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C1. Mobile High Bit-Rate Transmission

In fourth-generation mobile communication systems, the maximum bit rate is aimed at 1 Gbps [3GPP, 2011] and demand for higher bit-rate transmission has been rapidly growing. This section surveys experiments for the mobile high bit-rate transmission.

First, 12×12 Multiple-Input Multiple-Output (MIMO) transmission with the signal bandwidth of 100 MHz achieved 5 Gbps [Taoka, 2008]. In addition, 10 Gbps transmissions using higher frequency bands over 5 GHz were discussed at a 3GPP workshop focusing the post LTE-Advanced era [NTT DOCOMO, 2012].

Moreover, 11 GHz band super high bit-rate mobile communications attaining over 30 Gbps have been investigated [Suzuki, 2010], [Umeda, 2010]. As experiments of the super high bit rate, a 10 Gbps transmission experimental system using 8×16 MIMO-Orthogonal Frequency Division Multiplexing (OFDM) was developed [Suyama, 2012], [Suyama, 2013], and 10 Gbps transmission experiments succeeded as the world's first 10 Gbps experiment in outdoor mobile environments in December 2012 [Suyama, 2013]. On the other hand, in order to analyze a radio propagation mechanism, an 11 GHz band channel sounder that supports the maximum of 24×24 MIMO was developed [Konishi, 2012], and channel measurement and analysis were performed in indoor and outdoor propagation experiments [Kim, 2013], [Chang, 2013]. The MIMO channel sounder shares 11 GHz band transmitter and receiver with the transmission experimental system; however, the installed software packages are different. Although 24×24 MIMO transmission is expected to achieve over 30 Gbps bit rate, an 11 GHz band 30 Gbps transmission experiment has not been carried out because high power amplifiers (HPAs) for only 8 transmitter antennas were available [Suyama, 2013]. Therefore, to verify the feasibility of the 30 Gbps transmission for future mobile communications, performance of 30 Gbps MIMO-OFDM eigenmode transmission has been demonstrated by computer simulations using channel data that the 11 GHz band 24×24 MIMO channel sounder measured.

(K. Fukawa)

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C2. Wireless Local Area Network (WLAN)

(1) IEEE 802.11ac and DL MU-MIMO:

With the proliferation of IEEE 802.11 devices, wireless local area networks (WLANs) will play an important role in future wireless service. One of the most significant challenges during 2010-2013 is the development of the techniques for upcoming IEEE Gigabit Wireless LAN amendments, i.e. IEEE 802.11ac. Especially, downlink multi-user multiple-input and multiple-output (DL MU-MIMO) transmission has been extensively investigated [Ishihara, 2013]. In MU-MIMO transmission, the estimation of channel state information (CSI) is also an important issue, and the efficient CSI estimation scheme and CSI feedback method has been proposed [Kudo, 2012]. In addition, two frame sequences with implicit CSI feedback mechanism for DL MU-MIMO system with massive antenna was proposed [Murakami, 2013-1].

(2) Inter-Cell Interference under Overlapping BSS Environment:

Increase of the number of basic service set (BSS) causes overlapping cells where plural BSS operating at the same channel are located close enough. In the overlapping cell environment, inter-cell interference (ICI) severely degrades the throughput of WLANs. Since the available channel bandwidth is expanded to enhance the highest throughput (e.g., maximum bandwidth in IEEE 802.11ac is 160 MHz), ICI will become more serious in the deployment scenarios of WLANs based on IEEE 802.11ac std. As the countermeasures against this problem, interference-aware channel segregation based dynamic channel assignment (IACS-DCA) was proposed, and a transmit power control was additionally introduced to reduce the ICI [Matsumura, 2013]. In addition, an interference-aware multi-cell beamforming (IMB) technique was proposed [Murakami, 2013-2]. As an alternative way to reduce the ICI while keeping higher throughput, multi-bandwidth channel selection scheme by coordinated access points (APs) was proposed [Hanada, 2013]. In this channel selection scheme, through game-theoretic analysis, the coordinated APs dynamically select channels and the total throughput at Nash equilibria is significantly improved.

(3) Medium Access Control (MAC) for Adavanced Radio Resource Management:

Medium access control (MAC) layer is responsible for coordinating the access of stations to the shared medium, and the MAC protocol is a key issue that determines the efficiency of sharing the limited radio resource. A distributed dynamic resource allocation method that enables control of flexible bandwidth allocation to each specific station was proposed [Kishida, 2013]. The proposed method controls the priority level and can coexist with conventional DCF (Distributed Coordination Function) protocol. Centralized radio resource management (RRM) is another trend to improve the transmission performance of WLANs. To enhance the throughput of WLANs using multi-user diversity gain while keeping QoS requirements of each station, the centralized radio resource management (RRM) strategy was introduced in WLAN [Miyamoto, 2013]. In the centralized RRM, AP and associated stations form a cooperative group. Once the cooperative group reserves the radio resource in a traditional DCF-manner, the central controller gathers the channel and traffic states information (CTSI) and dynamically allocates the reserved radio resources to the stations. Of course, the estimation of CTSI required for the centralized RRM causes the signaling overhead, and the excessive signaling overhead due to centralized RRM can be overwhelming with the increase of stations. As the countermeasures against this problem, two-stage DCF-based channel access protocol [Shimamoto, 2012] and station clustering scheme [Endo, 2013] were proposed.

Besides the above mentioned areas, coexistence of different types of wireless networks operating in unlicensed band is a critical issue for the design of WLANs. Distributed active channel reservation for coexistence (DACROS) scheme was proposed to solve the coexistence of IEEE 802.11g-based WLANs and IEEE 802.15.4-based wireless sensor networks [Inoue, 2013].

(S. Miyamoto)

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C3. Microwave Filters

With the growing demand for high-capacity and high-speed data transmission services, the frequency bands allocated to mobile communication systems have been increasing. Future mobile terminals should be equipped to deal with various frequencies and bandwidths in order to function seamlessly in various mobile communication systems that have particular specifications such as the operating frequency bands and the bandwidths. Additionally, from the standpoint of a wideband transmission, future mobile terminals will be anticipated to use simultaneously the separated multiple frequency bands that have been allocated to mobile communication systems. In recent microwave filters, the following two topics are one of the most significant issues: One is to provide a reconfiguring operation for the operating frequency band and bandwidth, and the other is to provide a multiband simultaneous operation

There have been reports on the architecture to provide a reconfiguring operation for microwave filters [Kawai, 2010], [Kawai, 2012-1], which describe a reconfigurable resonator and a bandpass filter that provide independent tunability with regard to the resonant/center frequency and bandwidth while maintaining symmetric transmission characteristics; and a tunable resonator that can tune its resonant frequency and bandwidth independently using a single kind of MEMS variable device.

There have been reports on the filter architecture to provide multiband simultaneous operation for microwave filters [Takagi, 2012], [Takagi, 2013], [Kawai, 2012-2]. A new approach for configuring a parallel-planar dual-band bandpass filter by employing multilayered LTCC technologies has been proposed for the purpose of achieving frequency characteristics with an allowable deviation without precise alignment between resonators [Takagi, 2012]. The group has also proposed dual-band bandpass filter employing broad side coupling structure that provides flexibility in the sense of having a wide range in selecting two center passband frequencies [Takagi, 2013]. With regard to the reconfiguring operation and multiband simultaneous operation, a tunable dual-band bandpass filter has been proposed that can individually tune its center frequency and the bandwidth of its two passbands [Kawai, 2012-2].

Besides the above mentioned areas, high-performance microwave filters have been proposed by using new methods for filter design such as an even- and odd-mode method for a microstrip parallel-coupled dual-mode ring resonator [Ma, 2010], an optimization technique based on the genetic algorithm [Kido, 2011], a parameter-extraction method for general Nth-order transversal resonator array filter with a direct source/load coupling [Ohira, 2013], and a synthesis scheme for a new class of optimum Chevyshev-type ultra-wideband bandpass filters consisting of multistage stepped-impedance resonators and two short-circuited stubs positioned at input- and output-ports [Chen, 2013].

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C4. Tunable Antenna Design for the Mobile Terminals

With the rapid growth of the communication industry, mobile terminals such as smart phones and tablet PCs are required to meet various wireless standards scattered over a wide frequency range. On the other hand, a small form factor is desired for current and future mobile terminals. Multiple antennas, wideband antennas and multiband antennas require a large antenna space and there is insufficient space to place these antennas in the future mobile terminal. Tunable antenna is most promising candidate to cover many wireless communication bands without increasing antenna volume [Sorwar, 2010]. Some kinds of antenna design for mobile terminals that include tuning devices, such as MEMS switches, MEMS capacitors, PIN diodes, varactor diodes and GaAs devices have been reported.

Compact tunable antenna using GaAs switch was proposed to cover 800 MHz, 1.7–2 GHz, and 1.5 GHz bands [Koga, 2013]. Since 2012, LTE (Long Term Evolution) service using band 21 (1.5 GHz) has been launched in Japan. This band includes the anti-resonant frequency of the 800 MHz band. It is a challenge to cover 800MHz band and 1.5GHz band with one antenna because anti-resonating antenna is difficult to match to the 50 Ω line. To cover 1.5 GHz band and 800 MHz band with one antenna, reflection type GaAs switch is used to control the antenna element length.

Because of its low insertion loss and low power consumption over a wide frequency range, MEMS device is most suitable for the tunable antenna to cover many frequency bands such as LTE (0.7-3.5 GHz), GPS (1.5 GHz) and WLAN (2.45 GHz and 5.1-5.7 GHz). Using MEMS switches, tunable antennas which cover wide frequency range have been proposed. It was demonstrated that effective antenna length can be controlled by using two SPST (Single Pole Single Throw) MEMS switches [Koga, 2011]. The antenna operates with good matching and high efficiency from 0.67 to 6 GHz. The volume of this antenna is 5.75 cm^3. Using three SPST MEMS switches as the antenna matching circuit, the tunable antenna was designed and fabricated [Yamagajo, 2011]. The volume of the antenna element is 4.94 cm^3 and its operating frequency ranges from 0.64 to 5.85 GHz. Combining the techniques mentioned above, compact planar tunable antenna was designed [Yamagajo, 2012]. In this antenna, one MEMS switch is used to control the antenna length and other switches are used to match antenna impedance to 50 Ω. The antenna area and the operating frequency range are 6.5 cm^2 and 0.65-5.85 GHz, respectively.

Combination of the tunable device and meta-material antenna is one candidate for further size reduction. A design of tunable inverted-L antenna with a SRR (Split-Ring Resonator) was proposed [Takemura, 2013]. A varactor diode is used in the antenna to control the resonant frequency of the SRR. The antenna area is 5 cm^2. Simulation and measurement results shows that the antenna covers LTE700 (698-960 MHz), GSM850, GSM900 and LTE2600 (2.5-2.69 GHz) bands.

(T. Yamagajo)

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C5. Antenna Measurement

(1) S-Paramenter Method:

The S-parameter method using a standard network analyzer was proposed by Meys in 1998 to measure the input impedance of a balanced-fed antenna like a dipole antenna or a mobile terminal antenna. Several remarkable researches on the S-parameter method have been executed in Japan.

Four compensating methods using cascade matrices were adopted to reduce the influence of a jig for the S-parameter method by Konya. The results of the proposed methods were presented and compared with a calculated result using the moment method and the measured result of a monopole antenna on a ground plane [Konya, 2011]. Sasamori examined a jig fabricated by microstrip line for the S-parameter method in order to improve the measurement precision. The measured result of S-parameter method was examined after the SOLT calibration and the TRL calibration had been performed. In case of the SOLT calibration, three compensating methods using ABCD-matrix, called open-correction, short-correction, and open-short-correction were applied to eliminate the influence of the jig for the S-parameter method [Sasamori, 2013-1, 2013-2].

Radiation characteristics can be also measured by using the S-parameter method. Fukasawa proposed an extended S-parameter method that can be applied to radiation pattern measurements of amplitude and phase. In this method, two cables are connected to an antenna, and the excitation coefficients of the two cables are obtained from the S-parameters under the condition where the unbalanced current of the coaxial cables is reduced. From array patterns generated with these excitation coefficients, the radiation patterns with a reduced unbalanced current of the coaxial cables can be obtained [Fukasawa, 2012]. Yanagi proposed an S-parameter method including radiation characteristics and mutual coupling of antennas on a small ground plane. They showed also that accurate measurement results can be obtained using the proposed method [Yanagi, 2012].

(2) OTA (Over-the-Air) Measurement:

Multi-Input Multi-Output (MIMO) is one of the hottest technologies for mobile radio systems. In order to evaluate the performance of MIMO antennas accurately, actual antennas mounted on the mobile terminal or the base station must be used in actual multipath-rich propagation environments. MIMO-OTA (Over-the-air) measurement methods for mobile terminals and base stations have been recently studied and developed for mobile communications. Some researches on the topics in Japan are reported as follows.

Spatial correlation function in spatial channel emulator (fading emulator) for MIMO-OTA was formulated taking probe antenna configuration into consideration. It was qualitatively and quantitatively clarified that fundamental estimation error of spatial correlation depends on installation range and interval between probe antennas. Criteria for estimating the required installation range and interval between probe antennas were derived from formulated equation of spatial correlation coefficient. Spatial correlation characteristics depending on probe antenna configuration were validated from experiment [Imai, 2010]. A spatial fading emulator for the evaluation of a handset MIMO antenna was also developed by Yamamoto. The MIMO channel capacities obtained from the propagation test are good agreement with those of the OTA measurement both at 776 MHz and 2.35 GHz. The comparison of the MIMO performances between 2-by-2 handset MIMO arrays under a multipath fading environment with a uniform power distribution using a spatial fading emulator was presented [Yamamoto, 2010].

On the other hand, the OTA method for base station antennas has not been reported. Yamaguchi proposed a novel fading generator that was based on a near-field modified Jakes scattering model. Although metal patches on the dielectric disc as scattering objects are used to obtain fading waves in the conventional method, slots on the metal disc are newly adopted as scattering objects in order to get the same waves. The validity of the proposed generator was clarified by experiments using a prototype [Yamaguchi, 2011].

(R. Yamaguchi)

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C6. MIMO Systems

The growing popularity of smart phones and wireless LANs has set the demand for achieving broadband wireless transmission within a limited frequency band. Multiple input multiple output-orthogonal frequency division multiplexing (MIMO-OFDM) systems have been developed because they promise to increase the channel capacity compared to single input single output (SISO) systems. Moreover, multi-user MIMO (MU-MIMO) systems have recently attracted much attention as a technology that enhances the total system capacity by generating a large virtual MIMO channel between a base station and multiple user terminals (UTs).

In this period, the following topics have been attracted much attention. The detailed topics are shown as follows:

(1) Short Range MIMO

Since the distance between two array antennas that face each other is comparable to the size of the array antenna aperture in short range MIMO, the propagation characteristics are greatly different from those in conventional MIMO. Unlike conventional MIMO, the optimal element spacing, which maximizes channel capacity, exists in short range MIMO. Moreover, the channel capacity with optimal antenna spacing exceeds the Ergodic capacity of independent identically distributed (i.i.d.) channels since optimal eigenvalue distribution, which can maximize channel capacity, is obtained in the short range MIMO. When the optimal element spacing is obtained, the channel capacity obtained when employing ZF is almost the same as that obtained when using EM-BF [Nishimori, 2011]. From a point of view in simplification on signal processing part, the use of orthogonal polarized SR-MIMO was proposed and its effectiveness in an actual scenario was shown [Hiraga, 2013].

(2) MIMO Sensor

Intruder detection method by utilizing a time variation of Multiple Input Multiple Output (MIMO) channel (MIMO Sensor) has been proposed. Although the channel capacity on the MIMO transmission is severely degraded in time variant channels, we can take advantage of this feature in MIMO Sensor applications. It is shown that the detection probability by 4x1 SIMO sensor might be degraded due to single antenna at the transmitter site while 2x2 MIMO sensor obtains the high detection probability by both transmit and receive diversity effect [Ushiki, 2003]. The antenna arrangement which is suitable for 2x2 MIMO sensor was proposed and this arrangement can enhance the detection probability compared to the conventional antenna arrangement which is used in W-LAN systems [Honma, 2013].

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C7. Terahertz Technology

In a wide range of fields, including materials, bio-imaging/sensing, medical measurement, safety, and security through to telecommunications, developments related to terahertz (THz) frequencies have been attracting a lot of attention recently [Tonouchi, 2007] [Davies, 2008] [Siegel, 2004]. THz frequencies are electromagnetic waves within the ITU-designed band frequencies from 300 GHz to 3 THz. They are called "unexplored radio wave" previously and there is an engineering term of "THz gap" because practical technologies had not been existing in the THz region between radio waves and infrared light. However, in addition to the radiation of THz frequency using the quantum cascade laser (QCL) [Köhler, 2002], a variety of THz sources have been gradually filling the THz gap in recent years. Approaches for developing THz sources are optical generation, QCL, and solid-state electronic devices [Orihashi, 2005]. For THz detectors, bolometers, SBDs, and SIS junctions are widely used. The principle applications for THz technology are divided into two categories; sensing and communications. In order to realize a wide range of applications, higher-power THz sources, more sensitive THz sensors, and more functional devices and materials are necessary.

(K. Washio)

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