Distributed Cooperative Jamming with Multi-Reference Known-Interference Cancellation

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***Abstract*—Secure and reliable tactical communications within allied defense forces across a battlefield are often fundamental for achieving the forces' operational targets against an adversary. Likewise, limiting the adversary's capability to communicate securely and reliably promotes the host forces' chances for operational success. As such, armed conflicts typically involve an underlying battle in the electromagnetic (EM) spectrum to facilitate one's own communications and limit the opposition's. In this work, we propose the use of distributed cooperative jamming for augmenting tactical communications and gaining a technological advantage in that underlying battle. Specifically, we propose a multi-reference known-interference cancellation (KIC) method that allows the host force tactical communication nodes to cancel known interference (KI) from multiple cooperative jammers simultaneously. Relying on simulations, we then study how cooperative jamming affects the opposing forces' capabilities to use the EM spectrum in a simplified battlefield. Results show that cooperative jamming gives an advantage to those controlling the jammers, as the opposition's use of the EM spectrum is obstructed for both communications and signals intelligence.**

I. Introduction

Broadcasting an interference signal that is known to only authorized radio nodes allows securing transmissions between the authorized nodes from unauthorized interception if the authorized nodes have the technological capability to cancel the received known interference (KI) [1]. Furthermore, preoccupying the electromagnetic (EM) spectrum with interference that the unauthorized nodes do not have knowledge about and cannot cancel also prevents the unauthorized nodes from wirelessly communicating among themselves. Intentional use of KI together with known-interference cancellation (KIC) at authorized nodes is an intriguing concept that has the potential to improve the success rate of tactical operations, as more efficient use of the communication resources can lead to more effective military operations [2].

So far, the above concept has already been demonstrated feasible in controlled environments with a single interference transmitter [3], [4]. However, using a single interference source, often termed as a cooperative jammer, to secure an entire battlefield is likely impractical, as the output powers of practical jammers are limited and, thus, the effective range of a single cooperative jammer restricted.

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It would therefore be advantageous to distribute multiple cooperative jammers across the battlefield. Optimization methods have been developed that guide the placement of jammers to efficiently thwart an adversary's tactical communications when knowledge about node placement is available [5]. In some situations this goal may be achieved by placing the jammers so that any authorized node is in the range of only a single cooperative jammer. However, in practice when knowledge about node placement is not necessarily available, when the nodes are highly mobile, and when moving the jammers is not trivial, it would be beneficial to have the cooperative jammers placed so that their individual ranges overlap with each other to some extent as illustrated in Fig. 1. This would help ensure that an adversary cannot avoid the effect of the interference signals through fortunate nor careful positioning. However, this also complicates canceling the KI at the authorized nodes whenever in the range of multiple cooperative jammers.

In this work, we extend the single-reference KIC method of [3] to work in multi-reference configuration. Through simulations, we analyze how the developed method handles KI that is received together with a tactical communication signal, and how that performance potentially affects tactical communications on the battlefield.

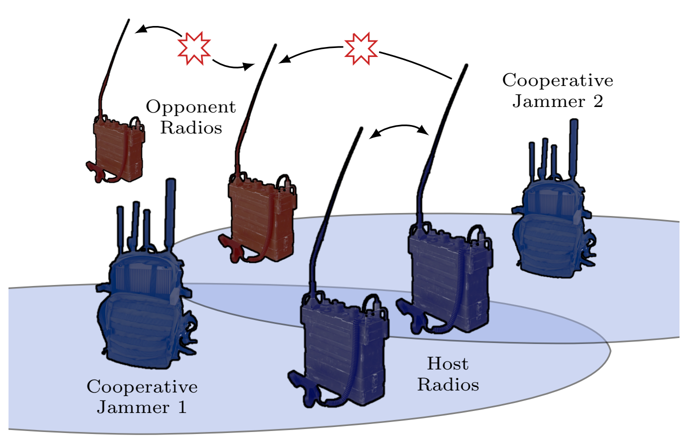


Fig. 1. Distributing cooperative jammers prevents unauthorized nodes from accessing the EM spectrum across a wide area. Where different jamming coverage areas overlap, multi-reference KIC becomes a necessity for authorized nodes to remain operational. These together yield localized EM advantage.

II. Multi-Reference KIC

Canceling KI is not trivial because even when the discrete-time baseband signal that is transmitted by one radio is known in advance to another radio receiving that signal, the signal undergoes significant changes as it travels from the transmitter to the receiver over the wireless channel. This is due to the typically time-varying multipath propagation, radio-frequency (RF) front-end nonlinearities, and frequency offsets across radios. Compensating for many of these changes has already been studied in the context of full-duplex (FD) radio technology [6], where the signal from the transmitter of a single radio transceiver propagates to its receiver, necessitating self-interference cancellation (SIC). Indeed, FD radio technology can also be advantageous in tactical scenarios by facilitating various same-frequency transmit and receive operations simultaneously [7], [8]. However, FD radio technology still limits the same-frequency simultaneous operation to a single transceiver and SIC methods are not directly applicable for KIC across radios as SIC methods do not need to account for the carrier and sampling frequency offsets that inevitably emerge when dealing with separate radios.

Few methods have been developed to account for these frequency offsets and facilitate KIC [3], [4]. However, these KIC methods have been developed and tested to work with a single KI source only. Herein, we extend the single-reference KIC method proposed in [3] to handle K different KI signals that are received superposed with a signal of interest as

$$d(n) = \sum_{k=1}^{K} \mathbf{h}_k^H \mathbf{y}_{k_n} e^{j\sum_{i=1}^{n} \boldsymbol{\epsilon}_k(i)} + \mathbf{h}_{\mathrm{tr}}^H \mathbf{s}_n + v(n), \tag{1}$$

where $\mathbf{h}_k \in \mathbb{C}^M \ \forall\ 1 \leq k \leq K$ and $\mathbf{h}_{\mathrm{tr}} \in \mathbb{C}^M$ are the channel impulse responses from the jammers and the signal-of-interest transmitter to the receiver respectively, $\mathbf{y}_{k_n}$ accounts for sampling the KI $x_k(n)$ from k-th jammer with time-varying sampling frequency offset $\boldsymbol{\eta}_k(n)$ according to (2) in [9], the multiplicative term $e^{j\sum_{i=1}^{n}\boldsymbol{\epsilon}_k(i)}$ accounts for the carrier frequency offset between the k-th jammer and the receiver, $\mathbf{s}_n = [s(n), s(n-1), \ldots, s(n-M+1)]^T$ is the signal of interest, and $v(n)$ is the measurement noise.

The proposed multi-reference KIC method is listed as Algorithm 1, where M denotes the number of filter taps used by the algorithm to model the channels, K is the number of reference KI signals, N is the number of received samples, the input matrix $\mathbf{X} \in \mathbb{C}^{K\times N}$ holds the reference KI signals, d holds the received signal, and $\boldsymbol{\mu}_h \in \mathbb{R}^K$, $\boldsymbol{\mu}_\epsilon \in \mathbb{R}^K$, and $\boldsymbol{\mu}_\eta \in \mathbb{R}^K$ are the step size vectors for controlling the rate of channel, carrier frequency offset, and sampling frequency offset estimation for each of the reference signals. Both the single-reference KIC method [3] and the multi-refence KIC method proposed herein build on the frequency offsets least mean squares (FO-LMS) algorithm that estimates a wireless channel under frequency offsets [9]. For multi-reference operation, Algorithm 1 carries out the steps of the original FO-LMS for all of the reference signals in parallel, combining the estimates of the received reference signals to get an estimate of the superposition of the received reference signals. By subtracting that from the actual received signal, the algorithm provides an error signal

$$e(n) = d(n) - \sum_{k=1}^{K} \hat{\mathbf{h}}_{k_{n-1}}^H \hat{\mathbf{y}}_{k_n} e^{j\sum_{i=1}^{n-1}\hat{\boldsymbol{\epsilon}}_k(i)} \approx \mathbf{h}_{\mathrm{tr}}^H \mathbf{s}_n + v(n), \tag{2}$$

which with very good estimates $\hat{\mathbf{h}}_k$, $\hat{\boldsymbol{\epsilon}}_k$, and $\hat{\boldsymbol{\eta}}_k$ for all k at sample index n, will approximate to the tactical communication signal and measurement noise, thus resulting in KIC.

Algorithm 1 multi-reference extension of the FO-LMS algorithm

procedure MR-FO-LMS($M, K, N, \mathbf{X}, d, \boldsymbol{\mu}_h, \boldsymbol{\mu}_\epsilon, \boldsymbol{\mu}_\eta$)
    $\hat{\mathbf{H}}_0 \leftarrow \mathbf{0}_{K\times M}, \hat{\boldsymbol{\epsilon}}_0 \leftarrow \mathbf{0}_K^T,\ \hat{\boldsymbol{\eta}}_0 \leftarrow \mathbf{0}_K^T$ // Initializing parameter estimates
    $\hat{\mathbf{Y}}_0 \leftarrow \mathbf{0}_{K\times M},\ \boldsymbol{\phi}_1 \leftarrow \mathbf{0}_K^T,\ \mathbf{t}_1 \leftarrow \mathbf{0}_K^T$ // Initializing internal variables

    for $n \leftarrow 1$ to N **do** // Iterating over received samples
        for $k \leftarrow 1$ to K **do**
            $\hat{\mathbf{Y}}_{n_k} \leftarrow [\mathbf{X}_k(\mathbf{t}_k), \mathbf{X}_k(\mathbf{t}_k - (1+\hat{\boldsymbol{\eta}}_k)), \ldots, \mathbf{X}_k(\mathbf{t}_k - (M+1)(1+\hat{\boldsymbol{\eta}}_k))]$ // Sampling rate conversion
        end for
        $\hat{\mathbf{d}}_n \leftarrow \mathrm{diag}\left(\hat{\mathbf{H}}_{n-1}\hat{\mathbf{Y}}_n^T\right) \circ \left[e^{j\boldsymbol{\phi}_n(1)}, \ldots, e^{j\boldsymbol{\phi}_n(K)}\right]^T$
        $e(n) \leftarrow d(n) - \sum_{k=1}^{K} \hat{\mathbf{d}}_n(k)$ // Estimation error calculation
        $\hat{\mathbf{H}}_n \leftarrow \hat{\mathbf{H}}_{n-1} + \boldsymbol{\mu}_h^T \mathbf{1}_M \circ \left[\hat{\mathbf{Y}}_n \circ \left[e^{j\boldsymbol{\phi}_n(1)}, \ldots, e^{j\boldsymbol{\phi}_n(K)}\right]^T \mathbf{1}_M\right]^* e(n)$ // Channel estimation
        $\hat{\boldsymbol{\epsilon}}_n \leftarrow \hat{\boldsymbol{\epsilon}}_{n-1} + \boldsymbol{\mu}_\epsilon \circ \Im\left\{\hat{\mathbf{d}}_n^* e(n)\right\}$ // Carrier frequency offset estimation
        $\hat{\boldsymbol{\eta}}_n \leftarrow \hat{\boldsymbol{\eta}}_{n-1} + \boldsymbol{\mu}_\eta \circ \Re\left\{\left[\hat{\mathbf{H}}_{n-1}\hat{\mathbf{Y}}'_n e^{j\boldsymbol{\phi}_n}\right]^* e(n)\right\}$ // Sampling frequency offset estimation
        $\boldsymbol{\phi}_{n+1} \leftarrow \boldsymbol{\phi}_n + \hat{\boldsymbol{\epsilon}}_n$
        $\mathbf{t}_{n+1} \leftarrow \mathbf{t}_n + (\mathbf{1}_K^T + \hat{\boldsymbol{\eta}}_n)$
    end for
end procedure

III. Simulation Setup

In order to assess the usability of the multi-reference KIC method described in Section II, we evaluated its performance when dealing with a combination of KI and tactical communication signals using simulations as described below.

1) Known Interference: We generated two jamming signals by drawing their samples from a pseudorandom number generator (PRNG) with normal distribution, using different seeds in the PRNG for the two signals. We then filtered both of these signals down to $100\,\mathrm{kHz}$ bandwidth from a $416\,\mathrm{kHz}$ sampling rate, resulting in different and uncorrelated bandlimited noise jamming signals. Knowledge of the seeds and filtering allows the jamming signals to be reconstructed at a receiver without transferring waveforms, hence forming two different KIs.

2) Signal of Interest: We recorded the RF output of a real tactical radio, a PRC-77, that was input with an audio recording of the NATO phonetic alphabet. This tactical radio modulates the input audio for RF transmission using analog frequency modulation and has a $50\,\mathrm{kHz}$ channel spacing. We recorded its RF transmission at a center frequency of $72\,\mathrm{MHz}$ over a coaxial cable using a vector signal transceiver (VST) with a sampling rate of $416\,\mathrm{kHz}$. This provided a baseband tactical communication signal that includes the effects caused by an actual tactical radio without any additional outside interference or noise. We used that baseband recording and the generated KI signals in the simulations to precisely control the received signal-to-interference-plus-noise ratio (SINR).

3) Impairments and Reception: The generated KIs and the recorded communication signal were put through an additive white Gaussian noise channel, with the two KIs received with some interference-to-noise ratios (INRs) plus the signal of interest received with some signal-to-noise ratio (SNR) on the same center frequency. The INRs and SNR consider the signals' power in the $50\,\mathrm{kHz}$ channel only. The KI signals were simulated to be received with carrier frequency offsets of $-1\,\mathrm{kHz}$ and $1\,\mathrm{kHz}$ and sampling frequency offsets of $-1\,\mathrm{Hz}$ and $1\,\mathrm{Hz}$. These are realistic offsets that can be expected in typical commercial off-the-shelf devices. In any given simulation, we always used the same KIs and the signal of interest but with a unique noise floor realization. The receiver then either canceled the KIs or not, depending on whether it was simulated to have the necessary knowledge and capability, before demodulating the baseband signal and outputting audio.

4) Speech Quality Assessment: To assess the quality of the received NATO phonetic alphabet reading, we relied on VISQOL, an objective speech quality metric that models human speech quality perception, providing a measure of similarity between a reference and a test speech signal [10]. VISQOL provides the measure of similarity as an estimate of the mean opinion score, in the range 1–5. However, the filtering applied inside the PRC-77 meant that after transmitting the audio through it, the audio quality was rated by VISQOL to be in the range 2–4.5. Still, VISQOL provided a consistent and qualitative measure of the received speech and, in that 2–4.5 score range, our subjective assessment is the speech to be intelligible above score 2.5 and decent above score 3.5.

5) Battlefield Model: We simulated the connections between 49 tactical communications nodes placed in a two-dimensional plane. The path loss between any two nodes in the simulations was calculated using the Egli model [11]. Within that model, antennas of all of the nodes were considered to be at a height of $1\,\mathrm{m}$ and have unit absolute gain. Carrier frequency of the transmissions was taken to be $72\,\mathrm{MHz}$. Jamming transmit power was taken to be $25\,\mathrm{W}$, tactical radios' transmit power to be $2\,\mathrm{W}$, and noise floor to be $-127\,\mathrm{dBm}$. In this work, each of the two-way tactical communication links were simulated in isolation. That is, without considering interference between nodes themselves. Although, admittedly, interference between co-existing nodes within a limited geographical area may further affect the success rate of the tactical communications [12]. Still, the presented approach provides insights about the impact of distributed cooperative jamming.

IV. Simulation Results

In this section, we present the simulated KIC results in three parts. First, we demonstrate how the proposed algorithm performs when receiving a single KI signal plus the tactical communication signal (translating the results of [3] to this military context). Secondly, we show how it performs when receiving multiple KI signals plus the tactical communication signal. Thirdly, we illustrate how that performance can potentially benefit tactical communication nodes in the battlefield.

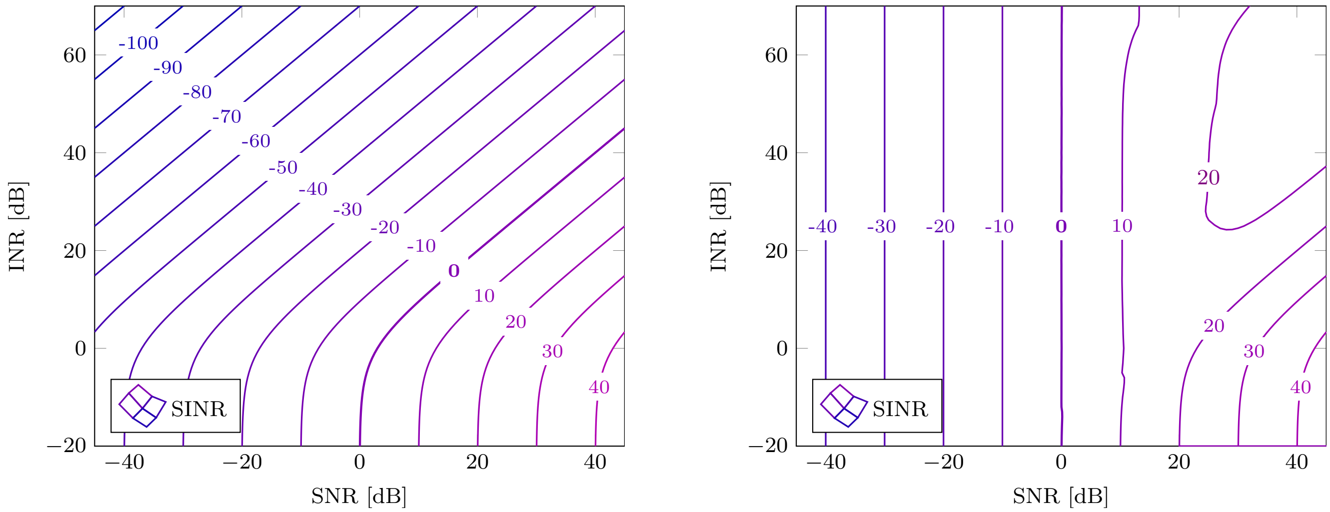
A. Single-Reference KIC

Fig. 2 illustrates Algorithm 1's capability to improve the SINR at a receiver by canceling a single KI signal that overlaps the signal of interest in both time and frequency. Specifically, these results show the SINRs without and with (or equivalently before and after) KIC at the receiver when receiving a superposition of the KI and the signal of interest, dependent on the individual received INR and SNR. Before the KI signal is canceled (Fig. 2a), the SINR is determined by the superposition of the two signals and increasing the INR decreases the SINR. However, after the KI signal is canceled (Fig. 2b), the SINR at the receiver is, for most SNR and INR combinations, considerably improved.

Ideally, the SINR after KIC would depend only on the SNR (i.e., all of the contour lines on Fig. 2b would be vertical), indicating that the KI was canceled completely. However, the simulated results deviate from the ideal results somewhat. This is further illustrated in Fig. 3, where the SINR loss without and with KIC compared to the ideal SINR is plotted. Without KIC, the loss in SINR compared to the ideal scenario is proportional to the received INR regardless of the SNR since

$$\frac{\mathrm{SNR}}{\mathrm{SINR}} = \frac{P_\mathrm{s}/P_\mathrm{n}}{P_\mathrm{s}/(P_\mathrm{i}+P_\mathrm{n})} = \frac{P_\mathrm{i}+P_\mathrm{n}}{P_\mathrm{n}} = \mathrm{INR}+1 \tag{3}$$

for all P_s, where P_s and P_i are the received powers of the signal of interest and KI respectively, and P_n is the receiver noise floor. With KIC, the loss in SINR is not as severe, but still exists in some cases — most notably when the two signals are received with comparable powers, as then the signal of interest somewhat hinders cancellation of the KI.



(a) Without KIC

(b) With KIC

Fig. 2. SINRs at the receiver without and with (or equivalently before and after) KIC with regard to the individual received INR and SNR.

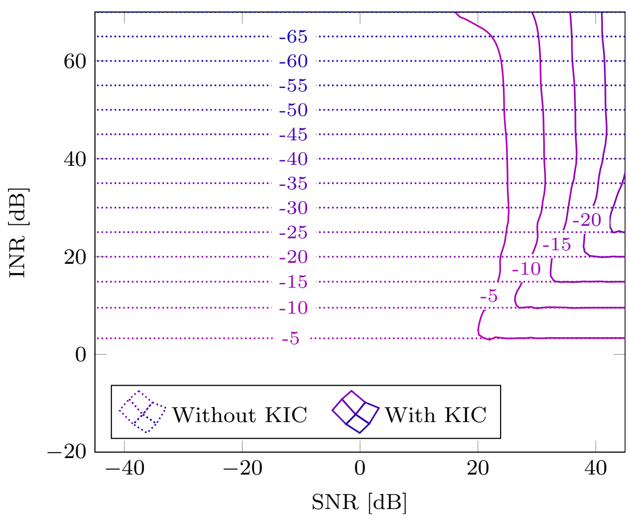


Fig. 3. SINR losses without and with KIC compared to perfect SINR (i.e., with perfect KIC or, equivalently, without cooperative jamming).

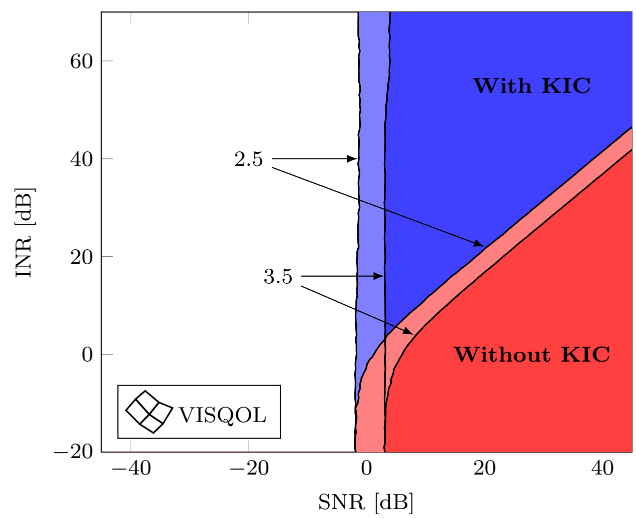


Fig. 4. VISQOL ratings of the received audio without and with KIC. The 2.5 and 3.5 thresholds represent the scores above which the perceived audio quality is "intelligible" and "decent", respectively.

Still, altogether Figs. 2 and 3 demonstrate that in the presence of a single KI and the tactical communication signal, the proposed KIC method is able to significantly improve the SINR even if some residual KI remains in some cases. Whether this residual KI has any meaningful negative effect on the following signal processing stages depends, however, on the SINR requirements therein. Fig. 4 illustrates how KIC affects processing the tactical communication signal by displaying the VISQOL score given for the demodulated audio at any point in the simulation grid. The results show that, if KIC is not used, then the received SNR in decibels needs to be positive and greater or on par with the received INR in order for the received speech to be intelligible. However, when KIC is used, then the received SNR merely needs to be positive regardless of the received INR. This all-around good performance with KIC is achieved despite the modest losses in SINR in some cases because the SINR in any case remains good enough for the tactical communication signal to be processed. These findings are analogous with the measurement results in [3], with some expected deviations due to the differing setups.

B. Multi-Reference KIC

Fig. 5 illustrates Algorithm 1's capability to improve the SINR at a receiver by canceling two KI signals that overlap the signal of interest in both time and frequency. Variations of the power-to-noise ratios of the three signals lead to a three-dimensional results space that is difficult to convey in its entirety. However, as seen from Fig. 4, an important boundary in the context of the tactical communications considered in this work is the $0\,\mathrm{dB}$ SINR threshold, above which the commu-

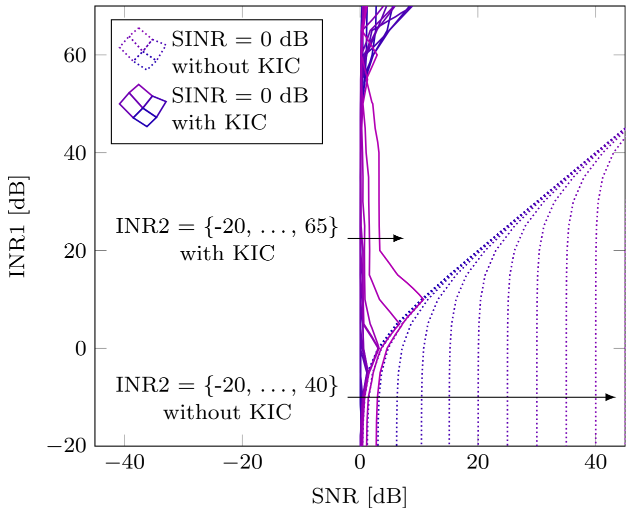


Fig. 5. $0\,\mathrm{dB}$ SINR thresholds without and with KIC with two KI sources.

nication signal is intelligible. Therefore, that $0\,\mathrm{dB}$ threshold without and with KIC is plotted in Fig. 5 while the INRs are varied with $5\,\mathrm{dB}$ steps. For each of the plotted curves, the tactical communication signal is then intelligible for the power-to-noise ratio combinations on the right-hand side of the curve. Fig. 5 shows that when KIC is not available, increasing the received KI power above noise floor (i.e., in decibels positive INR1 or INR2 or both) requires the received signal of interest power to be increased equivalently to reach $0\,\mathrm{dB}$ SINR. Expectedly, this means that without KIC capability, the only way to overcome the impact of distributed cooperative jamming is to receive a more powerful signal of interest. Fortunately, the results with KIC show that even with two KI signals, the $0\,\mathrm{dB}$ SINR threshold is achieved mostly as long as the SNR itself is positive. Again the results show some INR and SNR combinations where the KIC performance is not ideal. Specifically, when the differences in the received signal power levels are very large or very close. However, these results demonstrate that using the proposed multi-reference KIC leads to a substantial improvement in the receiver's ability to process the signal of interest under distributed cooperative jamming compared to when the jamming signals are not canceled at all.

C. Battlefield Performance

Given the performance of the proposed KIC method with single and multiple KI sources over a wide range of INRs and SNRs, it is interesting whether this performance potentially translates to augmenting tactical communications on a battlefield. In this subsection, that augmentation is looked at from two perspectives: Firstly by considering the extent to which distributed cooperative jamming prevents adversarial tactical nodes from communicating and how that affects the host nodes; and secondly by considering what effect distributed cooperative jamming has on adversarial eavesdroppers who are trying to intercept host communications.

In Fig. 6, the effect of a single cooperative jammer on host and adversarial tactical communications is demonstrated. Specifically, the simulation consists of a set of nodes that are placed in a two-dimensional plane so as to illustrate the effect that jamming and KIC have for a wide variety of node placements. The host nodes that have KIC capabilities are colored blue and the adversarial nodes without KIC are red. Based on the results and discussions in Subsection IV-A, it is assumed that any two same-team radio nodes in that plane can directly communicate with each other if the SINR at both of these nodes is greater than the threshold of $0\,\mathrm{dB}$. Functioning two-way communication links are drawn in black solid lines, jammed two-way communication links (i.e., those that without jamming would be functional) are drawn in dashed gray lines.

Fig. 6(a) demonstrates that a single cooperative jammer is able to effectively halt tactical communication links that span moderate distances in the jammer's vicinity while Fig. 6(b) illustrates that having the single-reference KIC capability allows tactical communication links under otherwise same conditions to remain functional. However, these results also illustrate that the single cooperative jammer has a limited effective range and that an adversary can overcome the effect of jamming, as long as the power of the received signal of interest is greater than that of the jamming signal. If the battlefield spans beyond the effective range of a single jammer then it becomes desirable to introduce additional cooperative jammers. And, to make it difficult for an adversary to overcome the effect of jamming, it would be advantageous to position the cooperative jammers so that the jammers' ranges overlap.

Using distributed cooperative jammers to extend the effective jamming range is demonstrated in Fig. 7. Indeed, Fig. 7(a) shows that placing multiple cooperative jammers with overlapping ranges allows to halt many of the tactical communication links that were unhindered by a single cooperative jammer, thus extending the effective range of cooperative jamming. However, Fig. 7(b) demonstrates that, with such cooperative jammer distribution, the single-reference KIC does not anymore provide adequate interference cancellation for the host nodes. This is visible from many of the wider spanning two-way links remaining halted as well as from the node in between the cooperative jammers that becomes completely disconnected. Clearly distributed cooperative jamming is efficient against nodes that it is meant to be effective against, but with only single-reference KIC capability, distributed cooperative jamming affects negatively the nodes that it is not meant to affect. Fig. 7(c) demonstrates that the multi-reference KIC method proposed in this work allows to overcome the limitations of single-reference KIC and enable host forces to communicate while preventing that for the adversary.

In Fig. 8, the effect of cooperative jamming on adversarial interception of host forces' tactical communications is considered. Note that the node placement in Fig. 6, 7 and 8 is the same, so it is readily visible which of the host nodes can communicate and also what impact the cooperative jamming has on their communications being potentially intercepted. Fig. 8(a) illustrates how simple it is for an adversary to intercept the

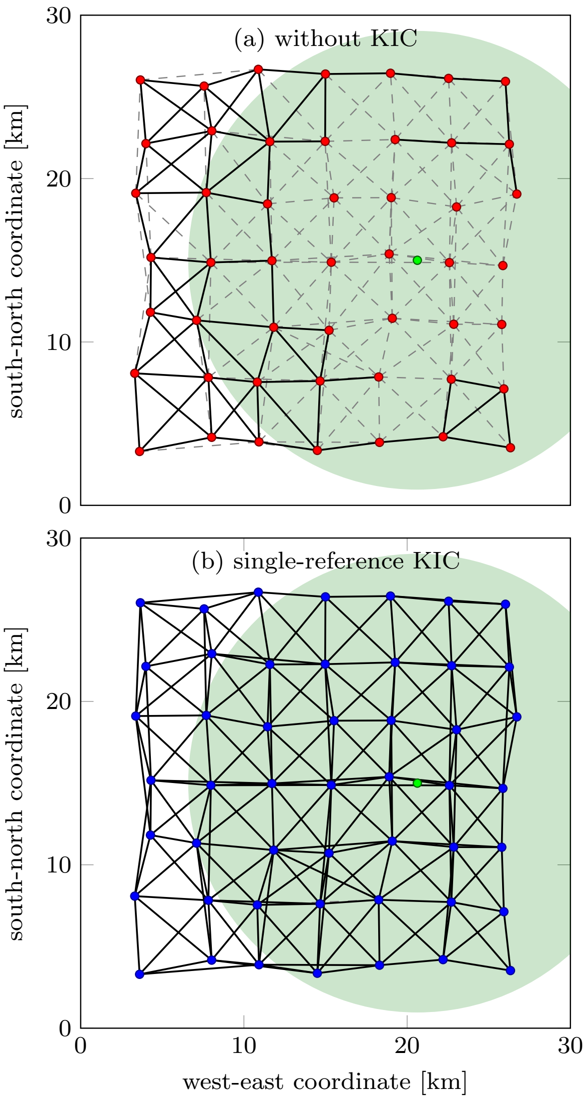


Fig. 6. Tactical communications with a single cooperative jammer. Red nodes are without KIC and blue nodes are with KIC. Green node is the cooperative jammer and the green background illustrates the area where the received interference is more powerful than the noise floor. Solid black lines indicate functioning links and dashed gray lines indicate jammed links.

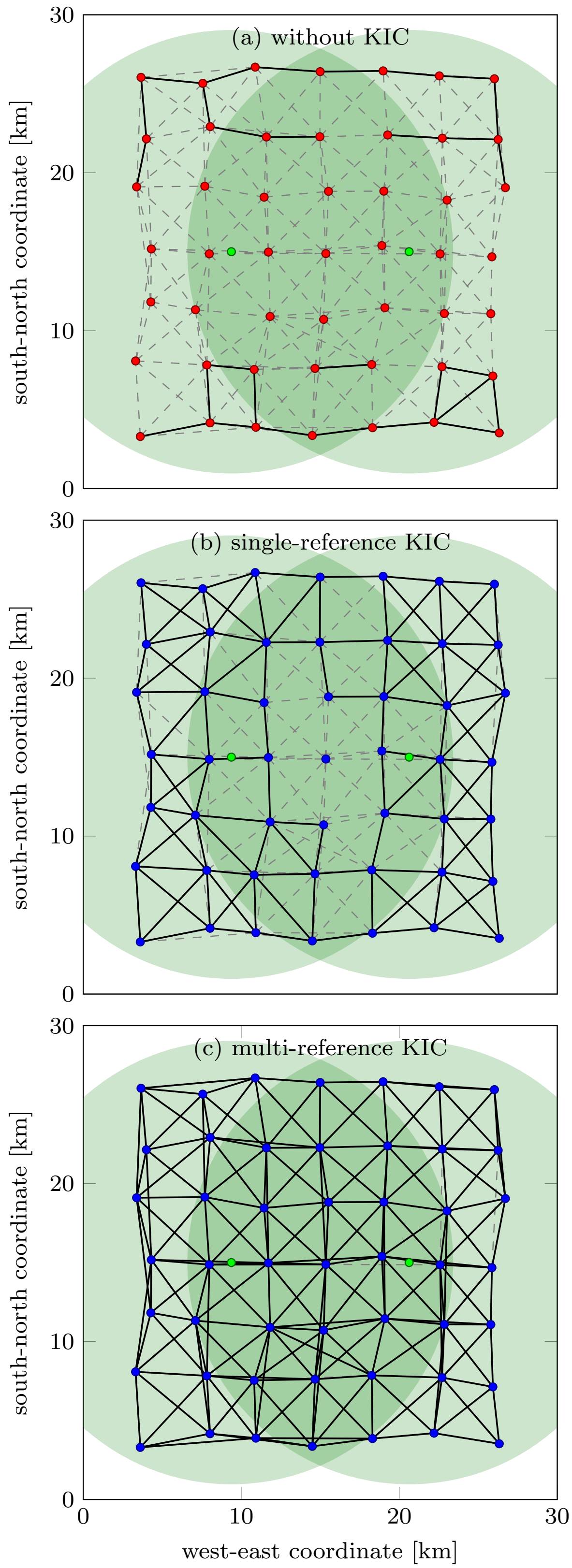


Fig. 7. Tactical communications with distributed cooperative jammers. Red nodes are without KIC and blue nodes are with KIC. Green nodes are the cooperative jammers and the green background illustrates the area where the received interference is more powerful than the noise floor. Solid black lines indicate functioning links and dashed gray lines indicate jammed links.

host communications if there are no preventive mechanisms in place as the interception range is solely determined by the SNR at the adversary. However, introducing one or two cooperative jammers (cf. Fig. 8) significantly reduces the interception ranges. It becomes especially difficult to eavesdrop on the host nodes that are near the cooperative jammers. Furthermore, it is not unreasonable to expect that, in comparable proportions to limiting eavesdropping, distributed cooperative jamming also limits an adversary's capability to detect the existence of host communications or to position the location of host nodes.

V. Conclusion

In this paper, we studied the concept of using distributed cooperative jammers for gaining a technological advantage against an adversary in the battle for superiority in the

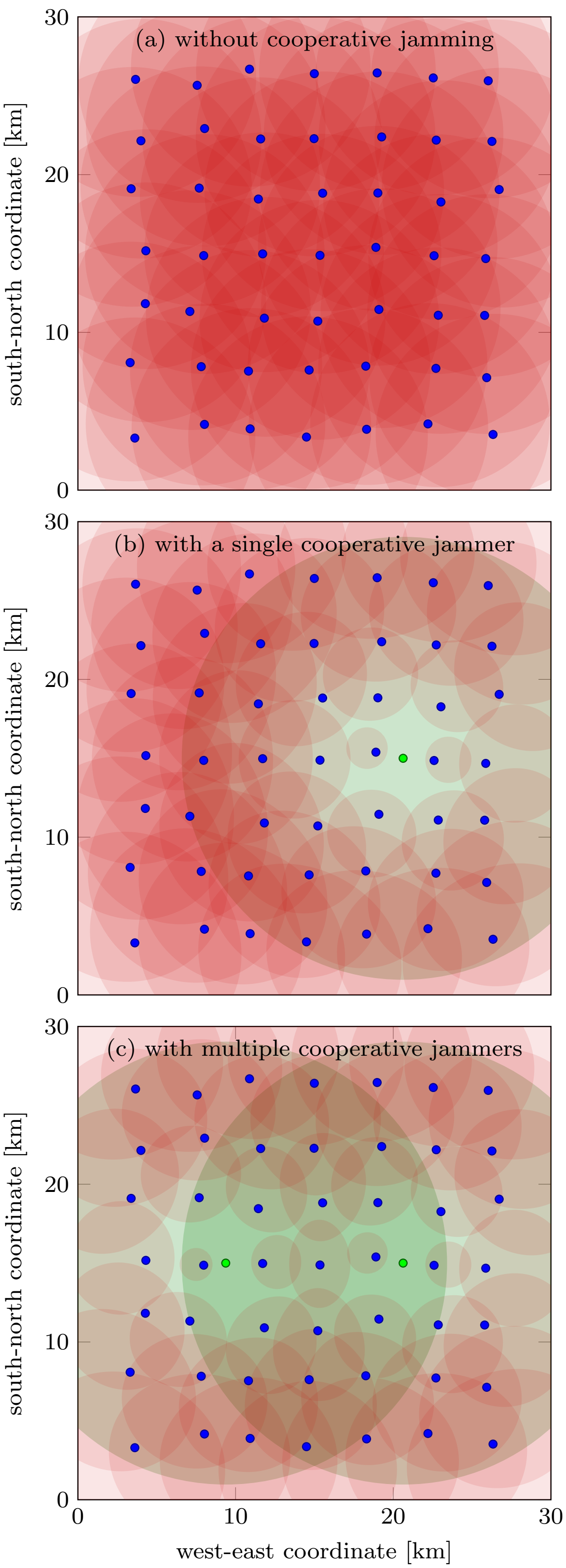


Fig. 8. Adversary's ability to intercept host's tactical communications. Blue nodes are host nodes with KIC capabilities and the red areas indicate where an adversary can intercept the communication signal from a host node. The green areas illustrate where the received jamming signal is more powerful than the noise floor.

electromagnetic (EM) spectrum. Specifically, we proposed an extended version of the single-reference frequency offsets least mean squares (FO-LMS) algorithm that then facilitates multi-reference known-interference cancellation (KIC). Simulation results demonstrated that the proposed algorithm is capable of suppressing known interference (KI) from multiple co-operative jammers with modest residual KI remaining after the KIC. Further analysis illustrated that, even though the residual KI is not negligible, its effect in case of processing realistic frequency-modulated tactical communication signals often is, due to the sufficient signal-to-interference-plus-noise ratio (SINR) after KIC. Considering the effect of employing multiple cooperative jammers in a battlefield-like scenario showed potential to drastically limit an adversary's capability for tactical communications while at the same time and same frequencies not limiting that of the host's. Also, cooperative jamming was shown to reduce an adversary's capability to intercept the host's tactical communications while not limiting the host's capability to carry out its communications. The proposed algorithm showed good performance from both of these points of view when within the range of single or multiple distributed cooperative jammers.

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