

Tactical Data Link Simulator with Cognitive Anti-Jamming Capability

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Abstract

In this paper, we design a simulator using Matlab/Simulink that evaluates the anti-jamming capability of a tactical data link (TDL) system, called Link-16. We analyze the BER performance of the Link-16 simulator over partial-band jamming. Especially, we consider a TDL system with a cognitive anti-jamming capability that senses the jamming signal and opportunistically avoids the jamming spectrum. By evaluating the presented simulator, we verify that TDL system with cognitive anti-jamming capability improves bit-error-rate (BER) performance over jamming environments.

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

1. Introduction

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 [1] 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 [2]. 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 partial-band 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 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 the jamming spectrum for secure data transmission. For practical channel conditions, in simulation, we take miss-detection of jamming channels into account [3]. 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 2 explains the proposed TDL system model and its simulator blocks including CCSK module, jamming module, and cognitive anti-jamming module. Section 3 presents the simulation results of the proposed TDL system model over fading and jamming channel environments. Finally, concluding remarks are given in Section 4.

2. TDL System Model

For the reliable TDL operation, safe and secure real-time data exchange under the jamming channels is mandatory [4].

A time division multiple access (TDMA)-based system, Link-16, provides 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 13 μ sec.

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.

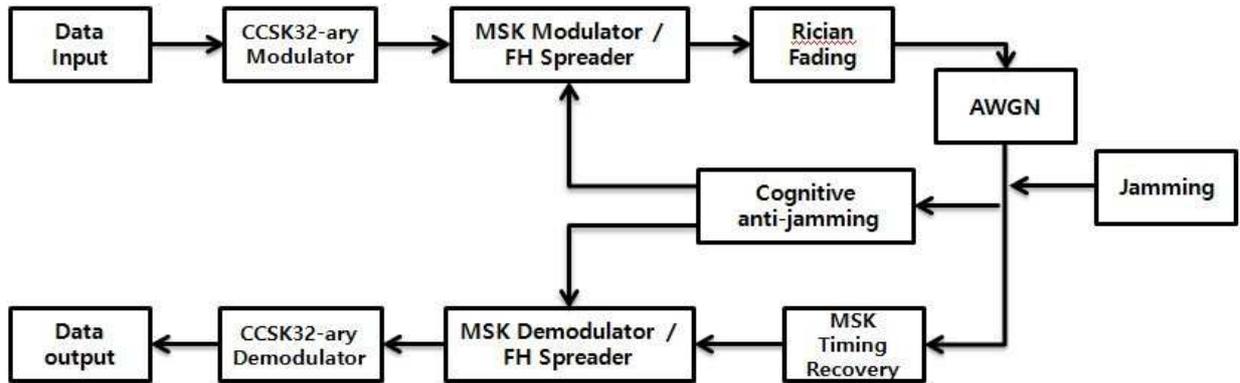


Figure 1. Link-16-based TDL simulator block diagram.

A. 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.

The TDL simulator has a jamming module, denoted “jamming A”, for the partial-band 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 (= 153MHz)). For a given bit energy (e.g., $E_b = 1$ (unit energy)), the noise spectral density is decided by E_b/N_o (=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 for partial-band noise jamming, several ($=\rho \times 51$) frequency hopping channels are jammed. Assume $E_b/N_o = 20\text{dB}$ in simulation. In simulation using this jamming module, we estimate both anti-jamming capability and signal quality of the TDL system.

B. Cognitive anti-jamming module

Figure 2 shows the proposed TDL simulator block diagram with the cognitive anti-jamming capability. In this simulator, we add a cognitive anti-jamming circuit, denoted “Anti-Jamming” in Figure 2, to conventional Link-16 system. Hence, TDL may improve its anti-jamming capability, especially for partial-band or tone jamming. For practicality, we consider the imperfect jammer signal sensing with non-zero miss-detection probability, i.e., $P_{\text{md}} \neq 0$ (but we assume zero false alarm probability for simplicity). We use a signal-to-noise ratio based jammer detection scheme. Once the jammer signal is detected, the receiver immediately feeds back the jamming channel status information (JCSI) including jamming hop number, jammer to signal ratio, etc, to transmitter. Then the TDL system can be robust to the jammer signal. The two input signals that are generated by two independent binary random (Bernoulli-distributed) signal generators (one for correctly-jamming-avoided signal and the other one for incorrectly-jamming-avoided signal) go through each different path (one for jamming signal path and the other one for no-jamming signal path). We change a threshold value in terms of E_b/N_j to decide (estimate) an adequate P_{md} ; we set $P_{\text{md}} = 0.1, 0.3, \text{ and } 0.5$, in simulation.

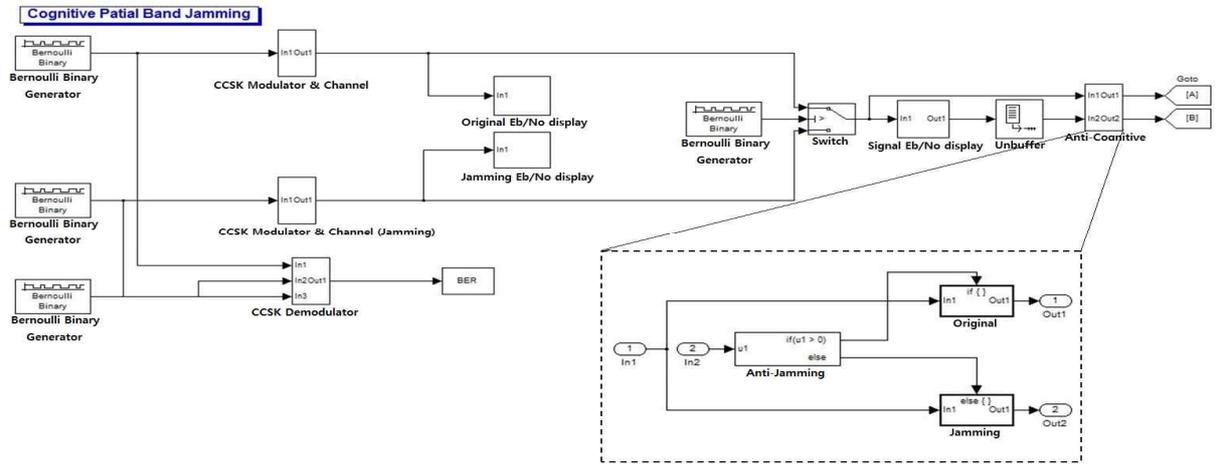


Figure 2. TDL simulator block diagram for cognitive anti-jamming capability testing.

3. Simulation Result

We have executed TDL system simulation using the presented Link-16 simulator over various jamming environments. For the TDL Rician fading channel, we use the two-ray fading channel model, where the k factor = 10 and the maximum Doppler frequency = 777 Hz are assumed. Figure 3 compares the system performance of Link-16 over partial-band noise jamming. Assume the uniformly-distributed maximum timing offset $\Delta = 3.75T$ and no-jammed channels with $E_b/N_0 = 20\text{dB}$. Jamming spectrum ratio ρ that defines the partial-band noise jamming level is set to 1/5, 2/5, 3/5, and 4/5, respectively. It is observable that the system performance is very much dependent on ρ . Note that when $E_b/N_j > 15\text{dB}$, the BER curve becomes flat. It means that for the range of $E_b/N_j > 15\text{dB}$, the system BER is mostly dependent on E_b/N_0 due to the reduced jamming signal strength; however, when $E_b/N_j \leq 15\text{dB}$, the BER curve is so affected by E_b/N_j . For a given ρ , the TDL system with timing synchronization has performance gain of approximately 2 ~ 5 dB over the one without time synchronization. It indicates that the TDL performance is so affected by time synchronization, especially in partial-band jamming.

We have analyzed the proposed TDL system with cognitive anti-jamming capability over partial-band jamming. 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 $P_{md} = 0.1, 0.3, 0.5$ (which means that 10%, 30%, 50% of number of jamming channels are undetected (vulnerable to jamming attack)), and $E_b/N_0 = 20\text{dB}$. Figure 4 shows that in the case of $P_{md} = 0.1, 0.3, \text{ and } 0.5$, the proposed TDL system ('PROV') performance gain of approximately 4dB, 1.6dB, 1.5dB, respectively, at the 10^{-3} BER compared to existing TDL system ('CONV'). The gain is reduced to 0 dB when $E_b/N_j > 15\text{dB}$ (it means that for that E_b/N_j range, the jamming effect is almost negligible) but the gain is increased and approaches to above 3 to 4dB as E_b/N_j decreases (smaller than 15dB). It shows that cognitive anti-jamming is so effective to partial-band jamming.

4. Conclusion

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 a partial-band jamming module. Simulation results verified that partial-band noise jamming is so severe to existing TDL system. We proposed a modified TDL system with cognitive anti-jamming capability and verified its performance superiority to existing TDL system, especially over partial-band jamming.

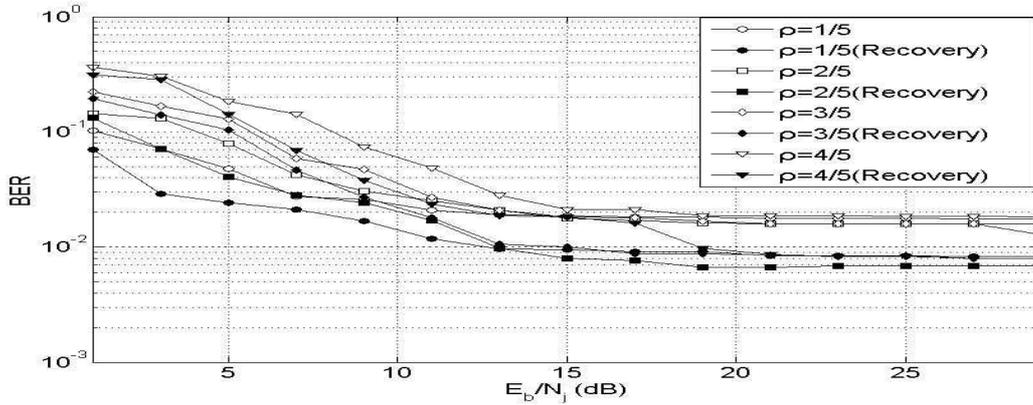


Figure 3. TDL system performance over partial-band noise jamming.

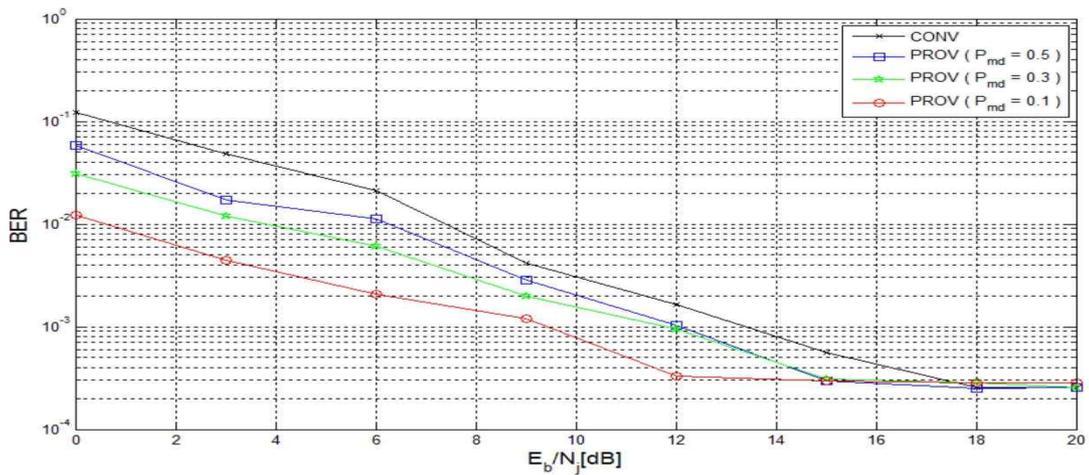


Figure 4. Performance of the proposed TDL system with cognitive anti-jamming capability over partial-band jamming.

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6. References

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