

# 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

- **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)

- **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

- **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

	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

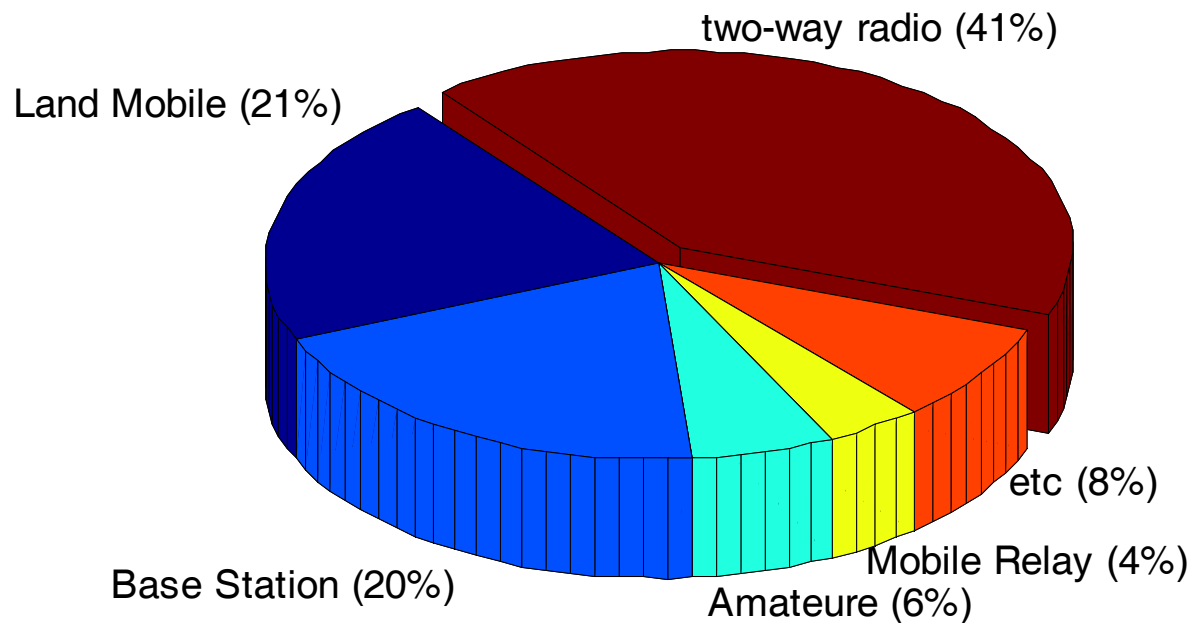


Fig. 1 Radio Station Use Status

## II. Freq. Use Investigation

- Some investigation results

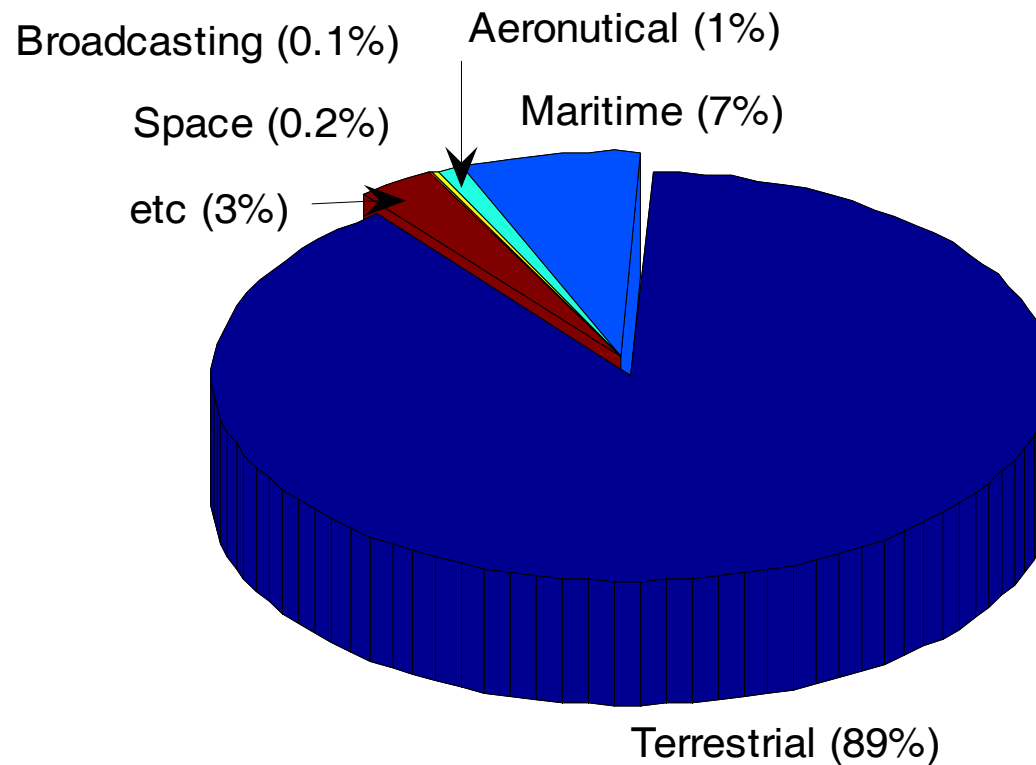


Fig. 2 Frequency Channel Use Status



## II. Freq. Use Investigation

### ● 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%

## II. Freq. Use Investigation

- Some investigation results

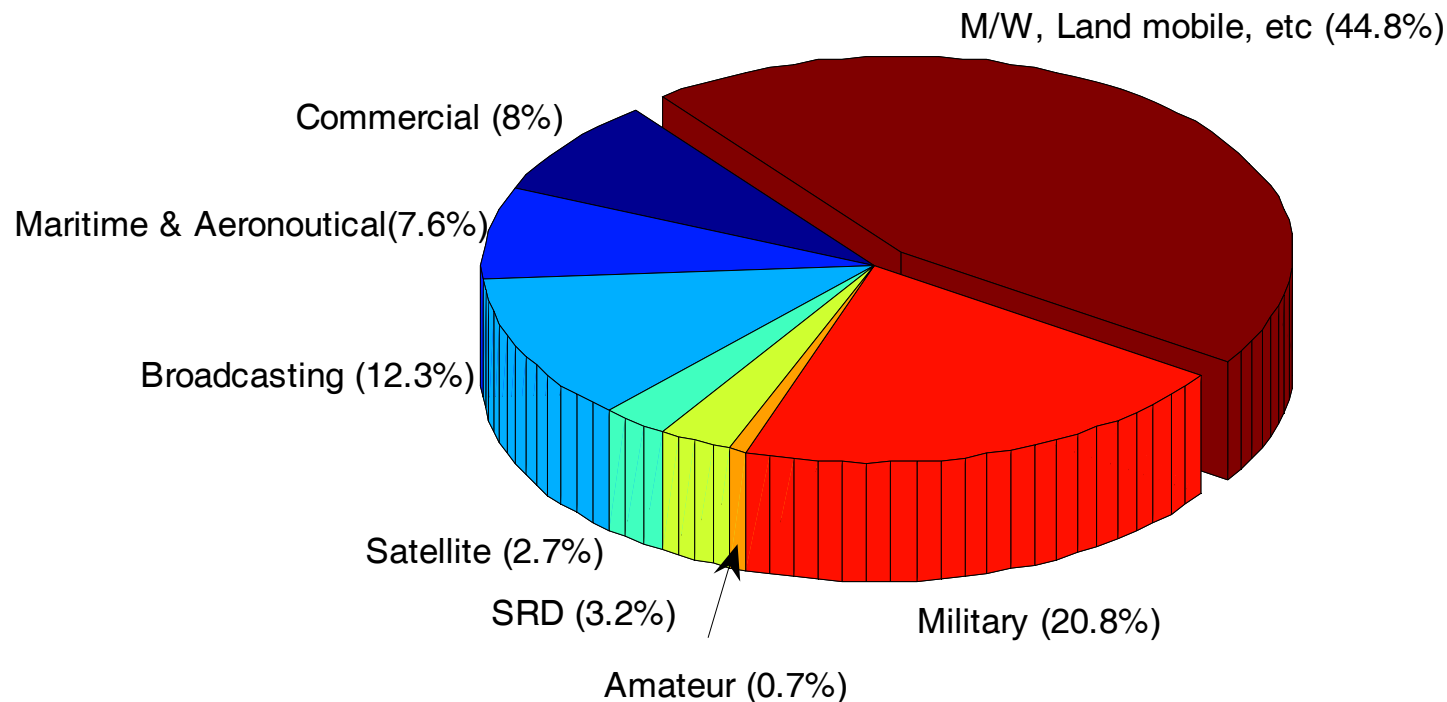


Fig. 3 Frequency Bandwidth Use Status (weighted version)

## II. Freq. Use Investigation

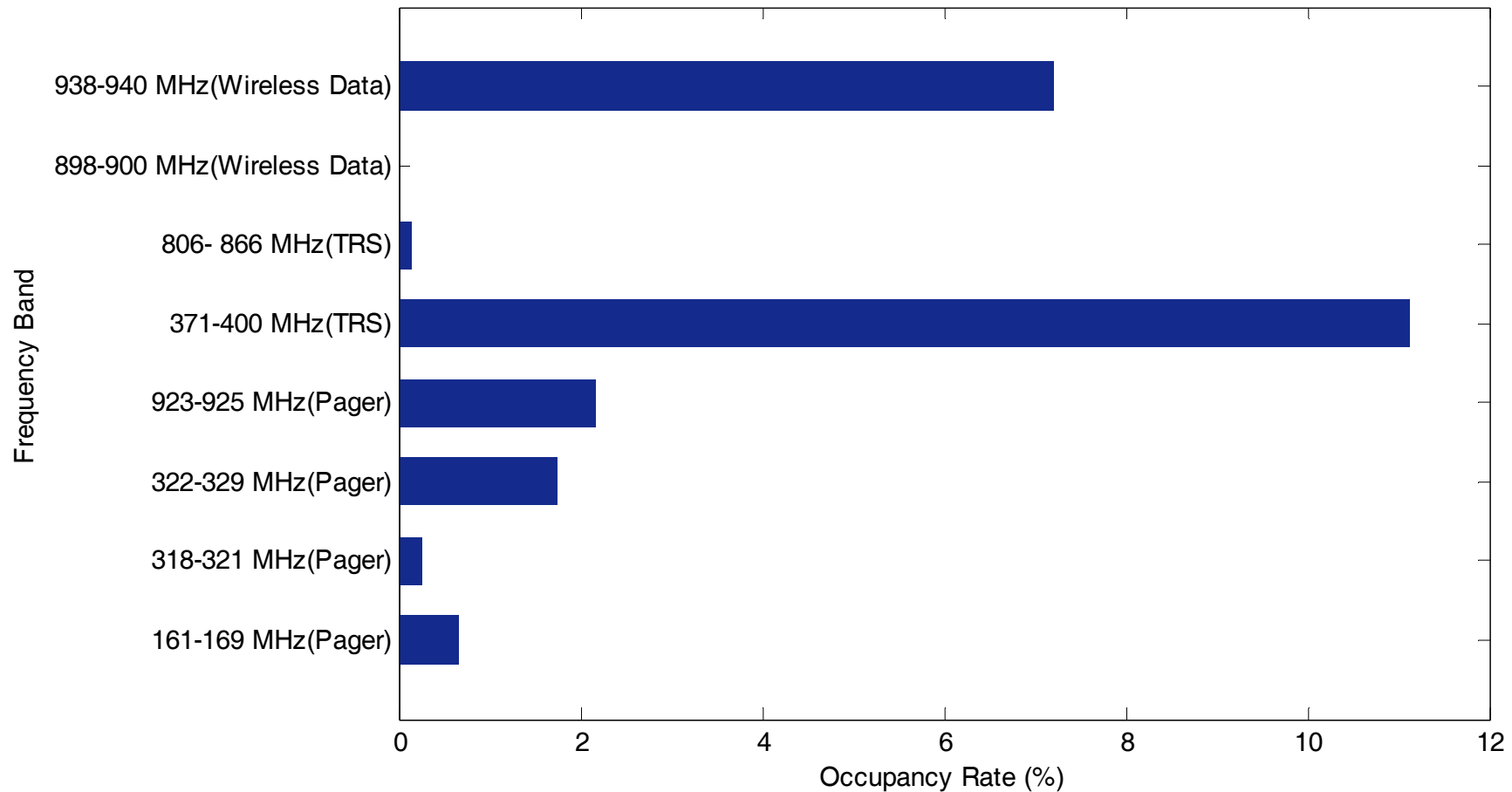
- **Freq. channel occupancy measurement**
  - Measured at 23 locations all over the country
  - Sweep period : 1.2sec (7,000 sweeps a day)
  - To determine threshold level, noise levels are measured

Table 2 Some measured threshold levels (unit : dB $\mu$ V/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

## II. Freq. Use Investigation

- **Freq. channel occupancy measurement result**



**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)

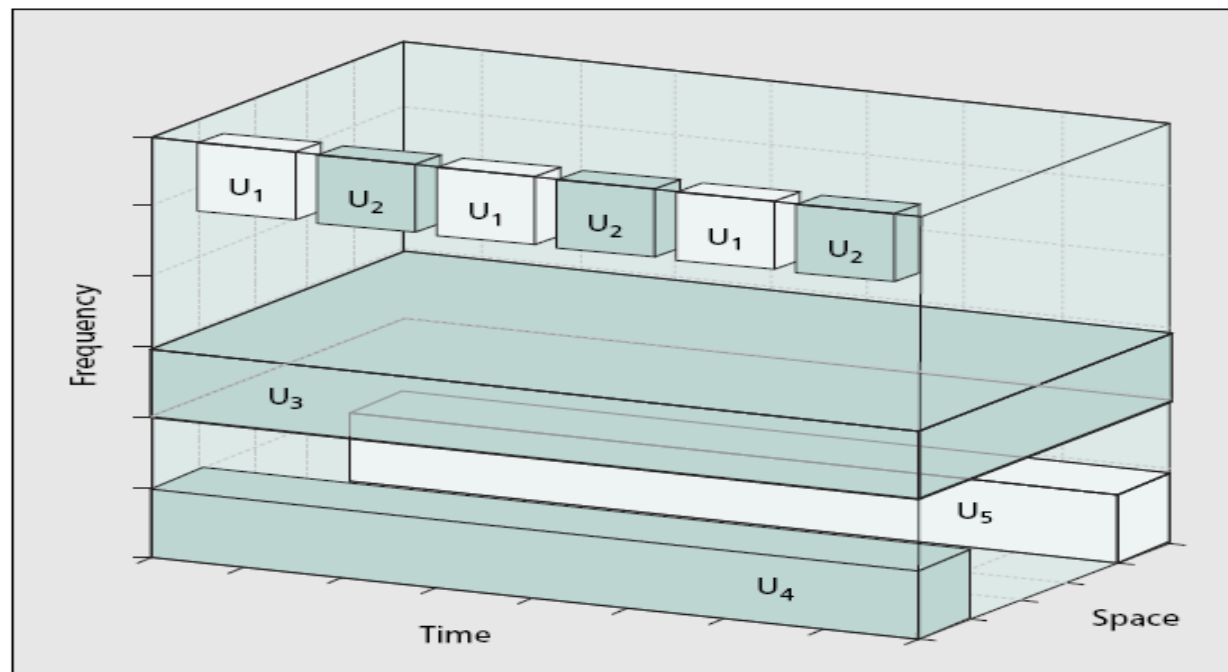


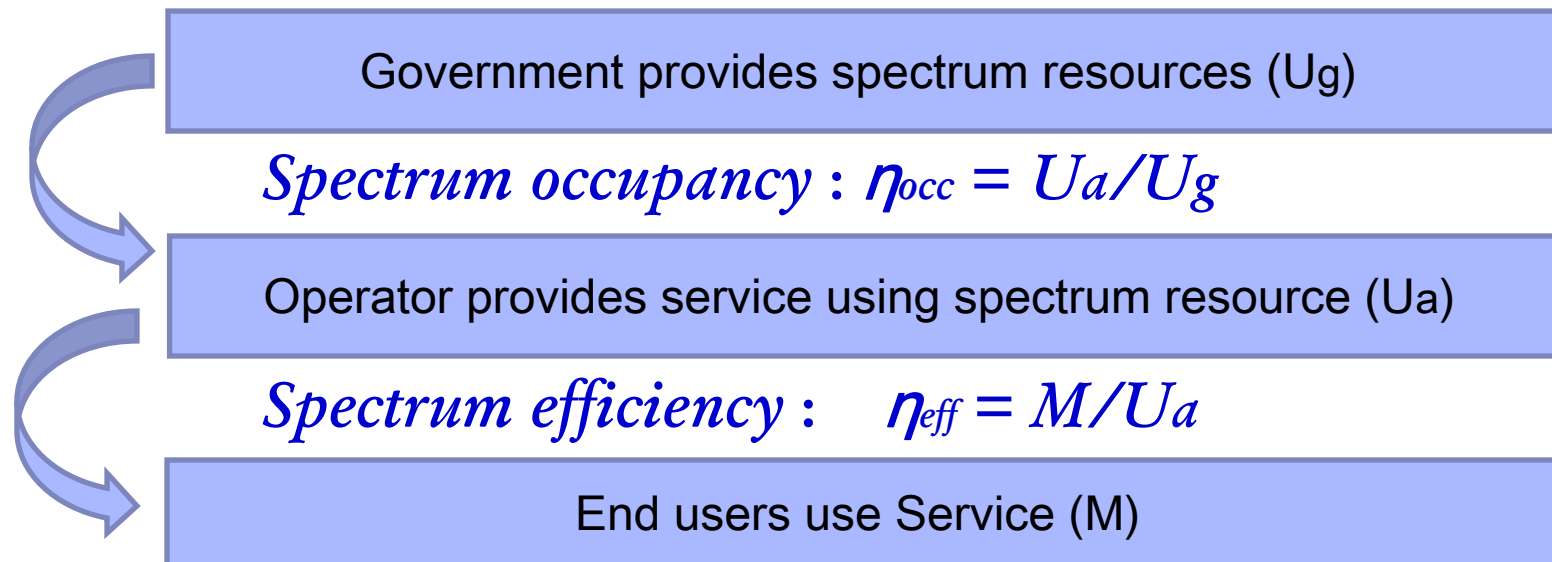
Fig. 5 Spectrum space multiplexed by 5 users (source : IEEE Commun. Mag. Jun. 2007)

- **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**
  - **$\eta_{eff}$  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



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

# III. Spectrum Utilization Metric

- M-SUE Space

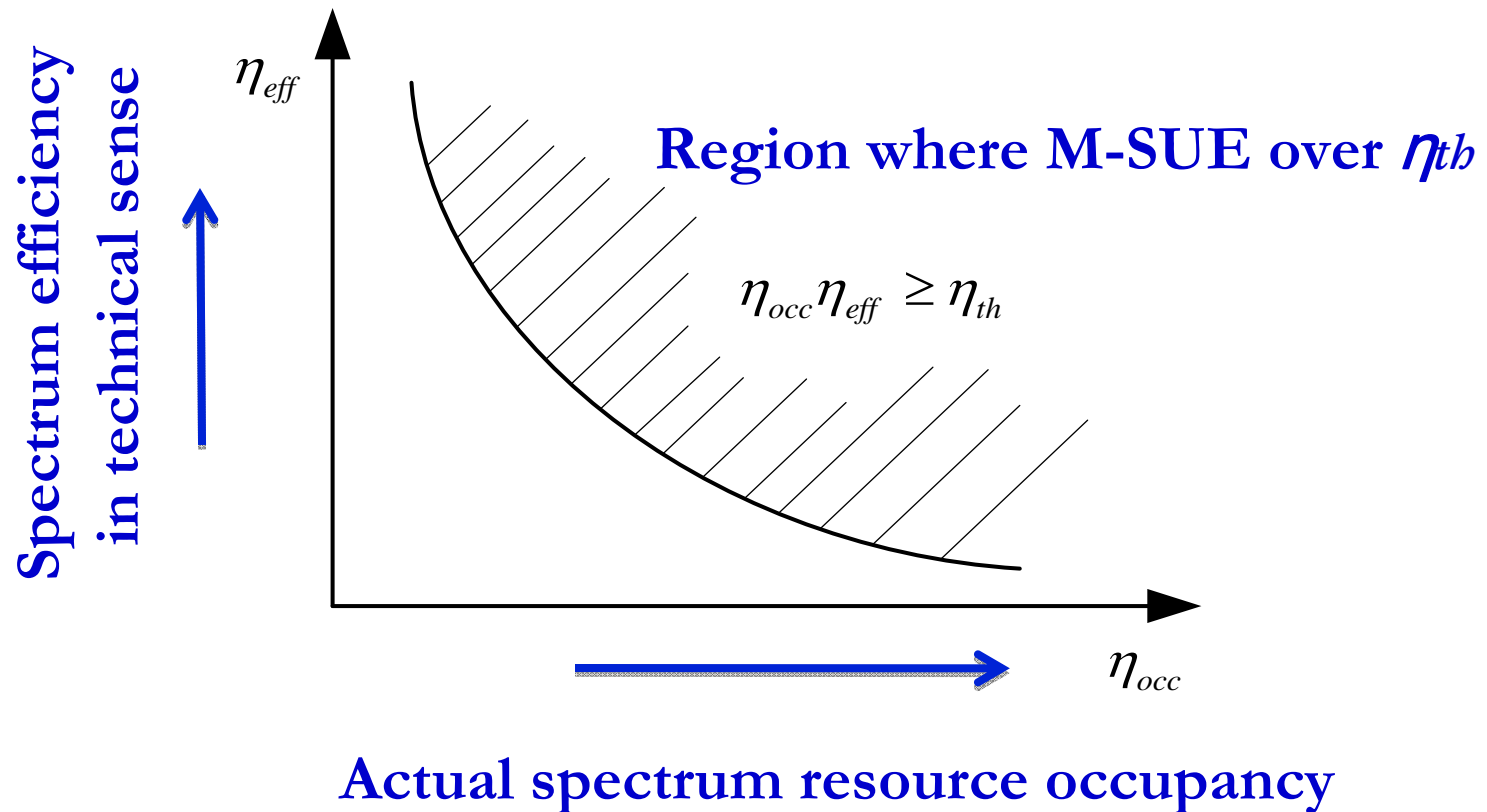


Fig. 6 M-SUE Space



# III. Spectrum Utilization Metric

- Spectrum occupancy ( $\eta_{occ}$ )
  - $\eta_{occ} = (Ba/Bg) (Sa/Sg) (Ta/Tg)$  : 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

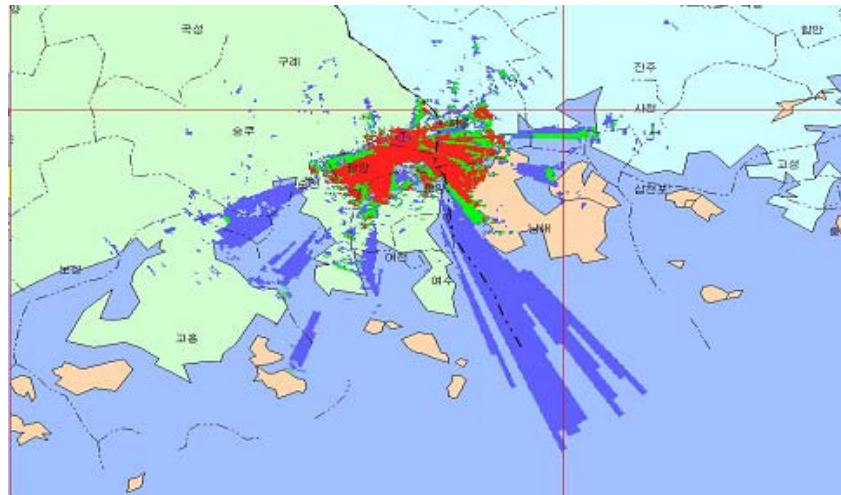


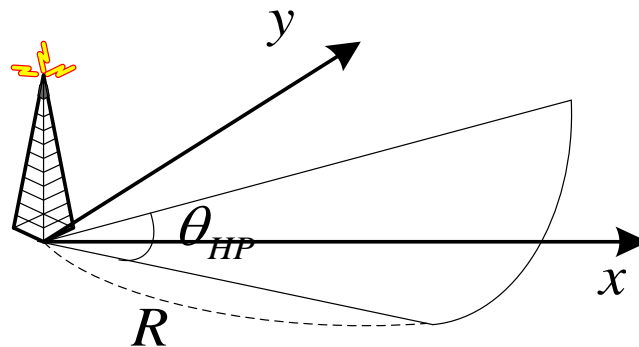
Fig. 6 Occupied area calculation example using radio propagation simulator

# III. Spectrum Utilization Metric

- Spectrum efficiency ( $\eta_{eff}$ )
  - Definition :  $\eta_{eff} = M / (BaSaTa)$
- Spectrum efficiency of cellular radio system
  - $\eta_{eff, cell} = E_t / (BS)$   
( $E_t$  : inform. rate(bps),  $S$  : service area(km<sup>2</sup>),  $B$  : bandwidth(MHz))
  - $E_t = \rho SE$  and  $\rho AE \leq C_{MAX}$  (Cell Capacity )  
( $\rho$  : subscriber density(1/km<sup>2</sup>),  
 $E$  : 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

# III. Spectrum Utilization Metric

- Spectrum efficiency of point-to-point relay radio system
  - $\eta_{eff} = E_r D / (BS)$   
( $E_r$  : inform. rate(bps),  $S$  : occupied area(km<sup>2</sup>),  
 $D$  : 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

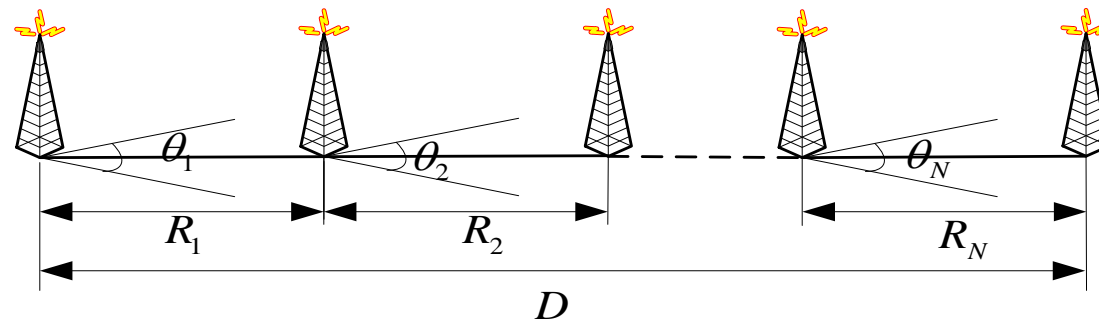


Fig. 8 Approximation of p-to-p relay radio system with  $N(\geq 2)$  stations

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

- Using Cauchy-Schwarz inequality

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

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

- 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.

- **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

- 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]

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