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F1. Wave Propagation

F1.1 Terrestrial Fixed Radio System

A. Effect of Precipitation

The most serious transmission impairment is caused by rain on radio links using frequencies above about 10 GHz. Demands for broadband wireless systems have been promoting the study on rain statistics.

In the system design, it is required to predict the rain attenuation distribution for radio link, and accordingly it is necessary to know one-minute rain rate distribution. Using the databank made at Kitami Institute of Technology, new different integration time rain rates conversion method is proposed. This method uses the M distribution and regional climatic parameters. As the results, it was found that this method is applicable with good accuracy for any integration time and any locations in the world [Ito and Hosoya, 2005]. On the world wide basis, however, the observations of rain rate are made mainly with longer integration times such as 60 minutes in Japan (e.g. 60-minute of AMeDAS: Automated Meteorological Data Acquisition System of Japan Meteorological Agency). Therefore, the conversion method of rain rate with longer integration time to that with one minute integration time

must be derived. A new global different integration time rain rate conversion method, in which Lavergnat-Gole model is extended by using regional climatic parameters, is proposed [Ito and Hosoya, 2006].

An accurate Cumulative Distribution Functions (CDF) statistics of high resolution 1-minute rainfall rate converted from low resolution 1-minute rainfall (precipitation) data measured by Japan Meteorological Agency using 0.5mm tipping bucket rain gauge at 136 locations is shown by using a newly developed conversion method. Based on the statistical analysis of obtained CDF curves, the suitable distribution function model for rain attenuation probability prediction method which is applicable to the wide range quality objective is studied. It is shown that M-distribution function model is superior to Gamma, Log-normal and Conditional Log-normal distribution function models [Ono et al., 2006a].

The distance characteristics of the rainfall spatial correlation are analyzed based on the rainfall data of high-resolution meteorological radar in addition to the rainfall data obtained through the AMeDAS. The dependency of the rainfall intensity on distance is confirmed. As a result of reflecting these study results in a typical link budget, and the rain attenuation margin is approximately 4.6 dB less than the one of the existing method [Akimoto and Watanabe, 2004]. As a result of the analysis of the rainfall data measured by 11 tipping bucket rain gages and a drop counting rain gage which are located at 11 sites around Otemachi in Tokyo, it is given that spatial correlation characteristics as a function of distance "d" can be approximated well by $\exp(-1.5\,d)$ for "d" of shorter than about 2km, while by $\exp(-0.25\,\sqrt{d})$ longer than about 3km. Considering that the specific rain attenuation is proportional to n-th (n=0.63 to 1.7) power of rainfall rate (ITU-R Rec.P.838-3), it is shown that spatial correlation characteristics depend greatly on the value of n, and equations to approximate the relation between n and spatial correlation characteristics are given. A method to integrate CDF of n-th power of point rainfall rate along a radio path using spatial correlation characteristics of n-th power of the rainfall rate is also given [Ono et al., 2005,2006b, 2007].

Accumulated number of events of given duration with rain fade or rain rate exceeding specific level are investigated, based on the experimental data of rain attenuation on 3 links at 15GHz, on 2 links at 22GHz, 1 link at 19GHz and 3 links at 32GHz, and of rain rate at 18 locations in Tokyo urban area. As the result, the relation between rain rate duration and rain fade duration, which approximates the measured data regardless of frequency and rain rate, is newly derived. And by using this relation, the versatile estimating equation of the number of events with the specific rain fade duration is obtained [Ishida et al., 2005].

A preliminary result is reported on a terrestrial wave propagation experiment made in Sapporo, Japan, where lots of snow falls in winter. The experiment was conducted along a 7.7 km path using Fixed Wireless Access (FWA) systems in 18 and 26 GHz bands. Typical wet snow event and dry snow event are illustrated [Yasuda et al., 2007].

B. Effect of Vegetation

Results of experiments conducted to examine the effect of space diversity (SD) in offsetting the attenuation through vegetation for quasi-millimeter wave band Fixed Wireless Access (FWA) systems are reported. The SD can improve the received signal level degradation due to attenuation through vegetation by up to 8 - 10 dB at cumulative probability of 1% comparing to single receiver [Takahashi et al., 2004, 2005, 2006].

C. Others

A statistical path loss model for broadband fixed wireless access service using the S band or C band is reported. The model is extended from the COST-231 Hata model in terms of the applicable frequency and the correction factor for the subscriber antenna height. The extensions were derived from the measured path loss data at 2.2 and 5.2 GHz in rural areas. The path loss model is applicable to base-to-subscriber distances of less than 20 km for suburban and quasi-open areas [Akimoto et al., 2006].

The distribution of the desired (direct) to undesired (reflected) wave ratio (D/U) for quasi-millimeter wave band fixed wireless access (FWA) systems and the technique to suppress undesired reflected waves were studied. The D/U was measured and simulated, and the ability of the passive beam forming (BF) technique to suppress undesired reflections was confirmed by simulations

and measurements [Takahashi and Ohmoto, 2007].

F1.2 Satellite Radio System

A. Effects of Rain

The rain attenuation characteristics of Ku-band satellite communications link are obtained at Equatorial Atmosphere Radar Observatory (EAR; 0.2°S, 100.3°E) in Indonesia for the past four years of 2003-2006, using Japan's domestic communication satellite Superbird C (144°E in orbit). The results are compared with simultaneous X-band radar observations of convective precipitating clouds at EAR. The yearly and worst month time percentages of both up- (14GHz) and down-link (12GHz) attenuation observed at EAR are, as a whole, in good agreement with the ITU-R predictions. In the attenuation range of larger than 10dB, however, the time percentages become much smaller than the ITU-R predictions, indicating remarkable reduction of equivalent path length down to 2 km. The X-band radar observations reveal that this short path length is caused by fairly localized convective precipitating clouds. Also, the intense echo cores of their typical rain cells are limited to about 2 km along the propagation path with elevation angle of about 40°[Maekawa et al., 2006a]. This equivalent path length as short as 2 km is shown to be a comparatively small value even in the tropical region compared with other observations in nearby locations [Maekawa et al., 2006b]. The rain attenuation is then estimated from the radar reflectivity factor (Z) of the X-band radar obtained along the same propagation path as the satellite link, indicating the almost same attenuation values when fairly large cloud cells have passed over the EAR site [Tsujino et al., 2007a]. The radar observations can estimate the attenuation with any elevation angles other than 40° from the RHI displays. The estimated attenuation, however, shows no such clear dependency upon the elevation angles of, say, 15-40°as in the temperate region where the attenuation tends to increases as the elevation angle decreases [Tsujino et al., 2007b].

Directions and speeds of the motion of rain areas are estimated for each type of rain fronts, using time differences detected in the rain attenuation of the Ku-band satellite radio wave signals that have been measured at Osaka Electro-Communication University (OECU) in Neyagawa, Osaka, Research Institute of Sustainable Humanosphere (RISH) in Uji, Kyoto, and MU Observatory (MU) of Kyoto University in Shigaraki, Shiga, for the past five years of 2002-2006. These directions and speeds are shown to agree well with those directly obtained from the motion of rain fronts in the weather charts published by Japan Meteorological Agency. The rain area motion is found to have characteristic directions according to each rain type, such as cold and warm fronts or typhoon [Nakatani et al., 2007]. For these rain types, a numerical estimate of the site diversity effects indicates that between two sites among the three locations (OECU, RISH, MU) separated by 20-50km, the joint cumulative time percentages of rain attenuation become lower as the two sites are aligned along the directions of rain area motion. In such a case, the distance required between the two sites may be considerably reduced compared with the conventional ITU-R recommendations [Maekawa et al., 2007].

The Ku-band and Ka-band rain attenuation and Ka-band XPD degradation are simultaneously measured at OECU in Neyagawa, Osaka, as well as DSD measurements for the past three years of 2004-2006. The cross-polar phase and frequency ratio of Ka-band to Ku-band attenuation observed at each rainfall event agree well with their theoretical values based on the DSD detected at the same time. Also, the Joss-drizzle type that contains comparatively smaller DSD tends to be found in the stationary fronts of Baiu season, while the Joss-thunderstorm type with relatively larger DSD tends to be found in evening showers of summer season and the cold fronts of spring or autumn season [Nishio et al., 2006].

Fading dynamics, such as fade slope, fade speed and fade duration, in satellite links is one of the important themes for recent broadband IP-networks. Fade slope characteristics are studied as follows.

The fade slope evaluation method using the received signal levels from four stations located in a region of about 12 km in diameter is studied. Although some well established dependencies such as the dependency on the rain region and on the applied filter's bandwidth have been verified, it appears that existing fade slope model does not fit the obtained distributions [Franklin et al., 2004]. An efficient approach to evaluate the fade slope of the received signal level is proposed. This approach is applied to experimental data obtained from four stations located in a region of about 12 km in diameter in Fukuoka, Kyushu Island, Japan. From that analysis, an improved fade slope model is

derived [Franklin et al., 2005a]. A rigorous method was applied for data analysis of the fade slope that was observed in some stations. The standard deviation of the fade slope as a function of attenuation has a maximum and does not match the model proposed by the ITU-R P.1623 recommendation. According to this observation, an improved fade slope model is proposed [Franklin et al., 2005b, Fondjo et al., 2006c]. Using a simple approach for data analysis, the derivation of fade slope conditional probability distribution was discussed based on its symmetry. From this analysis, it was found that a more accurate distribution function is obtained by modeling the fade slope distribution based on its symmetry property rather than carrying the modeling process on the whole fade slope data set [Fondjo et al., 2006a].

Fade duration is also important for analyzing the fade dynamics. Fade duration dynamics were observed in 4 close stations. Fade duration statistics derived from collected received signal during a critical period was analyzed. Based on the comparison of the obtained results and the model released by the ITU-R P.1623 recommendation, some modifications are proposed [Franklin et al., 2005c, Franklin et al., 2005d].

As a well known parameter for fade dynamics, the level crossing rate was observed on satellite links. It was shown that for a long run, the level crossing rate conservation law is verified and that it depends on the sampling period for an attenuation threshold greater than 3dB [Fondjo et al., 2006b].

The site diversity system has been proposed as a mitigating technique for the rain attenuation on satellite links using frequencies above about 10 GHz. A study to improve Morita-Higuti prediction method for satellite link site diversity improvement was made by using a global databank. This method was found to be improved by using newly derived estimation equation for rain rate spatial correlation parameter that included regional climatic parameters [Suzuki et al., 2005]. In site diversity systems, signals of two earth stations located apart each other are switched. Although two prediction methods for site diversity improvement are recommended by ITU-R, these methods do not consider regional climatic parameters that will affect diversity improvement. These methods may be further improved in prediction accuracy by considering the regional climatic parameters. Modified versions of the existing prediction methods are proposed, which are derived by using KIT (Kitami Institute of Technology) satellite link site diversity databank with 108 datasets in 12 countries and thunderstorm ratio as a regional climatic parameter [Ito et al., 2006].

B. Effects of Other Factors

The measurement method used to extract important statistical parameters for different propagation environments and elevation angles is explained and discussed and results obtained from the measured data are presented. These results are compared with those from other empirical models given in the Rec. ITU-R P.681-6 to show the feasibility of this technique in the study of Mobile Satellite (MS) link. The outcome of this report will enable MS link data to be acquired from any region of the world for any predefined environment of interest [Abidin et al., 2006a]. The measurement method utilizing a portable GPS receiver used to extract important MS propagation parameters is explained and discussed. Results obtained from the empirical data and made comparison between various MS environmental conditions were presented. [Abidin et al., 2006b, 2006c]. The analyses of the MS propagation data obtained using the cost effective portable, commercial GPS receiver was presented. The analyses results show the relationship between the MS received signal performance and the ground blockages. The feasibility of using GPS in the study of MS link performance is validated [Abidin et al., 2007a].

Studies were carried out in equatorial region (Malaysia) in order to determine the MS signal performance in this region using the commercially available GPS receiver. Results have shown that open space signal measured using this method are consistent between each other with SNR exceeding reference level of SNR even for low elevation angle values. Due to factors such as high receiver system noise and ionospheric effect, signal measured in Samarahan exhibit severe fluctuations than that of Fukuoka [Abidin et al., 2007b].

(A. Sato)

F1.3 Mobile Radio Systems

A. Macrocell/Microcell Systems

A theoretical analysis method for diversity gain is proposed assuming base station polarization diversity in W-CDMA. The evaluation model used for theoretical analysis is verified based on a comparison with the experimental results and the analytical results of the practical diversity gain are clarified [Fukushige and Imai, 2007]. A channel model for line-of-sight small street microcell in dense urban areas is proposed. The scattering power distribution in the channel seen from the receiver based on the physical phenomenon is obtained. The coefficients of the distribution are derived by approximation to a set of urban street microcell measurement data. The azimuth-power spectrum for the proposed model is compared to those for conventional elliptical model as well as to the experimental results obtained from measurements in three different streets of a dense urban area. It is shown that the proposed model in contrast to the conventional models produces results that closely agree with the experimental results [Ghoraishi, et. al., 2006a]. A series of measurements in two streets in a dense urban area were accomplished. The measurement scenario was small microcell line-of-sight with low antenna height at both link ends where dipole sleeve transmitter antenna, directive receiver antenna, wideband pseudo-noise signal and correlator were employed. The data obtained from the measurements by careful investigation of the single-bounce scattering power distribution conforming is analyzed to precise maps of the environments including all present objects. The single-bounce scatterers for the cluster received waves appearing in the single-bounce scattering power distribution is identified. A number of objects were identified by this method as single-bounce scatterers within the spatial resolution bins. The identified objects are signboards, traffic signs, etc. and it is concluded that any metallic object visible to both Tx and Rx with dimensions in orders of tens of wavelengths can be a significant source of scattering in small cell scenarios with low antenna heights. The contribution of the scattering from these identified objects to the received power compared to other micro-mechanisms is evaluated. Results show that the scattering from these objects can be comparable to the wall reflections [Ghoraishi, et. al., 2006b]. Based on a double directional measurement in a residential area of Tokyo, it is shown how human-made irregularities can affect the azimuth angle at the mobile station (MS). The propagation mechanism at the MS is studied by categorizing the propagation mechanisms into propagation classes based on the azimuth angle [Sivasondhivat et. al., 2006]. A procedure for identifying clusters around the mobile station of a small macro-cell is presented. It is based on the parameters of stronger clusters, which serve as the initial centroids. Using this method clusters were identified in an NLOS scenario. Employing this approach may aid in the identification of clusters when relatively strong paths below the centroids are included [Materum et. al., 2007]. The results of a study are shown on 3-D channel parameters, i.e. azimuth, elevation directions at MS (DMS), and delay. Both vertical and horizontal polarizations were transmitted and received in the measurement. By observing the azimuth power spectrum density, the analysis of the spatio-temporal channel parameters including full polarimetric behaviors was conducted. Power spectrum density (PSD) models are proposed for modeling measured azimuth, elevation DMSs and excess delay PSDs. The relationship between cross-polarization ratio (XPR) and best-fit parameters is discussed. The extension of the models studied here to the MIMO (Multi-Input Multi-Output) channel model is possible by the assumption of Kronecker model of the base station (BS) and MS [Sivasondhivat et. al., 2007]. In order to study the shadowing characteristics affected by the surrounding buildings in UHF-TV band, a measurement is carried out on the UHF-TV band radio wave with the mobile measurement system, using existent TV broadcasting wave and DGPS systems, in the urban environments with various ground cover factors. The shadowing characteristics such as the mean received level and the standard deviation of the log-normal approximation are analyzed. It is newly presented that the shadowing characteristics is a function of 50 x 50 m^2 ground cover factors [Nishi et. al., 2005]. Multipath propagation characteristics in a very large office with over 5000 m^2 of floor space were studied by measurement and ray trace simulation. The results indicate that the method for estimating the delay spread by using the floor space (Rec. ITU-R P.1238) is applicable to such a large office. Cross-floor interference was also studied experimentally. A coupling loss of approximately 20 dB on adjacent floors can be expected for a modern building with large windows [Kita et al., 2005a]. A new dynamic variation model of the delay profiles in LOS indoor environments based on the measured delay profile snapshots in some LOS indoor environments is presented. The difference between using the conventional and newly proposed dynamic delay profile model based on the evaluation of the MIMO channel capacity was also presented [Kita et al., 2005b]. Employing a shaped beam pattern from a base station array antenna in the IMT-2000 system, e.g., a cosecant beam

pattern, is preferable because employing a shaped beam pattern in a service area provides a sufficient received power level while imparting only a slight interference power level to other areas. A simplified method for shaping a beam pattern from the base station array antenna that maximizes the downlink system capacity of W-CDMA in IMT-2000 systems is proposed. Calculation results show that when 12.5% to 37.5% of the total number of array elements is shifted 60 to 150 degrees, an increase in the system capacity of 180% to 190% is achieved [Kimura et. al., 2006]. The characteristics are shown on the measured path loss in the 800 MHz and the 5 GHz bands assuming the macro-cellular environment where the base-station antenna is set on the roof of a high building. The measured data indicates that the frequency dependence of the path loss is almost the same as that in the free space. Using this result, the applicable frequency range of the path loss prediction formula of the Walfisch-Ikegami model is extended up to 5 GHz. The estimation errors in 5 GHz band were greatly improved by the modified new formula [Yonezawa et. al., 2005a]. It is expected that some higher frequency bands over 2 GHz will be used for future mobile systems. In Rec. ITU-R P.1411, the prediction formula for the over-rooftops environment, where the BS height exceeds the average building height, was extended up to 5 GHz based on the measurements conducted in a suburban city in Japan. However, the applicability to urban areas has not been tested, and in addition, the frequency range of the formula in cases where the BS height is lower than the average building height has not been extended. The path loss in urban and suburban environments is measured using multiple frequency bands. The path loss in the case where the BS height is lower was also measured. This paper proposes prediction formulae that can be applied to over 2 GHz in both urban and suburban environments; based on the measured frequency characteristics [Yonezawa et. al., 2005b]. A frequency range extended path loss prediction formula based on the measurement results using multiple frequency bands from 0.8 to 8 GHz is newly presented where the BS antenna height is lower than the surrounding buildings. Although the lower and narrower frequency bands are assigned to the current cellular/ mobile systems, the higher and wider frequency bands should be allocated to the future mobile systems for providing broadband multimedia wireless communications services. And the future mobile systems are assumed to be the multi-mode systems including the existing systems in the lower band. The proposed path loss prediction formula should be applicable to wider frequency range (from 0.8 to 8GHz) and will be able to contribute to the cell design for the future mobile systems [Yonezawa et. al., 2006].

B. MIMO Channel Modeling and Measurement Method

The statistical distribution of eigenvalues of correlation matrices in i.i.d. MIMO Rayleigh fading channels is presented. First, the statistical eigen-analysis of MIMO channel correlation matrices is carried out, and the exact expression of the marginal distribution of eigenvalues is presented. Then, a monomial approximation of above distribution with a simple form convenient for the calculation of MIMO performance is proposed based on the theory of space diversity in SIMO systems adopting maximal ratio combining. Through computer simulations, the effectiveness of the proposed approximation method is demonstrated. [Taniguchi et. al., 2005a and 2006] In MIMO communication systems, eigenvalues of channel correlation matrices play an essential role for the performance analysis, and particularly, the investigation about their behavior under time-variant environment ruled by a certain statistics is an important problem. This paper presents an approximation formula of the marginal distribution of all the eigenvalues of MIMO correlation matrices under i.i.d. Rayleigh fading environment. The authors show that the theory of SIMO space diversity using maximal ratio combining (MRC) is applicable to the approximation of statistical distributions of all eigenvalues in MIMO systems with same number of diversity branches. The derived approximation has a monomial form suitable for the calculation of various performance indexes used in MIMO systems. Through computer simulations, the effectiveness of the proposed method is demonstrated [Taniguchi et. al., 2005b]. A general approximation formula of the largest eigenvalue distribution in correlated MIMO Rayleigh channels is presented. The proposed formula is given by improvement of SIMO based analysis method of MIMO systems, and applicable to any type of correlation including the case covariance matrix has degenerated eigenvalues for which conventional exact formula could not be used. The effectiveness of the proposed equation for various correlated MIMO channels is demonstrated through computer simulations [Taniguchi et. al., 2007a]. An approximation method of statistical distribution of the largest eigenvalue in i.i.d. MIMO Nakagami-M fading channels is described. The given formulae are introduced based on the conversion of MIMO channels into those

of SIMO with the same number of diversity branches. The derived density function has a simple monomial form which is suitable for calculations of various performance indices of MIMO systems. Through computer simulations, the effectiveness and problems are discussed [Taniguchi et. al., 2007b]. An approximation method of statistical distribution of the largest eigenvalue of i.i.d. MIMO channel correlation matrices under Nakagami-Rice fading environment is presented. The equation is actually derived for MIMO Nakagami-M fading channel which is known as a good approximation of Nakagami-Rice fading, hence it well approximates the curves of the largest eigenvalue distribution of non-central Wishart matrices. In the proposed approximation method, MIMO MRC system is ascribed to SIMO space diversity theory with the same number of branches, and the statistical distribution becomes a monomial gamma distribution. As a result, the derived marginal density function does not contain any special functions, and has a simple monomial gamma form which is suitable for various calculations of performance indices. Through computer simulations, it is shown that the proposed approximation formula is effective and has a better precision than conventional method [Taniguchi et. al., 2007c and 2007d]. 2x2 and 4x4 MIMO channels were measured in LOS and NLOS indoor environments. Based on the measured data, fading correlations were obtained. Also, the performance of space division multiplexing and eigenbeam space division multiplexing were clarified. [Ogawa et. al., 2005a and 2005b] Based on the measured data, eigenvalue distributions were obtained, and channel capacity was calculated in a case where the channel state information is available at a transmitter side. Also, the bit error rate performance of eigenbeam space division multiplexing were clarified [Nishimoto et. al., 2007]. 4x4 MIMO channels were measured in time-varying LOS and NLOS indoor environments. Based on the measured data, channel autocorrelations and Doppler spectra were obtained. Also, the bit error rate performance of eigenbeam space division multiplexing were clarified [Bui et. al., 2007a and 2007b]. There have been only a few MIMO propagation characteristic studies that focus on antenna directivity under outdoor LOS conditions. Therefore, MIMO propagation characteristics are measured for outdoor mesh networking. And the results show that the MIMO with directional antenna can improve channel capacity, and eigenvalue than that of MIMO with an omni-directional antenna [Yamada et. al., 2005]. CSI (Channel State Information) error becomes a factor to decrease the communication quality in adaptive MIMO-OFDM system. The proposed empirical formula of prediction SIR (Signal to Interference Ratio) based on the measurement which is the ratio between the power of the eigenvalue and the interference power is proposed, so as to evaluate the communication quality. This empirical formula of SIR is possible to estimate the value of SIR by changing frequent correlation coefficient [Yamada et. al., 2007]. In MIMO eigenbeam space-division multiplexing, all transmission and reception antennas have been used to obtain the maximum transmission performance. However, the absorbed energy is wasteful when a part of the elements are blocked. A method is proposed for giving up the use of unfunctional elements. Result of ray tracing simulation showed that the proposed method outperformed the conventional MIMO that always used all array elements [Takahashi et. al., 2006]. The service area expansion of the data transmission by MIMO is expected, therefore, expansion of service to isolated space is expected through a repeater which has two or more relay antennas. This propagation channel is Multi-Keyhole environment in equivalence. The keyhole effects severely reduce the capacity of MIMO channel. However, if the number of keyholes increases, this influence decreases. In this paper, the MIMO repeater system and Multi-Keyhole Model are proposed, which realize the repeat function to isolated space where communication of high data rate and high reliability is needed. MIMO repeater system is supported the feature of MIMO function and performance. Eigenvalue distributions, average channel capacity and average BER performance of MIMO repeater channel are shown by computer simulation. Finally, it is shown that the number of relay antennas required for the repeat which keeps the function of MIMO [Tsuruta et. al., 2006]. MIMO leads to dramatic improvement in channel capacity and/or link reliability of wireless systems. However, a MIMO channel has only one degree of freedom in a keyhole environment. As a result, this environment reduces achievable channel capacity and link quality. This paper proposes a MIMO repeater system, which can realize a multi-stream transmission. Although the averaged channel capacity in the MIMO repeater system is discussed in several published papers, the probability density functions of eigenvalues of correlation matrix are not analyzed. MIMO transmission performance can basically be estimated from eigenvalues of the channel correlation matrix. An approximated formula for the probability density function of all eigenvalues linked to the space diversity is derived. It is shown that the calculated values based on the

proposed method agree very well with the simulated values [Tsuruta et. al., 2007]. An overview of research in channel modeling for MIMO data transmission focusing on a radio wave propagation is provided. A MIMO channel is expressed as an equivalent circuit with a limited number of eigenpaths according to the singular-value decomposition (SVD). Each eigenpath amplitude depends on the propagation structure not only of the path direction profiles for both transmission and reception points but also of intermediate regions. Inherent in adaptive control is the problem of instability as a hidden difficulty. In this paper these issues are addressed and research topics on MIMO from a radio wave propagation viewpoint are identified [Karasawa, 2005]. Recent antennas and propagation studies for MIMO systems are reviewed. A MIMO propagation channel model is firstly introduced in which an interesting nature can be found in eigenvalue statistics from a practical viewpoint. Multi-keyhole model is then introduced which is an efficient tool for designing a MIMO repeater systems, or MIMO radio-relay systems. For realization of compact MIMO antenna systems, effectiveness of using multiple polarizations such as dual polarizations and triple polarizations is demonstrated in multipath-rich propagation environments. With application of MIMO to OFDM systems, analysis on relation is focused between propagation and digital transmission characteristics under a severe multipath-rich environment where the delay profile exceeds the guard interval. Finally, transmission characteristics of MIMO-OFDM with MRC diversity in the environment are discussed [Karasawa 2007a]. A novel internal multi-antenna configuration employing folded dipole elements for notebook PCs is proposed. It is taken particular note of the properties of the folded dipole antennas that eliminate the undesired current on the ground plane. Employing folded dipole antennas in a multi-antenna configuration, mounted at the four corners of the upper ground plane of a notebook PC model, resulted in an approximate 5 dB increase in the pattern averaging gain compared to that for inverted-L antennas, which are popularly used as internal antennas equipped in mobile equipment. Furthermore, evaluated results of the multi-antenna performance showed that the proposed quad folded dipole antenna configuration achieves an approximate 6 dB higher beamforming gain and approximately double the MIMO channel capacity, respectively, compared to those for a quad inverted-L antenna configuration with a low correlation coefficient of less than 0.2 [Okano and Cho, 2006]. The rapid growth in mobile communication systems leads to a great demand for MIMO and multi-band systems to enhance the data rate and the capacity of the radio network, thus both multi-antenna and multi-band technologies must be employed for mobile terminals. In regard to the link budget, the performance of antennas is a vital element since the performance will not only affect the quality and the coverage of the mobile network but also the capacity of the entire networks. Hence, clarification of the performance of multi-band and multi-antennas mounted on actual mobile terminals is currently urgently needed. This is especially true in practical usage situations and since the size and style of mobile terminals has changed significantly over the last several years. This paper presents the available performance of multi-band and multi-antennas designed for 4x4 MIMO and triple-band operation covering the 800 MHz, 1.7 GHz, and 2 GHz bands, when the antennas are mounted on an actual mobile terminal. A multi-band folded inverted-L antenna is firstly introduced in this study. Then the influence of mutual coupling, implementation losses and multi-antenna performance are investigated when employing the multi-band folded inverted-L antennas. The investigation is based on the measurement in an anechoic chamber. The developed measurement facility that employs the multi-channel antenna pattern measurement system enables us to acquire the amplitude and phase patterns of multi-antennas at high speed [Okano and Cho, 2007a]. The influence of the XPR of the waves arriving at a mobile terminal on the MIMO channel capacity in multi-band and multi-antenna configurations is investigated. The propagation environment around a mobile terminal is assumed extremely diverse in future mobile communication systems. This is because it is desirable to support flexibly indoor areas as well as outdoor areas using the same air interface, and diverse antenna configurations will be employed for the base station such as space diversity configurations and polarization diversity configurations. This paper is aimed at evaluating the channel capacity for multi-frequency bands under the conditions of free space and in the data mode. An actual handheld device as a mobile terminal and we mount onto the handheld device unique antennas for MIMO transmission designed for multi-band operation is employed. Furthermore, the dependency of channel capacities on the XPR is quantitatively analyzed using detailed parameters including the mean effective gain (MEG), the correlation coefficient between antennas, and the eigenvalue of the correlation matrix based on the measured radiation patterns. As a result, it is shown that a low absolute

XPR of the arriving waves increases the channel capacity for all frequency bands due to the dual-polarized properties of the antennas mounted on the handheld device [Okano and Cho, 2007b]. In MIMO eigenbeam space-division multiplexing, all transmission and reception antennas have been used to obtain the maximum transmission performance. However, the absorbed energy is wasteful when a part of the elements are blocked. A method is proposed for giving up the use of unfunctional elements. Result of ray tracing simulation showed that the proposed method outperformed the conventional MIMO that always used all array elements [Takahashi, et. al., 2006].

C. Formulation of Mobile Propagation

A site-general type prediction formula is investigated based on measurement results in an urban area in Japan assuming that the prediction frequency range required for the Fourth - Generation (4G) Mobile Communication Systems is from 3 to 6 GHz, the distance range is 0.1 to 3 km, and the range in the base station height is from 10 to 100 m. Moreover, a correction formula for suburban areas is proposed based on the difference between calculated values using the prediction formula for urban areas and the received levels measured in the suburban area [Kitao and Ichitsubo, 2006]. Frequency dependence for spatial dispersion of radio wave arrived at base station was measured in 0.4, 2 and 8 GHz on urban area. It is made clear by measurement results that spatial dispersions do not depend on frequency and are the same in 0.4 to 8 GHz band [Kitao and Ichitsubo, 2007]. A statistical scattering model for mobile radio channels is proposed that has three features: 1) the effective scattering area is expressed by an ellipse the center of which is the MS location; 2) the major axis of the ellipse runs parallel along the street where the MS is located; and 3) the scattering power density function around the MS is expressed by a combination of two Laplacian distributions in which the standard deviations are different [Imai and Taga, 2006]. Multi-path phase difference distribution in a narrow mobile radio channel was studied on a domain and frequency axes using theoretical and simulated results. The multi-path phase was discussed in great detail by using the cumulative distribution, and both theoretical and simulated results were showed good agreement with a wide range of 0.001 to 99.999 %. Furthermore, a new phase difference cumulative value locus was devised. For the applications, using the cumulative value enabled the M-ary DQPSK-BER to be estimated and using the locus enabled a pilot signal on the domain to be allocated flexibly [Kozono 2007]. The urban physical propagation environment around the mobile station is often described as a multipath environment, where power is received through diffractions over rooftops and building corners, reflections from walls and scattering in general from other surrounding objects. Since there is only finite number of these scatterers, the waves are received in clusters each originating from one of the scattering sources. To study these scatterers, direction-of-arrival data measured along continuous routes in two small macro-cellular environments were analyzed. Multipaths received with approximately the same directions and delays were combined as clusters. Therefore each of the clusters corresponds to the signal received from one scatterer. This paper focuses on both the identification of the physical scatterers in the surrounding environment and studying the radio wave propagation in more detail, including the amount of significant scatterers in terms of contributed power, XPR values, and delay and azimuth spreads of the individual clusters. The results show that there are only a few dominant scatterers. They were usually building corners and walls, and building structures over the rooftop level. The delay and azimuth spreads inside the clusters were small, and depolarization was almost negligible. Both propagation over the rooftop level and propagation along the street canyons were significant in the considered environments [Vuokko, et. al., 2005]. The polarization behavior of the mobile MIMO radio channel is analyzed from polarimetric double-directional channel measurements, which were performed in a macro-cell rural environment in Tokyo. The recorded data comprise non-line-of-sight, obstructed line-of-sight, and line-of-sight conditions. The gradient-based maximum-likelihood estimation framework RIMAX was used to estimate both specular and dense multipath components. Joint angular-delay results are gained only for the specular components. The dense multipath components, which may be attributed to diffuse scattering, can be characterized only in delay domain. Different characteristics describing the polarization behavior and power-weighted cross- and copolarization ratios for both types of components are introduced. Statistical analysis of long measurement track segments indicates global trends, whereas local analysis emphasizes specific behavior such as polarization dependency on angle of incidence in streets and under shadowing conditions. The results also underline the importance of modeling changing and transient propagation scenarios which are

currently not common in available MIMO channel models [Landmann, et. al., 2007]. Results of measurements carried out at distances ranging from approximately 5 to 30 km are presented. In these measurements, frequencies in the 2 GHz and 5 GHz bands are used simultaneously to investigate the difference in path loss between the 2-GHz band and 5-GHz band. The difference in path loss is approximately 7 to 9 dB based on the analysis of these measured data for median values in 10-m intervals. The results enable us to estimate the path loss for the 5-GHz band from that of the 2-GHz band [Sato, et. al., 2005]. A new method for predicting the path loss in over-rooftop propagation environments in microwave bands is proposed. In the paper, it is clarified that the path loss due to distance can be divided into three regions where the direct wave, the reflected wave, and the diffracted wave are dominant, respectively. The validity of the model is tested by measuring the path loss at 2.2 GHz, 5.2 GHz, and 19.4 GHz (CW) in suburban areas in Tokyo [Kita et al., 2006a, 2006b]. A height variation model at subscriber station (SS) in the region more than 4 m high, which is reflected the dependency on location of SS for FWA/NWA systems in microwave band in suburban areas, is proposed. The validity of the model was tested by measurements of the height variation at SS in 2.2 GHz, 5.2 GHz, and 25.15 GHz (CW) in suburban areas in Japan [Kita, et al., 2007]. Propagation studies and models that are expected to contribute to the development of broadband wireless systems are surveyed and introduced. The survey focused on theory-based propagation models, experimental measurement data useful for modeling, and transmission characteristic evaluations using propagation models. The survey did not attempt to cover all papers in the research fields, but rather took key papers for various relevant subjects and described them in some detail. The basic characteristics of multipath propagation are summarized from the viewpoints of narrow-band (NB), wide-band (WB), and ultra wide-band (UWB). Recent studies on spatio-temporal propagation models and the relationship between models and systems are introduced. To clarify the relationship between OFDM, which is a representative of wideband data transmission schemes, and wave propagation factors, problems due to large delay spread and large Doppler spread are highlighted. Finally, studies on UWB propagation measurement and propagation models are introduced [Karasawa 2007a]. Theoretical analyses on level variation of wideband signals in Rayleigh fading environments are carried out. The model is based on eigenvalue analysis in frequency domain which is a new approach for making clear the characteristics theoretically [Inoue 2005]. In order to assess the effect of multipath fading on OFDM signal transmission when the delay profile exceeds the guard interval, a simple prediction model is developed based on the Equivalent Transmission-Path (ETP) model. This model, which is described in this paper, is referred to as the ETP-OFDM-statistical model. The validity of the model is demonstrated by comparing the calculated digital transmission characteristics to results obtained by computer simulation. Using the newly developed ETP-OFDM-statistical model, digital transmission characteristics of the OFDM signal in a multipath environment when the delay profile exceeds the guard interval are shown as a function of delay spread, guard interval and OFDM symbol period [Karasawa, et. al., 2005].

D. Ultra Wideband

The concept of measuring double directional channels in UWB systems is introduced. Antenna-independent channel data were derived by doing the measurements in a wooden Japanese house. The data were useful for investigating the impact of UWB antennas and analyzing waveform distortion. Up to 100 ray paths were extracted using the SAGE algorithm and they were regarded as being dominant. The paths were then identified in a real environment, in which clusterization analyses were done using the directional information on both sides of the radio link. Propagating power was found to be concentrated around the specular directions of reflection and diffraction. This led to the observation that the spatio-temporal characteristics of extracted paths greatly reflected the structure and size of the environment. The power in the clusters indicated that the estimated 100 paths contained 73% of the total received power, while the rest existed as diffuse scattering, i.e., the accumulation of weaker paths. The practical limits of path extraction with SAGE were also discussed. Finally, it is derived that the scattering loss and intra-cluster properties for each reflection order, which were crucial for channel reconstruction based on the deterministic approach [Haneda, et. al., 2005a]. Results from propagation channel measurements in a Japanese wooden house is reported. With the measured data, following analyses were conducted: 1) extraction of 100 waves using SAGE algorithm; 2) clusterization of the detected paths in a heuristic approach; 3) investigation of the spatio-temporal

cluster characteristics including path identification; and 4) consideration on the residual components [Haneda et. al., 2005b]. Results from measurement of UWB double directional channels in a standard Japanese wooden house are presented. Channel parameters which characterize the behavior of channels were introduced. The parameters help us not only interpret physical phenomena intuitively but also contribute to the antenna-independent channel models quantitatively [Haneda, et. al., 2005c]. The link budget evaluation scheme is proposed for UWB system based on the extended Friis' transmission formula. The template waveform is considered at the receiver side to maximize the SNR for evaluation. An experimental evaluation of the antenna transfer function needs the three types of broadband antennas. The technique gives very accurate results and is very useful for design and evaluation of UWB impulse radio transmission systems, especially for the evaluation of waveform distortion effects [Promwong and Takada 2005]. An UWB channel sounding scheme with a parametric channel estimation to seek accurate probing of the propagation channel. The channel sounder consisting of a vector network analyzer and synthetic array to measure spatial transfer functions is presented. The measured data are then applied to a maximum-likelihood (ML)-based estimator. The concepts implemented in the ML-based parametric channel estimation are: 1) to probe frequency-dependent effects in magnitude and phase of propagation paths and 2) to incorporate with robust concept of direction finding, namely, the spherical wavefront model of incident waves. The whole frequency band was divided into subbands, and the estimation of magnitude and phase was conducted in each subband. The spherical wavefront model includes a new model parameter, curvature radii, which is not covered in the conventional plane wavefront model. Performances of the proposed parametric UWB channel estimation scheme were assessed by anechoic chamber tests. The test demonstrated that: 1) the frequency-dependent magnitude and phase were accurately detected if the path was resolved and 2) the spherical wavefront outperformed the plane wavefront to model measured data given the short-range environment. Furthermore, fundamental performance of the sounding scheme, i.e., angular and time resolutions, was also evaluated in the test [Haneda, et. al., 2006a]. An UWB double-directional channel sounding measurement and spatio-temporal analysis of UWB propagation based on the clusterization approach were reported. After separating the propagation paths and diffuse components both on the transmitter antenna and receiver antenna positions, the propagation paths both on Tx and Rx positions were observed for clusters separately, while coupling the clusters between Tx and Rx position based on similar time of arrivals, and ray tracing by utilizing high temporal and spatial resolution, respectively. The relation between direction of departure and direction of arrival will then be investigated. For cluster properties, parameters of model characteristics are discussed and compared to other earlier works [Tsuchiya, et. al., 2006]. Results from double directional UWB channel sounding in a wooden house are described. The double directional channel sounder estimates directional information at both ends of the link, so that antenna directivity can be separated from the channel sounding results. The dominant propagation mechanisms are investigated by introducing cluster analyses. The detected propagation paths from the channel sounding were first classified into clusters in the angular-delay domain, and then properties of the clusters such as standard deviation of path positions, dynamic range of path power, and power distribution of clusters were derived. From the results, the similarities and differences are discussed between the measurement environment and the physical propagation phenomena. Finally, different types of scattering losses of the propagation paths were derived and modeled. The results from sounding and analysis contribute in the development of UWB propagation models and can be used in UWB propagation simulations [Haneda, et. al., 2006b]. The verification of the effectiveness of stored channel simulations for evaluating UWB communication system performances is described in realistic propagation environments. It was achieved by investigating the similarity of two received waveforms: one acquired by the real signal transmission and the other reconstructed using stored channel simulation. The actual received waveform was directly measured by a UWB testbed. On the other hand, the transfer function of the antennas and propagation channels measured by a vector network analyzer, i.e. the stored channel, together with the transfer functions of the transmitter and receiver of UWB testbed, were used in simulation to reconstruct the received waveform. The result shows that the actual measured received waveform is almost identical to the reconstructed received waveform via stored channel simulation [Haneda, et. al., 2007]. Numerical analyses are presented of the effects of errors realized in complex relative permittivity, in order to give guidelines for synthesizing UWB electromagnetic phantom materials. Liquid and solid recipes were developed through possessing the

permittivity of high-water-content human tissues within tolerable errors [Hara and Kobayashi 2005]. Ultrawide-band channel sounding scheme is proposed with a technique for estimating time of arrival (TOA) and angle of arrival (AOA) using an antenna array time domain smoothing. Experimental validation of the scheme was also presented [Iwakiri and Kobayashi 2007]. Ultra wideband signal propagation was measured and characterized in comparison with narrowband in a passenger-car compartment. Whereas narrowband channels resulted in a number of dead spots (deep fading points), UWB (3.1 to 10.6 GHz) yielded none, though some frequency dispersion was inevitable. Fading depth versus occupied bandwidth was derived, which indicated superiority of UWB over narrowband systems from the viewpoint of link budget [Kobayashi 2006a, 2006b]. An automated ellipticity measurement system is described for UWB circular polarization antennas. Ellipticity and wideband XPD of an axial-mode helical antenna were measured using this system [Maeda and Kobayashi 2005]. An omni-directional in azimuth, low VSWR, and easy-to-construct antenna was proposed for UWB systems. [Maeda and Kobayashi 2007] Results were presented from ultra wideband propagation channel measurements in an office environment at the 26 GHz band. To evaluate the differences in a multipath environment by antenna radiation pattern, two directional types of receiving antenna were used. The influence of the multipath can be reduced by using a direction [Rikuta, et. al., 2006]. Short-range propagation measurements were carried out using UWB and CW signals on a rectangular conductive plate, simulating typical office desks, with and without a low vertical metal partition panels. The effects of human bodies were also experimentally evaluated [Suzuki and Kobayashi 2005]. Ultra wideband double directional channels were modeled as the sum of ray paths. The paths were characterized by direction of departure, direction of arrival, and delay time of arrival. The complex amplitudes of the paths were modeled as a function of the frequency and represented by the values for subbands. These parameters were estimated by using a SAGE-based algorithm. [Takada, et. al., 2005] An omni-directional in azimuth and low VSWR (< 1.3 from 3 to 20 GHz) ultra-wideband monopole antenna is reported. Performance comparison was made between a prototype antenna and other representative wideband antennas [Taniguchi, et. al., 2006]. The development of liquid UWB electromagnetic phantom material and UWB arm and torso phantoms are presented [Zhou, et. al., 2006a, 2006b].

E. Intelligent Transportation System (ITS)

Assuming inter-vehicle radio communication systems (V2V), the propagation characteristic in non line-of-sight intersections is analyzed and the results of the analysis are shown. The propagation loss characteristics are evaluated using ray-tracing technique when various system and environmental parameters, such as carrier frequency, road width, building material and so on, are varied. In Japan, a new spectrum allocation to ITS services in the 700MHz band is now considered. Therefore the frequency characteristics of the propagation loss in the environments are one of the main themes of the study. Based on the analyzed results, the influence of the variation of the parameters on the propagation characteristics is presented [Tango, et. al., 2007]. Electronic Toll Collection (ETC), an application of Dedicated Short Range Wireless Communication (DSRC), had suffered from wrong operations due to multipath problems. To solve this problem, it is proposed to apply a simple configured path determination scheme for the ETC system. The system consists of a vector network analyzer, low-noise amplifier, and X-Y positioner and achieves an automatic measurement of the spatial transfer function with emphasis on accurate measurement and reproducibility. For the reliable identification of the propagating paths, 3-D Unitary ESPRIT and SAGE algorithms were employed. Having developed the system, field experiments at the toll gate of the highway was carried out. In the measurements, it is possible to determine many propagation paths so that the dominant propagation phenomena at the toll gate was identified. They included a ground-canopy twice reflected wave, which was a potential path that caused wrong operation. Consequently, their reflection coefficients and polarization characteristics were investigated. From the results, applicability of the path determination system for short range on-site measurement was confirmed [Haneda, et. al., 2004]. The prediction of received power in the out-of-zone of a DSRC system operating inside a typical arched highway tunnel is discussed. By conducting wideband directional channel sounding inside the tunnel, the gain, angle-of-arrival and delay of each propagation path are estimated by means of a multidimensional maximum likelihood estimation algorithm from the measured data. Using these estimated parameters and by employing simulations of application antennas according to the DSRC standard, the received

power in the out-of-zone is predicted for 2 roadside unit (RSU) antenna positions. The dominant scatterers causing the over-reach of radiated power to the out-of-zone were identified and attributed to the ground and sidewalk. These scatters can affect the received power level in the out-of-zone by as much as 10 dB. It can therefore be concluded that suppressing ground and sidewalk scatterings in the vicinity of RSU by installing composite pavement materials are needed to increase the electromagnetic absorption in order to guarantee DSRC services [Ching, et. al., 2007a, 2007b].

F. Others

Accelerating the ray-tracing process while maintaining a high level of prediction accuracy is an important problem. In order to solve the problem, this paper proposes the ray-tracing acceleration technique employing the genetic algorithm or GA. Its performance is also evaluated by computer simulation [Imai, 2006a, 2006b].

Earthquake observation using radio waves has started from 1998. During the observation period, co-seismic EM phenomena have been observed on three earthquakes, Tottori-ken-seibu earthquake in 2000, Geiyo earthquake in 2001 and Ibaraki-ken-oki earthquake in 2002. The observation method and co-seismic observation results associated with the earthquakes are presented [Yoshida, et. al., 2006]. A big earthquake occurred on October 23 in 2004, which is called the Mid Niigata Prefecture earthquake. FM tuners located at Nobeyama received the FM radio wave of 82.3 MHz broadcasted from FM Niigata radio station. They detected EM anomalies before the earthquake. The observation has been continued until now in order to clarify weather the anomalies were pre-seismic phenomena or usual tropospheric phenomena such as duct propagation. In the paper, the observation method and propagation characteristics of FM radio waves of 82.3 MHz measured for three years at Nobeyama observatory are described [Yoshida, et. al., 2007]. One approach to discern whether the noises originated from earthquakes or others is longstanding observations. Long term accumulating the data of EM waves can reveal the ordinal properties of EM waves at the observational sites. The characteristic features of EM waves vary in time, from day to day and according to seasons. Accurate grasp of EM waves over short and long spans is a matter of importance for exploration of the EM phenomena related with the earthquakes. In this paper, the properties of FM radio waves at Niijima in 2006 are reported. The ordinary states of FM waves in Niijima are helpful for discussion of the EM phenomena related with the possible future earthquakes in this area [Takahashi, et. al., 2007].

The characteristics of UHF band radio propagation over the Seto Inland Sea is investigated in order to obtain primary data to estimate interferences of the terrestrial digital TV system that will be operated in UHF band. The authors have measured UHF band TV broadcasting waves from the Matsuyama station at two observatories in Hiroshima prefecture since June in 2005. From the measurement data, it was clarified that short-term fading with a duration time less than 1 hour frequently occurred in summer season and that long-term fading related to sea level fluctuations occurred in winter season. It was also found that the received level became stable when the typhoon with strong winds hit the propagation paths [Nishi, et. al., 2006a].

New indoor human detection systems using VHF-FM and UHF-TV broadcasting waves are studied. In order to investigate the ability of VHF-FM and UHF-TV human detection systems and compare these systems, the received levels of VHF-FM and UHF-TV broadcasting waves in the room with or without human presence are measured. Consequently, both VHF-FM and UHF-TV detection systems could sense the human presence using an appropriate threshold of the received level fluctuation. And the monitoring period of only 5 seconds could achieve 100 % detection probability in both VHF-FM and UHF-TV detection systems [Nishi, et. al., 2006b].

A new human detection system using UHF band TV receiving waves is proposed. By use of the TV broadcasting waves as radio transmission waves, the proposed system does not need a transmitter; the system is composed of only receiving systems including a receiving antenna and a receiver. The proposed system can detect the presence or absence of human in a room based on the principle that the received level is fluctuated due to multi-path fading or shadowing with human presence. Remarkably, the proposed system utilizes the indoor multi-path propagation of UHF band TV broadcasting waves to detect human presence. In order to investigate the human detection abilities of the new system, in this study, the received levels of UHF band TV waves are measured in the room with or without human presence [Nishi, et. al., 2006c].

Reduction of AOA estimation error owing to amplitude and phase perturbation in the array response

using spatial smoothing preprocessing (SSP) is proposed. The performance improvement of the proposed method is validated by Monte-Carlo simulation. To show applicability of the proposed method in practice, it was applied to estimate AOAs of measured data obtained in an anechoic chamber and in an open site. According to the results, SSP can reduce the random error in the array response, thus reducing the error of estimated AOAs in the measured data [Cherntanomwong, et. al., 2006] .
(H. Iwai)

F2 Remote Sensing

F2.1 Atmosphere

In this section, the remote sensing of atmosphere from the ground to the altitude of about 100 km is reviewed.

A. GPS meteorology

GPS (Global Positioning System) meteorology is a sounding technique of the atmosphere, by measuring propagation delay time of radio waves transmitted by GPS satellites. It provides us with information of electron density in the ionosphere, temperature in the stratosphere and humidity (water vapor) in the troposphere. The receiver could be located on the ground, ship, airplane, or satellite. A global observation of atmosphere with a very high vertical resolution can be obtained by LEO (Low Earth Orbit) satellite with the radio occultation method. Such LEO measurements (e.g. CHAMP, SAC-C) have been used to study characteristics of tropopause, Kelvin and gravity waves in the troposphere and stratosphere, and so on [Ratnam et al., 2005; Ratnam et al., 2006a; Ratnam et al., 2006b; Tsuda et al., 2006]. Recently a huge number of LEO measurements become available due to the COSMIC (Constellation Observing System for Meteorology, Ionosphere, and Climate) mission (providing over 2,000/day soundings by 6 LEO satellites) and are expected to improve numerical weather forecasts by data assimilation.

B. Various techniques of observation in troposphere with MST radars

The angular and range resolutions of MST (Mesosphere-Stratosphere-Troposphere) radars (or wind profilers) are often limited by their beamwidth and system bandwidth, respectively. The high-resolution imaging techniques with the Capon processing method have been developed based on multi-receiver and/or multi-frequency interferometry using the MU radar (Middle and Upper Atmosphere Radar of Kyoto University) [Luce et al., 2006]. The high-resolution images have clarified the detailed structure of thin layers above the convective cells and of Kelvin-Helmholtz billows [Luce et al., 2007]. The Capon method was utilized to reduce ground clutter from the MU radar data [Kamio et al., 2004] and the Equatorial Atmosphere Radar (EAR) data [Nishimura et al., 2006].

Most contemporary wind profilers utilize the Doppler beam swinging (DBS) method to estimate horizontal wind from three (two adjacent oblique and one vertical) or four oblique beams. Adachi et al. [2005] showed that the four-beam method has better accuracy and precision of wind speed because the four-beam method is less susceptible than the three-beam method not only to patchy rain, but also to the vertical airflow with spatial variability.

The Japan Meteorological Agency (JMA) started operation of a wind profiler network called the WInd profiler Network and Data Acquisition System (WINDAS) in 2001 [Ishihara et al., 2006]. WINDAS is unique in that it uses 31 1.3-GHz profilers having the spatial resolution of 130 km on average. Tropical cyclones were observed with the WINDAS radar at Naze, Okinawa and it was revealed that both weak updrafts and downdrafts existed in the middle troposphere and downdrafts were dominant in the lower troposphere in the eye [Teshiba et al., 2005]. The 1.3-GHz radar observations revealed that a dual layer structure in the upstream of a line-shaped convective system appeared to the south of the stationary Baiu (Meiyu) front in southern Kyushu, Japan, and a solitary wave and a Kelvin-Helmholtz wave excited by gravity currents created by katabatic flow originating on the mountainous slopes west of the Kanto Plane, Japan [Adachi et al., 2004a, b].

The 47-MHz Equatorial Atmosphere Radar (EAR) has been operated at Kototabang, West Sumatra, Indonesia since 2001 and has been very successfully used for the study of equatorial atmosphere dynamics. A research project called Coupling Processes in the Equatorial Atmosphere (CPEA) was

conducted for studying the coupling processes in the equatorial atmosphere during 2001-2007 [Fukao 2006]. Various instruments, including rawinsonde balloons, X-band meteorological radars, meteor radar, MF radars, and Rayleigh/Mie lidar, have been assembled at and around the EAR site to cover as wide a height range. Direct evidence that atmospheric gravity waves are generated by deep cumulus convection was obtained with the EAR [Dhaka et al., 2005, 2006; Alexander et al., 2006]. The features of vertical motion have been revealed based on the EAR observations [Seto et al., 2006; Mori et al., 2006; Yamamoto et al., 2007; Nishi et al., 2007]. Atmospheric dynamics and raindrop size distribution observed with the EAR have been investigated [Seto et al., 2004; Sakurai et al. 2005; Renggono et al., 2006; Shibagaki et al., 2006a, b; Murata et al., 2006].

C. Mesosphere and Lower Thermosphere (MLT) Region

Mesosphere and lower thermosphere region exhibits special interests because it is a transient region between the neutral and ionized atmospheres, and eddy diffusive and molecular diffusive atmospheres. Variability of this region has been studied intensively by using ground-based/space-borne observations, modelings and theoretical works.

As for the observational study, two topics should be emphasized. The first is the very successful studies on equatorial region with CPEA (Coupling Processes of Equatorial Atmosphere) studies, which is a six-year project started in 2001. After the development phase of the equipment and observational network, a huge amount of observational results has become available from this project. MLT radar observation has clarified correlation between MLT diurnal tides and Elnino Southern Oscillation (ENSO) [Gurubaran et al., 2006]. Planetary scale waves with period of 5-8 days have been studied in detail by combining MLT radars and TIMED satellites [Sridharan et al., 2006]. Long-term trend of MLT winds have also clarified with the MF radar [Sridharan et al., 2007]. Combined observation with a metallic atom resonance lidar and a meteor radar has shown that occurrence of sporadic sodium layer at the equator is very different from what has been observed at mid latitude [Shibata et al., 2006]. Motion of E-region irregularity and neutral wind has been studied with the meteor radar and EAR (Equatorial Atmosphere Radar) over the equator [Patra et al., 2007]. Semidiurnal tides were studied with meteor radars, GCM (general circulation model) modeling and TIMED (Thermosphere Ionosphere Mesosphere Energetics and Dynamics) satellite observations [Du et al., 2007].

The second is radio-optical observations using the MU radar and Shigaraki MU observatory, of Kyoto University. Airglow rotational temperature and diffusion coefficient of meteor echoes are carefully compared [Takahashi et al., 2005]. Combining airglow imager and radar, momentum fluxes associated with gravity waves are measured [Suzuki et al., 2007a]. Concentric gravity waves in the MLT region is found to be associated with cumulous convection in the troposphere [Suzuki et al., 2007b].

D. Radio Acoustic Sounding System (RASS)

Radio Acoustic Sounding System (RASS) is a radar remote-sensing technique to monitor high-temporal resolution temperature profiles by combining a wind profiling radar (WPR) and ground-based acoustic transmitters. The transmitted acoustic pulses produce atmospheric refractive index fluctuation, which scatters radio-wave transmitted from a WPR. Atmospheric virtual temperature is calculated from the Doppler shift of the back-scattered radio signal. The RASS system for the MU (Middle and Upper atmosphere) radar (the MU radar-RASS) can obtain the temperature profiles in the troposphere and lower stratosphere with the temporal resolution of a few minutes. The temperature profiles were used to investigate the effect of atmospheric stability on the wave propagation and the detailed temperature fluctuation across the tropopause [Alexander et al. 2006, 2007]. The RASS technique developed for the MU radar was applied to the other radar systems such as 1.3GHz- and 400MHz-wind profiling radars and the Equatorial Atmosphere Radar (EAR) to monitor temperature profiles in the boundary layer and the tropical region [Furumoto et al. 2005, 2006; Imura et al., 2006]. Humidity profiles can be estimated from the turbulence echo and RASS observation data and successfully revealed the detailed structure of wind, temperature and humidity profiles during the passage of raincloud [Furumoto et al., 2005, 2007].

E. Spaceborne Sensors

The Greenhouse gases Observing SATellite (GOSAT) will observe the concentrations of carbon

dioxide and methane, two major greenhouse gases, from space. GOSAT project is a joint effort of JAXA, Ministry of the Environment, and the National Institute for Environmental Studies (NIES). The observation instrument onboard GOSAT is called the Thermal and Near-infrared Sensor for Carbon Observation (TANSO). TANSO is composed of two sensors: a Fourier transform spectrometer (FTS) and a cloud aerosol imager (CAI). Band 1 (0.76 μm), Band 2 (1.6 μm), and Band 3 (2.0 μm) of FTS will provide the spectra of sunlight reflected from the earth's surface in the daytime, and Band 4 (5.6 -14.3 μm) will observe light emitted from the atmosphere and the earth's surface throughout the day and night. The imagery data from TANSO-CAI will be used to determine the existence of clouds and to estimate aerosol parameters over a wide area. Several environmental tests of the proto-flight model of the TANSO sensor were preformed in 2007. Data retrieval algorithms of carbon dioxide and methane concentrations under the almost clear-sky conditions in operational data processing have also been developed by 2007.

JAXA and NICT are collaborating to develop a space-borne submillimeter-wave limb sounder called Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) to be aboard the Japanese Experiment Module (JEM) of the International Space Station. JEM/SMILES is designed to observe global three dimensional distributions of stratospheric ozone-depletion-related gases such as O3, ClO, BrO, HCl, HNO3, and HO2 in submillimeter-wave bands around 640 GHz by a highly sensitive SIS (Superconductor-Insulator-Superconductor) receiver operating at 4.5K. Simulation studies based on the detailed instrumental design have performed its capability of retrieving stratospheric minor constituents [Kasai et al., 2006]. The Balloon-Borne SMILES (BSMILES) was developed for the development of SMILES and data analysis software. Two flight experiments of BSMILES demonstrated advantages of low noise submillimeter-wave limb-sounder to the stratospheric observation. A weak stratospheric HO2 signal was detected by BSMILES [Irimajiri et al, 2006]. Stratospheric ozone and ClO were also successfully observed by the BSMILES. Calibration and data analysis of submillimeter-wave limb observation were studied. Retrieved profiles from BSMILES observation show reasonable agreement with other available stratospheric measurements [Ochiai et al, 2005].

F2.2 Hydrometeors and Other Particles

A. Ground-based remote sensing studies

The information of raindrop size distribution (DSD) is essential to improve the accuracy of radar rainfall remote sensing. Seasonal and diurnal variation characteristics of tropical DSD was extensively studied using disdrometer data at South India, Singapore and Kototabang, west Sumatra [Kozu et al. 2006a]. In addition, a clear intra-seasonal variation was found at Kototabang, west Sumatra, in which DSDs are generally wider in the inactive phase of Madden-Julian Oscillation (MJO) than in the MJO active phase. This is related to the dominancy of deep, localized convection rather than organized rain systems in the MJO inactive phase [Kozu et al. 2005].

Precipitation studies with wind profilers, which are normally considered to be clear-air instruments, have proved to be quite interesting. A retrieval method (ITRAN) for DSD from Doppler spectra measured with a wind profiler was proposed by Kobayashi and Adachi [2005]. Bringi et al. [2006] compared rainfall parameters estimated from a C-band polarimetric radar with those retrieved from the 443-MHz radar.

A 35-GHz radar to observe smaller particles such as clouds and fogs has been developed and revealed the moving cellular structure and shear-induced roll structure of fog echoes, and the influence of gravity waves on fog structure [Uematsu et al., 2005a, b, 2007]. The cirrus clouds were simultaneously observed with the 35-GHz radar and the MU radar [Wada et al., 2005].

B. Space-based remote sensing studies

The TRMM (Tropical Rainfall Measuring Mission) Precipitation Radar (PR) has a capability to estimate a path-averaged DSD parameter for moderate to intense rainfall cases. Kozu et al. [2006b] presented global characteristics of the DSD parameter estimated from TRMM PR, which shows a clear contrast between over land and over ocean, and a clear correlation with rain-top height and lightning activity. Most bright band (BB) models face a problem at the BB top, where the assumed DSD is very different from that of typical snow. To solve this problem, a new BB model is proposed.

The model assumes a linear change of precipitation rate with height and also a linear change in slope of DSD with height in the upper part of BB. A comparison of the model with an averaged height profile of radar reflectivity factor, Z, obtained by the TRMM precipitation radar shows a good agreement [Awaka et al. 2006].

The Global Precipitation Measurement (GPM) mission is a satellite-based Earth science mission that will study global precipitation and provide accurate rain distribution over the globe more frequently by using multiple satellites and better sensors than what are currently available. The Dual-frequency Precipitation Radar (DPR), which is one of the two key sensors on the core satellite in the mission, has been developed jointly by JAXA and the National Institute of Information and Communications Technology (NICT) in Japan. The DPR consists of two radars, KuPR (13.6 GHz radar) and KaPR(35.55 GHz radar), whose operations are synchronized to realize matched-beam dual-frequency observations of precipitation.

A Cloud Profiling Radar (CPR) will be installed on satellite mission named Earth Clouds, Aerosols and Radiation Explorer (EarthCARE). EarthCARE mission, proposed by European and Japanese scientists, has been selected for implementation as sixth Earth Explorer Mission of European Space Agency's, focuses on clouds and aerosols effect on the earth radiation flux budget. EarthCARE/CPR is millimeter-wave radar which has high sensitivity. Radar frequency is the same as CloudSat CPR (94GHz) launched in 2006 by NASA, but radar sensitivity is about ten times better because of the lower orbit and bigger antenna size. It is anticipated to detect 98 % of radiatively significant ice clouds and 40 % of stratcumulous. Vertical range of observation will be 20, 16, 12 km depending on the latitude. Minimizing observation window is necessary to achieve higher pulse repetition frequency (PRF) for accurate Doppler measurement.

JAXA is developing the Advanced Microwave Scanning Radiometer-2 (AMSR2). AMSR2 will be onboard the GCOM-W1 satellite, which is the first satellite of the Japan's Global Change Observation Mission (GCOM). AMSR2 is being developed based on the experience of the AMSR for the EOS (AMSR-E), which is currently in operation on EOS Aqua satellite. The instrument is a dual-polarized total power microwave radiometer system with six frequency bands ranging from 7 GHz to 89 GHz. Major changes in performance from AMSR-E include the larger antenna diameter (2.0m) for better spatial resolution, additional 7.3 GHz channels for mitigating radio-frequency interference, and improvements of calibration system. AMSR2 will observe various water-related geophysical parameters; precipitation, water vapor, sea surface wind speed, sea surface temperature, sea ice concentration, snow depth, and soil moisture content [Imaoka et al., 2007].

C. Others

A computer simulation of backscattering enhancement from randomly distributed spherical scatterers was made at 30 GHz [Oguchi and Ihara, 2006]. The simulation model was constructed to follow exactly the scattering environment used in the laboratory measurements made previously. The spherical wavefront and the directivity functions of transmitting and receiving antennas were taken into account. The simulation results agreed favorably with measurements for both copolar and cross-polar channels. It was also shown that the multiply scattered power in backscattering direction depends on the footprint size of a radar beam.

F2.3 Ocean and Ice

A method for estimation of the backscatter coefficient of the sea surface, which is needed for estimation of the sea wave period, is evaluated by a computer simulation. By utilizing the property that the average received power ratio directly represents the backscatter coefficient ratio, it is shown to be possible to estimate the sea wave period. It is also shown that the average received power can be derived with sufficient stability if the simulation parameters are set appropriately [Fukuda, et al., 2006]

When multilook processing is applied to produce SAR images of ocean, partially-overlapped sub-apertures are often used, because the overlapping area is considered as uncorrelated due to short decorrelation times of small-scale ocean waves which are responsible to radar backscatter. However, a detailed theory showed that the decorrelation times of small-scale ocean waves do not enter the inter-look speckle correlation, that is, the inter-look speckle patterns are correlated if partially overlapped sub-apertures are used; the theory was justified by the experimental analyses of JERS-1 L-band SAR and RADARSAT-1 C-band SAR over the waters around Japan [Ouchi and Wang 2005a,

2005b, Wang and Ouchi 2005].

For the Korean Coast Guard, determination of the coastal morphology in the shallow waters of the western coast of the Korean Peninsula is important for ship traffic and fishing practice. RADARSAT-1 SAR data were used to monitor the changes of morphology by bar charges on the estuary of the Han River, South Korea [Yang et al., 2006a]. In order to develop an automatic vessel detection system by incorporating AIS (Automatic Identification System), ground-based maritime radars, and spaceborne and airborne SARs, ship detection by MLCC (Multi-Look Cross-Correlation) technique was successfully applied to RADARSAT SAR and ENVISAT-ASAR multi-look images [Yang and Ouchi 2006b, 2007].

F2.4 Land, Vegetation, Subsurface Objects and Others

A. Land and Vegetation

Pi-SAR, a fully polarimetric airborne SAR system operative in the X- and L-band, developed by NICT and JAXA, respectively, has conducted experimental observations. A huge amount of high resolution data sets has been acquired with this system. Since scattering matrix data provides with 9 independent real-valued polarimetric scattering information as second-order statistics, it has much more information than the data by single polarization radar. These second-order statistics data can be used for various radar sensing applications such as decomposition of scatterers, classification of terrain, retrieval of some specific scatterers or physical features, environmental monitoring, disaster surveillance, etc.

Decomposition of scattering mechanism from objects is attractive issue for radar remote sensing. If the scattering mechanism is well retrieved, it becomes possible to classify and identify scatterers precisely. In this regard, a model-based four-component decomposition method has been developed by [Yamaguchi et al., 2005a,b, 2006a]. This decomposition method was applied to monitor seasonal change of wetland [Sato, R. et al., 2007], forest monitoring [Yamaguchi et al., 2006b], earthquake [Yamaguchi et. al., 2006c], and Oyster farm [Lee et al., 2006]. Theoretical considerations were given to examine the polarimetric scattering response by finite dihedral corner reflector [Sato, R. et al., 2005, Hayashi et al., 2006], for interpretation of building wall to ground surface scattering. [Yang el al., 2006] showed the stability for decomposition of Kennaugh matrix with respect to noise for the case of sufficient number of samples.

Classification of terrain is also attracting feature of polarimetric data. Correlation coefficients are used to classify man-made structures as well as vegetation area in the HV basis by Moriyama et al. [2005], and in the circular polarization basis by Yamamoto et al. [2007] by combination use of radar cross section. Iribe and Sato [2007] used polarimetric SAR data for estimation of target orientation in urban area. It is shown that orientation angle is proportional to aspect angle of building blocks.

Estimating forest parameters using SAR data is an important issue for studying the function of forests for carbon cycle and global warming. High degree correlation was found between the above-ground biomass of the coniferous forests and the order parameter of K-distribution in the cross-polarization images acquired by the airborne Pi-SAR L-band data, and an empirical regression model was developed to estimate forest biomass [Wang et al., 2006, Ouchi et al., 2005]. This non-Gaussian texture analysis is capable of estimating forest biomass beyond the saturation limit imposed by the conventional techniques based on radar cross section. Comparison of the model-based and ground-truth biomass yielded the accuracy of the model of the order of 85% [Ouchi et al., 2006a]. Another approach for estimating biomass is to seek tree height by polarimetric SAR interferometry using ESPRIT (Estimation of Signal Parameters via Rotational Invariant Techniques) method [Yamada, H et al., 2005]. By the location difference of scattering center, canopy and ground scattering centers are retrieved, which in turn yields tree height of forest.

A fully polarimetric dual frequency AIRSAR scene from a rice-growing area in Japan was classified by a maximum likelihood method based on the Wishart distribution, and a justification of increasing the classification accuracy by using fully polarimetric data was shown [Davidson et al., 2006]. On the other hand, JERS-1 SAR data and 4-component decomposition analysis of fully polarimetric dual polarization Pi-SAR data showed that L-band SAR was not favorable for rice monitoring because of long penetration depth into rice plants and the Bragg resonance scattering from machine-transplanted rice paddies of Japan [Ouchi et al., 2006b, 2006c].

A compact, fully polarimetric and interferometric FM-CW SAR system was developed at Niigata University [Ikarashi et al., 2006a,b, Nakamura et al., 2007a,b] for the purpose of laboratory measurements. The system is highly flexible and high resolution radar system, operative in the X-and Ku-band. Various measurements and validations can be conducted in laboratory [Aoyama et al., 2007a,b].

B. Subsurface Objects and Landmine Detection

Ground-penetrating radar (GPR) uses radio-wave to image the subsurface. Various applications and effective algorithms of GPR have been investigated for humanitarian demining [Feng and Sato, 2004], velocity analysis in inverse scattering [Zhou et al., 2005], estimation of oil-contaminated soil distribution [Qi and Sato, 2005], estimation of accurate buried position [Takahashi and Sato, 2006], and classification of buried targets from a single GPR trace that was applied to landmine detection [Savelyev, et al., 2007]. Qi and Sato [2007] used GPR to monitor the dynamic movement of ground water table, and proposed a technique to estimate hydraulic parameters.

Borehole radars is a method to image the subsurface with an antenna put into a borehole that is drilled around the target area. It can estimate the hydraulic characteristic of subsurface fractures [Liu and Sato, 2005] and to evaluate hard rock structure in large scale with radar and DC resistivity tomography techniques [Yi, et al., 2005]. Zhao and Sato [2006, 2007] showed that radar polarimetry approach was effective in characterization of subsurface fractures by a borehole radar. Zhou, et al. [2007] proposed an inversion algorithm which include radiation characteristics of antennas and applied it to field measured data of a borehole radar. A new directional borehole radar system was introduced [Sato and Takayama, 2007] and a new algorithm for direction finding system was proposed [Takayama and Sato, 2007].

Sato, et al. [2005] summarize research activities for humanitarian demining carried out at Tohoku University, including a few test evaluation in mine affected courtiers such as Afghanistan.

C. Others

Microwave emissions due to hypervelocity impacts and their dependence on the target material are investigated. The signals were composed of two kinds of waveform: intermittent sharp pulses and white noise. The energy of the pulses was greater for conductors than for insulators. It was hypothesized that the microwaves were emitted from a discharge along a micro-crack in the target [Maki, et al., 2005]. Experimental study of microwave emissions due to rock fractures is made. When samples of rocks were pressed by uniaxial loading to fracture, the signals were detected at 22 GHz, 2 GHz and 300 MHz and 0.3- 300kHz. The pulse signals were detected after the decrease of the load, and even after the stop of the fracture process. A hypothesis of the generation mechanisms of the microwaves is considered on the basis of the electrical charge accumulation due to piezoelectricity or triboelectricity and the resultant discharges in micro-cracks [Maki, et al., 2006]. In order to clarify the mechanism of charging and discharging across the micro-crack, experiments are carried out and its results suggest that electrons are excited both thermally and by transition from a crystalline state to an atomic state [Ohnishi, et al., 2007]. Takano, et al. [2007] discuss the experimental setup, the results, and the applicability of the phenomena to geophysical explorations including material characteristics, change of the underground structure, and earthquake detection. Waveforms of the microwave emission are compared to the simulated one on the basis of a micro-crack model, and its frequency spectra are compared to the calculated one. The results show the microwave emission is not noise but a sequence of independent pulses [Chiba, et al., 2007].

Anomalies of the electromagnetic field or the ionosphere have been observed before earthquakes, in the frequency ranges up to VHF (3- 30 MHz). Microwave emission on the occasion of earthquakes is also suggested, but it has not been measured. The level of microwave (S-band, 2GHz) that is used for the communication between tracking stations and earth-orbiting satellites is extracted corresponding to major earthquakes broken out all over the world from 1986 to 2004. As a result, some anomalies have been found out [Maeda. et al., 2006].

As space debris are increasing in orbits around the Earth, its measurement is a key issue for the investigation and monitoring of space environment. A bistatic radar which is composed of transmitter and receiver stations is proposed for the debris measurement. The received radio wave is processed on the basis of VLBI (Very Long Baseline Interferometry) techniques. The system has significant

advantages over monostatic radar. A bistatic radar system was formed to verify the validity experimentally [Yajima et al., 2007]. SELENE, SELenological and ENgineering Explorer, launched in 2007, will execute four-way Doppler measurements and differential VLBI observation to make global mapping of the lunar gravity field, together with two small sub-satellites: Relay Satellite (Rstar) and VLBI Radio Satellite (Vstar) [Iwata et al., 2005].
(M. Satake)

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