, 7], we have

$$h_{ji} = \sum_{n=0}^{V} h_n(j,i)\delta(t-\tau_n) \tag{1}$$

$$= \sum_{n=0}^{V} \beta_n(j,i)\alpha_n(j,i)\delta)t-\tau_n)$$

$$\text{here} \quad , 1 \le i \le N_t, 1 \le j \le N_r$$

It is noted the integer valued number V of received paths over a signaling period T_s is a Poisson distributed random variable with mean value $E\{V\} = \lambda T_s$, where λ is rate in ns^{-1}, τ_n is the non-negative arrival time of the nth path, in ns. We use $h_n(j,i)$ for the nth path gain of SISO link going from the ith transmit antenna to the jth receive one. The random variable (r.v.) $\beta_n(j,i) \in \{-1,1\}$ and the non-negative r.v. $\alpha_n(j,i)$ are the corresponding phase and amplitude, respectively. As the previous references [1, 7, 13. 14, 15 19] show that the statistic of the fading affecting rich-scattered medium-range quasi-LOS UWB-IR links may be well modeled by resorting to the Nakagami distribution, long-normal distributed channel amplitudes, $\alpha_n(j,i)$ may be suitable for less scattered LOS short-range indoor propagation environments and the log-normal distribution is recommended by IEEE 802.15 workgroups for WPAN and sensor applications [1-2]. The central limit theorem [2, 20] underpin the fact that zero-mean Gaussian distributed channel coefficients well model highly scattered outdoor NLOS propagation environments.

For the space-time orthogonal PPM (OPPM) modulated the size M of the employed OPPM format equates LN_t and N_t columns of the l-th matrix codeword $\mathbf{\Phi}_l$ are constituted by the N_t unit-vectors of $\mathbb{R}^M$ with index i ranging from $i = lN_t$ to $((l+1)N_t)-1$, i.e.

$$\Phi_l = [e(lN_t)...e((l+1)N_t-1)], \quad 0 \le l \le L-1 \tag{2}$$

Because of orthogonal and unitary we have:

$$\Phi_l^T \Phi_m = 0, \quad \text{for } l \ne m$$

$$\Phi_l^T \Phi_l = I_{Nt}, \quad \text{for any } l \tag{3}$$

We also have the relation between Bit-Error-Probability $P_E^{(b)}$ and the corresponding Word Error Probability P_E [7] as shown below:

$$P_E^{(b)} = (\frac{L}{2(L-1)})P_E \tag{3}$$

As the general equation from [7] we have the decision statistics set $\{z_l\}$ can be expressed by

$$\Phi_{ML} = \arg\max_{0 \le l \le L-1}\{z_l\} \tag{4}$$

Now we can take z_l as different statistics for the three cases we mentioned, namely Nakagami distribution, log-normal distribution and Gaussian distribution, which will be presented in the next section.

III. Models of MIMO UWB-IR of Different Statistic Channels

We first investigate how the r.v. parameter, V to affect the S/N in the three different statistic channels.

For the Nakagami distribution multipath dading channel, we have [7]

$$z_l = \sum_{n=0}^{V}\sum_{j=1}^{N_r}\sum_{i-1}^{N_t} \ln\{\cosh[\phi(y_j(n)^T e_i(l))]\} \tag{4}$$

$$\text{where, } l = 0....,L-1$$

and ϕ_n is defended as

$$\varphi_n = \beta e^{c\mu_n}, \quad n = 0,...,V \text{ and } c = \frac{1}{20}\ln(10),$$

$$\mu_n = E\{\alpha_n(j,i)\}.$$

Also from the Appendix of [7] we have the word error probability (WEP):

$$P_E \le (L-1)(\frac{4e^2\Gamma(2m)}{\Gamma(m)})^{N_tN_r(V+1)} \cdot \prod_{n=0}^{V}[\frac{(1+\frac{\sigma_n^2\beta^2}{m})}{(1+2\frac{\sigma_n^2\beta^2}{m})}]^{mN_tN_r} \tag{5}$$

Here G(.) is the Gamma function [11, 13-15], it is noted that if r.v. V is large enough equation (5) can be simplified further format.

If we consider the case of log-normal distributed multipath fading, i.e. the fading amplitudes $\{\alpha_n(j,i)\}$ is log-normal distribution with $m \ge 0.5$, we have[16]:

$$P_E \le (L-1)(\frac{2}{\sqrt{\pi}})^{(V+1)N_tN_r} \prod_{n=0}^{V} \times$$

$$[\int_{-\infty}^{+\infty} \exp\{-t^2 - \beta\phi_n e^{c\mu_n} \exp\{c\sqrt{2}\sigma_r t\}\}dt]^{N_tN_r} \tag{6}$$

Now let's have a closer look at the Gaussian distribution again from [16], we have

$$P_E \le (L-1)\prod_{n=0}^{V}[\frac{(1+\sigma_n^2\beta^2)}{(1+\frac{1}{2}\sigma_n^2\beta^2)^2}]^{N_tN_r/2} \tag{7}$$

It is noted that the situation similar to equation (5) and when r.v. V is larger than unit we can simplify equation (7).

The following section we shall

IV. Simulations of MIMO UWB-IR of Different Statistic Channels

We are going to investigate two situations that lead the optimal designs for MIMO UWB-IR communications, namely (a) as we don't want to have expensive channel state information (CSI), we take the "single cluster Poisson Model for capturing the behavior of each $h_{ji}(t)$ we need to know how the r.v. V impact on the S/N of the MIMO UWB-IR transceiver channels? (b) As Nakagami distribution is of important wireless communication distributions and the major parameter, m, will impact on the Nakagami distributions therefore how the m fact affect the S/N of the MIMO UWB-IR transceiver channels?

For the first investigation without loss generality we take simple case, L = 2, and the corresponding SISO impulse responses $\{h_{j,i}(t)\}$in equation (1) have been generated according to the CM 6 UWB-IR channel model, i.e. IEEE 802.15.4 with λ = 1.13 (1/ns), T_{μ} = 15.9 (ns), γ = 9.3 (ns), N_f = 8, and the spectral efficiency of 1/200 (bit/sec/Hz). The simulations first take N_r = 1 and let N_t = 1, 2, 3 ,4, namely investigating the MISO situations.

Under the above conditions, Figures 2, and 3 show the V = 5, 15 with Nakagami distribution multipath channels. It is clearly to show that under the same statistic distribution the random variable V has impact on the S/N under the same BER. For example, for the targeted BER, 10^{-5}, when the N_t = 2 there are 1.6 dB draped and in general case it is obviously that with V increasing the S/N will significantly dropped.

Figures 4 and 5 show the similar situation results as that in Figures 2 and 3 did except for the distribution changed from Nakagami distribution to log-normal distribution. The similar conclusions can be obtained by the observations from Figures 4 and 5. It is noted that under the similar conditions log-normal distribution will cause more S/N drops if we compare the results in Figure 2 with Figure 4.

Figures 6 and 7 show another similar comparisons but the distribution becomes zero mean Gaussian distribution, which models highly-scattered outdoor NLOS propagation environments. It is indeed, as we observed, the more drops under the same conditions.

As the r.v. V represented the value of received paths over a signaling period with the mean E{V} = λT_s, therefore when we fix rate (l), Ts will be larger when E{V} larger, which the channel will have larger possibility to get more noisy. The simulations underpinned this situation as our first conclusion in this paper.

Also we have the second conclusion that the statistic models did affect the SNR in the multipath channels and the worst situation is Gaussian distribution, which models high-scattered outdoor NLOS propagation environments.

In order to investigate how does the m factor affect the Nakagami distribution as we our second target mentioned, we presented m= 0.6 and 0.9 for the random variable V = 5 and 15 in figures 8, 9, 10, and 11.

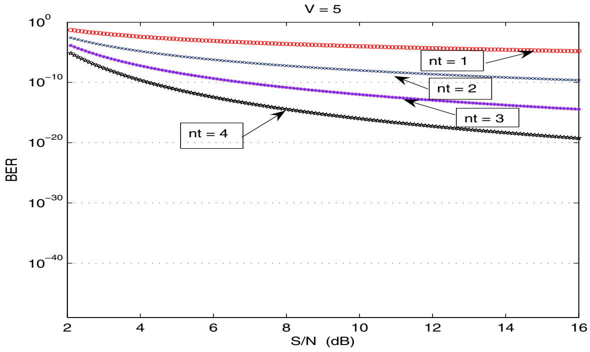

Figure 2: Nakagami distribution multipath channel with N_r =1 and N_t = 1, 2, 3, and 4 the S/N is in “dB”.

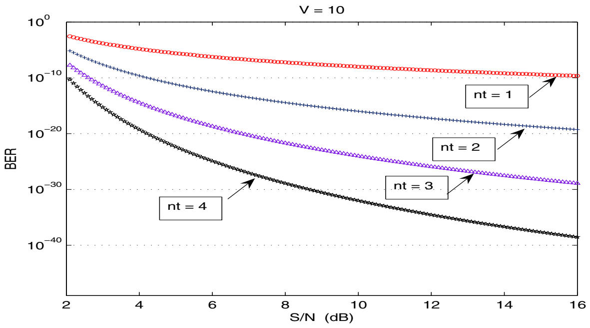

Figure 3: Nakagami distribution multipath channel with N_r =1 and N_t = 1, 2, 3, and 4 the S/N is in “dB”.

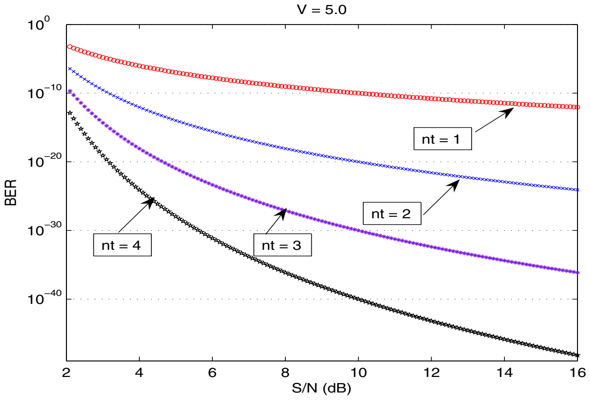

Figure 4: Log-normal distribution multipath channel with N_r =1 and N_t = 1, 2, 3, and 4 the S/N is in “dB”.

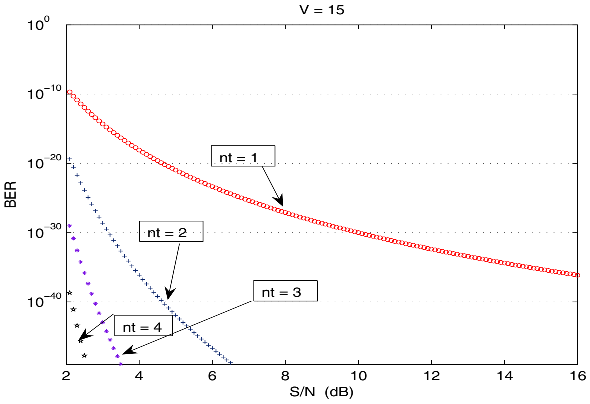

Figure 5: Log-normal distribution multipath channel with N_r =1 and N_t = 1, 2, 3, and 4 the S/N is in “dB”.

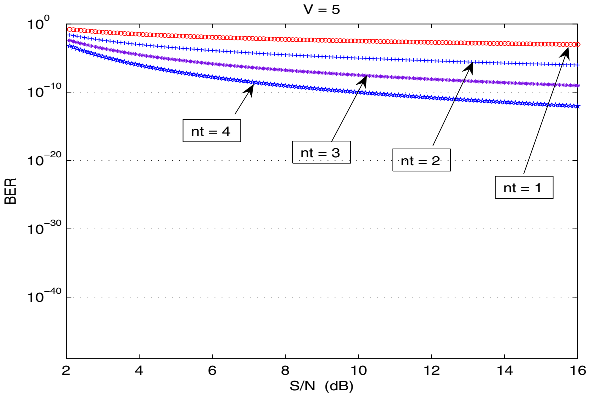

Figure 6: Gaussian distribution multipath channel with N_r =1 and N_t = 1, 2, 3, and 4 the S/N is in “dB”.

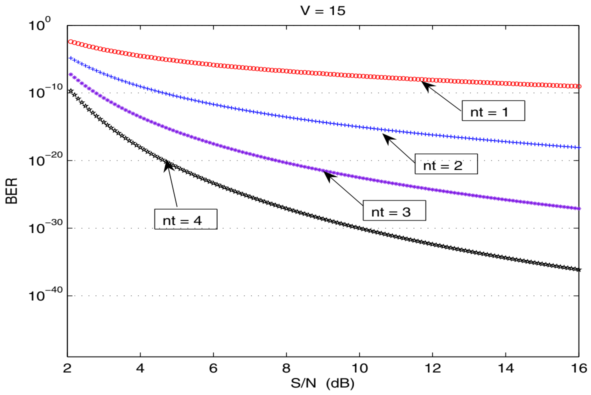

Figure 7: Gaussian distribution multipath channel with N_r=1 and N_t= 1, 2, 3, and 4 the S/N is in “dB”.

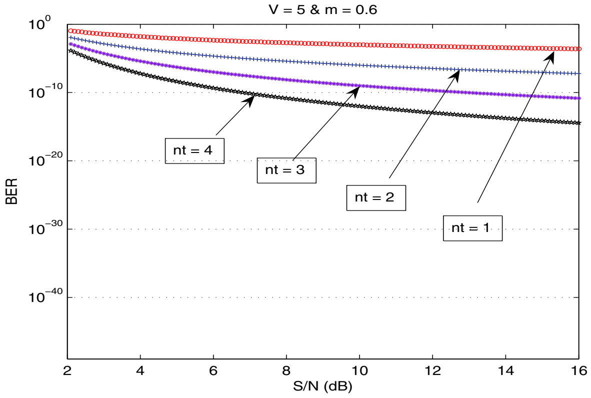

Figure 8: Nakagami distribution with m =0.6 V = 5 the rest parameters are the same as that in previous figures.

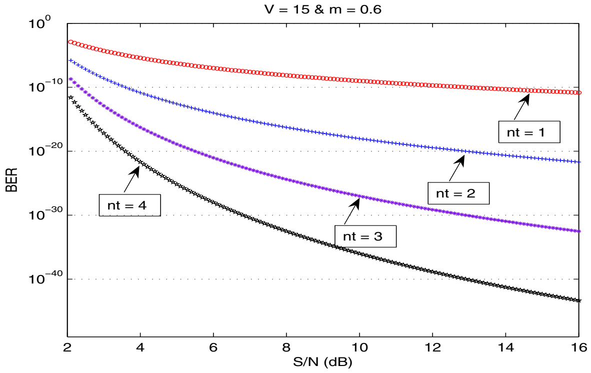

Figure 9: Nakagami distribution with m =0.6 V = 15 the rest parameters are the same as that in previous figures.

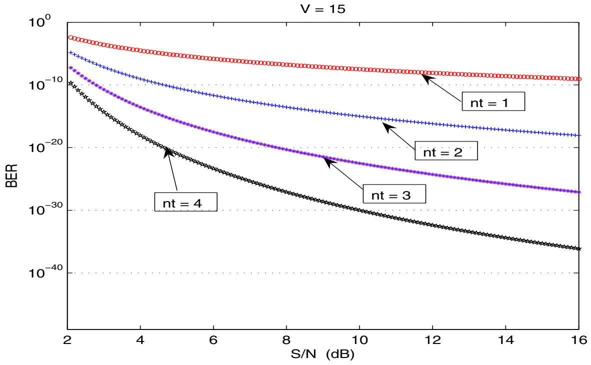

Figure 10: Nakagami distribution with m =0.9 V = 5 the rest parameters are the same as that in previous figures.

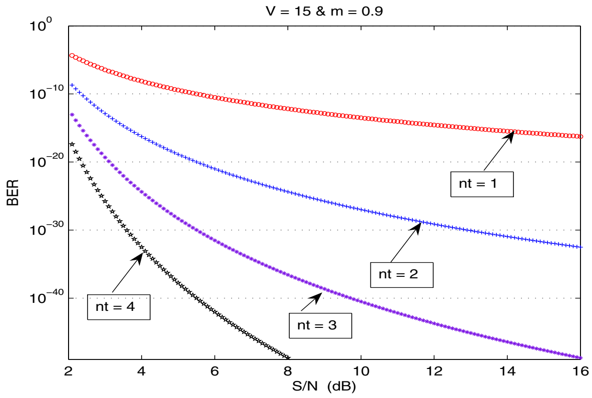

Figure 11: Nakagami distribution with m =0.9 V = 15 the rest parameters are the same as that in previous figures.

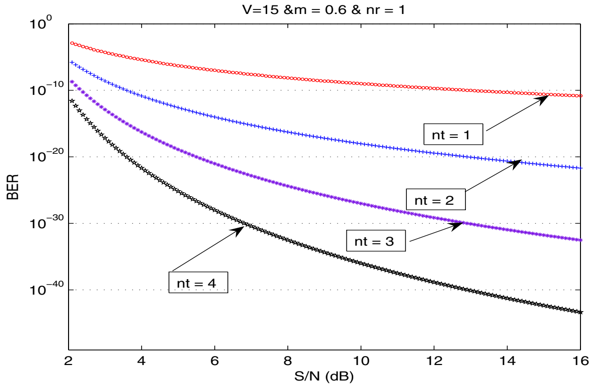

Figure 12: BER vs. S/N with the same condition as mentioned above and N_r=1, m =0.6, V=15 for the Nakagami distributions.

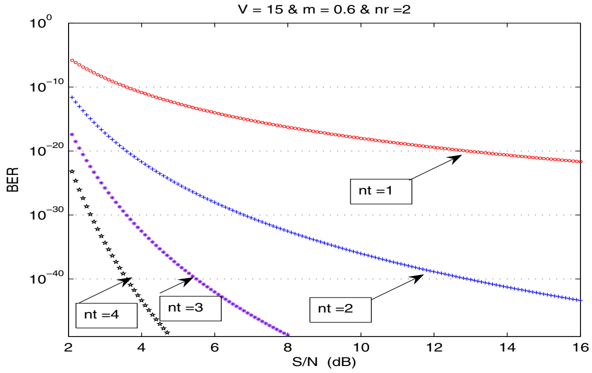

Figure 13: BER vs. S/N with the same condition as mentioned above and N_r=2, m =0.6 and V = 15 Nakagami distributions.

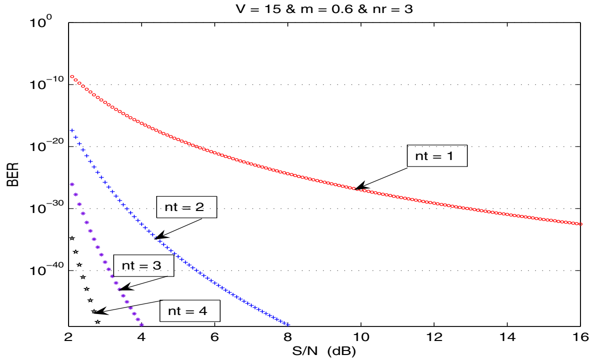

Figure 14: BER vs. S/N with the same condition as mentioned above and N_r=3, m =0.6 and V = 15 Nakagami distributions

For example, for the targeted 10_{-5} when N_t =2 under the same conditions except for m = 0.6 and m = 0.9 the former S/N dropped 1.9 dB in comparison with later (referring Figures 9 and 11). Also from Figures 8 and 10 for N_t = 3, at the targeted 10^{-5}, we have S/N dropped about 2 dB from m = 0.6 to m = 0.9 with the same r.v. V values.

Figures 12, 13 and 14 show the same BER vs. S/N with almost the same parameters except for receiver number, N_r = 1, 2 and 3. we can observe that as the receiver number increasing for the Nakagami distribution multipath communication channels the S/N will drop as this model focus on the case that the communication situation approaches to quasi-LOS, which is now deviating the assumptions when the N_r becomes lager.

V. Conclusions

In this paper, in order to have optimal designs for MIMO UWB-IR transceiver multipath communication channels, in particularly there is without CSI due to too expensive we have established statistic models for three major situations in MIMO UWB-IR communications, namely Nakagami distribution, log-normal distribution, and Gaussian distribution. Our special focuses are (a) how does the random variable V affect MIMO UWB-IR multipath communication channels? (b) if we stick with general LOS case, Nakagami fading channel, how does the major "m" factor affect the MIMO UWB-IR communication channels? Our simulations show the answers for above questions and offer better information for the optimal designs for MIMO UWB-IR transceiver multipath communication channels. Finally we also investigate how the receiver number affects the MIMO UWB-IR S/N. All those results will offer the optimal designs for MIMO UWB-IR transceiver multipath communication channels.

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