Trend of Multiple Antenna Beamforming Technology in Mobile Wireless Communication Field

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Abstract

Spatial division multiple access (SDMA) wireless communication systems, where multiple user signals are simultaneously transmitted and received over same conventional time/frequency channels by using multiple antennas, have great potential to dramatically increase spectral efficiency. The iBurst, a TDD-TDMA based mobile broadband wireless internet network, is the first commercial system in the world to realize and demonstrate the potential benefits of SDMA technology with the help of adaptive array antenna (AAA) processing. This paper presents and discusses the structure of the iBurst system, its antenna array configuration, system specifications, and field performance test results. Next, by adding OFDMA transmission technique to this multiple antennas system, the simulated performance results of beamforming are presented.

1 Introduction

This paper, dedicated to the memory of Prof J R James, introduces the latest technology of Adaptive Antenna Array (AAA) as applied in a mobile communication system known as the iBurst.

The iBurst System is designed to provide portable broadband wireless Internet access to all subscribers including business customers anytime, anywhere. The iBurst System promises an always on, IP-centric, high-speed wireless access that provides downlink packet data services at 1 Mbps per a subscriber while sustaining the system's spectral efficiency, coverage and capacity. The iBurst Base Station (BS) provides high spectral efficiency and high speed data transmission by using AAA. This system realizes Space Division Multiple Access (SDMA) with the beam and null forming. The iBurst BS can suppress the co-channel interference in the service cell. Therefore, the iBurst User Terminal (UT) does not need to implement an explicit Interference rejection function.

The iBurst System has an air interface with a Time Division Duplex (TDD) / Time Division Multiple Access (TDMA) frame structure design optimized to support an efficient AAA/SDMA processing. The iBurst air interface also supports Frequency Division Multiple Access (FDMA) there by allowing aggregation multiple carriers in a given bandwidth of operation. An adaptive algorithm at BS computes and applies the reception array weights upon receiving uplink channel signal from a desired UT to compensate propagation spatial characteristics. Then the iBurst BS uses the reception Array Weights as the transmission array weights for downlink transmission. Therefore, the iBurst BS can make the optimized beamforming toward the desired UT while rejecting the interference from undesired UTs [1]-[8].

In the paper, we present the performance of commercial iBurst System with 12 element antenna array at BS. In Section 2, we explain the iBurst system specification and it's Physical Layer Protocol [9]. In Section 3, we describe the AAA algorithm implemented at BS. In Section 4, the results of computer simulations and field experiments are presented. Finally, the result of computer simulation is presented for a case when OFDM transmission is considered for the iBurst with AAA.

2 AAA/SDMA Structure of iBurst System

BS with circular antenna array and the system parameters of the commercial iBurst System used for field experiments are shown in Fig.1 and Table 1, respectively.

System	TDD-TDMA/SDMA
Carrier frequency	2005.3125 MHz
Symbol rate	500 kbps
Down-link modulation type	$\pi/2$-BPSK, QPSK, 8PSK, 12QAM, 16QAM, 24QAM
BS	
Pulse shaping filter on BS transmitter	Root-raised cosine filter with roll-off factor 0.25
Number of antenna elements	12
Antenna topology	Circle
Antenna spacing	3.5λ
Adaptive Antenna Processing Criterion	MMSE

Table 1: Parameters of iBurst System

Mod Class	Down-link target SINR (dB)	Single stream down-link throughput (kbps)	Aggregated 3 stream down-link throughput (kbps)
0	-0.5	35.2	105.6
1	1.3	49.6	148.8
2	2.8	81.6	244.8
3	5.7	126.4	379.2
4	7.9	161.6	484.8
5	10.1	198.4	595.2
6	12.2	262.4	787.2
7	13.5	307.2	921.6
8	15.4	353.6	1060.8

Table 2: User Data Throughput at Various ModClasses

Fig.1: iBurst Base Station

In Table 1, the iBurst System supports the link adaptation where in a pair of modulation and coding combination, referred as ModClass, is adaptively selected based on the wireless channel conditions. Therefore, throughput is strongly influenced by wireless link conditions. The target downlink Signal to Interference plus Noise Ratio (SINR) value and the user data throughput (i.e., delivered end-user data rate after removing overheads) for each ModClass are shown in Table 2 [7]. The commercial iBurst BS employs an antenna array with 12 elements. For the field experiments (Fig. 1), an antenna array with uniform circular topology where adjacent antenna elements are spaced apart by 3.5λ is considered. The AAA processing and SDMA operation are executed in baseband. The block diagram of AAA/SDMA signal processing at the iBurst BS is shown in Fig. 2. The TDD-TDMA frame and time slot structure that includes training sequence for spatial processing is shown in Fig. 3. The iBurst BS mitigates received power fading of desired signal by steering the beam to the desired UT. In addition, when the BS communicates with multiple UTs on the same channel, BS picks up the desired signal while nullifying interfering signals from other iBurst UTs. The array weights for these beam patterns can be generated by processing the received uplink training sequences by using Minimum Mean Square Error (MMSE) criterion. For downlink transmission, the array weights determined for the uplink are applied, because of the reciprocity nature of TDD channel. Therefore, the desired signal is transmitted only to the desired iBurst UT and not to other UTs. The TDD-SDMA can be obtained by applying this operation to two or more UTs.This TDD method offers simpler system architecture as compared to Frequency Division Duplex (FDD) operation. Furthermore AAA system can reduce the communication overhead and improve the user throughput in TDD operation.

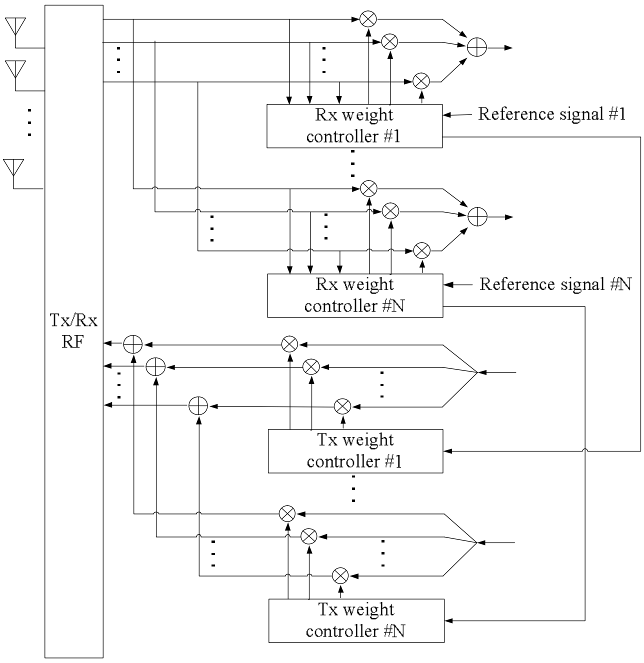

Fig.2: AAA Signal Processing at Base Station

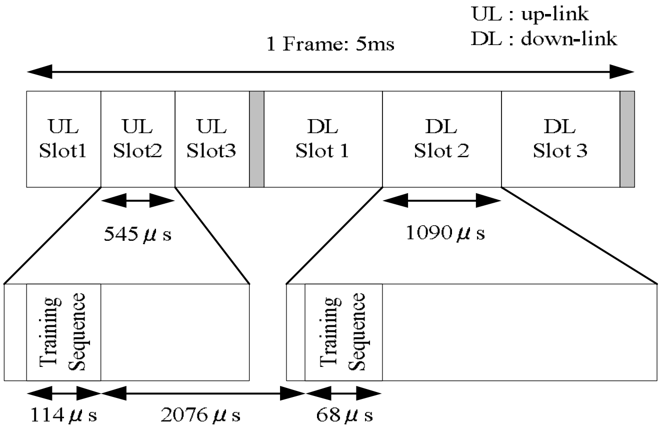

Fig.3: The iBurst Frame and Slot Structure

3 Array Weights Calculation in iBurst system

The baseband processing portion of the commercial iBurst BS calculates the array weights based on the MMSE criterion [10]. The MMSE is one of the popular and very effective

criteria to mobile communication system because the Angle of Arrival (AoA) information of the received signals is not required. The optimum array weights for MMES criterion are determined by minimizing the mean square error between the reference signal and the received antenna array signal. An uplink training sequence of 50 symbols is used as reference signal. The weight controller uses simple matrix inversion (SMI) algorithm [11]. In SDMA operation, the iBurst BS provides the orthogonal training sequence to each UT when each session is established. Therefore, the iBurst BS can detect and identify signals from each UT. The current commercial iBurst System supports 3 spatial channels to allow SDMA in the same conventional channel. The commercial iBurst System has 8 carrier channels in 5MHz bandwidth of operation. The frequency spacing of a channel is 625 kHz and each channel is controlled independently.
The Array Weights $\boldsymbol{w}(m)$ are calculated as

$$R_{xx}(m)=\frac{1}{m}\sum_{i=1}^{m}\boldsymbol{x}(i)\boldsymbol{x}^{H}(i)\,. \tag{1}$$

$$\boldsymbol{r}_{xr}(m)=\frac{1}{m}\sum_{i=1}^{m}\boldsymbol{x}(i)r^{*}(i)\,. \tag{2}$$

$$\boldsymbol{w}(m)=R_{xx}^{-1}(m)\boldsymbol{r}_{xr}(m)\,. \tag{3}$$

where $\boldsymbol{x}(i)$ are the received array signals converted to the baseband, $r(i)$ is the reference signal and m is the number of samples [12].

4 Simulation and Field Experiment Results

Parameter	Condition
Number of Cell	19
Radius of Cell	1km
Frequncy	1900MHz
Bandwidth	5MHz(625KHz×8)
Channel Model	ITU M.1225 Pedestrian-B
Propagation Model	ITU M.1225 Pedestrian-B
Shadowing	Log Normal Fading 10dB standard Deviation
Number of User	24 Users/Cell
BS Transmission Power	33.8 dBm/Carrier
BS Antenna Height	30m
BS Antenna Gain	11dBi
UT Transmission Power	21dBm
UT Antenna Height	1.5m
UT Antenna Gain	0dBi
BS Adaptive Array Antenna	enable

Table 3: Parameters for iBurst System Simulation

The parameters for the iBurst Protocol System Simulation are shown in Table 3. The antenna structure is same as that of commercial iBurst System, i.e., BS has 12 element antenna arrays, the UT has single antenna element. On transmission side, ModCalss is selected based on the estimated SINR of received signal. The uplink and downlink data throughputs provided by each ModClass are shown in Fig. 4(a) and Fig. 4(b) respectively. Table 4 shows the spectral efficiency (bits/sec/Hz/Cell) achieved on uplink and downlink of iBurst system with 19 cell lay out. This simulation result is calculated by using the physical throughput as shown in Fig. 4(a) and Fig. 4(b).

Frequency Efficiency		Unit
DownLink	UpLink	
3.5	2.3	bits/sec/Hz/sector

Table 4: Simulation Result of Spectral Efficiency

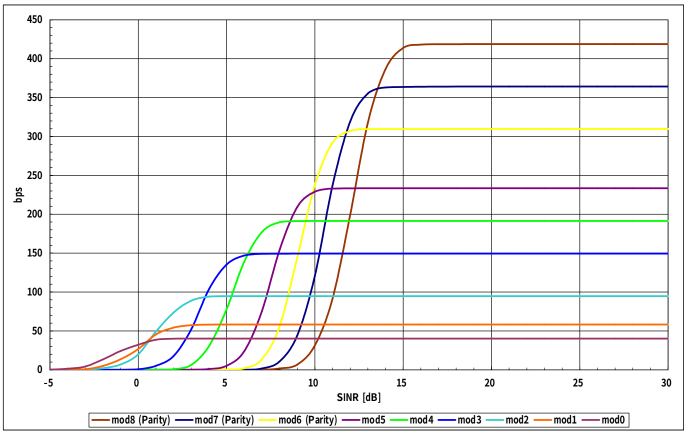

Fig. 4(a): Uplink Data Throughput of Each ModClass

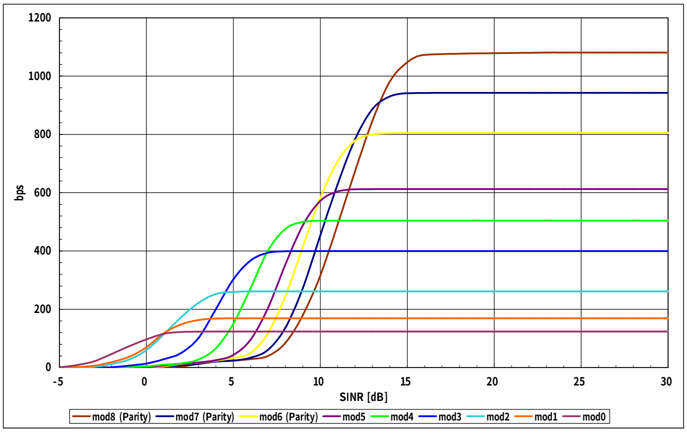

Fig. 4(b): Downlink Data Throughput of Each ModClass

As shown in Table 4, the iBurst System achieves high spectrum efficiency by using AAA techniques in multi-cell structure, which offers excellent interference suppression and enables frequency reuse factor of 1. The field performance of the iBurst, shown in Fig. 5, demonstrates the achieved total downlink data throughput with 24 UTs in a system bandwidth of 5MMz. The commercial iBurst BS has 8 independent 625kHz carrier channels, and each carrier serves 3 iBurst UTs in SDMA fashion. Therefore, though the number of physical carriers is 8 channels, the total number of channels increased to 24 due to SDMA mechanism. Each channel carries three time slots on both uplink and downlink. However, the first time slot of each channel is reserved for logical control channel known as Broadcast Channel (BCH), and it can not be used for user data transmission. As a consequence, as shown In Fig. 5, each of 21 UTs achieve a downlink throughput of 1Mbps by 3 time slot aggregation, while each remaining 3 iBurst UTs achieves a downlink throughput of 700kbps by 2 time slot aggregation by leaving a time slot for exclusive BCH signalling. Thus, in this field test, the total downlink throughput achieved by one BS is 21.616 Mbps. The maximum theoretical downlink throughput under same test conditions is 24.402Mbps. The efficiency, both theoretical as well as experimental, value is found to be 92.7%. This efficiency value shows that the effectiveness of AAA/SDMA operation in the iBurst is very high. The high downlink system spectral frequency efficiency of 4.52[bits/sec/Hz/cell] (=22.616Mbps/5MHz), the experimental result, exhibits the efficient AAA processing and SDMA operation of iBurst.

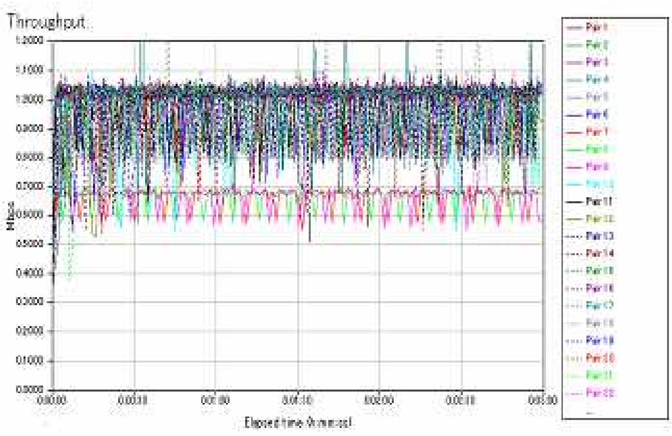

Fig 5: Downlink Throughput of Field Experiment

Next we discuss the interference rejection capability of the iBurst's AAA operation by a set up as shown in Fig. 6. In this experimental test, the iBurst BS provides a data connection to 3 iBurst UTs on a single channel, i.e., same carrier channel and same time slot. Then the uplink and the downlink throughputs of each of these UTs are measured while changing distance of separation between UTs in steps of 1cm, 5cm, 10cm, 50cm, 3m, and 5m. The throughput is measured at each point. The distance of between BS and 3 UTs is approximately 100m, and wireless environment is Non Line of Site (NLOS).

In Fig. 6, Each UT1, UT2, and UT3 is allocated always same carrier channel ***f1***. The results of throughput measurement are plotted in Fig. 7(a) and Fig. 7(b), which show Uplink and Downlink total Data Throughput of each UT as well as total throughput, respectively. In both uplink and downlink, maximum data throughput was achieved as soon as spacing between UTs is more than 20cm. On uplink, each UT achieved throughput of approximately 320kpbs and the total throughput being approximately 980kbps. Similarly, on downlink, each UT achieved throughput of approximately 1020kbps, and the total throughput is approximately 3070kbps.

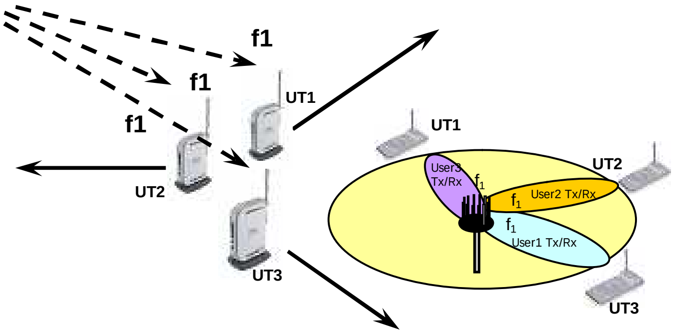

Fig. 6: Interference Testing Environment

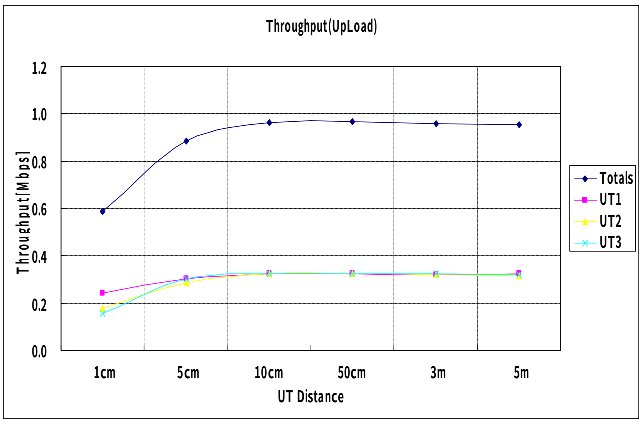

Fig 7(a): Uplink Throughput of 3SDMA vs. UT Distance

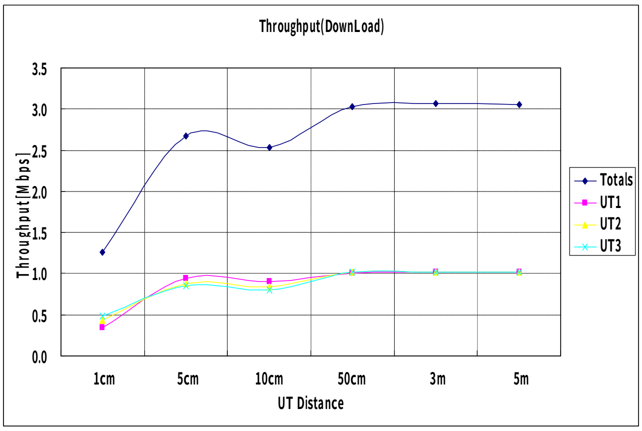

Fig 7(b): Downlink Throughput of 3SDMA vs. UT Distance

The results of this experiment confirm that the commercial iBurst system's AAA processing yields high interference rejection capability that nullifies signals from UTs in their neighbourhood. BS of the commercial iBurst system is able to deliver the high performance by using 12 antennas with real-time adaptive signal processing operation. In other words, the commercial iBurst system can always provide high data throughput service to subscribers in both environments of indoor and outdoor. For example, even when a large number of subscribers with iBurst UT exists in business office environment, each subscriber can have great experience of high data rate transfer services of 350kbps on uplink and 1Mbps on downlink.

Fig. 8 shows the demonstration setup of crowded scenario with a large number of subscribers of iBurst system. This demonstration is carried out and available at Yokohama R&D office of Kyocera Corporation in Japan. The commercial iBurst BS is set up on roof-top of Yokohama Office that has 7 floors and this demonstration corner, which is on 1F, has 21 laptops with PCMCIA type iBurst UT. Each Laptop with UT can connect to the iBurst BS on roof top, and always can execute data transfers of applications: FTP, HTTP, VIDEO Streaming, and VoIP. In one of the demonstrations, 21 Laptops with UT are able to simultaneously download large sized files using FTP and each of these 21 Laptops is able to experience high downlink speed of 1Mbps. In this simultaneous file download demonstration, the iBurst BS is able to support 3 spatial channels by SDMA operation and 7 conventional (frequency-time) channels for each spatial channel. Therefore, the total downlink data throughput achieved is approximately 21Mbps by a BS. This demonstrate the capability of the commercial iBurst System that can provide portable broadband wireless Internet access to all subscribers, anytime, anywhere.

Fig 8: Demonstration corner

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