Abstract - In this paper, we present a Link-16-based tactical data link (TDL) simulator with cognitive anti-jamming capability (CAJC). CAJC improves anti-jamming capability of existing TDL by adding the cognitive radio (CR) spectrum sensing-based jammer detection. In the presented TDL, each terminal that senses (or detects) the jammer signal can avoid the jammer spectrum opportunistically. For jammer signal detection, each terminal employs generic CR spectrum sensing schemes like signal energy sensing (SE) and signal-to-jammer-plus-noise ratio sensing (SJNR) or hybrid CR spectrum sensing schemes like beacon plus signal strength sensing (BC_SE) and beacon plus signal-to-jammer-plus-noise ratio sensing (BC_SJNR). In this paper, we design a Matlab/Simulink-based simulator for the verification of presented TDL. This simulator includes a cyclic code shift keying (CCSK) modulator for baseband modulation, a minimum shift keying (MSK) modulator for chip spreading and modulation, a Rician fading channel module, and a partial-band noise jamming (PBNJ) module. Using this simulator, we can evaluate the bit-error-rate (BER) performance of the proposed TDL and verify that the proposed TDL is more robust to conventional TDL over PBNJ environments.

Keywords: Tactical Data Link; Partial-Band Noise Jamming; Cognitive Radio; Spectrum Sensing

1 Introduction

Link-16, that is a TDL currently installed and operating in the U.S. Air Force, is a centric weapon system for the joint tactical information distribution system (JTIDS) [1]. Link-16, an ad-hoc-based local area network that consists of several (or many) sky or ground terminals, is typically used for the C4I information transfer from these terminals to air platform, or vice versa [2].

In this paper, we propose a Link-16-based TDL with the cognitive anti-jamming capability (CAJC) that senses the jamming signal and opportunistically avoids the jammer spectrum for secure data transmission. CAJC combines conventional frequency hopping (FH)-based anti-jamming function with cognitive radio (CR) spectrum sensing (SS)-based jammer detection function. For jammer signal detection, the presented TDL implements generic SS schemes like signal energy sensing (SE) and signal-to-jammer-plus-noise ratio sensing (SJNR) or hybrid SS schemes like beacon plus signal strength sensing (BC_SE) and beacon plus signal-to-jammer-plus-noise ratio sensing (BC_SJNR); that is, in hybrid SS, beacon detection (BC) is additionally used for the jammer signal sensing.

In this paper, we design a Link-16-based TDL simulator using Matlab/Simulink. This simulator includes a cyclic code shift keying (CCSK) modulator for baseband modulation, a minimum shift keying (MSK) modulator for chip spreading and modulation, a partial-band noise jammer (PBNJ) module, a time synchronization block, a bit-error-rate (BER) check block, and a channel module implementing additive white Gaussian noise (AWGN) plus Doppler-shifted Rician fading [3]. In that channel module, we can set the Rician fading channel parameters including k factor and maximum Doppler frequency.

Especially, the designed simulator also has a cognitive anti-jamming block including CR spectrum sensing (SS)-based jammer detection and jamming channel status information (JCSI) generation functions. In that block, we can set a threshold value satisfying given jammer signal miss-detection & false alarm probabilities. In this paper, the false alarm probability is assumed to be almost zero [4]. Via simulation, we evaluate the proposed TDL system performance over PBNJ environments and verify its superiority to the conventional TDL [5-6].

The rest of this paper is organized as follows: Section II explains the proposed TDL system model including TDL simulator design. Section III addresses cognitive anti-
jamming operation and jammer signal detection, and Section IV presents the simulation results of the proposed TDL over PBNJ conditions. Finally, concluding remarks are given in Section V.

2 TDL System Model and Simulator Design

TDL system requests reliable real-time data transmission over severe tactical channel conditions including jamming and fading [5]. Link-16, a time division multiple access (TDMA)-based TDL system, allocates a time slot channel with the period of 1/128 sec to its terminals (users) with a transmit packet. A Link-16 terminal operates 51 FH frequencies within the signal bandwidth of 3 MHz and randomly hops to one of those FH frequencies every 13 μsec [6]. Fig. 1 shows a block diagram of the presented Link-16-based TDL with CAJC. This TDL consists of a random data signal generator, a CCSK module for base-band modulation and demodulation, a MSK/FH module for chip signal modulation and FH spreading, a time synchronization block, a bit-error-rate (BER) check block, and a channel module for the AWGN, Rician fading, partial band noise jamming (PBNJ) channel setting. The proposed TDL also includes a cognitive anti-jamming block (the shaded one in Fig. 1) that can detect (sense) the jammer signal and opportunistically avoid the jammer spectrum. We assume that for anti-jamming operation, every TDL terminal has a frequency hopping table, termed ‘t-Hop-Frequency’, and randomly hops to one of those hopping frequencies in that table every hop time. For simulator simplicity, we omit channel encoder/decoder.

The presented TDL can simulate the partial-band noise jammer using a jamming sub-block which is included in the channel module (see Fig. 1). In that jamming sub-block, we can set the jamming spectrum ratio \( \rho \) (= jamming bandwidth / total signal bandwidth (= 153MHz)) and \( E_b(N_o + N_j) \) (= bit energy per noise plus jammer spectral density). In simulation, we assume that no-jamming channel has \( E_b/N_o = 20\text{dB} \).

Fig. 2 shows the block diagram of proposed TDL simulator with CAJC. For CAJC, the presented simulator implements a cognitive anti-jamming circuit (see a broken-line box in Fig. 2). This circuit combines conventional frequency hopping (FH)-based anti-jamming function with cognitive radio (CR) spectrum sensing (SS)-based jammer detection function such that TDL anti-jamming capability is improved. For practicality, we consider the imperfect jammer spectrum sensing with non-zero miss-detection probability, i.e., \( P_{md} \neq 0 \) (but we assume almost zero false alarm probability for the improved system robustness to channel noise conditions). As seen in Fig. 2, 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) pass through each different path (one for jamming signal path and the other one for no-jamming signal path). For a certain \( P_{md} \), we can set a corresponding threshold value in terms of \( E_b/N_j \).

3 Cognitive Anti-Jamming Operation and Jammer Signal Detection

3.1 Cognitive anti-jamming

In the presented TDL, each terminal can choose one of two FH operating modes: fixed operation mode and adaptive operation mode (or cognitive anti-jamming operation mode). While a terminal at the fixed operation mode performs conventional FH operation where a fixed frequency table ‘t-Hop-Frequency’ is used, a terminal at the adaptive operation mode executes cognitive FH operation where a varying table ‘t-Hop-Frequency’ depending on the jamming channel conditions is used.
Fig. 2. TDL simulator using Matlab/Simulink (SE detection: red-coloured box / SJNR detection: blue-coloured box).

Fig. 3 shows a flow chart of the cognitive anti-jamming operation mode of the presented TDL. First, once a jammer signal is detected, the receiver terminal generates (updates) the jamming channel status information (JCSI) which includes a list of jammed FH channels and signal-to-jammer-plus-noise ratio (SJNR) per channel and feedbacks JCSI to the transmitter terminal. Then, the transmitter terminal sends ACK back to the receiver and as soon as ACK is received, the receiver terminal uses the updated t-Hop-frequency for FH operation. Hence, the presented TDL system can effectively and timely avoid the jammer spectrum for reliable data transmission.

3.2 Jammer Signal Detection

In the designed simulator, we choose either SS-based jammer signal detection techniques such as SE or SJNR or hybrid SS-based jammer signal detection techniques. In hybrid techniques, we use both beacon detection and SS-based detection such that the detection reliability is improved. Assume that the proposed TDL is able to scan the entire frequency spectrum by hopping all the allocated FH channels in equal probability matter. Below explains each of jammer signal detections in further detail.

Fig. 3. Cognitive anti-jamming operation.
3.2.1 Signal Energy Detection

The light-red-coloured box in Fig. 2 indicates the signal energy detection (SE) module in the designed simulator. SE is relatively simple but has a faster processing time than other methods. Assume that average received signal energy per channel has been limited due to power resource control. Hence, in the SE module, the average signal power of the $h$th ($=1, 2, \ldots, H$) channel

$$\bar{P}_{h,r} = \frac{1}{N} \sum_{n=0}^{N-1} |r_{h,n}|^2$$

(where $r_{h,n}$ denotes the $h$th channel received signal samples and $N (>> 1)$ denotes the observed sample size) compares to a given threshold $\Delta_{SE}$. If $\bar{P}_{h,r} \geq \Delta_{SE}$, a jammer signal is detected at the $h$th channel, otherwise a normal signal is detected. Through this scanning process, if the jammer signal is detected on adjacent $H (>1)$ channels, we can hypothesize that the PBNJ event occurs. During this scanning process, the receiver terminal periodically generates (or updates) JCSI for the jammed channel and feedbacks it to the transmitter terminal.

3.2.2 Signal-to-Jammer-plus-Noise Ratio Detection

The light-blue-coloured box in Fig. 2 indicates the SJNR detection module in the designed simulator. Assume that the received signal at the $h$th channel is denoted as $r_{h,k} = s_{h,k} + j_{h,k} + n_{h,k}$. The signal power to jammer-plus-noise power ratio (SJNR) representing signal quality is given as [7]

$$SJNR = \frac{\sigma_s^2}{\sigma_j^2 + \sigma_n^2} = \frac{\left(\frac{1}{N} \sum_{k=1}^{N} |r_{h,k}|^2\right)^2}{\left(\frac{1}{N} \sum_{k=1}^{N} |r_{h,k}|^2 - \left(\frac{1}{N} \sum_{k=1}^{N} |r_{h,k}|^2\right)^2\right)}$$

For the jammer signal detection, the measured SJNR per channel is compared to a threshold $\Delta_{SJNR}$. If $\text{SJNR} < \Delta_{SJNR}$, then the jammer signal is detected at the $h$th channel, otherwise the normal signal is detected. Through this scanning process, if the jammer signal is detected on adjacent $H (>1)$ channels, we can hypothesize that the PBNJ event occurs. During this scanning process, the receiver terminal periodically generates (or updates) JCSI for the jammed channel and feedbacks it to the transmitter terminal.

3.2.3 Hybrid Detection

In simulator, we also implement a hybrid detection method that combines beacon (pilot data) sensing with SS-based sensing. Fig. 4 shows the hybrid detection block. In simulator, for simplicity, we consider two kinds of hybrid methods depending on the SS scheme: energy-based spectrum sensing with beacon detection (BC_SE) and signal-to-jammer-plus-noise rate (SJNR)-based spectrum sensing with beacon detection (BC_SJNR).

In hybrid detection block, a pre-known pilot data is used to double check the validity of the jamming signal detected by one of spectrum sensing-based techniques (SE or SJNR). We assume that beacon channel is uniformly distributed over all hopping channels.

![Cognitive Pulsed Band Jamming with Beacon(Energy or SJNR)](image)

Fig. 4. Beacon + SE or Beacon + SJNR-based hybrid detection block.

In these hybrid methods, only when the jammer signal is sensed by both SS and beacon sensing, we decide that the jammer event occurs. Hence, the reliability of the jammer signal detection is improved by keeping the false alarm probability $P_{fa}$ below threshold $(\max \{P_{fa}\} \leq 0.01\%)$ while reducing the miss-detection probability $P_{md}$. 
4 Simulation Results

![Graph](image)

**Fig. 5.** BER performance versus $P_{md}$ of the proposed TDL.

that the $k$ factor is equal to 10 and the Doppler frequency is 777 Hz (where the carrier frequency $f_c = 8.4$ GHz is assumed) considering the real terminal speed.

Fig. 5 shows the BER performance versus $P_{md}$ of the proposed TDL with cognitive anti-jamming capability. As $P_{md}$ increases, we can observe that the difference from the ideal curve (i.e., $P_{md} = 0\%$) becomes larger. Specifically, the curve of $P_{md} = 10\%$ has approximately 4dB gain as compared to the one of $P_{md} = 20\%$ at the basis of BER $= 10^{-3}$ and approximately 6dB gain as compared to the one of $P_{md} = 30\%$ at the basis of BER $= 10^{-3}$.

![Graph](image)

**Fig. 6.** BER performance of the conventional TDL and the proposed TDL over partial-band noise jamming with $\rho = 10\%$.

In simulation, we assume that $P_{ja}$ is less than 0.01%. Assume that every normal FH channel (i.e., no jamming channel) has $E_b/N_0 = 20$dB. Then, SJNR, defined as $E_b/(N_j + N_0)$, of any jammed channel would be less than 20dB. We also assume

![Graph](image)

**Fig. 6.** BER performance of the conventional TDL and the proposed TDL under partial-band noise jamming conditions.

5 Conclusions

We designed a TDL system simulator with cognitive anti-jamming capability using Matlab/Simulink. Numerical results using the simulator proved that the proposed TDL is more robust to the conventional TDL over partial-band noise jamming conditions. We confirmed that hybrid SS-based detection with some additional complexity due to beacon channel is superior to generic SS-based scheme. We also observed that even simple detection schemes like SE or BC_SE improve the system gain of existing Link-16-based TDL 0.5dB up to 3dB.
6 References


