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"A STUDYAND ANALYSIS OF SMART ANTENNAS FOR BROADBAND WIRELESS ACESS NETWORKS IN WIRELESS COMMUNICATION APPLICATION"

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ABSTRACT

This paper is an overview of smart antenna (SA) applications At millimetre wave frequencies, it is possible to expect increased system performance through the use of smart antenna configurations associated with some signal processing capabilities. in fixed broadband wireless access (BWA) networks. Different smart antenna techniques are described including recent advances such as "spatial multiplexing" that can dramatically increase the performance of BWA networks. The impact of SA techniques on capacity and throughput of BWA networks is discussed.

Keywords: Broadband wireless access, smart antennas, capacity, co-channel interference cancellation, spatial multiplexing.

INTRODUCTION

Future broadband wireless communication systems require the development of smart antennas that are perform ant, small, and affordable to a large number of users. These smart antennas must also go broadband to provide newer generation technology the possibility of offering more capacity to the busiest cell sites or create specific beams for each mobile user while continuously adapting to the changing environment**.** The rapid growth of the Internet user base and of bandwidth-hungry applications in recent years has created a need for 'last mile' broadband access for residential and business consumers. This demand for high-speed access is becoming a market force for advanced broadband access technologies and networks. We define "broadband" access as one that provides at least 5 Mbps peak (bursty) rate per user in the downlink direction and 500 Kbps peak (bursty) rate in the uplink. The average bit rates may be significantly lower in many applications. This bit rate asymmetry arises because applications such as web browsing are asymmetric. The growing demand for streaming audio and video will increase downlink throughput and quality of service (QoS) requirements. Other applications such as telephony and video conferencing need symmetric and constant bit rate services. Internet services and content are evolving in ways hard to predict. The only predictable trend is that bit rates and QoS requirements will increase rapidly.

Early applications of broadband access technologies were 'big pipe' applications aimed at large offices and business campuses offering 10 to 100 Mbps connectivity. However, new deployments increasingly target 'small pipe' volume markets such as medium-sized businesses, SOHOs (Small Office/Home Office) and residential customers. Broadband data access services are currently offered through a range of competing wired (Digital Subscriber Line - xDSL, fiber to the home (FTTH), hybrid fiber coax (HFC) and cable) and wireless (Multichannel Multipoint Distribution Service (MMDS), Local Multipoint Distribution Service (LMDS), High Altitude Long Operation (HALO) and satellite) technologies. Each approach has different cost structures, performance and deployment trade-offs.

While cable and DSL are currently gaining momentum in the broadband access marketplace, BWA is emerging as a third access technology with several advantages over its wired counterparts. These include rapid deployment, high data (Mbps/sq.mile) scalability, low maintenance and upgrade costs of the wireless facilities, and granular investment to match market growth.A typical BWA system uses radio hubs called base transceiver stations (BTS) to serve a group of subscribers. The customer premises equipment (CPE) uses a rooftop directional antenna. The licensed frequencies for BWA lie in the 24-48 GHZ band (e.g., LMDS) or below the 5 GHz (e.g., MDS, WCS and MMDS bands). There are also a number of unlicensed bands at 2.4, 5, 5.7, 24 and 38 GHz.

Despite the advantages of wireless access, there remain a number of critical issues to be resolved before BWA can successfully penetrate the market. The chief concerns are spectrum efficiency, network scalability, self-installable CPE antennas, and reliable non-line of sight operation. Smart antennas (SA) offer a powerful tool to address these problems.

SA is an emerging technology that has gained much attention over the last few years for its ability to significantly increase the performance of wireless systems. SA is being inserted into 2.5 generation (GSM-EDGE) and third generation (IMT 2000) mobile cellular networks [1]. In this paper we outline why smart antennas constitute a particularly good match for emerging BWA systems. The rest of the paper is organized as follows. In the next section, we describe BWA architectures and its challenges with emphasis on spectrum efficiency and on scalability. In section 3, we give an overview of the leverages offered by smart antennas in fixed BWA. We present a classification of smart antenna techniques and describe some applications and performance value. Section 4 concludes the paper.

1.BWA Architectures and Challenges

In this section we first describe alternate architectures – single (mega) cell currently proposed and macro cells being actively developed for BWA. We then describe the main challenges faced by BWA technologies.

1.1Architectures Single (Mega) Cell

In a mega cell architecture, a large service area with a radius of upto 30 miles is covered by one or two cells. The base station antenna is typically located on a very high tower or hill top (height of 500 to 1200 ft) to provide line of sight (LOS) paths to subscribers. A high gain CPE rooftop mounted antenna pointing towards the base station is used.

Macro Cell

Macro cellular systems use spatial frequency reuse to cover the service area. The BTS heights are similar to cellular infrastructure. Macro cells therefore typically use 4 QAM modulation, a spatial reuse factor of 3 to 4 and no angle reuse. LOS propagation is usually not possible, and cell ranges are therefore much smaller (1 – 4 miles) due to higher path loss.

The following table compares two different cellular architectures for BWA.

Table 1. *Mega Cell vs Macro Cell Deployment*

	MEGA-CELL	MACRO-CELL
No. of Cells	One	Multiple
BTS Antenna Height	High(>500’)	Low(~100’)
CPE Antenna height	Rooftop (>30’)	Medium(~15’)
Propagation	LOS needed	NLOS acceptable
Frequency Bands	<5 GHz	<5 GHz and millimetric
Reuse	Angle Reuse	Spatial Reuse
Coverage	<30-40 miles	<3-4 miles

1.2BWA Challenges

The successful deployment of BWA technology faces a number of critical challenges. These are discussed below.

Capacity/Spectrum Efficiency

The rapid increase, both in access minutes and average bit rates, along with limited radio spectrum calls for the development of networks with very high spectrum efficiency. This is particularly acute in the downlink where higher bit rates (several Mbps average throughput per square mile) are needed. We can increase spectrum efficiency through aggressive frequency re-use and higher order modulation. However, frequency reuse increases co-channel interference and reduces modulation order. The spectral efficiency of a wireless network is measured by bps/Hz/Cell (BHC). BHC is the bits per second delivered by one cell divided by the total spectrum (Hz) in the network. BHC is a good measure based on the premise that base stations are high cost items and throughput per base station is a key metric. Because of the traffic asymmetry in BWA, the downlink BHC is a key figure of merit in BWA networks.

In macro-cell (cellular) deployments, frequency reuse in a spatially separated cell gives rise to co-channel interference (CCI) and depends on reuse factors and sectorization plans. In single cell systems frequency reuse in angle is the source of co-channel interference and depends on side lobe leakage at BTS antennas and scattering from reuse sectors [Fig 1(b)]. Assuming that co-channel interference can be treated as additive white gaussian noise (AWGN), the classical Shannon’s formula can be rewritten to yield the theoretical limit on BHC in a frequency reuse network:

$$BHC = \frac{\log(1 + C/I)L}{mK}$$

Where C/I is the signal to interference plus noise ratio, m is an overhead factor for excess bandwidth and frequency guard bands, K is the spatial reuse factor and L is the angle reuse factor. In macro-cell systems, K is equal to the cluster size and L is one. In single cell systems, L is the number of times a channel is reused in angle and K is one. The above equation suggests that aggressive reuse (decreasing K in macro-cell architectures or increasing L in single cell systems) would increase system capacity. However, frequency reuse increases CCI, thereby reducing the C/I and modulation order. C/I is approximately proportional to K^2 in macro-cell networks and 1/L in single cell networks. In general, BHC is maximized by aggressive reuse i.e. smaller K or larger L. Optimum tradeoff of K, L and C/I depends on target BER, propagation conditions, C/N, fading, antenna sidelobes and diversity schemes. Single cell systems can have high downlink BHC (3-6) because of LOS propagation and absence of interference. Macrocell systems have much lower downlink BHC (0.15-0.5).

Another figure of merit is throughput density - bps/Hz/sq.mile (BHS). This metric is independent of the number of base stations required, but captures the scalability in the network to support increasing load. For a medium sized city with 300 square miles area a single cell network has a low BHS (0.04), while a macro cell (one mile cell radius) network has a higher BHS (0.15).

Coverage

During initial deployment stages, the load density can be very low (<0.1 Mbps/sq.mile). As the number of users and load per user increases, load density can grow by two orders of magnitude. Therefore, initially the network is likely to be coverage limited. With very high BTS antennas, directional CPE antennas and LOS propagation, high coverage is indeed possible (with mega cells). However, lower BTS antennas, and presence of foliage and terrain blocking, good coverage can be a challenging task. Therefore, coverage is a challenge for macrocell networks. Of course, when the demand has grown to a point when cells have to be shrunk due to capacity reasons, coverage problems become less important.

Throughput and QoS

As the types of service grow, the demand for higher throughput and quality of service (QoS) will increase. While spectrum efficiency is important, other factors such as an efficient medium access control (MAC), link layer adaptation and control (LLC), data and voice convergence, scheduling and queuing etc, become critical to ensure high throughput and good QoS features such as bit rate guarantees, latency, delay jitter and packet loss.

Other Challenges

Coverage Reliability: Wireless links face significant attenuation from rain, foliage and blocking by terrain features. BWA networks should provide better than 80% coverage reliability to subscribers in the service area despite these problems.

Demand Scalability: Assuming 800 homes per square mile, 80% areal coverage, 5% market penetration, 20% active subscribers and 50 Kbps average load per user, the estimated load is 0.15 Mbps/sq.mile. As the market penetration increases to 20% and per subscriber load increases to 400 Kbps, the load per square mile may grow to 10 Mbps/sq.mile. Mega cell systems have large coverage but limited capacity. A mega cell with a 10 mile radius and 50 MHz spectrum can support about 0.2 Mbps/sq.mile. Therefore, it barely covers the initial load demand. The situation is better in a smaller city with a 5 mile radius mega cell where the system can scale to 0.8 Mbps/sq.mile. However, mega cell systems must cover the entire service area and therefore are either limited to very thin load large cells or medium load small cells. The situation is much better with macro cells where a one mile cell can scale to 1.5 Mbps/sq.mile. This can be even higher with smaller cells. In addition, macro cell systems can cover any amount of service area by simply extending the cellular network, a feature not possible in mega cells.

Reuse of cellular infrastructure: Significant investments have been made in existing PCS/cellular infrastructure. A BWA system should maximally reuse such infrastructure.

1.Smart antennas

This section introduces the principles of smart antennas and discusses the leverages offered by this technology.

1.1Smart Antenna Advantages

Smart Antenna technology exploits multiple antennas in transmit and receive with associated coding, modulation and signal processing to enhance the performance of wireless systems in terms of capacity, coverage and throughput. A detailed overview of smart antenna systems for use in cellular networks is available in [2]. The CPE can also use multiple antennas in BWA networks. SA techniques can therefore be used for downlink and uplink both at the BTS and CPE. SA leverages (on transmit and receive) include:

- **Array Gain**: Multiple antennas coherently combine the signal energy improving the carrier-to-noise ratio (C/N). Available both on transmit and receive.
- **Diversity Gain**: Spatial diversity obtained from multiple antennas helps combat channel fading. Available on transmit and receive.
- **Interference Suppression Gain**: Multiple antennas can be adaptively combined to selectively cancel or avoid interference and pass the desired signal. Available on transmit and receive.
- **Spatial Multiplexing**: Spatial multiplexing uses multiple antennas at both ends to create multiple channels and improves spectrum efficiency (bps/Hz).

These leverages can translate into improved capacity (large number of users per square mile), coverage (higher penetration of service area) and throughput (high user bit rates) in BWA networks. Typically, some of the leverages are mutually conflicting depending on the algorithms used.

1.1Smart Antennas in BWA

BWA provides special opportunities for application of SA technology. These are:

- Very high data rates (100 times that of cellular voice in burst mode) need high spectrum efficiency. SA can increase spectrum efficiency dramatically.
- Fixed data modems (or future portable services to lap-tops) allow the use of multiple antennas at the CPE. Coupled with multiple BTS antennas, powerful SA leverages are possible. In contrast, multiple antenna schemes are usually not practical in the cellular phone.
- Downlink – uplink asymmetry emphasizes downlink spectrum efficiency. Multiple antennas at the CPE enable high downlink performance.
- Low channel variability in fixed radio networks enables good channel estimation. This is key to successful SA exploitation.
- In fixed applications, the CPE is line powered and additional power typically needed by SA technology is not a constraint.
- BWA systems are expected to compete in quality and availability with wireline networks. SA technologies (in particular diversity) improve quality/availability.

We now give an overview of SA applications for BWA . We assume that the CPE and BTS has multiple (3~4) antennas. The antenna element specifications and array topology at each end are chosen to maximize SA performance.

2.3 Spatial Multiplexing

Frequency reuse in angle [also known as Spatial Division Multiple access (SDMA)] exploits beamforming/directional antennas to support more than one user in the same frequency channel. Signal separation of co-channel beams has to be accomplished at the BTS for both transmit and receive, since the CPE with a single antenna has no signal separation capability. Angle reuse has not been a successful technology in cellular networks because heavy scattering and mobility makes signal separation impractical particularly on the downlink. However, in BWA mega-cells due to high BTS antennas, the inter-sector scattering is small and angle reuse may be possible. If the BWA systems use higher order modulation schemes that require large C/I (~30 dB) angle reuse is still challenging and may need substantial SA complexity. With lower order modulation (4 QAM), angle reuse may be possible. Typically, mega cell systems use angle reuse (or SDMA) on the uplink with 4 QAM modulation.

Spatial Multiplexing (SM) [4], also sometimes referred to as BLAST [5], is a SA technology that can dramatically increase the bit rates in wireless radio links. SM requires multiple antennas at both ends of the wireless link. Under favorable channel conditions, SM offers increase in spectrum efficiency linearly, proportional to the number of antennas. Unlike SDMA, SM does not need channel knowledge at the transmitter thus making it a far more robust technique.

At the transmitter, the stream of information symbols {b1, b2, b3, b4, b5, b6..} is split into three independent lower rate sub streams {b1, b4,..}, { b2, b5,..}, {b3, b6,..} . These substreams are modulated and transmitted, one stream per antenna, all in the same radio channel using the required bandwidth to support the lower rate substreams. If the spatial signatures of each transmit antenna induced at the receiver antennas are well separated, the receiver can separate the three transmitted signals which can then be merged to yield the original high bit rate stream. Different linear or non-linear transmit and receive techniques can be used with a range of performance/complexity trade-offs (D.Gesbert, internal document, Gigabit Wireless Inc.). With two antennas, SM and transmit-receive diversity techniques have comparable performance. However, for three or more antennas or when the channel exhibits low fading, SM provides higher capacity gain [6].

Spectral efficiency gain in SM depends on physical separation of antennas, location and strength of scatterers, number of antennas at the transmitter and receiver, transmit-receive separation and the wavelength. In practice, antenna degrees of freedom have to be allocated across a number of competing needs such as diversity, CCI cancellation and SM. Ideally, the product of the number of antennas at the CPE and at the BTS represent the total number of degrees of freedom available for combining purposes. These degrees of freedom can be allocated freely, under ideal channel conditions, to any of the leverages above.

2.4 Channel Estimation

SA techniques need accurate channel knowledge to be implementable. On receive, the channel can be directly estimated since the transmitter can embed training sequences that can be exploited by the receiver. Simple transmit techniques such as beamforming for array gain need only approximate channel knowledge [i.e. general direction of subscriber]. More complex transmit interference avoidance techniques need accurate channel estimation. Two techniques are available: reciprocity and feedback. The performance of these techniques depends on a number of factors such as the duplexing technique and doppler spread of the channel (see [2] for further discussion).

2.5Performance Advantages

SA technology offers many advantages in BWA networks including improved BHC and BHS, coverage and deployment improvements. We believe that SA technology can yield a BHC of 2.5 bps/Hz/cell and a BHS of 0.8 bps/Hz/sq.mile (one mile cell). With 50 MHz of spectrum the demand scalability reaches 12.5 Mbps/sq. mile. Smart Antenna macro cells therefore offer excellent scalability and economics. Fig. [6] shows the scalability of different BWA technologies.

Conclusion

A large market opportunity is opening up for providing broadband wireless access to residential, SOHO and business markets. Successful BWA systems need to be scalable, should have high spectrum efficiency, should offer high bit rates and should be easy to deploy at the infrastructure and subscriber end. SA technology offers significant leverages to enable such features. Use of multiple antennas at both ends of the wireless link along with efficient modulation, radio resource management, coding and diversity can increase spectrum efficiency by a factor of three to ten while greatly enhancing other desirable features. The challenge is to develop and deliver a well designed BWA system that captures the capabilities of SA technology without sacrificing robustness, simplicity and cost.

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