WIRELESS BACKHAUL IN CELLULAR NETWORKS USING PHASED ARRAY ANTENNA WITH OPTICALLY CONTROLLED PHASE SHIFTER

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Abstract

Introducing relay stations into cellular networks has recently been seen as an effective way to develop high speed wide-area wireless networks since the use of wireless backhaul from relay station to the base station increases the flexibility and cost effectiveness of the deployment. A novel and fast approach to relay station deployment is proposed using phased array antennas and passive direction of arrival. A phased array antenna with electric beam steering ability is used to communicate between the base station and relay station. In this paper, antenna design issues for the phased array antenna to be used by the relay station are described that exploits a new optically controlled phase shifter.

Keywords: Antenna arrays, wireless networks, phase shifters, organic semiconductors

1. INTRODUCTION

To enhance capacity and coverage quality for cellular networks, additional relay stations (RS) may be built on selected sites to improve service probability and quality of service (QoS) [1]. How to create a relay based cellular network or add RSs into an existing cellular network quickly and provide high capacity and QoS is a network planning problem. However, if time is short and the demand distribution changes then the original planned deployment may be sub-optimal. In [2] a novel fast deployable relay station approach has been proposed. A beam steering phased array antenna has been assumed to be used as wireless backhaul by RSs to communicate with base stations (BS).

Existing antennas for cellular networks have down-tilting capability (magnitude alteration) and can apply different sets of fixed weights (phase alteration), but it is not controlled in real time by a smart system. Rather the adjustment is manually controlled. Structurally such antenna will still work on a single transceiver with an array mounted in front as in current base stations. Hence proposed antennas are a step ahead of existing systems, with essentially no more hardware requirements.

A phased array antenna uses the phase shifters to control either the phase of the excitation current or the phase of the received signals [3]. Beam forming and beam scanning are generally accomplished by phasing the feed to each element of an array so that signals received or transmitted from all elements will be in phase in a particular direction. The design of a phased array antenna with an optically controlled phased shifter is analyzed in terms of the performance of wireless backhaul. The relative phase variation between neighboring radiating antenna elements can be created by light-induced variation of the refractive index of media adjacent to the transmission lines associated with a given array element which is based on organic semiconductor material [4]. Preliminary proof-of-concept work has established the capacity for such materials to effect variable and reversible relative phase control to radiating elements of an antenna array. Furthermore the phase response-time is potentially on the order of seconds (if desired).

Hence, this paper looks at how to put a "smart" RS into an existing cellular network more efficiently with limited network planning by using:

- simple and cheap forms of phased array antenna with passive direction of arrival (DoA) estimation
- new kind of phase controlling devices based on optically controlled organic semiconductors

2. SCANNING ARRAY FOR RS

2.1. BASIC CONCEPT

Compared to conventional cellular networks, deployment of ad hoc wireless networks offers low cost, plug-and-play convenience, and flexibility [5]. In this work, the fast deployment and some adaptive routing ideas are taken from ad hoc networks. Although prior planning will normally always be advantageous, the aim of the approach developed is to allow efficient and quick deployment of a RBCN that is inherently more flexible than conventional deployments, at a reasonable cost.

The use of smart antennas and beam forming technology to improve the propagation characteristics in wireless networks has been investigated in recent years, but most of this research is concentrated on the smart antenna usage in BSs and entails the expensive costs of smart antenna development. In the approach described here, a phased array antenna is assumed used in the RSs. The potential capability of beam steering lets the main beam of a RS change direction and hence the assignment of RS to BS. Moreover this reassignment is achieved in a coordinated manner to enhance the performance over the whole network. With the help of the passive direction of arrival algorithm, RSs can explore the network environment and find the best directions to connect to nearby BSs. When a new RS is dropped into a desired coverage area, it will be able to integrate itself into an existing network quickly and reliably. Should a BS fail, reassignment can ensure backhaul through another BS.

The concept of optimal path selection is used in RSs to provide the flexibility capability to adapt to a changing environment in real time. The phased array antenna with beam steering lets the RS continually adjust its radiation pattern so that the main beam always points at the direction of a suitable BS receiver or transmitter. The proposed approach is also suitable for emergency situations and when temporary coverage is needed and where automatic deployment and recovery from failure of elements in the system is extremely important.

2.2. PHASED ARRAY SCANNING

In this work, a RS has two antenna systems, where one is an omni-directional antenna system for communication with the mobile users surrounding it, and the other one is a phased array antenna system with electric scan ability for communication with the BS.

For a given array the main beam can be pointed in different directions by mechanically moving the array. This is known as mechanical steering. An engineer can control the main lobe of the antenna system to point it in any direction using mechanical steering. However, this will not provide immediate real time control and rapid response to traffic demand changes over time. Beam steering can also be accomplished by appropriately delaying the signals before combining. The process is known as electronic steering, and no mechanical movement occurs [6].

Beam forming and beam scanning are generally accomplished by phasing the feed to each element of an array so that signals received or transmitted from all elements will be in phase in a particular direction. This is the direction of the maximum of the radiation pattern. This can be accomplished by changing the phases of the signals at the antenna elements. When the all signals are combined, a beam is formed in the desired direction.

A linear phased array with equal spaced elements is used to analyze in the phased array antenna designs. Although it is the simplest, it is still widely used. By controlling the phase and amplitude of excitation to each element, we can control the direction and shape of the beam radiated by the array. If the maximum radiation of the array is required to be oriented at an angle θ, then, to accomplish this, the phase excitation β between the elements must be adjusted so as:

$$\beta = -kd\cos\theta \qquad (1)$$

Thus by controlling the progressive phase difference between the elements, the maximum radiation can be targeted towards a desired direction (within scanning limits that are defined by geometrical and physical restrictions), hence forming a scanning array. For simplicity only one dimensional steering is considered in the electronic beam scanning below.

2.3. DOA ALGORITHM

Passive DoA was first developed for military radar systems (passive radar or passive covert radar) used in the navy. It is used to detect and track objects by processing reflections from target sources [7]. It has several advantages compare to the smart antenna DoA algorithms used for the optimal path finding. Firstly, the phased array antenna system only perceives the direct signal from the transmitters (BSs) when finding the direction of the optimal path. This is very suitable for quick RS development and network upgrades, as no output signal means there will be no interference to the existing network. Secondly, the equipment is considerably cheaper than smart antenna systems. It does not need the complex adaptive beam forming schemes or real time adaptive DSP processor for each antenna element.

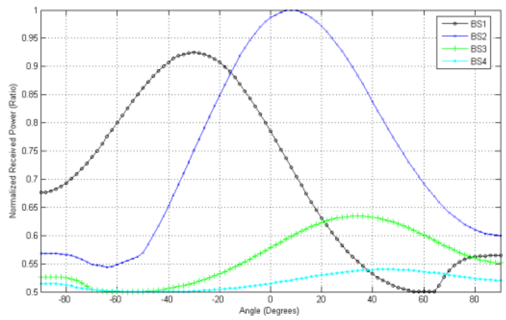

Fig. 1. Normalized received power from four neighboring BSs using a 20º beam width.

Passive DoA is analogous to mechanically steering the main beam direction towards the target direction to maximize the received signal quality. Phase shifters control either the phase of the excitation current or the phase of the received signals. When all the signals are combined, a beam is formed in the desired direction. If the main lobe is directed towards the target site, it will maximize the transmitted or received signal. The performance evaluation of passive DoA with four neighboring BSs around is illustrated in Fig. 1. The steering locations that result in maximum received power at the RS yields the DoA estimates. It is also possible to use signal-to-noise ratio, but the simulations presented here use received power.

2.4. OPTICALLY CONTROLLED PHASE SHIFTERS

An optically controlled phase shifter described in [4] is designed to be used in the phase array antenna system. The optically controlled phase shifter is comprised of an aluminum transmission line separated from an indium tin oxide _ITO_ ground plane by the semiconducting poly 3-hexylthiophene (P3HT) acting as a dielectric. The relatively high drift mobility, optical absorption and small band gap properties of P3HT have resulted in significant attention to P3HT as an active device layer. P3HT in a microstrip structure is illustrated in the Fig. 2. and an electron-hole plasma region is induced. If one engineers a signal to travel through two regions where only one is illuminated, a relative phase shift can be induced between the two outputs. As has been shown in [4], phase shifters based on the proposed technology can achieve stable linear dependence of the differential phase shift with amplitude of up to 30 degrees for the first experimental samples.

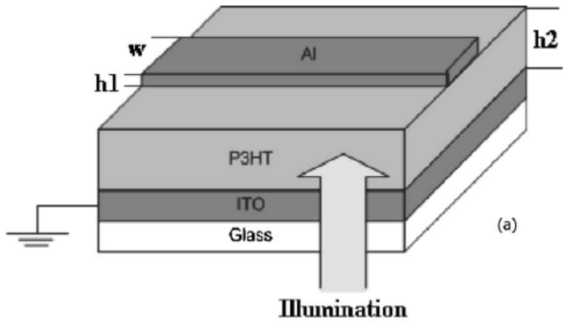

Fig. 2. Schematic cross section of the optically controlled phase shifter (taken from [4]).

2.5. ANTENNA ARRAY DESIGN ISSUES FOR RS

The elements of phased array antenna must be spaced properly in order to avoid grating lobes. For the given scanning angle (although in the ideal scenario when mutual coupling is not taken into account), the maximum spacing between the array elements is a function of operational wavelength:

$$d_{\max} = \frac{\lambda}{1+\sin\theta}, \qquad (2)$$

where θ is the given scanning angle and λ is a wavelength. For example, in order to scan the main beam to 60° without grating lobes d_{max} should be not more than 0.54λ Hence larger values of scanning angles would require closer spacing (to obtain those angles and to avoid grating lobes). As has been stated in the previous sub-section, optically controlled phase shifters can produce continuous but small amounts of phase shift. Hence, even close proximity of array elements cannot guarantee scanning angles more than 15-20 degrees (see, Eq. 1). However, it can ensure that grating lobes do not appear as a result of scanning.

For the given application, 360° scanning can be complicated and expensive, actually cancelling declared advantages of a cheap and flexible solution. From the other hand, since the relative positions of base station is likely to be known, the phased array can be pointed in the approximated direction. After that, RS becomes self sufficient and can find DoA for the best QoS using a phased array with limited angles of scanning. Moreover, in case of signal deterioration due to weather conditions, unexpected circumstances, etc. the RS can re-tune DoA for the best QoS within seconds due to real-time controlled organic semiconductor phase shifters.

3. CONCLUSION

With the phased array antenna system based on optically controlled phase shifters and passive direction of arrival algorithm, a flexible and rapidly adjustable wireless backhaul for RSs could be setup quickly. Furthermore, the wireless backhaul can discover its local area propagation environment and respond the environment changes and failures and e.g. movements of BS, in the wireless network. With the help of the new optically controlled phase shifter, the exploitation of directional transmissions could suffice to ensure a wireless backbone with high speed and a high degree of spatial reuse at reasonable cost.

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