Research Article

Microstrip Antenna Design for Femtocell Coverage Optimization

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A microstrip antenna is designed for multielement antenna coverage optimization in femtocell network. Interference is the foremost concern for the cellular operator in vast commercial deployments of femtocell. Many techniques in physical, data link and network-layer are analysed and developed to settle down the interference issues. A multielement technique with self-configuration features is analyzed here for coverage optimization of femtocell. It also focuses on the execution of microstrip antenna for multielement configuration. The antenna is designed for LTE Band 7 by using standard FR4 dielectric substrate. The performance of the proposed antenna in the femtocell application is discussed along with results.

1. Introduction

Femtocell, also known as femtocell access point (FAP), is a short-ranged, low-powered, and low-cost base station that has been shrunk down to the size of a paperback book. Femtocell is similar to a wireless internet router and easy to install in offices and residences. It is a mini base station for the indoor coverage purpose and an extension of outdoor network. It provides high quality indoor coverage and increases the capacity of the network by diverting a portion of the traffic through wired-backhaul connection [1]. Cellular operators throughout the world are facing challenges in increasing system capacity, coverage, and residential connectivity in suburban and urban environments due to the huge investment that follows. Femtocell offers an economically appealing way to improve the quality, coverage, and the service of the existing network. However, dense deployment of femtocell induces interference concern, which remains a strong challenge so far [2, 3]. Moreover, the indoor wireless environment and short distances among the cells have made the situation more complex. Since the cellular operators prefer cochannel deployment for better spectral efficiency, femtocell increases

the capacity without considering the fairness of per femtocell user capacity.

Network planner has no control over femtocells deployment. Femtocell has extensive autoconfiguration capability to ensure plug and play deployment [4]. For successful residential deployment, several technical challenges need to be overcome. Large-scale deployment of femtocell in dense area increases the mobility events and overshoots the network subscribers in an unwanted level. Femtocell is usually placed in the corner of any residential places or offices where the wire connection is easier. Therefore, instead of omnidirectional antenna, multielement antenna is better to optimize the coverage area. Such a switched based multielement antenna configuration is proposed in [5]. Switching between the antennas makes it easy to optimize the coverage by controlling a simple circuit. Femtocell switches off the antenna at that direction where there is no user, thus lowering the chances of intercell interferences. Another coverage optimization tactic using multielement antenna with tunable attenuator is shown in [6]. Tunable attenuator is a reliable option for coverage optimization. It tunes up the radiation power to confirm the required radiation pattern. Since a power amplifier for

FIGURE 1: Multielement antenna configuration in femtocell (microstrip antenna).

each antenna will be costly for commercial use, a common power amplifier with digital actuator for each branch is conventional.

Multielement antenna in femtocell application divides the coverage area into multisections and each of the antennas occupies same portion of scanning-area. As such, four directional antennas have the angular coverage of 90° for each of them.

In this paper, a microstrip antenna is designed for multielement antenna configuration for femtocell coverage optimization (Figure 1). The performance of the antenna is simulated in a 4-element femtocell like assembly. The antenna design and substrate choice result in a flexible beam forming in femtocell application. The rest of the paper is arranged as follows: antenna design in Section 2, results in Section 3, array configuration in femtocell in Section 4, discussion in Section 5, and conclusion in Section 6.

2. Antenna Design

Inside the femtocell, the available space is limited for antenna patterns. Only few antenna types are possible for femtocell operation, for example, planar inverted F antenna, microstrip antenna, and wire antenna [7–11]. Microstrip antenna is a smart solution for small, efficient, and economical wireless communication system. Features like small size, light weight, low profile, low assembly cost, ease of mounting on the surface, and integration with printed circuits board (PCB) enable its use in a wide range of wireless appliances [12, 13]. However, compared with the nonprinted antennas, it has few disadvantages, for example, poor radiation pattern due to the excitation of surface wave, narrow impedance bandwidth, and low gain. Since the femtocell coverage region is small (around 10 m), microstrip antenna is a suitable choice for a multielement femtocell configuration. It is capable of miniaturizing design and cost effective solution [14–16]. However, to improve the bandwidth, radiation-efficiency, and directivity of the patch antenna, there are methods that use thick substrate, low dielectric substrate, multiresonator, stack configurations, and various impedance matching and feeding techniques. The use of substrates with low thickness and permittivity helps to reduce the dimension of the antennas [17]. One of the methods of widening the bandwidth is using

slot on the patch of different shapes such as I, H, M, and U [18, 19].

The patch antenna in this paper is designed for LTE Band 7. It is widely used in European, South American, Australian, Asian, and African regions [20, 21]. It has one of the highest bandwidth among the LTE bands and it is suitable for femtocell operation. LTE Band 7 has uplink from 2500 MHz to 2570 MHz and downlink from 2620 MHz to 2690 MHz. Therefore, the coverage bandwidth of the antenna is from 2.5 GHz to 2.7 GHz. Substrate FR4 is used to design the antenna. FR4 is a low cost and available substrate and popular for commercial microstrip antenna production.

The length and width calculation of the antenna is determined by using the following formulas.

The width of the patch is given by Bhartia et al. [22] as

$$W = \frac{c}{2f_r \sqrt{(\epsilon_r + 1)/2}}, \quad (1)$$

where f_r and ϵ_r are resonant frequency and relative dielectric constant of the substrate, respectively.

Now, the effective dielectric constant is expressed by Gilb and Balanis [23] as

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-1/2}, \quad (2)$$

where h is the height of dielectric substrate.

The actual length of the patch is given by [9] as

$$L = \frac{c}{2f_r \sqrt{\epsilon_e}} - 2\Delta L, \quad (3)$$

where ΔL is the extension of the patch length on both ends of the patch that is given by Hammerstad [24] as

$$\Delta L = 0.412h \frac{(\epsilon_e + 0.3)((W/h) + 0.264)}{(\epsilon_e - 0.258)((W/h) + 0.8)}. \quad (4)$$

The ground-plane length and width can be calculated as [9]

$$\begin{aligned} L_g &= 6h + L, \\ W_g &= 6h + W. \end{aligned} \quad (5)$$

FIGURE 2: Design layout of the proposed antenna.

TABLE 1: Design specification parameters.

Parameters	a	b	c	d	E	f	g	L	W	L_g	W_g
Unit (mm)	20	3	7.5	2.5	9.5	21	0.5	35.5	27	46	37

The beamwidth of each microstrip antenna and the resultant of any two particular antenna elements is a key fact in antenna designing. For design flexibility, two resonant frequencies were considered to safeguard the whole band coverage. Though the band is not that wide, two resonant points are taken so that it cutbacks the narrow beamwidth characteristics of the patch antenna. The resonant frequencies are about the middle points of the uplink and downlink bands: 2.53 GHz and 2.66 GHz. The theoretically calculated patch length and width for the two frequencies are 35.5 mm and 27.3 mm and 26 mm and 34 mm, respectively. The parameter for these two frequencies is then optimized with a rectangular slot in the lower middle portion of the patch. The dimension and position of the slot are also optimized according to the full coverage of the bandwidth [25]. The opposite copper layer of the substrate is considered as the ground plane. The antenna and array structure are modelled through a commercially available finite element package CST Studio Suite. The main patch is set on the top with 1.6 mm FR4 dielectric substrate with relative permittivity of 4.6 and tangent loss of 0.02. Figure 2 shows the dimension of the antenna and Table 1 contains the overall design specification parameters.

Rectangular shape microstrip antenna is a basic shape in antenna engineering field. However, the intention of designing is to keep it as simple as possible. The antenna is excited with general microstrip line-feeding technique. The

FIGURE 3: S_{11} -parameter of the designed antenna.

advantage of this method is that the connection of the patch and the feed is direct and all on the same substrate to provide planar structure [26, 27].

3. Results Analysis

The impedance bandwidth of the antenna is given in Figure 3. The return loss (S_{11}) of the antenna is <-10 dB ranging from 2.48 to 2.71 GHz. Two resonant frequencies overlap with each other covering the required uplink and downlink of LTE Band 7.

FIGURE 4: Radiation pattern at 2.53 GHz and 2.66 GHz.

FIGURE 5: Surface current on the patch at (a) 2.53 GHz and (b) 2.66 GHz.

Figure 4 illustrates the radiation characteristics of the antenna at 2.53 GHz and 2.66 GHz. In both frequencies, it shows broad beam and maximum radiation at the front side. The direction of the main lobes is almost at 0° . Besides, the peak-gains are 6.1 dB and 6.5 dB in 2.53 GHz and 2.66 GHz, respectively. However, the backward radiation in the measurement cannot be ignored. Since the antennas are placed in the outer surface of the house that contains the circuitry board of the femtocell, a shielding plane or cavity can reduce

the backward radiation level. However, a shielded plane can reduce the antenna efficiency, while cavity can narrow down the beamwidth [28–30].

Figure 5 shows the current density on the antenna patch. At 2.53 GHz, maximum surface current density occurs on the middle of the patch and above the slot. However, at 2.66 GHz, the maximum surface current shifts to lower portion of the slot. For uplink and downlink bands, different side of the slot on the patch gets higher surface current density.

FIGURE 6: Multielement antenna configuration.

4. Array Configuration in Femtocell Application

Single antenna femtocell with coverage optimization feature can help very little in interference reduction. Due to omnidirectional radiation pattern, it cannot optimize its radiation pattern according to the shape of the house and users' position. A switch based multielement antenna coverage with self-optimization technique can select one or a combination of two or three antennas according to the users' position and the shape of the house. Although single antenna femtocell ensures a faster convergence time comparing with the multielement antenna, it also increases the mobility events that result in unnecessary core network signalling. However, multielement antenna decreases the mobility events and increases the indoor coverage more effectively without overshooting the outdoor users.

To analyse the performance of the antenna in femtocell application, four microstrip antennas are placed outside of a rectangular box on the same plane. The four antennas are faced in four directions, mounted on each surface of the box, and separated by uniform angle of 90° as given in Figure 6.

Figure 7(a) illustrates the radiation pattern of the two antennas and their resultant beam that is directed almost at 45° angle with respect to their individual beams. Figure 7(b) shows the resultant beams of antennas 1 and 2 with variable feeding power through the digital attenuator for each antenna. The higher the amplitude of the feed-signal with respect to one another, the more the resultant beam deflects to that direction. Thus, by changing the power level in each port, the direction and coverage of the resultant beam can be changed. This is an advantage that femtocell can exercise to narrow down the beamwidth to serve a particular subscriber without interfering with other subscribers. Figure 7(b) shows the radiation pattern of four antennas and the resultant

combinations. One mentionable effect that might have an array coupling is the spacing between the elements. However, in this case, the directions of the antennas are separated by 90° , so it is not a bigger concern. However, the antennas are positioned keeping the same distance among each other alike the commercially available femtocell.

Finally, Figure 8 shows the resultant path-loss of the antenna combinations. As all the antennas are directed 90° apart from one another, the side lobes do not have any mentionable effect on their radiations.

5. Discussion

The Femtocell operates on the same frequency band along with the existing neighbouring femtocell and outdoor macrocell. Therefore, significant impetus towards the deployment of femtocell in the dense coverage area is essential. The user-equipment measurement report (UMR), informs the measurement results on the uplink regarding the coexisting FAPs and macrocell service level. An effective interference detection algorithm senses the UMR and femtocell cooperation message (FCM). Using multielement antenna configuration with adjacent power controller (attenuator), femtocell can choose proper radiation pattern to serve particular home users without overshooting the neighbouring femtocell user or outdoor macrocell user. Assigning the required SINR threshold level will make it more convenient to femtocell to adjust the radiation pattern for each user.

6. Conclusion

The design of a microstrip antenna for multielement antenna configuration for femtocell device and analyses of its performance for femtocell operation are presented. The proposed

FIGURE 7: Radiation patters (a) two antennas and their resultant beam, (b) resultant beam of antennas 1 and 2 with different power feeding, and (c) resultant beams of possible combinations.

FIGURE 8: S_{11} parameters for different combination of antennas.

configuration allows each of the four antennas to adjust the pilot power to optimize the antenna coverage. Along with the switching techniques, the microstrip antennas shape up the radiation pattern according to the house model and users' position. The antenna characteristics and the substrate choice indicates that it is suitable for commercial deployment in femtocell devices. It will also reduce the co-tier and cross-tier interference in dense femtocell network.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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