Frequency Use Status Investigation and Spectrum Utilization Metric

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I. INTRODUCTION

II. FREQUENCY USE STATUS INVESTIGATION

III. SPECTRUM UTILIZATION METRIC

IV. CONCLUSIONS AND FUTURE WORKS
I. Introduction

- **Growing needs for spectrum resources**
  - Auctions for 3G spectrum (UK), 700MHz band (US) etc.

- **Spectrum management for efficient use of spectrum resources**
  - Technical measure: Develop and adopt techniques with high spectral efficiency (e.g. MIMO, CR, etc.)
  - Administrative measure:
    - Market based approach (e.g. spectrum auction, secondary market)
    - Rather command and control approach (e.g. spectrum refarming)
I. Introduction

- Bases for spectrum management to improve spectrum efficiency
  - Frequency use status investigation
    - Radio station and frequency channel use status
    - Frequency channel occupancy measurement
    - Investigation results of Korea in 2007
  - Spectrum utilization metric
    - M-SUE (Modified Spectrum Use Efficiency) :
      Incorporates actual spectrum resource occupancy and spectrum efficiency into a single quantity
    - Spectrum efficiencies for simple cellular and relay radio system
II. Freq. Use Investigation

- Frequency use status investigation
  - In order to find frequency band where its use level is low according to Korean Radiowave Act
  - By CRMO (Central Radio Management Office) and KORPA (Korea Radio Promotion Agency) annually

- Two investigation approaches
  - Radio station and frequency channel use status investigation using radio station registration DB
  - Frequency channel occupancy measurement using radio monitoring system
## II. Freq. Use Investigation

### Radio station and freq. channel use status

**Table 1 Investigation items**

<table>
<thead>
<tr>
<th>Items</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radio Station Use Status</strong></td>
<td></td>
</tr>
<tr>
<td>Distribution over region</td>
<td># of Radio stations registered in local commun. office</td>
</tr>
<tr>
<td>Distribution over time</td>
<td>Temporal change on radio station #(for 5 yrs.)</td>
</tr>
<tr>
<td>Distribution over station type</td>
<td># of radio stations by type</td>
</tr>
<tr>
<td>Distribution over operator</td>
<td># of radio stations by operator</td>
</tr>
<tr>
<td><strong>Freq. Channel Use Status</strong></td>
<td></td>
</tr>
<tr>
<td>Designation and actual use status</td>
<td># of designated and actually used freq. channels</td>
</tr>
<tr>
<td>Distribution over region</td>
<td># of channels by region</td>
</tr>
<tr>
<td>Distribution over operator</td>
<td># of channels by operator</td>
</tr>
<tr>
<td>Total used bandwidth</td>
<td>Sum of all bandwidth including reused channel</td>
</tr>
</tbody>
</table>
II. Freq. Use Investigation

- Some investigation results

![Pie chart showing radio station use status]

- Base Station (20%)
- Land Mobile (21%)
- two-way radio (41%)
- Mobile Relay (4%)
- Amateure (6%)
- etc (8%)

**Fig. 1 Radio Station Use Status**
II. Freq. Use Investigation

- Some investigation results

- Terrestrial (89%)
- Maritime (7%)
- Aeronutical (1%)
- etc (3%)
- Broadcasting (0.1%)
- Space (0.2%)

Fig. 2 Frequency Channel Use Status
II. Freq. Use Investigation

- Some investigation results

Table 2 Frequency Bandwidth Use Status

<table>
<thead>
<tr>
<th>Band</th>
<th>960MHz~2900</th>
<th>2.9~10GHz</th>
<th>10~30GHz</th>
<th>30GHz~</th>
<th>Total</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>103.74</td>
<td>396</td>
<td>0</td>
<td>1700</td>
<td>2199.74</td>
<td>0.88%</td>
</tr>
<tr>
<td>Maritime &amp; aeronautical</td>
<td>66.6686</td>
<td>388</td>
<td>686</td>
<td>260</td>
<td>1400.669</td>
<td>0.56%</td>
</tr>
<tr>
<td>Broadcasting</td>
<td>450.243</td>
<td>5</td>
<td>255</td>
<td>2015.6</td>
<td>3725.843</td>
<td>1.49%</td>
</tr>
<tr>
<td>Satellite</td>
<td>0</td>
<td>30</td>
<td>234.36</td>
<td>1695</td>
<td>2459.36</td>
<td>0.98%</td>
</tr>
<tr>
<td>SRD</td>
<td>22.3532</td>
<td>88.8</td>
<td>500</td>
<td>240</td>
<td>1851.153</td>
<td>0.74%</td>
</tr>
<tr>
<td>Amateur</td>
<td>8.935</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>5258.935</td>
<td>2.10%</td>
</tr>
<tr>
<td>Military</td>
<td>195.8242</td>
<td>564</td>
<td>2565.5</td>
<td>3613.2</td>
<td>8470.524</td>
<td>3.39%</td>
</tr>
<tr>
<td>Terrestrial(M/W, etc)</td>
<td>112.236</td>
<td>468.2</td>
<td>2859.14</td>
<td>10426.2</td>
<td>224633.8</td>
<td>89.85%</td>
</tr>
<tr>
<td>Total</td>
<td>960</td>
<td>1940</td>
<td>7100</td>
<td>20000</td>
<td>2500000</td>
<td>100.00%</td>
</tr>
</tbody>
</table>
II. Freq. Use Investigation

• Some investigation results

Fig. 3 Frequency Bandwidth Use Status (weighted version)
II. Freq. Use Investigation

- **Freq. channel occupancy measurement**
  - Measured at 23 locations all over the country
  - Sweep period: 1.2 sec (7,000 sweeps a day)
  - To determine threshold level, noise levels are measured

### Table 2 Some measured threshold levels (unit: dBµV/m)

<table>
<thead>
<tr>
<th>Region</th>
<th>300MHz</th>
<th>800MHz</th>
<th>900MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seoul (Urban)</td>
<td>26.00</td>
<td>20.80</td>
<td>11.30</td>
</tr>
<tr>
<td>Seoul (Suburban)</td>
<td>4.63</td>
<td>4.75</td>
<td>6.23</td>
</tr>
<tr>
<td>Jeju (Urban)</td>
<td>16.79</td>
<td>15.47</td>
<td>14.23</td>
</tr>
<tr>
<td>Jeju (rural)</td>
<td>5.47</td>
<td>1.73</td>
<td>0.85</td>
</tr>
<tr>
<td>Daejun (Urban)</td>
<td>11.37</td>
<td>17.43</td>
<td>16.20</td>
</tr>
<tr>
<td>Daejun (Urban)</td>
<td>8.20</td>
<td>9.66</td>
<td>8.43</td>
</tr>
</tbody>
</table>
II. Freq. Use Investigation

- **Freq. channel occupancy measurement result**

![Bar chart showing the frequency channel occupancy rate for different bands.](image)

**Fig. 4 Measured Temporal Frequency Channel Occupancy**
III. Spectrum Utilization Metric

**Spectrum resource** ($U$)

- Defined as physical resources which is used exclusively or denied to other users due to interference
- \[ U = B \times S \times T \] (\(B\) : Bandwidth, \(S\) : Space, \(T\) : Time)

![Diagram of spectrum space multiplexed by 5 users](source: IEEE Commun. Mag. Jun. 2007)
III. Spectrum Utilization Metric

- **Spectrum efficiency**
  - **Definition**: $\eta_{\text{eff}} = \frac{M}{U}$
    - ($M$: Useful effect, $U$: Spectrum resource)
    - $M$ is usually defined as transmitted information (bits)
    - Can be defined in various ways according to the purpose of system in question
  - Depends on Tx/Rx scheme, network configuration
  - $\eta_{\text{eff}}$ of different systems may not be commensurate
    - E.g. Land mobile and radar system cannot be compared
III. Spectrum Utilization Metric

- **M-SUE (Modified-Spectrum Use Efficiency)**
  - From spectrum use process, spectrum resource occupancy and spectrum efficiency can be defined

Government provides spectrum resources (Ug)

**Spectrum occupancy**: \( \eta_{occ} = \frac{U_a}{U_g} \)

Operator provides service using spectrum resource (Ua)

**Spectrum efficiency**: \( \eta_{eff} = \frac{M}{U_a} \)

End users use Service (M)

- **Overall efficiency**, \( \eta_{M-SUE} = \eta_{occ} \cdot \eta_{eff} \), incorporates spectrum occupancy measurement and spectrum efficiency in a single quantity \( \rightarrow M\text{-SUE} \).
III. Spectrum Utilization Metric

- M-SUE Space

Spectrum efficiency in technical sense

Region where M-SUE over \( \eta_{th} \)

\[ \eta_{occ} \eta_{eff} \geq \eta_{th} \]

Actual spectrum resource occupancy

Fig. 6 M-SUE Space
III. Spectrum Utilization Metric

- Spectrum occupancy ($\eta_{occ}$)
  - $\eta_{occ} = (B_a/B_g) (S_a/S_g) (T_a/T_g)$: all factors can be obtained from measurement results.
  - $(B_a/B_g)$: used and allocated bandwidth ratio
  - $(S_a/S_g)$: avg. occupied area ratio
  - $(T_a/T_g)$: avg. frequency channel occupancy

Fig. 6 Occupied area calculation example using radio propagation simulator
III. Spectrum Utilization Metric

- **Spectrum efficiency** ($\eta_{\text{eff}}$)
  - Definition: $\eta_{\text{eff}} = M / (BaSaTa)$

- **Spectrum efficiency of cellular radio system**
  - $\eta_{\text{eff, cell}} = Et / (BS)$
    $(Et : \text{inform. rate (bps)}, S : \text{service area (km}^2\text{)}, B : \text{bandwidth (MHz)})$
  - $Et = \rho SE$ and $\rho AE \leq C_{MAX}$ (Cell Capacity )
    $(\rho : \text{subscriber density (1/km}^2\text{)}, E : \text{avg. inform. rate per subscriber (bps)})$
  - $\eta_{\text{eff, cell}} \leq C_{MAX} / BA$
    - Spectrum efficiency can be increased by increasing system efficiency, i.e. $(C_{MAX} / B)$ or the number of cell in a given service area increase
III. Spectrum Utilization Metric

- Spectrum efficiency of point-to-point relay radio system
  - $\eta_{eff} = \frac{E_r D}{(BS)}$
    - ($E_r$ : inform. rate (bps), $S$ : occupied area (km²), $D$ : transmit distance (km), $B$ : bandwidth (MHz))
- Occupied area ($S$)
  - ($R$ : sector radius (km), $\theta_{HP}$ : halfpower beamwidth (rad))

$$S = \frac{1}{2} R^2 \theta_{HP}$$

Fig. 7 Simple occupied area calculation model (Tx only)
III. Spectrum Utilization Metric

- Spectrum efficiency of a p-p relay radio system with \( N(\geq 2) \) stations

\[
\eta_{\text{eff, relay}} = \frac{E_r D}{SB} \approx \left(2E_r \sum_{i=1}^{N} R_i\right) / \left( B\theta \sum_{j=1}^{N} R_j^2 \right) \tag{1}
\]

- Using Cauchy-Schwarz inequality

\[
\eta_{\text{eff, relay}} \leq \frac{2E_r}{B\theta R_1}, \tag{2}
\]

equality holds when \( R_1 = \cdots = R_N = D / N \)

- Spectrum efficiency can be increased as system efficiency i.e., \((E_r/B)\) or the number of relay stations within given transmit distance \( D \) is increased.

Fig. 8 Approximation of p-to-p relay radio system with \( N(\geq 2) \) stations
IV. Conclusions

- Frequency use status investigation in Korea
  - Radio station and frequency channel use status
  - Frequency channel occupancy measurement

- Spectrum utilization metric
  - Proposed M-SUE (Modified Spectrum Use Efficiency)
    - Incorporates spectrum occupancy measurement and spectrum efficiency in a single quantity
  - Spectrum efficiencies for cellular, relay system are analyzed.
  - Shows tradeoff between spectrum efficiency and economical efficiency
IV. Future Works

- Tentative evaluation of M-SUE for cellular and relay systems
- Derivation of theoretical spectrum efficiencies for various systems and channel models
- Study on spectrum utilize metric which includes economical and functional efficiency as in [15]


