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Joint assignment of frequency and polarization to minimize the chromatic number[☆]

Bon-Hong Koo[a], H. Birkan Yilmaz[a], Chan-Byoung Chae[a,*], Sung-Ho Park[b], Hwi-Sung Park[c], Jae-Hyun Ham[c,*]

[a] *School of Integrated Technology, Yonsei Institute of Convergence Technology, Yonsei University, Republic of Korea*
[b] *Open SNS, Republic of Korea*
[c] *Agencies of Defense Department, Republic of Korea*

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Abstract

In this letter, we propose graph theory-based heuristics for jointly assigning frequency and antenna polarization in a cluster-based tactical communication environment (e.g., military communications). In addition to considering the frequency assignment problem (which is an NP-hard problem), we also consider the polarization assignment issue. A practical antenna and a 3D ray tracing-based simulator are exploited to measure the interference. We show that the suggested heuristics are nearly optimal in terms of chromatics and their low complexity makes them suitable for practical usage.

Keywords: Graph theory; Frequency assignment problem; Polarization

1. Introduction

Since the spectrum is a scarce and valuable resource, maximizing the use of radio resources is the aim of the frequency assignment problem (FAP). To optimize such an objective for the FAP, a well-known tool is graph theory [1]. A familiar topic in graph theory is determining the graph's chromatic number, which is related to the number of used frequencies in the FAP. The task of minimizing the chromatic is an NP-hard problem [1]. In the literature, different suboptimal heuristics have been devised for FAP including greedy and tabu searches [2,3]. The authors in [4,5] consider a realistic antenna pattern and filtering techniques.

A frequency assignment plan is feasible under the premise of having manageable interference between communication links. Frequencies that are assigned to interfering devices must be separated sufficiently to mitigate the interference; hence, decreasing the number of used frequencies is limited by the interference constraints. The literature has yet to consider only the frequency but rarely to the polarization. By adopting dual-pol antennas as in [6], a device can choose either vertical or horizontal polarization of the antenna. When transceivers use different polarizations, additional signal attenuation can occur compared to using identical polarization. Therefore, we must devise an adaptive and time efficient algorithm for assigning both the frequency and the polarization.

In this letter, we propose graph coloring-based sub-optimal algorithms that jointly assign, within a reasonable time, frequency and polarization. We demonstrate that the proposed algorithms are close to the optimal (in terms of number of frequencies) using analytically derived lower bounds.

2. System model

Topology. The target environment is a practical setup where the communication nodes use implemented antennas and are distributed on an actual map, as illustrated in Fig. 1. The

* Corresponding authors.
E-mail addresses: harpeng7675@yonsei.ac.kr (B.-H. Koo), birkan.yilmaz@yonsei.ac.kr (H.B. Yilmaz), cbchae@yonsei.ac.kr (C.-B. Chae), shpark@opensns.co.kr (S.-H. Park), 7hwisung7@add.re.kr (H.-S. Park), mjhham@add.re.kr (J.-H. Ham).

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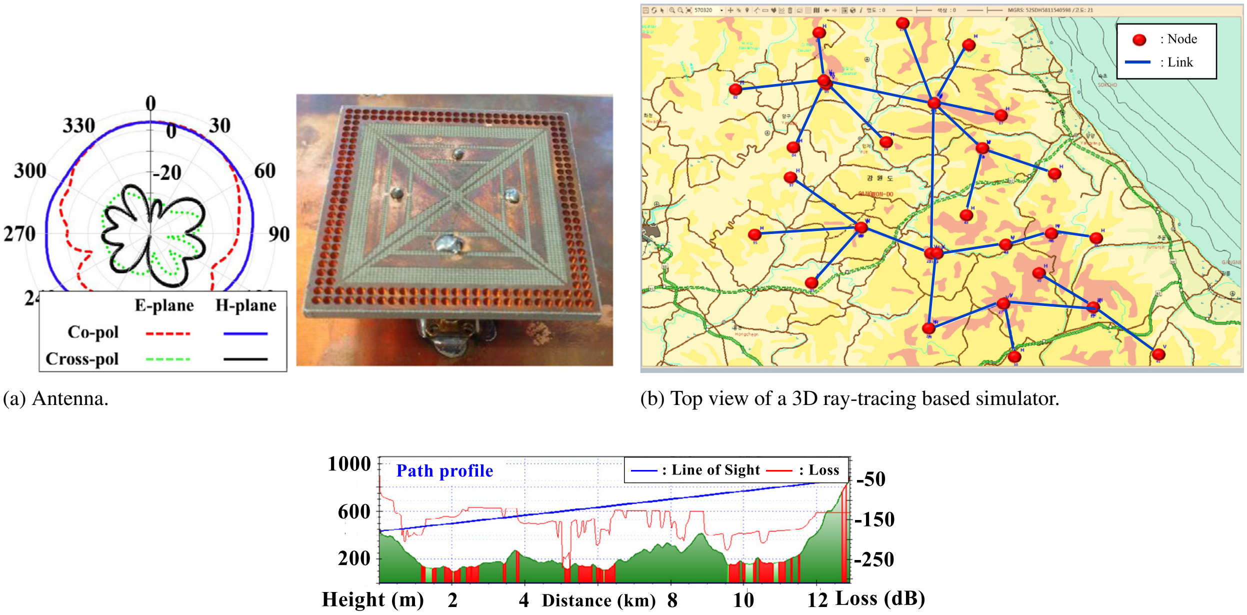

(a) Antenna.

(b) Top view of a 3D ray-tracing based simulator.

(c) Front view of a 3D ray-tracing based simulator.

Fig. 1. Practical antenna pattern and target environments including exact locations on an actual map and 3D path profiles.

communication devices are distributed in clusters on a 100 km × 100 km map. Each cluster contains a maximum of four devices and each of the devices has only one communication link with another node in a different cluster; a device can perform two-way communication. The communication distances have a limit of 20 km. Nodes are assumed to use the same transmit power ($\mathcal{P} = 1$ W) and the antennas are directed toward their pairs to maximize the antenna gain.

Interference measurements. To evaluate the proposed algorithms, we utilized the interference graphs of real and artificial cases. For the realistic scenario, we considered cases with 20, 50, and 200 nodes. 3D ray tracing was used to measure the power attenuation considering the antenna patterns, frequency separation, geographical data, climate, and wave propagation path profiles. 3-D ray tracing exploits our own implemented antenna, as indicated in Fig. 1(a) and the exact locations of the nodes, as indicated in Fig. 1(b) (for the 50-node case). Each antenna had two valid polarizations—vertical and horizontal; additional power attenuation is realized when the assigned antenna polarizations are different.

For the artificial scenario, we generated 10 random node topologies on the 2D space. Approximately 240 nodes within 80 clusters were generated over a 100 km × 100 km sized map. A transmitted signal experiences attenuation from line losses, antenna filters and propagation until it arrives at the receiver. If the received power is greater than the level of the receiver sensitivity, the gap must be attenuated by separating frequencies and polarizations. It can be obtained by (1) and defined as interference between the devices.

$$X = \max(\mathcal{P} + \mathcal{A} - PL(f, d) - \mathcal{L} - \mathcal{T}, 0). \quad (1)$$

The power attenuation due to the physical distance $PL(f, d)$ follows the ITU P.525 model [7] which is a function of a transmitted frequency f and the distance d. Antenna gain $\mathcal{A}$ is determined by the measured antenna pattern. The attenuation by frequency and polarization separation is obtained by the measurements of net filter discrimination (NFD) [8] and cross polarization discrimination (XPD), respectively. The latter is assumed to be a constant value of 30 dB. Line loss $\mathcal{L}$ is given as 3 dB for each transmitter and receiver; the receiver sensitivity level is given as −70 dBm.

Graph construction. The interference graph $G = (V, E)$ consists of a set of vertices V where the elements correspond to the communication links, and the edge matrix E, which indicates the interference between the communication links (i.e., vertex nodes). The interference from link-i to link-j is defined as the received power at link-j that is emitted from link-i. To ensure that the graph is undirected, values for E_{ij} and E_{ji} are taken as the maximum of the reciprocal interference between link-i and link-j.

Problem definition. We first assign the polarizations (i.e., transform the input graph) and continue with the frequency assignment. The polarization assignment function $P : G \rightarrow G_P = (V_P, E_P)$ assigns *vertical* or *horizontal* polarization to each of the nodes in V. The interference element is maintained constant (i.e., $E_{Pij} = E_{ij}$) when V_{Pi} and V_{Pj} have the same polarization; otherwise it is $E_{Pij} = E_{ij} - 30$. After the polarizations are set, the frequency assignment function $A : G_P \rightarrow G_A = (V_A, E_A)$ assigns a frequency from a set of all the frequency bands F to the links that consider the updated G_P. The ith element of V_A contains the assignment information of link-i, and E_{Aij} denotes the interference between the links after the final assignment. We define f_i as the ith element in F, which physically indicates that the band has its center frequency at f_i. The frequency bands have the same bandwidth and the centers of adjacent elements are equally separated.