Down Link Beam forming for Capacity improvement of Wireless Indoor Communication Systems

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Abstract

In this paper, a beam forming method has been used to design sector antennas for the locally centralized radio communication system covering one building floor. Its ability to increase the capacity is investigated. The results show that the capacity can be increased by about (35%) when replacing the omnidirectional antennas by the designed antennas if the Dynamic Channel Allocation (DCA) is used. The increase in the capacity can be as high as (500%) when Fixed Channel Allocation (FCA) is used. This improvement really marks out the problem FCA has with the co-channel interference when using omnidirectional antennas. The results also indicate how well the studied wireless system can coexist with similar systems located in the vicinity. The use of the proposed antennas reduces the transmitter power and therefore improves the performance of closely located wireless networks.

الخلاصة

تم في هذا البحث استخدام إحدى طرق تركيب الهوائيات لتصميم هوائي ذي نمط إشعاع يغطي قطاع محدد من الزوايا(sector antenna) . تمت دراسة تأثير استخدام هذا الهوائي في نظام اتصالات لاسلكي يغطي طابق في بناية. بينت نتائج التمثيل على الحاسوب أن استخدام هذا الهوائي أدى إلى زيادة السعة(capacity) بمقدار ٣٥%، مقارنة بالهوائي الذي يبث في جميع الاتجاهات في حالة استخدام نظام التعيين المتغير للقنوات. لقد كانت الزيادة في السعة تصل إلى حد (٥٠٠%) في حالة استخدام الهوائيات الموجهة مع نظام التعيين الثابت للقنوات، إذ يشير هذا التحسن الكبير الى انخفاض اداء هذا النظام مع الهوائيات التي تبث في كل الاتجاهات. بينت النتائج كذلك اهمية استخدام الهوائي المقترح في تقليل قيمة قدرة الإرسال، والذي بدوره يقلل التداخل بين انظمة الاتصالات المتجاورة والتي تستخدم الترددات نفسها.

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1. Introduction

Wireless indoor multimedia communication has a bright future. The success of cellular telephony and the explosive development of Internet services will have a great impact on indoor communications. A variety of services must be offered in order to maintain the high interest in wireless communications. Future customers will demand to have Internet in their pockets and in their laptops wherever they are at a very low cost. One major drawback of today's indoor communication systems is that they are not designed to give the quality-of-service guarantees needed to support different applications. Future wireless indoor networks will very likely be implemented at places where the concentration of users is very high, like airports and downtown business centers. At these hot spots, the radio resources must be used efficiently. This will increase the system capacity and improve the capability of coexistence with other wireless networks located in a nearby area. Several networks will very likely be operating in the same building, supporting different companies. The interference created from these external sources must be handled in some way.

A good guess is that wireless multimedia will be popular and widely used in the future because of its great advantages. Several networks must be able to coexist close to each other. A wireless network located in a tall building can easily be heard a long distance. In a business complex, many companies may use networks operating on the same frequency band. This puts the research in Radio Resource Management (RRM) in focus. To utilize the scarce radio spectrum in future Mobile communication systems better, there is a need to use the available Radio resources (transmitter powers, channels and base stations) in a more efficient way. Different wireless services require different quality of service, such as delay, data rates and error rate. Differences in quality of service must be handled in multi-service communication systems and centralized systems were used as a solution. In [1-2], locally centralized (bunched) RRM concept is presented. The system is proposed as a solution for the requirements of difference in quality in multi-service communication systems. The proposed system appeared to have a low capacity especially in indoor environments [3-4]. This paper investigates the use of Woodward-Lawson beam forming technique to design a sector antenna, which can be used in the locally centralized communication system in an indoor environment to improve the system capacity. Sector antennas have shown to perform well in indoor scenarios [5-7]. The systems in [5] and [6] have architectures with only one base station and do not consider co-channel interference. The sector antennas in [7] are constrained to transmit on one sector at a time. This paper studies a dense indoor architecture with the ability, by the beam forming technique used, to transmit on every sector simultaneously on different channels.

2. The Bunch Concept

The bunch concept [1] consists of a Central Unit (CU) connected to a cluster (bunch) of Remote Antenna Units (RAUs), see Fig (1). A RAU can be either a base station or just a radio head that transmits the RF signal. The area that the RAUs cover is called a *bunch*. The central unit controls and manages the radio resources in the bunch system. The RRM in a bunch relies on the knowledge that the CU has about the system in combination with a signal to interference ratio (SIR)-based power control.

A lot of overlap between cells is quite common in micro-cells and especially indoor pico-cells. This overlap makes it difficult to predict interference between cells and thus a lot of resources are usually wasted when channels are assigned. To improve the trunking efficiency in such a case, we would like to share the resources better between cells. This is the primary application for the bunch concept. A bunch can cover for instance a group of streets and buildings where the traffic intensity is high. Since the interaction between CUs is very limited, interference caused by other bunches cannot be properly controlled. Other actions must therefore be taken to handle the inter-bunch interference. Smart selection of channels can be one way.

3. Resource Management Algorithm

The resource management algorithm can be divided into four parts. They are; the RAU *selection*, which finds the most suitable RAU. In this study, it is only considered the case when the terminals are connected to the strongest RAU (e.g. with the lowest path loss); *Channel Selection*, which selects resources to try. The Channel Selection determines the order in which to test the available channels in an RAU for feasibility. More or less complex algorithms can be used to find a channel. They can for instance be based on measurements, central calculations or just picked at random.

If no channel is available at the selected RAU, the resource request is blocked; *Feasibility Check*, which calculates if the selected resources can achieve an acceptable quality (SIR) without disturbing the existing users; The task of the feasibility check is to protect the existing links and users in the system from a quality drop when a new resource is allocated. Calculating the effect of an allocation before it is actually performed does this. Data of the current system situation is continuously gathered and stored centrally. From these data, all link gains are calculated from all RAUs to every terminal in the system and the result is stored in the *link gain matrix*, [8]. This matrix is used in the calculations to ensure that the selected channel is feasible. A channel is feasible if both existing and new links can meet their specified SIR targets. An example of G-matrix construction is shown in Fig. (2) where the link gain from terminal (i) to RAU (j) is denoted with (g_{ij});

Initial power algorithm, which decides what transmitter power the new and existing connections should have, in order to have an acceptable value of SIR without causing interference with the previously admitted users.

4. Bunched Resource Management

After the user has been connected to an RAU, he requests a resource, and a channel is first selected by the channel selection method. The powers and gain values are then used in the feasibility check as follows: in a system with (M) co-channel users, the SIR for mobile *i* is given by [9]:

$$\gamma_i = \frac{p_i\, g_{ii}}{\sum_{j=1, j\neq i}^{M} p_j\, g_{ij} + N_i} \qquad \ldots(1)$$

i = { 1, 2, … M }

where p_i is the power transmitted by mobile *i'* s station, g_{ij} is the link gain from mobile *j*'s base to *i*, and finally N_i is the thermal noise in the receiver (*i*) plus any inter-bunch interference.

Equation (1) can be written as:

$$\gamma_i = \frac{p_i}{\sum_{j=1}^{M} p_i\, a_{ij} + \eta_i} \qquad \ldots(2)$$

where the M * M matrix (**A**) is defined by;

$$a_{ij} = \begin{cases} 0 & if\ i = j \\ g_{ij} / g_{ii} & otherwise \end{cases} \quad ...(3)$$

and finally;

$$\eta_i = \frac{N_i}{g_{ii}} \quad ...(4)$$

From equation (2), we get:

$$P_i = \gamma_i \left(\sum_{j=1}^{M} P_j a_{ij} + \eta_i \right) \quad ...(5)$$

Now solving for the power vector (***P***), we get an equation on matrix form:

$$P = (\lambda - A)^{-1} . \eta \quad ...(6)$$

where the M*M matrix (λ) is defined by;

$$\lambda ij = \begin{cases} \frac{1}{\gamma_i} & if\ i = j \\ 0 & otherwise \end{cases} \quad ...(7)$$

Equation (6) can be solved directly with Gaussian Elimination in order to get the power levels. The allocation is feasible if all of them are positive and below the maximum power limit. Things get a bit more complicated when the dynamic range of the power levels is limited. In this case, we cannot be sure that the allocation is feasible unless;

$$P_{\min} < P_i < P_{\max}, \quad ...(8)$$

If the minimum power ($P_{\min}$) is strictly greater than zero (limited dynamic range of the power control) Gaussian Elimination is not suitable. In this case, we have to restore to linear programming techniques such as the Simplex Method [10] which is used in this work.

The power control test runs with all the co-channel users to find out if all their SIRs can be maintained. If the channel was feasible, all the powers of the affected users are adjusted and the new user can be admitted, otherwise another channel is tested with the procedure repeated.

5. Models and Assumptions

The models for this investigation, the bunch concept in an indoor environment, are the similar to the office models given by ETSI (European Telecommunications Standards Institute) to evaluate the different UMTS (Universal Mobile Telecommunications Systems) proposals [11]. One difference between the ETSI models and the one used here is the use of mobility for the terminals. It is assumed here that the advantage of high-speed wireless access to a fixed network is more a matter of freedom of location than freedom of mobility so no mobility will be modeled in this work.

The investigations in this work are done with snapshot simulations using MATLAB. In this section, the models and performance measures used in these simulations will be described.

5.1 Indoor Office Scenario

The scenario is one-floor building with offices and corridors. The office cubicles are separated by concrete walls. One office is 10 by 10 by 3 meters and the corridors are five meters wide. An RAU is placed in every second office as can be seen in Fig. (3). The RAUs are installed at the ceiling level and the terminals are assumed to be on 1.5 meters above floor level. The number of RAUs is assumed to be (20).

5.2 Radio Wave Propagation

The path loss model, which is used to form the gain matrix, is based on the COST 231 model [11] and is simplified as:

$$L_p[dB]=37+30Log(R)+18.3\times n^{\left[\frac{n+2}{n+1}-0.46\right]}+X_\sigma \quad \ldots(9)$$

where R is the transmitter-receiver separation given in meters, n is the number of floors in the path between them, n =0 in this work, and X_σ is the added shadow fading. The shadow fading has a log-normal distribution with a standard deviation of 12 dB. The high standard deviation of the shadow fading is a result of the partitions that are separating the offices. These partitions create a large degree in signal variation. Perfect knowledge of the link gain matrix is assumed, i.e. all the path losses between the base stations and mobiles are known.

5.3 Traffic Model

A very simple traffic model is used for the investigations performed in this work with a constant number of active users in the building. The number of users equals the load times the number of RAUs and the number of available channels in the system. This generates a binomial distribution of the number of users per cell. Since all users are active in the system and the number of cells is relatively large, the number of active users per cell can be approximated with a Poisson distribution [12]. Poisson distributions are often used to model the traffic with speech communication in cellular systems. Even if the traffic in future wireless high-speed networks will be dominantly data traffic, the model is adequate for snapshot simulations.

5.4 Performance Measures

In most cases, the *relative load*, $\overline{\omega}_c$, is used to present the different performances. The relative load is defined as the fraction of C requested channels in a cell, which results in $(C.\overline{\omega}_c)$ users per cell on average. The *assignment failure rate* v is the fraction of users that did not get a feasible channel (blocking) or got a channel that had to low quality (outage) to meet the specified SIR-target.

The instantaneous capacity $\omega(v_o)$ is defined as the maximum allowed load in order to keep the assignment failure below a specified threshold v_o.

$$\omega(v_o)=\{\max \omega : v \le v_o\} \quad \ldots(10)$$

We define capacity ω as the load where $v_o = 0.02$ [11]. The capacity in a communication system is closely related to the income that can be generated to make a profit for the investors. The investments made have to be paid for and more users mean in general more money. The selection of 2 percent assignment failure is from the UMTS goal of 98 percent satisfied users. The capacity can then easily be read from the graphs of the results as the load where the assignment failure plots cross the 2% assignment failure line.

Another performance measure used in the work is the *CDF* of the transmitter powers, where CDF is the Cumulative Distribution Function. The CDF is defined as the probability of the event $\{P \le p\}$. That is, it is the probability that the random variable P takes on a value in the set $(-\infty, p)$.

The CDF of the transmitter powers is plotted for a specific load, which is normally set to the center load in a simulation. Several benefits come from transmitting with low powers. Wireless systems that operate in the same frequency spectrum will interfere less with each other using lower powers. This will enhance the coexisting capabilities of the systems. From the distribution, one can also see the power control range that is needed to maintain the capacity. A large dynamic power control range requires very advanced transmitters, especially in the downlink. Transmitting multiple signals with different powers requires linear amplifiers in order not to cause damaging intermodulation products in the combined signal.

5.5 Snapshot Simulations

As a basis for the performance evaluations, lie snapshot simulations where only the downlink is considered. For every simulation, the minimum number of users is set to (5000) and the number of channels available at every RAU is 36 (with reuse 1). At a load of 0.5, on average 36×0.5 = 18 users are requesting a channel on every RAU. The adjacent channel interference is neglected.

At a total of 20 RAUs, we then have (20×18 = 360) users. To meet the minimum (5000) users that are required for every simulation, (14) iterations are used for the load 0.5. All iterations are considered uncorrelated, i.e. the users are regenerated and distributed over the building with new link gains calculated. There is no correlation between the different links in the system and we consider the path loss from one RAU to one user to be the same for all possible channels. If sector antennas are used, the sectors are treated as separate RAUs, i.e. the links from a user to sectors located at the same place can have different shadow fading.

The users are assigned the strongest RAU and they request one channel each. The channel requests are processed one by one until there are no requests left. One by one, the available channels are tested for feasibility at the assigned RAU. Once a feasible channel is found, that channel is assigned to the requesting user and the next request is processed. In addition, when the allocation is made, the powers of all co-channel users are adjusted so that their SIR targets are maintained. The SIR-targets are set to 10dB for all connections [11]. The transmitter powers are bounded between (1 mw) and (1 w) giving a dynamic range of 30dB. If we could not find a feasible channel or if the RAU has no available channels, the request is considered a failure. All assignment failures are added up and used as a performance measure. There is no dropping of a user from the system. Once a connection has been established, it is kept during the current iteration of the simulation. The users are also considered static (no mobility) during an iteration and they are distributed evenly over the area with the exception that the probability is 0.85 of being located in the office and 0.15 in the corridor [11].

The 95 percent confidence interval for the assignment failure v can be approximated with [11];

$$v = v' \pm 1.96\sqrt{\frac{v'(1-v')}{u}} \qquad \ldots(11)$$

where v' is the average assignment failure and u is the number of users. With v' = 0.02 and u = 5000, the assignment failure becomes 0.02 ± 0.0038. The probability for v = 0.02 to lie in the interval [0.016 -0.024] is 95 percent. The number of users used in the simulations is therefore considered large enough.

5.6 FCA Comparison

When the bunch concept is evaluated, DCA system is usually assumed to be used. The performance will be compared with Fixed Channel Allocation (FCA). To implement FCA, the feasibility check is ignored when assigning a new user. This means that a channel is used at the selected RAU regardless of the interference the allocation might cause to other users. In an FCA system, the interference can be lowered by splitting the resources between the base stations. In the FCA implementation, the power control is still in use and the mobiles are still connected to the strongest RAU.

Two methods are used for splitting the channels with FCA. The first method is to split the channels between the RAUs. The channels are split into clusters over the area like in Fig. (3). The second method is used when beam forming is used to design sector antennas. In this case, the channels are split between the sectors and not between the RAUs.

6. Antennas Beam forming

Let us now investigate beam forming as a means to reduce the co-channel interference and increase the capacity. The cell is broken into wedges and the available channels are split between multiple antennas with special radiation pattern, which is called a sector antenna. This split reduces the trunking efficiency compared to non-sectoring. The investigation will find out if this decrease is compensated by the fact that the number of interfering co-channel users is reduced at the same time. Reduction in the number of co-channel users will increase SIR and therefore lower the transmitted power. Frequency reuse between sectors could be implemented but left for future studies. The available channels are divided between the sectors, e.g. the channels in a non-sector system are split into 18 channels per sector in a two-sector system. This will reduce the trunking efficiency of the system but also the number of strong co-channel users that produce interference. The investigation will be made with one floor building. Antenna beam forming problem will be posed as one of determining the excitation of a given antenna type that leads to a radiations pattern which suitably approximates a desired pattern. The desired pattern can vary widely depending on the application. In this work, the desired pattern is a sector type.

A sector pattern is a shaped beam pattern that ideally has uniform radiation over the main beam (a sector of space having a beam width $2\theta_0$) and zero side lobes. The desired radiation pattern of this antenna is:

$$f_d(\theta)=\begin{cases}1 & -\theta_0 \le \theta \le \theta_0 \\ 0 & elsewhere\end{cases} \qquad \ldots(12)$$

or equivalently:

$$f_d(w)=\begin{cases}1 & |w| \le c \\ 0 & \text{elsewhere}\end{cases} \qquad \ldots(13)$$

where $c = \cos\theta_0$.

Generally, antenna beam forming methods can be classified into three categories [13]. The first group that normally utilizes the Schelkunoff method requires the antenna patterns to possess nulls in certain desired direction. The next category, which requires the patterns to exhibit a desired distribution in the entire visible region, can be achieved by using the Fourier transform, Fourier series and Woodward-Lawson methods. Finally, the Binomial Technique and Dolph-Chebyshev method are usually used to produce radiation patterns with narrow beam width and low side lobes. However, only the Woodward-Lawson method will be used in this work as it produces the lowest side lobe with minimum ripple in the pass band and these characteristics are required in the application of this work.

Before presenting Woodward-Lawson method, the array configuration will be modeled for use with this method.

Consider an equally spaced linear array along the Z-axis with interelement spacing (d). For simplicity, the physical center of the array is located at the origin. The total number of elements in the array (E) can be either even (then let E = 2N) or odd (then let E = 2N +1). For an odd element number, the elements location is given by [12];

$$Z_m = md \qquad |m| \le N \qquad \dots(14)$$

For an even number of elements, the elements position is;

$$Z_m = \mp\frac{2m-1}{2}d \qquad 1 \le m \le N \qquad \dots(15)$$

The total array length is L = Ed.

Using the Woodward-Lawson method, the synthesized array factor is the superposition of array factors from uniform amplitude, linear phase arrays:

$$f(w) = \sum_{n=-N}^{N} a_n \frac{Sin\left[(E/2)(w-w_n)(2\pi/\lambda)d\right]}{ESin\left[\frac{1}{2}(w-w_n)(2\pi/\lambda)d\right]} \qquad \dots(16)$$

where (λ) is the wavelength. The sample values are;

$$a_n = f_d(w = w_n) \qquad \dots(17)$$

and the sample points are;

$$w_n = n\lambda/Ed = \frac{n}{L/\lambda} \qquad |n| \le N, |w_n| \le 1 \quad \dots(18)$$

The element currents required to give this pattern are found from:

$$i_m = \frac{1}{E}\sum_{n=-N}^{N} a_n \; e^{-j2\pi(Z_m/\lambda)w_n} \quad ..(19)$$

In this equation all values of (Z_m) from equation (15) are taken into consideration. These results hold for arrays with either an even or odd number of elements.

Let us now use Woodward-Lawson method to design sector antennas with different beam widths. Assuming a 20-element, half wavelength spaced linear array and using equation (15), element positions can be found. With the help of equations (17-19), the array currents can be calculated, see Table (1).The resulted patterns are shown in Fig. (4). The side lobe level is about (-30dB) and the ripple in the pass band is approximately (0.3 dB).

7. Results of Computer Simulation

The sector antennas designed using Woodward-Lawson method will now be used in a locally centralized communication system in an indoor environment and their effects on the overall performance will be studied.

The sector antenna will be assumed to have a sector pattern in the azimuth while the pattern is omnidirectional in the elevation. With an almost constant gain pattern (over a sector), the position of a mobile determines which sector it is located in. In, for example a three-sector system, we will have three possible links from a mobile to a site with sector antennas. In the simulations, these links are independent and treated as if transmitted from different RAUs located at the same position. The only difference is that the load is related to the whole site, i.e. there are equal numbers of users in systems both with and without sectoring at a specific load.

Using the previously discussed algorithms with MATLAB, the following results are obtained. In Fig. (5), the capacity for systems with different number of sectors (N.sec), as well as when using the omnidirectional antenna (Omni), are shown assuming Dynamic

Channel Allocation (DCA). There is a large capacity increase for a two-sector system compared with a non-sector system, i.e. a system that uses omnidirectional antennas. The capacity is 0.65 compared with 0.47; a 35 percent improvement. A further increase in the number of sectors does not improve the capacity. A narrower antenna beam does not necessarily mean a better performance in a single bunch system.

In Fig. (6), the effect of beam forming on the capacity improvements for FCA system is shown. For FCA, the increase is large because of the poor performance without sectoring. The co-channel interference is reduced with increased number of sectors and the trunking loss, due to fewer channels per sector, is lower than the gain from the reduction in interference. Even for twelve sectors this is true. The capacity is increased from 0.06 to 0.35, i.e. about 500 percent increase in the capacity, with a twelve sector-antenna system compared with an omnidirectional system. This improvement really marks out the problem FCA has with the co-channel interference without using sector antennas. The comparison between the high performance of DCA and the low performance of FCA systems can be seen clearly in Fig. (7).

Another important benefit from using sector antennas can be seen by studying the distribution of transmitter powers. More sectors result in lower transmitter powers. Fig. (8) shows the CDF of transmitter powers for different number of sectors at the load 0.5. Clearly, increased number of sectors reduces the power control range needed for serving the users. About 78 percent of the users transmit with minimum power when using six sectors while only 30 percent when omindirectional antennas are used.

Let us now investigate the system performance when external and uncontrolled interference is present. This is important if the capability of coexistence in a wireless network is desirable. Instead of having one single bunch covering the building floor, two bunches are used. It is assumed that the two bunches use the same channels. Of the twenty RAUs located on the floor, see Fig. (3), the ten leftmost RAUs belong to one bunch and the ten rightmost RAUs to another bunch. Using the previously discussed algorithms with MATLAB, variation of the assignment failure with the relative load can be predicted. It is shown in Fig. (9). The system performance appears to be lousy without beam forming and the capacity is as low as (0.11). With beam forming, the capacity can be increased to (0.45) when using six sectors, so (4) times the load can be carried at (2%) assignment failure compared with a system using omnidirectional antennas. The effect of channel blocking when too many sectors (narrow antenna beam width) are used at the base stations can be seen in Fig (9).

8. Conclusions

The important conclusion that can be drawn from the simulations carried out in this work is that antenna beam forming techniques can be used to improve the capacity of a locally centralized indoor communication system. The improvement is larger for systems that do not handle the co-channel interference well enough without sectoring, such as the FCA system. The peak performance for the bunch system is with two sectors when using DCA, while it is at six sectors with FCA.

Another real benefit from using beam forming is the reduced transmitter powers that sector antennas result in. Narrower beam width, i.e. more sectors mean fewer co-channel users and therefore lower transmitter powers. The necessary dynamic range of the power control can therefore be kept smaller.

The results also show that antenna beam forming is suitable when several wireless networks operate close to each other. The load that can be offered increases by four times if six-sector antennas are used in a building floor covered by two systems using the same channels as compared to the use of omnidirectional antennas.

9. References

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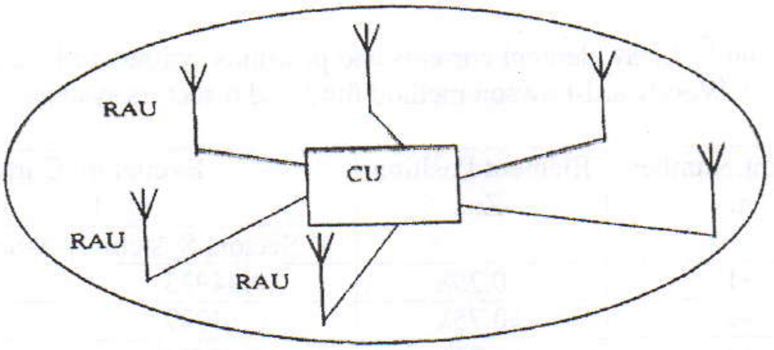


Fig.1: The Bunch concept with the Central Unit (CU) and the Remote Antenna Units (RAUs).

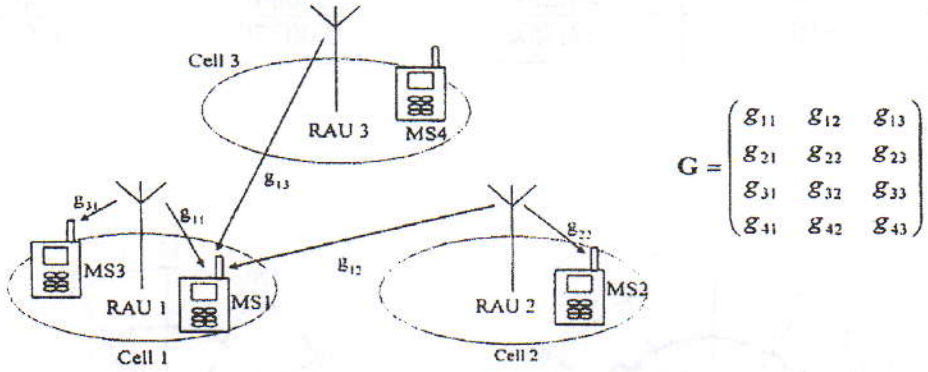


Fig.2: Construction of the Gain Matrix [8].

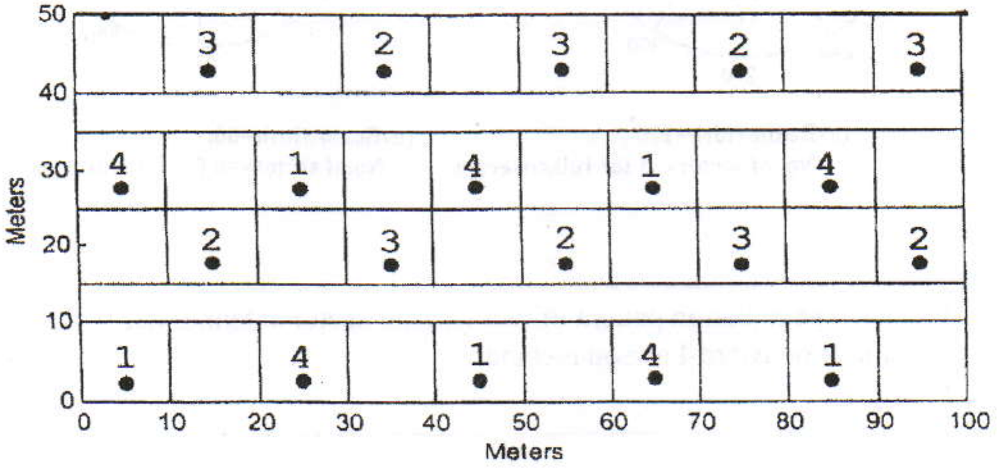
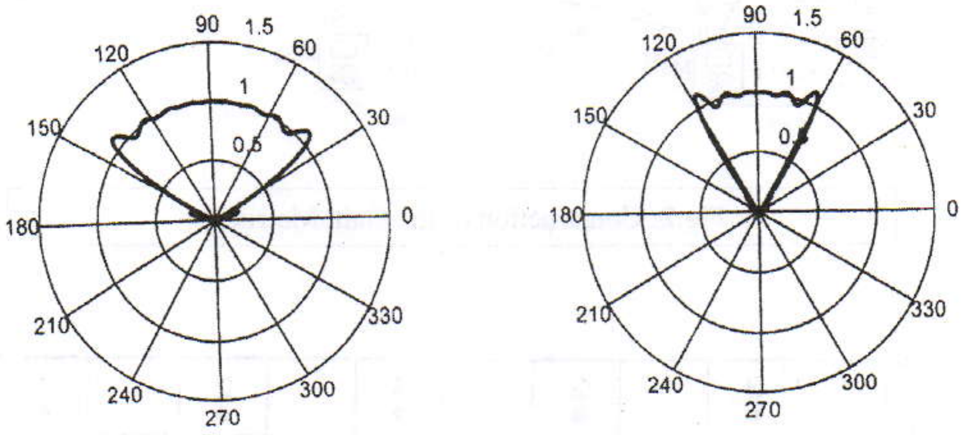


Fig.3: One floor in the indoor office environment with 20 RAUs Represented by the filled circles. Channel group numbering when using FCA with a cluster size of four is also shown.

Table 1: Array element currents and positions synthesized from the Woodward-Lawson method for 3 and 6 sectors systems.

Element Number m	Element Position Zm	Excitation Current Im	
		6-Sectors System	3-Sectors System
±1	±0.25λ	0.44923	0.6197
±2	±0.75λ	0.14727	-0.1629
±3	±1.25λ	-0.08536	0.0500
±4	±1.75λ	-0.05770	0.0075
±5	±2.25λ	0.04140	-0.0402
±6	±2.75λ	0.03020	0.0561
±7	±3.25λ	-0.02167	-0.0585
±8	±3.75λ	-0.01464	0.0500
±9	±4.25λ	0.00849	-0.0334
±10	±4.75λ	0.00278	0.0117



**(a) Beamwidth=120°,
No. of sectors=3 for full coverage**

**(b)Beamwidth=60°,
No.of sectors=6 for full coverage**

Fig.4: The radiation pattern of two types of sector antennas designed using Woodward-Lawson method.

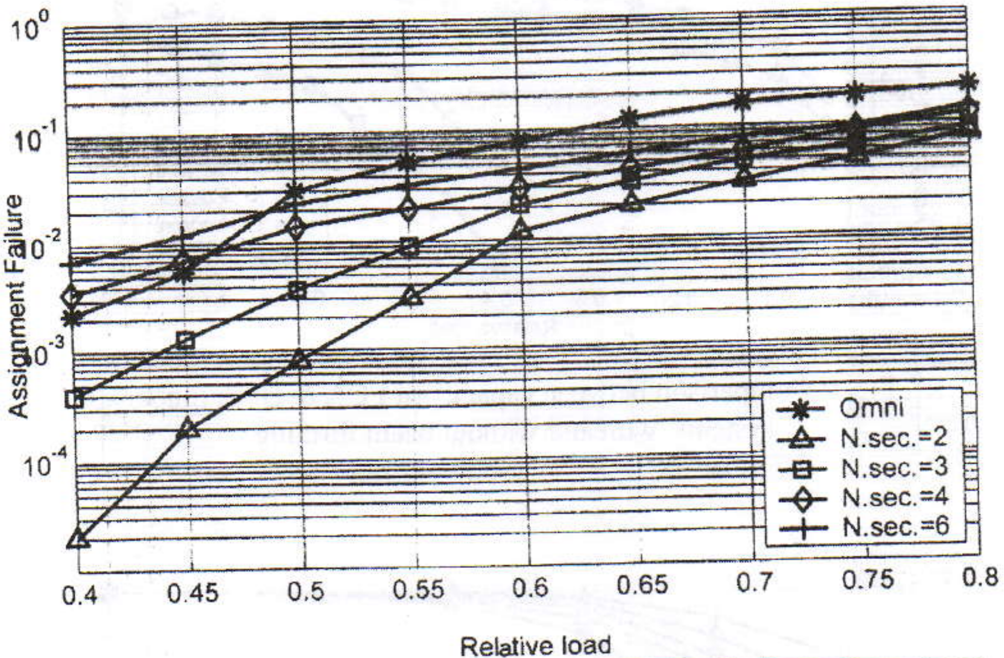


Fig.5: Effect of beamforming on the capacity of indoor wireless system assuming dynamic channel allocation (DCA).Omni; refers to omnidirectional antenna, N.sec.; refers to number of sectors.

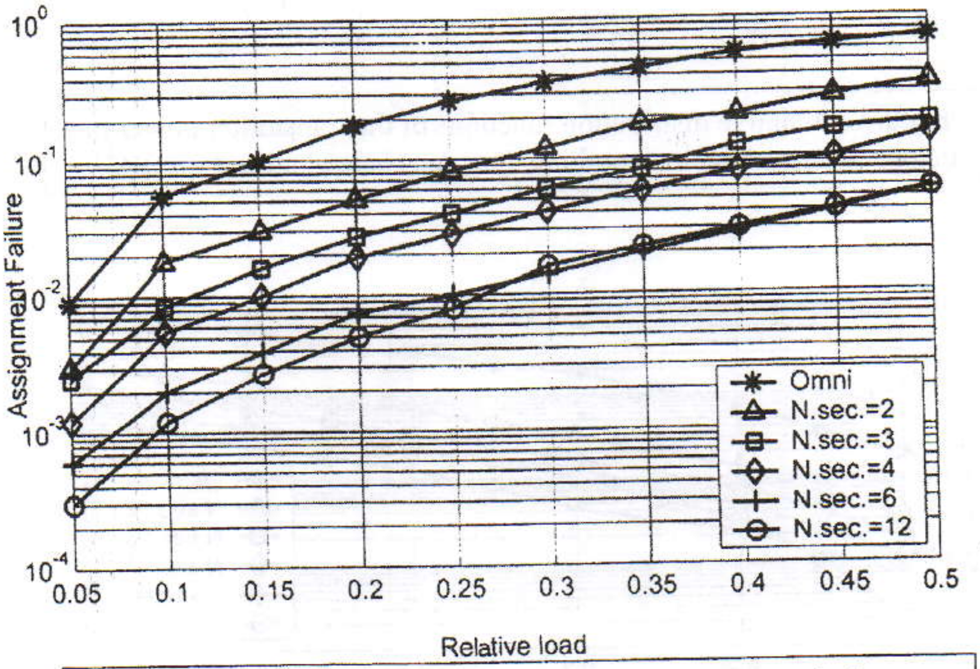


Fig.6: Effect of beamforming on the capacity of indoor wireless system assuming fixed channel allocation (FCA).

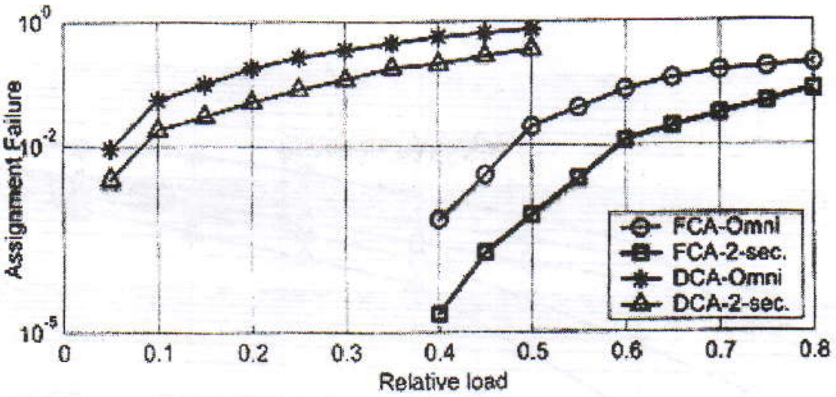


Fig.7: Comparison between capacity of FCA & DCA indoor systems, with and without beam forming.

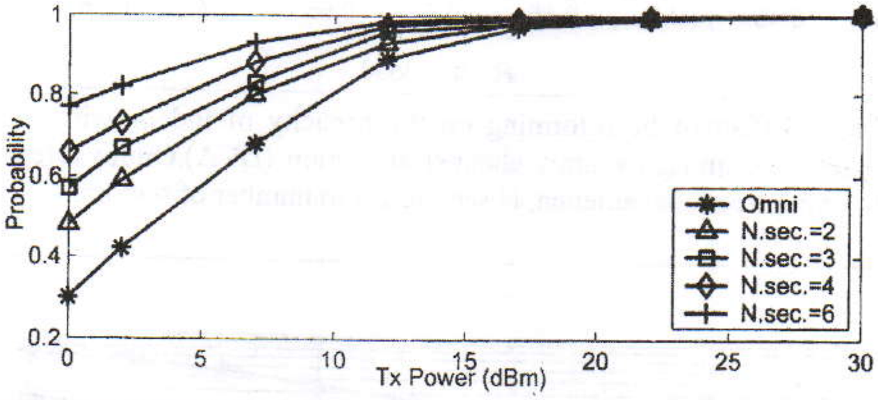


Fig.8: Cumulative distribution functions of the transmitter power for indoor wireless system, assuming dynamic channel allocation (DCA).

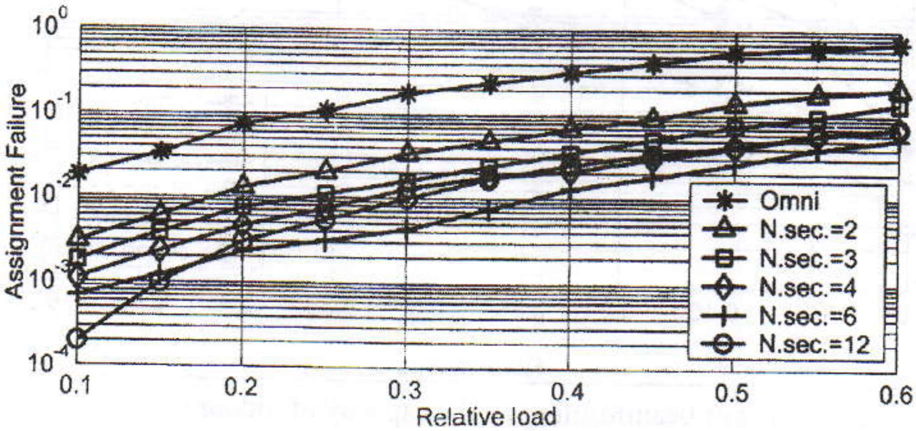


Fig.9: Effect of beamforming on the capacity of indoor wireless system assuming two bunches covering one floor and DCA.