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Passive and active antenna systems for base stations of IMT systems

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REPORT ITU-R M.2334-0

Passive and active antenna systems for base stations of IMT systems

(2014)

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1 Scope

This Report addresses several aspects of active and passive antenna systems for base stations of IMT systems, including the definitions of antenna systems, associated components and terminology; definitions for common performance parameters and tolerances; guidelines on performance parameters and tolerances; and considerations of advanced concepts.

2 Related documents

- Recommendation ITU-R M.1457 – Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2000 (IMT-2000).
- Recommendation ITU-R M.2012 – Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications Advanced (IMT-Advanced).
- Report ITU-R M.2040 – Adaptive antennas concepts and key technical aspects.

3 Introduction

Mobile communication systems are developing towards more environmental friendliness and lower operating and construction costs. Wireless access systems employing multi input multi output (MIMO) and beamforming put forward higher requirements relating to beamforming systems and integration of antennas and radio. In addition, forwards compatibility towards new antenna systems will improve the competitiveness of IMT systems, which can protect the long-term investment of telecommunication operators. Consequently, development of base station antenna design will be important to solve these issues.

4 Technical and operational aspects of passive antenna systems for base stations of IMT systems

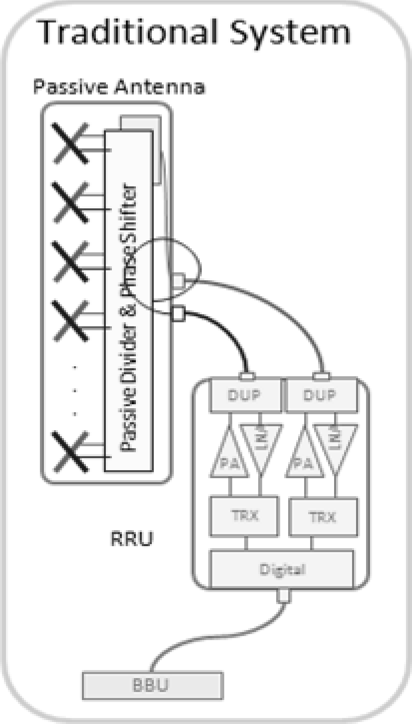
4.1 Definitions of passive antenna systems and associated components and terminology

Each column of a traditional base station antenna array is driven by only one active transceiver. The passive smart antenna of a traditional base station has beamforming capabilities, but it is limited due to being implemented in analogue phase shifters whose effects apply to the whole bandwidth of the antenna.

The typical RF structure of traditional passive antenna systems is given in Fig. 1.

FIGURE 1

An example RF structure of traditional passive BS antenna systems



4.2 Definitions for common performance parameters and tolerances

The list below provides definitions of the most important parameters for traditional antennas.

– Frequency range

The operating bandwidth of the antenna is defined by a continuous range of frequencies, specified in MHz.

– Polarization

This parameter specifies the polarization or polarizations of the electric field radiated by the antenna; the antenna can be linear polarized typically defined as Horizontal and Vertical polarization, slant polarization typically defined as +45°/−45°, circular polarization typically defined as right-handed or left-handed.

– Gain

The antenna gain is a measure of input power concentration in the main beam direction as a ratio relative to an isotropic antenna source. It is determined as the ratio of the maximum power density in the main beam peak direction, at a defined input power, compared to the power density of a loss-less isotropic radiator with the same input power. It is defined in the far field of the antenna.

– Azimuth beamwidth

The 3 dB, or half power, azimuth beamwidth of the antenna is defined as the angular width of the azimuth radiation pattern, including beam peak maximum, between points 3 dB down from maximum beam level (beam peak).

– Elevation beamwidth

The 3 dB, or half power, elevation beamwidth of the antenna is defined as the angular width of the elevation radiation pattern, including beam peak maximum, between points 3 dB down from maximum beam level (beam peak).

– Electrical downtilt angle

For a fixed electrical tilt antenna, this parameter specifies the main beam pointing angles of the elevation pattern; for a variable electrical tilt antenna, it defines the range of specified main beam pointing angles of the elevation pattern.

– Elevation downtilt deviation

This parameter defines the maximum absolute deviation from the nominal tilt value in the elevation beam pointing angle, which is supposed to be a measure of the accuracy of electrical tilt settings.

– Impedance

The characteristic impedance is the ratio between voltage and current flowing into an infinite length guide, specified in Ohms.

– VSWR

The Voltage Standing Wave Ratio (VSWR) is defined as the ratio of the maximum amplitude to the minimum magnitude of the voltage standing wave at an input port of an antenna. The VSWR is a measure of the matching of the antenna to the source and feeder cables. A low VSWR will mean that the reflections from the antenna are minimized.

– Return loss

This parameter is a measure of the difference between forward and reflected power measured at the antenna port over the stated operating band. Return loss and VSWR both characterize the mismatch between the transmission line and the antenna and are mathematically related.

– Cross polarization isolation

This parameter specifies the ratio of the power coupling between the two orthogonally polarized ports of a dual polarization antenna.

– Passive intermodulation

Passive intermodulation is a low level signal created as the result of multiple high power transmit signals in an antenna generated by ferromagnetic materials or by metal-to-metal discontinuities. This relatively low power signal is generated at a frequency that is a mathematical combination of the frequencies of the high power signals. It may degrade the uplink reception if it falls in the receive bands.

– Front-to-back (F/B) Ratio, total power, ±30°

The front-to-back ratio is a performance requirement stating the relationship between the beam peak and the highest antenna gain in the rear ±30 angular region of the azimuth cut, using the backward (180º) direction as the reference. It can be supposed to be a measure of the interference radiated backwards by the antenna. Here, the total power is the sum of the co-polarized and cross-polarized radiation from an antenna port.

– First upper side lobe suppression

This parameter specifies the minimum suppression level of the side lobe above the horizon that is closest to the main beam.

– Upper side lobe suppression, peak to 20°

This parameter specifies the minimum suppression level of the side lobes above the main beam peak to a 20° angle referenced to the main beam peak.

– Cross-polar discrimination over sector

The cross-polar discrimination is defined as a ratio of the copolar component of the specified polarization compared to the orthogonal cross-polar component over the sector. Cross-polar discrimination is important for a low level of correlation between the orthogonally polarized propagation channels. Correlation generated by the antenna can negatively affect receive diversity and MIMO downlink performance of the system.

– Maximum effective power per port

This parameter specifies the maximum power which can be transmitted into one antenna port without performance degradation.

– Interband isolation

This parameter defines the worst case coupling between any and all pair of ports in a multiple-band, or broad-band antenna, specified as a minimum value in dB measured between any and all pair of ports. Coupling between both co-polarized and cross-polarized pairs of ports is included. Coupling between antenna ports can influence the level of filtering required for a given site configuration.

4.3 Guidelines on performance parameters and tolerances

Energy efficiency (EE) has been recognized as another important issue. Along with the transmit power, circuit and system power are also important. Compared with traditional passive antennas, some active antenna systems can provide an advantage in power saving.

Traditional antennas and feeder systems may give rise to considerable RF transmission loss. A traditional mobile communication base station using a passive antenna, an antenna and feeder subsystem consists of an indoor jumper (1/2"), a main coaxial cable (7/8"), a top tower jumper (1/2") and an antenna. In this subsystem, a part of the BTS RF output power will be lost in the cable. As an example, consider a set-up with antenna height of 20 m, indoor jumper length of 4 m, a top tower jumper length of 2 m and a main coaxial cable length of 30 m. Table 1 shows the calculation of RF power path loss in the feeder system.

TABLE 1

Calculation of RF power path loss in the feeder system

Frequency (MHz)	Loss in main feeding cable (30 m)	Loss in jumper (6 m)	Loss in connector (4)	Total loss (dB)	Power loss (%)
900	0.038×30	0.1056×6	0.1×4	2.17	39%
1 800	0.056×30	0.1555×6	0.1×4	3.01	50%

From the calculation results, it is evident that the RF loss in a feeder system is considerable. And for an active antenna system, the radio power loss in a feeder system may be smaller

4.4 Consideration of advanced concepts (e.g. remote control of pattern and tilt)

The remote control of the pattern is divided into two aspects: horizontal and vertical, the idea of the remote control is proposed for adaptive coverage.

5 Technical and operational aspects of active antenna systems for base stations of IMT systems

5.1 Definitions of active antenna systems and associated components and terminology

An active antenna implementation in a base station may incorporate many different forms of smart antenna implementation, such as beam forming and/or MIMO with spatial multiplexing. An active antenna implementation is differentiated from transmit diversity systems in that the propagation patterns from its antenna elements are at least partially correlated such that spatial beam forming patterns may be generated. To characterize an active base station antenna that is inclusive of all possible implementations, adoption of reference architecture is needed to serve as a common baseline.

The radio architecture is represented by three main functional blocks, the transceiver unit array (TXRUA), the radio distribution network (RDN), and the antenna array (AA). The transceiver units (TXRU) interface with the base band processing within the base station, which depending on implementation may also influence the radiated beam pattern.

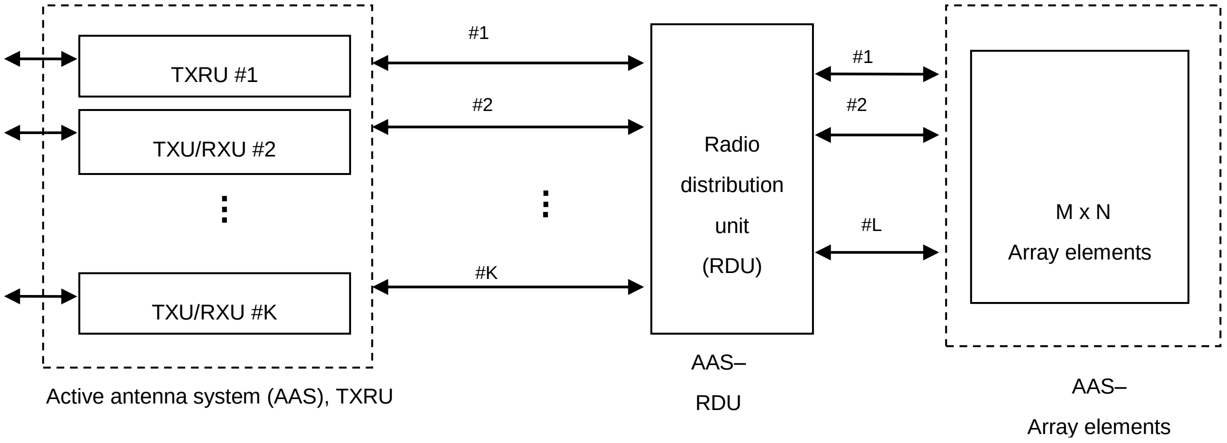
The TXRUA consists of multiple transmitter units (TXU) and receiver units (RXU). The transmitter units take the baseband input from the base station and provides the RF TX outputs. The RF TX outputs may be distributed to the AA via a RDN. The RXU take the RF inputs from the antenna elements to which they are mapped and provide input to the baseband processing. The number of transmitters and the number of receivers may be unequal.

The RDN, if present, performs the distribution of the TX outputs into the corresponding antenna paths and antenna elements, and a distribution of RX inputs from antenna paths in the reverse direction. Note that the groups antenna elements involved in the TX and RX directions may be the same for each direction, may be partially the same or may differ.

Figure 2 describes a general radio architecture that is generic to all types of active antenna system structures.

FIGURE 2

General radio architecture



An active base station antenna may integrate the RF power amplifier, the low-noise amplifier (LNA), the power supply system, the detection and control system, and may also incorporate the baseband processor system. Techniques used for micro-cellular base station may be used, such as radio-over-fibre (ROF) and optical fibre transmission, allowing the signal to be transmitted a longer distance with smaller loss.

An example of an active antenna system (AAS) is given in Annex 1.

5.2 Definitions for common performance parameters and tolerances

Besides traditional passive antenna parameters, the following non-exhaustive list of performance parameters is relevant for AAS:

1) Adjustment range of the maximum output power of the array, i.e. antenna radiated power adjustment range;
2) Maximum allowable input level, i.e. maximum input signal level that can maintain the antenna performance and will not damage antenna;
3) Input dynamic range;
4) Spurious emission of integrated transmitter;
5) Adjacent channel interference of integrated transmitter;
6) Ripple in band of integrated PA;
7) Receiver sensitivity;
8) Antenna pattern for receiving;
9) Antenna pattern for transmitting;
10) Directivity;
11) The total power of the antenna, i.e. The total electrical power consumption by antenna;
12) Equivalent isotropic radiated power (e.i.r.p.);
13) Effective isotropic reference sensitivity (e.i.r.s.);
14) Polarization related parameters, e.g. XPR (cross-polarization ratio) and so on.

In addition, intra-band isolation might also need to be considered along with inter-band isolation.

5.3 Consideration of advanced concepts (e.g. remote control of pattern and tilt, 3D-beamforming and massive MIMO)

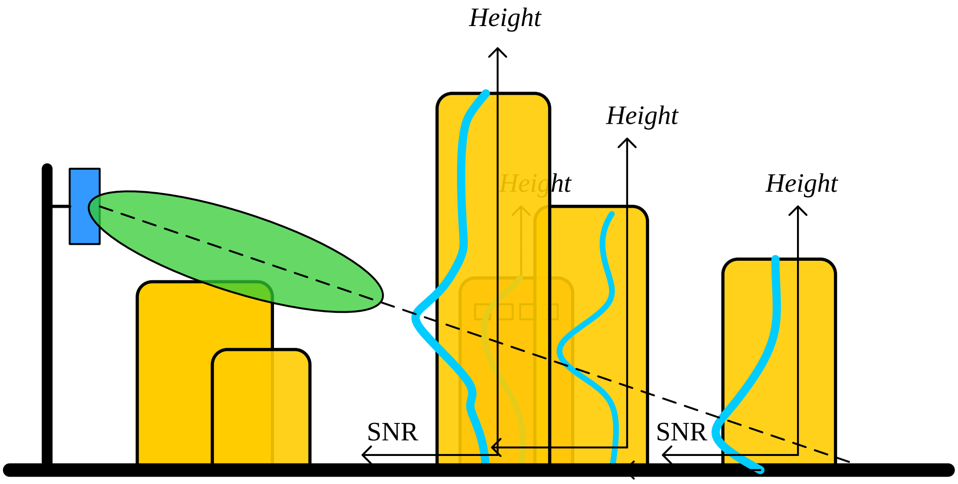
In active antenna, radiation element is integrated with RF module; this structure can improve the power efficiency of base station RF power amplifier (PA). The future key technology is for miniaturization of remote device and integration of multi-system.

3D-beamforming, user specific beam forming and massive MIMO attracts significant interest recently because it can enhance system performance through the use of antenna systems having a two-dimensional array structure providing adaptive weighting factor control over elevation dimension and azimuth dimension. Since by now there is only mature 2D channel model, e.g. ITU-R M.2135, a new channel model which can model both vertical and horizontal dimension is needed to evaluate the gain of 3D-beamforming and massive MIMO.

For the traditional base station antenna with only horizontal beamforming ability, the maximum gain point in vertical plane only have one main lobe that can be tilted. As displayed in Fig. 3. The SNR of the users away from the maximum gain point on main lobe will deteriorate. The terminals departing from the main lobe coverage direction will have SNR decreasing significantly. Such situation also exists for users in vertical plane. For the move towards the base station, the gain of fixed antenna will be reduced obviously, as well as the SNR, which affects the throughput improvement.

FIGURE 3

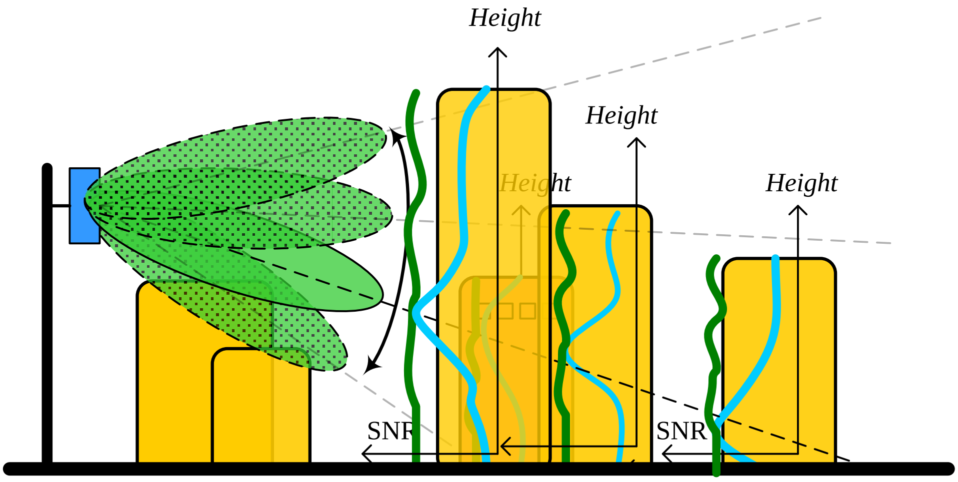
The improvement limitations on SNR of horizontal beamforming



For active antenna, we can dynamically adjust the beam to cover the users in the system within the maximum gain of the antennas, so that the SNR, as well as the throughput, will be improved. This gain is more efficient and obvious to the mobile terminals on the vertical direction, just as shown in Fig. 4. Such adjusting ability of vertical beam also provides efficient solutions to such hot point as tall buildings. Dynamical beam adjusting is also useful to mobile terminal in horizontal plane. It is worth pointing out that the adjusting capability of beam must cover the main users in a cell in order to achieve a specific gain. This needs to be considered with specific parameters of network optimization, which includes the base station installation height, mechanical downtilt adjusting. The higher demand of the beam adjusting in wide angle range needs more transceivers to drive each column of antenna array, which further brings the problem of system cost-benefit optimization.

FIGURE 4

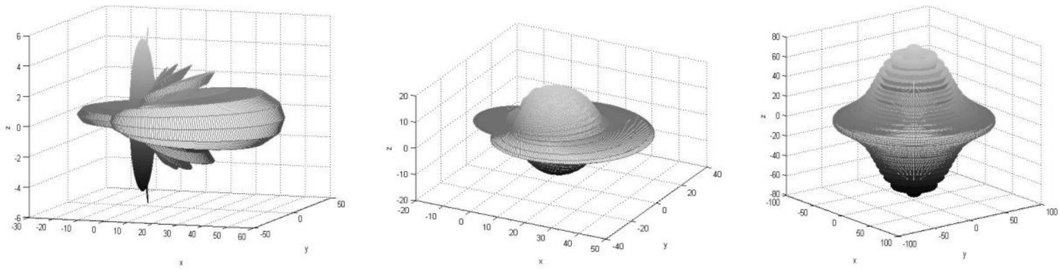
Examples of SNR improvement by horizontal and vertical beamforming



Array antenna might also beamform out-of-band (OoB) signals differently to in band signals, while the radiation pattern of OoB signals brings the pattern of ACLR. This is an obvious difference between the active base station and traditional passive base station antenna. In the traditional base station, each transmitter connects to an independent antenna. Generally speaking, the output signals lie in three categories: useful signal for communication, OoB nonlinear signal generated by the nonlinearity of transmitter, and thermal noise. All of the three kinds of signals transmit by the same antenna, so the spatial radiation patterns for them are all the same. As is known to all, ACLR is defined as the power ratio of the in-band useful signal and OoB signal that leaks to adjacent bands. For the traditional base station, the patterns for these two signals are the same, so the ACLR is the same for all spatial directions. In a three-dimensional space, the pattern of ACLR of traditional base station is spherical. Compared with the traditional base station, each dipole may connect to different transmitter. For signals useful to beamforming, signals from various transmitters exhibit strong correlation. However, the OoB signals show low correlation, as the nonlinearity of each transmitting channel does not converge. For example, the third-order intermodulation from different amplifiers, even from the same generation, does not show complete correlation. The thermal noise from different transmitters is independent. Uncorrelated signals will show different spatial pattern. As shown in Fig. 5, the power ratio, or ACLR, exhibits spatial direction because of the different directional characteristic of useful signals and OoB signals. This feature should call for attention for system coexistence and disturbing analysis.

FIGURE 5

An example of the formation of ACLR direction for active base station with a particular beam pattern (left: useful signal; middle: OoB signal with correlation of 0.3; right: ACLR)



5.3.1 Tilt and radiation pattern control

Antennas are usually manufactured with a fixed beam width, and antenna manufacturers typically offer a limited number of beam width variations within their conventional product lines. Conventional BS installations often introduce physical tilt to the antenna in order to orient the main lobe of the antenna response towards the ground. Antenna tilt is selected to optimize desired cell coverage and to minimize interference to and from adjacent cells. Remote Electrical Tilt (RET) devices can be installed to allow mechanical adjustment of the phase shift so that the antenna tilt angle is remotely controlled.

An AAS may dynamically control the elevation and azimuth angles, as well as the beam width of its radiation pattern via electronic means. Electronic control may be used along with mechanical means. The AAS radiation pattern may be adapted to the specific deployment scenario and possibly to changing traffic patterns. The AAS radiation pattern may also be independently optimized for different links such as independently for uplink and downlink, for coverage and beam forming gain purposes.

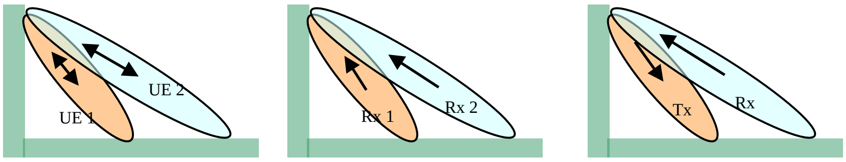
5.3.1.1 Cell partitioning in the horizontal and vertical plane

The concepts of tilt and beam width control can be extended by a technique known as cell partitioning in which the cell is subdivided in vertical or horizontal directions by adjustment of the antenna pattern. For example one cell partition is located close to the BS and the other cell partition is located farther away from the BS.

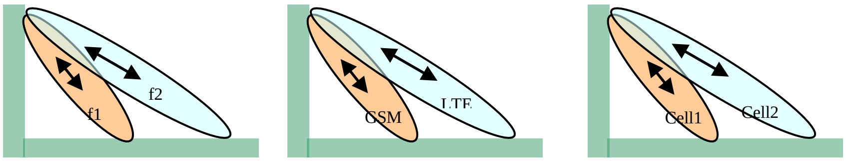
As stated above, active antenna have the ability of vertical and horizontal beamforming, and can extend the spatial signal processing ability from horizontal plane to vertical plane. Fig. 6 shows typical applications of active antennas.

FIGURE 6

Typical application for active antenna base station



a) Beam-forming for terminals, b) diversity receiving agilely, c) independent adjusting of uptilt and downtilt



d) Independent carrier tilt adjusting, e) independent modulation tile adjusting, f) vertical-horizontal cell splitting

Obviously shown as Fig. 6 f), active antenna technique can realize the vertical and horizontal cell splitting. It can also adjust to the change of service environments by configuring beams. For example, active antennas can dynamically adjust the beam coverage according to each cell load to maximize the system throughput. It can also statically configure vertical and horizontal stationary beam to form multiple cells, to theoretically improve the resource multiplexing ratio by fold increase.

Traditional passive base station antenna only supports horizontal beamforming, i.e. 2D-beamforming. Active antenna can dynamically adjust the spatial signal beams vertically and horizontally, named 3D-beamforming. If the multi-stream transmission is extended to vertical plane, the active antenna will extend MIMO from 2D to 3D. The inter-cell interference coordination (ICIC) will bring greater system benefits for active antenna by dynamical adjusting for both vertical and horizontal dimensions of beams between cells.

5.3.2 Multiple input multiple output (MIMO)

MIMO is a general term that includes the various spatial processing techniques: beam forming, diversity, and spatial multiplexing. Brief description of each is provided below.

– Beam forming: The use of dedicated beam formed towards the UE when the data demodulation based on dedicated reference signal is supported by the UE;

– Diversity: The use of diversity techniques to jointly optimize in the spatial and frequency domain through the use of, for example, spatial-frequency block code (SFBC) or frequency switching transmit diversity (FSTD), or combinations of them;

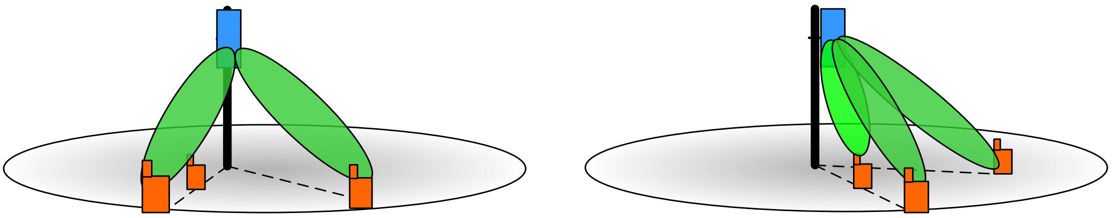
– Spatial multiplexing: The transmission of multiple signal streams to one (SU-MIMO) or more (MU-MIMO) users using multiple spatial layers created by combinations of the available antennas.

Multi user MIMO means that users multiplex the same time slot. For traditional antenna, the multiple users can only exist in horizontal direction. If two users have identical horizontal angle, but different vertical angle, the traditional base station cannot take advantage of resource multiplexing, which is shown as the left figure in Fig. 7. For active antenna, different mobile terminals can be distinguished both horizontally and vertically due to vertical and horizontal adjusting ability of the beams, so the possibility of multi user MU matching increases significantly, which greatly improves the system throughput, as shown in the right figure in Fig. 7. Similar to 3-D beamforming, 3D-MU-MIMO under various scenarios requires different adjusting range and resolution.

The specific parameters are optimized by application situations. Cost-benefit analysis is an important aspect of optimization, as shown in the left figure in Fig. 7.

FIGURE 7

2-D and 3-D MIMO multiplexing (left: 2-D-MU-MIMO, right: 3-D-MU-MIMO)



5.3.3 Differentiated antenna behaviours at different carrier frequencies

AAS supports the use of a different number of antennas at different carrier frequencies and for different RATs. For example the AAS may create 4 virtual antennas for a long term evolution (LTE) carrier and 2 antennas for a GSM or HSPA carrier.

5.3.4 Per resource block (or user equipment) transmission and reception

In this case, each user equipment (UE) may get its own beam that tracks the movement of the UE.

The support for spatial multiplexing, beam forming and transmit diversity includes the ability to schedule transmission and reception to one UE within one resource block. This allows beam forming to individual UEs with adaptation to mobility, as an example.

5.3.5 Applications in IMT Systems

For future development of active antennas in IMT system, there are several requirements for consideration:

1) Wide band or multi-band characteristics.

2) Dual-polarized antenna technology integrated with multi-antenna technology, supporting MIMO, and meeting the IMT-Advanced requirements. Furthermore, active antenna design will be developed to support 3D MIMO (massive MIMO).

ROF technology may be beneficial for reducing RF interference caused by the link between a digital unit such as the base band unit (BBU) and a high-power RF unit. Optical fibres facilitate installation of a large number of BBUs in one site, enabling centralized construction and management, hence reducing network construction costs and station site rental costs. Furthermore, the cost of optical fibre transmission system will be lower than the coaxial cable system.

Application scenarios of active antennas in IMT systems can be roughly divided into macrocells, microcells and picocells.

In macrocell scenario, such as suburb and rural scenarios, the system mainly serves long distance and fast moving user equipments. In these scenarios, base station RRU output power may be greater than 20 W. If the passive antenna is replaced by active antenna, cable path loss will be eliminated; the reduction of RF transmitting power could be expected and will give rise to lower power consumption of base station, which will make mobile communication networks more “green” and low-carbon.

In future, active antennas will be applied widely in microcells, picocells. In the urban areas, user equipments are intensive and vehicles are low-speed, high data rate transmission in short distance is required, so the system is required to reduce the RF output power, and the key consideration is improving service capacity in complex scenarios. Furthermore, multi-point coordination or multi-antenna enhancement technology may be used to meet the IMT-advanced requirements for spectrum efficiency in cell border.

Smaller active antennas, with only one radiation element and RF output power at 100 mW or less, will be used in the indoor coverage systems assuming frequency band below 4 GHz. It is now generally considered that much higher frequencies will be used in future IMT system, possibly up to 100 GHz. At these frequencies, more output RF power and more radiation elements will be required to cover a similar range. Active antennas of micro-power may be small and light, so they can be installed in the walls of buildings, poles or street lights conveniently, to eliminate the blind spots of wireless coverage.

6 Conclusions

Several aspects of active and passive antenna systems for base stations of IMT systems have been studied in this Report, including the definitions of antenna systems, associated components and terminology. The development of base station antenna design along these lines is foreseen to solve a number of important issues in IMT systems, such as environmental friendliness and lower operating and construction costs.

7 Terminology, abbreviations

AA	Antenna array
AAS	Active antenna system
ACLR	Adjacent channel leakage ratio
BBU	Base band unit
BTS	Base transceiver station
EE	Energy efficiency
EIRP	Equivalent isotropic radiated power
EIRS	Effective isotropic reference sensitivity
FSTD	Frequency switching transmit diversity
ICIC	Inter-cell interference coordination
LNA	Low-noise amplifier
LTE	Long term evolution
MIMO	Multi input multi output
MU-MIMO	Multi user MIMO
OoB	Out-of-band
PA	Power amplifier
RAT	Radio access technology
RDN	Radio distribution network
RDU	Radio distribution unit

RET	Remote electrical tilt
ROF	Radio-over-fibre
RRU	Remote radio unit
RX	Receiver
RXU	Receiver unit
SFBC	Spatial-frequency block code
SNR	Signal-to-noise ratio
SU-MIMO	Single user MIMO
TX	Transceiver
TXRUA	Transceiver unit array
TXRU	Transceiver unit
TXU	Transmitter units
UE	User equipment
VSWR	Voltage standing wave ratio
XPR	Cross-polarization ratio

8 References

[1] Huawei Technologies Co., Ltd. Active Antenna System: Utilizing the Full Potential of Radio Sources in the Spatial Domain, November 27, 2012.

[2] Recommendation on Base Station Antenna Standards, NGMN Alliance, version 9.6.

Annex 1

Example of an AAS

Figure A1.1 demonstrates a BS system engineering prototype with ROF transmission and an active integrated antenna. Fibre is used for providing IQ samples to the radio. In general, alternative technologies can be used for providing IQ, or even the whole base station can be integrated. However the IQ is provided to the radio, the radio requirements should be similar.

A detailed structure of active integrated antenna is shown in Fig. A1.2. In the system, digital and Intermediate Frequency (IF) processing units are inserted, so BBU and RRU can be separated. The digital IF processing unit is used as proximal machine, active integrated antenna is used as a remote machine. In this example, advanced technology has been able to realize 4-channel FDD active integrated antenna and 4-channel TDD active integrated antenna.

It should be noted that this is just one example of AAS implementation.

FIGURE A1.1

A BS system equipped with ROF transmission and active integrated antenna

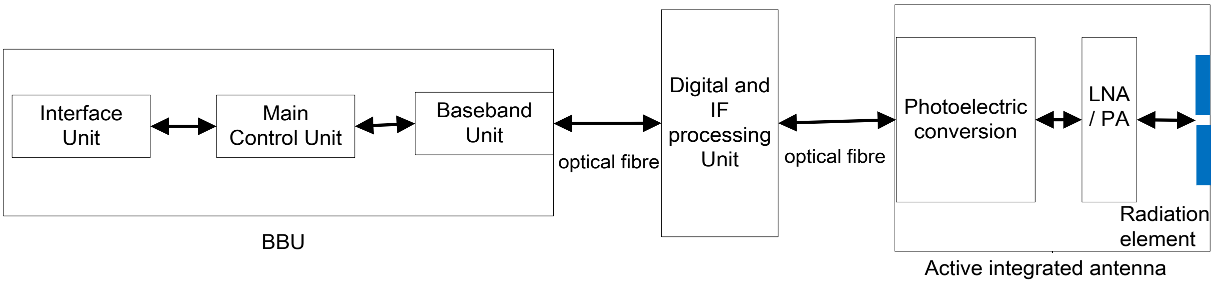


FIGURE A1.2

Detailed structure of an active integrated antenna