# Smaller Cells for Greater Performance

## A new microcell architecture that reduces interference, increases system capacity, improves voice quality, and demands fewer handoffs is ideally suited for PCS systems

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The Advanced Mobile Phone Service (AMPS) cellular system at 850 MHz, as used in North America, is a high-capacity system. Its spectrum utilization is based on the frequency re-use concept, in which a frequency can be re-used repeatedly in different geographical locations. Various locations using the same frequencies are called cochannel cells.

The minimal separation ($D_S$) required between two nearby cochannel cells is based on specifying a tolerable cochannel interference, which is measured by a required carrier-to-interference ratio $(C/I)_S$. The $(C/I)_S$ ratio also is a function of the minimum acceptable voice quality of the system. In an AMPS system, $(C/I)_S$ is equal to about 18 dB (the point at which 75 percent of the users call the system "good" or "excellent"), and the minimal required separation $D_S$, based on $(C/I)_S = 18$ dB, is about 4.6R, where R is the radius of the cell. In a cellular system, the number of cells K in a cell re-use pattern is a function of the cochannel separation $D_S$. For $D_S = 4.6R$, then $K = 7$. This means that a cluster of seven cells can share the entire allocated spectrum. In each of the two bands allocated for cellular, there are 395 voice channels; each cell can have 57 channels on average.

In 1991, the conventional cellular systems in use since 1984 began to reach their capacity in the larger markets. In order to increase system capacity, we may take approaches based on what will be called the cochannel interference reduction factor (CIRF), $q_S$, which is defined as [1]

$$q_S = D_S / R \overset{\Delta}{=} \sqrt{3K} \qquad (1)$$

$D_S$ is the minimum required distance between any two cochannel cells in a cellular system (see Fig. 1a) where $D_S$ is corresponding to the required carrier-to-interference ratio (C/I) received at both the cell site and the mobile unit in a cell. R is the cell radius, K is the number of cells in a cell re-use pattern. K is also called cell re-use factor. The three approaches for increasing capacity are stated as follows. The first two are conventional approaches; the third one is the new approach. Equation (1) is derived from an idealized hexagonal cell layout and is commonly used.

- Split cells. In this approach, capacity can be increased by reducing R but keeping $q_S$ unchanged as in Equation (1) (shown in Fig. 1b), i.e., rescaling the system. When R is smaller than one mile or one kilometer, the cell is commonly called a microcell. As a first-order approximation, every time R is reduced by one half, capacity increases by four. The measurement of capacity in this approach is the number of channels per square kilometer. The cell splitting approach leads to an increase in radio capacity [2]. Splitting cells is system scale independent, i.e., the value of $q_S$ remains unchanged. This approach can be used in any analog or digital system.
- Reduce the cell re-use factor (also called "a reduction of the required D/R" approach). In this approach, we seek to increase capacity by determining methods by which D can be reduced, i.e., forming a new configuration, but keeping R unchanged in Equation (1) (shown in Fig. 1c). Therefore, $q_S$ can be reduced, and thus is the cell re-use factor K, as shown in Equation (1). The value of $D_S$, however, is a function of the required $(C/I)_S$. For example, if a new cellular system can achieve a frequency re-use factor of $K = 3$, then the capacity of the new system can be obtained by comparing it with the AMPS system of $K = 7$. Since K is reduced from $K = 7$ to $K = 3$, the capacity is increased by $7/3 = 2.33$ times. The measurement of radio capacity in this approach is the number of channels per cell.

$$m = \frac{\text{total voice channels}}{K} \qquad (2)$$

The reduction of the cell re-use factor approach would increase radio capacity m, as shown in Equation (2).

In the past, sectorization was used to reduce the value of K in an analog system. When the cochannel interference in a cell increases, either a three-sector or six-sector cell configuration should be used in order not to expand the required cochannel cell separation $D_S$. In other words, with a given interference, the sectorization seems to be able to reduce

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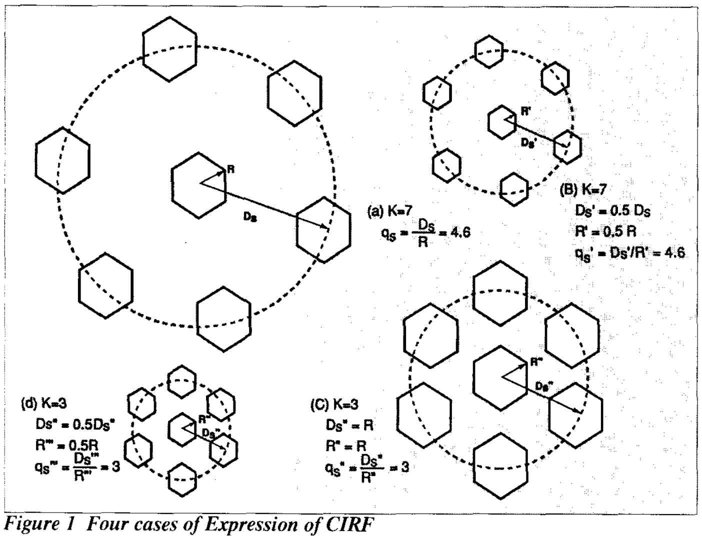

*Figure 1 Four cases of Expression of CIRF*

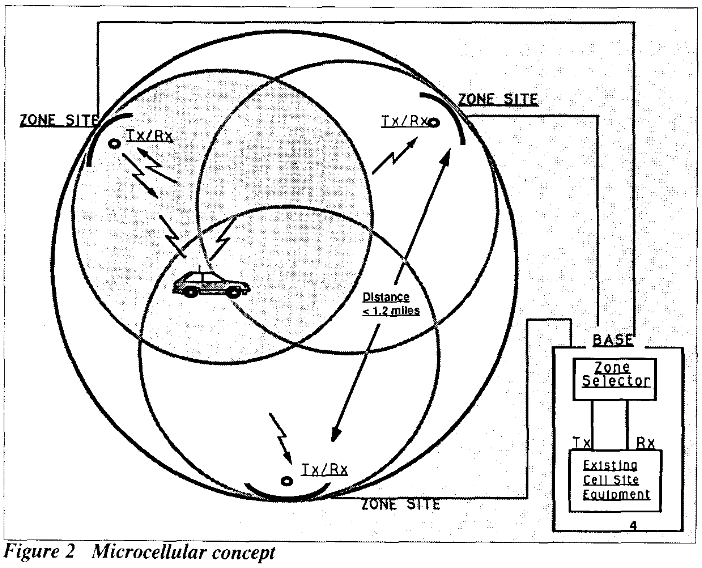

*Figure 2 Microcellular concept*

the value of $D_s$. However, when we take a good look at sectorization, the method of assigning a set of frequency channels in each sector is the same as if assigned in a cell. The handoffs occur as the vehicle passes among the sectors, the same as among cells. Therefore, if in a K = 7 system of three-sector cells, the number of channels per sector, assuming a total of 395 voice channels, is

$$\frac{395}{7\text{x}3} = 19 \text{ channels/sectors}$$

In a K = 4 system of six-sector cells, the number of channels per sector is

$$\frac{395}{4\text{x}6} = 16 \text{ channels/sectors}$$

From the above two values, there is not much difference in radio capacity between the two cellular configurations. In order to gain further capacity by using the splitting cells concept as stated in the split cells approach, the size of each sector can be reduced. The problem for the sectorization is that the trunking efficiency of the utilized channels decreases. The cell usage with the same number of channels in an omni cell is much higher than that of a sector cell. Therefore, sectorization is not an effective method of reducing $q_s$.

- Reduce the required D/R by a new microcell approach. The concept of the new microcell system is shown in Fig. 1d. In this case, not only the cell radius reduces, but the CIRF also reduces. Furthermore, there is no degradation in trunking efficiency; it is a true K = 3 system. The advantages of this system include both reduction of cochannel interference and confining the cochannel interference relative to the signal to a small area. It will be described in the following section.

## Description of New Microcell System Design

Generally this new microcell consists of three zones, as shown in Fig. 2[4]. (It can be more than three zones when needed.) Each zone has a zone site, and one of the three zone sites usually is colocated with a base site. All radio transmitters and the receivers that serve a microcell are installed at the base site. Every zone site physically shares the same radio equipment installed at the base. To serve a vehicle from a zone site, an 800 MHz cellular signal can be up-converted to a microwave or optical signal at the base and then down-converted back to an 800 MHz signal at the zone site to serve the vehicle at that zone as if the vehicle is located at the base.

Conversely, the received cellular signal, after boasting with a low-noise amplifier at a zone site, can be up-converted to either a microwave or optical signal, then down-converted to 800 MHz at the base. In this case, the zone site only requires an up/down converter, power amplifier and a low-noise broadband pre-amplifier, which is easy to install because of the small size and the light weight of the zone-site apparatus.

**Signal coming from mobile unit.** A mobile unit driving in a microcell sends a signal. Each zone site receives the signal and passes it through its up/down converter, up-converting the signal and sending it through either the microwave or optical signal medium, then down-converting the signal at the base site. Thus, the mobile signals received from all zones are sent back to the base site. A zone selector located at the base site is used to select a proper zone to serve the mobile unit by choosing the zone having the strongest signal strength. Then the base site delivers the cellular signal to the proper zone site through its up-converting processing.

**Signal coming from base site.** The proper zone site receives the cellular signal from the base site through a down-converting process and transmits to the mobile unit after amplification. Therefore, although the receivers at three zones are all active, only the transmitter of one zone is active in that particular frequency to serve that particular mobile unit. When the mobile unit is moved from zone to zone, the assigned channel frequency remains unchanged. The zone selector at the base site simply shifts the transmitting signal (base-to-mobile) from one zone to another zone according to the mobile unit's location. Only one active base-transmitting zone at one time is serving a vehicle (one assigned frequency) in a cell. Therefore, no handoff action is needed when the mobile unit is entering a new active zone.

## Analysis of Capacity and Voice Quality

In order to prove the increase of capacity and the improvement of voice quality in this new microcell system as shown in Fig. 1d, we may calculate the cochannel interference reduction factor (CIRF), $q_S$, which is a key element in designing the cellular system. In the conventional macrocell system, $q_S$ is used for taking care of both the voice quality and the capacity since they are related. In this microcell system, which is different from the macrocell systems, there are two CIRFs to be considered. One CIRF $q_{S1}$ is used to measure the voice quality and the other, CIRF $q_{S2}$, is used to measure the radio capacity, because in this microcell system the voice quality and the capacity are measured differently. The microcell system is shown in Fig. 3.

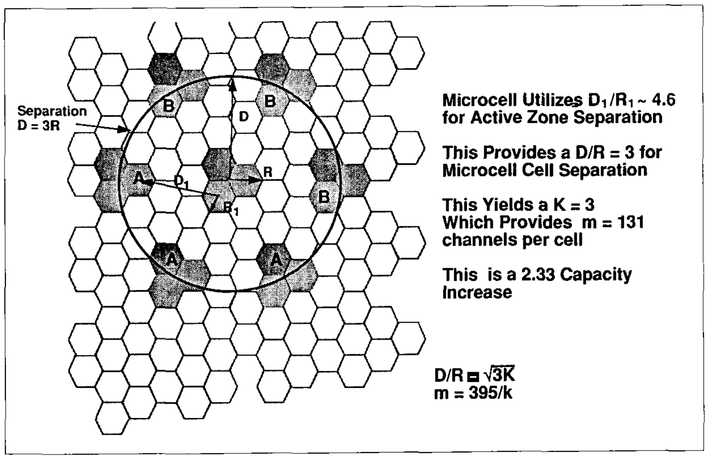

*Figure 3. Microcell application*

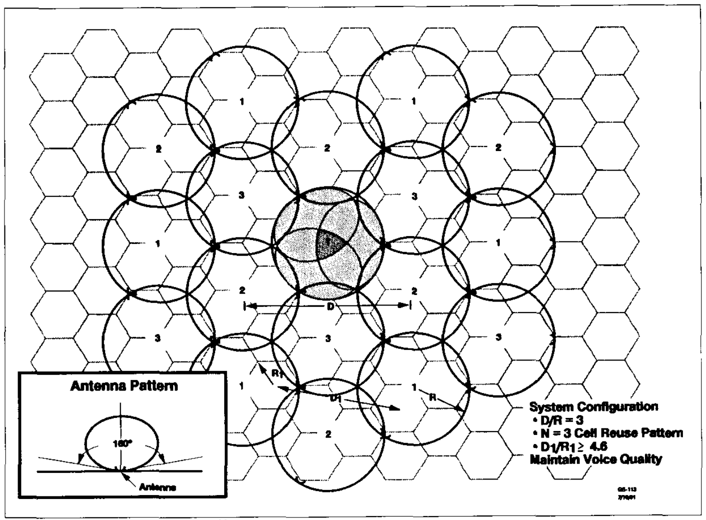

*Figure 4. A K-3 microcell system*

**The CIRF between two active base transmitting cochannel zones.** This is a new CIRF $q_{S1}$ defined as $q_{S1} = D_1/R_1$, where $D_1$ is the distance between one active zone in one microcell and the corresponding active zone in the other microcell, as shown in Fig. 3. $R_1$ is the radius of each zone. Although the antenna is mounted at the edge of each zone, the real coverage area of each zone is used for estimating interference. Therefore, the radius $R_1$ of a real coverage area is used to confine the zone area.

There are many values of $q_{S1}$, depending on which two active cochannel zones are considered. Among them, the two closest cochannel active zones are the worst case to be used for measuring CIRF, $q_{S1}$. As we know, in an AMPS system, C/I has to be 18 dB, thus implying that $q_S$ must be 4.6 in order to maintain an acceptable voice quality when using 30kHz analog FM radios. In the AMPS system, the earlier simulation shows that $q_{S1} = 4.6$ was adequate for omni-directional cells [5].

When the cell site antenna height is normally 100 ft. to 150 ft. high and the ground is not flat, however, the cochannel interference received on the reverse link (mobile-to-base) is larger than expected. Therefore, a sectorization architecture was introduced for the macrocells. In a microcell system, the microcell antenna height is always lower than 100 ft., normally 40 ft. to 50 ft., and generally the ground in a small area around the antenna is flat. Under this condition the cochannel interference on the reverse link is reduced, and the sectorization arrangement becomes unnecessary for a K = 7 system configuration. This is supported by measured data. Since the same radios are used in the microcell system, $q_{S1}$ has to be at least the same as 4.6 in order to be back on the K = 7 configuration.

By construction, it is shown that the $q_{S1}$ of the two closest cochannel active zones in their corresponding microcells is 4.6, as shown in Fig. 3. In this microcell, normally, the $q_{S1}$ between any two active zones in two corresponding cochannel microcells is always equal or greater than 4.6, as shown in Fig. 3. It is proven that the voice quality in this microcell system based on $q_{S1} \geq 4.6$ is equal or better than the voice quality of AMPS system. This $q_{S1}$ is used to measure the voice quality only in the new microcell system.

**The CIRF between two cochannel microcells.** The radio capacity is based on the separation of two neighboring cochannel cells. In the microcell system, the CIRF, $q_{S2}$ is defined as $q_{S2} = D/R$ where D is the distance between two cochannel microcells and R is the microcell radius as shown in Fig. 3. In this case $q_{S2} = D/R = 3$, equivalent to K = 3 shown in Equation (1). The three zones per microcell and the K = 3 system is illustrated in Fig. 4. The antenna pattern for each zone coverage is 160°, as depicted in Fig. 4. Thus, the entire cell is covered. Since K is reduced from K = 7 of the AMPS system to K = 3, the microcell system has increased 7/3 = 2.33 times, as is shown by Equation (2). Therefore, $q_{S2}$ is used to measure the capacity.

The frequency assignment in a K = 3 system is shown in Fig. 4. The total allocated 395 channels can be divided into three groups. The first group consists of channels 1, 4, 7, 10, etc. The second group consists of channels 2, 5, 8, 11, etc. The channels of the third group are 3, 6, 9, 12, etc. Each group will be assigned to each cell according to the cell number shown in Fig. 4.

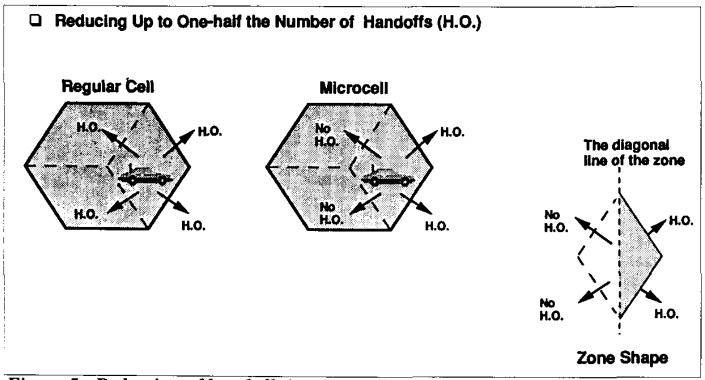

*Figure 5 Reduction of handoffs in microcell system*

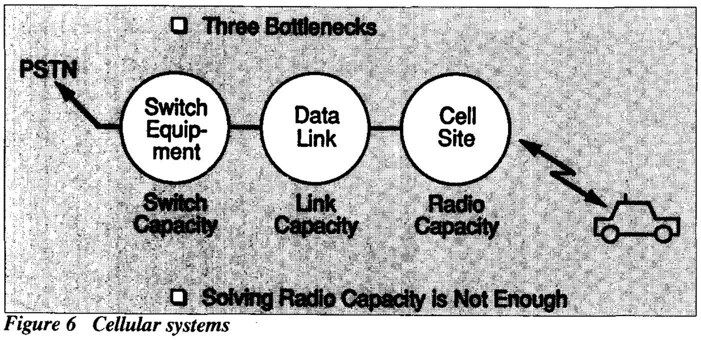

*Figure 6 Cellular systems*

## Improvement of Carrier-to-Interference Ratio

The $q_S = D_S/R = 4.6$ in an AMPS system is based on two requirements: all cochannel cells are a distance of 4.6R away from the serving cell, and the value of $q_S = 4.6$ is based on C/I = 18 dB, where the interference is received from six cochannel cells at the first tier [3], as shown in Fig. 1a. The C/I of 18 dB at RF averaged over Rayleigh fading, provides a good or excellent signal to the user in an analog system.

In a microcell system, the separation $D_1$ of any two nearest cochannel zones between two active zones in two corresponding microcells is $4.6R_1$, as shown in Fig. 3. All other cochannel zones in their microcells are separated farther than $4.6R_1$. For consideration of the worst case scenario, we can choose between an active zone in the center cell and individual cochannel zones in six corresponding microcells, and calculate the C/I received at that zone in the center cell of the microcell system, as shown in the following (in Fig. 4).

$$\frac{C}{I} = \frac{R_1^{-4}}{\sum_{i=1}^{6} D_i^{-4}} = \frac{R_1^{-4}}{3(4.6R_1)^{-4} + 3(5.75R_1)^{-4}} = 105 (=) 20\text{dB} \qquad (3)$$

3 A-zones 3 B-zones

Equation (3) shows that C/I in a microcell system according to the worst case is 2 dB better than that of an AMPS system. Since Equation (3) shows the worst case, where all the cochannel zones are in either A or B zones, the C/I can be even better if all of the active cochannel zones are other than A or B zones. The C/I in the normal case then is always greater than 20 dB. The C/I ≥ 20 dB is at least 2 dB better than the required $(C/I)_S$ of the AMPS system. This proves that the voice quality of the microcell system is always better than that of the AMPS system. One remark is that this calculation is based on the signal coverage in each zone regardless of the type of antenna. This is because the shape of the coverage takes care of the antenna pattern.

## Reduction of Handoffs

The definition of handoffs is to hand off a frequency to another frequency while the vehicle enters a new cell or a new sector. Within each microcell, no handoffs from zone-to-zone are needed; zone-to-zone switchings are handled by a zone selector. The active zone follows the mobile unit as it moves from one zone to another. The channel frequency assigned to the mobile unit remains unchanged.

In this section we may roughly estimate how many handoffs can be eliminated relative to a microcell plan in which three zones are used. In a regular cell, there are three sectors. The car can move in any one of three directions, as shown in Fig. 5. When a car moves through the other two sectors, it needs handoffs. When it enters, as well as when moving out of a cell, a handoff occurs. In a microcell, a car moving to either of the other two zones does not need handoffs. A handoff only occurs when the car moves in or out of the cell. Since the shape of a zone is based on the hexagonal cell, it is diamond shaped. Symmetry to its diagonal line can be observed from the left side of the diagonal line where no handoffs are required, and on the right side handoffs are needed. Therefore, we may estimate that only one half of the handoffs required in a regular cell configuration will occur in a microcell configuration. This reduction in handoffs in the microcell system makes a great contribution to the system capacity.

## System Capacity

In any cellular system, system capacity is the overall capacity of each system, and can differ from system to system. System capacity may be capped by three limiting elements: radio capacity, control link capacity, and switch capacity, as shown in Fig. 6.

- Radio capacity is the element most often addressed in the public domain and in published literature [3].
- Link capacity/switch capacity are the two elements often overlooked in measuring system capacity. Control link capacity measures the capacity of the fast control link between the cell site and the switches. If the number of microwave links or T1 carrier lines are not sufficient, a bottleneck will result. Switch capacity measures the capacity of traffic at the switching office. Again, if the switch is not big enough to handle the radio capacity, a bottleneck problem occurs.

Among these three elements (capacities), the weakest element must be used to gauge the system's capacity. Therefore, improving the radio capacity in the system is not enough. Improving system capacity requires upgrading the lowest capacity of the three. With this in mind, every system operator should be aware that radio capacity is not the entire problem nor the entire solution.

In a microcell system design, because fewer intercell handoffs are needed as compared to a regular system, both the switching load and the control link load are cut roughly by half, leaving two times the load to be handled by the present capacity. The easing of half the load means twice the load can be added back onto the system. This roughly two times (2.33 times to be exact) radio capacity is exactly what the microcell system will offer without changing the present switching equipment.

## Attributes of Microcell

The new microcell design contains many attributes:

- Increased system capacity. Based on the cell reuse pattern (reduced from $K = 7$ to $K = 3$), it is 2.33 times the AMPS system capacity.
- Voice quality improved. The voice quality of the microcell system always is better than the quality of AMPS.
- Interference reduced. (a) Since the antennas of all zone sites in one cell are facing toward each other, the interference signal has to cross the cell before interfering with the neighboring cell. Furthermore, the coverage is only served in one active zone; therefore, the interference is very weak compared with the interference from a transmitter from the center of a regular cell. (b) The three zone sites receiving the mobile signal simultaneously from three zones form a three-branch different-site diversity that is suitable for low-power portable units. It is increasing the probability of signal reception at the base due to diversity schemes. (c) The microcell system is the best arrangement to control interference. The active zone follows the vehicles.
- Adaptability. This microcell design can be added to any vendors' system without modifying the vendor's hardware or software.
- Size of the zone apparatus. The zone up/down converters are small, and they can be mounted on the side of a building or on poles. Therefore, it is a PCS (Personal Communications Service) type system because of the tight control of interference. Also, it is easy to remount from pole to pole when the signal coverage requirement is changed.

## Conclusion

This new microcell system is easy to implement, and poses a very low risk investment. Capacity, based on the $K = 3$ system, is 2.33 times higher than the existing analog system of $K = 7$. Furthermore, this microcell system can provide better voice quality than the AMPS system. It also can be used with digital cellular with slight modification. A microcell can serve in a small area; therefore, it is suitable for inbuilding communications. This microcell system is currently being implemented in west L.A.

*In a microcell system design both the switching load and the control link load are cut roughly by half.*

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## Biography

William C. Y. Lee, a Fellow of IEEE, received his B.S. degree from the Chinese Naval Academy, Taiwan, and his M.S. and Ph.D. degrees from Ohio State University at Columbus in 1954, 1960, and 1963, respectively. From 1959 to 1963 he was a research assistant at the Electroscience Laboratory at Ohio State University. He was with AT&T Bell Laboratories from 1964 to 1979. Mr. Lee worked for the ITT Defense Communications Division from 1979 to 1985. In 1985 he joined PacTel Mobile Companies. Currently, he is the vice president of research and technology at PacTel Corporation. Mr. Lee has written more than 150 technical papers and three textbooks.