Bluetooth RF Layer Performance Evaluation

N.P. Kontakos and J.K. Pollard

University College London

Abstract: The Bluetooth RF Layer performance is evaluated by simulation. The Gaussian Frequency Shift Keying (GFSK) radio link is modelled including a channel for a multipath indoor environment. Following a component-based architecture of simulation the Bit Error Rate (BER) performance of the system is observed. Results of BER versus SNR are presented and are in agreement with other results in the literature. The performance of the system is suitable for Synchronous Connection-Oriented (SCO) link. Using the two types of Forward Error Correction (FEC) and Automatic Repeat Request (ARQ) schemes is believed that the BER performance will be further enhanced and will be suitable for reliable communication of data between Bluetooth enabled devices.

1 Introduction.

The increasing demands for mobility in the modern world, as well as the idea of the integration of telecommunications have created a requirement for an inexpensive transceiver that replaces the need for wire connections over a short-range ($10\,m$). A wireless system that can operate worldwide without any license is called "Bluetooth" [1].

Simulation is the most powerful tool to investigate the properties of the Bluetooth radio system. Bluetooth mainly operates in a miscellaneous indoor environment and except from measurements and mathematical models, simulation is also required in its analysis.

The consumption of energy in a system should be low due to the fact that Bluetooth is oriented for portable devices connected as Personal Area Networks (PAN). Proposed uses of Bluetooth are inside a PC, a laptop, a personal digital assistant (PDA), a fax, a printer, a mobile phone, a projector and many more, all connected together in a cordless network.

This project examines, with the aid of simulation, the significant telecommunication parameters of Bluetooth radio system. In this paper section 2 describes an overview of the Bluetooth radio system, section 3 presents the transceiver model and the statistical indoor multipath channel model that have been followed and section 4 contains evaluation results of Bit Error Rate (BER) as a function of Signal-to-Noise Ratio (SNR).

2. Bluetooth Radio System.

The main applications of Bluetooth radio system are [2]: wire replacement, local area network (LAN) access points, and personal area networks. The spectrum band of Bluetooth has been decided to be the Industrial, Scientific and Medicine (ISM) Band, with frequency range in most countries from 2400 MHz to 2483.5 MHz. The use of frequency-hopping multiple access schemes has enabled the simultaneous operation of different networks in the same area and narrow band Frequency Hopping (FH) ensures tolerance to of in-band interference.

The Bluetooth radio system adopts a slotted Time Division Duplex (TDD) transmission scheme, where each slot is 625 ms length and two slots form one frame. In addition, forward error correction and automatic repeat request for retransmission are used as authentication of reception. The bit rate is 1 $MBits/s$. A Gaussian-shaped Frequency Shift Keying (FSK) modulation is applied to ensure the efficient use of available bandwidth and to minimize the transceiver complexity.

3. Transceiver and Channel Model.

3.1 Modulation

The modulation scheme that is employed for Bluetooth radio system is a binary Gaussian-shaped FSK, with modulation index between 0.28 and 0.35 [1]. The choice of this type of modulation is due to bandwidth efficiency, the simple and small transceiver implementation of GFSK system and its characteristic of constant envelope, which is desirable in fading environments. A transmitted GFSK signal can be written as:

$$p(t) = \mathrm{Re}\left\{ \sqrt{\frac{2E}{T}} \exp\left\{ j2\pi \left\{ f_c t + h \int_{-\infty}^{t} g(t)\,dt \right\}\right\}\right\} \tag{1}$$

where E is the energy per symbol, T is the symbol period, f_c is the carrier frequency, h is the modulation index and $g(t)$ is the output of Gaussian Low Pass Filter (GLPF) for a Non Return to Zero (NRZ) data signal as an input. The output of GLPF can be expressed as:

$$g(t) = \sum_{k=-\infty}^{\infty} a_k u(t-kT) \tag{2}$$

where $a_k = \pm 1$ and

$$u(t) = \frac{1}{2}\left\{ erf\left(-\lambda B_b T\right) + erf\left(\lambda B_b T(t+T)\right)\right\} \tag{3}$$

In equation (.3), $\lambda = \sqrt{2/\ln 2\pi}$, $B_b T = 0.5$, B_b is the 3 dB bandwidth of GLPF, and

$$erf(t) = \frac{2}{\sqrt{\pi}} \int_0^t e^{-t^2} dt\ . \tag{4}$$

The block diagram of the GFSK transmitter, which corresponds to these equations, is shown in Figure 1.

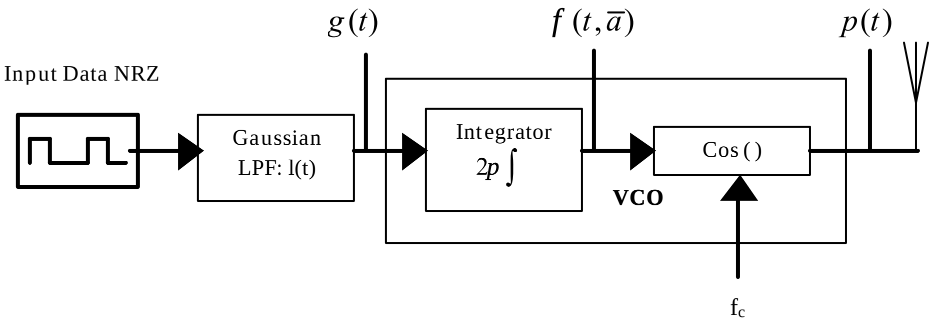

Figure 1: The block diagram of the GFSK transmitter.

3.2 Statistical Channel Model

A model of the indoor multipath propagation channel has been simulated. This statistical model agrees with the measurement results at 2.4 GHz [6, 9]. This model is also extendable to many buildings and time varying channels by changing the parameters. The model assumes that the electromagnetic waves are received in clusters of reflected rays that are distributed uniformly in arrival angle.

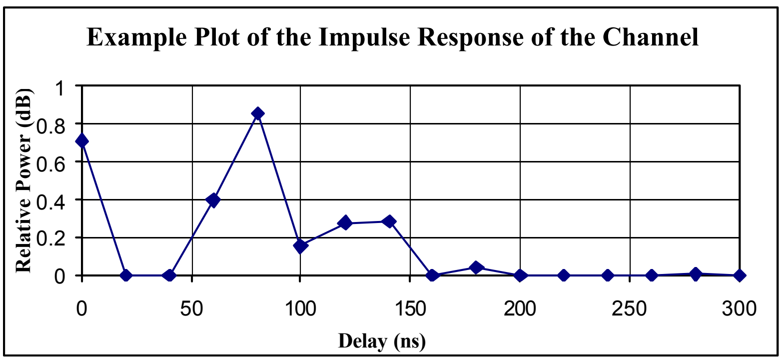

Figure 2: Example plot of the impulse response of the channel.

The baseband complex representation of impulse response of the channel is given by

$$c(t) = \sum_{l=0}^{\infty}\sum_{k=0}^{\infty} b_{kl} \exp(jq_{kl}) d\,(t - T_l - t_{kl}) \tag{5}$$

where T_l is the arrival of the l-th cluster, t_{kl} is the arrival time of the k-th ray measured from the beginning of the l-th cluster, q_{kl} is the phase shift, which is uniform distributed random variable over $[0, 2p\,)$, and b_{kl} is the power gain of the k-th ray in the l-th cluster, which is Rayleigh distributed random variables whose mean square values is monotonically decreasing functions of time. The rms delay spread is 60 ns and the maximum delay spread is 300 ns [6, 7, 9]. In general, the path weightings b_{kl} are known to be Rician but the worst-case scenario was examined where b_{kl} are subject to Rayleigh fading. The channel is assumed to be constant within one time slot. Random variable generators have been implemented to calculate the new parameters of the channel every 625 ms in order to model the parameters of the new FH channel.

An example of the impulse response of the channel is shown in figure 2. That statistical channel model is a Tap Delay Line (TDL) model with Rayleigh distributed tap weights and uniform distributed tap phases.

3.3 Additive White Gaussian Noise (AWGN)

Using the Box-Muller method, the additive white Gaussian noise samples were generated. The method uses a Rayleigh and two uniform random number generators in the interval (0,1) [12].

3.4 Differential GFSK Demodulator

The block diagram of the channel, noise and receiver is shown in Figure 3. The receiver contains a one bit differential demodulator and a memoryless threshold detector. The differential GFSK demodulator is sub-optimum for partial response Continuous Phase Modulation (CPM) signals. However, previous simulation results [10] showed performance only 1 dB worse than that the performance of an optimum Maximum Likelihood Sequence Estimator (MLSE). In addition, the differential detector is easily implemented in hardware. This is important in Bluetooth devices where reduction in size and complexity is required.

At the demodulator the complex baseband was sampled and multiplied by its complex conjugate that was delayed by a bit period. The resulting signal is:

$$y(t) = \cos(f_n - f_{n-1}) + j\sin(f_n - f_{n-1}) \tag{6}$$

where the $f_n - f_{n-1}$ represents the variation of the phase in one bit period. The threshold detector then decided that “1” was sent if $f_n - f_{n-1}$ was greater than or equal to zero and “0” if it was negative.

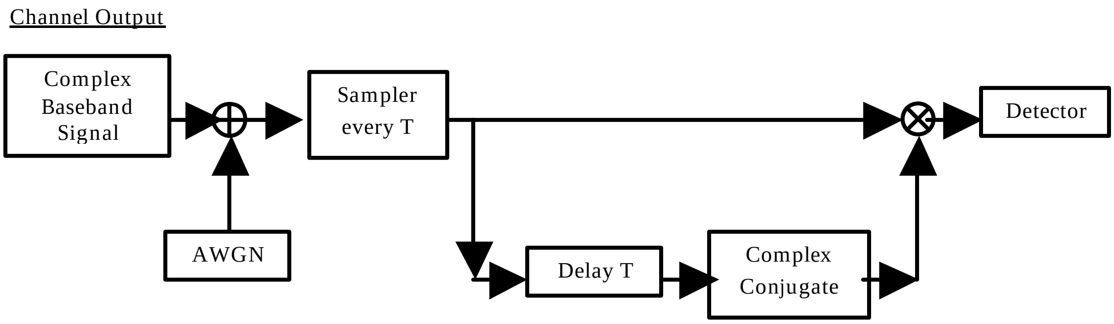

Figure 3: The Block diagram of the channel, noise and receiver.

4. Simulation Results and Discussion.

The modulator, channel, noise, differential detector and detector were simulated using pseudo random binary source data that were generate using the method that were charged in literature [12]. The received data after the detector were compared to the source data. The proportion of bits was the calculated Bit Error Rate (BER). The size of the input data was required to be at least significant to observe 10 errors so that BERs were 50% accurate within 95% confidence interval [4]. Figure 4 shows the simulation results for AWGN channel together with theoretical results presented in literature [10, 11, 13]. The difference between the AWGN simulation and the theory is in the order of $1dB$, which is due to sub-optimality of the detector. The BER versus SNR for the statistical multipath channel is also presented in the same figure.

The bit error floor for the multipath channel is of the order of 10^{-3}, which is acceptable BER for the lower layer of radio communication systems. This is expected to be improved with the bit stream manipulations of baseband layer, which follows the RF layer. Moreover, taking in account that a Rayleigh fading model is used, an enhanced BER performance is expected in applications where a Line Of Sight (LOS) communication takes place.

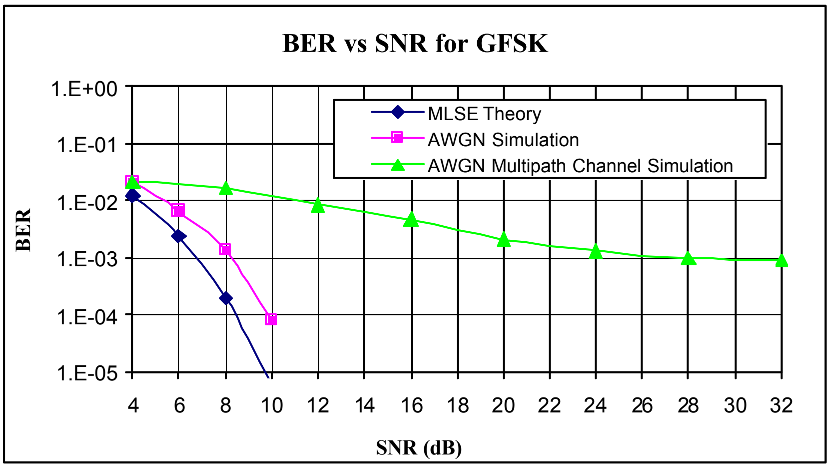

Figure 4:Average BER performance of the system under AWGN and multipath fading channel.

5. Conclusion.

This paper details the BER performance of Bluetooth RF layer. The performance of the system is satisfactory for Synchronous Connection-Oriented (SCO) link – voice, which needs no FEC. Using Forward Error Correction (FEC) and Automatic Repeat Request (ARQ) schemes, which belongs to baseband layer, is believed that the BER performance will be further enhanced and will be suitable for reliable data communication between Bluetooth enabled devices.

References.

[1] Specifications of the Bluetooth System V1.0B - Core, http://www.Bluetooth.com, (Dec. 1999).
[2] http://www.Bluetooth.com, “The official Web site of the Bluetooth Special Interest Group (SIG)”.
[3] J.C. Haartsen, “The Bluetooth Radio System”, IEEE Personal Com. pp 28-36 (Feb 2000).
[4] M.C. Jeruchim, P. Balaban and K.S. Shanmugan, “Simulation of Communication Systems”, Plenum Press, New York,(1992).
[5] J.K. Pollard, "Component-based Architecture for Simulation of Transmission Systems", COMPSAC 2000: Proc. IEEE Comp. Software & Applic. Conf., Taiwan, (Oct., 2000), pp 363-368.
[6] A.M. Saleh and R.A. Vanezuela, “A Statistical Model for Indoor Multipath Propagation”, IEEE Journal on Selected Areas in Comm., Vol. 5, No. 2, pp 128-137 (Feb 1987).
[7] C-H. Park, J-H. Paik, Y-H. You, M-C. Ju and J-W. Cho, “Techniques for Channel Estimation, DC-OFFSET Compensation and Link Quality Control in Bluetooth System”, IEEE Trans. on Consumer Electronics, Vol 46, No. 3, (Aug 2000).
[8] G.F. Pedersen and P. Eggers, “Initial Investigation of the Bluetooth Link”, Veh. Tech. Conf., IEEE VTS 2000, Fall VTC 2000, 52nd Vol. 1. pp 64-69.
[9] S-C. Kim, H.L. Bertoni & M. Stern, “Pulse Propagation Characteristics at 2.4 GHz Inside Buildings”, IEEE Trans. on Veh. Techn., Vol. 45, No. 3 (Aug 1996).
[10] R. Steele, “Mobile Radio Communication”, Pentech Press, (1994).
[11] J.G. Proakis, “Digital Communications”, McGraw-Hill, (1995).
[12] J.G. Proakis and M. Salehi, “Contemporary Communication Systems Using Matlab”, PWS Publishing Company.
[13] K. Murota and K. Hirade, “GMSK modulation for digital mobile radio telephony ”, IEEE Trans. Comm. Vol. COM-29, pp 1044-1050, (Jul 1981).