

THE PERFORMANCE EVALUATION OF AN OFDM-BASED iNET TRANSCEIVER

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ABSTRACT

The nXCVR-2000G transceiver is an 802.11a OFDM-based system undergoing performance studies that uses both simulation and laboratory tests. The multi-path channel model used in the simulation experiments is based on a telemetry multi-path channel model described in the iNET Telemetry Experimental Standard document.

To date, the results using the simulation have been confirmed by outdoor laboratory tests. They show that multi-path has less impact on the OFDM performance when the channel spread is within a limit of 800ns; the same specified guard interval (GI) used by 802.11a. For example, with a channel spread of 144ns (τ_1) and a reflection coefficient of -0.26dB (Γ_1), the Error Vector Magnitude (EVM) is on the order of 2.5%. As the channel spread expands beyond the standard GI 800ns, the demodulated signal degrades. The performance penalty depends upon the channel spread factor and the total Signal to Interference plus Noise Ratio (SINR).

KEYWORDS

iNET, OFDM, telemetry, networking, wireless, multi-path, performance

INTRODUCTION

The TTC nXCVR-2000G is the first iNET-ready OFDM-based IP transceiver available to the U.S. telemetry industry. The transceiver has been undergoing evaluation and testing since the early design phase. This paper reports on the unit's performance, based on recent outdoor laboratory tests held under various heavy wireless multi-path channel conditions.

It is known that a wireless radio channel places fundamental limitations on the performance of wireless communication systems; we will first review the theoretical fundamentals of wireless channel estimation and estimation methodology. Following that discussion, we will discuss the results of tests held under various outdoor channel conditions.

PERFORMANCE EVALUATION: THEORETICAL CONSIDERATION

Wireless channel fundamentals: Review [1-5]

The concerns of wireless communication channel impairment may differ depending on the application. In this report we assume, (i) communication links have Line-of-Sight (LOS) transmission condition and (ii) the channel is resolvable, i.e., the Channel Impulse Response (CIR) can be represented in discrete time. Those presumptions are reasonable for airborne telemetry wireless communication applications [6].

It is known that virtually all radio transmission medium may be regarded as random time-variant linear channels [1]. Denoting $x(t)$, $y(t)$ as the input and output of the channel, respectively, the output of the channel may be expressed as:

$$y(t) = \int_{-\infty}^{\infty} x(t - \xi) h(t, \xi) d\xi \quad (1.1)$$

$h(t, \xi)$ is the Channel Impulse Response (CIR) and t and ξ denote the real time-variable and the channel excitation time, respectively.

The rate of variation of the channel can be characterized by its Doppler frequency-spread and the channel time-spread. The product of the frequency spread and the time-spread is an important quantity in wireless communication time-variant-channels. A discussion is given in the following section titled “Channel detectability and sampling rate consideration”.

Channel estimation: a simple method

A simple method to perform channel estimation is to employ a random sequence as a channel sounding signal, then determine CIR at the output of the cross-correlator of the receiver.

Let $R_{\xi, t}$ denote a cross-correlation function between channel input $x(t)$ and its output $y(t)$, by eq.(1.1), it can obtain:

$$R_{\xi, t}(\xi, t) = \langle y(t, \xi) x(t - \xi) \rangle = \int_{-\infty}^{\infty} h(t, s) \langle x(t - s) x(t - \xi) \rangle ds \quad (2.1)$$

In practice, a repetitive random sequence is utilized. Let ΔT and $x_o(t)$ denote the repetition period and a finite length elementary random sequence, respectively. A channel sounding signal may be expressed as:

$$x(t) = \sum_k x_o(t - k\Delta T) \quad (2.2)$$

If $x_o(t)$ is white, by equation (2.1) and (2.2), the channel impulse response can be obtained at the receiver cross-correlator output as:

$$R_{\xi, t}(\xi, t) = \sum_k h(t, \xi - k\Delta T) \quad (2.3)$$

Channel detectability and sampling rate consideration

1. Channel detectability

Let f_{\max} and L_{\max} denote the maximum Doppler-frequency spread and the maximum time-spread, respectively. A necessary and sufficient condition for a detectable channel is given by [1-5]

$$L_{\max} B \leq 1 \quad (2.4)$$

$$B = f_{\max} / 0.423 \quad (2.5)$$

Within a CW channel excitation signal, f_{\max} is the maximum frequency dispersion due to Doppler motion and L_{\max} represents the maximum “memory” length of the channel. A physical intuition of the channel detectability condition given in equation (2.4) is that the sampling rate of the statistical samples of the channel measurement is constrained by Nyquist Sampling Theory. If the maximum channel time-spread $L_{\max} > 1/B$, by Sampling Rate Theory, the channel measure will be aliased in an unpredictable way depending on the shape and the strength measured. Previous studies have found that the detectability exhibits a sharp deterioration for $BL_{\max} > 1$ [2].

2. Channel unambiguous measure

Notice the maximum channel spread $L_{\max} > 0$, with a sounding signal shown equation (2.2), it could cause the channel measurement to be smeared if the repetition period $\Delta T < L_{\max}$. To ensure correct channel estimation, the channel sounding repetition period ΔT should satisfy the unambiguous channel estimation condition [1][2].

$$L_{\max} \leq \Delta T \leq 1/B \quad (2.6)$$

PERFORMANCE EVALUATION: METHODOLOGY

The specifics of the test boundary conditions were as follows:

1. Wireless point-to-point link performance test setting

- a) Signal bandwidth: 16.25MHz; $f_c \approx 2.4$ GHz
- b) Data: 1024byte/frame
- c) Modulation: OFDM/QPSK
- d) FEC: $1/2$ Convolutional code
- e) MAC: TDMA with ARQ mechanism
- f) IP data transfer: FTP, TCP/IP protocol;

2. Channel estimation test setting
 - a) Sounding signal (as part of preamble): repetitive sequence of $3.2 \mu\text{s}$ chirp signal;

$$\Delta T_{\min} = 3.2 \mu\text{s}; \Delta T_{\max} \leq 1\text{ms}$$
 - b) Payload modulation: 802.11a OFDM/QPSK
 - c) Bandwidth: 16.25MHz
 - d) Channel resolution (ADC sampling rate): 8ns

3. Test site environment presumptions
 - a) Reflector/scatterer mobility: $< 4 \text{ m/s}$ (10 miles/hour); Doppler-frequency spread

$$f_{\max} < 30\text{Hz} (@2.4\text{GHz}), \text{ i.e. the coherent time} = 9/16\pi f_{\max} = 6\text{ms}$$
 - b) Channel time-spread $L_{\max} < 10 \mu\text{s}$

4. Theoretical justification of the channel sounding parameter setting
 - a) Channel detectability condition: $L_{\max} \ll 1/f_{\max}$
 - b) Channel measure unambiguous condition: $\Delta T > L_{\max}$

5. Outdoor field test description as shown in Figure 1

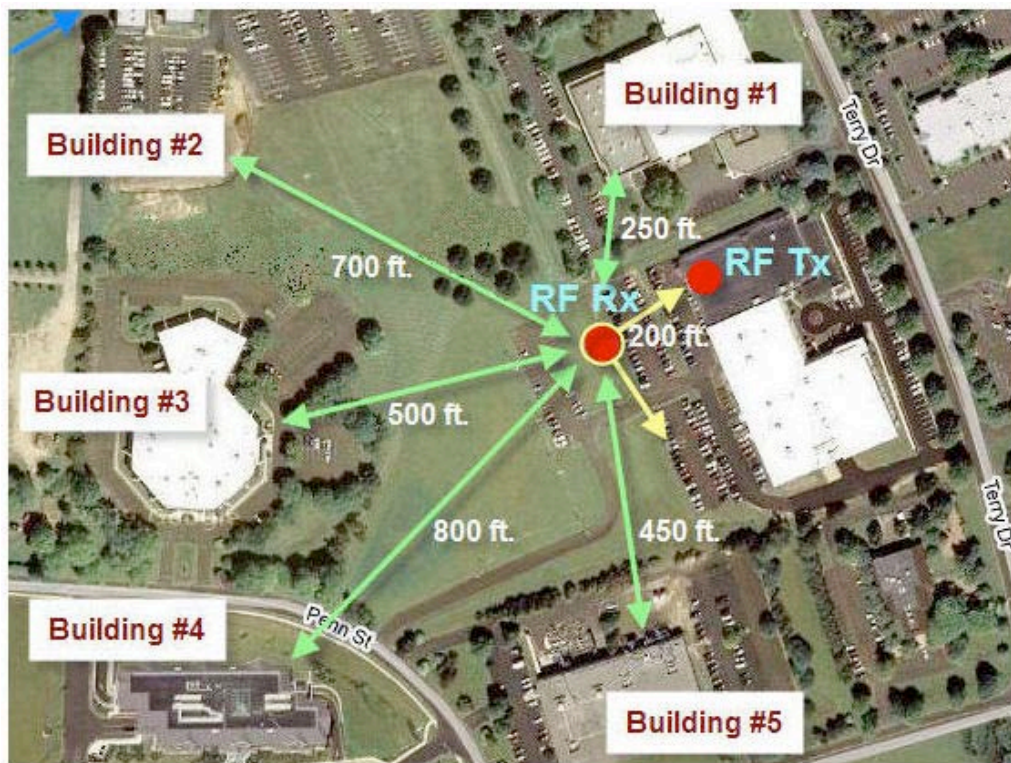


Figure 1: Test site description

- a) **Building #1:** office building; brick walls, two floors
- b) **Building #2:** office building; brick walls with metal roof
- c) **Building #3:** office building; brick walls, flat level
- d) **Building #4:** office building; brick walls, metal roof, four floors
- e) **Building #5:** manufacturing building; complex exterior with metal tanks, brick walls

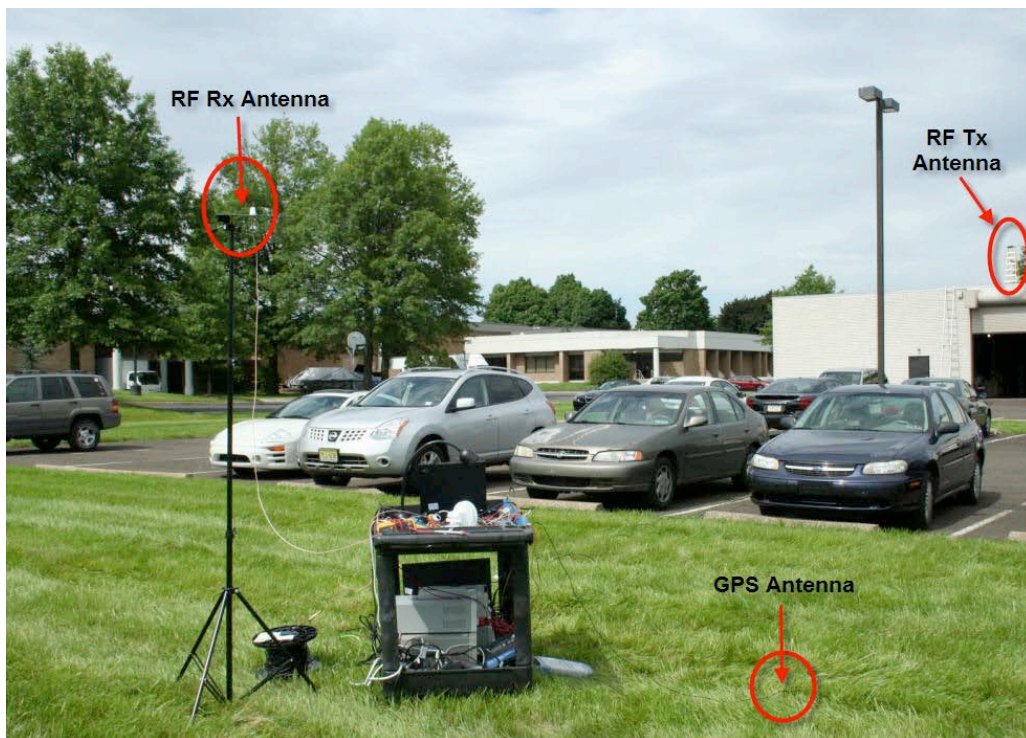


Figure 2: Antenna locations

6. Two-node link setting:

- a) Node #1: Tx omni. antenna is located on the building roof (30ft high, 200ft away from Rx antenna);
- b) Node#2: Rx omni./directional antenna is located in the parking lot as shown in figure 2; the directional antenna used is a wideband DRG horn antenna.

PERFORMANCE EVALUATION: RESULTS

1. Channel sounding results: see Table 1, Figure 3 and Figure 4

Table 1

Rx antenna direction	Echo#1 <i>ns / AM%</i>	Echo#2 <i>ns / AM%</i>	Echo#3 <i>ns / AM%</i>	Echo#4 <i>ns / AM%</i>	Echo#5 <i>ns / AM%</i>	Total C/I Power(dB)
LOS(0deg)	N/A					
Left 90deg	121/0.62 (-4.2dB)	315/0.093 (-20.6dB)				4dB
180deg	145/0.125 (-18dB)	290/0.2 (-14dB)	776/0.08 (-22dB)	1,040/0.26 (-11.7dB)	1,600/0.085 (-21.4dB)	8.6dB
Right 90deg	97/0.24 (-12.4dB)	751/0.12 (-18.4dB)	921/0.053 (-25.5dB)	1042/0.214 (-13.4dB)		9.2dB

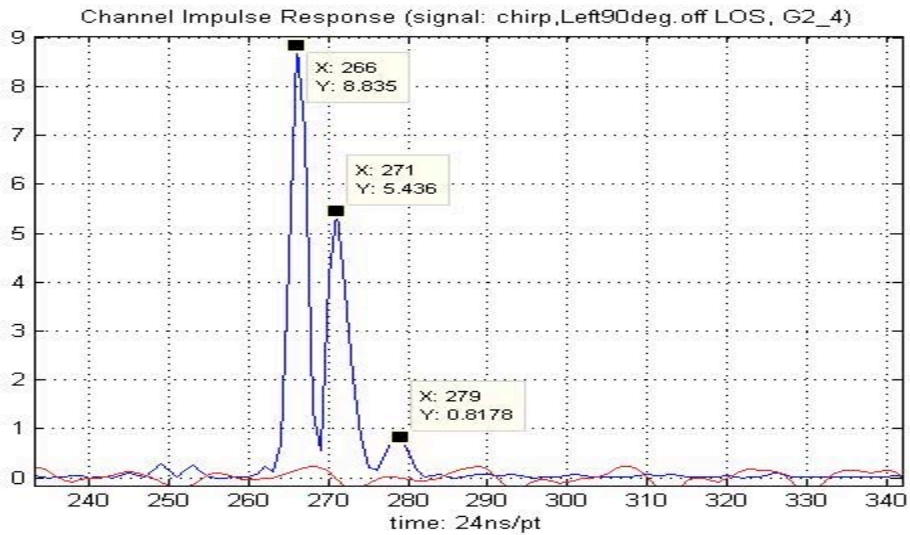


Figure 3: CIR estimation for LOS off by left-turn 90°

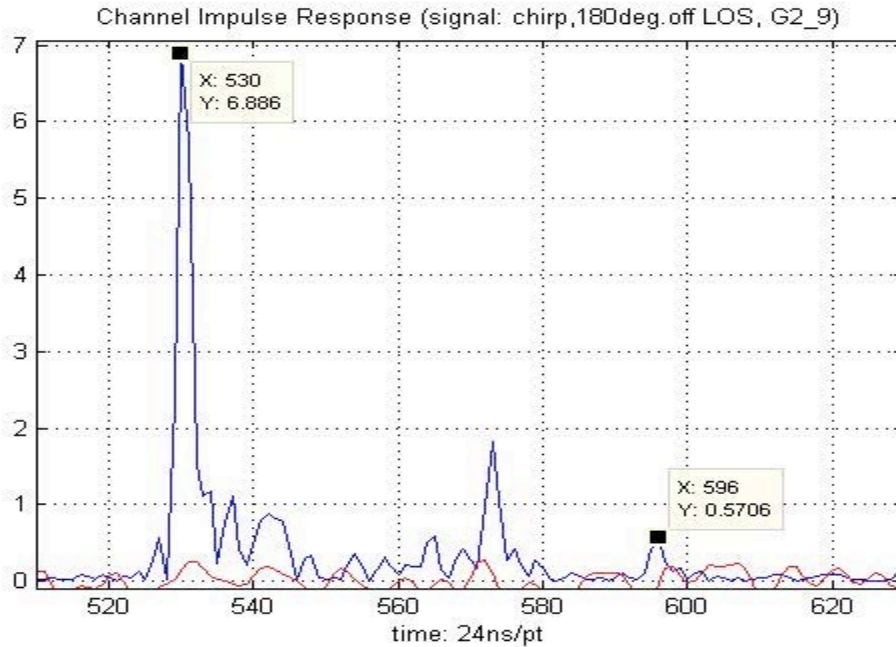


Figure 4: CIR estimation for LOS off by 180°

2. Wireless link performance test results:

Case A

Modulation: OFDM/QPSK with FEC ½ rate
 Tx antenna: Omni-directional located on roof.
 Rx antenna: Omni-directional located in parking lot
 Link condition: LOS
 Rx power: -65dBm

Trail	Link Time(sec)	Total Tx. frame	Total ARQ frame	Pkt Drop rate
#1	17.13	11,249	1	8.9E-5
#2	17.03	5,100	0	0
#3	17.05	5,093	0	0
Total	51.21	21,442	1	4.7E-5

Case B

Modulation: OFDM/QPSK with FEC ½ rate
Tx antenna: Omni-directional located on roof.
Rx antenna: Directional horn, located in parking lot
Link condition: LOS (0 deg.)
Rx power: -55dBm

Trail	Total Comm.. Time(sec)	Total Tx Frame	Total ARQ Frame	Pkt Drop rate
#1	17.06	5,095	0	0
#2	17.05	5,092	0	0
#3	64.48	19,347	0	0
#4	64.56	19,353	0	0
#5	64.51	19,613	0	0
Total	227.66	68,500	0	0

Case C

Modulation: OFDM/QPSK with FEC ½ rate
Tx antenna: Omni-directional located on roof.
Rx antenna: Directional horn, located in parking lot
Link condition: 80deg. Right turn off LOS
Rx power: -55dBm

Trail	Total Comm.. Time(sec)	Total Tx Frame	Total ARQ Frame	Pkt Drop rate
#1	64.56	19,356	0	0
#2	64.56	19,486	0	0
#3	117.16	20,692	72	3.5E-3
Total	246.28	59,354	72	1.2E-3

Case D

Modulation: OFDM/QPSK with FEC ½ rate
Tx antenna: Omni-directional located on roof.
Rx antenna: Directional horn, located in parking lot
Link condition: 90deg. Left turn off LOS
Rx power: -66dBm

Trail	Total Comm.. Time(sec)	Total Tx Frame	Total ARQ Frame	Pkt Drop rate
#1	64.85	19391	2	1E-4
#2	64.66	19361	1	5E-5
#3	70.56	19605	24	1.2E-3
Total	200	58,357	27	4.6E-4

Case E

Modulation: OFDM/QPSK with FEC ½ rate
Tx antenna: Omni-directional located on the roof.
Rx Antenna: Directional horn, located in parking lot
Link condition: 175deg. Right turn off LOS
Rx power: -68dBm

Trail	Total Comm.. Time(sec)	Total Tx Frame	Total ARQ Frame	Pkt Drop rate
#1	64.56	19378	0	0
#2	64.5	19366	0	0
Total	129.06	38,744	0	0

CONCLUSIONS

In this paper we present the outdoor wireless channel estimation result and the iNET transceiver performance under various wireless outdoor channel conditions. It can be observed that:

- (i) Using LOS, the packet drop rate in the test is well below 10^{-4} .
- (ii) Using Non-LOS (due to off-angle directional antenna), the packet drop rate varies depending on the multi-path conditions. For example, in test case D, the packet drop rate is correlated with its low signal to interference (C/I) ratio; however, in test case E, with a strong reflection signal, the C/I is relatively higher, and the performance is as good as LOS case B.
- (iii) Using LOS and the omni-directional antenna as shown in test case A, the link performance is well below the benchmark 10^{-4} , which is consistent with the comment (i).

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