

Simulator for Tactical Data Link System with Anti-Jamming Capability

Bareum Lee, Eunkyeong Jeong, and Sangho Choe

Information, Communications, and Electronic Engineering, The Catholic University Of Korea, Korea
leebr35@nate.com, pooh89124@nate.com, schoe@catholic.ac.kr

Abstract—In this paper, we design a simulator using Matlab/Simulink for the jamming performance analysis of a tactical data link (TDL) system, called Link-16. Using the implemented simulator, we analyze the BER performance of Link-16 over tone, partial-band, and pulse jamming and evaluate its anti-jamming capability. In simulation, the main channel parameters including the jamming bandwidth, maximum Doppler frequency, and k factor of Rician fading are defined. In this paper, especially, we first propose a modified TDL system with the cognitive anti-jamming capability that senses the jamming signal and opportunistically avoids the jamming spectrum. Using the designed simulator, we verify that the proposed TDL system with cognitive anti-jamming capability improves bit-error-rate (BER) performance compared to existing TDL system over partial-band jamming.

Keywords— Tactical Data Link, Link-16, CCSK, MSK, Jamming, Partial-Band Jamming, Cognitive Anti-Jamming.

I. INTRODUCTION

The basic paradigm of the future military environment is rapidly changing from the platform-centric to the network-centric with the sensor-to-shooter concept. For the network-centric mission accomplishment, the role of tactical data link (TDL) is being more emphasized [1].

Link-16, a TDL currently installed and operating in the U.S. Air Force, is the centric weapon system for joint tactical information distribution system (JTIDS). Link-16 is a kind of ad-hoc-based local area network that consists of several (or many) sky or ground terminals and is usually used for the propagation of the C4I information from those terminals to that air platform [2] or vice versa.

In this paper, we implement a TDL simulator for Link-16. That simulator includes two kinds of modulators: cyclic code shift keying (CCSK) modulator for baseband modulation and minimum shift keying (MSK) modulator for chip modulation, where a baseband symbol from the CCSK module is translated into a CCSK symbol and the CCSK symbol is modulated (and spreaded) as MSK chips, respectively [3]. As the basic receiver channel model of that simulator, additional white Gaussian noise (AWGN) channel and Rician fading channel are designed. In simulation, Rician fading channel parameters including k factor and maximum Doppler frequency are

properly set. The implemented simulator has a jamming module that models the real jamming environments, including partial-band jamming, pulse jamming, and tone jamming.

The simulator implements a frequency hopping (FH) function that provides the TDL system with anti-jamming capability. FH frequency is randomly selected among 51 frequencies (each channel spacing = 3MHz) with the FH period of 13 μ sec. The designed Link-16 simulator includes a time synchronization circuit, where the MSK chip-based timing synchronization using the received preamble is established. To further evaluate the Link-16 anti-jamming capability, we estimate the bit-error-rate (BER) of the TDL system with or without the (chip) timing synchronous circuit.

In this paper, we first propose a modified TDL system with the cognitive anti-jamming capability that senses the jamming signal and opportunistically avoids that jamming spectrum for secure data transmission. For practical channel conditions, in simulation, we take miss-detection of jamming channels into account [4]. Using that simulator, we analyze the performance of the proposed TDL over partial-band jamming and verify its superiority to the conventional TDL.

The rest of this paper is organized as follows: Section II explains the proposed TDL system model and its simulator blocks including CCSK module, jamming module, and cognitive anti-jamming module. Section III presents the simulation results of the proposed TDL system model over fading and jamming channel environments. Finally, concluding remarks are given in Section IV.

II. TDL SYSTEM MODEL

Recently, several nations' army including U.S. army has deployed TDLs that relay (and exchange) various useful tactical information such as terrain image, picture, SMS, voice, etc, that is obtained through the information, surveillance, and reconnaissance (ISR) activities. For the reliable TDL operation, safe and secure real-time data exchange under the jamming channels is mandatory [5].

A time division multiple access (TDMA)-based system, Link-16, provide a time slot channel, whose period is 1/128 sec, to its terminal with a transmit packet. In simulator, for simplicity, we assume a single user who has a pre-allocated

channel resource (i.e., a TDMA time slot). A Link-16 terminal operates 51 hopping frequencies within the signal bandwidth of 3MHz and randomly hops to one of those hopping frequencies every 13μsec.

In this paper, as seen in Figure 1, we construct a Link-16 simulator using Matlab/Simulink and evaluate the TDL anti-jamming capability in terms of the BER performance.

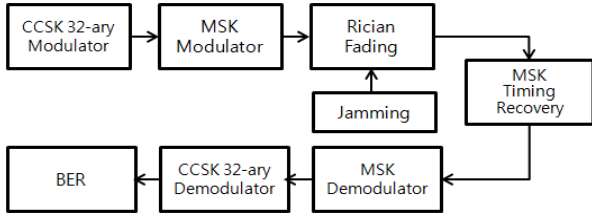


Figure 1. Link-16-based TDL simulator block diagram.

III. TDL SIMULATOR DESIGN

The TDL simulator includes a random data signal generator, a CCSK module for baseband modulation and demodulation, a coherent MSK module for chip modulation and demodulation, a delay module for timing delay, an AWGN & Rician fading channel module, a jamming block simulating various kinds of jamming, a uniformly-distributed offset generator, bit error checker, and so on. The proposed TDL simulator also includes a cognitive anti-jamming block that senses the jammer signal and avoids its spectrum use; thus, its anti-jamming capability is improved over conventional TDL. The following explains some main modules of the proposed TDL simulator.

A. CCSK module

Link-16 uses CCSK modulation for the baseband modulation & spreading, where each incoming 5-bit symbol is translated into a corresponding 32-chip sequence. Table 1 lists the Link-16 32-chip sequences; any cyclic shift of the base sequence S_0 could be another sequence in Table 1. The CCSK symbol period is denoted T_f ($= 32T$, where T is the MSK chip period).

TABLE 1. 32-CHIP SEQUENCE

5-bit symbol	32-chip sequence
00000	$S_0 = 011111100111010010000101011101100$
00001	$S_1 = 11111001110100100001010111011000$
⋮	⋮
11111	$S_{31} = 00111110011101001000010101110110$

The CCSK modulation module modulates a 5-bit source symbol to a corresponding 32-chip sequence at the look-up

table (see Table 1). The CCSK demodulation module executes the reverse process of CCSK modulation using the auto-correlation between received sequence and cyclic-shifted 32-chip sequence, which is especially implemented with embedded Matlab in Simulink for the real-time simulation.

B. Jamming module

Figure 2 shows the TDL simulator block diagram with a jamming module, denoted “jamming A”, for the partial-band and tone jamming simulation. In that “jamming A” module, transmit source signal (randomly generated) experiences the jamming channel, whose bandwidth is decided by the given jamming spectrum ratio ρ ($=$ jamming bandwidth / total signal bandwidth ($= 153\text{MHz}$)). For a given bit energy (e.g., $E_b = 1$ (unit energy)), the noise spectral density is decided by E_b/N_0 ($=$ bit energy per noise spectral density) and the jamming signal spectral density is decided by E_b/N_j ($=$ bit energy per jamming noise spectral density). We assume that whereas, in the case of partial-band noise jamming, several ($= \rho \times 51$) frequency hopping channels are jammed and, in the case of tone jamming, a single channel is jammed. Assume $E_b/N_0 = 20\text{dB}$ in simulation. In simulation using this jamming module, we estimate both anti-jamming capability and signal quality of the TDL system.

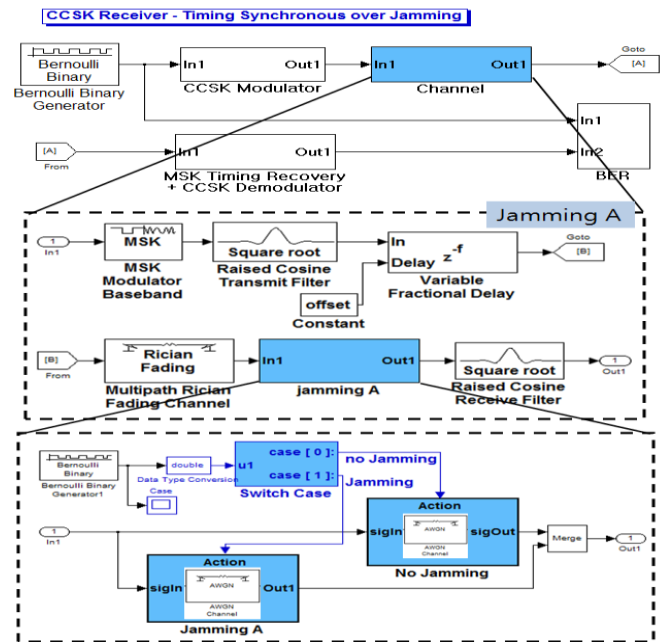


Figure 2. TDL simulator block diagram for the partial-band and tone jamming simulation

affected by time synchronization, especially in partial-band jamming.

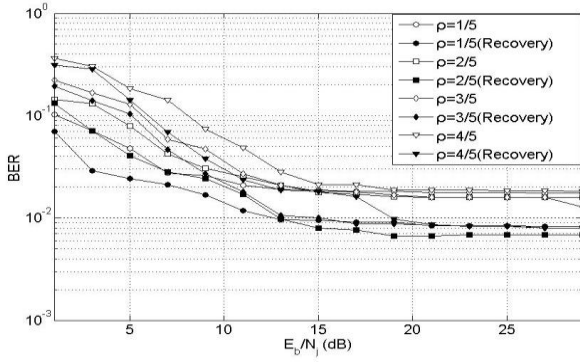


Figure 5. TDL system performance over partial-band noise jamming

Figure 6 compares the performance of TDL system with or without timing synchronization over tone jamming, whose simulator block diagram is referred to Figure 2. Assume a single tone jammed channel with $E_b/N_j = 0\text{dB}$ and no-jammed channels with $E_b/N_0 = 20\text{dB}$, and $\Delta = 3.75T$. Even for this single-tone jamming, we can observe that the system performance is dependent on time synchronization. Specifically, as the BER criterion increases above 10^{-3} , TDL scheme with good (perfect) synchronization ('tone jamming(recovery)') has a performance gain of approximately 1.5dB compared to the one with bad (jammed or imperfect) synchronization ('tone jamming'). Especially, when the BER criterion is below 1.3×10^{-3} , the performance gain difference between those two schemes gets greater.

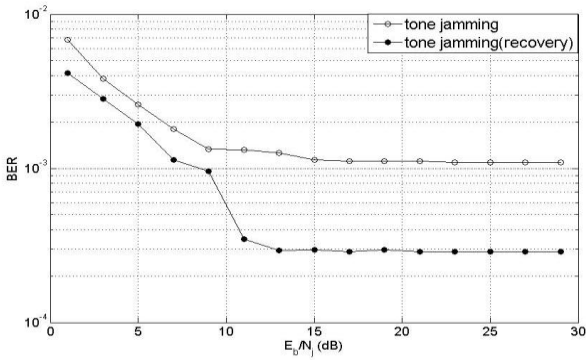


Figure 6. TDL system performance over tone jamming

Figure 7 shows the performance of TDL system over pulse jamming, whose simulator block diagram is referred to Figure 3. In that simulator, BER versus E_b/N_0 rather than BER versus E_b/N_j is used since pulse jamming is not frequency-domain jamming (like partial-band jamming) but time-domain jamming. We set T_p (the pulse jamming duration) = $1/128 T_f$ ($1T_f = 32T$) and the pulse jamming period = $1/128$ sec (= one time slot period = one 5-bit CCSK symbol period). We

assume perfect jamming of the corresponding MSK chips during T_p . In Figure 7, we can observe that no-jammed signal has a performance gain of approximately 0.8dB at BER 10^{-2} compared to jammed signal. Also TDL with timing synchronization provides a gain of approximately 1dB at BER 10^{-2} compared to the one without time synchronization, regardless of jamming; but there is no flat region like partial-band or tone jamming. Therefore, pulse jamming is relatively not so severe compared to partial-band jamming.

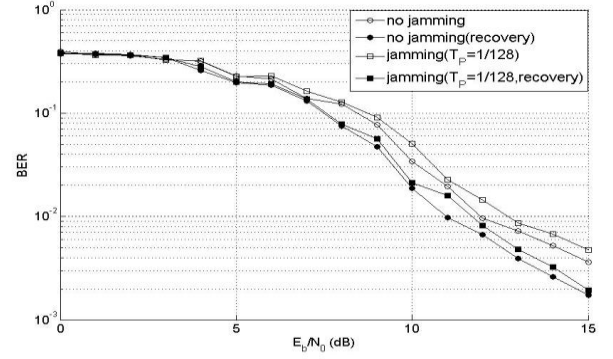


Figure 7. TDL system performance over pulse jamming

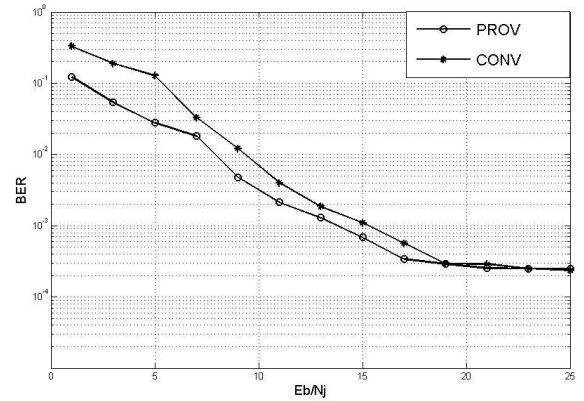


Figure 8. Performance of the proposed TDL system with cognitive anti-jamming capability over partial-band jamming

B. Cognitive Anti-Jamming

We have analyzed the proposed TDL system with cognitive anti-jamming capability over partial-band jamming, whose simulator block diagram is referred to Figure 4. When the jamming signal is detected, the cognitive TDL terminal opportunistically avoids those jamming frequency channels. In the proposed simulator, for the practical considerations, we assume imperfect detection for the jammer signal. Assume $\rho = 40\%$, miss-detection probability $P_{md} = 0.1$ (which means that 10% of number of jamming channels are undetected (vulnerable to jamming attack)), and $E_b/N_0 = 20\text{dB}$. Figure 8

shows the proposed TDL system ('PROV') performance gain of approximately 3dB at the 10^{-3} BER compared to existing TDL system ('CONV'). The gain is approximately 0 dB when $E_b/N_j > 18\text{dB}$ (it means that for that E_b/N_j range, the jamming effect is almost negligible) but the gain increases and approaches to 3 to 4dB as E_b/N_j decreases (smaller than 18dB). It shows that cognitive anti-jamming is so effective to partial-band (or tone) jamming.

V. CONCLUSIONS

We designed a TDL simulator using Matlab/Simulink for the Link-16 performance analysis over jamming environments. In that simulator, we included a Doppler-faded Rician channel module and various jamming modules. We also added a timing synchronization circuit to that simulator to test the anti-jamming capability of Link-16 with/without synchronization. Simulation results verified that partial-band noise jamming is so severe to existing TDL system, compared to tone or pulse jamming. TDL system over partial-band or tone (even single tone) jamming is very much dependent on the performance of synchronization; it indicates that a robust synchronization circuit for secure tactical communications is mandatory. We proposed a modified TDL system with cognitive anti-jamming capability and verified its performance superiority to existing

TDL system, especially over partial-band (or tone) jamming.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (2010-0010130).

REFERENCES

- [1] David S. Alberts, John J. Garstka, and Frederick P. Stein, "Network Centric Warfare," DoD C4ISR Cooperative Research Program (CCRP), Feb. 2000.
- [2] Handong Kim and Taebong Choe, "Tactical Data Link Technology Standardization Trends," Journal of the Korea Information and Communications Society, vol.24, no.10, pp.7-14, Aug. 2007.
- [3] Seungmin Baek, Suwon Park, and Young-uk Chung, "Performance Evaluation of Non-Coherent Detection Based Cyclic Code-Shift Keying," Journal of the Institute of Electronics Engineers of Korea-TC, vol.47, no.6, pp.42-48, June 2010.
- [4] R. Prabhu, E. L. Vallés, and P. A. Dafesh, "Cognitive Anti-jam Radio System (CARS)," in Proc. of the Software Defined Radio Forum Technical Conf., Dec. 2009.
- [5] Manuel Martinez-Ruiz, and Antonio Artes, "Progressive still image transmission over a tactical data link network. a case study: JPEG2000 compressed images over a LINK-16 network," in Proc. IEEE MILCOM, pp. 1163-1168, April 2008.