Frequency Use Status Investigation and Spectrum Utilization Metric

June 2, 2008

Korea Radio Promotion Agency

Sang Yun Lee

(sylee76@gmail.com)

Contents

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

- **Radio station and freq. channel use status**

Table 1 Investigation items

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

II. Freq. Use Investigation

- **Some investigation results**

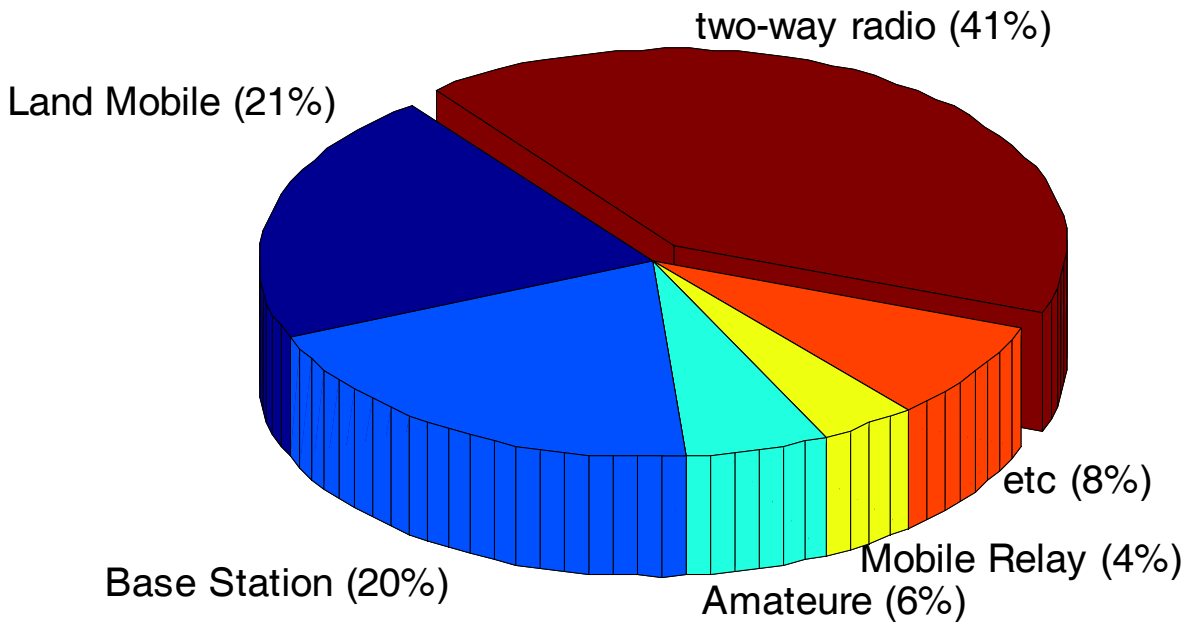


Fig. 1 Radio Station Use Status

- **Some investigation results**

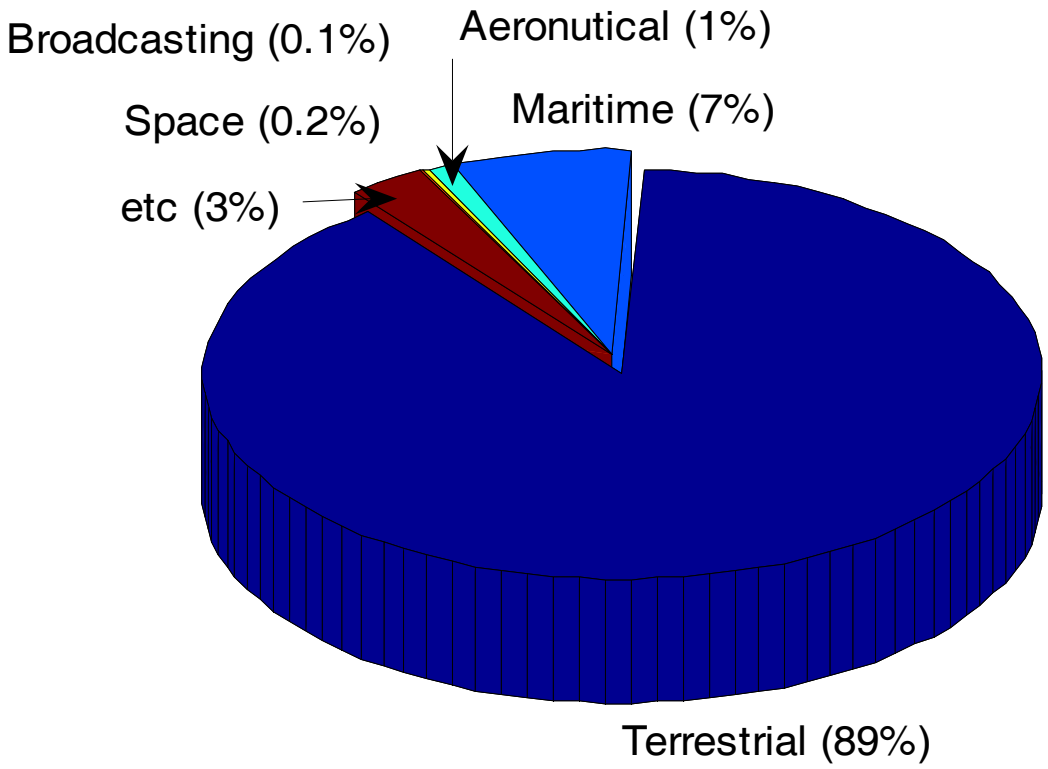


Fig. 2 Frequency Channel Use Status

- **Some investigation results**

Table 2 Frequency Bandwidth Use Status

Band	~ 960MHz	960 MHz ~ 2900	2.9~ 10GHz	10~ 30GHz	30GHz ~	Total	Ratio
Commercial	103.74	396	0	1700	0	2199.74	0.88%
Maritime & aeronautical	66.6686	388	686	260	0	1400.669	0.56%
Broadcasting	450.243	5	255	2015.6	1000	3725.843	1.49%
Satellite	0	30	234.36	1695	500	2459.36	0.98%
SRD	22.3532	88.8	500	240	1000	1851.153	0.74%
Amateur	8.935	0	0	50	5200	5258.935	2.10%
Military	195.8242	564	2565.5	3613.2	1532	8470.524	3.39%
Terrestrial(M/W, etc)	112.236	468.2	2859.14	10426.2	210768	224633.8	89.85%
Total	960	1940	7100	20000	220000	250000	100.00%

- **Some investigation results**

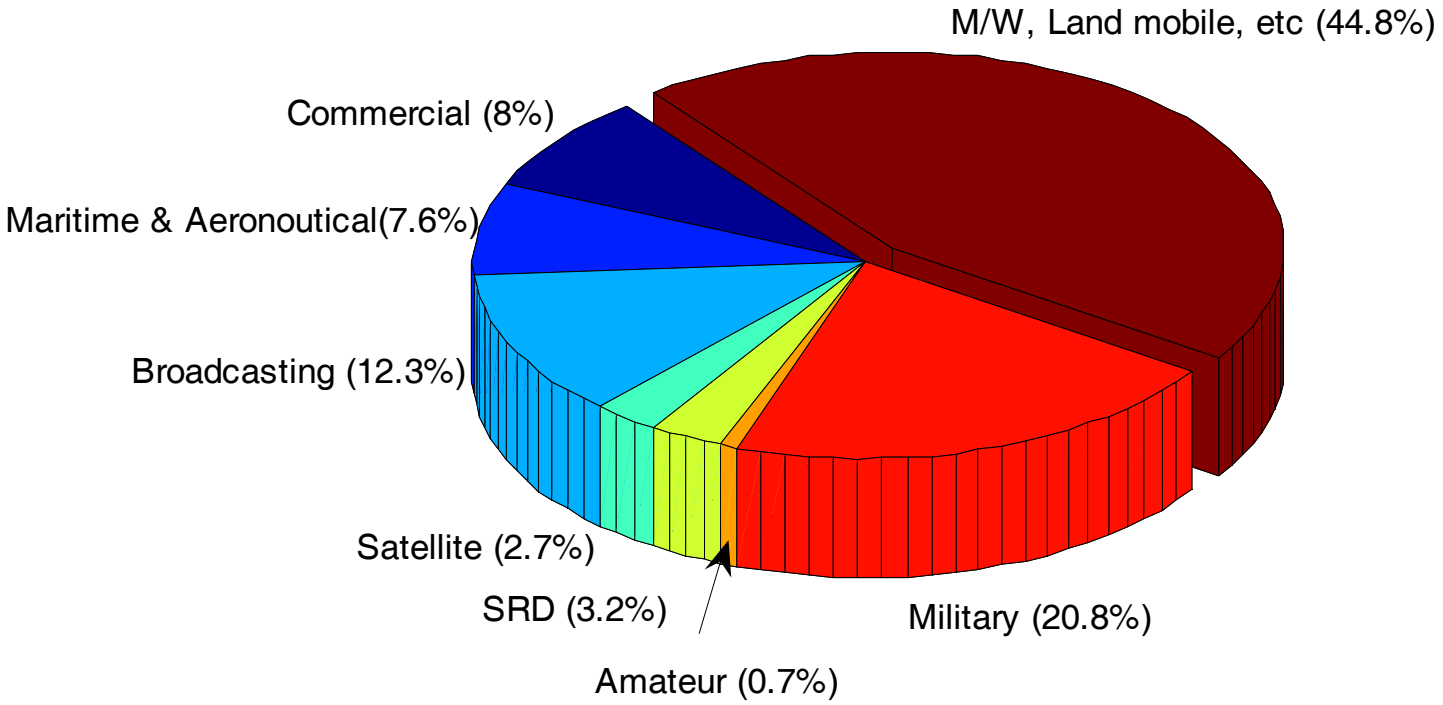


Fig. 3 Frequency Bandwidth Use Status (weighted version)

II. Freq. Use Investigation

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

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

Region	300MHz	800MHz	900MHz
Seoul (Urban)	26.00	20.80	11.30
Seoul (Suburban)	4.63	4.75	6.23
Jeju (Urban)	16.79	15.47	14.23
Jeju (rural)	5.47	1.73	0.85
Daejun (Urban)	11.37	17.43	16.20
Daejun (Urban)	8.20	9.66	8.43

- **Freq. channel occupancy measurement result**

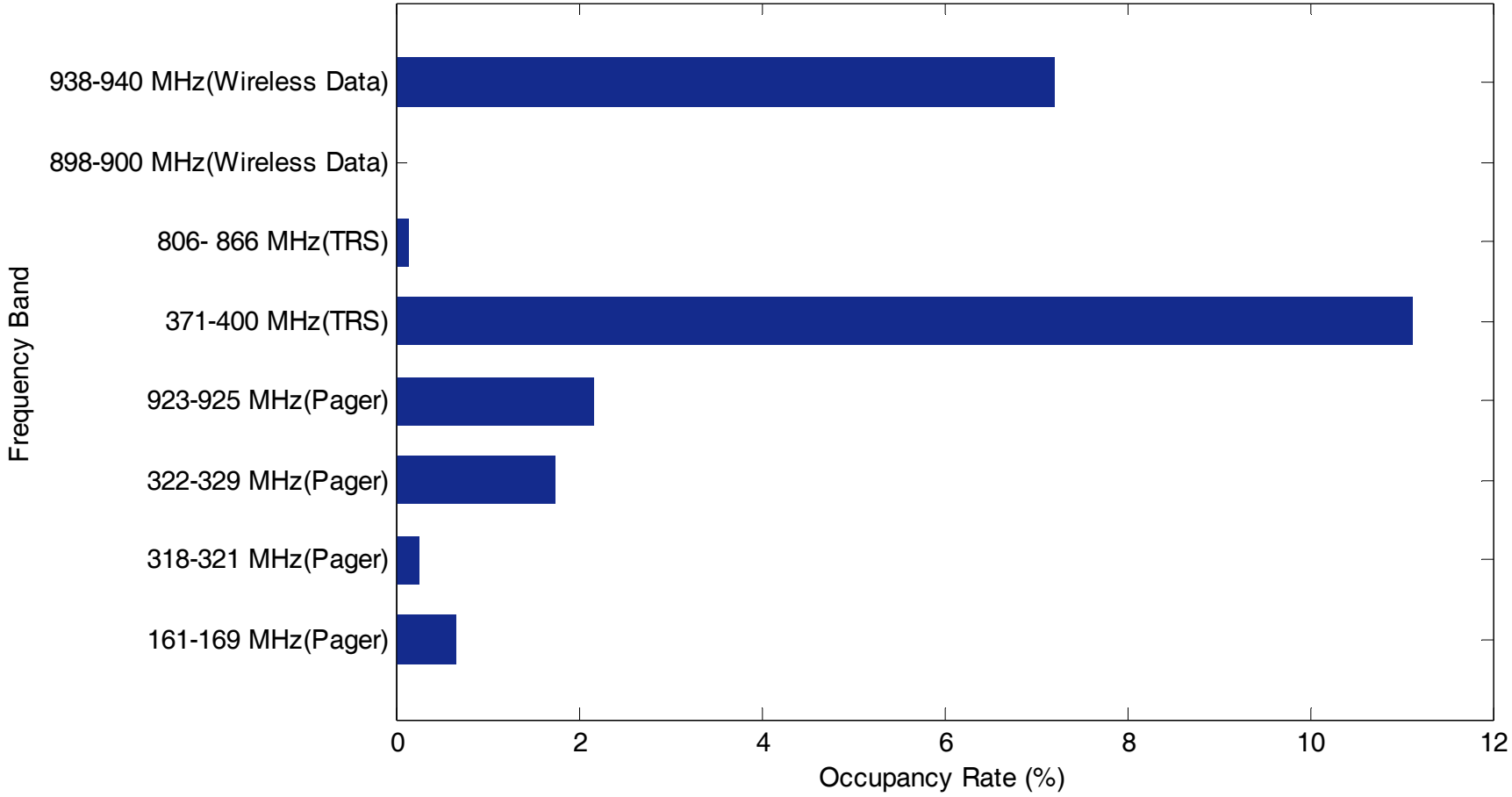


Fig. 4 Measured Temporal Frequency Channel Occupancy

- 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)

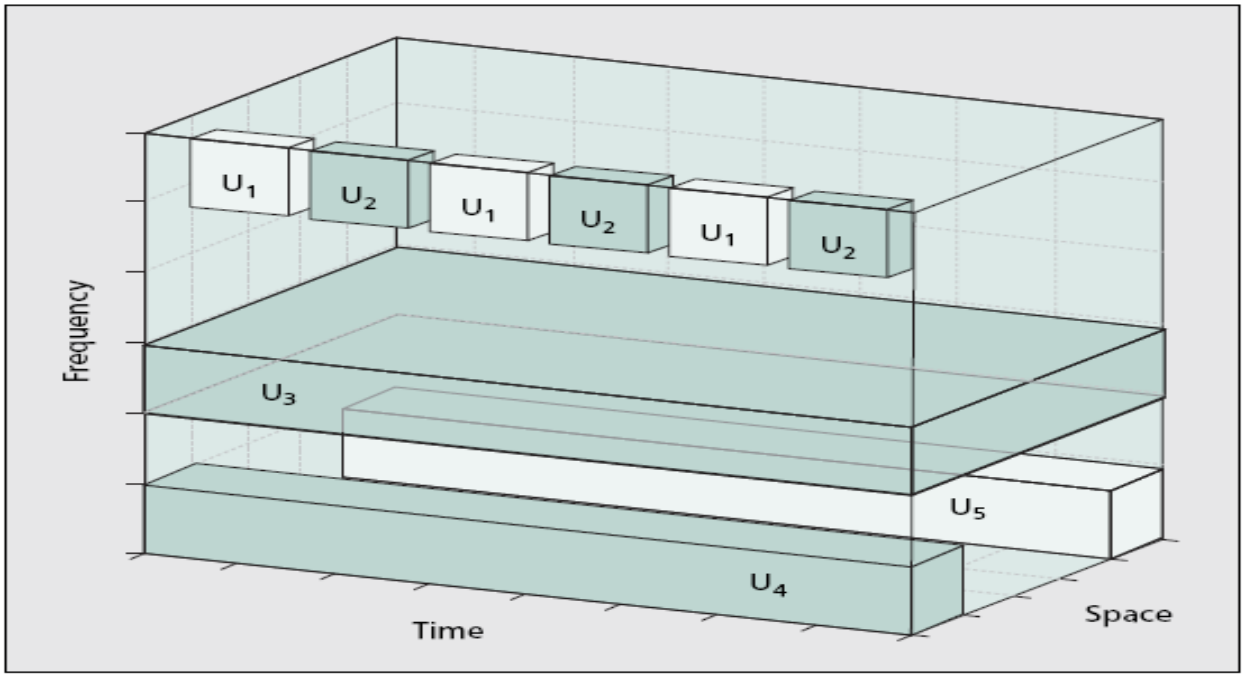


Fig. 5 Spectrum space multiplexed by 5 users (source : IEEE Commun. Mag. Jun. 2007)

III. Spectrum Utilization Metric

- **Spectrum efficiency**
  - Definition : $\eta_{eff} = M / U$

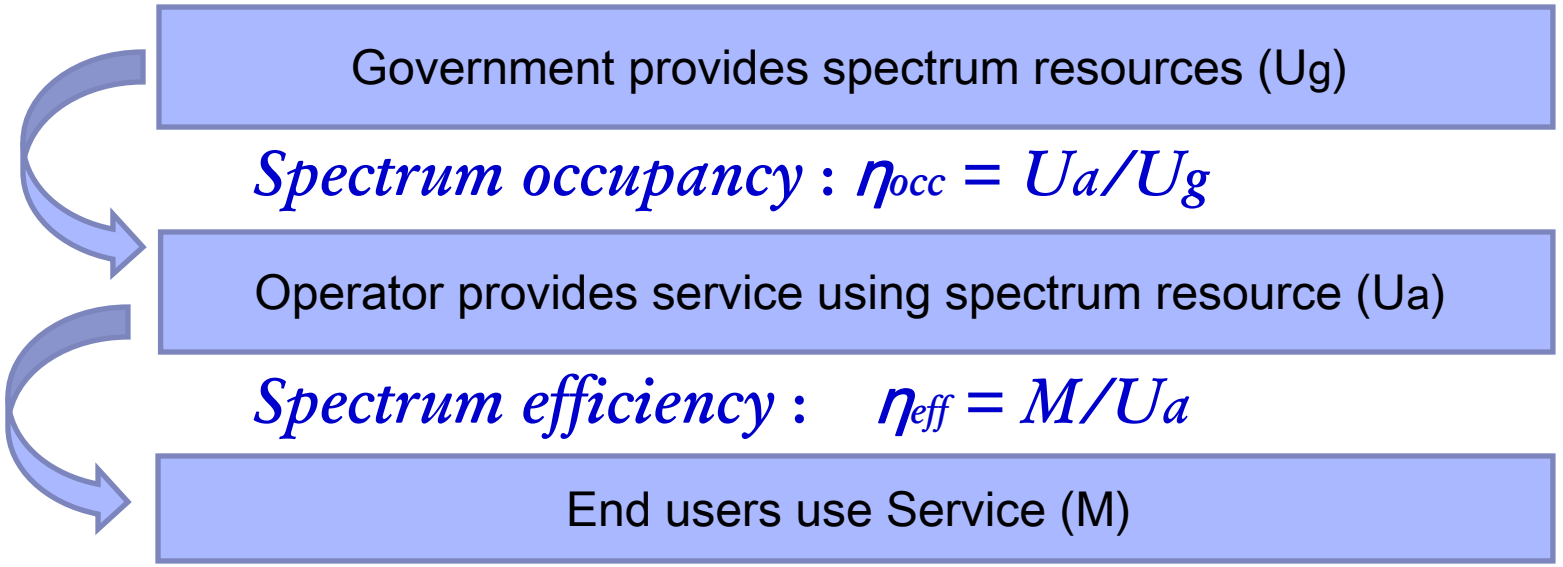
    (M : Useful effect, U : Spectrum resource)

    - 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
  - η_{eff} of different systems may not be commensurate

    - E.g. Land mobile and radar system cannot be compared

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



  - Overall efficiency, $\eta_{M\text{-}SUE} = \eta_{occ} \cdot \eta_{eff}$, incorporates spectrum occupancy measurement and spectrum efficiency in a single quantity → *M-SUE.*

- **M-SUE Space**

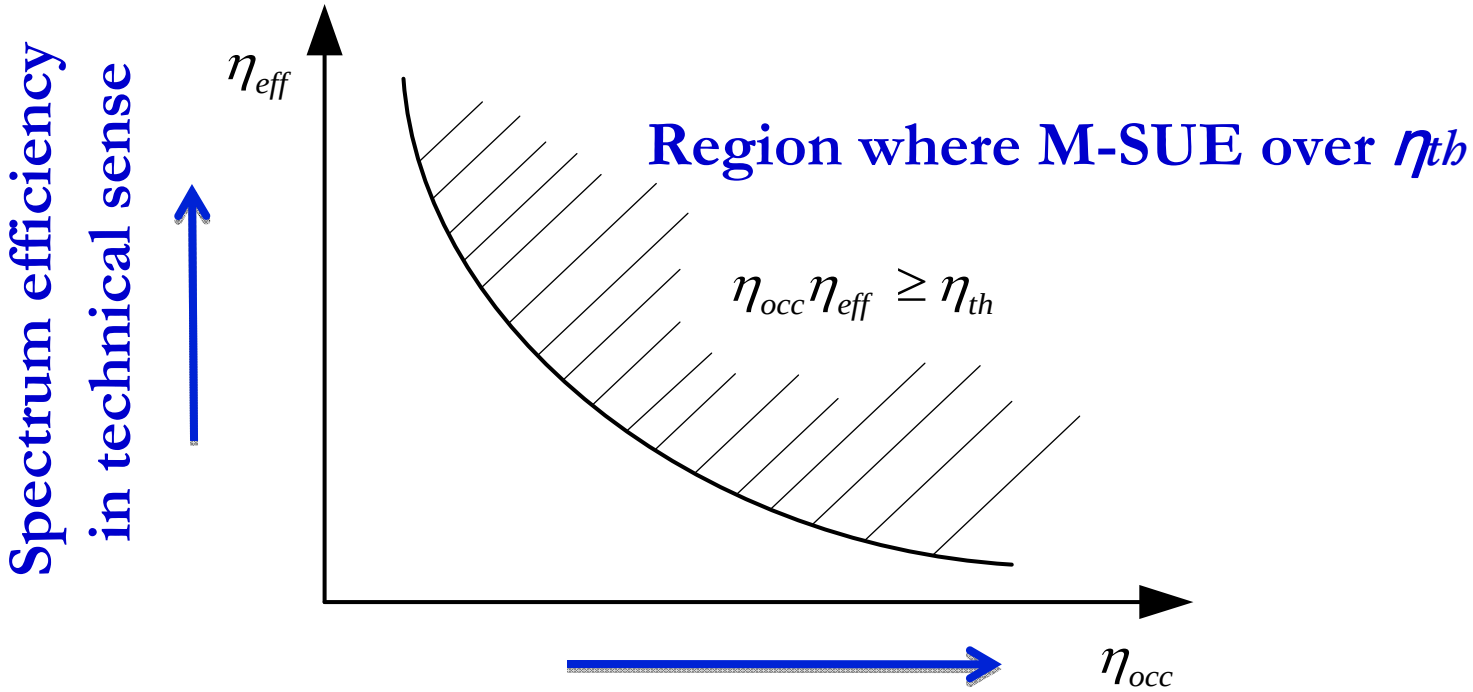


Fig. 6 M-SUE Space

- Spectrum occupancy (η_{occ})
  - $\eta_{occ} = (Ba/Bg)\,(Sa/Sg)\,(Ta/Tg)$: all factors can be obtained from measurement results.
  - (Ba/Bg) : used and allocated bandwidth ratio
  - (Sa/Sg) : avg. occupied area ratio
  - (Ta/Tg) : avg. frequency channel occupancy

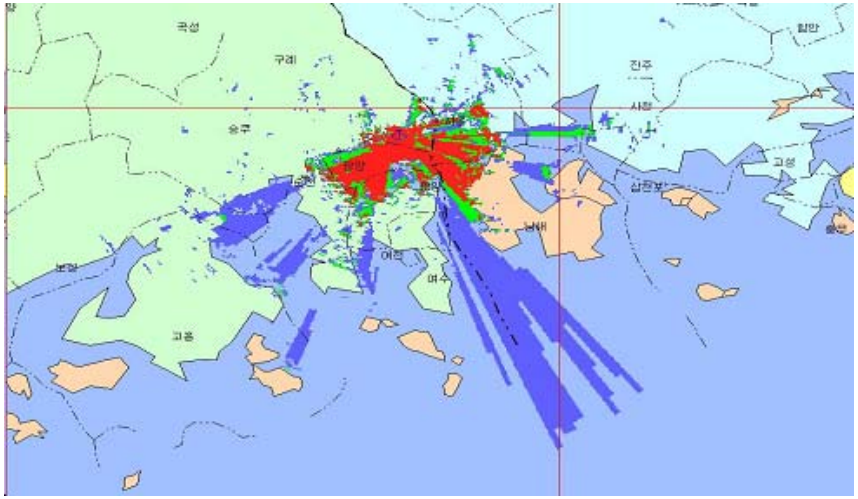


Fig. 6 Occupied area calculation example using radio propagation simulator

III. Spectrum Utilization Metric

- **Spectrum efficiency (η_{eff})**
  - Definition : $\eta_{eff} = M/(BaSaTa)$
- **Spectrum efficiency of cellular radio system**
  - $\eta_{eff,\,cell} = Et/(BS)$

  (Et : inform. rate(bps), S : service area(km²), B : bandwidth(MHz))
  - $Et = \rho SE$ and $\rho AE \leq C_{MAX}$ (Cell Capacity)

  (ρ : subscriber density(1/km²),

  E : avg. inform. rate per subscriber(bps))
  - $\eta_{eff,\,cell} \leq C_{MAX}/BA$

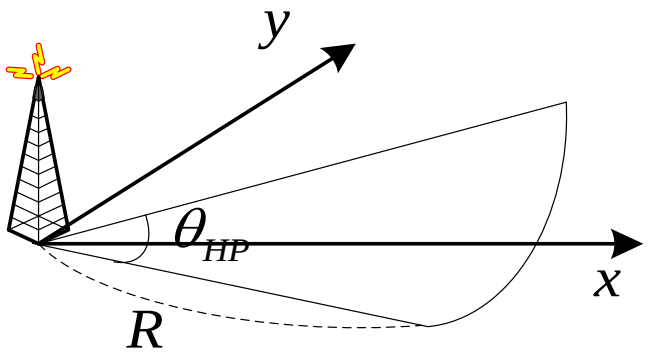
    - Spectrum efficiency can be increased by increasing system efficiency, i.e. (C_{MAX} /B) or the number of cell in a given service area increase

- **Spectrum efficiency of point-to-point relay radio system**
  - $\eta_{eff} = Er\,D/(BS)$

    (Er : inform. rate(bps), S : occupied area(km²),

    D : transmit distance(km), B : bandwidth(MHz))
  - Occupied area (S)

    (R : sector radius (km), θ_{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**

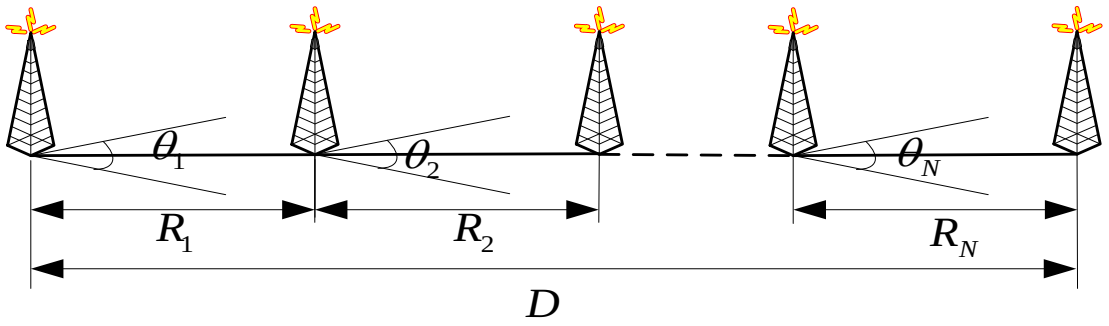


Fig. 8 Approximation of p-to-p relay radio system with $N(\geq 2)$ stations

$$\eta_{eff,relay} = E_r D / SB \cong \left(2E_r \sum_{i=1}^{N} R_i\right) / \left(B\theta \sum_{j=1}^{N} R_j^2\right) \quad (1)$$

- **Using Cauchy-Schwarz inequality**

$$\eta_{eff,relay} \leq 2E_r / B\theta R_1, \quad (2)$$

equality holds when $R_1 = \cdots = R_N = D/N$

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

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]

References

[1] D. Gesbert, M. Shafi, D. Shiu, P. Smith, and A. Naguib, "From theory to practice: an overview of MIMO space-time coded wireless systems," *IEEE J. Select. Areas Commun.*, pp.281-302, 2003.

[2] Q. Zhao and B. M. Sadler, "A Survey of dynamic spectrum access," *IEEE Sig. Proc. Mag*. Vol. 24, pp.79-89, May 2007.

[3] D. Porcino and W. Hirt, "Ultra-wideband radio technology: potential and challenges ahead," *IEEE Commun. Mag*., vol 41, pp. 66-74, July, 2003.

[4] B. Razavi, "Gadgets gab at 60 GHz," *IEEE Spectrum*, vol 45, pp. 46-58, Feb, 2008.

[5] ECC Report 16, "Refarming and secondary trading in a changing radiocommunications world," Sept. 2002.

[6] Ofcom, *Spectrum Framework Review*, 2004.

[7] CRMO, KORPA, *Frequency Use Status Investigation* (in Korean), 2007.

[8] Rec. ITU-R SM.1536, "Frequency channel occupancy measurements," 2001.

[9] A. Ghasemi and E. Sousa, "Spectrum sensing in cognitive radio networks: requirements, challenges and design trade-offs," *IEEE Commun. Mag.*, vol 46, pp. 32-39, April, 2008.

[10] L. Berry, "Spectrum metrics and spectrum efficiency : proposed definitions," *IEEE Trans. Electromagn. Compat.*, vol. EMC-19, no. 3, pp. 254-260, 1977.

[11] M-S. Alouini and A. J. Goldsmith, "Area spectral efficiency of cellular mobile radio systems," *IEEE Trans. Vech. Tech*., vol. 48, no. 4, pp 1047-1066, 1999.

[12] Rec. ITU-R SM.1046-2, "Definition of spectrum use and efficiency of a radio system," 2006.

[13] G. Chan and B. Brown, "A measure of spectrum utilization in land mobile bands," in *Proc. of Canadian Conference on Electrical and Computer Engineering*, 1996, May, pp. 52-55.

[14] J. Robinson, "Spectrum allocation and economic factor in FCC spectrum management," *IEEE Trans. Electromagn. Compat.*, vol. EMC-19, no. 3, pp. 182-190, 1977.

[15] J.W. Burns "Measuring spectrum efficiency - the art of spectrum utilization metrics", in *Proc. of IEE Conf. on getting the most out of radio spectrum*, 25 Oct. 2002, London, UK.