A new area-based primary protection method with received power-based 3D antenna rotation range prediction for dynamic spectrum access

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Abstract: In this letter, we propose and evaluate a new area-based primary protection method for dynamic spectrum access, in which a secondary system uses a frequency band assigned to a primary system while it keeps an aggregate interference below an acceptable level of the primary system. We consider that a location information of a primary system’s reception station (PRS) whose antenna boresight faces towards a moving primary transmission station is ambiguous. To accurately calculate the aggregate interferences from the secondary system to the PRS in such a situation, the proposed method predicts a range of the PRS’s antenna rotation. Our simulation results show that the proposed method can increase availability of the secondary system significantly in a practical urban scenario.

Keywords: 5G, cognitive radio, spectrum sharing, dynamic spectrum access, field pickup unit (FPU), microwave link

Classification: Wireless communication technologies

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1 Introduction

Dynamic spectrum access (DSA) have been globally developed to overcome the depletion of frequency resources for mobile communication systems. DSA allows to allocate frequency resources which are unused by a primary system (PS) in terms of time and space to a secondary system (SS) while keeping an interference level caused from the SS to the PS lower than an allowable level of the PS (hereinafter, this technology is called primary protection). To implement the primary protection into practice, DSA introduces a spectrum management entity, which calculates potential interference levels and adjusts transmission parameters of the SS to avoid harmful interference to the PS. In the U.S., DSA has been commercialized as Citizens Broadband Radio System (CBRS) for the 4G systems in a 3.5 GHz frequency band [1]. CBRS has introduced Spectrum Access System (SAS) as the spectrum management entity.

In Japan, a commercial deployment of DSA with a spectrum management entity will begin in a 2.3 GHz band from 2021 [2]. In the 2.3 GHz band, Field Pickup Unit (FPU) systems have already been operated by broadcasters as the PS. An FPU is composed of a pair of a primary transmission station (PTS) and a primary reception station (PRS). The PTS moves along a predefined route like a
marathon course. The PRS is fixedly deployed at a higher location like a roof of a building. The PRS has a receive antenna and rotate a boresight direction of the antenna to the moving PTS to establish stable communications with sufficient signal quality [3][4]. To maximize availability of the 4G/5G system operation as the SS and to take care of the PRS’s antenna boresight rotation in interference calculation, we have proposed new primary protection methods [3][4]. In [3], we proposed a point-based primary protection (PPP) method, which took variations of the PRS’s antenna boresight directions into account. And then, we presented how to predict ranges of the variation of the PRS’s antenna boresight direction based on the location of the PRS and the predefined route of the PTS. In [4], we modified our proposed method from PPP to an area-based primary protection (APP), which does not require accurate location information of the PRS. Furthermore, we addressed an antenna rotation range prediction algorithm which is based on received powers from the PTS to the PRS. Our simulations showed that the proposed APP with the antenna rotation range prediction can improve the availability of the secondary systems more than a conventional method even if it is hard for the broadcasters to provide accurate information about the PRS for DSA.

However, in [4], we evaluated our proposed methods under simple scenarios. To elaborate on the effectiveness of our method towards the commercial deployment, it will be required to show further evaluation results in practical scenarios. Therefore, in this letter, we evaluate the proposed APP in a practical urban scenario, which must be a most important one for DSA in the 2.3 GHz band. In the following we describe details of our proposed method. Then we demonstrate by simulations that our proposed APP is superior to a conventional method and that it is useful in practical scenarios.

2 Proposed area-based primary protection
2.1 Concept of proposed APP
In Japan, the FPU is mainly used for video content delivery of a road race. The PRS which is temporarily installed on buildings or mountains receives video signals sent from the PTS moving on a road as shown in Fig. 1 (a). For stable video transmission, the PRS’s antenna boresight is rotated for tracking the moving PTS. In such situations, a variation of the PRS’s antenna boresight direction is limited into a certain range as shown in Fig. 1 (a). The PRS can communicate with the PTS stably within the range. The proposed PPP predicts this limited ranges of the fixed PRS and calculates aggregate interference from the SBSs by using the predicted range. Furthermore, we consider practical scenarios of the commercial deployment of DSA, in which the PRS’s location information is likely to be provided as a protected area (PA) and the PRS may be installed within the PA. Therefore, in the proposed APP, the antenna rotation range prediction and aggregate interference calculation are performed for each protection point (PP) defined within the PA.

2.2 Procedure of proposed APP
The proposed APP can be divided in three steps: PP definition, PRS’s antenna
boresight rotation range prediction and SBS suspension list (SBS-SL) calculation. The SBS-SL is a list of SBSs that must suspend transmission for the protection of the PRS.

First, the proposed APP defines the PPs as grid points within the PA. Here, the \( p \)-th PP in the PA is represented as \( R_p \).

Second, the ranges of the variation of the PRS’s antenna boresight direction is predicted at each PP. Fig. 1 (b) shows a positional relationship of a PRS at \( R_p \) and a route \( f \) where a PTS moves. The point \( T_\phi \) on \( f \) and the elevation angle of the PRS’s antenna boresight \( \theta_\phi \) are determined by the azimuth angle of the PRS’s antenna boresight \( \phi \). When the angles of PRS’s antenna boresight are \( \phi \) and \( \theta_\phi \), a received power from the PTS at \( T_\phi \) to the PRS at \( R_p \), \( P_{T_\phi \rightarrow R_p} \), can be expressed as follows in dB:

\[
P_{T_\phi \rightarrow R_p} = P_{TX} - L_{T_\phi \rightarrow R_p} - L_{RX} + G_{RX} \tag{1}
\]
where \( P_{TX} \) is an EIRP of the PTS, and \( L_{RX} \) and \( G_{RX} \) are a feeder loss and the maximum antenna gain of the PRS, respectively. \( L_{T_\phi \rightarrow R_p} \) is a propagation loss from \( T_\phi \) to \( R_p \). Here, a range of the azimuth angles \( \phi \) that satisfies the condition
$P_{\text{required}} \leq P_{T_{p} \rightarrow R_{p}}$ is represented as $\varphi_{\text{start}}^{p} \leq \varphi \leq \varphi_{\text{end}}^{p}$, where $\varphi_{\text{start}}^{p}$ and $\varphi_{\text{end}}^{p}$ are the minimum and maximum azimuth angles that satisfy $P_{\text{required}} \leq P_{T_{p} \rightarrow R_{p}}$, respectively. $P_{\text{required}}$ is the required received power for stable video reception at the PRS.

Finally, the SBS-SL is calculated as the union of SBS-SLs corresponding to all PPs. To calculate the SBS-SL corresponding to $R_{p}, M_{p}$, the range $\varphi_{\text{start}}^{p} \leq \varphi \leq \varphi_{\text{end}}^{p}$ is sampled with a sampling number $N_{s}$. The sampled azimuth angle is expressed as $\varphi_{i} \ (0 \leq i < N_{s})$. Next, an SBS-SL corresponding to each $\varphi_{i}, M_{i}$, is calculated. $S = \{BS_{0}, BS_{2}, ..., BS_{NBS-1}\}$ is a list of all SBSs to which evaluation of the interference is required. The SBSs in $S$ are sorted in ascending order of $P_{BS_{j} \rightarrow R_{p}}^{p_{i}} \ (0 \leq j < N_{BS})$ which is the interference power from the $j$-th SBS $BS_{j}$ to the PRS at $R_{p}$ when $\varphi = \varphi_{i}$. As shown in Fig. 1 (c), $P_{BS_{j} \rightarrow R_{p}}^{p_{i}}$ can be expressed as follows in dB:

$$P_{BS_{j} \rightarrow R_{p}}^{p_{i}} = P_{BS_{j}} + G_{BS_{j} \rightarrow R_{p}} - L_{BS_{j} \rightarrow R_{p}} - L_{R_{p}} + G_{R_{p} \rightarrow BS_{j}}^{p_{i}}$$  \hspace{1cm} (2)$$

where $P_{BS_{j}}$ is a conducted power of $BS_{j}$, $G_{BS_{j} \rightarrow R_{p}}$ is an antenna gain of $BS_{j}$ in the direction to $R_{p}$, $L_{BS_{j} \rightarrow R_{p}}$ is a propagation loss from $BS_{j}$ to the PRS at $R_{p}$, $L_{R_{p}}$ is a feeder loss of the PRS, and $G_{R_{p} \rightarrow BS_{j}}^{p_{i}}$ is an antenna gain of the PRS at $R_{p}$ in the direction to $BS_{j}$ when $\varphi = \varphi_{i}$. After calculating $P_{BS_{j} \rightarrow R_{p}}^{p_{i}}$, the largest $j_{i}$ which satisfies a condition that the aggregate interference power $I_{\text{aggregate},j_{i}}$ is less than or equal to an allowable interference power $I_{\text{allowed}}$ is selected. The condition of the $I_{\text{aggregate},j_{i}}$ can be expressed as follows:

$$I_{\text{aggregate},j_{i}} = \sum_{j=0}^{j_{i}} P_{BS_{j} \rightarrow R_{p}}^{p_{i}} \leq I_{\text{allowed}}$$  \hspace{1cm} (3)$$

By using the largest $j_{i}$, the SBS-SL corresponding to $\varphi_{i}$ is determined to be $M_{i} = \{BS_{j_{i}+1}, BS_{j_{i}+2}, ..., BS_{NBS-1}\}$. Then the SBS-SL corresponding to $R_{p}, M_{p}$, can be obtained by calculating the union of all $M_{i}$.

3 Evaluation by simulation

3.1 Simulation parameters

Table I (a) shows the conditions of the clear-air method of ITU-R P.452-16 used as a propagation model in our simulation [5]. The propagation loss is calculated based on actual topography and building height. Table I (b) shows radio parameters of the FPU [7]. Table I (c) shows radio parameters of the SBSs. We assumed LTE (Long-term evolution)-Advanced for the SBSs and followed parameters of small cell BSs described in [8].

3.2 Deployment scenario

We assumed that a PRS with very high antenna height was deployed in an urban area. In Fig. 2 (a), a blue dot represents the location of this PRS. A circle with radius $r$ centered on the PRS was defined as the PA. A red line represents a route where the PTS moved along with.

In this letter we focus on simulation results of availability of SBSs within line-of-sight (LOS) distances from the PRS because these SBSs may have strong impacts on the aggregate interference to the PRS. Fig. 2 (b) illustrates the SBSs
within the LOS distances by green dots. 6354 SBSs were deployed in Tokyo’s 23 wards and densely inhabited districts (DIDs) [11].

3.3 Evaluation results
We compare our proposed method with a conventional method in this subsection. The conventional method is an APP method without the antenna boresight rotation range prediction and has been adopted in the CBRS [12]. In the conventional APP, the range of $\varphi$ is set to $0^\circ \leq \varphi < 360^\circ$ because the range of variation of the PRS’s antenna boresight cannot be specified.

Figs. 2 (c) and 2 (d) show the results of the SBS-SL calculation by the conventional and proposed APP in the case of $r = 100$, respectively. The red dots

\[\text{Table I. Simulation parameters} \]

(a) Conditions for clear-air method in ITR-R P.452

| Parameters | Value |
|------------|-------|
| Required time percentage for which the calculated propagation loss is not exceeded | 20 % between the PRS and SBSs [6], 0.001% between the PTS and PRS |
| Polarization | Vertical |
| Clutter category | Dense urban |
| Dry air pressure [hPa] | 1013 |
| Air Temperature [degree] | 28 |

(b) FPU radio parameters

| Parameters | Value |
|------------|-------|
| Carrier Frequency [GHz] | 2.35 |
| Bandwidth [MHz] | 17.2 |
| Tx Power [dBm] | 46.0 |
| Antenna Gain [dBi] | 5.2 |
| Horizontal Antenna Pattern | Omni-directional |
| Vertical Antenna Pattern | Directional [8] (HPBW: 23 degrees, Maximum attenuation: 30 dB) |
| Antenna Height [m] | 3.5 |
| Feeder Loss [dB] | 1.5 |
| Antenna Gain [dBi] | 14.0 |
| Horizontal/Vertical Antenna Pattern | Directional [8] (HPBW: 30 degrees, Maximum attenuation: 30 dB) |
| Antenna Height [m] | 400 |
| Feeder Loss [dB] | 1.5 |
| Noise Figure [dB] | 4.0 |
| $P_{\text{required}}$ [dBm] | $-81.4$ |
| Allowable I/N [dB] | $-10.0$ [6] |
| $I_{\text{allowed}}$ [dBm] | $-107.4$ |

(c) SBS radio parameters

| Parameters | Value |
|------------|-------|
| Carrier Frequency [GHz] | 2.35 |
| Bandwidth [MHz] | 18.0 |
| Tx Power [dBm/MHz] | 20.0 |
| Antenna Gain [dBi] | 5.0 |
| Horizontal Antenna Pattern | Omni-directional |
| Vertical Antenna Pattern | Directional [9] |
| Antenna Height [m] | 10.0 |
| Feeder Loss [dB] | 0.0 |
| Interval between SBSs [m] | 600 (Tokyo’s 23 wards), 1200 (DID) [10] |

1 Note that there were also 1944 SBSs beyond the LOS distances in the simulation. These SBSs will be allowed to become available unconditionally because of large NLOS propagation losses.
The blue dots are available; even when the FPU is operated. In other words, the aggregate interference from these SBSs is below the allowable level. In the case of $r = 100$, the conventional and proposed APP can make 405 and 1378 out of the 6354 SBSs available, respectively. The proposed APP can increase the number of available SBSs by 3.4 times compared to the conventional APP.

**Fig. 2.** Evaluation by computer simulation.

Fig. 2 (e) shows the number of available SBSs versus the radius $r$. The case of $r = 0$ is equivalent to the result of the PPP. The proposed APP can increase the number of available SBSs by 2.9 times compared to the conventional APP, even in the case of $r = 500$. This result indicates that the proposed APP has the effectiveness in term of the availability of the SBSs even if the broadcasters cannot provide accurate location information of the PRS. Note that Fig. 2 (e) also
implies an additional advantage that the proposed method can increase the available SBSs more by accurate location information of the PRS, i.e. small PAs.

4 Conclusion

In this letter, we proposed and evaluated our APP method with antenna boresight rotation prediction to increase the availability of the SBSs without accurate location information of the PRS. The simulation results indicate that the proposed APP can increase the availability of the SBSs significantly in the practical urban scenarios.

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